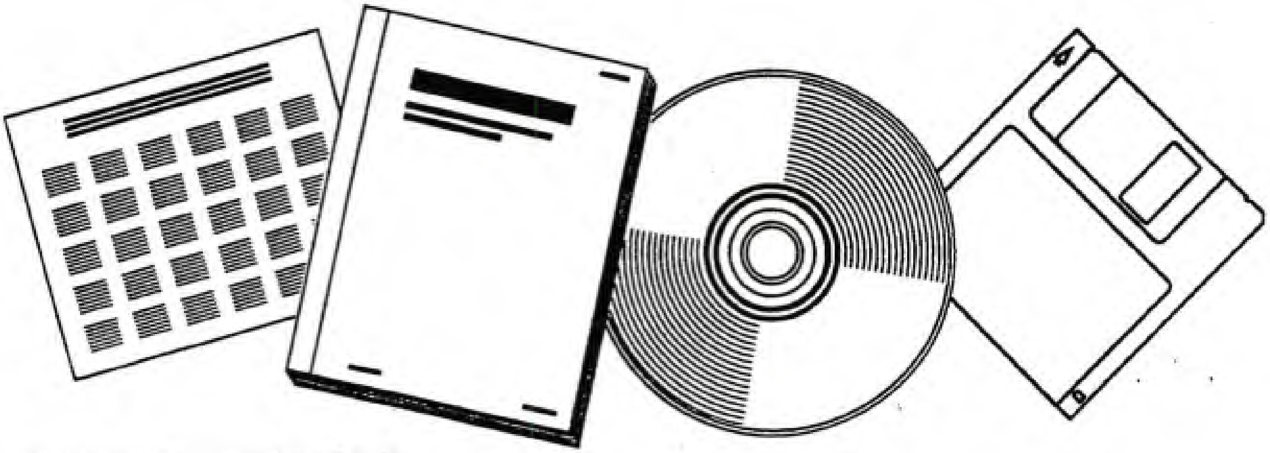
PB91185959

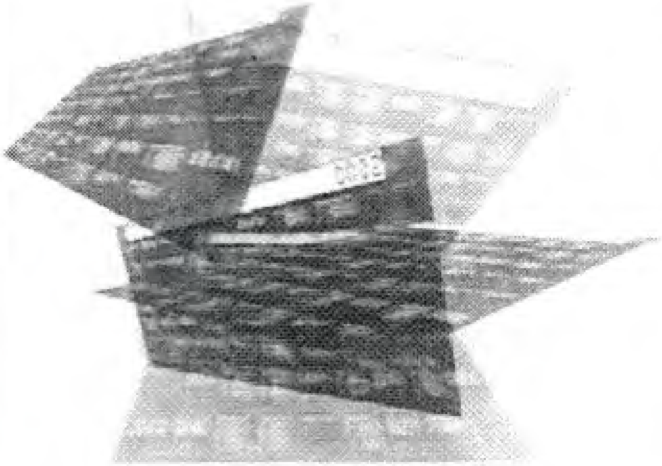
STRUCTURAL WOOD PROTECTION

MAY 1991



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

Tailored to Your Needs!



Selected Research In Microfiche

SRIM® is a tailored information service that delivers complete microfiche copies of government publications based on your needs, automatically, within a few weeks of announcement by NTIS.

SRIM® Saves You Time, Money, and Space!

Automatically, every two weeks, your SRIM® profile is run against all *new* publications received by NTIS and the publications microfiched for your order. Instead of paying approximately $15-30 for each publication, you pay only $2.50 for the microfiche version. Corporate and special libraries love the space-saving convenience of microfiche.

NTIS offers two options for SRIM® selection criteria:

Standard SRIM®–Choose from among 350 pre-chosen subject topics.

Custom SRIM®–For a one-time additional fee, an NTIS analyst can help you develop a keyword strategy to design your Custom SRIM® requirements. Custom SRIM® allows your SRIM® selection to be based upon *specific subject keywords*, not just broad subject topics. Call an NTIS subject specialist at (703) 605-6655 to help you create a profile that will retrieve only those technical reports of interest to you.

SRIM® requires an NTIS Deposit Account. The NTIS employee you speak to will help you set up this account if you don't already have one.

For additional information, call the NTIS Subscriptions Department at 1-800-363-2068 or (703) 605-6060. Or visit the NTIS Web site at *http://www.ntis.gov* and select SRIM® from the pull-down menu.

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161 (703) 605-6000
http://www.ntis.gov

Structural Wood Protection

by Robert Z. Page

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. PB91-185959

4. Title and Subtitle
Structural Wood Protection

5. Report Date
May 1991

6.

7. Author(s)
Robert Z. Page

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes This document was originally prepared for the U.S. Navy, but was adapted by John W. Hounsell for more general use.

16. Abstract (Limit: 200 words)

This publication provides information and guidance in design, construction, and maintenance of structures built wholly or in part of wood. It covers properties of wood and their relation to use, decay, and preservation; wood deterioration from chemical and physical damage, fungi and bacteria, insects, marine organisms; preventive protection of wood by moisture control, proper construction; decay of structures on land and waterfront structures; insect and marine borer control; methods and materials for the preservative treatment of wood; selecting which treatment to use; and preventive maintenance and corrective controls.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement Release unlimited	19. Security Class (This Report) Unclassified	21. No. of Pages 301
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

Table of Contents

FIGURES

TABLES

CHAPTER 1. INTRODUCTION

SECTION 1.1 PURPOSE AND SCOPE

1.1.1 PURPOSE. This publication provides information and guidance concerning design, construction, and maintenance of structures built wholly or in part of wood.

1.1.2 SCOPE. This publication describes the basic structure and nature of wood, explains the causes of damage to, and losses of wood, and provides guidance on the protection and preservation of wood. This information is based on widely-gathered practical U.S. Navy experience and on a series of research studies conducted by the U.S. Forest Service for the Naval Facilities Engineering Command at many naval shore activities. Because of regional climatic differences, some of our recommendations are more applicable in some areas than others. Where there are questions concerning the efficacy and propriety of local application of this information, these questions can be answered by professional biologists or other recognized experts.

SECTION 1.2 RESPONSIBILITIES AND GUIDANCE

1.2.1 RESPONSIBILITIES. It is important that a clear outline of responsibility be developed for the protection of wooden structures and that each person involved know his responsibilities. For instance, at a U.S. Naval Shore Activity, the Public Works Officer has responsibility to the Commanding Officer for periodic inspections of grounds and structures and for routine maintenance and such repairs as may be required. The Commanding Officer is responsible for informing his Senior Commander of the personnel and money required to maintain his shore activity. The Naval Facilities Engineering Command has the responsibility for providing the technical guidance needed to most effectively and economically inspect, maintain, and repair the facilities. This guidance is provided directly by specifications, directives, and technical manuals such as this one, and indirectly through the NAVFAC Engineering Field Divisions which can provide on-site guidance for the Public Works Officer in the conduct of inspection, maintenance and repair.

1.2.2 GUIDANCE. Guidance is herein provided on the selection of preservative treatments for wood in use in various exposure conditions. At the time of publication, this guidance is based on the most current science and the most current industrial technology and production. However, there will be new developments, and the information provided will become outdated. Professional biologists should be consulted in case of any question regarding selection of treatments. Wood preservatives are selective biocides. As such they are legally identified as pesticides within the definition provided by Public Law 92-516, the Federal Environmental Pesticide Control Act of 1972 (FEPCA). They may legally be applied only by persons trained in their use and certified as competent. While application of the preservatives is so regulated, the use of preservatively treated wood is not. For clarification in specific situations and for certification of personnel to apply preservatives to structural wood in place, professional biologists should be consulted. The selection of pesticidal chemicals for control of wood-destroying insects is regulated by the FEPCA, and by the Environmental Protection Agency (EPA) through use limitations on pesticide container labels and through guidance published in the form of Pesticide Enforcement Policy Statements (PEPS). While it is normally not legal to use a pesticide in some manner not cited on the label, the PEPS permit some uses contrary to labels. The situations are frequently changing. The appropriate professional biologist can advise on the most effective controls which can be legally used.

SECTION 1.3 WOOD IN USE

1.3.1 AVAILABILITY AND COSTS. Wood is the only renewable natural resource available for use as a structural material. Much of the wood harvested for use today was planted by man in tree farms. This is in direct contrast to other structural materials which are being produced in ever larger amounts from ever diminishing supplies of raw materials. Planted, grown, harvested, sawn, preservative-treated when needed, and delivered to the construction site, wood requires less total energy than do other construction materials. In the completed structure, wood is often less expensive than other materials. Though wood is our most versatile structural material, it is generally not as well understood as other structural materials because of its considerable complexity. One purpose of this manual is to help promote a better understanding of the usefulness of this structural material.

1.3.2 DESTRUCTION OF WOOD. Wood begins its existence as a living thing. Each year, in the growing tree, some of the wood changes from sapwood to heartwood and ceases its function in support of life processes of the tree. From that time on it can provide only physical support for the tree. With or before the eventual death of the tree, the wood may be attacked by various living organisms that reduce it to simple compounds which support the growth of other life. If this did not happen, if there were no living organisms to destroy wood, man could not live on earth. The land would be deep with dead trees, and the seas filled with them. Our earth would be a graveyard of forests which flourished eons ago. There would be neither room nor nourishment for any green thing. While man may in part owes his existence to wood-destroying insects and fungi, he competes with these organisms for the use of wood. He admires their work on the forest floor while he fights them in his wood structures. In this continuing fight, man has learned many techniques to protect wood.

1.3.3 PROTECTION OF WOOD. Since antiquity, man has sought the means to obtain the longest possible service life from wood. In many areas, primitive man learned by experience which woods available to him resisted destructive attack. Civilized man used his developing commerce to make highly durable woods widely available. The cedars of Lebanon were prized for their natural resistance as well as for their physical attributes. Early Mediterranean sailors sought durable woods, and then pitched them for added protection. Noah built the ark of shittim wood from the shittah tree. This is an acacia with close grain and with excellent structural characteristics. While the wood is fairly resistant to decay, the ark was pitched within and without. With the advent of a chemical industry, with a young steel industry beginning to produce coal tar as a byproduct, and with patent laws to protect inventors, modern wood preservation began to emerge over 250 years ago. In 1705, mercuric chloride was used as a wood preservative; and in 1767 copper sulfate was used. Patents for use techniques were issued in 1832 and in 1837. The use of coal-tar creosote was patented in 1836, and high-pressure creosote treatment was patented in 1838. In the years that have followed, many new techniques have been developed. Today there is a good combination of material and method for every need; and there is far greater need, because the "naturally resistant" woods of yesteryear are not readily available for modern construction. Preservation can be specified for each end use of wood where it is needed. For some uses, wood may be protected without chemical preservation.

1.3.4 RESEARCH AND TECHNOLOGY. Though today there are solutions to many of the known problems in protecting wood in use, there is a continuing search for cheaper and better systems for protecting wood when it is used as a structural material. Some of the studies involve techniques for barring termite access to wood in ways that are more environmentally acceptable than is the use of chemical barriers. Some involve the development of highly effective and long lasting preservative treatments that produce no environmental hazard. Some involve maintenance procedures for greatly extending structural life.

CHAPTER 2. PROPERTIES OF WOOD

SECTION 2.1 SUITABILITY OF WOOD FOR CONSTRUCTION

Mankind has been fortunate, indeed, to have a building material such as wood. It is a renewable resource. Moreover, trees may grow under a wide variety of site and climatic conditions, some of which are unsuitable for agriculture. The important role that forests play in storing moisture and minimizing erosion is well recognized as is their contribution to outdoor recreation. Furthermore, wood has characteristics that enable it to be fabricated with relatively simple skills and tools. The great variety of forms and decorative features available with its use are limited only by the skill, resourcefulness, and imagination of the user. When properly used, it has consistently given many years of service.

2.1.1 WORKABILITY. Ease of working is one of the virtues of most woods, especially of construction woods available in the United States. Logs can be sawn into lumber and timbers by small portable mills as well as by large and highly mechanized mills. Building lumber can be sawn, shaped, and bored on the building site with hand tools. Framing items can be securely joined together for building purposes merely by nailing. Bolts and reinforcing connectors may be readily used when additional strength of joints is needed. The great variety of finish items, such as exterior and interior woodwork, trim, paneling, and cabinetry, can be formed accurately and finished attractively without particular difficulty if appropriate species are selected. Wood can also be modified relatively easily. This often is of great practical advantage in that it permits modification and repairs without entailing difficult arrangements for materials or highly specialized services.

2.1.2 STRENGTH. For many uses none of the advantages of workability would be significant if wood did not possess a relatively high degree of strength. Weight for weight it is stronger than steel. Broadly, the strength of wood is correlated with its specific gravity, the denser wood being the stronger. Except for toughness, dry wood is stronger than wet wood. In general, the effect of drying on improving strength does not begin until the moisture content has been reduced to about 30% (based on the dry weight of wood). Below this level, as moisture content diminishes, most strength properties increase progressively.

Obviously, the dimensions of a piece of wood and properties such as size and location of knots and checks as well as straightness of grain can determine how large a load a piece can support. By using standard formulas, these factors, together with specific gravity and moisture content can be taken into account in designing wood structures.

2.1.3 DURABILITY. A considerable portion of the world-wide acceptance of wood as a construction material must be attributed to its capacity to withstand weather for a long time and, in many species, to a substantial capacity to resist degradation by fungi and insects. The continuing serviceability of frame buildings, in some instances several hundred years old, bears witness to a high order of durability. Certain precautions in construction and maintenance are, of course, necessary to fully obtain the durability that wood has to offer.

SECTION 2.2. HARDWOODS AND SOFTWOODS

Two broad kinds of woods are recognized in both general and commercial usage, particularly in the United States: hardwoods and softwoods. The terminology does not apply to the actual hardness of the wood, for such hardwoods as basswood and yellow-poplar are not especially hard and many softwoods (for example the so-called hard pines) are not especially soft. It would be technically more meaningful to refer to these two groups as broad-leaved and coniferous (cone-bearing) woods, as they are commonly referred to by botanists. The hardwoods come from trees with relatively broad leaves, and in most cases in the temperate zones of the world, the leaves are shed in the fall (deciduous). The softwoods come from trees that have needle-like or scale-like foliage. Because of the persistence of this foliage, the softwoods are also sometimes called evergreens. The structure of the hardwoods is considerably more complex than that of the softwoods. Some of the more prominent differences in this respect may be noted in the section General Physical Character of wood (2.4).

SECTION 2.3 FORMATION IN THE TREE

2.3.1 BIOLOGY OF WOOD FORMATION. Many elements of wood growth discussed in this section are illustrated in Figure 2-1. Simply stated, wood is formed in the trees by a chemical combination of carbon dioxide from the air, and the water and certain minerals taken up by the roots. The combining in large part takes place within the leaves, employing energy derived from sunlight. The first products formed in the leaves are sugars, and these are transported down the stem or trunk to the active zone, where further combinations take place to form wood. The zone in which the new wood is formed is known as the cambium, and is located in a very narrow region - often only one cell wide - at the extreme outside of the trunk, next to the bark.

All chemical reaction involved in the production of wood occur inside elemental structural units called cells (2.4.1). While forming wood, the cells in the trunk are alive; later they die and serve to support the tree. Fed by sugars from the leaves and minerals from the roots, the layer of cambium cells divides to form three parts of the tree trunks: (1) New cells formed toward the outer side of the cambium become bark, (2) the new cells formed toward the interior of the trunk become wood, and (3) some of the new cells continue to function as cambium, thus repeating the process. The newly formed wood cells gradually enlarge and harden until they acquire the typical physical and chemical characteristics of mature wood. This happens within a period of a few days.

2.3.2 ANNUAL AND SEASONAL GROWTH. A tree grows only when the temperature is favorable. In the tropics, temperatures are continuously favorable, and wood is formed throughout the year. In temperate zones, characterized by relatively cold weather in the winter season, the growth of trees is interrupted by the lower temperatures, thus limiting the formation of wood largely to the spring and summer months.

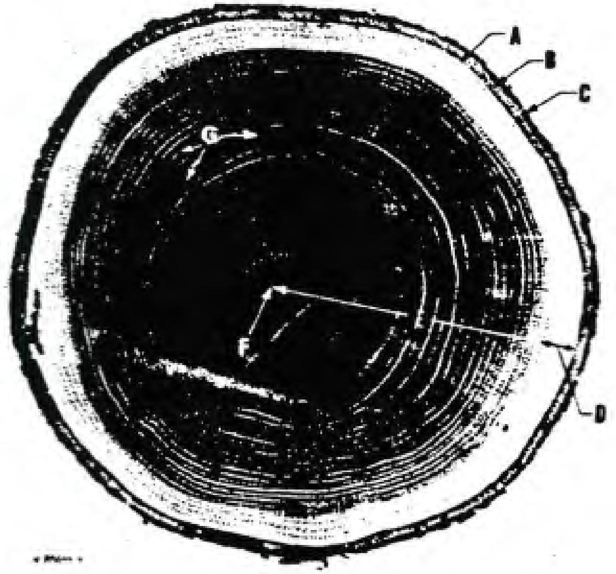


Figure 2-1. *Cross-section of an oak tree trunk:* **a.** *Cambium just inside the bark forms new wood cells;* **b.** *Inner bark which transports food from the leaves;* **c.** *Dead outer bark, a protective layer;* **d.** *Sapwood which contains both live and dead cells;* **e.** *Heartwood (inactive) which is colored by various extractives;* **f.** *the pith, the oldest part;* **g.** *Wood rays which connect various layers from the pith to the bark. The circular lines denote annual rings of porous springwood and dense summerwood. (M88620F)*

THE STRUCTURE OF WOOD

The structural elements of wood are cells of various sizes and shapes which are firmly bound together. Dry wood cells are either empty or filled with such materials as gums and resins. Most wood cells are elongate and pointed at the ends (fibers and tracheids) and vary from 1 to 8 mm in length (Fig. 2-2). In addition, hardwoods have vessels or cells of larger diameter that conduct sap upwards.

Fibers, tracheids, and vessels are oriented mainly along the longitudinal axis of the tree stem. Wood also contains simple blunt-ended cells (parenchyma) used mainly for the storage of food. Some parenchyma cells and tracheids are aligned radially in the stem to form rays which in quarter-sawn wood appear as bands across the grain. Rays are particularly conspicuous in the oaks and sycamore, giving them their characteristic figure.

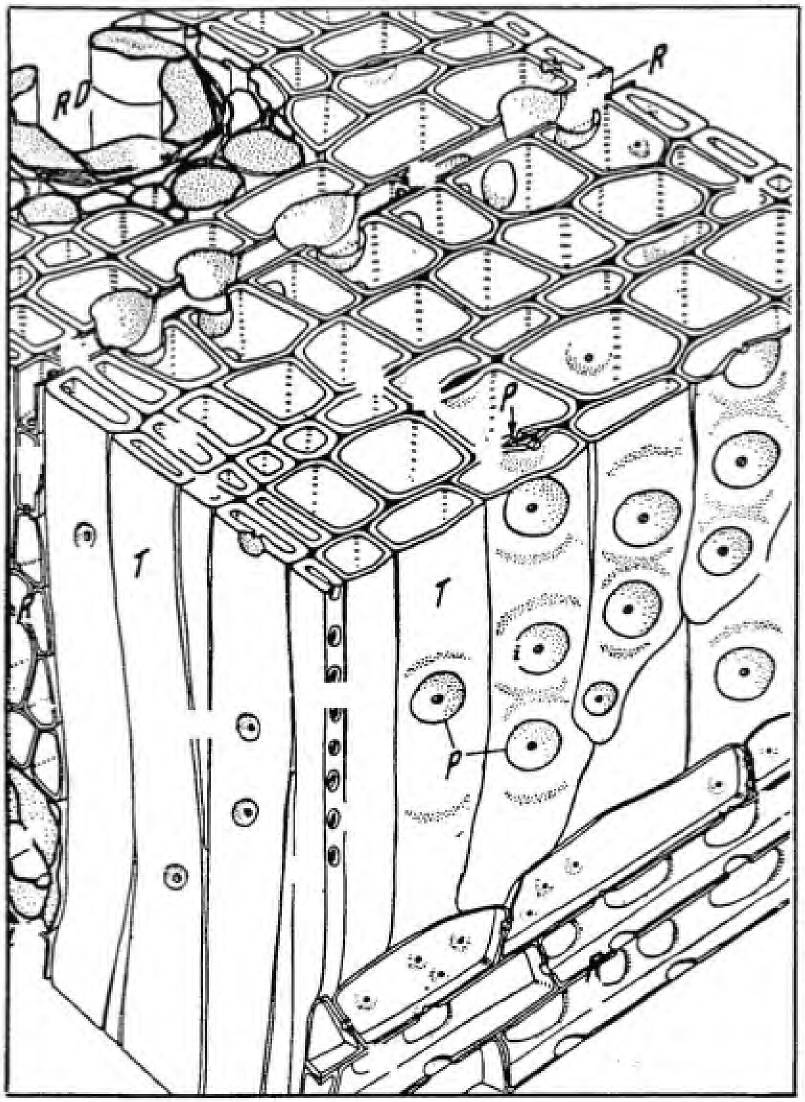


Figure 2-2. *Typical cellular structure of a softwood:* **RD,** *resin duct, a tubular structure lined with parenchyma cells and in which resin is formed.* **P,** *pit, connecting cell cavities.* **R,** *wood ray, used for storage and transport of materials across the grain.* **T,** *tracheid or the principal strength-giving cell. (M124880)*

2.3.2.1 Growth Rings. With most timber species in temperate climates, there is sufficient difference between the wood formed early and that formed late in a growing season to produce well-marked growth rings. These are commonly referred to as annual rings. In a practical sense, the number of these growth rings tells how long it took the trees to produce the cylinder of wood at that particular height. Because there is less seasonable variation in growth of trees in the tropics, tropical woods seldom have distinct growth rings. Growth rings are most conspicuous in timber species belonging to the yellow pine group and in hardwood species such as ash and oak which, early in the growing season, produce relatively large cells popularly known as pores (2.4.1.2). In some species such as birch and maple, the growth rings are less prominent and require a moderate amount of magnification for counting.

2.3.2.2 Earlywood and Latewood. The inner part of the growth ring, which is formed first in the growing season, is called earlywood or springwood, and the outer part, formed later in the season, latewood or summerwood. Earlywood is characterized by cells having relatively large cavities and thin walls. Latewood cells have smaller cavities and thicker walls. The contrast in appearance between earlywood and latewood is what makes the growth rings visible; the greater the contrast between earlywood and latewood, the more prominent are the annual rings. The proportion of latewood in the annual ring largely determines the weight and strength of the wood. It also considerably determines how much a piece of wood may shrink or swell with changes in moisture content.

2.3.3 HEARTWOOD AND SAPWOOD. When viewed in cross section, the trunk of most trees in temperate climates will show wood of two colors. There will be an outer zone of wood, next to the bark, which is light colored and often might be properly described as "white". This is called the sapwood. The central cylinder of wood inside the sapwood is called heartwood, and usually--but not always--is distinctly darker than the sapwood. The sapwood zone contains living cells and has an active part in life processes of the tree. It is located next to the cambium and functions in sap conduction and storage of food. The heartwood consists of dead cells and serves only to give needed strength to the trunk and branches. The sapwood may vary in thickness and in number of growth rings it contains. It commonly ranges in thickness from 1 1/2 to 2 inches. Usually, the faster the growth of the tree the thicker the sapwood. In some second-growth timber, notably the southern pines, the sapwood comprises most of the trunk.

The oldest sapwood cells change to heartwood when they slow down in their functions--as the first step toward death. In the process of heartwood formation, certain materials are deposited in the dying cells; and these materials give the heartwood its darker color in those species in which there is a distinct color differentiation between heartwood and sapwood. The deposited material does two additional things that are noteworthy. It tends to plug up the tiny passageways (pits) between cells, thus reducing the permeability of the wood, and in some species, such as the cedars, the deposits include fungus-inhibiting chemicals that tend to make the wood decay resistant. In considerably fewer species the deposits may provide significant termite resistance. Only heartwood has decay or termite resistance of any practical significance. Unless treated, all sapwood is nondurable when exposed to the damp weather. There is no consistent difference in strength between the sapwood and heartwood when dry. In general, the moisture content of sapwood is greater than that of heartwood.

SECTION 2.4 GENERAL PHYSICAL CHARACTER OF WOOD

2.4.1 CELLULAR ORGANIZATION. Many features of wood structure discussed in this section are illustrated in Figure 2-2. The cells, which are the unit building items of which wood is formed, are hollow, tubular structures. They vary in size and length, but an individual cell is always much longer than it is wide. The cells overlap one another and are firmly held together, thus creating a comparatively firm and rigid structure. The hollow portion of the cell is known as the cell cavity and the solid portion as the cell wall. These features can be seen on the end grain of most woods if they are magnified with a hand lens. Wood cells have three primary functions. To provide strength, to conduct water and nutrient materials, and to hold reserve food materials for the tree. The cells differ in size and shape according to their major function in these respects.

2.4.1.1 Strength-Giving Cells. The strength-giving cells are customarily called fibers or fiber tracheids, and they make up the bulk of the wood. Their tubular construction and overlapping or intermeshing arrangement with respect to one another result in a high ratio of strength to weight. Although the length of fibers and tracheids may vary considerably, the fact that their length considerably exceeds their width contributes greatly to the strength of wood in bending. As might be expected, the thicker the wall of fiber and fiber-tracheid cells, the greater the strength of wood in a piece of given size. The specific gravity of the cell wall, excluding extractable materials, is approximately 1.5 in all species of wood, but because of the hollow character of the cells, the specific gravity of the entire wood usually is only about one-fifth to one-half that amount.

2.4.1.2 Liquid-Conducting Cells. In the softwoods, moisture and minerals from the ground are carried upward through the tracheids of the sapwood. This general movement is commonly referred to as sap flow. Passage of sap from tracheid to tracheid occurs chiefly through tiny circular passageways in the cell wall known as pits. Pits occur in all wood cells; they do not present fully open passageways from cell to cell but are partially obstructed by the pit membrane. In the hardwoods, some sap moves through the wood fibers of the sapwood, but the larger amount of it is carried in cells with relatively large cavities, the pores.

The pores, more technically known as vessels, not only have relatively large cavities but the cells forming them are joined end to end for considerable distances without obstruction so long as--in some species--ingrowths known as tyloses are not formed. In some hardwoods, notably the white oaks, the pores become plugged to a greater or lesser degree by ingrowths known as tyloses, which arise from surrounding sapwood cells in early stages of dying. The tyloses may make the wood highly impermeable, so white oak wood is often used for barrels in which liquids will be kept.

In addition to the vertically oriented cells that conduct sap upward, certain cells are oriented horizontally and carry sap and dissolved food materials radially in the trunk. These cells, which cut across the grain, are called rays or wood rays. The rays are particularly prominent in the oaks, and when viewed on a cross section of the trunk they are seen to radiate outward from the center like spokes in a wheel.

2.4.1.3 Food-Storing Cells. Wood also has other cells, known as wood parenchyma cells, that function mainly for the storage of food. The wood rays are largely comprised of such cells. Starch is the principal stored food; in early spring this is rapidly converted into sugar, which provides energy for resumption of growth.

2.4.2 SURFACE APPEARANCE

2.4.2.1 Grain. The word "grain" in connection with wood is commonly used in two ways. In one sense, it may refer to the long direction of the fibers and fiber tracheids. Thus wood is cut across the grain, with the grain, and diagonally across the grain. In the additional sense, grain refers to the general appearance of the wood as seen on a smooth surface. In this connection, the visual impressions are made by such things as the complexity of the wood structures (hardwood versus softwood structure), the spacing of the annual rings, the abruptness of transition between summerwood and springwood, the width of the rays, the direction of cutting (flatsawed versus quartersawed), the specific position of the surface with respect to the growth rings (flat grain or side grain versus end grain) and the like. Undesirable deviations in grain or color are called blemishes.

2.4.2.2 Knots. Except for special decorative effects, such as in knotty pine paneling, knots are considered a defect in lumber, for they reduce its strength in bending. The various conditions of knot size and location are prominently considered in the establishment of lumber grades. Knots are the remnants of branches. Most branches originate at the pith, and their bases are intergrown with the wood of the trunk as long as they are alive. A knot will generally be "tight" if the branch producing it was alive when the board was cut. A "loose" knot results when the tree trunk grows over a dead branch, in which case there is no continuity between the wood of the trunk and the branch. After a dead branch drops off or is removed close to the trunk, wood subsequently formed at that position will be clear. The older a tree gets, the fewer side branches and branch stubs it will have, which explains why the clearest and strongest wood generally comes from the largest trees.

2.4.2.3 Discolorations and Disfigurement. Wood discolorations are of two general types, those caused by fungus infection, such as sap stain or blue stain, and those due to strictly chemical changes in certain wood constituents. The fungus-caused discolorations are confined almost entirely to the sapwood, except where they are the result of early stages of decay. The chemical discolorations are preponderantly but not exclusively in the sapwood.

Chemical discoloration may occur in the standing tree or after the tree is cut, but the basic nature of the discoloration in these two ways is different. In the tree, chemical discoloration commonly is caused by injury to the cambium, which generates the new wood. Fire damage, bark beetles, bark feeding by birds, and frost cracks are common causes of cambium injury, and mineral stains and mineral streaks, worm streaks, and bird pecks are familiar manifestations of such injury. Discolorations originating in the sapwood of the standing tree usually persist into the heartwood. Mineral streaks and stains are mostly a problem in hardwoods. Where there has been a sizable injury to the cambium, as by fire, ax cut, or debarking by falling trees, there is likely to be uneven grain as well as discoloration in wood subsequently formed near the injury. This may also reduce the strength of lumber, depending on the degree of grain deformation.

Most chemical discolorations developing in the outer sapwood are caused by air coming in contact with the freshly exposed, moist wood; hence this type may be appropriately referred to as oxidation stain. The oxygen unites with certain wood constituents with a result analogous to the browning of the interior of an apple when it is exposed to the air. Such discolorations are especially troublesome in hardwoods, in which they impart to the normally white sapwood an off color ranging from light to very dark gray, often varied with shades of brown. It is serious among the softwoods only in lumber of sugar pine and the soft pines. In the pines, the discoloration is a more or less pure brown ranging from tan to deep chocolate. Oxidation stains can best be controlled by rapid drying at as cool a temperature as possible. In some woods the discoloration seems to depend on enzymatic action, and in these cases it can be prevented by preheating the lumber to destroy the catalyzing enzymes before attempting to dry it.

An entirely different type of chemical stain is produced in many woods by contact with iron or with water bearing considerable iron. The iron reacts with tannins in the wood, forming iron tannate, which imparts a grayish to bluish-black color to the affected areas. (When concentrated, iron will also sometimes damage strength--see 2.6.3.2.)

2.4.3 MOISTURE CONTENT OF GREEN WOOD. The moisture content of green wood is never less than 30% based on the ovendry weight of the wood, and it usually is considerably greater. Among the softwoods, the green sapwood contains considerably more moisture than the heartwood. In Douglas-fir, for example, the average moisture content is 37% for green heartwood and 115% for green sapwood. Individual values may be as low as 30% for heartwood and as high as 154% for sapwood. Table 2-1 shows data on the average moisture content of green wood. Among the hardwoods, the difference in moisture content between sapwood and heartwood is smaller, and the heartwood in many cases may even contain more moisture than the sapwood. Moreover, the average moisture content in the green hardwoods tends to run substantially below that in the sapwood of softwoods as shown in Table 2-1.

Moisture content influences the strength and dimensions of wood, as will be considered in the following section. It also determines the susceptibility of the wood to attack by organisms, as is discussed in Chapter 3.

SECTION 2.5 PHYSICAL PROPERTIES OF WOOD

The physical properties of greatest significance in the use of wood are weight, strength, working qualities, appearance, dimensional stability, and absorptivity and penetrability. Only some of the factors which affect these properties in wood can be considered here.

2.5.1 WEIGHT OF WOOD. The weight of wood varies greatly due to variations in specific gravity and moisture content. For example, a low-specific-gravity wood like balsa may weigh only about 12 pounds per cubic foot whereas a cubic

TABLE 2-1. Average Moisture Content of Green Wood

Common Name	Botanical Name	Moisture Content	
		Heartwood	Sapwood
	SOFTWOODS		
Douglas-fir (coast type)	*Pseudotsuga menziesii*	37	115
Fir, white	*Abies concolor*	98	160
Hemlock, western	*Tsuga heterophylla*	85	170
Larch, western	*Larix occidentalis*	54	119
Pine, lodgepole	*Pinus contorta*	41	120
Pine, ponderosa	*Pinus ponderosa*	40	148
Pine, southern loblolly	*Pinus taeda*	33	110
Pine, southern shortleaf	*Pinus echinata*	32	105
Pine, sugar	*Pinus lambertiana*	78	219
Pine, western white	*Pinus monticola*	62	148
Redcedar, western	*Thuja plicata*	58	249
Redwood, old growth	*Sequoia sempervirens*	86	210
Redwood, young growth	*Sequoia sempervirens*	100	200
Spruce, Engelmann	*Picea engelmanni*	51	173
Spruce, sitka	*Picea sitchensis*	41	142
	HARDWOODS		
Ash, white	*Fraxinus americana*	46	44
Aspen, quaking	*Populus tremuloides*	95	113
Beech, American	*Fagus grandifolia*	55	72
Birch, yellow	*Betula alleghaniensis*	74	72
Cottonwood, eastern	*Populus deltoides*	160	145
Elm, American	*Ulmus americana*	95	92
Maple, silver	*Acer saccharinum*	58	97
Maple, sugar	*Acer saccharum*	65	72
Oak, northern red	*Quercus rubra*	80	69
Oak, northern white	*Quercus alba*	64	78
Oak, southern red	*Quercus falcata*	83	75
Oak, southern white chestnut	*Quercus prinus*	72	
Pecan	*Carya illinoensis*	71	62
Poplar, yellow	*Liriodendron tulipifera*	83	106
Sweetgum	*Liquidambar styraciflua*	79	137
Tupelo, black	*Nyssa sylvatica*	87	115
Tupelo, water	*Nyssa aquatica*	150	116
Walnut, black	*Juglans nigra*	70	73

N.B. Based on weight when ovendry

foot of a high-specific-gravity wood such as black locust may weight 50 pounds. Air-dry wood of the structural softwoods weighs between about 25 and 35 pounds per cubic foot. Table 2-2 shows the weight of green wood at various specific gravities and moisture content. From these data, transportation weights and the needed load capacities of wood-handling equipment can be calculated with sufficient accuracy.

2.5.2 STRENGTH PROPERTIES OF WOOD, AND FACTORS AFFECTING THEM. As has been noted (2.1.2), weight for weight wood is stronger than steel. Thus, it can be used to build structures of comparatively large size and height. Moreover, wood has a degree of flexibility that permits it to be bent or twisted considerably without failure or permanent distortion. The strength properties most commonly considered in designing for use of wood are capacities of the wood to withstand loading of the following primary forms: Static bending, impact bending, compression parallel to grain, compression perpendicular to grain, shear parallel to grain, tension perpendicular to grain, and hardness. These properties, as with those of any other building material, are incorporated in formulas that can be used to ascertain needed working sizes of the items used. The property or properties emphasized in a particular case depend on the manner in which the wood is to be stressed.

2.5.2.1 Moisture Content and Specific Gravity. The chief variables affecting strength, and therefore considered most in design, are moisture content and specific gravity. Wood increases in strength as it dries below the fiber saturation point. For example, with small, clear specimens, the strength in endwise compression is about twice as great for a moisture content of 12% as for green wood. It may be emphasized that increase in strength does not begin until the fiber saturation point is reached in drying. At this point the free water in the cell cavities has been evaporated, but the cell walls are still saturated; the moisture content at the fiber saturation level averages about 30%, based on the ovendry weight of the wood. (See also 2.5.4.1.) An exception to the rule that dry wood is stronger than green wood is toughness or shock resistance. Toughness may be greater in green wood because green wood can bend farther than dry wood without failing.

Other things being equal, specific gravity is an excellent index of the amount of wood substance in a piece of lumber and, therefore, is an index of its strength properties. Quantitative expressions of strength properties can be adjusted according to prescribed formulas to consider different moisture contents and specific gravities. Basic strength data are usually shown for wood at two moisture levels--with 12% moisture content and when green. Besides the basic factors (specific gravity and moisture content) that determine the strength of wood, the following secondary factors must be kept in mind:

2.5.2.2 Heat. Wood can be exposed to temperatures below about 150°F for a year or more without an important permanent loss in most strength properties, but its strength while heated will be temporarily reduced. The temperature effect is greater in moist wood than in dry wood. When wood is at a temperature of 150°F or more for extended periods of time, it will be permanently weakened even if normal temperatures are restored.

2.5.2.3 Duration of Stress. The times during which a load acts on a wood member will determine somewhat the load that the member can safely carry. Because of long-term loading, posts or beams in a warehouse can carry only

TABLE 2-2. Average Specific Gravity and Approximate Weight of 1,000 Board Feet of Various Species of Lumber

Species	Average[1] Specific Gravity	Average Weight[2] of 1000 Board Feet (pounds)
	SOFTWOODS	
Douglas-fir (coast type)	0.45	3301
Fir, white	.37	2669
Hemlock, western	.42	3055
Larch, western	.48	3512
Pine, lodgepole	.38	2774
Pine, ponderosa	.38	2774
Pine, southern loblolly	.47	3442
Pine, southern short leaf	.46	3371
Pine, sugar	.35	2529
Pine, western white	.36	2599
Redcedar, western	.31	2248
Redwood, old-growth	.38	2774
Redwood, young-growth	.33	2388
Spruce, Engelmann	.32	2318
Spruce, Sitka	.37	2669
	HARDWOODS	
Ash, white	.55	4074
Aspen, quaking	.35	2529
Beech, American	.56	4144
Birch, yellow	.55	4074
Cottonwood, eastern	.37	2669
Elm, American	.46	3371
Maple, silver	.44	3231
Maple, sugar	.56	4144
Oak, northern red	.56	4144
Oak, northern white	.60	4460
Oak, southern red	.52	3823
Oak, southern white (chestnut)	.57	4214
Pecan	.60	4460
Poplar, yellow	.40	2915
Sweetgum	.46	3371
Tupelo, black	.46	3371
Tupelo, water	.46	3371
Walnut, black	.51	3758

---

[1] Based on ovendry weight and green volume

[2] Weights were calculated for lumber 1 1/8 inches thick at 20% moisture content. Weights for lumber at moisture content values between 0% and 30% can be estimated by using the following formula: Weight at MC_x = weight at MC_20 + 13 (MC_x - 20)

about 60% of the load required to produce failure in a standard strength test of only a few minutes duration. Thus, the duration of stress must be considered in establishing safe working stresses. As a rule of thumb, the strength may be said to increase or decrease 7% or 8% as the duration of loading time is decreased or increased by a factor of 10.

2.5.2.4 Cross Grain. If the grain direction (orientation of the strength-giving fibers or fiber tracheids) is parallel to the axis of the piece, the piece is said to be straight grained. Conversely, if that is not the case, the piece is said to be cross grained. Cross grain may be described as spiral, diagonal, wavy, interlocked, or curly. For practical considerations, the slope of grain in structural timbers is measured in the face having the greatest slope of grain. The greater the slope of grain, the weaker the piece will be; consequently this should be taken into account in establishing working stresses. The lesser strength of cross-grained wood is familiar to those who have had a baseball bat with grain of this type fracture in their hands.

2.5.2.5 Knots. Knots decrease strength because their grain is at a large angle to the grain of the piece, and because the grain around them is distorted. Also, checking may occur in and around knots in drying. The amount of weakening by knots is largely dependent upon the location of the knot and the manner in which the wood is to be stressed. For example, in a horizontal beam, knots on the lower side will have much more effect than knots on the upper side in determining the load that can be carried. In long columns, in which stiffness is the controlling factor, knots are not important. Clusters of knots across a board at about the same general position clearly will weaken a board more than if the knots were scattered through its length.

2.5.2.6 Abnormal Wood and Compression Failures. Abnormal wood is comprised of juvenile wood and reaction wood; the latter includes compression wood and tension wood. The three types of abnormal wood not only make a piece weaker but also subject it to longitudinal shrinkage and warping.

(1) Juvenile Wood occurs next to the pith of a tree and is characterized by indistinct growth rings.

(2) Compression Wood may occur in all softwood species, being found most commonly on the underside of leaning trees and on the underside of limbs. It is denser and harder than normal woods, and is characterized by wide growth rings that are usually eccentric. Also, the proportion of summerwood tends to be exceptionally large and the contrast between springwood and summerwood is usually less than normal.

(3) Tension wood occurs in hardwood species, generally on the upper side of leaning trees and on the upper side of limbs. The wood fibers comprising it are abnormal in structure, and tend to hold together tenaciously; sawed surfaces usually have projecting fibers and planed surfaces often are torn or have raised grain.

(4) Compression Failures. In wood with compression failures, the individual fibers or fiber tracheids have been overly stressed and are crumbled or buckled. The fractures in individual cells can be seen only with the microscope, but with proper lighting a series of them may appear as fine, white lines across the wood. Compression failure is caused by excessive bending of

the trees by wind or snow, or by rough felling of the tree over ground irregularities; they also may be caused by rough handling of logs or lumber. When a piece with compression wood or tension wood fails, the break is likely to be brash (without much splintering). This brash character of break is usually evidence that the wood lacks normal strength.

2.5.2.7 Infection by Fungi. Infection by wood-invading fungi, especially by those that cause decay, will weaken wood. The extent of weakening varies with the particular strength property, the type of fungus, and the extent of the infection. This is discussed in Section 3.2.

2.5.3 DIMENSIONAL STABILITY. Wood that shrinks and swells least is said to have high dimensional stability. High dimensional stability is desired to keep construction joints as tight as possible, to minimize splitting, to avoid serious buckling of tightly fitted boards during damp weather or unsightly openings between boards during dry weather, and so forth. In ordinary structures the changes in dimensions are caused by changes in the moisture content of the wood. No practicable means has yet been found to avoid changes in moisture and dimensions. They can be held to tolerable levels, however, by having the moisture content of the wood at the time of construction at the approximate average level to be expected when the wood is in service. In this way a compromise is reached between maximum swelling and maximum shrinkage.

Surface treatment with a water-repellent preparation containing wax, or a paint or varnish coating, will retard moisture pickup; and may thereby keep wood from swelling objectionably where it is subjected to short periods of high relative humidity or rain wetting. However, these treatments only delay moisture absorption; where exposures to damp conditions are comparatively long, they may not be very helpful in minimizing swelling.

For wood to be used under cover, the controlling factor in dimensional changes is the relative humidity of the surrounding air. In turn, the relative humidity is determined largely by the factors of climate, amounts and duration of artificial heat, and air humidification or cooling. Denser woods undergo greater dimensional change than the less dense, because they contain more wood substance to be affected by changes in moisture content.

2.5.4 ABSORPTIVITY AND PENETRABILITY OF WOOD. Absorptivity and penetrability are important considerations for construction wood for three reasons in particular: (1) They determine the rate at which wood can absorb water and thereby undergo dimensional change, (2) they determine the susceptibility of the wood to the wetting adequate for invasion by wood-attacking fungi, and (3) they determine the relative ease with which the wood can be preservative treated. Strictly speaking, absorptivity denotes the capacity of the wood to pick up a quantity of moisture, whereas penetrability denotes the relative ease with which the moisture can move inward. Often, for practical purposes, no distinction is made between these two characteristics. Moisture is absorbed either in vapor or in liquid form, and the consequences may differ substantially.

2.5.4.1 Absorption of Moisture Vapor. Wood will give off or take on moisture from the surrounding atmosphere until the amount of moisture in the wood balances that in the atmosphere. The moisture content of the wood at the point of balance is called the equilibrium moisture content and is expressed as a percentage of the ovendry weight of the wood. In the usual range of temperature, the equilibrium moisture content depends chiefly upon the relative humidity of the atmosphere.

The moisture content of wood at a given relative humidity varies with the temperature. At ordinary temperatures and at a relative humidity of 100%, the moisture content is approximately 30% based on the ovendry weight of wood (fiber-saturation point). As might be inferred, this amount of moisture is the maximum that can be absorbed from moisture in vapor form. At the 30% point, the walls of the wood cells are saturated, but there is no significant moisture in the cell cavities; all changes in strength associated with change in moisture content occurs only below this point (2.5.2.1.) Similarly, all dimensional changes, and warping, twisting, cupping, and so forth, occur only when the moisture changes are in the range below the fiber saturation point. For each 1% loss in moisture content below the fiber saturation point, wood shrinks about one-thirtieth of its total possible shrinkage. Thus, the fiber saturation point has a great deal of significance in the use of wood. As will be noted further on, this point is also the approximate lower moisture limit for attack by decay fungi.

2.5.4.2. Absorption of Liquids. When water, as rain or droplets of condensate, or as splash or drip, comes in contact with wood, it is drawn into the wood by capillary action. It moves inward most rapidly through the tube-like cell cavities. With a continuing source of supply the water will continue inward at a significant rate until the capillary forces are offset by built-up air pressure and the drag imposed by friction. As it travels through the cell cavities, water will also enter the cell wall--and saturate it. Water will also enter the cell wall directly at the surface of the wood, but absorption in this manner is relatively small compared with that through the cell cavities.

It is the water that is absorbed as a liquid (as distinguished from water vapor) which supports most fungus attack on wood. The rate of water absorption is much faster than the subsequent rate of loss as vapor. Consequently, a relatively brief period of wetting may create a dangerous moisture level that will remain for a considerable time.

Oils are absorbed into wood in the same manner but with a very important exception: Oils do not enter the cell wall. Therefore, the introduction of preservation oils does not cause wood to swell.

2.5.4.2.1 Basic Factors of Liquid Absorption. The movement of a liquid along the pathway of cell cavities is influenced by a number of factors, which can be considered with the aid of Figure 2-2. The most important of these are the pits through which most of the liquid must pass in going from one cell into another. Some pits are readily traversed, whereas others are relatively impenetrable; it is largely for this reason that some woods can be rather easily impregnated with preservatives, whereas others are practically impossible to treat well. Among the hardwoods, the presence or absence of large vessels and the condition of the vessels with respect to tyloses also are major factors in determining absorptivity. Specific gravity is another factor. An additional factor of liquid absorption is back pressure. Air in wood becomes compressed as the liquid is absorbed, until finally the back pressure may become the dominant factor determining the rate of absorption.

For this reason, with some methods of preservative treating, part of the air is first withdrawn from the wood.

A liquid can move into wood much easier along the grain than across the grain. That is because the wood cells are much longer than they are wide, thus the liquid must move through a great many more cells when going across the grain than when going in the direction of the grain. Therefore, water in contact with the side of a board is absorbed in a far smaller amount in the same length of time than is water in contact with the end of the same board. This great difference in absorptivity between side grain and end grain is important in determining the susceptibility of different kinds of wood construction to decay. This will be discussed in Chapter 7, which deals with the protection of wood by moisture control.

As noted above, liquids are drawn into wood by capillary force. The rate of absorption of a given piece of wood can be greatly increased by putting pressure behind the liquid. Pressure is used commercially to treat wood requiring the greatest amount of protection. Pressures vary from about 100 to 200 pounds per square inch, depending on the species and the ease with which the wood takes the treatment. Movement of liquids into wood can be additionally facilitated by evacuating the air from the wood before applying the liquid. Where the deepest penetrations are not required, vacuum alone is sometimes used, in which case the normal pressure of the air acts as the additional driving force. The different variables of wood structure that govern the penetration of liquids by capillary attraction are also operative where external pressure is applied to increase the speed and depth of penetration. Both their absolute and relative influences may vary with different conditions of treating.

Irrespective of differences in penetrability, the total amount of a given liquid that wood can hold varies with the specific gravity. The denser the wood the larger the amount of space taken up by the cell wall and, therefore, the smaller the volume of cell cavities available to receive the liquid. Douglas-fir, having an average specific gravity of about 0.45, can absorb about 160% water, that is, 160 pounds of water per 100 pounds of ovendry wood. A denser wood such as oak, having a specific gravity of about 0.60, can absorb only about 100%; but a very light wood such as balsa with a specific gravity of about 0.25 can absorb as much as 300%. For oils, which do not penetrate the cell wall, the total absorptive capacity is roughly 30% less than that for water. The difference represents the average percentage of water required to saturate the wall. In commercial treatments of thin pieces of readily treatable species, the actual retentions achieved may approach the theoretical maxima quite closely. In large pieces, however, even in so-called refusal treatments, retentions generally fall considerably short of the values that are theoretically possible.

2.5.4.2.2 General Differences in Wood Penetrability. As noted, the rate at which liquids can move into wood is determined largely by the ease with which they can move from cell to cell through the interconnecting pits. In most species, heartwood is more difficult to penetrate than sapwood. This is because, in the process of heartwood formation, certain changes occur in the pits that tend to plug them. There is an extremely great difference between species in the degree to which the heartwood may be penetrated. In addition, within some species individual pieces may vary considerably in the treatability of the heartwood.

2.5.4.3 Effects of Fungus Infection on Permeability. Fungus infection tends to increase the permeability of wood. The increased permeability may be pronounced even where the wood is not noticeably affected in other respects. The earliest changes in wood structure brought about by the infection occur in those wood elements that affect permeability most. Most fungi, as they move into wood, pass through the pits; in doing so they remove portions of the pit membrane and of any occluding substances, thus enlarging the pit openings. In addition, they commonly remove portions of the cells comprising the wood rays, and thereby may facilitate radial flow of liquids into wood. Although degradation of the pits and the wood rays by fungus infection essentially does not reduce wood strength, the increased permeability can be disadvantageous in that it favors absorption of water and therefore decay of wood exposed to weather (3.2.1.3.(1)). Decay fungi will penetrate cell walls as well as the pits (3.2.1.3.(3)).

SECTION 2.6 CHEMICAL PROPERTIES OF WOOD

2.6.1 MAJOR CHEMICAL CONSTITUENTS. Wood has four primary chemical constituents: cellulose, lignin, extractives, and ash-forming minerals. The minerals make up only 0.2% to 1.0% of the wood.

2.6.1.1 Cellulose. Cellulose, the most abundant constituent, comprises about 70% of the wood. It is the main source of food for wood-destroying fungi and for insects, such as termites, that feed on wood. There are two types: alpha-cellulose and hemi-cellulose. The alpha-cellulose is the main basis of the useful products obtained from wood, such as paper, explosives, synthetic textiles, and plastics.

2.6.1.2 Lignin. Lignin comprises from 18% to 28% of the wood. It cements the structural units together and thus imparts rigidity to the wood. Most of the lignin serves in this way, and it can be observed microscopically between adjacent wood cells. Additional lignin occurs in intimate association with the cellulose of the cell wall. This cell-wall lignin provides some protection against cellulose-destroying fungi and bacteria. Some fungi use the lignin very little, whereas others use it as freely as cellulose (3.2.1.3(3)).

2.6.1.3 Wood Extractives. The extractives are not part of the wood structure, but they contribute such properties to the wood as color, odor, and taste, as well as some resistance to decay and insects. They include tannins, coloring matter, oils, resins, fats, and waxes. Their name derives from the fact that they can be removed, or extracted, from the wood by neutral solvents such as water, alcohol, acetone, benzenes, and ether. The quantity of extractives in wood varies greatly; in most woods the amount is less than 10% by weight, but in some of the heavy, dark-colored woods the amount may range as high as 20% or more.

2.6.2 EXTRACTIVES AS NATURAL WOOD PRESERVATIVES. The extractives that are effective against decay seem to fall chiefly within a large chemical group known as phenolics. They vary considerably in specific composition, however, and in their preservative potency. Although some preservative extractives may occur in the sapwood, they are present in effective amounts only in heartwood. Within the heartwood of many durable species, the decay-retarding extractives tend to diminish in quantity from the outer heartwood to the center of the tree. As a rule, at a given radial position in the tree these extractives become progressively less from the base to the top of the trunk. These within-tree differences in quantity of preservative extractives are generally greater as the tree is larger and older; the greatest decay resistance in a given species is most likely to be found in the outer basal heartwood and the least resistance in the inner basal heartwood. The radial decline in resistance from outer to inner heartwood appears to be the result of chemical changes over long periods. The potent preservatives that are deposited when the heartwood is first formed gradually are altered as the heartwood ages, and become relatively ineffective compounds. This is particularly true in California redwood. Extractives that are effective against fungi are not necessarily the same as those which are effective against insects.

2.6.3 SUSCEPTIBILITY OF WOOD TO CHEMICAL CHANGE. If protected against the elements and organisms, wood is capable of giving service for centuries. It is subject to slow chemical change by oxidation but the rate is so slight as to be of virtually no practical significance. Chemical changes under water are more rapid, but these also can generally be disregarded. Users of wood are universally concerned about the rapidly destructive chemical change caused by fire, which essentially is violent oxidation of the wood. For certain special uses, something must be known about the stability of wood when in contact with certain chemicals.

2.6.3.1 Combustibility. All wood is combustible. The lighter woods will generally burn more readily than the denser woods because oxygen can get to the interior of the pieces more readily; but such differences in combustibility are usually ignored for building purposes. In the past, heavy timber construction was considerably used in industrial building to take advantage of the slow rate of burning of wood in massive form. This practice is little followed today; instead, fire-retardant chemicals are impregnated into lumber of ordinary structural dimensions, and more attention is paid to building designs that will retard the spread of fire.

2.6.3.2 Effects of Chemicals on Wood. Wood is highly resistant to a number of chemicals. For this reason, it is used for various types of tanks, containers, and equipment in which chemicals are used and for structures near such equipment that may contact chemicals through spillage, leakage, or condensation. Wood owes its extensive use in equipment largely to its superiority over cast iron and ordinary steel in resistance to mild acids and solutions of acidic salts. Iron is far superior to wood in resistance to alkalies, however, and wood is therefore seldom used in contact with solutions that are more than weakly alkaline.

Highly acidic acid salts, such as zinc chloride, tend to hydrolyze wood if they are present in appreciable concentrations. The concentrations used for fire-retardant treatment usually are sufficiently small, and are used in combination with other, neutralizing chemicals, so that strength properties other than toughness are not greatly affected under normal use conditions. The same can be said of other fire-retardant formulations. Commercial wood preservatives are considered to have no marked effect on strength; oil-type preservatives have no effect, although if excessive heat is used in treating, there will, of course, be some strength reduction. Embrittled and softened wood, accompanied by a dark gray to black discoloration, is often found around iron fastenings or plates. The weakening is due to the development of an acidic condition that results in slow hydrolysis of the wood. The acidic condition is caused by electrolytic action between particles of iron and associated impurities, which causes hydrogen to be released from the surrounding water. So-called iron deterioration is especially pronounced in acidic woods such as oak, Douglas-fir, and redwood, which contain considerable tannin and related compounds. It can be prevented by using zinc-coated, aluminum, or copper nails. The accompanying dark discoloration is produced by the combining of iron and tannins to form iron tannate, an ink-like compound (see also 2.4.2.3).

Damage by acids and alkalies can frequently be distinguished by appearance. Broadly speaking, acids tend to give wood a more or less charred appearance with a tendency to crack across the grain, whereas alkaline materials tend to make the wood fibers separate, creating a fuzzy or fibrous surface. Laboratory studies along with practical experience have shown that the chemical and biological deterioration of wood in cooling towers may be influenced greatly by chemicals present in the water in relatively small amounts. It is now recommended that the concentration of free chlorine, added as an algicide, be held at not more than 1 ppm, and that the water be kept as close to neutrality as is practical with a pH not higher than 8. Experience has shown that the heartwoods of Douglas-fir and redwood are the most suitable among practically available woods for water tanks. Douglas-fir heartwood is additionally suitable where resistance to chemicals in appreciable concentrations is an important factor. Both woods combine moderate to high resistance to water penetration with moderate to high natural resistance to decay and hydrolysis.

SECTION 2.7 NATURAL DECAY RESISTANCE OF WOOD

Consideration of the natural decay resistance of wood might logically be covered in the preceding section, inasmuch as the natural resistance is derived chiefly from chemical constituents of the wood. The subject is such an important practical one, however, that it deserves separate treatment.

2.7.1 RESISTANCE ASSOCIATED WITH HEARTWOOD. As observed earlier, any natural decay resistance of all common native species of wood resides in the heartwood only. Under conditions that favor decay, the sapwood will usually rot quickly. In a few species, such as the spruces and the true firs (not Douglas-fir), the color of the sapwood and of the heartwood is so similar that frequently the two cannot be easily distinguished. As a general rule, both the heartwood and the sapwood of such species have low resistance to decay.

Relatively young, second-growth trees generally contain a higher proportion of sapwood than those of virgin timber. Because most lumber coming from areas east of the Rocky Mountains is from second-growth timber, it contains a large percentage of sapwood. For example, there are few remaining all-heart supplies of baldcypress lumber. Consequently, it is now impractical, and for most purposes excessively expensive, to use any substantial amount of baldcypress material where decay resistance is desired.

Heartwood from virgin redwood and western redcedar timber comprises the chief source of softwood lumber with any natural decay resistance. Because of the considerable variations in the natural resistance of redwood, pressure-treated wood should be specified rather than redwood where resistance to insect and fungus attack is a firm requirement. The sometimes present natural resistance of redwood cannot be relied upon for structural protection. Douglas-fir heartwood is only moderately decay resistant in contact with the ground but in most exterior service above ground it will considerably out-perform such other untreated structural woods as the spruces, true firs, and hemlocks. However, where long life is to be desired and expected, such as in waterfront superstructures, including deck planking, only pressure-treated wood should be used. White oak heartwood has been extensively used in shipbuilding because of its combination of strength and of decay resistance through resistance to water penetration; but is is not available in sufficient amounts for general use. The heartwood of black locust has unusually high decay resistance. It is not readily available in dimension lumber, but is suitable in other respects, primarily for post wood.

2.7.2 SPECIES CLASSIFICATION FOR DECAY RESISTANCE. Comparisons of the relative heartwood decay resistance of different species must be general approximations. They cannot be precise with respect to particular species of wood because wood of the same species may vary considerably in resistance. This basis of comparison can be useful, however, if it is recognized that specific cases may differ considerably from these averages. Table 2-3 is a classification of common native United States species in groups according to the average decay resistance of the heartwood. To aid in interpreting the groupings, it may be helpful to note that fence posts containing a large proportion of the resistant or very resistant heartwood would be expected commonly to last 10 to 20 or more years and those with the nonresistant heartwood about 5 years. Similar quantitative comparisons of service life for woods in above-ground service are not available. However, it can be said that the relative lengths of above-ground service to be expected of woods in the respective decay-resistance classes are generally comparable to those of the woods when in ground contact; the actual years of service would, of course, normally be longer above ground in many geographical areas.

A number of foreign hardwoods have very high decay resistance. The most familiar one of these is teak. Among the mahoganies, those from Central and South America (species of Swietenia) might be generally classified as decay resistant. African mahogany (Khaya species) seems to have moderate decay resistance. The Philippine mahoganies (species of Shorea, Parashorea, and Dipterocarpus) have exhibited no more than moderate or slight resistance in tests. An exception is Shorea quiso, which showed high resistance. The woods classed as red lauans usually were somewhat more resistant than the white lauans.

2.7.3 EFFECT OF CUTTING PERIOD AND OF SEASONING ON RESISTANCE. The season of the year in which wood is cut is not known to have any practical effect on its inherent power to resist decay, but wood cut or peeled in late fall or winter is usually safer from immediate damage than that cut in warm weather. In cold weather decay fungi are not as active as in warm weather; so freshly cut timber exposed then may be moved to a safe place or may become dry enough to avoid fungus attack before warm weather begins.

Seasoning wood that is later to be used untreated in contact with the ground does not increase its natural resistance to decay. Seasoning may, however, have a very important influence on the life of wood to be used in certain parts of buildings or in other unexposed places. Unseasoned wood built into spaces in which it cannot dry out rapidly may retain moisture so long that decay may destroy it before it becomes safely dry.

TABLE 2-3. Grouping of Domestic Wood for Heartwood Decay Resistance

Resistant or very resistant	Moderately resistant	Slightly or nonresistant
Baldcypress (old growth)[3]	Baldcypress (young growth)[3]	Alder
Catalpa	Douglas-fir	Ashes
Cedars	Honeylocust	Aspens
Cherry, black	Larch, western	Basswood
Chestnut	Oak, swamp chestnut	Beech
Cypress, Arizona	Pine, eastern white[3]	Birches
Junipers	Pine, longleaf[3]	Buckeye[2]
Locust, black[1]	Pine, slash[3]	Butternut
Mesquite	Tamarack	Cottonwood
Mulberry, red[1]		Elms
Oak, bur		Hackberry
Oak, chestnut		Hemlocks
Oak, gambel		Hickories
Oak, Oregon white		Magnolia
Oak, post		Maples
Oak, white		Oak (red and black species)[2]
Osage-orange[1]		Pines (most other species)
Redwood[4]		Spruces
Poplar		Sweetgum[2]
Sassafras		Sycamore
Walnut, black		Willows
Yew, Pacific		Yellow poplar

[1] These woods have exceptionally high decay resistance.

[2] These species, or certain species within the groups shown, are indicated to have higher decay resistance than most of the other woods in their respective categories.

[3] The southern and eastern pines and baldcypress are now largely second growth, with a large proportion of sapwood. Consequently, it is no longer practicable to obtain substantial quantities of heartwood lumber in these species for general building purposes.

[4] This resistance <u>cannot</u> be relied upon because of variations from tree-to-tree and even within a single tree.

CHAPTER 3. WOOD DETERIORATION

When properly used and cared for, wood will give long and satisfactory service. There are three principal groups of destructive agents against which most protective measures are directed: Biological deterioration (wherein the wood is destructively used by various organisms); various types of chemical breakdown, including fire; and physical damage in the form of breakage or deformation. Fortunately, decreased utility or service life of wood due to these causes can be held to very low levels by observing comparatively simple and inexpensive precautions.

SECTION 3.1 CHEMICAL AND PHYSICAL DAMAGE

3.1.1 FIRE AND OTHER CHEMICAL DAMAGE. Some types of chemical damage to wood such as the damage caused by alkalies, by strong acids and acidic salt solutions, and by such metalic compounds as iron oxides and tannates are discussed earlier (2.6.3.2). The most destructive of all chemical changes is the rapid oxidation caused by fire. As pointed out earlier (2.6.3.1), all wood is combustible.

In the United States, fire accounts for an estimated annual property damage of $1.5 billion. A large portion of this cost involves burning of wood structures and their contents. Nevertheless, if recommended building practices are followed, the chances of catastrophic fire damage to any particular building are relatively small, as is attested by the comparatively moderate fire insurance rates.

Where fire danger is considered to be a matter of more than ordinary concern, substantial protection can be provided by impregnating the wood with certain chemicals. Chemicals commonly used for this purpose are ammonium salts, borax, boric acid, and zinc chloride. For a high degree of effectiveness, 5 to 6 pounds of the more effective chemicals are required per cubic foot of wood in thicknesses less than 2 inches, or approximately 400 to 500 pounds per thousand board feet. Lumber in thicknesses greater than 2 inches requires proportionately less material. The retentions needed are considerably greater than those required of toxic salt to control decay. The ammonium-salt fire retardants, although not fungicidal in the usual sense, will prevent decay when used in retentions required for fire control and in situations where leaching will not occur.

The principal effects of fire-retardant impregnation treatments are to retard the normal increase in temperature under fire conditions, to decrease the rate of flamespread, to lessen the rate of flame penetration or destruction of wood in contact with fire, and to make fires more easily extinguished. Fire-retardant chemicals are water-soluble and, therefore, will leach out of wood if exposed to rain wetting. Therefore, wood treated with them should be placed in strictly dry service.

Wood fire-retardancy can also be obtained by applying coatings or layers of protective materials over the surface of the wood. This means of protection is useful in existing structures. As with impregnation treatments, the amount of protection given by a coating depends on the amount and thoroughness of application and on the severity of the fire. The active ingredient of a fire-retardant coating is usually ammonium phosphate, borax, or sodium silicate. These chemicals are combined with other constituents to provide other properties required or desirable in a paint, such as adherence to wood, appearance, and brushability.

3.1.2 PHYSICAL DAMAGE

3.1.2.1 Seasoning Defects in Lumber. As wood dries, and moisture leaves the walls of the wood cells, it shrinks. With lumber, the shrinkage is never perfectly uniform throughout the piece; as a result of the uneven stresses thus created, the piece tends to warp and split. Fortunately, serious damage in these respects can generally be prevented by appropriate attention to the manner of drying. Drying lumber too rapidly, for example, will cause checking and splitting. With some woods, special care in kiln drying must be exercised to avoid internal checking, known as honeycombing.

3.1.2.1 (1) Warping and Twisting. When a board becomes bent in one plane, it may be said to be warped, and if it is bent in more than one plane it would be described as twisted; however, the two terms are used interchangeably. Warping and twisting are caused by changes in the moisture content of the wood, but moisture change does not necessarily result in these defects; there must be one or more additional factors which can cause unbalanced stressing of the lumber. Factors largely responsible for unbalanced stressing that leads to warping and twisting are unequal changes in moisture on different sides of the piece, excessive slope of grain in the piece, or the presence of compression or tension wood. Warping and twisting are among the major problems encountered in drying lumber. If lumber arrives on a construction job dry and free of serious deformation, it is not likely to cause trouble later. A tendency toward moderate warping and twisting usually is offset by the restriction imposed by nailing.

3.1.2.1 (2) Checking and Splitting. Checking and splitting commonly occur as lumber is dried from the green condition, and here also the basic cause is uneven shrinkage. Splitting is common at the ends of boards. To control it, the ends of the green stock are sometimes coated with a vapor-retarding compound, making the rate of drying from the ends more nearly the same as that from the other surfaces. Paint-type and emulsified-wax coating materials are used for this purpose.

Checking might be described as the formation of initially shallow splits in the surfaces of the lumber. Checking tends to increase in severity in surfaces that are exposed to alternate wetting and drying over long periods. Small checks that at first may be slight or invisible will gradually enlarge. Because checks will hold rainwater, they commonly are focal points of serious wetting that can lead to decay. The largest and deepest checks generally occur in the widest and heaviest lumber such, for example, as is often used for steps. That is because the bigger pieces undergo larger dimensional changes and, therefore, greater inequalities of stressing responsible for the checking.

3.1.2.2 Weather Damage. The physical damage to wood caused by the various components of weather are of two distinctly different types: the very slowly accumulating effects commonly called weathering, and very sudden destructiveness wrought by storms.

3.1.2.2 (1) Storm Effects. Among the various kinds of weather damage, storm effects are the most spectacular and in individual cases likely to be most costly. Nevertheless, buildings of wood can be made strong enough to withstand all but the worst storms - such as tornadoes.

Although not a form of weather, earthquake damage may conveniently be mentioned here. It is well established that a properly built wood structure can withstand earthquake shocks better than a conventional structure of concrete, stone, or brick. The joints in a wood building are comparatively strong and yet have sufficient flexibility to absorb the stresses caused by quakes.

3.1.2.2 (2) Weathering. Wood that is exposed to the weather undergoes surface changes referred to as weathering. The surface tends to assume a grayish color, and the outermost fibers of wood become separated so that they can easily be scraped away with a knife blade or a fingernail. In addition, weathered wood when dry usually will reveal numerous closely spaced small checks. Another conspicuous feature of weathered wood commonly noted in softwood species is a sharply ridged surface; this is caused by the early wood in the annual rings eroding away more rapidly than the harder latewood. In some situations, such as at the tops of poles, posts and exposed piles, water collecting in the eroded areas leads to early decay.

Weathering is caused by a combination of factors. In addition to the rain erosion of the springwood, moisture is important in other ways. Repeated moisture changes at and in the surface of exposed wood cause dimensional changes at surface which do not occur at depth. This repeated stressing effects a separation of the outermost wood fibers as well as causing many checks which are initially small. Frosts can have even more immediate and drastic effects at the surface; and hard freezes involving penetrated water carry the surface effects to depth. Sunlight alone can cause a slow type of weathering by actinic degradation in which the polymeric structure of cellulose is broken down to shorter and shorter groups - finally to molecules of a hydroglucose ($C_6H_{10}O_5$) and water. Sandstorms cause a type of damage more like weathering than like typical storm damage. Some soft-rot and mold fungi (3.2.1.3(4)) are frequently found associated with surface weathering and may play an active role.

Weathering can be prevented and splitting and warping lessened by keeping wood always well painted. It is not economical to paint merely for this purpose, however, as the cost of repeated paintings in time exceeds the value of the wood. But painting or some other form of surface protection against the weather--such as a water-repellent stain--is generally well worthwhile for the sake of appearance.

3.1.2.2 (3) Weakening of Fastenings. In addition to weathering of the kind that affects mainly the surface, weathering also may appear in the form of splitting and loosening of boards at their fastenings. Such effects are caused by stresses brought about by repeated changes in dimension with changes in moisture content of the wood. The wood upon wetting swells against the initially tight fastening. In doing so, the cells near the fastener are stressed beyond their elastic limit and become permanently collapsed. When the wood again dries, the opening for the fastener is larger because the collapsed cells take up less space. As the cycle is repeated, loosening is accentuated. The greatest and most frequent dimensional changes of significance normally occur in wood that is exposed to rain wetting followed by direct sunshine. Consequently, building features that minimize these extremes of exposure can go far toward reducing mechanical weakening of the structure.

3.1.2.2 (4) Paint Failure. Exterior paint is subject to weather damage, as is familiar to anyone who has had to contend with checking, cracking, crumbling, or flaking of a paint finish. These forms of paint deterioration are the result of a combination of factors, among which wetting and micromovements of the paint and underlying wood, and the character of wood surface, have a dominant influence. During the first year or two after an exterior wood surface has been painted properly, the nature of the wood usually has little effect on the behavior of the paint coating. But later certain coatings become somewhat embrittled and the character of the wood then may determine how rapidly the coating disintegrates. As the moisture content of the wood changes, localized variations in dimensional change over the surface seem to influence paint failure. Large amounts of summerwood, or knots, present especially dense areas of wood, which are high in swelling and shrinking.

Wood characteristics that favor the persistence of a good exterior paint coating are: (a) light weight, (b) narrow growth rings, (c) edge-grain rather than flat-grain surface, (d) absence of knots or other degrading surface imperfections, and (e) proper seasoning of wood. Almost all native softwoods of commercial importance can be kept well painted for long periods if proper care is given to selection of primers and paints and to choice of programs of maintenance in accordance with the painting characteristics of the wood. Species on which exterior paint can be most easily maintained are the edge-grain surfaces of cedars, baldcypress, and redwood. Softwoods that require more care with paint maintenance are the flat-grain surfaces of Douglas-fir, red pine, southern yellow pine, tamarack, and western larch, all of which have relatively pronounced bands of summerwood.

The "chalking" of paint is a normal process of weathering. This is not usually regarded as a disadvantage because the chalking automatically eliminates the oldest and dirtiest paint, thus tending to keep the surface relatively cleaner and brighter than it would otherwise be. Chalking also reduces the thickness of the paint coating after repeated painting, which is an added advantage because thick coatings are especially prone to flaking.

Rain wetting resulting in paint failure on siding is due chiefly to water that gets behind the siding or that enters it at the ends. Paint peeling on siding near windows and doors can be attributed to rainwater entering the board ends, after penetrating the joints between siding and window or door frames. Entrance of rainwater along the edges of the siding may cause trouble anywhere along the surface. One of the most practical means of retarding entrance of rainwater at siding joints is to treat the joints with a water-repellent solution (5.3.2).

3.1.2.2 (5) Removal of Natural Preservatives. All natural preservatives of wood are to some extent water soluble and, therefore, will leach out in time if the wood is placed in service in direct contact with water and even if it is exposed to rain wetting or damp ground. The rate of leaching is generally rather slow if only occasional rain wetting is involved, so, for such semi-protected exposure, if an item is large in cross section, many years of service could be obtained from highly resistant woods before the losses allow serious fungus attack. Differences in heartwood resistance to decay among different species of wood appear to be determined much more by the potencies of the respective preservatives than by differences in the susceptibility of the preservative extractives to leaching. Where a firm requirement exists for resistance to biological attack, pressure-treated wood should be used; natural resistance should not be relied upon. (See Chapter 6.)

3.1.2.3 Heat (Kiln Drying). The rapid oxidation of wood caused by fire has been described as a form of detrimental chemical change (3.1.1). Heat at lower temperatures can sometimes also produce detrimental changes in wood.

Many lumber mills employ kilns for drying lumber rather than relying on air drying and on the vagaries of the weather. Kiln drying is faster than air drying, and so reduces the chances of down-grading of lumber due to surface molds and blue-stain fungi. Kiln drying is usually more thorough than air drying and so provides a greater reduction in weight and in shipping costs. Kiln drying can reduce the moisture content of wood to that which it would be expected to reach in service in a given location, and so can provide for dimensional stability in completed wooden structures. As the moisture is removed, so are naturally existing organic liquids (such as turpentine) removed from wood resin. This has the effect of setting or hardening the resin so that it cannot later move or be a problem in painting. Kiln drying is often used to remove water from wood as a first step in preparing it for preservative treatment, and is often used as a follow-up for wood treated with water-borne salts.

With all of its advantages over air drying, kiln drying has some disadvantages that are sometimes serious in that it can reduce the strength of wood. It can detrimentally affect the specific gravity, the crushing strength, the bending strength, the toughness, and the manner of failure in impact tests. In some tests, temperatures of 280°F had conspicuously greater effects in reducing strength than did temperatures of 220°F; but optimum drying temperatures varied with wood species. The amount of damage done relates to both time and temperature. Modern kilns are high temperature kilns, but they are high speed kilns so that properly stacked lumber is dried and removed from the kiln before any appreciable damage is done. However, large-dimension timbers require greater exposure periods, and if dried in high temperatures kilns they can be damaged. Considerable damage has been done to some marine piles treated to high retentions of water-borne salts or given the dual treatment (5.3.1.2(3)) when they were kiln dried both before and after the salt treatment. Damage has been so severe that the piles could not be handled in the treating-plant yard without breakage.

SECTION 3.2 FUNGUS DAMAGE AND BACTERIAL DECOMPOSITION

On the whole, fungi destroy more wood than do any other organisms. The fungi in their simple growing stage are branched, thread-like bodies, some of which are barely visible to the naked eye. Technically, one of the thread-like bodies is called a hypha, and a mass of hyphae is known as mycelium. When conditions are suitable, the mycelium of a given fungus will form into special structures known as fruiting bodies of sporophores, on which are borne simple microscopic objects called spores. The spores are analogous to seeds and may germinate to produce new hyphal strands. Fruiting bodies of different fungus species differ from one another in appearance, and this furnishes the chief means of identifying the respective species and of classifying the fungi generally. Various mushrooms, for example, are fruiting bodies of different species of fungi growing on wood or other plant debris in the ground.

3.2.1 CLASSIFICATION OF FUNGI. Botanically, the fungi are plants, but unlike the higher plants they have no chlorophyll. Therefore they cannot manufacture their own food, but instead must depend on food already produced by green plants (e.g., wood). Fungi convert the wood, which they are invading, chiefly into carbon dioxide and water. Thus, the wood being attacked loses weight and strength. The degree of damage depends considerably on the type of fungus.

3.2.1.1 Biological Position of Fungi. As has been noted, fungi are low forms of plant life without chlorophyll, which must depend on organic material for nourishment.

Fungi may be broadly placed in two groups: Parasites, which are capable of destroying living cells, and saprophytes, which attack only dead materials. Many parasitic fungi damage or destroy living trees. The fungi that invade wood are mostly saprophytes; the wood cells must be dead or at least dying before these fungi will enter them.

Fungi are classified for identification according to sex characteristics: primarily the kind of structure on which or in which their spores are borne, and secondarily, according to difference in makeup and appearance of the spore-bearing structures or of the spores themselves.

3.2.1.2 Fungi in the Living Tree Versus Those in Wood Products. Wood-attacking fungi occur in the living tree as well as in wood products. The most prevalent, conspicuous, and costly form of fungus damage to wood in the tree is known as heartrot. One of the most familiar heartrots is seen in pecky cypress, which is used for some decorative paneling; another is the so-called "white pocket" that is common in low-grade lumber from over-mature stands of Douglas-fir. Heartrot fungi are saprophytic, and typically do not invade healthly, living sapwood cells.

In general, heartrot fungi do not progress seriously in wood products, and therefore are of little concern after wood is placed in service. Conversely, most fungi that attack wood in service do not occur to any significant extent in the living tree, and those that do are usually of minor significance.

3.2.1.3 Grouping of Fungi According to Damage Caused. Wood-attacking fungi have popularly been classified into four principal groups according to the kind of damage they cause. These are the molds, the sap stain fungi, the decay fungi, and the soft-rot fungi. A fifth group is recognized by those who believe that soft-rot fungi, found in a marine environment, should be called marine fungi. This scheme of classification has practical advantages but the technical distinctions in many cases are not sharp. Mold and sap stain fungi live on the cell contents such as sugars and starches. Decay and soft-rot fungi break down the cell walls.

3.2.1.3 (1) Molds. If the fungus discoloration is largely superficial and can be removed by brushing or shallow planing, it is commonly termed "mold." In coniferous woods the discoloration imparted by molds typically is caused by the color (green, black, orange) of masses of spores produced by the surface mycelium. In most hardwoods the wood itself often is superficially discolored-typically in the form of dark spots of various sizes. Molding does not seriously affect the strength of wood, but heavily molded wood is objectionable where strength is of prime importance. Its presence signifies that moisture and temperature conditions have likewise been favorable for the development of decay fungi; hence incipient decay may be present but not observed because of masking by the mold. Also, molding can make wood more permeable to rainwater, as previously mentioned (2.5.4.3), and thus more subject to decay infection in exterior service.

3.2.1.3 (2) Sap Stain Fungi. Sap stain fungi, as the name implies, discolor the sapwood. This discoloration is brought about by the dark color of the mycelium of the invading fungus. Unlike the relatively shallow discoloration that may occur with molding, sap stain tends to go deep into the wood. Thus, it constitutes permanent blemish which cannot be surfaced off. The color of sap stain usually ranges from a brownish gray or steel gray to almost black, depending on the fungus and wood species. Sap stain fungi usually do not seriously affect most strength properties, but toughness (shock resistance) may be reduced by 12 percent or more. Also, wood that is heavily stained may, even more than heavily molded wood, harbor incipient decay, and it invariably will be more permeable than sound wood.

3.2.1.3 (3) Decay Fungi. As the name implies, the fungi that cause decay or rot seriously reduce the strength of wood as well as cause the lesser form of degradation noted for the molds and sap stain fungi. Whereas the molds and stain fungi do not ordinarily damage the cell walls in the wood microstructure, decay fungi depend primarily on the walls for their source of food. The cell walls may, in fact, be severely affected by the biochemical action of these fungi before there is any pronounced change in the external appearance of the wood. Thus, even early decay can dangerously weaken a wood structural component, and advanced decay can render it entirely useless.

Two major kinds of decay fungi are recognized - those causing brown rot and those causing white rot. With brown rot, only the cellulose is extensively removed, the wood takes on a browner color, and it tends to crack across the grain and to shrink and collapse. The name "dry-rot" has sometimes been given to brown-rot when first seen in a dry condition. With white rot, the lignin is removed and cellulose may also be removed by some species; the wood may lose color, and appear "whiter" than normal, it does not crack across the grain, and until it has been severely degraded it retains its outward dimensions and does not shrink nor collapse.

3.2.1.3 (4) Soft Rot Fungi. Another form of severe wood degradation-known as soft rot was unrecognized until comparatively recent years. Soft rot tends to be shallower than typical decay, and often can be distinguished by this characteristic. However, white rot which is initially shallow and easily compressed may be mistaken for soft rot. At the depth to which it is present soft rot may cause such severe breakdown that the wood becomes conspicuously soft especially when wet. The transition between the rotted wood and the wood beneath often is very abrupt; if one scrapes away the damaged wood with a knife the blade may suddenly strike wood that seems to have almost normal hardness. Cracked and rough surfaces on weather beaten wood may often be infected with soft rot fungi which are thought to be responsible for a considerable amount of the surface deterioration commonly ascribed to "weathering". The soft rotters are of an altogether different class of fungi from those that cause the more familiar and destructive decay. Physiologically, they also seem to tolerate both wetter conditions and drier conditions. The wettest parts of cooling towers, for example, are notably subject to soft rot. Some of the molds and sap stain fungi can cause soft rot if appropriate conditions are present for a long enough time, but the periods required usually extend substantially beyond those required for processing and handling lumber.

As soft rot for the most part is relatively shallow and progresses inward rather slowly, it ordinarily is not of great concern to the wood user. But where the wood member is comparatively thin, as in the case of the fill members of a cooling tower, even rather shallow soft rot can cause severe loss of strength. Most fungi decaying wood in the marine environment are soft rot fungi.

3.2.1.4 Bacterial Decomposition. Bacteria as well as fungi can invade wood. Bacteria have been troublesome in ponded pine logs in which they remove certain sapwood constituents, resulting in increased porosity of the wood. This makes the wood more susceptible to serious rain wetting later; also, millwork of this wood absorbs excessive amounts of preservative solution when dip treated. Occasionally, they weaken wood seriously, but normally they do not affect strength materially.

3.2.2 DEVELOPMENT AND SPREAD OF FUNGUS INFECTION

3.2.2.1 Growth of Fungi in Wood. Wood-attacking fungi penetrate and ramify inside wood until they reach all the individual cells in zones having favorable moisture content and temperature for fungal growth. The thread-like hyphae grow from one cell to another in two ways: they go through the pits - which are the thinnest part of the cell wall (Figure 2-2) - and at some stage in their development they penetrate the cell wall at places other than the pits. Enzymes and acids produced at the advancing hyphal tips dissolve holes in the wood cell walls through which the hyphae grow. These openings in the cell walls are commonly called "bore holes." Penetration by means of bore holes is particularly common among decay fungi; if many bore holes are observed in the course of microscopical examination, this is usually considered positive evidence of infection by a decay fungus. Enzymatic action also causes the more general destruction of the cell wall with either decay or soft rot.

3.2.2.2 Spread of Fungi to New Wood. Wood-attacking fungi may spread from one piece of wood to another in any of three ways:

(1) Direct Contact. The fungus can grow directly from one piece into another with which it is in contact. Moist, sound wood is especially vulnerable to infection in this manner. An analogous situation occurs if decay-susceptible wood is placed in contact with moist ground. Fertile soil harbors all kinds of fungi that are capable of invading wood.

(2) Resistant Spores. Wood-attacking fungi spread themselves more widely-often for great distances - by means of spores. Spores are analogous to the seeds of the higher plants in their function, but they are much simpler; those of the wood attackers commonly are composed of but a single cell. These tiny bodies are transported in innumerable quantities by wind, insects, and water, and those that come in contact with susceptible wood may germinate and create new infections.

(3) Living Fragments. Fragments of hyphae on the surface of wood can also be carried about like spores and start new infections, but their relative importance in this respect is not known.

Spores of various types are produced both on the simple mycelium and on special structures formed by the mycelium. These structures are called fruiting bodies or, more technically, sporophores. The larger fruiting bodies of decay fungi are rather familiar sights; they appear on tree trunks, logs, dead branches, and rotting structures as small to moderate sized shelf-like bodies. A few are umbrella-like in form and belong to the same botanical group as the mushrooms. Millions of spores may be produced by single sporophores such as these. Because the spores are so light and readily transported, there is danger of spore infection anywhere that susceptible wood becomes sufficiently wet and the temperature is favorable.

3.2.3 RECOGNITION OF FUNGUS INFECTION. Advanced decay is familiar and easily recognizable by odor, by discoloration, by loss of strength and hardness, and by shrinkage and collapse. Early or incipient decay, on the other hand, may not be readily apparent but nevertheless is a cause for concern because of possible serious strength losses accompanying progression of decay. It is important that those who build load-bearing structures of wood be acquainted with the initial signs of decay infection.

3.2.3.1 Infection Denoted By Discoloration. As decay progresses, it often imparts to wood an abnormal color. On smooth surfaced wood the discoloration commonly will show up as a shade of brown deeper than that of the sound wood. With other species of wood or fungi a lighter shade of brown may be produced. In still other cases the surface might be called "white" or bleached. If such bleaching is accompanied by fine dark lines (zone lines) on the wood, decay infection is virtually certain. Bleaching of areas of blue-stained or molded wood is highly indicative of decay. Staining or molding, if present, typically occurs first, and subsequent infection by a decay fungus tends to mask or remove the preceding discoloration. Bleached spots or streaks on a dark background of discolored wood are especially prominent. Often an abnormal variation in color, creating a mottled appearance, is more helpful in detecting early decay than the actual hue or shade of discoloration. Along with the color change, there may also be an absence of normal sheen on the surface of the infected wood. Obviously, familiarity with the normal appearance of the wood can be of great help in diagnosing wood for early decay on the basis of color abnormalities. Occasionally, in relatively damp situations, the presence of infection will be denoted by surface growth of the attacking fungus.

3.2.3.2 Loss of Strength and Hardness. Where color leaves one in doubt as to whether wood has undergone decay, simple tests of the toughness of the wood fibers, and of hardness, can often be quite conclusive. Toughness is the strength property most severely reduced by early decay. The so-called "pick test" is the most helpful and widely used simple means of assaying wood for diminished toughness. An ice pick, small chisel, sharpened screwdriver, or similar sharp-pointed or edged instrument of tough steel is jabbed into the wood a short distance, and a sliver pried out of the surface. The resistance offered by the wood to lifting and the character of the sliver when it finally breaks are indicative of its toughness. Sound wood tends to lift out as a single long sliver or as two relatively long ones before breaking and the breaks are of a splintering type. Where there has been an appreciable loss of toughness, the wood tends to lift out with less than usual resistance and usually two relatively short slivers are developed. These short slivers break brashly at points of fracture, that is, square across the grain with virtually no small slivers protruding into the zone of fracture.

On infested lumber that has been planed, the lesser toughness of wood with early decay is sometimes manifested by surface areas that are abnormally rough or fibrous. Similarly, the end grain of an infested board or timber may be rougher than usual after sawing.

When using reduced toughness as a criterion of infection, it should be kept in mind that compression wood, tension wood, or compression failures also may affect toughness (2.5.2.6). There usually need be little doubt about infection, however, if the weakening is accompanied by discoloration.

The hardness of infected wood is reduced and this can be detected in many cases by prodding with a sharp tool. Softening, however, usually is not evidenced as early or as clearly as a decrease in toughness.

3.2.3.3 Shrinkage and Collapse. Frequently, decay in the more advanced stages causes the wood to shrink and collapse. Under paint, this may be manifested by a depression in the surface-providing the first evidence that the wood beneath is decaying. Often the paint itself may acquire a brown discoloration from soluble materials migrating from the interior zone of decay to the outside.

3.2.4 GROWTH REQUIREMENTS OF FUNGI. In forestalling or combatting fungus attack without resorting to preservative treatment, it can be of great help to know what conditions favor the development of the organisms and what conditions inhibit them. Wood-attacking fungi have four requirements for their development: source of food; air (oxygen); a favorable temperature; and a suitable supply of water. Through the control of one or more of these requirements, growth of fungi can be restricted and damage to wood prevented.

3.2.4.1 Food Requirements. Wood-attacking fungi depend on constituents of the wood for their nourishment. They do not all depend on the same constituents however. In the course of mold and sap stain development, the causal fungi are for the most part limited to sapwood, and ordinarily to nonstructural elements in the sapwood such as sugars and starch. Heartwood is not suitable for mold and sap stain fungi because it does not contain these nutritional elements in sufficient amount. Decay fungi, as noted, depend largely on the cell wall itself; therefore they can be nourished by either heartwood or sapwood, and attack both.

Wood can be made unavailable to fungi by keeping it dry or by "poisoning" it with a preservative chemical. The fact that heartwood of some timber species contains naturally occurring preservative chemicals and can resist infection without special treatment was covered in 2.7. Such natural resistance should not be depended upon for construction.

3.2.4.2 Need For Air. All wood-attacking fungi need air for a supply of oxygen. However, they can grow with a greatly restricted supply of oxygen, maintaining essentially a normal rate of development with the oxygen concentration reduced to a level considerably below that of ordinary air. Normal growth by a prominent decay fungus has been observed at oxygen concentrations ranging between one-fourth and one-fifteenth (depending on the temperature) of the amount usually present in air. But no wood-destroying fungi will grow if the oxygen pressure is much less than the one-fifteenth amount, which is equivalent to a partial pressure of about 10 millimeters or an average concentration of about 1.3 percent.

If wood is held under water it cannot receive sufficient oxygen to support serious fungus attack. One of the earliest and simplest means of protecting stored logs is to submerge them in fresh water ponds. Similarly, good protection against fungi can be obtained by keeping the logs wet with a water spray, but water spraying can lead to sapwood infection by bacteria and molds with resultant undesirable increases in permeability. Certain specialized strength reducing fungi, the soft rot fungi, can invade wood under water but their damage is typically quite shallow and would ordinarily be overlooked. Such fungi obviously are able to get along with less oxygen than those that give trouble on land. The fungi that grow superficially on wood in salt water, the "marine fungi", are of additional interest because they are believed by some to make the wood more susceptible to attack by marine borers.

3.2.4.3 Temperature Relations. Wood-attacking fungi require moderate temperatures for rapid development. Decay fungi can attack wood, although very slowly, when the temperature is a few degrees above freezing, and some of them are able to maintain their attack at the opposite end of the temperature range up to a little above 100°F. The majority of decay fungi can attack most rapidly in the temperature range 75° to 90°F. As a rule the rate of damage caused by them will be relatively slow at temperatures below 50°F, and it will fall off markedly with temperature increased to above 90°F. The molds seem to be somewhat more tolerant of temperature extremes than the wood destroyers, and some molds cause serious damage to wood at temperatures lower than those favoring decay.

Subzero temperatures do no permanent harm to wood-attacking fungi, but high temperatures will kill them. The lethal effect of a high temperature depends on the specific temperature and the length of time over which it is applied. To kill most fungi, the temperature need not be far above the level required to inhibit growth, but at such temperature a rather long time is required. For decay fungi, anything less than about 150°F would not be practical as an eradication measure because it would have to be held for an excessive length of time. If decay fungi are subjected to wet heat, many will be killed at 150°F in 1 to 1 1/2 hours; at 170°F in 30 minutes, at 180°F in 20 minutes, and at 200°F in 10 minutes. At 212°F probably none of the fungi survive for more than a few seconds. In sterilizing lumber or larger material by heating, sufficient time must be allowed for the center of the piece to reach the required temperature. Precautions must be taken to avoid reducing wood strength if heat is used for sterilization (2.5.2.2 and 3.1.2.3).

3.2.4.4 Moisture Requirements. Serious decay will occur only when the moisture content of the wood is above the fiber saturation point (approximately 30 percent above oven-dry weight). This amount of moisture cannot be developed from moist air but requires wetting of the wood by water (2.5.4). It follows that initially dry wood which is kept under dry shelter and protected against condensation will not have sufficient moisture to rot.

As a precaution against decay, the recommendation is frequently made that lumber be dried to a moisture content of 20 percent or less. This may be confusing to those who are aware of 30 percent minimum moisture level. The lower figure is advocated to provide a margin of safety. An average moisture content of 20 percent can be easily attained by air drying, but in a load of dried lumber a number of boards may have a moisture content considerably above the average for the group. Also, to minimize dimensional changes, the moisture content of lumber at the time of construction should be substantially below 20 percent. Ideal moisture contents for interior finishing, for example, vary with the region, because of differences in climate.

The optimum moisture content for decay covers a rather broad range from some point not far above the fiber saturation level to somewhere between 60 and 100 percent. The upper moisture level for rapid decay is determined to some extent by the specific gravity of the wood. The same is true for the maximum moisture content at which decay can occur. The cross-sectional size of the wet wood has a bearing here also, as the upper moisture limit for decay is determined by the rate of air exchange between the inside and outside of the piece.

3.2.4.4.1 Meaning of "Dry Rot". The term "dry rot" is an unfortunate misnomer because it implies that wood can decay without getting wet. Actually, it cannot. This notion of rot occurring in dry wood probably originated from the appearance of brown-rotted wood (3.2.1.3) when dry. Wood that had undergone brown rot often looks unusually dry, being brown and cracked as though it had been severely heated.

3.2.4.4.2 Water-Conducting Decay Fungi. Certain decay fungi, sometimes called water-conducting fungi, can conduct water over a considerable distance from an external source, such as in the ground, to the wood that they are attacking. In some cases the wood may rot even though it was initially dry and was covered. Decay caused in this way also is sometimes called dry rot. Even for this specialized type of decay; however, the generalization still holds that the wood must be wetted in advance before it can be attacked. From the practical standpoint, the means of protection here against wetting must be aimed directly at the fungus rather than at one of the usual sources of moisture. There are only two important species of water-conducting fungi. Fortunately, decay by the water-conducting fungi, although often severe in individual cases, is comparatively minor in the overall building-decay picture. Damage by these fungi is not often found in the United States outside the milder climates in which subterranean termite damage is serious.

SECTION 3.3 INSECT DAMAGE TO WOOD

A great variety of insects belonging to several major biological orders attack living trees. Only a comparatively few destroy seasoned wood. In the order Hymenoptera are the carpenter ants and carpenter bees. The various types of termites all belong to the order Isoptera; and though they are commonly called "white ants", they are considerably different from all of the hymenopterous insects. The third order of insects important in the destruction of wood is Coleoptera which contains the beetles.

3.3.1 CARPENTER ANTS AND BEES. Both carpenter ants and carpenter bees bore or tunnel into wood, and so can be destructive. But the purpose of the boring is not really the same.

3.3.1.1 Carpenter Ants. Carpenter ants are so named because they tunnel into wood and excavate to provide the galleries that form a home for the colony. Although they are general feeders and will not eat the wood, they can sometimes do serious damage. Common black carpenter ants are large ants, sometimes over 1/2 inch in length. They build their nests in a variety of places, such as the dead heartwood of living trees, logs, house timbers, poles, and almost any wood material. They are most destructive in soft woods. Most of their tunnels are approximately parallel and run lengthwise with the grain of the wood. Other shorter tunnels that cut across the grain connect the longer parallel tunnels within the wood and open to the outside. Where wood is seriously damaged by carpenter ants, it should be replaced. Controls for carpenter ants are provided (4.6.1.1).

3.3.1.2 Carpenter Bees. Carpenter bees belonging to genus Xylocopa are large bees, sometimes an inch long. The majority of these bees are found in the southern portions of the United States and in the Tropics. Carpenter bees, like carpenter ants, do not eat wood but excavate tunnels for nesting sites. Unlike ants and some other bees, carpenter bees are not social insects developing large colonies. Tunnel openings are usually perfectly round, or nearly so. The tunnels, which may extend as much as a foot, are divided into brood cells. In each cell is placed one egg and enough food to last the bee larva until time for pupation and development of the adult. The occasional tunneling of structural timbers by carpenter bees should cause no alarm to building occupants; however, repeated attacks in the same area may result in significant damage. Controls for carpenter bees are provided (4.6.1.2).

3.3.2. WOOD-DESTROYING BEETLES

3.3.2.1 Powder-Post Beetles

3.3.2.1.1 A Group of Beetles. Powder-post beetles are so named because of their ability to reduce wood to finely powdered frass. They belong to four families: (1) Lyctidae, the lyctus powder-post beetles; (2) Bostrichidae, the large powder-post beetles; (3) Anobiidae,the deathwatch beetles or anobiid powder-post beetles, and (4) Ptinidae, the spider beetles. The larval stages of the beetles comprising these four families are so similar that accurate identification is difficult. The larvae are white or yellow, soft-bodied and hairy, with well-developed, five-jointed legs. The larval mines are tightly packed with frass. Most powder-post beetle larvae can work in dry, well-seasoned wood, damaging finished products such as tool handles and gun stocks, joists, beams, and flooring, and high grade lumber in storage. The replacement costs of the damaged wood and the inconvenience caused by attack are often of greater consequence than the actual loss of material. They are moved from one storage area to another in infested supplies and infested pallets.

3.3.2.1.2 Recognition Characters and Biology. (1) *Family Lyctidae*. The beetles are small (1/8 to 1/4 inch long), slender, slightly flattened or oval, and dark-brown to black. They cause annual losses of thousands of board feet of seasoned lumber and large supplies of tool handles and gun stocks. They readily attack the sapwood of large-pored hardwoods. Ash, hickory, pecan, oak, and walnut are particularly susceptible to attack. The eggs are laid in the large pores of the wood, a factor that determines the type of hardwoods attacked. Wood with moisture content of about 15 percent or less is most susceptible to attack and destruction. The two most destructive species of *Lyctus* in the eastern half of the United States are *Lyctus planicollis* and *Lyctus parallelopipedus*. *L. parallelopipedus* can complete its life cycle in 3 months in the extreme South, whereas other species there take from 9 to 12 months. All species in the North require 1 year under outdoor conditions.

(2) *Family Bostrichidae*. The large powder-post beetles belong to this family. The beetles are reddish, brown, or black, 1/8 to 3/4 inch long, and cylindrical. The heads of both anobiids and bostrichids are directed downward and are covered by a "hood." Some species infest hardwoods, and some infest softwoods. Many of them may be imported in lumber or in such wood products as veneer plyboards and furniture, where their destructive action on a limited scale may result in considerable financial loss. The red-shouldered shothole borer, *Xylobiops basilaris*, is probably the most common bostrichid of the East, attacking practically all freshly cut and partially seasoned hardwood, and frequently is injurious to furniture and rustic work. *Polycaon stouti* is an important powder-post beetle in California, attacking willow, hickory, many other woods, and furniture. It is especially injurious to veneer plyboard, attacking the center softwoods, like bass wood. Such veneer stock frequently becomes infested while in storage prior to being made into furniture. The bamboo powder-post beetle, *Dinoderus minutus*, infests bamboo and bamboo products such as furniture, blinds, baskets, fans and fishing poles. It is very destructive in the West Indies and is frequently shipped to this country in bamboo articles.

(3) *Family Anobiidae*. Anobiid powder-post beetles are small, usually 1/8 to 1/4 inch in length. The family is represented by a number of destructive species, some attacking both softwoods and hardwoods, and some being selective. The larve can cause considerable damage. The common furniture beetle, *Anobium punctatum*, is a small, elongated, subcylindrical, brown beetle, about 1/8 inch in length. The larvae often damage pine flooring, joists, and furniture. *Ptilinus ruficornis* is a small black, cylindrical beetle, about 1/8 inch in length, which rather commonly infests hardwood woodwork in houses and stored wood products. The death-watch beetle, *Xestobium rufovillosum*, is an oblong, rather stout beetle, 1/4 inch in length, dark brown, and spotted with patches of yellowish hairs. It is occasionally found in the woodwork of moist cellars in the New England States.

(4) *Family Ptinidae*. Of this family, the most widely known beetle is the brown spider beetle *(Ptinus brunneus)* which may occasionally damage pine

boards in old buildings. The white-marked spider beetle (Ptinus fur) is a small, brown, oval, long-legged beetle, about 1/8 inch in length, which resembles a spider. It is frequently found in buildings and warehouses, where it generally feeds on dried vegetable or animal matter, but it has been found boring in pine and oak woodwork.

3.3.2.2 Power-Post Borers (Cerambicidae)

3.3.2.2.1 The Roundheaded Borers. These borers belong to the family Cerambycidae; and as a group the larvae are generally referred to as roundheaded borers while the adults are called long-horned beetles. They are primarily feeders on dry woods. Under natural forest conditions, they play an important role in the reduction of dead trees to permit new growth. Their destructiveness in structural woods, however, can result in considerable economic losses. The roundheaded borers can be distinguished from all other wood-boring larvae by a few prominent characteristics. They are fleshly, thin-skinned, white or yellowish, and more or less cylindrical. Though they may taper posteriorly, the anterior segments are never suddenly and conspicuously larger than the following segments. The larvae may or may not have small legs. Within this family, the oviposition habits of a species is one indicator of its specific destructiveness. Usually, the eggs are placed firmly in deep crevices of the bark; others are deposited by strong ovipositors deep within the bark or wood; still others, like the eggs of the old house borer, are deposited in season checks of exposed wood. The one group of greatest importance as structural pests is composed of those roundheaded borers found typically in dry, seasoned wood. Though oviposition in this group may take place where trees are felled (certain borers attacking only recently cut wood), the use of infested wood for construction can result in serious destruction later. Borers that attack only freshly cut wood normally develop in a year or two. However, if the wood is stored or used under dry conditions after attack, the active larval period may be extended several years, and occasionally 8 to 12 years. These powder-post borers (not to be confused with powder-post beetles) may continue to work in the same wood until nothing is left but a thin outer shell filled with powdery frass. Their activity may often be indicated by the presence of small piles of powdery dust collecting beneath infested timbers. Though the larva of a single powder-post borer can effect considerable damage, the fact that most species do not deposit eggs on wood after it has seasoned limits the danger of reinfestations and the total damage. The exception is the old house borer.

3.3.2.2.2 Recognition Characteristics and Biology. (1) The Old House Borer, Hylotrupes bajulus. This beetle places its eggs in the season checks and crevices of wood, and can infest seasoned wood years after it has been used for construction. It attacks only coniferous wood. It attacks the sapwood but not the heartwood. It is a European species that has become well established in this country and is becoming more abundant and destructive each year. In Europe and South Africa, it is a major insect enemy of coniferous wood. The adult Old House Borer is a flattened, slaty-brown beetle, about 1/2 to 3/4 inch long. The thorax is rounded, with several small tubercles at the sides, and has a black polished line and spots on the disk. The wing covers are marked with whitish spots which form two irregular bands across their middle. Distinguishing characteristics of the larva are the thin texture of the skin, the fact that the head is wider than long, the apex of the mandible is rounded, and there are three ocelli on each side of the head. The prothorax is smooth and shining. Legs are present. The larval mines are loosely filled with frass, which is composed of tiny pellets and fine powdery material. The Old House Borer completes its life cycle in 5 to 7 years in the North, and usually in 3 to 5 years in the South.

(2) The Flat Oak Borer, Smodicum cucujiforme. This is a small, elongate, dorso-ventrally flattened, shining beetle of dull yellow color, that is 1/3 to 2/5 inch long. The species occurs throughout the Eastern States. The larvae excavate long meandering galleries in the dry heartwood of oak and hickory, packing them tightly with fine granular frass. The pupal cell is merely an enlargement of the gallery brought near the surface of the wood and it may be in either sapwood or heartwood. Stored lumber is frequently infested, the larvae continuing to feed in it until the wood is thoroughly riddled. Although the life cycle may be completed in 1 year in green logs and under forest conditions, the drying of timber may extend the period of larval development for several years.

(3) The Ivory-Marked Beetle, Eburia quadrigeminata. This beetle is elongate, 1/2 to 1 inch long, and pale yellow. It has two pairs of ivory-white spots on each wing cover, the first pair longitudinal and near the base, and a second similar pair just behind the middle of the wing. The larvae are robust and wedge-shaped, tapering posteriorly, with tough, shining integument sparsely covered with golden hairs. The legs are distinct, long, four-jointed. The heartwood of hardwoods is seriously damaged by the large, contorted larval mines, which are tightly packed with frass. Mature trees having "catfaces," or scars, through which the larvae can reach the heartwood are often badly damaged. Lumber in the process of seasoning is also subject to occasional attack by the adult beetles. Oak, hickory, ash, chestnut, maple, and cypress are susceptible to infestation. Beetles sometimes emerge from flooring or furniture several years after they are placed in buildings.

(4) The Bamboo Borer, Chlorophorus annularis. This is an elongate, subcylindrical, blackish beetle, about 2/5 inch long, with x-shaped markings of yellow on the wing covers. The outer part of the 11-jointed antennae is black and the inner is red. The first two pairs of legs are red and the third pair black. The mature larvae are about 3/4 inch long and are slender, with one ocellus on each side of the head. The legs are minute and 3-jointed. They make long mines in the culms of bamboo, packing the fine powder tightly behind them as they bore. They are a serious pest of bamboo in Japan and India, and may become established in this country where quantities of stock are kept in storage continually. Infested material has been found in a number of states including California, Oregon, Michigan, Georgia, and Texas.

(5) Other Roundhead Borers. Many other cerambycids attack wood under a variety of conditions. They may be found occasionally in buildings or in stored lumber where, in rare cases, they may do considerable damage. Because their attacks on clean seasoned wood are not to be expected, they are not at present considered a great economic threat to wooden structures.

3.3.2.3 Other Wood-Destroying Beetles.

3.3.2.3.1 General. Other beetles sometimes encountered are the broadnosed bark weevils (family Curculionidae), the pinhole borers, most commonly represented by the ambrosia beetles (family Scolytidae), and the timber worms (family Brentidae). The larvae of most species of bark weevils cut meandering galleries across the grain of seasoned coniferous wood and pack them tightly with frass. Adult bark weevils are small, oblong or elongate, black or brown, with or without eyes, and the beak is often short and broad at the apex. The following are examples of these weevils. Hexarthrum ulkei is sometimes destructive to coniferous woodwork in old buildings and to cypress piling in the eastern part of the United States. Tomolips quercicola has caused damage in buildings to seasoned coniferous woods such as pine flooring and pecky cypress paneling. Pselactus spadix has been taken from salt water piling just above the high-water mark in railroad piers in East Boston, Massachusetts. Occasionally, it is found in damp woodwork beneath buildings. Ambrosia beetles and timber worms usually attack living or recently felled trees and require moist wood favorable to fungus growth. With regard to these latter beetles, the chief concern is to observe the need for lumber to be dry and well-seasoned.

3.3.2.3.2 Wharfborer. The wharfborer, Nacerda melanura (family Oedemeridae) is of economic importance in that it hastens the destruction of piling and decks under wharves, piling under buildings near the water, and boardwalks along the seashore. It is occasionally a pest of utility poles. This insect is nearly always found in very moist wood, and wood-rotting fungi are associated with its work.

3.3.3 TERMITES

3.3.3.1 Destructiveness. Termites are the most destructive insect pests. They may so severely damage a building as to require its condemnation and replacement. They eat wood and other cellulose products such as paper, cardboard and fiber board, and will destroy structural timbers, pallets, crates, boxes, tool handles, furniture, books, and other wood products. Also, in their search for food, they will damage many materials which they don't normally eat. In tunneling through the ground, subterranean termites will penetrate lead-covered and plastic covered electrical cable and short-out electrical systems. They may live for years in buried tree stumps or form lumber beneath concrete buildings, and then, penetrating hairline cracks in floors and walls as well as expansion joints, suddenly erupt in search of edible materials such as interior door frames and rarely-moved furniture such as file cabinets and book cases. In attacking packaging and crating in storage areas, they will seriously damage stored items such as nylon parachutes and woolen clothing. On their bodies, they carry fungus spores from the soil, and so contribute to structural decay. They sometimes feed on living plants.

3.3.3.2 Recognition Characteristics and Biology. Though termites can inflict extensive damage, an understanding of their habits and of simple and effective control techniques can provide for satisfactory control before serious damage has been done.

3.3.3.2.1 General Characteristics. Termites are commonly but erroneously called "white ants". However, not all species and castes of termites are white, and no termite is a true ant. Termites are about ant size. The workers and nymphs are white or cream-colored, while the "reproductives" of most species are dark brown or black. Reproductives can readily be told from ants by two distinguishing characteristics: the wings, and the body shape.

The termite has four wings of approximately equal length, and about twice as long as the body. The ant's wings are only a little longer than the body, and the second pair is much shorter than the first. The ant is typically wasp-waisted, having the abdomen connected to the thorax by a thin petiole, while the "slab-sided" termite is not pinched-in at the waist.

3.3.3.2.2 Types of Termites. There are many species of termites in the world. For practical purposes, those in the United States are commonly divided into two major groups, one of which has further subdivisions. Termites receive their common names from the location of their colonies or nests and from their feeding habits. Subterranean termites often work in wood above ground, but must have direct communication, by means of their tunnels, with the underground colony. The nonsubterranean termites colonize above ground and, although they have the common habit of feeding on the cellulose usually derived from wood or wood products, their life cycles and methods of attack, and consequently methods of control, are quite different. Depending on these factors, the nonsubterranean termites may be of the powder-post, drywood, or dampwood varieties.

3.3.3.2.3 Life History. The biology or life history of termites is best presented under the subjects of colony development and life requirements.

(1) Development of Termite Colony. Colony development follows definite, predictable patterns for various species and in various climatic areas.

(a) Emergence and Colony Establishment. The presence of termites is most often noticed by building occupants during or shortly after an emergence of the sexually mature, winged reproductives. After the emergence and the pairing of male and female reproductives, the swarm is rapidly dissipated as individual pairs leave to establish new colonies. The dry-wood termites will normally seek the shelter of cracks and crevices in sound, dry wood above the ground when establishing new colonies. The subterranean termites establish the new colonies in the soil in close proximity to wood.

(b) Colony Development. In areas of temperate climate, a termite colony develops slowly. A relatively new colony of dry-wood termites (Kalotermes) will consist of only the original reproductives and no more than six nymphs. At the end of 2 years, the young colony may consist of the original reproductives, 1 soldier, and 12 or more nymphs. Old colonies have fewer than 3,000 individuals, and winged reproductives capable of establishing new colonies are never found in colonies less than 4 years old. No worker caste is found in Kalotermes colonies. A relatively new colony of subterranean termites will normally consist of the original pair of reproductives, a few dwarf workers, and one dwarf soldier. During the second year, young reproductives may be found. A full 2 years is required for the complete development of the reproductive. In older colonies, supplementary reproductives may assist in colony development, and thousands of eggs and a quarter of a million termites may be found. In the colonies of subterranean termites, the worker caste predominates. The workers are small, cream colored, soft bodied, and are sexless. The soldiers have large heads with specialized mouth parts, and are normally incapable of feeding themselves. The nymphs are immature individuals, often immature reproductives. They may be observed to have "wing pads" which, upon the maturity of the individual, develop into wings.

(c) New Emergence. During periods of favorable weather, mature colonies may produce new swarms of dark-bodied, winged reproductives. The time of emergence will depend upon geographic area, climatic conditions, the species of termite involved, and other factors such as the heating of the building infested. In temperate areas, emergences of termites may be expected in the spring, and depending on species, also at odd times during the summer and fall. If the emergence occurs within a building, the flying termites may constitute a considerable nuisance. As the reproductives may be emerging as rapidly as the limiting size of the openings permit, the existence of residual insecticides in the area or the use of contact insecticides as sprays or mists will be of little value. Injecting contact insecticides into the emergency openings can provide a measure of relief, but if nothing is done, the emergence will last for only a few hours.

(2) Requirements. Termites have specialized food requirements which make them destructive, moisture requirements which make them vulnerable to control by soil poisoning, and requirements for protection which can make their early detection difficult.

(a) Food. Termites characteristically live on wood and other cellulose materials. Depending on the type of termite involved, the wood may or may not serve as the nesting site, but always serves as a source of food. The food which the termites ingest in small pieces is not digested directly by the termites, but by microscopically small protozoa living within the termites' digestive tract. The termites use the byproducts of the protozoan metabolism for their own nourishment.

(b) Moisture. Termites, like most other forms of animal life, contain considerably large quantities of water in their body tissues. Because they are typically soft-bodied and delicate insects, termites must be protected against excessive drying. The dry-wood termites may tightly seal their nests and tunnels during periods of low atmospheric humidity; but despite this, they are normally limited in their distribution to regions of high humidity. The subterranean termite constructs its own air-conditioning system in that it maintains its nest in the moist soil and connects the nest and the feeding galleries with airtight tunnels. However, despite their air-conditioning, subterranean termites must normally return to the moist soil several times each day, a fact which makes them particularly vulnerable to control at or below the groundline. In extremely wet soil conditions, subterranean termites may construct "sub-nests."

(c) Protection. Termites have several natural enemies, the most serious of which are probably the ants which can easily enter the termite tunnels in search of food. The ability of some termite species to plug up their galleries almost as rapidly as they are invaded provides some degree of protection against ants. The greatest deterrent to sustained attack by ants is the ability of the soldier termites to plug up the tunnels with their heads or to defend them with rather formidable jaws. The soldiers of some tropical species are equipped to wage a form of defensive "chemical warfare".

3.3.3.3 Damage By Termites. Termite damage to buildings follows predictable patterns. If permitted to continue, the damage can become extensive.

3.3.3.3.1 Damage Pattern. Depending upon the design and building materials used, the quality of workmanship, and certain environmental factors, a given structure will be subject to attack by a given species of termite in a particular manner. Termite attacks in several similar buildings will be so similar that a predictable pattern may be found. It is this very predictability of the attack pattern which permits the ease of both understanding and executing programs of preventive inspection and control. In their blind probing for new sources of food, subterranean termites construct exploratory tunnels through the soil. These tunnels emerge above the ground level, and are then usually cemented securely to solid objects such as foundation walls and piers or pipes. These tubes of earth and other materials will, when protected, continue upward until food is found, often reaching heights of several feet. If solid objects block their path, the termites will continue probing until they have found or created a passage. Expansion joint fillers may be penetrated. Natural cracks in foundation walls may be utilized. As the spaces between bricks or building blocks are rarely completely filled, these areas may be used. Hollow tile foundations can provide a nearly perfect approach to structural wood as the termite tubes are well protected and are not detected during inspections. Once gaining entry to the wood of a building, the termites may carry on their destruction for several years before they are found. The use of termite shields will, if the shields are properly installed and maintained, force the termites to extend their tubes out over the surface of the shields and will so facilitate inspections. In buildings comprised primarily of concrete and masonry, damage may be limited to such wooden items as doors and window frames, base boards, and insulating materials composed of wood fibers. In masonry and concrete buildings with wooden floors, damage may be most severe below the floor level. In frame buildings with solid concrete decks, the damage may be first evident in door or window frames or base boards, but more extensive hidden damage to studs, sheathing, and sole plates may exist. In wooden frame buildings the pattern will vary depending on the type of construction and environmental factors, but may be of all these types.

3.3.3.3.2 Extended Damage. Though it is unusual, a new building may be severely damaged during its first few years. This will happen when wood debris, usually tree stumps and roots, containing large, active colonies is left in the soil at the building site. Under such conditions, the extended pattern of damage will be the same as that found in older buildings with well established colonies, the control of which has been neglected. The emergence of termites at a point much above the first floor level in a frame structure would normally indicate a large colony and considerable damage. An emergence of subterranean termites may occur in the attic of a two-story building. Subterranean termite tubes have been found at an elevation 62 feet above ground level in buildings.

SECTION 3.4 DAMAGE TO WOOD BY MARINE ORGANISMS

3.4.1 DESTRUCTIVENESS OF MARINE BORERS. Marine borers have been carried by commerce and by driftwood to all marine areas that can support them. But, transplanted, they do not all survive, for the optimum environmental conditions differ for various species. Some thrive only in warm-water harbors where they may destroy improperly protected piling in three years or less.

Some thrive in colder areas. In some Alaskan harbors, untreated piles are completely destroyed in less than a year. Through research studies we are learning more about the interrelationships of some borers and their environments, and research on improved preservatives continues. But in spite of all that is known about their habits and their control, marine borers cost the United States Navy well over five million dollars per year in preventable damage. This is a little more than the damage to fixed concrete structures caused by marine fouling organisms. The reasons for the losses are varied; but the losses could be considerably reduced by applying what is known today. One purpose of this manual is to provide this helpful information.

3.4.2 MOLLUSCAN BORERS

3.4.2.1 Mollusks. The mollusks, as a group, comprise one of the eleven basic animal phyla. They include both fresh water and marine forms, although no destructive species are known to inhabit strictly fresh water. Included in the group are snails, slugs, clams, oysters, squid, and octopods. Although these animals appear superficially to differ considerably from each other, all mollusks have certain characteristics in common which link them together. These usually include a shell; an organ called a foot used for digging, crawling, or plowing; and a fairly high degree of body organization. While the mollusks are further subdivided into five major subdivisions, all of the pertinent destructive forms belong to the class which includes clams, mussels, and oysters. This class (Pelecypoda) is characterized broadly by a shell which is made up of a symetrical pair of valves, as contrasted with snails, for instance, which have only a single shell. In some of the other classes, shells are either present only in embryonic stages or have been reduced to a small internal structure. More than ten thousand species of mollusks have been described, about eight thousand of which are marine. Molluscan marine borers belong to two biological families: Teredinidae includes the shipworms; Pholadidae includes the rock borers.

3.4.2.2 Teredinidae

3.4.2.2.1 Life Cycle and Distribution. The various species of Teredinidae have been recorded from all inhabited areas of the world, from as far north as Spitzbergen above the Arctic Circle to Tierra del Fuego in the southern hemisphere. The known ranges of the species of Teredinidae are constantly changing, due to increased field research finding heretofore unknown locations. Its ranges are also extended by infected wood carrying adults to new locations where they breed. In general, more different species occur at a given tropical location than occur towards the polar regions. For example, nineteen species of Teredinidae have been recorded in Subic Bay in the Phillippine Islands and but one species at Whittier, Alaska. Most species are limited to water of 9 to 35 parts per thousand salinity. However, the rare species, *Teredo healdi*, in Lake Maracaibo, Venezuela is known to be active in salinities of 0.8 to 1.3 parts per thousand.

(1) *Teredo*. The external appearance of the *Teredo* when removed from the wood it inhabits is worm-like, giving rise to the old popular name "shipworm." As compared with those of other mollusks with paired shells, the shells of the adult *Teredo* have been reduced in size and have become so specialized in structure that they cover only the foremost end of the body. They are used to excavate the tunnel used by the animal for protection. At the opposite end of

the body are the siphons, which project into the water when the animal is feeding, and are withdrawn and replaced by two auxiliary structures called pallets when the animal is disturbed. The pallets together make up a plug which serves to keep out predatory organisms and also protects the Teredo from an unsuitable environment such as fresh water, chemically polluted water, or as in the case of pilings during extreme low tides, no water at all. For the taxonomist these pallets serve as the most reliable single means of identifying the many species of Teredinidae. Although there are as many variations in pallet configuration as there are species, the pallets of the Teredo can be described as spade-shaped. Each pallet consists of a narrow cylindrical stalk to which the muscles are attached and an expanded portion, called the blade, which is hemispherical in cross-section. Three quarters of the worm-like body of the Teredo contains the gills, with the remaining vital organs occupying the foremost quarter. The Teredo secretes a calcium carbonate lining for its tunnel, beginning at the entrance and stopping just behind the shells. This lining helps the animal to maintain the hydrostatic pressure it uses to increase the efficiency of the motion of its rasping shells and to some extent protects it from chemical or physical irritation by the wood.

(2) Bankia. The Bankia resembles the Teredo in all parts except the pallets. Where the stalk of the Teredo pallet supports a single spade-shaped blade, that of the Bankia is ramified into a series of cup-in-cup segments, giving it a feather-like appearance. In general adult Bankia are considerably larger than adult Teredo.

(3) Teredine Reproduction. The life cycle of the teredine borers, as in all marine mollusks in general, consists of four stages; egg, embryo, free-swimming larva, and adult. Sexes are separate in most bi-valves, with eggs and sperm being expelled into the water where fertilization occurs in a more or less fortuitous manner.

In the Teredinidae the processes of reproduction have become highly specialized as have the body shape and function. Although sexes are usually separate, some hermaphroditic individuals occur in most populations, and the change of sex within an individual has been demonstrated in several species. In common species, such as Teredo navalis, males mature and produce sperm at an age of five or six weeks, and even before discharging the sperm have started to develop eggs. Thus a specimen of Teredo navalis that is male at an age of six weeks could be female at an age of 8 to 10 weeks. This female stage usually lasts for the remainder of the first season and through the winter months. In the spring when the 6 week old males discharge their sperm into the water they may be taken up by the incurrent siphons of females that had been male the preceding season. In some cases a reversion of sex to male has been seen in old specimens, but this occurs less than the single sex-change.

In most species of Bankia both eggs and sperm are expelled into the water where fertilization takes place. However, in some species such as Bankia gouldi, what appears to be internal fertilization has been observed. The excurrent siphons were inserted into the incurrent siphons of others and quantities of a clear fluid were passed. Although the sex of the individuals at that time was not determined it seems probable that this was an actual case of internal fertilization.

(4) Teredine Development. After fertilization, the development of Teredo and Bankia differ somewhat.

(a) Egg Stage. Teredo navalis females take in sperm through the incurrent siphon to the gills, where they meet and fertilize the eggs. After fertilization the eggs remain in the gills and in two to three weeks develop to the veliger, or free-swimming stage. Bankia expels eggs and sperm from separate individuals into the water through the excurrent siphon. Fertilization takes place in the water and development from the egg to veliger larva takes place in one day.

(b) Larvae. At this stage the larval Teredo or Bankia possess a large swimming organ, the velum, and a large foot, both of which project considerably from the hemispherical, typically bivalve, embryonic shells. The diameter of the shells at this time is approximately 8/100 of a millimeter. The free-swimming stage lasts an average of two to three weeks, during which time the larva spins like a top, propelled by its velum. It is acutally moved from place to place by ocean tides, winds, and currents much more than by purposeful swimming. Many times during the veliger stage the larva will drop to the bottom and, after retracting the velum, crawl by means of the foot over whatever surface it is on. Eventually it finds a suitable surface and attaches itself by means of a single, long byssal thread secreted by special cells at the base of the foot. At this time the shells measure approximately 1/4 mm in diameter, and the larva is just visible to the naked eye. Using the byssus and foot for leverage, the larva scrapes at the surface of the wood with the edge of the shells and accumulates minute particles of wood which are cemented together by secretions from the mantle. This particular material is formed into a conical cap which covers the entire animal. This cap provides both protection and a new basis of leverage for the shells. Under this cover the larva undergoes a series of rapid and drastic changes. Within a period of 48 hours the large, pointed foot becomes pestle-shaped, and the shells change from simple hemispheres, hinged at the dorsal margin and capable of closing completely, to complicated structures that are hinged at right angles to the former axis, and gape widely so that the foot and siphons project from them in opposing directions. A row of small teeth have been secreted separately by the mantle and cemented in place on the anterior edge of the shells. Using the cap of cemented wood scrapings as a base, the larval teredinid scrapes at the wood with its now toothed shell and rasps a spherical depression into which it just fits. Within a week the larval form has been completely changed and the cap of wood scrapings is lost. The velum and byssus, used for swimming and initial attachment respectively, have also been lost. The borer is now approximately 1 mm long and completely contained beneath the surface of the wood. Auxiliary structures, called pallets, have started to form, and the alimentary canal has been reorganized so as to be able to ingest wood scrapings from one end of the body and plankton from the other.

(c) Adults. The young teredinid grows rapidly in length as it extends its burrow, and increases in diameter (though at a much slower rate) so that it becomes a captive within its burrow. After the first abrupt changes in shell and body form no other major morphological changes take place. The single row of teeth on one edge of the shell becomes many rows, and the proportions of the body change so that the visceral mass occupies one quarter of the total length, the remainder being gills and siphons. Under ideal conditions of temperature and salinity, and with no overcrowding, Bankia gouldi reaches a length of 4 mm in 2 weeks, 12 mm in 3 weeks, and as much as 100 mm, or approximately 4 inches, in 4 to 6 weeks. At this age the animal is sexually mature, with males containing sperm and females ripe eggs. Unless growth is stunted because of adverse conditions teredine borers continue to grow as long as they live, which may be from 10 weeks to 2 years depending on species and environment.

3.4.2.2.2 Teredine Damage. Attack in wooden structures by the teredine borers quite often goes entirely unnoticed until the sudden collapse of a pier or bridge occurs. The entrance hole of an adult Teredo is seldom more than 1/16" in diameter, and that of Bankia seldom exceeds 1/8". The adult Teredo under optimum conditions will grow to a length of from 1 to 2 feet with a maximum diameter of about 1/2", while the Bankia may grow up to 5 to 6 feet in length with the same maximum diameter. Specimens obtained from test panel studies in many cases will be somewhat smaller than those of borers found in an infested pile because panels are removed at regular intervals, whereas attack in piles is not limited by the volume of the wood present. The teredine borers appear to be able to sense the amount of wood lremaining between individual tubes or the outside surface of the pile or panel. Because of this fact, the tunnels which normally follow the line of least resistance along the grain of the wood, often turn to avoid obstructions, such as another Teredo tube, or the outer surface of the wood. This turning within the wood often results in 90% or more of the wood being destroyed without any obvious visible evidence of damage on the outside. Since millions of Teredo attack wood in infested locations, (the exact length of given individuals is of only academic importance), the end result is the same whether the specimens involved are 6 inches or 6 feet long.

3.4.2.3 Pholadidae

3.4.2.3.1 Life Cycle and Distribution. All members of the family Pholadidae are borers; a few species bore into wood, and the majority into clay, soft rock, and other shells. Insofar as economic importance is concerned, one species, Martesia striata, is responsible for by far the largest amount of damage to man-made structures.

The Pholad, when removed from the wood into which it bores, looks much like a clam with an elongated, pear-shaped shell. The animal is capable of withdrawing completely into its shell.

The family Pholadidae is worldwide in its distribution. The most destructive species, Martesia striata, occurs worldwide within the approximate limits of 35° North latitude and 35° South latitude. Xylophaga, another woodboring pholad, was recently found at a depth of 5652 ft. in a deep water test panel of the U.S. Naval Oceanographic Office. Much less is known of the physiology of the Pholadidae than of the other marine borers, but as far as is known, all pholads occur in strictly marine or only slightly brackish water.

(1) Pholad Reproduction. Relatively little is known of the methods of reproduction of Martesia. It is probable that sperm and eggs are exuded into the water in typical fashion. Change of sex has been attributed to pholad specimens in Australia, and as this occurs in some of the non-wood boring forms, it is possibly true of Martesia also.

(2) Pholad Development.

(a) Egg Stage. No literature is available that delineates the development from egg to larva.

(b) Larvae. The larval period lasts approximately one month. The original shell form is hemispherical as in all pelecypods and the foot is large in relation to the body. Martesia attaches itself by a byssal thread. Closely related forms are known to construct a cap of wood similar to the Teredinidae.

(c) Adults. The change in shell and body shape from larval to adult form in Martesia is not nearly as drastic as that of the Teredinidae, although considerable specialization of function occurs in this mollusk also. Martesia does not at any time in its life span following the larval stage grow larger than its shell. The two valves gape considerably at both ends to allow the siphons and foot to protrude and would not provide complete protection if it were not for the wood surrounding the animal. As the pholad increases in length it also increases in girth, although at a slower rate, and this results in its being captive in the wood as is the Teredo. Whereas the Teredinidae twist, turn and even stop boring to avoid one another's tunnels, the pholad bores straight into the wood, often through Teredo burrows. The genus Martesia reaches sexual maturity at an age of approximately 1 month and has a life span of approximately one to two years.

3.4.2.3.2 Pholad Damage. The pholad, Martesia, bores into the wood, at a right angle to the surface, regardless of the grain structure of the wood. Although its entrance hole is small at first, approximately 1/32" in diameter when the pholad first enters the wood, it increases to about 1/4" in diameter and is visible to the naked eye after the pholad inside has reached its full size. Pholad burrows average 2" to 2 1/2" in length under favorable conditions and can be as numerous as 450 to 500 per square foot. This type of attack can result in complete destruction of 4" bracing timbers under water, and in the annual loss of the outer 2 to 3" of wood piles. Because the attack is visible on the surface as a series of 1/4" holes, and because complete destruction of piles does not occur unnoticed, relatively few structures are destroyed by pholads before repairs are made.

3.4.3 CRUSTACEAN BORERS

3.4.3.1 Crustaceans. The Crustacea comprise a large group (class) of the Phylum Arthropoda. Certain species are very destructive to waterfront structures. The Crustacea have segments or parts arranged in a longitudinal series composing the body, and all exhibit a tendency for the different segments to be grouped into three regions, namely head, thorax and abdomen. Another characteristic of the group is that typically each segment bears one pair of jointed appendages. They carry on respiration by means of gills, although some of them become adapted to terrestrial life. Many of the aquatic forms are found in fresh water, but most are marine. Wherever found, the individuals are usually numerous and frequently occur in vast numbers. In the more than 25,000 species of Crustacea are included barnacles, shrimp, crayfish, lobsters, and the destructive gribble. The Crustacean borers associated with wood damage are members of the three genera: Limnoria, Sphaeroma, and Chelura.

3.4.3.1.1 Types of Crustacean Borers

(1) Limnoria. The Crustacea borer Limnoria, or gribble as it is commonly known, is almost always found in a tunnel in wood. It is a small animal somewhat resembling the wood louse, from three to six mm in length with a semi-cylindrical body divided into segments. It has seven pairs of short legs, each terminating in a sharp curved claw, by which the animal holds on to the sides of the burrow. Under the posterior end of the body there are five additional pairs of legs, each having two wide plates which act as gills and which keep up continuous motion during the life of the animal, thus circulating the water needed for respiration. Limnoria bores into the wood with a pair of mandibles, one on either side of the mouth. The right hand mandible has a rasplike roughened edge which fits into a groove, while the left hand mandible has a rasp-like surface, the whole forming a rasp and file combination. The tunnel is about one millimeter in diameter running into the surface of the wood at a slight angle. There are about sixteen described species, of which two are possibly the most important, economically speaking.

(a) L. lignorum. This species is the most familiar and is identified by its relative length, shape and the shape of the telson (the terminal segment at the end of the abdominal section). There are no tubercles on the telson.

(b) L. tripunctata. This species of Limnoria is similar in appearance to L. lignorum, but has three tubercles on its telson. Although there are other characteristics involved in the identification of the species, the presence of three tubercles on the telson serves as an identification guide.

(2) Sphaeroma. Crustacean borers of the genus Sphaeroma closely resemble in structure borers of the genus Limnoria. Sphaeroma, however, are much larger and stouter organisms, measuring 3/8 of an inch or more in length and about 1/5 of an inch in diameter. They have, in a more marked degree than Limnoria, the habit of contracting the body into a ball when threatened. Usually borers of the genus Sphaeroma are not of economic importance, although one or two species occasionally cause considerable damage.

(3) Chelura. The members of this amphipod genus differ markedly from the isopod genera Limnoria and Sphaeroma. The body is more attenuated, somewhat laterally compressed instead of dorso-ventrally (back-underside) flattened. Chelura are equipped with more prominent appendages than the isopod borers. Their bodies turn red when removed from the water, a characteristic which makes their identification sometimes obvious.

3.4.3.1.2 Life History of Crustacean Borers. The crustacean borers have a somewhat different life history than do molluscan forms.

(1) Reproduction.

(a) Limnoria. In Limnoria the two sexes are separate, and fertilization of the eggs takes place within the female. The fertile eggs are retained by the female and carried in a sac, called the brood pouch, on the under portion of the body. Development within the eggs continues until the young are approximately one millimeter (1mm) in length. The number of eggs varies from six to seventeen. When the young hatch they have the same form as the adult and are capable of establishing their own tunnels. During most of the year the female remains in the close confines of the tunnel where breeding apparently is impossible. Although little is known regarding the detail of some phases of the reproductive process, it has been demonstrated that during certain months of the year, varying with location, the adult Limnoria leave the tunnels and move into the open water. After a period of several weeks the animals return to the wood. Within a short time eggs appear in the brood pouch. It is possible that fertilization takes place in the water during the free swimming period.

(b) Sphaeroma. Few observations concerning the reproduction of Sphaeroma have been made. The eggs are carried in the abdomen of the female as in the case of Limnoria. Immature individuals live in the burrows with the adults.

(c) Chelura. Unlike Limnoria and Sphaeroma, Chelura produce small numbers of minute eggs in their tunnels or burrows. Chelura are swimmers and are more active than Limnoria in this respect.

(2) Crustacean Development. Because crustacean borers do not have several succeeding embryonic stages, their development consists primarily of growth. The newly hatched young are miniatures of the adults and are capable of carrying on the necessary functions, such as feeding and boring, independently of the adult specimens.

3.4.3.1.3 Crustacean Borer Damage. Damage by crustacean borers is practically worldwide and has called forth all the protective measures known to man from ancient times to the present. The destructiveness of these crustaceans varies somewhat in different waters and environments. No wood is completely immune to attack.

The damage caused by crustacean borers is typically superficial and so may be visible externally to its full extent. In this situation erosion takes place by wave action, exposing the deeper layers to attack, hence the damage is progressive until the timber is entirely destroyed. Damage can also be internal. Crustacean borers, particularly Limnoria, can gain entrance to the untreated cores of treated piles and timbers through bolt holes, bracing ends, surface abrasions, and knots. Once entrance occurs, the colony expands and hollows out the wood with little evidence of damage.

(1) Limnoria. These are by far the most destructive crustacean borers and have the widest distribution. They are abundant in almost all harbors in northern waters as well as in the tropics. Limnoria destroy timber by gnawing interlacing branching tunnels into the surface of the wood. The tunnels are about 1/20 of an inch in diameter, the same size throughout. Generally speaking, they bore into the softer spring wood, leaving the harder layers of summer wood exposed in ridges. Their tunnels are so numerous that the surface layers of timber are easily eroded by water action, which in turn exposes more wood for more extensive tunneling. This continued tunneling, followed by surface erosion, results in the ultimate destruction of unprotected timber. Limnoria have been found to eat their net weight in wood in ten days, therefore a population of 200,000 individuals could consume nine pounds of wood per year. The diameter of a pile may be reduced approximately one inch per season. Limnoria are particularly dangerous in their attack on poorly creosoted timber. They sometimes enter at a knot or a point where the

treatment is thin or has been abraded, and work their way in until they reach the untreated center wood which is destroyed, leaving the outside treated shell intact. Limnoria are sometimes found above normal high tide, but the greatest intensity of attack is usually found between the mudline and the high water mark. They tend to make an hour glass shape of timbers and in some cases the timber is entirely cut off at the point of maximum activity. Limnoria can easily and quickly abandon their burrows when conditions are unfavorable, and swim, crawl, and drift to a new abode. Since they can exist for many weeks without food and still maintain their normal activity, it seems probable that any migration might eventually lead to a suitable home.

(a) L. lignorum has been reported as occurring along practically the entire coast of Europe, from the Lofoten Islands off the coast of Norway north of the Arctic Circle to the Black Sea. In Eastern American Waters it is found from Newfoundland to Florida and in the Gulf of Mexico, Bermuda Islands, Cuba, Puerto Rico, Virgin Islands, Canal Zone and British West Indies. On the west coast of the United States it is found from Alaska to California and the Pacific end of the Canal Zone. In the Pacific it is found in Japan and the Philippine Islands; and in the southern hemisphere in the Falkland Islands, South Africa, Australia and New Zealand.

Due to its wide distribution Limnoria lignorum is a serious wood-boring pest throughout the world where salinities are not markedly reduced by the influx of fresh water. Severe attack may result in a complete destruction of more than a half inch of the outside wood of a pile or timber in one year. Since this is the equivalent of an inch in diameter, a new pile measuring eight or more inches at the mud line many be rendered practically worthless in five or six years. The individuals must be very numerous to accomplish this task. It is known that where destruction is severe there are more than two hundred individuals to one square inch of wood surface. The harder woods offer a marked resistance to Limnoria. Spruce and white pine are more quickly destroyed than hard pine, and oak is more resistant than any of the native woods commonly used in marine construction. Nevertheless, even the hardest woods known are injured to some extent by L. lignorum.

(b) L. tripunctata is found at various localities around the world. It is a hardy species which has been found to survive and reproduce under conditions unfavorable to those less hardy. Although its habitat is primarily in warm waters, it has been found along the Atlantic Coast at Cuttyhunk (Elizabeth Islands) Massachusetts, Rhode Island, New York, North Carolina, Florida; in the Caribbean at Bermuda Islands, Texas, Cuba, Costa Rica, Puerto Rico, Canal Zone and Venezuela; in the Pacific Ocean at California, Mexico, Hawaiian Islands, Japan, Philippine Islands and the Marianas.

Though this species may at times be found in relatively cold water, it is considered to be a serious problem only in warm-water harbors where it can be highly destructive. Exposure of test panels has shown that L. tripunctata can destroy wood heavily impregnated with creosote that contains very small amounts of petroleum oils (aliphatics, or open-chain hydrocarbons). Marine piles treated with completely aromatic creosote (no aliphatics) have been destroyed in the tide zone and the splash zone in tropical harbors where there have been frequent oil slicks around the piles. As of the date of this writing, the only commercially available treatments that can assure complete protection are the heavy "salt" retentions or the dual treatment.

(2) Sphaeroma. In general, Sphaeroma is of little economic importance, but one species, Sphaeroma destructor, is reported as causing considerable damage. Sphaeroma is generally found occupying and sometimes enlarging the tunnels which were made by Limnoria. The excavations made by Sphaeroma are up to nearly one-half inch in diameter, and often considerably longer than wide and follow the grain of the wood. The tunnels are usually shallow, although some may be three or four inches deep. These animals do not seem to attack the wood as freely as other species of borers, even when present in timber in considerable numbers. They also seem to prefer soft wood or wood previously bored by another organism, but they do not constitute as serious an economic problem as Limnoria. Sphaeroma has been reported as a wood destroyer along the coast of North Carolina, Georgia, Florida, the Bermuda Islands, Louisiana, Texas, Puerto Rico; in the Pacific Ocean at Washington and California; also in the Indian Ocean at Bombay, and in Australian ports.

(3) Chelura. Normally, Chelura works with Limnoria and in much the same manner as Sphaeroma, although it does seem to enlarge the tunnels made by Limnoria. Because Chelura is rarely, if ever, found apart from Limnoria, while Limnoria is often found alone, it is probable that its importance as a wood destroyer has been underestimated. It is certain that in many cases damages attributed by engineers and others to Limnoria alone has been due to the two species working together. Chelura has been found at many points on the coasts of Europe from Norway to the Black Sea. It has also been identified from Auckland, New Zealand and the Christmas Islands in the Indian Ocean; in the Atlantic Ocean from Maine to New York, the Bermuda Islands, the Virgin Islands; and in the Pacific Ocean from Washington to California.

3.4.4 DISTRIBUTION OF MARINE BORERS AND OTHER ORGANISMS

3.4.4.1 Some Factors Controlling Distribution. Although representatives of the major biological classifications are found in all the oceans of the world where conditions are favorable for life to exist, very few individual species are universally distributed. Most species require conditions within certain limits for successful existence. In some instances these limits may be very broad and the organism may be found in widely scattered locations, while in others the distribution is limited. A number of factors control the presence of types of organisms. The geographical boundaries separating the species are seldom distinct and there is considerable overlapping of types. Over a considerable period of time long range variations in environment affect the prevalence of some organisms. Species may reappear in a given area after a long absence if the environment again becomes suitable. This is important when the design of marine structures is considered.

(1) Depth Effects. Most familiar marine organisms exhibit some sensitivity to depth effects. In some cases this is due to their requirements for light or to increased water pressure. For instance, most green algae (seaweeds) are found only very near the surface or in the tidal zones because of their need for light to carry on the process of photosynthesis. Some species of barnacles are found only in tidal areas. The depths usually encountered in the vicinity of marine structures do not seem to be critical as far as the needs of marine borers are concerned. Maximum attack has been recorded at all common elevations from the mudline through the tidal zone. The form of the animal usually becomes adapted to the environment it prefers. Deep water organisms have structures to protect them from the increased pressures. At depths of more

than 200 feet the general population may be expected to decrease progressively. Recent interest in the biology of great depths has initiated the study of areas concerning which little has been known. Boring pholads have been found in test panels submerged at a depth of approximately 5600 feet.

(2) Geographic Effects. The distribution of marine borers is more often studied from the standpoint of geographic locations than any other factors since this is a very convenient method for a suitable description. However, the actual physical condition of the water determines the presence or absence of an organism rather than its geographic location.

(a) Longitude. Strictly speaking the degree of longitude is not often referred to in distribution studies. It has been shown that a large number of previously described species from broad areas of different longitude are actually identical. They were originally set apart because of relative lack of communication between taxonomists and of less advanced systems of identification. In the case of long shore lines extending approximately north and south, there has been apparently some isolation of true species.

(b) Latitude. The degree of latitude is often used as a reference point when discussing the distribution of marine organisms. In general this is because of the close correlation of latitude and temperature, although individual broad stream currents such as the Gulf Stream affect the correlation. The degree of activity of the marine organisms and the number of species present usually increase progressively towards the equator.

(3) Migration. To describe and explain the distribution of marine borers, conflicting circumstances are often created by the presence of groups whose normal habitats have been influenced by migration.

(a) Water Currents. The free swimming forms of marine borers are often carried long distances by water currents. These currents transfer organisms from their point of origin over considerable distances into areas not ordinarily native to them. Some of the hardy individuals survive and manage to adapt to changed conditions. These have often been erroneously described as new species. Species native to southern waters have been known to attack floating equipment off New England waters because the embryonic forms were transplanted in the Gulf Stream. Under some circumstances, particularly active borers may be introduced by these methods into areas ordinarily less susceptible to damage.

(b) Mechanical Means. Various marine organisms are often disseminated by infested wooden ship hulls or floating wooden debris. These objects infest one harbor until their movement introduces the species into new areas if the environmental conditions are suitable. Thus, harbors uninfested for long periods, may suddenly be invaded by introduced marine borers.

3.4.4.2 Ecological Effects on Borer Distribution and Survival

3.4.4.2.1 Relationship of Organisms to Environment. In order to carry on their activities with maximum efficiency, the organisms must have access to certain necessary conditions. While most organisms can survive moderate deviations from necessary conditions, these changes can not be prolonged for long periods of time without lethal effects. Often changes in even one phase of the environment results in greatly decreased activity or in local elimination of the species. Marine borers do not have any mechanism by which they may survive for prolonged periods in an unsuitable environment. Some other organisms, such as some of the fungi, may form spores which remain dormant during periods of unfavorable conditions. When the environment is again suitable, the spores germinate and resume their normal life processes. Thorough studies of the environment, when correlated with biological activity, contribute greatly to the knowledge necessary for control.

(1) Water Characteristics. Water is the natural habitat of marine organisms, and therefore they are completely dependent upon it for their survival. It follows that the characteristics of the water play a vital part in their activities.

(a) Salinity. Salinity can be defined as the total amount of solid material in grams contained in one kilogram of sea water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine and all the organic matter completely oxidized. Salinity is usually expressed as the number of parts of salt per thousand. The salt content of full sea water is usually slightly over 30 parts per thousand. Unlike some groups of animals, many marine organisms, particularly the groups of borers, cannot exist in fresh water. Even though the salinity requirements may be extremely low, some salinity must be present. One species of borer, Teredo healdi, is most active in water where the salinity can be so low the water is potable. A marine organism ordinarily cannot exist throughout the entire range of salinity, but has optimum limits within this range. These ranges of salinity may consist of high, extremely low, or intermediate values. The activity of marine borers may be critically affected by such factors as annual rainfall in harbors supplied by sizeable fresh water rivers. All or portions of such harbors may often contain brackish water species. The extent and location of these species is dependent upon the salinity of the water reflected by the river flow.

(b) Oxygen. Except for a number of anaerobic micro-organisms, most marine life requires oxygen for existence. The oxygen is obtained from the water in its dissolved state. Any condition existing in the water which results in the reduction of the oxygen content below a critical limit will seriously affect the metabolism of the organisms. The oxygen content is expressed in terms of parts of dissolved oxygen per million of water. By chemical laws the amount of dissolved gas in a liquid is determined largely by the temperature and pressure on the liquid. Low temperatures and high pressures can result in maximum amounts of dissolved gas while, conversely, high temperature and low pressure reduce the amount. The salinity of the water also affects the solution of oxygen. When the dissolved oxygen is present in the maximum amount for the existing temperature and pressure the condition is described as saturated. The process of restoring oxygen to water is called aeration. It can be accomplished by turbulence of wave action. Sea water in uncontaminated areas is usually in an oxygen saturated condition.

(c) Acidity and Alkalinity. Sea water is normally slightly alkaline. Within narrow limits this condition must be maintained for the survival of most types of marine organisms.

(d) Temperatures. The physiology of marine organisms is such that the metabolic rates are directly proportional to the temperature of the environment. These organisms are not equipped with internal heat regulating mechanisms so that the entire body temperature is that of the surrounding water. Upper limits of temperature are critical whereas relatively long periods at lower temperature can be survived. While some species of marine animals exist in water temperatures up to 90°F, exposure for just a few moments to water temperature of 110°F will result in death. In colder waters, organisms survive the winter seasons at temperatures as low as 26°F. The life processes during these periods are in an extremely slow state. Little, if any, boring activity takes place, and reproduction is at a standstill. The geographic limits of species is determined by the average range of water temperature.

(2) Pollution. Pollution may be defined as the presence of abnormal constituents in the water. It is of two general types.

(a) Industrial. Industrial pollution is introduced into the water often as waste products from industrial processes and almost always as chemical compounds. When present in sufficient quantities pollution is usually detrimental to living organisms. In harbors or streams pollution may come from metallurgical and chemical processes. While the introduction of such compounds are controlled by law, they manage to accumulate, particularly in industrial areas. Often their presence is used to advantage, since marine structures in industrially polluted areas rarely are attacked by marine borers. Some manufacturing plants have even diverted the flow of industrial waste to run under their structures for protective purposes. Oil pollution is a different matter. There is evidence that oil from ships' bilges, spillage from fuel oil piers, and other sources of oil impair the preservative effectiveness of creosote treated piling in Limnoria tripunctata infested waters.

(b) Biological. This type of pollution is commonly described as being composed of those biological wastes which make up sewage. The composition is usually predominantly organic in nature and therefore possesses its own oxygen demand. When the proportion of biological waste in sea water is high, the dissolved oxygen content is considerably lowered. This low level usually results in the death of marine organisms. However, unless biological pollution is present in such quantities as to lower the oxygen content, the marine life is not seriously affected. Some organisms may even serve as food for marine borers.

(3) Water Stratification. Stratification of water in harbors can be brought about by several conditions. Thermal stratification and density stratification are the most common.

(a) Thermal stratification. Elevated air temperatures will warm surface water to a depth of many feet. The warmer water will tend to rise and remain near the surface. After a prolonged spell of hot weather a sharp break often develops between the colder bottom water and the warmer surface water. The zone where this break occurs is called the thermocline. The water temperature either above or below the thermocline may or may not be conducive to marine borer attack.

(b) Density stratification. Another cause of water stratification is salinity. High salinity water being more dense usually forms the bottom water layer and intrudes from the sea. The surface water, particularly if of fresh water origin, is less dense and remains on the surface. Between these layers some mixing occurs. It is not uncommon to find that the salinity of the surface water is not conducive to development of Limnoria populations, while the higher salinity bottom waters are ideal for Limnoria attack. Stratified water layers may show differences in oxygen content, biological oxygen demand, pH, and pollution as well as temperature and salinity. Stratification can change rapidly. The cooling of surface water can result in more dense water at the surface. This situation is unstable and a complete overturn and mixing of the water layers results. Storms also can result in the mixing of the water layers. If the relationship between the boring organisms and the environment is to be used to evaluate the attack potential on waterfront structures, water samples must be taken periodically, and at various depths.

3.4.4.2.2 Biological Relationships. When different biological organisms exist together in the same area, there is usually some form of interrelationship between them. These relationships may be either beneficial to both or harmful to one or the other. Because of the highly specialized nature of the groups of marine borers, these relationships do not appear to be particularly significant.

(1) Predators. Marine borers, because of their well protected burrows in the interior of the wood, are not subject to the activities of most predators. The siphons of the teredine borers normally extending into the water from the wood are often damaged by fish or other carnivorous forms. However, these siphons are very sensitive and easily retractable. If lost, they can be regenerated. Tightly adherent surface organisms can be lethal to borers as they cover tunnel access holes. Often the crustacean and molluscan borers conflict with each other. The destruction of the surrounding wood by crustaceans resulting in the exposure of teredine tunnels may be fatal. However, the teredine borers are often able to survive by increasing the thickness of the protective lime lining in the tunnel.

(2) Parasites. Little is known regarding the existence of organisms parasitic to marine borers although there is evidence that some parasites may exist. Scavenger organisms commonly found in tunnels feeding on already dead animal matter may often be mistaken for parasites.

(3) Disease. No known diseases have been definitely identified in marine borers.

3.4.5 MICROORGANISMS AND MARINE FOULING

3.4.5.1 <u>The Primary Film</u>. When objects are submerged in the waters of our harbors they become coated with a layer of living organisms of various types. Various factors such as temperature, salinity, and type and amount of pollution will affect both the rate of development and the composition of the primary films. Various bacteria are usually the first organisms to attach; and these are followed by fungi and algae. However, some marine algae attach as zoospores and normally attach no earlier than larvae or other immature forms of marine-fouling animal life. Some free-swimming larval forms will attach only to surface with well-developed primary films. This primary film causes no harm to wood in marine environments, though some of its constituent organisms can damage concrete and can destroy steel.

3.4.5.2 Microorganisms and Corrosion. A variety of "corrosion-resistant" irons and steels are available for special purposes. Their high prices preclude most uses in waterfront structures. Most irons and steels used are subject to microbiological degradation.

It is well established that the immediate chemical reaction called corrosion is an electrochemical reaction rather than biochemical. Microorganisms release chemicals into the immediate environment of the iron and steel, or remove them from this environment thereby causing changes in the corrosion rate. The discharge of metabolic by-products of bacteria can even cause rapid, severe corrosion to occur in an environment where corrosion would otherwise not occur at a significant rate.

Aerobic corrosion of iron and steel proceeds quite readily in the presence or absence of bacteria. Bacteria, however, can accelerate aerobic corrosion if they have the proper substrate upon which to grow. In an environment of abundant air and water, for example, some bacteria can convert sulfur or a number of sulfur compounds into sulfuric acid of sufficient concentration to rapidly perforate steel pipe (and even concrete pipe). It is well established that carbon dioxide accelerates aerobic corrosion, but the influence the majority of the other bacterial products cited have on aerobic corrosion is not well known.

Anaerobic corrosion i.e., in the absence of oxygen, of iron on the other hand, does not proceed at an appreciable rate unless the metabolic wastes, such as hydrogen sulfide, produced by certain anaerobic bacteria are present. Under such circumstances corrosion may occur more rapidly in the absence of oxygen than in the presence of oxygen. For example, when conditions are ideal, bacterially induced anaerobic corrosion can destroy a heavy steel casing in a three month period.

In the thin film of bacteria and slime that readily accumulates on the surface of iron and steel structures in the ocean, the concentration of dissolved gases differs considerably from that in the surrounding water. Both the bacteria in the film and the iron to which it is attached remove oxygen from the water faster than it can diffuse through the film, and consequently, conditions in the film are frequently anaerobic and ideally suited for the growth of hydrogen-sulfide-forming bacteria. Anaerobia corrosion can, therefore, occur even in well-oxygenated areas of the ocean. Iron buoy chains, for example, are frequently covered with heavy black deposits and have the telltale odor of hydrogen-sulfide. Deep craters and grooves are found on the chains when the black deposits are removed. However, the adhering film of bacteria and slime can serve to merely lower the concentration of oxygen, not to create anaerobic conditions. In such instances, the bacterial film probably retards corrosion significantly.

The presence of unicellular photosynthetic organisms in the ocean is well established, and in sunlight they liberate oxygen, one of the principal agents accelerating corrosion. Where and how extensively diatoms and other photosynthetic organisms accumulate on the surfaces of iron and steel structures immersed in the ocean has received but scant attention. Some of them settle early in the formation of the primary film. Their production, or liberation, of oxygen has no detrimental effect on wood or on concrete, but their potential for contributing to the losses of iron and steel is very real.

3.4.5.3 Marine Fouling. Marine fouling is one of the oldest problems known to mariners. Not only does it impede ship movement, but it contributes to the destruction of both fixed and floating structures. Larval forms settle or attach after formation of the primary film or during its development. Mostly they are sessile or encrusting when attached and growing, but are free-swimming in the larval stage. Some are plants. Others are animals, most of which are plant-like in general structure. There are many species belonging to three major groups of plants and eight major groups of animals. The sum total of those on a structure are considered as comprising the fouling community. In some harbors where pollution is mild, fouling communities may consist of nearly a hundred different species of attached plants and animals.

Fouling can, to a limited degree, provide some protection against marine borers by covering the surface with encrusting forms. Some forms live relatively short lives; but all forms die. And when they die the bacterial decomposition products are much more harmful to steel and to concrete than they are to wood. Acids formed at the surfaces pit into the steel and penetrate the concrete. This is repeated over and over. Though all fouling dies, very heavy growths cover some surfaces. The many tons attached to a pile exert no force on the pile in calm water. But during a storm, the pull of the water on the attached growth can cause severe spalling of concrete, particularly of concrete which has been penetrated by acids and so damaged earlier by the fouling.

CHAPTER 4. PREVENTIVE PROTECTION OF WOOD

SECTION 4.1 PROTECTION OF WOOD BY MOISTURE CONTROL

4.1.1 FORMS IN WHICH WATER IS ABSORBED

4.1.1.1 Water Vapor. Wood will absorb water vapor from the air until its moisture content is in equilibrium with the vapor pressure of the atmosphere. The equilibrium moisture content is closely correlated with the surrounding relative humidity, and this is generally used for predicting moisture contents to be expected in various environments and climates. Lumber can be correctly termed "air-dry" if it has been dried by exposure to the air either outdoors or in an unheated shed until its moisture content is about in balance with that in the outdoor air. Lumber that has been air dried for a sufficient length of time may have a moisture content ranging from 5%, as in summer in the arid Southwest, to 20%, as in winter in the Pacific Northwest. For the United States as a whole, the minimum moisture content range of thoroughly air-dry lumber is 12% to 15%, and the average is somewhat higher. Air-dry wood is not subject to fungus attack except occasionally for a slight amount of molding. Lumber that has been kiln dried will ordinarily have a moisture content of 6% to 12%, although kiln dried softwood lumber of the common yard grades is likely to have a somewhat higher content.

4.1.1.2 Liquid Moisture. In protecting wood in buildings against decay by controlling moisture, two related rules stand out: (1) See that the wood is contacted as little as possible by water, and (2) where wetting cannot be avoided, see that the air-dry condition is reached as rapidly as possible thereafter. Particular attention should be given to the lumber or building part at five stages in its processing and use: (1) the building part should minimize prolonged wetting, such as by not trapping rainwater; (2) the lumber should be procured dry and mold and decay free, and should be stored properly; (3) the lumber should be protected against wetting at the construction site; (4) water-repellent treatment should be used where this can aid materially in reducing rain wetting; and (5) preventive maintenance should assure that items stay safely dry.

4.1.2 PRIMARY CAUSES OF WET WOOD AND CONTROL OF MOISTURE SOURCES. The water needed to support wood decay can come from several sources: rainwater, ground moisture, condensation, artificial wetting (like plumbing leaks), the original sap in the wood, or sea water. In this section these moisture sources and their control will be discussed in a general way. The details of controls will be presented in succeeding chapters.

4.1.2.1 Rainwater. Except for wood in water or in direct contact with the ground, rainwater is by far the most common source of water leading to decay. This applies particularly to wood exposed on the outside of buildings such as in porches, steps, fire ladders, siding, and fascia. However, rainwater may also penetrate the outer shell of a building and wet the roof decking, framing, and even such interior items as flooring. The rain wetting of framing and other hidden items may be mistakenly attributed to condensation or the use of unseasoned lumber.

4.1.2.1.1 Keeping Stored Lumber Dry. Lumber and other wood products should not only be stored off the ground, but also protected from rain wetting. This is necessary to prevent incipient fungus infections and to insure that the lumber is maintained at the correct moisture content for a particular use.

At permanent storage areas, lumber should be protected by sheltering it under a roof; in transit or at a building site it may be kept under tarpaulins or plastic covers. Finish items should not be delivered to a building site until the structure has a tight roof and walls, so that they can be stored indoors.

Lumber at permanent storage sites should be placed on foundations of concrete or treated wood. In areas with appreciable termite hazard, the foundations should be high enough to permit inspection below the piles, and the soil should be treated with an insecticide. Even for temporary storage, as at a building site, lumber should be kept from direct contact with the ground.

When lumber is stored in sheds with dry concrete floors, it may safely be kept on untreated skids or pallets.

Lumber with less than 20% moisture content can be bulk piled under cover with safety. Wet lumber should be put on dry stickers in a regular air-seasoning pile in a ventilated space.

4.1.2.1.2 Limiting Water-Trapping Construction. The harmful effect that rainwetting has on wood in buildings occurs primarily at joints. Joints, with their surface-to-surface contacts not only form capillary openings which draw water into the structure but they present end grain into which capillary absorption is at a maximum. Furthermore, they act as traps from which water evaporates slowly between rains. In exterior construction, joints exposed to rain wetting should be avoided wherever possible. Exterior bracing can be a water-trapping hazard whereas interior bracing is safe, Similarly, an exterior step newel constructed of two pieces of 2- by 4-inch lumber is more likely to decay than one piece of 4 by 4. The use of subflooring for stoops is much more hazardous than a single floor. (Of course, when double construction is accomplished by laminating with a water-proof glue, a piece is essentially solid and without joints so long as the glueline is intact.)

Tight joinery, paint, and caulking are aids rather than primary means in preventing rain seepage. They are of most value under light to moderate exposures. On structures exposed to heavy rain wash, they should not be relied upon as major methods of preventing hazardous rain seepage.

Where there is heavy rain wash, or some other form of intermittent, heavy wetting of the surface, a good water repellent properly applied will be more effective than tight joints, paint, and caulking in preventing rain seepage. True, water repellents will not prevent gravity flow of water into loose joints with comparatively wide openings, or penetration of rainwater when driven by unusual wind pressures. However, by interfering with wetting they do tend to prevent capillary movement of water into reasonably tight joints. Under the severest exposures, water-repellent-treated wood gradually wets, but such failure should be attributed to unsatisfactory designs, not to failure of the water repellent.

4.1.2.1.3 Water-Shedding Construction. The general principle involved here is to design buildings so that a minimum of water will reach wood surfaces, and whatever reaches the wood will drain off rather than be trapped to soak into the wood.

4.1.2.1.3.1 Proper Roof Drainage. For a minimum of maintenance, roofs should be sloped sufficiently to allow rainwater to drain rapidly. The number, location, and size of drains and the needed roof and valley pitch will vary with climatic areas, particularly with amount of rainfall. Long, low pitched valleys on large buildings are particularly troublesome. Interior drains, strategically located, often are desirable. Roofs must be designed so that runoff does not strike a wood surface or another roof below. Adequate overhang or baffles can accomplish this.

Flat roofs must be especially well protected against leakage to offset their relatively poor drainage features, and this requires careful maintenance.

4.1.2.1.3.2 Advantage of Sloping Surfaces and Absence of Water-Trapping Ledges. Flat wood surfaces exposed to the weather are hazardous. Sloping the step treads, porch or stoop flooring, and window sills, facilitates drainage. Unnecessary horizontal projections from the building wall, such as a water table, should be avoided. Decay is frequent at such projections. When boxing a roof beam, the soffit is sometimes extended beyond the exposed fascia board and rainwater seeps into the boxing. If the facia is extended down beyond the soffit, seepage is prevented.

4.1.2.1.3.3 Advantage of Noncupping Lumber. In general, flatsawn lumber shrinks and swells more than quartersawn (edge-grained), and this disadvantage is particularly pronounced in wide boards. Flatsawn step treads or flooring are more likely to cup and hold water, and siding and trim to split, warp, or twist after attachment, thus breaking paint films or caulking. Most trouble in this respect is in proportion to the severity of exposure. Much lumber cut from present day timber supplies is flatsawn, but quartersawn material is available if specified.

4.1.2.1.4 Avoiding Molded or Sap-Stained Wood. Infection by molds or by staining fungi may seriously increase water absorption by wood. The degree of increase depends on the type of infection and the stage of fungus development. Furthermore, wood with appreciable mold or stain frequently has incipient decay infections that can develop rapidly when the wood is rewetted. Much of the rapid decay of exterior woodwork, the occasional decay of perimeter framing in crawl spaces, and in exterior walls is directly traceable to the use of infected wood. Thus, wood to be exposed on the surface of a building, or for use anywhere it may be periodically wetted, should be essentially free of visible mold and stain, and preferably kiln dried. The kiln not only dries the wood but kills fungus infections. When infected lumber must be used on the exterior of a building, a water-repellent treatment is particularly advisable (6.3.1.3).

4.1.2.1.5 Avoidance of Ground Splash. In localities where heavy rains occur, roof runoff, even with a one story building, may splash up and dangerously wet the lower portion of walls. Decay from this cause occurs in sheathing and plates behind asbestos cement, metal, or wood siding. Most serious splash occurs where the ground adjoining the foundation wall is surfaced with concrete, brick, or other hard material. Splash also occurs from stoops, roofs, canopies, and so forth, below the main roof. Grass is a much less troublesome splash surface. Splash can be minimized by the use of eaves gutters, and danger from it can be virtually eliminated by a wide roof overhang (4.2.3.2.4).

4.1.2.1.6 Flashing. Metal or paper flashing is used in many ways to prevent rain seepage. The roof edge, window and door openings, juncture of corner and roof, and horizontal butt joints between panel-type siding are some items that regularly need flashing. Flashing must be of durable material. Particularly necessary is roof-edge flashing (as a gravel stop) that is resistant to corrosive roof cements.

In applying flashing there must be no exposed nailing except in unusual cases where nailing is through a surface that will not be rain wetted. Nailing through the exposed vertical part of roof-edge flashing should be placed below the underlay paper. This is particularly necessary in the case of a tile roof in a tropical area because, during heavy rainfall, water flows over the tile cup edges and drains over the underlay paper to the roof edge.

Flashing is frequently used to correct faulty construction such as the projection of roof beams or the exposing to the weather of large wood arches. It is better to redesign structures to remove the hazard or to use adequately treated wood than to temporize with flashing.

4.1.2.1.7 Water-Repellent Treatment. Water repellents, by coating the cell walls in the outer layers of wood with waxes or synthetic resins, reduce the wettability of wood. They are of most value in combination with designs that also restrict wetting. Under severe exposure, water-repellent-treated wood gradually becomes soaked after several months. A water-repellent treatment, moreover, does little to retard absorption of water vapor.

Dip treatments for protection during storage should be considered temporary for protection in use. Any cutting or considerable weathering will expose untreated wood; consequently, lumber should be retreated in approved manner for protection in use. Lumber given a dip in a water-repellent preservative after being cut to size is resistant to rain wetting for many uses, provided that the worst wetting hazards are removed by adequate design. Some items that are commonly so protected are: screens, sash, doors, siding, and trim. High-hazard items, such as porch rails and outdoor steps, may need pressure treatment for best protection in areas of high rainfall; elsewhere dip treatments will give considerable protection. Limited protection to siding, trim, and other items under moderate to light wetting exposures can be attained in all areas by brush or spray treatment after the wood is attached to the building. A water-repellent 5% pentachlorophenol solution for this use is available as a standard stock item.

4.1.2.2 Ground Moisture. Ground water is an important source of the moisture that promotes wood decay. It wets wood chiefly in four ways: (1) by direct migration into wood in contact with the soil, (2) indirectly, by capillary movement through hygroscopic foundation material, (3) by being transported through the conducting strands of the rare water-conducting decay fungi (3.2.4.4.2), and (4) by acting as a source of vapor leading to condensation. Therefore, on wet sites either soil moisture must be controlled or structures on them designed or treated to withstand the moisture condition.

4.1.2.2.1 Site Drainage. The first drainage factor to be considered is surface drainage. Unless the water table is at or very near the surface, collection of surface moisture creates the most damaging source of water under buildings, and outward draining channels should be provided for moisture from roof runoff or other moisture about the building. With such surface drainage provided on a site with reasonable subsurface drainage, the crawl space soil will remain dusty dry at the surface even if the crawl space is a foot or more below the outside grade. Below-grade structures (such as basements) may require special drainage and sealing treatment to avoid seepage - including that due to hydrostatic pressure.

If the ground water is still a problem after surface drainage, the site may have to be drained by ditching or tiling to lower the water table to a safe level. Sometimes the same benefit can be secured by filling. The type of fill used has an effect on the capillary rise of moisture and should be considered if used under slab-on-ground construction. For instance, capillary action will raise water only 0.01 foot in fine gravel, compared to 0.25 foot in coarse sand, and 1.20 feet in medium sand. Thus the fine gravel would be best of these for fill.

4.1.2.2.2 Avoiding Wood-to-Ground Contacts. The dangers of wood to ground contacts vary with the climate because of associated differences in opportunities for decay and termite attacks. However, as a general policy, no part of a wood building, except for pressure-treated pile foundation should be in contact with the ground. If it is to be in ground contact, wood going into emergency or low-cost construction should -- like any other -- be adequately impregnated with a suitable preservative.

4.1.2.2.3 Use of Moisture- and Vapor-Barrier Membranes. Concrete slabs on ground and cellar floors and walls must be highly resistant to water vapor if dry conditions are to be maintained. Membranes restricting both vapor and water should be used under slabs or outside basement foundation walls. These may be asphaltic or polyethylene films or epoxy coatings. In the case of slabs, effective barriers can be installed above the slab but this limits the finish flooring to a type that can be installed on flush sleepers (4.2.1.2.2.). Use of a soil cover in crawl spaces can prevent the evaporation of soil water and keep the crawl space dry.

4.1.2.3 Condensation. The phenomenon of condensation is quite simple. The amount of water that air will hold varies with temperature and, to a much smaller degree, barometric pressure. The warmer the air, the more water vapor it will hold. When air is cooled it gradually approaches the saturation point. Continued cooling causes some of the water vapor to condense into droplets of water. The temperature at which condensation begins is the dewpoint temperature. Any surface at or below the dewpoint temperature of an atmosphere will become wet with condensate. In practice, the amount of condensate forming and collecting on a given wood surface will be governed by two factors in addition to dewpoint temperature: (1) the vapor permeability of materials between the condensing surface and the warmer atmosphere beyond, and (2) the rate at which the condensate can escape from the surface during any period when the temperature is above the dewpoint.

The main condensation problems in buildings are: (1) winter condensation in crawl spaces, at slab-on-ground perimeters, or in walls, ceilings, and attics;

(2) condensation in floors, walls, and ceilings of cold-storage rooms and to a lesser extent in the floor below air-conditioned rooms; (3) condensation on outside surfaces at night and on indoor surfaces; (4) condensing of escaping steam; and (5) the redistribution by evaporation and condensation of rainwater behind siding. The condensate developed in these ways does not always result in decay, but it often does in construction where preservatives have not been used. Condensation can be controlled by: ventilation, vapor barriers, avoiding dewpoint temperatures, or in such special cases as repairing steam leaks.

4.1.2.3.1 Ventilation. Ventilation is an effective means of preventing cold-weather condensation in the crawl space or in living and work areas. However, the air being admitted to prevent or relieve condensation must be basically drier than the enclosed atmosphere from which the condensate comes. In general, ventilation of the crawl space is effectively attained by vents in the foundation wall (4.2.1.1.3). Condensation inside a building is often a problem of small living quarters where the room capacity is too small to permit adequate dispersal of moisture given off by such activities as laundering, bathing, and cooking. Condensation in this case usually does not constitute a decay hazard but frequently leads to objectionable molding of wall surfaces. Interior condensation may be similarly troublesome--and even result in decay--in situations where large amounts of steam are released, as in central laundries and sculleries. A remedy is to arrange for greater exchange of air between the inside and outside of the building, so moisture vapor cannot build up to the dewpoint. This will mean some heat loss during the heating season, but this expense usually is nominal.

In damp climates a reverse situation may occur at times; there may be condensation and molding on walls of living quarters during warm weather. Here the relative humidity of the outside air is so high that very little cooling is needed to attain the dewpoint; when the air enters the building, necessary cooling is brought about at the surface of the walls by the lower nighttime temperatures (or ground temperatures in the case of basements) retained in them. Because basement walls tend to remain especially cool in summer, they are particularly prone to warm-weather condensation. To minimize condensation of this kind, it is better not to ventilate the quarters unless the outside air is relatively dry. If warm, outside air is admitted, it must be appreciable drier than the enclosed atmosphere or it will increase the condensation hazard.

4.1.2.3.2 Vapor-Resistant Membrane. Placing a vapor-resistant membrane as near as possible to the warm side of a wall, ceiling, or floor, will prevent vapor from reaching the condensing surface. Such membranes are standard in construction of cold-storage facilities and in walls of houses in cold climates. In hot climates vapor barriers can at times be used to advantage in reducing condensation associated with air conditioning. A vapor barrier used as ground cover can help greatly in preventing serious winter condensation in crawl spaces.

4.1.2.3.3 Surface-Temperature Elevation by Insulation. Thermal insulation is used to control condensation in roofs of occupied buildings; in peripheral parts of slab-on-ground construction in cold climates; in walls, ceilings, and floors of cold-storage rooms; and in buildings' walls in cold climates. By reducing heat loss the insulation can maintain the temperature of a particular surface above dewpoint and thereby prevent condensation on that surface. But in accomplishing this, a still lower temperature with increased condensation hazard is developed behind the surface. This hazard can be offset by installing, along with the insulation, a vapor barrier on the warm side of the insulation. Without the barrier, moisture problems in an insulated wall can be serious. This has been shown by numerous instances in the North in which condensation on sheathing was sharply increased when insulating materials were blown into wall voids without the addition of a vapor barrier.

4.1.2.3.4 Prevention of Wetting by Steam. In laundries, sculleries and other places where steam is released in the atmosphere of a building, a situation is created favoring surface condensation on walls and windows. This can lead to molding on surfaces or to stain and decay in wood window-sash. When any adjoining space is air conditioned, more serious condensation can occur within the walls or ceiling unless they have vapor seals. If exhaust pipes do not extend sufficiently far outside the structure, condensation may wet wood near the outlet. Leaks also frequently develop in live steam pipes or at valves and traps. This can cause condensation on floors or other wood members, resulting in swelling or in decay. Locating valves and traps under buildings with wood floors should be avoided whenever possible.

4.1.2.4 Plumbing Leaks, Seepage, and Sprinkling

4.1.2.4.1 Plumbing Leaks. Most plumbing leaks are found and corrected before serious damage results. One exception to this general rule is the shower stall, where it is extremely difficult to maintain a watertight lining. At military establishments decay has been common in wood framing and sheathing near showers-particularly in wood under the stall. Related to this has been minor decay occurring around tubs, kitchen sinks, toilets, and wash tubs, as a result of water seepage into adjoining wood.

4.1.2.4.2 Care in Use of Water. In sprinkling lawns, care is needed to see that a minimum wetting of wood surfaces occurs. Frequent, heavy wetting of siding can lead to moisture problems. This is particularly a consideration in arid and semiarid areas where sprinkling is the main source of lawn moisture. Wetting sufficient to support decay can occur through a stucco facing.

Frequent and excessive washing of wood floors by hosing and mopping can also lead to sufficient accumulation of moisture to promote decay. Difficulty in this respect has been noted particularly in kitchen and drill-hall floors.

4.1.2.5 Original Wood Moisture. The problems inherent in the use of inadequately seasoned wood for construction, and the methods of storing and dip-treating lumber are discussed in paragraph 4.1.2.1.1.

4.1.2.6 Sea Water. Wetting by sea water usually results in an accumulation of salt, which has mild antiseptic properties. In wood boats in sea use most decay is traceable to the seepage of rainwater through the deck, or to condensation. However, a moderate amount of wetting by sea water may support decay; therefore, untreated wood should be protected from wetting by sea water as well as by tapwater or rainwater.

SECTION 4.2 PROTECTION OF PRINCIPAL BUILDING PARTS

4.2.1 FOUNDATIONS. The foundation is an extremely important item in the protection of a wood building against either decay or termites, because it keeps the wood separated from the ground. If properly constructed, it bars moisture movement from the ground into the wood substructure, it prevents serious wetting by rain splashing, and it can defend the wood against unseen attack by subterranean termites nesting in the ground. For a foundation to be effective in these respects, however, it should do more than merely separate the wood from the ground. Requirements in this respect differ with the type of foundation-crawl space, slab, or basement.

4.2.1.1 Crawl-Space Foundations. Buildings set over crawl spaces usually rest on perimeter foundation walls. Many buildings also have interior supports in the form of piers of supplementary walls. Piers are sometimes used for the perimeter support.

4.2.1.1.1 Foundation Materials. The perimeter foundation almost invariably is of concrete, or brick or stone masonry. The concrete wall has some advantage over the more loosely constructed masonry wall in that the concrete is less likely to have internal openings through which termites or the water-conducting type of fungus (4.2.2.4) may pass unnoticed. Pier supports may be of concrete, masonry, or wood. If of wood, they must be pressure-treated and must stand on well-elevated concrete footings; otherwise, on damp soil they are certain to decay. Precast footings for this purpose are widely available. If termites are a problem in the area, the wood pier footings should be placed on treated soil as termites will bridge-over concrete and some treated wood. As a rule, no wood in a building foundation should be permitted to touch the ground even though the wood may be preservative treated. An exception is pressure-treated foundation piling. Good pressure treatment will add greatly to the service life of wood in contact with damp ground, but it will not insure that the wood remains serviceable throughout the life of the building it supports.

In regard to concrete pier supports, no wood or paper forming should be left around the pier. The forming leaves a bridge between ground and wood above and thus provides easy access to the wood by termites or water-conducting decay fungi.

4.2.1.1.2 Foundation Height. Having the crawl-space foundation well elevated above the ground level provides room beneath the building for inspections and prevents serious wetting of the substructure wood by rain splash. A lesser advantage of a good foundation height is that it reduces the likelihood of dirt accumulating alongside the foundation until it reaches the wood.

A good rule is to place the top of the foundation at least eight inches above the exterior grade, and to have at least six inches of foundation exposed below the siding. A somewhat greater height above grade should be used in areas where hard rains are frequent, because of the water splash. In the crawl space itself, allow at least 24 inches between joists and ground and 18 inches between ground and girders. The greater interior spacing between ground and wood, as compared with the exterior spacing, allows for crawl space inspection. The need for ample crawling space cannot be too strongly emphasized; a building that cannot be easily inspected is likely to be neglected at times when the substructure is scheduled for inspection. The result can be serious damage by either decay or termites, which might have been easily corrected if observed earlier.

4.2.1.1.3 Vent Openings. Good ventilation of the crawl space tends to make conditions unfavorable for both decay and termites. The vent openings in the perimeter foundation wall should provide good cross movement of air. This is accomplished by placing them uniformly around the perimeter and as near the corners as possible without harming the strength of the wall. Placement near the corners is desirable because "dead air" is most common there in a crawl space. The total effective opening of the vents should be proportional to the size of the space. One recommendation is to make the openings total 1/160 of the ground area. Accordingly, a crawl space of 900 square feet would require a total vent area of a little more than 5-1/2 square feet.

If the vents are to be covered by screens, passage of air through them may be retarded by 25% or more; this can be compensated for by making the vent area about a third larger than the amount prescribed above. Also, if the vents are below grade level, a somewhat larger size of opening is needed to accomplish the desired ventilation. Furthermore, shrubbery placed in front of a vent can materially reduce its effectiveness. It is hardly logical to carefully make provision for ventilating the crawl space but then block the vents with shrubbery.

4.2.1.1.4 Soil Covers. Crawl space condensation can be reduced by use of soil covers (4.2.2.1.3).

4.2.1.2 Slab Foundations. The concrete slab-on-ground type of foundation has been widely used for military construction in some areas. It may have some advantages of economy, but does preclude inspection beneath it for termites. To offset this disadvantage, the fill must be properly treated before the slab is placed above it. Condensation sometimes collects on the slab at places where ventilation is restricted. All wood to be placed in direct contact with the slab must be treated (6.1.2.1).

4.2.1.2.1 Elevation of the Slab. As with the perimeter wall of the crawl space foundation, the top of the slab foundation should be at least eight inches above the finish grade, and the building siding should come no closer to the grade than six inches. Where considerable rain splashing is likely, as in the Gulf States, a greater clearance is desirable.

4.2.1.2.2 Underlying Vapor Barrier. A membranous vapor barrier should be placed under the slab (4.1.2.2.3). A membrane with suitably high vapor resistance will prevent ground moisture from migrating through the slab-and thus avoid warpage of wood floor resting on the slab, or degradation of the flooring finish.

The barrier should have high resistance to vapor transmission, immunity to damage by moisture or microorganisms, and ability to withstand rough usage before the concrete is poured. One sheeting material having all these qualities in high degree is 6-mil polyethylene.

4.2.1.2.3 Slab Insulation. In the colder climates it is desirable to insulate the perimeter of the slab. This not only helps to keep the floors comfortably warm but it also limits condensation on the slab and wetting of the contacting wood. The exact location of the insulation will depend somewhat on the manner in which the slab is constructed. In addition to the perimeter insulation, gravel under the slab can help to reduce heat loss. The insulation for floor slabs should be nonabsorbent, and have high resistance to heat transmission, resistance to breakdown by moisture, microorganisms, or insects; and mechanical strength to withstand loads or expansion forces.

4.2.1.3 Basement Foundations. The substructure wood is easiest to protect against decay and termites when the building is set on a basement foundation. The basement permits frequent inspection beneath the building to watch for troubles; also, inasmuch as the ordinary basement is cemented in, there is no condensation associated with damp soil, such as must be contended with in many crawl spaces.

The basement foundation, like the other types, should have a wall height above the exterior grade level of at least eight inches, with at least six inches of the exterior surface showing.

Wood bearing posts in the basement ideally should be elevated above the floor on footings, to keep the basal ends dry.

4.2.1.4 Porch Foundations. The porch foundation should be constructed according to the same rules as for the building foundation. If the porch is constructed with a wood floor, provision should be made for ventilation and inspection beneath it, and the height of the foundation above grade preferably should be at least eight inches. The bottom of the platform joists should be high enough above the ground to permit inspection from underneath.

Whether the porch floor is of wood or concrete, it should slope away from the building to drain off rainwater.

Particularly liable to decay or termite attack is the earth-filled porch, constructed by pouring a slab platform on a dirt fill. The proximity of the dirt fill to the building substructure violates the guiding principle of keeping wood and soil well separated. Unless an appropriate barrier is interposed between the porch and building, certain fungi and termites can move without difficulty from the soil into the building substructure along the line of juncture. Earth-fill must be chemically treated.

The dirt-filled porch can be made reasonably safe by building the porch as an independent unit, separate from the house at all points by 2- to 3-inch air space which can be covered at the top. This necessitates adding a porch foundation wall at the end toward the house, but the gain in damage insurance is well worth the extra time and cost. An alternative measure is to build the porch, using both concrete and noncorrosive flashing as a barrier between the porch fill and the building proper.

The safest type of porch is one that avoids the dirt fill and uses a self-supporting slab for the platform. If this is done, provision must be made for removal of any wood forms.

4.2.1.5 Termite Control Measures for Foundations. Both preventive and corrective control measures applicable to building foundations as well as to other parts of structures are discussed in paragraph 4.6.4.

4.2.2 SUBSTRUCTURE WOOD. After foundation design, the next item of consideration in building is the substructure wood. There are only two ways to protect the substructure against decay: design and build so that the wood stays dry or, where a dry condition cannot be assured, use preservative--treated wood.

4.2.2.1 Chief Moisture Problems of the Substructure

4.2.2.1.1 Ground Contact. With few exceptions, the load-bearing wood substructure should never rest on the ground. Where special circumstances dictate the use of wood in contact with the ground, pressure-treated material should be used.

Even if the structure is kept off the ground, in later years the exterior grade may be built up to such a height that the soil comes in contact with the wood. The increase in grade elevation often occurs in one or two ways: fresh dirt is moved onto the lawn from time to time, and sometimes extra dirt is raked toward the building with the idea that the smaller the amount of exposed foundation wall the more beautiful the landscaping. Splashing at times of lawn and yard water will frequently raise the soil level at the building several inches above the level a few feet away.

4.2.2.1.2 Inadequately Seasoned Lumber. Danger of decay in lumber in the substructure comes not only because the lumber is wet enough to support fungal growth, but also because lumber that comes on the building site incompletely seasoned is likely to be already infected by a decay fungus.

If the moist, infected lumber is closed in whereby it cannot dry out readily, and temperatures are favorable, the decay may progress rapidly. An additional factor favoring decay in this case is the production of metabolic water by the fungus as it breaks down the wood. This additional moisture weighs about half as much as the destroyed wood; therefore it may be sufficient, in a poorly ventilated space, to keep the wood wet enough to support decay despite losses by evaporation. Decay incurred by using inadequately seasoned lumber is not common but, when it does occur, repairs are relatively costly because the affected wood usually is not readily accessible. It has necessitated repairs costing many thousands of dollars at some installations.

A second situation of particular danger with this kind of lumber develops in crawl spaces that are subject to cold-weather condensation. This is discussed in the following section on condensation.

4.2.2.1.3 Condensation

4.2.2.1.3.(1) Crawl-space Wetting. Wetting of the substructure wood by condensation is known to be occasionally serious in crawl spaces during cold weather. The general conditions necessary for condensation are described in 4.1.2.3. The specific factors leading to condensation in the crawl space of a heated building are: (a) Moist or wet ground, (b) resultant comparatively warm, damp air in the space, and (c) prevailing outside temperatures of approximately 50°F. or below. Under such conditions, the relatively cold air outside cools the sills, plates, and joists located on and near the foundation so that a dewpoint is created on the exposed surfaces of these members. Over a period of time enough condensed moisture can be absorbed by the wood to support decay. Recent observations suggest that crawl-space condensation is most likely to be capable of supporting relatively rapid decay if the wetted wood is already infected at the time it is installed. The lumber may have dried out after reaching the building site, but the dormant decay infection can again become active upon wetting.

Occasionally, condensation leading to decay occurs in the crawl space of an unheated building. In such cases, the decay is not largely in wood near the perimeter of the space but is more likely to be present in centrally located wood as well, especially in the subfloor. Problems of this kind have not been specially studied, but the factors seem to be basically the same as those just described. Outside temperatures must be low, but not low enough to freeze the ground in the crawl space. Under these conditions, a significant amount of water vapor presumably accumulates in the unventilated space, and the air in the space is warmed somewhat by residual heat in the ground. Such a condition, coupled with the lower temperature of the unheated floor area, results in a dewpoint and condensation on the underside of the floor. Preventive measures here are the same as those for the crawl space of a heated building.

4.2.2.1.3 (2) Condensation on Slab Foundations. In humid climates, condensation is common on slab foundations. The slab is cooled by the supporting ground sufficiently to acquire a dewpoint temperature. The same can occur in a building that is artificially humidified. Because condensation occurs frequently on slabs, and because of the load-bearing importance of substructural components touching the slab and their inaccessibility, the plates should be pressure treated. The tendency for condensation can be substantially reduced by insulating the perimeter of the slab and also beneath the slab (4.2.1.2).

A vapor barrier should never be placed above wood resting on the slab. No ordinary barrier will entirely prevent condensation on the slab, and what does occur will be prevented from evaporating by the overlying barrier. In addition, a moisture barrier so placed can be doubly dangerous if any moisture comes through the slab from the ground.

4.2.2.2 Spacing Between Substructure Wood and the Ground. Appropriate spacing between the substructure members and the ground was discussed in 4.2.1 of this chapter. Make the minimum clearance between the outside finished grade and the top of the foundation wall or slab foundation at least eight inches, and with at least six inches of the foundation exposed. This means that the bottom of sills and joists, or of plates if used, would be at least eight inches above finished grade. The minimum interior clearance between the ground and bottom of joists in crawl spaces should be 24 inches; for girders, 18 inches. These amounts of separation should avoid serious wetting by rain splashing, and provide adequate space for inspection. Also, the spacing between wood and ground helps prevent hidden termite attack.

4.2.2.3 Maintaining A Dry Crawl Space. If the crawl space is dry, the opportunity for decay in the associated substructure will be small, and the danger of termite attack will be substantially reduced. Three ways of keeping the crawl space dry are as follows.

4.2.2.3.1 Soil Drainage. By providing good drainage, either by selecting a naturally well-drained site or by employing recognized good methods of promoting local drainage, the surface soil in the crawl space can be kept dusty dry, so it does not act as a source of substructure wetting.

4.2.2.3.2 Ventilation. Good ventilation of the crawl space will minimize buildup of high relative humidities that lead to condensation in the crawl-space area. Ventilation also will promote drying of any substructure part that gets wet. To be effective against winter condensation, the vents must be kept open in cold weather - a precaution which commonly is not observed because it may lead to cold floors or to pipes freezing. The simplest alternative is to use a soil cover.

4.2.2.3.3 Soil Cover. A good vapor-resistant ground cover laid on damp soil will generally keep the substructure wood as dry as it would be if the soil were dry. It largely eliminates the likelihood of serious condensation that results from closing the vents in wintertime.

For the cover, it is often desirable to use a material that not only has adequate vapor resistance but also has sufficient strength to permit some traffic on it. Besides the need to crawl on the cover while making inspections, it also will be necessary from time to time to work on the cover in making repairs to plumbing, heating ducts, and electrical wiring. Not infrequently the crawl space may be used for storing certain materials, in which case an additional traffic burden would be placed on the ground cover. Materials that will serve these dual functions in the crawl space, at very little expense, are 45-pound or heavier roll roofing and 6-mil polyethylene sheeting. The strips of ground cover should be overlapped slightly and the outer edges should be carried to the foundation wall. It is unnecessary to take any special measures to limit escape of water vapor at the seams or edges. Also, the ground need not be perfectly flat as the cover will conform in time to moderate surface irregularities, however, the surface should be smoothed of all sharp irregularities. A two-to-three inch sand cover is often advised. In some cases a sand cover has been used without a sheeting, but in many areas the sand cover alone will not provide adequate protection.

4.2.2.4 Controlling the Water-Conducting Decay Fungus. The water-conducting type of fungus can attack dry wood by conducting water from the ground to the wood (3.2.4.4.2). The water is carried through special vine-like structures (rhizomorphs) which sometimes appear on the surface of the foundation wall or pier. More often the rhizomorphs are completely contained within wooden columns and heavy timbers. By dividing at structural joints, rhizomorphs may enter new timbers and so carry moisture throughout a large building. Decay caused by this fungus is not an exception to the rule that wood must have about 30% or more of water in order to support decay; the fungus in fact wets the wood immediately ahead of the points being attacked.

Fortunately, this type of decay is not very prevalent and warrants special attention in buildings mainly in the warmer coastal areas of the United States, such as the Gulf States, the South Atlantic Seaboard, and the damper portions of the Pacific Coast. However, the potential for damage should not be overlooked even in arid climates. Though uncommon, severe structural damage has occurred unseen when interior plumbing leaks have provided moisture for the water-conducting fungus. Although one of the minor decays in regard to the total damage caused, nationwide, it often develops with spectacular rapidity, and in a single structure it can be devastating.

The precautionary measures of good drainage, good ventilation beneath the building, and good spacing between wood and ground are particularly important in protecting the substructure against decay by the water-conducting fungus. Furthermore, it is especially important that all wood debris be removed from beneath the building and that no wood forming be left. Like termites, this fungus can readily bridge the space between ground and substructure by moving through forming connecting the two; with the fungus growing inside the forming, this initial stage of the decay may not be apparent to the inspector.

The foregoing precautions are likely to be overlooked in constructing the dirt-filled type of porch; consequently, special attention should be given to the design of such a porch (4.2.1.4).

Finally, to avoid this kind of decay, see that no lumber with any discoloration suggestive of incipient decay ever gets on the building site. There is considerable evidence that the chief water-conducting fungus in the United States, Poria incrassata, is distributed to a large extent in lumber that is infected in the seasoning yard or storage yard. When infected lumber is brought to the building site, the fungus may get a start in the ground by developing in lumber trimmings that are inadvertently covered by soil.

4.2.2.5 Termite Control Measures for the Substructure. If the substructure wood is protected against subterranean termites, the wood above usually will also be safe. The principal protective measures center around the construction of the foundation and soil treatment (4.6.4.1).

4.2.2.6 Preservative Treatment of Substructure Wood. Preservative treatment of substructure wood and of other parts of the building is taken up in Chapters 5 and 6. Wood items in or on concrete laid on the ground should be pressure treated. Items in contact with a foundation wall also require pressure treatment.

4.2.3 EXTERIOR WALLS AND ASSOCIATED ITEMS

4.2.3.1 Primary Moisture Problems in Walls. The water that promotes deterioration of exterior walls, trim, doors, windows, and so forth, arises from several sources including rain wetting, condensation, use of wet lumber, sprinkling, and splash.

4.2.3.1.1 Rain Wetting of Walls. More deterioration of exterior woodwork on buildings is traceable to rain wetting than any other moisture source. Rain may be driven directly against a wall, or the actual wetting may be roof runoff or water splashed up against the wall. Some entry into joints may be wind pressure or gravity flow. However, winds of less than 40 miles per hour have surprisingly little effect on total rain seepage into siding. The main effect of strong wind is to reduce the protective influence of roof overhang and gutters by driving the rain onto the siding, windows, and doors. Entry of rainwater takes place largely by capillary movement. The most serious wetting occurs as a result of water getting trapped in joints, particularly in joints comprising end grain--such as those where siding abuts trim. Water can enter even through hairline checks in the paint at joints. Longitudinal splits through lumber also can cause troublesome amounts of water to enter a wall.

The amount of rainwater accumulating in exterior woodwork depends on the amount of wetting and the rapidity of drying. The degree of wetting is a function of the amount and frequency of rainfall, amount of wind accompanying rains, and building design. The rate of drying, while influenced by the weather, is governed mainly by construction details, such as the type of sheathing paper used.

Damaging amounts of rain seepage may occur in any decay-susceptible wood exposed on the surface of a building. The greatest danger is with roof edges, appendages, and exposed structural members (4.2.4, 4.2.5 and 4.2.6). Important amounts of decay, however, may occur in siding trim, sash, framing, and such decorative structures as shutters. Sidings of the comparatively durable heartwood of cedar and redwood rarely decays; sapwood siding, which generally is of pine species, molds when wet and this generally is more troublesome than decay. But even when wetting does not cause decay, it can lead to serious paint failure.

Paint failure in siding may develop at a considerable distance from the point through which leakage occurred. This happens where water, after entering a joint at the end of a siding board, flows along the top edge of the board to a different location. Or the water near the siding joints may raise the humidity of the air between siding and sheathing, so that cooling at night results in condensation on the back of the siding. A thin film of water on the back of wood siding can put large stresses on the surface paint film.

4.2.3.1.2 Condensation in Walls. Condensation may occur either in or on walls. Except for cold-storage rooms (4.3.2.1), condensation in walls seldom leads to decay but may cause serious paint problems. Condensation in air-conditioned buildings (4.3.3) is mainly in floors, not exterior walls.

With these exceptions, condensation that leads to trouble in exterior walls occurs during the winter mainly in the North, although occasionally as far South as the Gulf Coast. During cold weather the temperature of the siding or sheathing may be lower than the dewpoint temperature of the inside atmosphere. Warm inside air will then move outward (at a rate determined by the vapor-pressure differential and the permeability of the wall components) and condense on the cold wood. In loose construction with no materials of high vapor resistance in the walls, condensate accumulation in walls is rare. It becomes most serious when a vapor-resistant paper is used under the siding or when the siding itself is vapor impervious. Thermal insulation without a vapor barrier on the warm side of the wall is likely to bring about condensation within the wall--and at least a paint problem-- especially if coupled with unregulated winter humidifying (4.2.2.1.3).

The condensation occurring in crawl spaces (4.2.2.1.3) may also affect the exterior wall or attic, particularly when wood skirting is extended below the sill or if design permits crawl-space air to enter the wall void. When the wall space is heated artificially or by the sun, a stack effect may be created, causing the air to rise in the space and new air to move in at the base.

Condensation sometimes occurs on cold water pipes in walls but seldom to a bothersome degree. Occasionally, a restricted amount of decay is found where pipes penetrate a sill plate.

Exposed surfaces cool at night by heat radiation. On a clear, still night the surface of a building may drop 10°F or more below the adjacent air. In the southern States and the tropics, this leads to condensation on exterior surfaces. The condensate is absorbed by unpainted wood but collects as a fine film on painted surfaces. This commonly leads to surface molding and the non-adhesion of oil paints in repainting jobs.

Although not completely verified, condensation induced by heat radiation probably explains mold occurrence on the underside of thin roofs, as in carports, stoops, or exposed unboxed eaves. In some localities, condensation may be heavy on screens, streaking the wire and and wood below or soaking into the frames as it runs down.

Steam exhaust pipes, if of insufficient length, may lead to steam condensing on the wall.

4.2.3.1.3 Wet, Infected Lumber in Walls. When wet lumber is used in wall construction, it usually dries before serious decay occurs. However, if it is infected as well as wet and is enclosed within a relatively vaportight wall, decay may develop. The presence of wet plaster on the inner face of the wall can add to the decay danger.

Infected wood used in an exposed position also can become seriously decayed if the climate is damp. Even nondestructive fungus infection - as mold or stain - can make wood markedly more absorptive and thus subject to rain wetting (2.5.4.3). Increased wetting favors decay; once started, some decay fungi can persist for years in a dormant state in dry wood and resume their attack on rewetting.

Installation of wet or incompletely seasoned lumber in a building can create other difficulties besides decay. In drying there is danger of splitting, warping, and twisting that can both favor rain seepage and objectionably deform the structure. For best performance, siding and trim items should have an average moisture content when installed of 9% for the dry Southwest and 12% in the remainder of the United States.

4.2.3.1.4 Miscellaneous Wetting of Walls. (1) Cooling towers for air conditioning sometimes lead to important wall wetting. If located on a sloping roof, overflow can cause continuous flowage over the eave or the mist from the condenser can be blown against the wall. (2) Sprinkling of lawns and gardens can result in important wall wetting. (3) If siding or trim is extended too low, or if the outside grade is raised excessively, the wood can be wetted by ground water.

4.2.3.2. <u>Protection for Exterior Wall Items</u>. Most of the controls discussed under 4.1.2.1, 4.1.2.3, 4.1.2.4, and 4.1.2.5 apply to this section. The following protective measures are particularly applicable to exterior walls.

4.2.3.2.1 Dry, Infection-Free Lumber. Fortunately, dry, sound lumber usually can be obtained for exterior walls if a reasonable effort is made. Insurance of proper moisture content and freedom from infection can be most reliably obtained in kiln-dried lumber that has been stored and shipped under cover. Air-dry lumber can be essentially infection-free if the producer properly dips or sprays it with protective solution at the time of sawing.

4.2.3.2.2 Roof Overhang and Gutters. The amount of roof overhang is the most important single design factor determining the amount of wall wetting in a given climatic region. The addition of gutters adds little to the effectiveness of roof overhang in keeping the wall dry, but is important in preventing splash wetting. The protective value of roof overhang varies with climatic factors; e.g. amount of rainfall, duration of rains, and the amount of wind accompanying the rain. An overhang of at least 2 feet on a one-story building has much to recommend it in areas of substantial rainfall. For effective protection, multi-storied structures require intermediate canopy roofs.

4.2.3.2.3 Tight Joinery and Paint Surface. On walls exposed to moderate or high rain wetting hazard, joints cannot be made sufficiently tight to exclude deteriorating amounts of seepage due to capillary water movement. Tight joints, however, reduce the amount of water entering by gravity flow and thus are generally beneficial as a supplementary means of moisture control.

Painting only temporarily seals joints. Once water is inside, the paint retards the drying rate and thus may actually increase rather then decrease stain and decay hazard; therefore, it should not be depended on as a means of controlling decay at joints. An exception to this general rule is the use of paint to prime the backs and ends of siding, trim, and so forth. This is an effective means of reducing wetting by rain seepage. On exposed surfaces, paint can reduce wetting associated with surface checking and ring separation, and in this respect can be useful as a means of protecting against surface weathering as well as for improving appearance.

4.2.3.2.4 Avoidance of Splash Wetting. Decay can be caused by roof runoff splashing up onto walls from the ground. Damage is most likely in regions where rainfall is frequent, and with siding material overlapping the top of the foundation so that splash can reach the back of the siding and also the sheathing and sill plate. Splash is most serious when roof runoff strikes a flat, hard surface as a concrete walk. The amount of wetting also varies with height to eave and width of eave. Splash wetting of masonry walls having water-permeable joints can lead to decay of wood joists or beams embedded in them. The logical control of splash wetting is wide roof overhang or the use of an eave gutter.

4.2.3.2.5 Flashing at Siding. Noncorrosive metal or sometimes durable waterproof felts are used as flashing to separate wood from water at certain critical points on the siding or openings in the siding. These include the juncture of siding and roof surfaces (as with dormers, porches, and canopies, in multi-story buildings), the top of window and door trim where unprotected by sufficient roof overhang, and the juncture of a concrete porch slab and the wall. Thus, flashing should be used anywhere a horizontal projection from the wall occurs in an exposed location.

4.2.3.2.6 Wall Vapor Barrier. In areas with long, cold winters, serious condensation resulting chiefly in paint failure may occur in walls, particularly if artificial humidification is used to maintain comfortable indoor conditions (4.2.3.1.2). During cold weather, indoor heating creates a vapor-pressure gradient from the inside to the outside of the wall. Vapor tends to move outward and, if it contacts a surface at or below the dewpoint temperature, condensation results. Danger is greatest in insulated walls. The condensate may freeze, in which case the most serious wetting will occur with the advent of warm weather. This type of condensation can be prevented by the use of a vapor barrier near the inner surface of the wall, that is, the warm side, and by avoiding excessive artificial humidification of the living quarters.

The only modification of this rule is in the warmer, humid climates of the South, where summer air conditioning by artificial cooling is used for particularly long periods, or near the inner walls of cold-storage rooms (4.3.2.1, 4.3.3.1) with refrigerant cooling. Here, the vapor barrier should still be located on the warm side of the wall, but the vapor-pressure gradient is reversed and the barrier therefore should be near the outer surface of the wall.

4.2.3.2.7 Breathing-Type Sheathing Paper. The primary object of sheathing paper is to prevent the entry of wind and water. In addition, sheathing papers used under lumber, plywood, or other wood siding should be relatively permeable to water vapor. Vapor permeability in the sheathing paper is important in the colder climates in helping to prevent a buildup of moisture vapor in the wall that could result in a condensation problem. It also allows any rainwater that seeps behind the siding to escape into the wall void rather than accumulate in the siding. Papers of suitable permeance in these respects are sometimes referred to as a breathing type. This and other types are described in Table xx . However, where major rain seepage is a problem, a breathing paper will not permit sufficiently rapid drying to prevent damage. In such a circumstance, breathing papers must be used with good roof overhang or water-repellent treatment of the siding.

4.2.3.2.8 Miscellaneous Measures. Steam exhaust pipes and air-conditioning cooling towers should be so located that wetting of walls will be avoided. The location of a cooling tower on a pitched roof may lead to wall deterioration because of the continual flow of water over the eave.

4.2.3.3 Siding Construction For Decay Resistance. The following general measures should be followed:

(1) See that wood siding is dry and fungus-free (4.1.2.1.4 and 4.2.3.1.3).

(2) Use adequate roof overhang, at least 2 feet where practicable on a one-story building (4.2.3.2.2).

(3) Use naturally decay-resistant woods or water-repellent preservative treatment under conditions listed in 4.2.3.4.

(4) Use eave gutters and downspouts where needed to prevent basal splash or aggregated roof runoff striking walls (4.2.3.2.4).

(5) With board or plywood siding, omit solid sheathing where type of building and climate permit.

(6) Use sheathing paper of the breathing type under lumber, plywood, or other wood siding (4.2.3.2.7).

(7) Where siding joins a roof, as on a dormer, leave a two-inch clearance between siding and shingles in high-rainfall areas and one -inch clearance elsewhere (thus exposing one or two inches of flashing).

(8) Leave a minimum of six inches clearance between siding and gradeline and one inch between siding and slabs of porches.

4.2.3.3.1 Lumber, Plywood and Hardboard Siding. If the siding is vertically aligned (boards and battens, or boards with interlapping joints), no special construction details are necessary to protect it; the general measures listed at the beginning of this section will be adequate.

For the siding to be horizontally aligned, as is most common, certain specific precautions can be taken in addition to the general measures listed above. Added protection can be given to drop siding, where appearance permits, by applying trim over the ends of the siding. With bevel siding, the corner design giving greatest protection against rain seepage is the commonly available metal corner applied over the ends of each individual siding course. These additional protective features are mainly of value in high-rainfall areas. If plywood or hardboard is used to simulate lumber siding used horizontally, the protective needs can be regarded as essentially like those of lumber siding.

For plywood or hardboard panels, only exterior-type material is acceptable. Good construction procedure would be as follows: (a) After the panels are in place, flood the joints with double-strength preservative (10% pentachlorophenol plus water repellent if this can be obtained locally). Preparation of this strength solution from the concentrate used to make a 5% water-repellent solution may contain excess waxes that can prevent paint bonding to wood (5.2.2.2). A squirt-type oil can can be used to advantage for this. (b) Prime the joints with suitable priming paint. (c) Also protect the horizontal joints with flashing and do not use batten strips. (d) Protect the vertical joints by filling them with the best grade of weather-resisting mastic or caulking compound, allowing space in the joint for this, or by covering them with batten strips of preserved wood. Both caulking and battens on vertical joints are warranted in the wettest climates. (e) Carry the bottom edge of the lowermost panel down over the supporting framing, to form a drip edge.

4.2.3.3.2 Shingles. Almost all wood shingles are of naturally decay-resistant species. Consequently, there are few decay problems with them, if common practices are followed. With a shingle coursing the overlap must be sufficient to ensure a continuous double layer so that water will not seep behind the shingles. Any nailing strips used should be of decay-resistant or preservative-treated wood.

Apply asbestos-cement shingles according to the "Manual of Application Methods for Asbestos-Cement Siding" (by Asbestos-Cement Products Association). Special attention must be given to the proper application of felt backer strips at all vertical joints, to proper flashing at corners and trim, and to caulking at juncture of siding and trim.

4.2.3.4 Preservative Treatment of Exterior Wall Items

4.2.3.4.1 Siding Treatment

4.2.3.4.1 (1) Board Siding. Treatment of board siding with a suitable water-repellent preservative can be of benefit in the wetter climates in two ways; it minimizes fungus damage and reduces the tendency toward paint blistering caused by rainwater. A good water-repellent preservative protects siding of all species against paint blistering. As blistering is a major problem of paint maintenance, the use of water-repellent preservative is advisable wherever the rainfall and type of roof construction subject the siding to considerable wetting.

The need for preservative treatment of siding, and the type of treatment, depend on geographical area, the kind of siding and wood used, and amount of roof overhang. The conditions under which dip and pressure treatments are recommended are given in Chapters 5 and 6.

In general, treatment of the siding is a desirable safeguard against fungus or paint troubles in the wetter climates, with all two-story houses, and with one-story houses having a roof overhang of less than two feet and especially where there are no gutters. Treating relatively unsheltered siding will provide worthwhile protection in all tropical regions, and in areas within the United States where the climate index is high (6.1.1.2). The value of such protection will be greater where the rainfall usually comes in prolonged spells rather than as short, heavy showers, and where winds commonly are sufficient to blow the rain against the siding.

When untreated wood is used, with roof overhang providing the main protection, some paint peeling may develop at joints, indicating limited rain seepage. In such cases the joints should be flooded by spraying or brushing with a water-repellent preservative prior to repainting.

In treating new siding before it is installed, a 3-minute dip or an equivalent vacuum treatment in water-repellent preservative meeting Federal Specification TT-W-572 generally should be adequate. A widely used treatment for this type for exterior millwork is covered by National Woodwork Manufacturers Association Industry Standard 4-70 (NWMA IS4-70) "Water Repellent Preservative Non-Pressure Treatment for Millwork." The ends of boards cut on the job should be re-treated by dipping or by several brushings with the preservative solution. Siding may be treated in place but this is considered less effective than a dip treatment before installation, especially for protection against decay. Treating in place involves applying the preservative solution generally around board ends at windows, doors, and corners, and where the upper course of siding lies against the next lower course, so the fluid can work up into the lap between the boards.

In the colder climates where winter condensation may occur sometimes on the inner surface, siding of redwood or western redcedar should not be completely covered with water repellent. Treat just the edges and ends. If a water repellent is present on the inner surface, condensed moisture is not absorbed but tends to accumulate into sizable drops, which commonly pick up colored extractives from the wood. As the drops roll downward on to the painted surface of the siding board below, the extractives are deposited, causing unsightly discoloration. However, paint blistering may be expected.

4.2.3.4.1 (2) Panel Siding. Plywood panel siding should be given water-repellent treatment in accordance with standard NWMA IS4-70. If the siding is destined for the tropics, it should be pressure treated according to Table II of Federal Specification TT-W-571 or according to Table II stating that cleanliness, paintability, and water-repellency are required.

4.2.3.4.2 Window and Door Treatments. Exterior wall trim, sash, doors, shutters, and decorative panels should be treated with a water-repellent preservative. The degree of protection needed depends on rainfall, species of wood, and width of eave. The criteria for determining type of treatment are the same as noted for siding.

4.2.4 PROTECTION OF ROOF EDGES

4.2.4.1 Primary Moisture Problems. The roof edge is especially subject to decay because it is altogether in the open and so is exposed to both direct rain wetting and to roof runoff. Roof runoff, particularly with asphalt shingles, tends to curl around shingle butts and wet the various items comprising the roof edge. Corroded, undersized, blocked, or sagging eave gutters can lead to overflow at the back edge and wetting of the wood. In high rainfall areas, particularly in the tropics, rains are frequently of sufficient intensity to cause water to overflow the joint channel in roof tiles and flow over the underlayment. When this happens the roof edge is subject to more wetting than with surface flow dripping from the protruding tile edge. With flat roofs, gravel stops cannot be effectively sealed for long periods without maintenance. Leaks at horizontal lap joints may occur unless frequent attention is given to joint seals. Some roofing compounds appear to be corrosive to metal, resulting in gravel-stop leaks. Also severe gutter corrosion and eave decay have occurred where the condensing towers for air conditioning are placed on roofs. Some chemicals used in tower water can be corrosive to some metals. Thus the roof edge is particularly subject to decay and requires careful attention in designing buildings.

4.2.4.1.1 Fascia. Greatest chance of decay occurs at joints between two fascia pieces but can occur anywhere that constant wetting occurs, as under a lapjoint in a gravel stop, or at points where gutters are faulty. When roll roofing is nailed to the roof edge, either with or without a surface nailing strip, moisture seepage problems can become severe in moderate-to-high rainfall areas.

4.2.4.1.2 Soffits. Normally, soffits are less subject than fascia to decay. Decay can occur when: (1) There is a prolonged leak in the roof cover that is neglected, (2) a built-in gutter corrodes, (3) fascia are permitted to decay to a point where water flows through them, or (4) in cold climates, when roofs are not flashed against wetting from melting ice dams.

4.2.4.1.3 Sheathing Edges. The sheathing edge gets wet mainly by water curling around the shingle edge (particularly with asphalt shingles). In high rainfall areas, if fascia are absent and the sheathing is not flashed, the edge board at the eave may need replacement before the shingles do.

4.2.4.1.4 Moldings. Any molding used at the roof edge is subject to decay in the same way as fascia.

4.2.4.1.5 Rafter Ends. Unless specially protected, exposed rafter ends (and also beam ends) are highly vulnerable to decay in areas with high rainfall. If decay of fascia or sheathing edge progresses unchecked, it usually involves rafter ends and thus greatly increases the cost of repairs.

4.2.4.2 Construction For Protection At Roof Edges.

(1) In northern areas where melting ice dams cause trouble, install flashing to protect against them. Lay smooth surface, 55 pound roll roofing or roof sheathing from the eave upward, 6 inches beyond the inside face of stud line.

(2) Use metal flashing on all roof edges not protected by a gutter. With roofs covered with gravel or other aggregate,a gravel stop serves as the flashing. In other places an L-shaped flashing is used. At the eave, place underlay over the top of the flashing. Do not nail through exposed vertical part of flashing. Let the flashing extend away from the building sufficiently to provide a free drip edge. Occasionally, the flashing is brought down to cover the fascia completely. This also is a good practice provided the lower edge of the flashing extends down far enough or is turned out sufficiently to carry the runoff away from the fascia.

(3) Let shingles, tile, slats, or metal coverings extend at least one inch beyond the fascia.

(4) Avoid nailing roll roofing to the fascia (either with or without an exposed nailing strip) unless the fascia and nailing strip are naturally decay-resistant or preservative-impregnated wood. The exposed edges of roll roofing should be secured so far as possible with a suitable adhesive rather than nail.

(5) Particularly if the roof is flat, see that the soffit area is appropriately ventilated.

4.2.4.3 Preservative Treatment At Roof Edge. For fascia, nailing strips with roll roofing, and exposed molding in high rainfall areas, use: (1) Wood impregnated with a water-repellent preservative; (2) for better paintability, wood impregnated with a waterborne salt or penta in liquefied gas, and after drying, brush, or spray it with a water-repellent preservative (Federal Specification TT-W-572).

In moderate rainfall areas, use a naturally decay-resistant wood or other wood given a 3-minute dip in a water-repellent preservative, or brush or spray it with a water-repellent preservative.

4.2.5 BUILDING APPENDAGES

4.2.5.1 Primary Moisture Problems

4.2.5.1.1 Rain Wetting. Most decay in steps, porches, loading platforms, fireladders, and other appendages results from rain wetting. Step treads and decks are particularly vulnerable because mechanical wear and flat exposure to the sun favor surface checking, through which rainwater can enter. Also, appendages present numerous joints in which rainwater can collect as they generally are little protected by roof overhang. Thus, in most cases, these exterior building components are subject to maximum rain wetting.

4.2.5.1.2 Ground Contact. Step treads, bases of fireladders, and supporting columns that come in contact with the ground either by design or regrading of the site, are subject to wetting by ground water. In addition to decay, they are subject to termite attack in most areas. Damage from ground contact can occur to dirt-filled porches, steps, and terraces unless the wood sill is specifically protected.

4.2.5.1.3 Condensation. If the space below a porch is enclosed from the outside but open to a damp crawl space, winter condensation can develop on the deck and framing (4.2.2.1.3 and 4.2.2.3). In hot, humid areas condensation resulting from heat radiation at night can add appreciably to wetting of screen frames (4.2.3.1.2). The effect is similar to, and the control the same as for rain wetting.

4.2.5.2 <u>Construction of Appendages to Resist Decay</u>. In high-rainfall areas, little can be done through design alone to prevent decay in wood building appendages. It amounts to providing cover by an unusually wide eave, sloping the decks to drain off rainwater, and keeping the construction simple to minimize joints and contacting surfaces in and between which water can be trapped. Such precautions need to be supplemented by the use of treated wood. In moderate- to low-rainfall areas, however, design alone can do much to alleviate decay.

4.2.5.2.1 Porches, Stoops, Loading Platforms, and Other Flat Decks. Broad, flat items exposed to the weather are especially vulnerable to wetting, but several things can be done to minimize serious trouble from this. Perhaps most important of all, do not use double flooring. Caulk the joints in flooring with white lead in oil if water-repellent-treated wood is not used. Provide drain holes through the bottom screen rail or other obstruction.

Where feasible do not cover framing with trim boards. Use as little molding and other trim around column bases as possible. In boxing the roof beam across the front of a porch, have the fascia board extend below the soffit, thus preventing a horizontal ledge favoring seepage. Provide an eave gutter to prevent roof runoff from striking porches and other decks.

Self-supporting concrete slabs are preferable to those on dirt fills. If a dirt fill is used, the porch should be separated from the building by a two to three-inch air space or otherwise constructed as described in 4.2.1.4. All forms used in pouring concrete must be removed.

4.2.5.2.2 Steps and Fireladders. Concrete bottom steps or supports should be used. The wood should rest on the concrete, not be imbedded in it. Regardless of design, which seems to have no marked effect on decay hazard, wood steps and fireladders in high rainfall areas should be pressure-treated wood. (See 6.1.2.1.4 if they are to be painted.)

4.2.5.2.3 Railings. The simpler the design, the fewer the joints into which water can seep and the easier any pieces that become decayed can be replaced. Step rails should be placed over the top of the newel, not abutted to its side. In high-rainfall areas only treated wood should be used.

4.2.5.2.4 Supports. Except in the driest areas, structural supports (such as porch columns) not completely protected from rainfall should be of treated wood. Hazard can be considerably reduced by resting supports on concrete or metal footings with the top of the footing no larger than the support base.

4.2.5.3 Preservative Treatment of Appendages. In high-rainfall areas, wood steps, porches, fireladders, or other appendages exposed to considerable rain wetting should be made of pressure-treated woods. Framing or items to be left unpainted can be treated with any preservative covered by TT-W-571, but it must be remembered that oils may creep along nails and discolor the wood. Items to be pressure treated and painted can be impregnated with either waterborne salts or penta in liquefied gas. Water repellent as well as fungicidal protection is desirable for items to be painted. If not present in the preservative solution, the water repellent can be added later by dipping.

In moderate rainfall areas a dip or short soak treatment (3 to 15 minutes), with a mixture of penta and water repellents in light, volatile oil, will add a great deal to the service life of appendages. Woods with moderate decay resistance, as Douglas-fir heartwood, will give especially good service after a dip treatment in a water-repellent preservative. The lumber should be fully cut, bored, and shaped before treating.

4.2.6 EXPOSED STRUCTURAL MEMBERS

4.2.6.1 Primary Moisture Problem. For architectural effects, structural members are sometimes exposed to rain wetting. Thus laminated or solid arches in drill halls and chapels are extended beyond the wall; rafters are extended beyond the roof decking; and the sides of heavy rafters or beams, particularly in flat beam-and-plank roofs, are exposed at the building end. In high-rainfall areas, protruding structural members are exposed to a high seepage and decay hazard. Under such conditions Douglas-fir arches have been destroyed within 4 years in New Orleans.

4.2.6.2 Construction to Protect Structural Members. If structural members must be exposed to appreciable rain wetting, they should be pressure-treated. In low- to moderate-rainfall areas, metal caps or flashing will give considerable protection, but they should not be depended on alone for long-time protection in moderate- and high-rainfall areas. Metal sockets in which wood arches or columns rest should have drain holes at the lowest points, lest they serve as a water reservoir.

4.2.6.3 Preservative Treatment of Exposed Structural Members. In high-rainfall areas, use pressure-treated wood. The preservative should be chosen with regard to appearance, paintability, and, in the case of glued laminates, effect on gluing. In low- to moderate-rainfall areas, it will help to brush exposed wood with a water-repellent preservative prior to installing a metal cap. Also, penta-grease treatment should be especially effective on the end grain of exposed members, but can effect paintability. Because of the relatively high cost and load-supporting requirements of exposed arches, they should be given maximum protection by pressure treating, irrespective of the area of use.

4.2.6.4 Rainfall Areas. It is generally considered that low-rainfall areas receive never more than 20 inches of precipitation per year and never more than 10-12 inches during the "rainy seasons". Areas of high rainfall receive 40 or more inches per year. Areas of moderate rainfall range between these limits (6.1.1.2).

SECTION 4.3 SPECIAL PROBLEMS OF BUILDING DECAY

In this section, information is included on moisture and decay problems of special parts of buildings, namely, shower rooms, cold-storage rooms, air-conditioned rooms, swimming pool areas, and kitchens and laundries. Frequently the problems are pernicious because the affected wood is hidden from view and damage first becomes apparent through failure of wood members. Fortunately, on the other hand, as with condensation in floors of air-conditioned rooms, there may be signs of wetting (4.3.3.1.2) before any decay occurs. Most of the problems covered by this chapter can be solved only by a conscientious application of rigid specifications. Shortcuts are frequently dangerous.

4.3.1 CONTROL OF DECAY IN SHOWER ROOMS. Moisture problems have been acute in walls and floors of shower stalls and rooms, particularly in barracks, where use is heavy. In wood-frame construction, this frequently leads to failure of wood framing and sheathing by decay. In nonwood construction, damage takes other forms, such as plaster failure and rusting of steel members.

4.3.1.1 Moisture Hazards in the Shower Room

4.3.1.1.1 Plumbing Leaks. Plumbing leaks play only a minor role in the shower room--as they do elsewhere. When major leaks occur they usually become evident by water pools or wetting of wall surfaces, and can be repaired before decay sets in. Occasionally, however, a minor leak can be serious if it wets a limited area within a wall and is not evident on the surface. In the South, such leaks have led to destruction, by water-conducting fungi, of the framing under some 200 square feet of flooring before discovery.

4.3.1.1.2 Wall and Floor Leaks. Wetting from wall and floor leaks leads to most shower room decay. During use, large volumes of water flow over the walls and floor of a shower room. Even minor breaks in the waterproof continuity of these surfaces can result in volumes of water entering the walls and floor structure below the pan. Some common causes of leakage are inadequate sealing around the drain hole through the pan, inadequate height of the pan curb, inadequate overlap on the pan curb of sheet wall coverings, loose joints between the sheet material and inadequately sealed entrance holes for water pipes. Only the most carefully designed and constructed shower room goes many years without leakage damage. Any wood trim, sash, and so forth, in heavily used shower rooms is subject to a severe seepage hazard. The window decay hazard exists mainly in quarters with a combination tub and shower.

4.3.1.1.3 Condensation. When in use, shower rooms and adjacent dressing rooms become hot and humid. This creates a pronounced vapor-pressure gradient through walls, ceilings, and floors with large vapor movement outward from the hot, humid space. During winter weather or where there is cooling by air conditioning in an adjacent area, the vapor-pressure gradient will be especially strong. Large amounts of water vapor may pass through walls, and, if dewpoint temperature exists in the structure, serious condensation can result. Condensation severe enough to support decay also may occur on wood window frames in showers or adjacent dressing rooms.

4.3.1.2 Decay-Resisting Construction of Shower Rooms. Basically, protection of shower rooms consists of four things: (1) tight plumbing, (2) watertight lining of the walls and floor of the shower room, (3) use of a vapor barrier as near as possible to the warm side of walls, floors, and ceilings of shower stalls and adjacent dressing rooms, and (4) use of decay-resistant wood framing, sheathing, or trim in the walls or floors. Chief features to be considered in the shower room design are concrete mixture in the slab, shower pan, vapor barrier, and the walls. The type of construction will determine design details.

4.3.1.2.1 Concrete Slab. Mixtures of ingredients in the slab should be chosen to minimize water penetration. One can use, for example, cement, sand, and gravel in the proportions 1:2:4 by weight, with sufficient water to provide a slump not to exceed 4 inches.

4.3.1.2.2 Shower Pan. The shower pan should be made of lead (four pounds per square foot) or copper (12 ounces per square foot). It must extend at least six inches up the wall and all corners must be formed by folding. The pan is the waterproof layer in the floor structure, and it is assumed that some water will penetrate to it. Therefore, drains must be of the double-drainage flange pattern with weep holes and a flashing clamp device for the attachment of the pan. In temporary construction a pan of 3-ply mopped asphalt is acceptable. In individual shower stalls, prefabricated waterproof receptors may be used without special pans.

4.3.1.2.3 Vapor Barrier. Vapor barriers meeting current Federal Specifications should be used on the walls of the shower room and on outside walls of adjacent dressing rooms. The pan serves as a vapor barrier under the shower room. A vapor barrier should be installed in the ceiling and floor and all walls of the shower room and dressing room, if the adjoining space is air conditioned by refrigeration. If any wood treated with an oil preservative is used in shower room construction, the vapor barrier should be a polyethylene film. Oils may damage asphaltic materials.

4.3.1.2.4 Shower Walls. Walls must be waterproof and overlap the upturned pan edge by at least two inches. Satisfactory materials include waterproof plaster on galvanized wire lath, particularly when covered with tile and sheet metal with waterproof crimped or soldered joints. The effectiveness of sheet liners will depend on how well one seals the holes formed by attaching nails. Special grades of smooth-surfaced asbestos-cement sheets have been satisfactory, particularly in barracks showers, if joints between the sheets are properly sealed. Seals can be secured by using well-designed metal connectors or by gluing on strips of asbestos cement.

Holes for the entry of water pipes are weak points in shower walls - particularly in those with sheet liners where sealing is difficult. Danger can be reduced by locating entry holes as high as possible. The problem of entry holes can, of course, be avoided by using surface piping within the shower.

4.3.1.2.5 Ventilation. All shower, dressing room, and toilet areas should be provided with forced-draft ventilation to prevent condensation and damage to the structure.

4.3.1.3 Preservative Treatment of Wood in Shower Rooms. Wood windows in shower rooms subject to heavy usage or located above the tub equipped with showers should be pressure treated. Framing or sheathing in the floors and walls should be protected likewise. For this, one preferably should use a waterborne preservative. Asphaltic vapor barriers should not be used if the treatment is with an oil-type preservative. Any wood trim in the shower or at the opening from the shower to dressing room should also be pressure treated.

4.3.2 CONTROL OF DECAY IN COLD-STORAGE ROOMS. Any wood used in the walls, floors, or ceilings of cold-storage rooms may be subject to decay promoted by condensation. Hygroscopic materials, as fibrous thermal insulation, become waterlogged and metal parts rust. Surface molding is common. The damage caused warrants consideration of all condensation factors in the design. The designs discussed in this part should be applied to all refrigerated space held at temperatures below 65°F.

4.3.2.1 Condensation Difficulty. Two distinct zones of condensation are involved: Condensation on inside walls and stored products, and condensation within walls, floors, and ceilings.

4.3.2.1.1 On Inside Walls and Stored Products. Because the vapor pressure outside a cold-storage room usually is higher than inside, vapor flows in when the doors are opened. This is accentuated by the natural tendency of the warm, lighter air to flow in near the upper part of the door opening and the heavier, cold air to flow out near the floor. The wall surface and stored products near the door, being colder than the incoming vapor, act as condensing surfaces and become wet. If doors are used frequently, some surfaces may be wet for long periods and lead to heavy mold development. As the temperature of the cooling coils is several degrees below that of the room and the coils act as condensers, moisture entering the room will sooner or later collect on the coils. Therefore, wet wall surfaces gradually dry if the door is kept closed sufficiently long. Worn or inadequate gaskets on door jambs and on pipe openings through walls also are points of entry for water vapor.

4.3.2.1.2 Condensation Within Walls, Floors, and Ceilings. The factors of condensation inside walls, floors, and ceilings of cold-storage rooms are basically almost the same as those of condensation within walls of houses in cold climates. The only difference is that the temperature and vapor-pressure differentials are reversed. In all but the coldest winter weather the cold air and low vapor pressure are inside the cold-storage room, and the vapor movement is from the outside toward the inside. The highest and most prolonged differentials exist in the warmer climates, explaining the greater deterioration rate of cold-storage rooms in warm climates.

Most materials used in constructing cold-storage rooms are to varying degrees permeable to water vapor. Vapor will move inward at a rate determined by differences in vapor pressure and the resistances offered by the materials. If moisture entering the wall could pass freely through all materials and exit from the inner surface, there would be no condensation problem. As it happens, some materials are more resistive than others. Some point in the wall will, of course, be below the dewpoint temperature. For example, in normal summer weather, the asphalt between two layers of cork will be below the dewpoint temperature outside. With an inadequate vapor barrier, some moisture vapor entering the wall will reach this more resistive asphalt adhesive line where it will tend to collect. Moisture accumulation at the asphalt line may be quite slow but, as it builds up, the efficiency of the insulation decreases and the dewpoint isotherm moves outward. It is not uncommon after several years of service to have insulation fall off in sections due to water accumulation.

A dewpoint temperature may occur outside the insulation or even outside the wall liner, in which case condensation will wet structural materials. When insufficient insulation is used, or when insulation becomes wet, the dewpoint temperature may be moved to the outer wall surface. This has occurred in portable units. Then condensate runs down the outer wall and wets the floor and joists below the unit.

Condensation may take place within doors not protected by an adequate vapor barrier. Doors faced with sheet-metal bumpers on the cold side may become water-soaked under the bumper. The bumper acts as a vapor barrier to prevent escape of moisture that has worked into the door from the warm side. Moisture also collects in wood doorjambs.

Oftentimes, various rooms in a battery of cold-storage rooms are designed for at least two temperature ranges. Less thermal insulation is used on those in the higher temperature range. Changing cool rooms to cold rooms can be very dangerous from the standpoint of condensation. The amount of insulation may be insufficient and the dewpoint isotherm moved outside the vapor barrier. No trouble may be evident from the inside because the insulation will remain dry, but condensation may occur within the wall. If any wood is present, serious decay can result.

4.3.2.2 <u>Construction to Minimize Condensation in a Cold-Storage Room.</u> Specific requirements are particularly essential in regard to vapor barriers and thermal insulation for a typical cold-storage room of frame construction, built next to an outside wall.

4.3.2.2.1 Vapor Barrier. A vapor barrier must be installed in floors, ceilings, and in all walls except those between rooms of the same temperature. All joints should be lapped at least two inches on walls, ceiling, floors, and at the junction of walls with ceiling and floors.

The vapor barrier should be of the heavy-duty type with a permeability not to exceed 0.25 perm and rugged enough to withstand considerable abuse. Typical barriers of this kind are smooth-surface roll roofing weighing at least 45 pounds per square foot and 6-mil polyethylene film. If the barrier is to be placed against wood that has been creosoted or treated with a preservative containing a petroleum solvent, polyethylene film should be used.

The location of the vapor barrier will vary with the type of construction, but it <u>must be</u> on the warm side of the thermal insulation. In frame construction the barrier will be attached to the inner faces of the studs and ceiling joists before the plywood sheathing is attached. In the floor the barrier is laid over the supporting sub-floor before the thermal insulation is installed.

A vapor barrier also is needed on the warm side of doors of wood or other vapor-permeable material. Steel bumper plates mounted flush on the inner sides of doors are not recommended because they act as vapor barriers on the wrong side of the door. It is safer to have an air space between bumper and door. Flush steel bumpers would possibly be safe if heavily perforated to permit vapor passage.

4.3.2.2.2 Thermal Insulation. All thermal insulation must be on the cold side of the vapor barrier. The amount needed should be calculated on the basis of the severest temperature conditions expected, to insure that the dewpoint temperature will always be on the cold side of the vapor barrier. Thermal insulation is not needed in partitions between rooms of the same temperature but is needed in all other walls, floors, ceilings, and doors.

4.3.2.2.3 Inner Wall Facings. If an effective vapor barrier and adequate thermal insulation are used, the nature of the inner wall surface is immaterial. However, lining material should be as vapor permeable as possible. Some vapor leakage is likely to occur and if it can escape to the inside it will not build up within the wall. Unpainted cement plaster is recommended.

4.3.2.2.4 Vestibules. A double entrance to the refrigerated space will minimize the problem created by inflow of warm, humid air. Thus the first door will be closed before the second one is opened. Such vestibules need tight-fitting entrance doors.

4.3.3 CONTROL OF DECAY IN AIR-CONDITIONED ROOMS. Air conditioning by refrigeration sets up condensation factors identical to those in cold-storage rooms. In living and working space, however, the more moderate degree of cooling involves less condensation than in a cold-storage space. This, coupled with a difference in construction, requires different details of control.

The temperature in certain storage spaces, such as that for storing photographic film, frequently lies below 75°F in a range between that of air-cooled living space and cold-storage. Such space is not specifically considered here, but it can be treated as cold-storage space.

4.3.3.1 Condensation Problems With Air Conditioning. In air conditioning a house by refrigeration, the inside atmosphere usually is both cooled and dried. This establishes a vapor-pressure gradient decreasing from the outside toward the inside. Because vapor diffuses toward regions with lower vapor pressure, warm outside vapor tends to move through floors, walls, and ceilings into air-cooled buildings. Most building materials, including plaster, wood, concrete, various kinds of brick, and many building papers, are permeable to vapor. If cooling is sufficient to create a dewpoint temperature, the moisture in the warm air will condense when it reaches that point.

Most trouble occurs in floors where a dewpoint temperature is most likely to occur near the juncture of the finish and subfloors. Subfloor thermal insulation will lower the dewpoint isotherm; linoleums and asphalt tiles may move it upwards. Inside temperature, outside temperature and humidity fluctuate. Therefore, the dewpoint isotherm is not fixed in a given structure but moves with varying conditions. These would include presence of condensate because, once wood is wet, its thermal conductivity increases.

Serious condensation can also occur in walls between air-conditioned rooms and kitchens or shower rooms. Theoretically, the amount of condensate forming on a surface will depend on: (1) the duration of temperatures at or below the dewpoint temperature, (2) the amount of water available in the atmosphere adjacent to the structure in question, (3) the vapor permeability of any material between the free, warm atmosphere and the condensing surface, and (4) the vapor-pressure gradient. In addition, accumulation will be influenced by vapor permeability of materials between the zone of condensation and the cold atmosphere.

Outside temperatures and humidities fluctuate from day to day and between day and night. In a dry crawl space, the humidity lags somewhat behind that outdoors, but the lag is surprisingly slight with good ventilation. In a wet confined crawl space, humidities may be continuously high. Because of these variables, weather records are unreliable for predicting condensation. However, with any air conditioning for long periods in the Gulf States and the tropics, dewpoint temperatures will exist at least part of the time when indoor temperatures are in the low 70's and almost continuously at temperatures below 70°F.

4.3.3.1.1 Condensation Causes in Floors. General condensation in floors of air-conditioned rooms is likely to occur when one or more of the following conditions prevail:

(1) Wet crawl space. This is the most critical factor leading to heavy condensation and the accumulation of moisture in the floor of an air-conditioned room. A wet soil is most dangerous where ventilation is substandard, resulting in a continuously high humidity in the crawl space. Also, danger is increased if the crawl space is heated by steam pipes.

(2) Continuous air conditioning.

(3) Low room temperatures. Most damage is with indoor temperatures of 70°F or below.

(4) Cooling the floor. Directing cold-air streams from conditioners at the floor can create a severe condensation problem in a localized area in a building otherwise free of condensation.

4.3.3.1.2 Types of Damage. The types of damage occurring with air-conditioning condensation are:

(1) Paint peeling, blistering, and molding on walls or ceiling.

(2) Plaster failure and rusting of metal lath.

(3) Dimensional changes in flooring is the most common damage. Cupping is the usual deformation; that is, the floor boards remain attached but curl up at the edges due to greater swelling of the lower than upper surfaces - making slight ridges at the longitudinal seams. Cups will show through most tile and linoleum surfacings. When flooring is laid tightly at low moisture contents, the swelling can buckle the floor raising high ridges and involving several boards.

Severe deformation sometimes occurs with moisture contents only slightly above those at equilibrium with crawl-space atmosphere. Conversely, sufficient condensate to promote decay can occur with little or no floor deformation.

Floor buckling or cupping can occur in air-conditioned buildings without condensation. In the upward passage of vapor, the crawl space vapor pressure will decrease because the warm-to-cool temperature gradient gradually will reduce it. However, the relative humidity will increase with upward passage due to the same cooling. This will result in an increasing equilibrium moisture content (2.5.4.1) in the wood from the crawl space to the upper floor surface. Some wood swelling problems with moderate air conditioning can thus be explained without condensation. Occasionally, wall paneling also cups or buckles.

(4) Loosening of tile or linoleum occurs when condensate accumulates at the adhesive line.

(5) Decay occurs only in the most serious cases of condensate accumulation. It usually is restricted to the top of the subfloor but sometimes includes all the subfloor, the tops of joists, and the lower face of the finished floor.

With moderately a dry crawl space and usual inside temperatures, there will seldom be sufficient water accumulation in floors to promote decay. Because of the restricted amount of water vapor in a dry crawl space, any condensed water tends to dissipate as rapidly as it forms, thus keeping wood moisture content below fiber saturation. This dissipation occurs as vapor transmission through the finished floor to the interior. Rate of loss will be influenced by the type of cover or finish on the floor. Linoleum and tile surfacings will retard vapor movement more than varnish or paint.

4.3.3.2 Minimizing Condensation From Air Conditioning. Condensation problems are too complex and buildings too variable to formulate hard and fast rules for preventing or correcting condensation associated with air conditioning. However, three general recommendations should be considered in designing new buildings or correcting trouble in present buildings: (1) Prevent dewpoint temperatures by moderating temperatures in the air-cooled space, (2) Prevent condensation, or at least serious condensate accumulations, by reducing the humidity of the crawl space atmosphere or of other adjacent noncooled space, and (3) use a vapor barrier on the warm side of the floor to prevent vapor migration to surfaces at or below the dewpoint temperature.

4.3.3.2.1 Moderate the Conditioned Temperatures. The safest procedure is to ascertain the dewpoint temperatures of the crawl space and thus determine what temperatures indoors will give safe conditions. In general, assuming a dry crawl space, indoor temperatures of 75°F or above are safe even with continuous air conditioning. Some minor floor deformation may occur, particularly if floors are laid tight at a low moisture content. In mess halls, and other rooms where large numbers of people congregate, the temperature may safely be lowered during periods of heavy use to maintain reasonable comfort. When conditioners are operated only during the daytime, lower temperatures usually are safe. Intermittent cooling is highly effective in avoiding condensate accumulations. Presumably, even if some condensation occurs, drying occurs when conditioners are turned off.

4.3.3.2.2 Reduce the Relative Humidity of the Crawl Space. Drying the crawl space to prevent condensation in floors due to air conditioning can be accomplished by site drainage, ventilation, or the use of a soil cover (4.2.2.3). Ideally, the soil under a building should be dusty dry. This not only prevents winter condensation in the North, but in the South it reduces mildew problems inside buildings as well as condensation from air conditioning in the space above. Rain downspouts should direct water away from the building. The condensate from air conditioning units should be drained to the outside and away from the building. Similarly, drainage from cooling towers should not be allowed to seep into the crawl space.

Live steam pipes in the crawl space may increase temperatures so that even with comparatively low relative humidities the dewpoint temperature rises to the high 70's or 80's. If there is a steam leak, or other source of moisture, serious trouble can occur rapidly with even moderate air conditioning. Where possible, pipes that will carry live steam in the summer should not be run under air-conditioned space.

4.3.3.2.3 Use Vapor barriers. Vapor barriers, properly placed and installed, are effective in preventing condensation caused by air conditioning when dewpoint temperatures cannot otherwise be avoided. The barriers are especially appropriate for use in walls between an air-conditioned room and an adjacent one, but if necessary, they can be used to protect floors against wetting from the crawl space atmosphere. When a vapor barrier is needed below the floor in a crawl space, practical difficulties arise. Its installation is complicated by bridging, beams, pipes, electrical conduit, and so forth. A heavy film such as 10-mil polyethylene will be satisfactory provided it is not broken by persons working the crawl space. A rigid insulation board with a vapor barrier attached is much safer. Install the board with the vapor barrier on the underside. A blanket insulation with a vapor barrier on one side is even better. Attach the blanket flush against the underface of the subfloor between joists and with the vapor barrier exposed on the lower surface. Pliable films are extremely difficult to maintain if applied to the lower edges of joists. Close stapling of the flanges to the upper flat surface of the joists is adequate for most air-conditioned space.

Vapor barriers may be needed on the warm side of walls between an air-conditioned space and kitchen or barracks shower rooms. Forced ventilation of kitchens and shower rooms will help but alone may not be adequate. If kitchens, laundries, and rooms having swimming pools adjacent to an air-conditioned space are reasonably ventilated and the warm side of the walls are painted with one of the more vapor-impervious paints, little trouble should occur. However, the materials in the wall, except for the warm face, should be as permeable to vapor as possible, for example, plaster on studs with the cold face covered by a paint having a low resistance to vapor. Where large volumes of steam or hot-water vapor are released, forced-draft ventilation is recommended.

4.3.4 PROTECTION AGAINST DECAY IN INDOOR SWIMMING POOL AREAS

4.3.4.1 Condensation Difficulty. The indoor swimming pool area is particularly prone to condensation and associated decay unless special precautions are taken to prevent them. The precautions need not be elaborate, but they should be planned with particular care to see that nothing is overlooked.

The basic feature of a swimming pool is that it presents a large surface of heated water. This water gives off a great deal of moisture to the air, favoring condensation on or in walls and roof members. In cool or cold weather the situation is essentially the reverse of that of cold-storage rooms or air-conditioned rooms. The warm, moist atmosphere is in the swimming pool area and the relatively cold temperatures are outside. In this respect, the conditions are the same as in a shower room area, but the moisture problem is not as severe as that associated with a heavily used shower room.

4.3.4.2 Wall and Roof Construction for Swimming Pools. To avoid serious condensation in the swimming pool area: (1) ventilate the area as much as practicable so as to decrease accumulation of moisture in the air, (2) install an appropriate thickness of thermal insulation within the walls and roof so that a dewpoint temperature is not reached on the inner surfaces, (3) install a vapor-barrier membrane on the warm side of the wall studding and on the warm side of the roof framing, to reduce the amount of moisture vapor leaking into the walls and roof, (4) avoid a highly vapor-retardant membrane in the outer part of the wall, and (5) provide for a certain amount of ventilation just below the roof cover. Precautions (4) and (5) allow water vapor to escape to the outside if the vapor-barrier membrane on the inside does not wholly exclude vapor in amounts that might form condensation.

4.3.4.3 Preservative Treatment Around Swimming Pools. If the foregoing precautions can be taken, it should not be necessary to use preservative-treated wood to shelter the swimming pool in warm climates. However, it is justified as a margin of safety in temperate and cold climates, especially for the roof members.

4.3.5 PRECAUTIONS AGAINST DECAY IN KITCHENS AND LAUNDRIES. Decay in kitchens appears mainly in flooring and supporting joists, and results almost entirely from plumbing leaks. Control of decay in the kitchen, therefore, is largely a matter of regular and careful plumbing maintenance. There is some additional danger of wood decay in kitchen floors if excessive amounts of water are used in the daily mopping. It is advisable to avoid flooding the floor, and to get it dry as soon as possible.

In laundry areas, there will be no special decay problems unless large quantities of steam are released inside. Then the hazards of decay promoted by condensed moisture will be similar to those described for the swimming pool, and comparable precautions can be used to minimize the danger.

In air-conditioned buildings, special condensation problems may arise in kitchens and laundries. These can usually be handled by appropriate ventilation and use of a vapor barrier on the warm side of contiguous walls (4.3.3.2).

SECTION 4.4 DECAY OF GROUNDS STRUCTURES

The term "Grounds Structures" excludes waterfront structures and most buildings but includes all other man-made, fixed (as differentiated from mobile) structures. This group contains roads and railroads, runways and walkways, parking aprons and parking lots, utility distribution systems and fence lines, retaining walls and small bridges, guard rails and antenna arrays. Wood is used in many of these, and in some is the primary structural material. When used in grounds structures, wood is subject to decay, and so requires preventive protection.

4.4.1 DECAY HAZARD BY STRUCTURAL TYPE. Grounds structures are typically in or on the ground continuously, though some types have a greater percentage of their total surface exposed to the weather than exposed to the ground. Because of the continuing exposure to the changeable weather as well as to the soil, grounds structures require preservative protection. For most grounds structures this includes commercially provided preservative treatments. In a limited number of cases, locally applied preservative treatment can provide some initial preventive protection. Local applications of preservatives in maintenance programs are discussed in 7.5.2.

4.4.1.1 <u>Poles: Utility, and Antenna Systems</u>. Millions of wooden poles are used to support utility and communication systems. By their very nature, utility poles and antenna poles stand with one end buried in the soil and most of their surface exposed to the extremes of weather. The decay hazard to a pole, and therefore the length of its life, depends upon five basic factors: (I) the wood species used, (2) the type of preservative treatment used, (3) the climate to which the pole is exposed, (4) the condition of the soil in which the pole is standing, and (5) the pole maintenance program.

4.4.1.1.1 Wood Species. The species of wood used for utility poles can influence the length of their useful life. Some northern species with very thin sapwood have considerable heartwood resistance to decay in above-ground exposure while protected by the sapwood. Heartwoods of Alaskan yellow cedar and Western redcedar are quite decay resistant.

4.4.1.1.2 Treatment. All utility poles must have preservative treatment. Even those poles of Alaskan yellow cedar and Western red cedar must have preservative treatment in at least the portion to be buried. The treatment limited to the pole butt is applied in accordance with AWPA Standard C7 which covers the requirements for preservative treatment of incised pole butts by the thermal process. Because this does not provide treatment for the above-ground sapwood, a condition known as "shell rot" is common. In this, the thin shell of sapwood is susceptible to decay after a short weathering period. Very little decay is evident at the surface due to quick drying after rains. But nearer the heartwood, the wood remains damp longer and so supports decay under a shell of nearly sound wood. Hence, the term "shell rot". Progressive growth of shell rot will eventually reach the surface. But before that time it can be a serious hazard to linemen. When the thin-sapwood species are given full length thermal treatment in accordance with AWPA Standard C8 or are pressure treated in accordance with AWPA Standard C4, there is very little chance of shell rot development. Most utility poles are pressure treated to the depth needed to provide long-lasting protection. Treating standards require penetration of 2.5 inches in some pine species.

4.4.1.1.3 Climate. The climate to which a pole is exposed will have considerable influence on the length of its service life. In semiarid areas, the low rainfall and moderate temperatures can permit many years of life for well-treated poles, while areas of heavy rainfall create water-trapping erosion of the springwood of the annual rings at the pole top and assurance of prolonged moist conditions at depth in all vertical pole checks. These both promote decay with the leaching of preservative caused by heavy rains. The climate combines with the soil conditions to influence the condition of the buried portion of the pole.

4.4.1.1.4 Soil Conditions. Variations in soil conditions, like climate, play a considerable role in the service life of poles. In light and porous, or well drained soils, water is not held in contact with pole butts. Decay fungi, while normally present, are less active than in continually damp soils. Unfortunately for shore areas, a majority of poles are in low-level, poorly-draining soils; and the pole butts are set at or very near the normal water table. Because of this, it is necessary to assure that only the most effective preservative treatments are used for such poles (6.3.2) and that pole inspection and maintenance programs be established and maintained (7.3.3).

4.4.1.1.5 Maintenance. Replacement of a utility pole cost approximately $500 in 1977 and an estimated $1,000 by 1990. There are inexpensive maintenance procedures which can extend the pole life for many years at a very small fraction of the replacement costs. Utility pole maintenance programs are explained in Section 7.5.3.

4.4.1.2 <u>Posts: Fence, Guardrail System, and Sign</u>. Fence posts and guardrail posts should always be preservative treated. Without this preventive protection, their service life is short; and when they fail a fence fails or a guardrail system fails. Very small expenditures for treatment of these in-ground structural members will prevent costly replacement of the entire systems. Fed. Spec. TT-W-571 provides for the treatment of these items as do the AWPA Standards. Fence posts are covered by AWPA Standard C5. Standard C14 includes guardrail posts under wood for highway construction. Sign posts are less expensive to install and to replace than are most fence posts and guardrail posts because they are usually single structures supporting removable signs. However, the economy obtained by treatment is measurable if the signs are to remain in place one-to-three or more years in most locations. This is repeatedly proven by local highway departments across the country; and most will not now consider untreated posts for even temporary signs. Commercial preservative treatment for sign posts, like guardrail posts, is specified in AWPA Standard C14.

4.4.1.3 <u>Railroad Crossties</u>. There are billions of railroad crossties and switch ties in active service. While most ties received quality treatment prior to installation, they do eventually fail; and most ties are many years old. Some lack the end-irons and tie-pins needed to prevent further checking in service and have opened to depths greater than the preservative treatment. These now have internal decay and are prevented from crushing only by the rail support provided by other ties. Some ties have received excessive tie-plate wear and spike damage due to poor or no ballast maintenance programs. Replacement costs are considerably above the costs of just the properly treated ties themselves. Preventive protection should include commercial preservative treatment of ties and programs of track and ballast maintenance. Treatment should be in accordance with TT-W-571 or AWPA Standard C6.

4.4.1.4 Miscellaneous Grounds Structures. Throughout the shore establishment there are many retaining walls, small bridges, towers, loading ramps and other grounds structures constructed partially or completely of wood. Because of their diversity and dissimilarity they can be spoken of here only in generalities. But they have in common their requirements for preservative treatment of the wooden parts of these structures. Guidance in the selection of the proper treatment is provided in Chapter 6.

4.4.2 CONSTRUCTION TO PREVENT DECAY IN GROUNDS STRUCTURES. For some groundline structures, there is little that can be done to provide protection against decay beyond preservative treatment except that, for a few of these, a protective coat of paint may be added. A four-by-four sign post preservative treated and pointed at the top can gain added protection from a coat of paint. It will then be protected from decay as well as it can be. A utility pole is a similar but larger structure. Its top is not protected by painting but rather by application of one of the commercially available mastic compounds produced for this use. Some will not adhere to tops of freshly creosoted poles. It is sometimes advisable to delay application of pole capping to creosoted poles for a two-year period.

For structures more complex than posts and poles, water-trapping at joints can be a serious problem. For these structures, the recommendations provided in Sections 4.2.5 and 4.2.6 should be applied.

4.4.3 PREVENTIVE TREATMENT OF GROUNDS STRUCTURES. Mention has been made of preservative treatments of poles (4.4.1.1) and posts (4.4.1.2). Chapter 5 describes treating materials and methods; and Chapter 6 provides guidance in the selection of treatment for various structural components placed in differing exposure conditions.

SECTION 4.5 DECAY OF WATERFRONT STRUCTURES

An in-depth study of decay problems at some 75 facilities provides information of value in reducing financial losses due to decay of waterfront structures. The decay hazard was found to vary with the species of wood used and with the preservative treatment provided, with the type of structural members and the construction techniques, and with the climate where exposed.

The two species of wood predominately used on U.S. waterfront structures are Douglas fir and southern pine. The Douglas fir in timbers and planking is nearly 100 percent heartwood. It has a small degree of natural resistance to decay and so can last longer, untreated, than can southern pine in similar exposure conditions as the pine is nearly all sapwood and will quickly decay. But pine sapwood accepts penetration by preservatives while Douglas fir heartwood is not well penetrated. Surface checking and on-the-job cutting of timbers can have a more deleterious effect on Douglas fir than on southern pine. However, use of some construction-time techniques and maintenance procedures can extend the useful life of waterfront structures. One of the most important conclusions drawn from the indepth study of Navy waterfront structures is that the use of preservative-treated wood, versus untreated wood, and its proper protection on the job in the above-water parts of the structures will reduce prorated annual costs of the structures to 1/2 or to

1/4 depending on the degree of exposure; and this is based on a constant dollar value and does not take into account inflation and high replacement costs.

4.5.1 DECAY HAZARD BY TYPE OF STRUCTURE. The various types of structural members each experience individual decay hazards due to the different exposure conditions they face. However, for some of the members, exposure, and therefore decay hazard, differ but little.

4.4.1.1 Decay in Wooden Decks. Nearly all Navy wooden decking is either Douglas fir or southern pine. Pine tends to predominate on the East Coast, and Douglas fir on the West Coast. Cost per board foot delivered usually determines species. The conditions leading to decay in decks is the same for both species, but the rates of deterioration differ. Untreated pine will decay much faster than untreated Douglas fir; but preservative-treated pine can often last longer than treated Douglas fir because of its deeper treatment and because of the surface checking of Douglas fir penetrating the thin treated layer.

(1) Surface Decay. Incipient decay at the surface of untreated deck planking not only promotes increased rain erosion and mechanical wear, but because it increases the water-holding qualities of the wood surface it speeds up all forms of weathering including surface checking. Some individuals with experience sharply limited in types of structures and exposure conditions have questioned the value of preservative treatment of decking subject to considerable vehicular traffic. But it has been conclusively demonstrated for all climate zones that the weakening of the surface fibers by fungi permits much more rapid wear than found in treated decking.

(2) Surface Weather Checking. The major factor leading to decay of deck planks is weather checking of the upper surface of the planks. Much of this type of checking is a conspicuous feature of decks that have been in service for a few years. Checks favor decay in two ways: (a) They create cavities in which rainwater is trapped, thereby the wood is wetted and can support attack by decay fungi; and (b) in treated planks of Douglas fir they tend to penetrate through the zone of treated wood, and expose the untreated wood beneath to infection. Were there no checking, decay of decks would be much less of a problem. Consequently, an obvious aim in protecting decks should be to treat the planking to reduce the amount of checking and to protect against infection in the checks that do develop.

It should additionally be noted that weather checks not only promote decay, but they also may physically disrupt the deck surface and increase the rate of deck wear from traffic.

(3) Decay Development in Checks. The rate of checking and of any associated decay is rather variable. In untreated decks, the amount of decay has no particular correlation with the degree of checking. This shows that serious decay can begin at the surface and in very small checks as well as in a heavily checked surface. As a rule, preservative treated decking is freer of checks than untreated decking of similar kind and history. This is true of salt-treated as well as of creosote-treated decking, but to a lesser degree. Development of interior decay beginning at checks occurs at an accelerating rate. For some years incipient infection may become established in numerous

checks but without causing conspicuous breakdown of wood, then with the attacking fungus established in the interior of the wood, the decay proceeds rapidly to the visible stages. Untreated decks with considerable checking might commonly not appear to be decayed but nevertheless can be deeply infected and very likely to undergo damaging decay within a short time.

(4) Fresh-Water Washdown. Some piers subject to heavy personnel traffic are given frequent washdowns; and fresh water is usually used. This will materially shorten the service life of the decking if it is untreated wood or if it is treated Douglas fir. If it is known that a pier deck will have need of frequent washdown it should be constructed of only pressure-treated southern pine; or if treated Douglas fir is used, it must be given frequent maintenance treatment.

(5) Double-Plank Construction. Examples are occasionally found where two layers of deck planking have been used. This most definitely is not a good design solution to the need for added strength. It should never be used. It traps and holds water rather than permitting run-off, and so favors decay and speeds destruction. Placing new decking over decayed decking speeds the destruction of both.

4.5.1.2 Decay Beneath Deck Pavement. Blacktopped and concrete decks, though providing a nominally protective cover against wetting of the wood beneath, are not wholly effective. Blacktopped surfaces are not normally given the annual of biennial weatherproof coatings required to prevent the checking which permits water percolation to the supporting wood. Concrete decks are normally thicker than blacktop, and are reinforced. Where they develop cracks through which water can move they can lead to decay of supporting timbers. Condensation on wooden subdecking as well as on timbers can lead to early loss of the structure. All wood beneath blacktop or concrete decks requires preservative treatment.

4.5.1.3 Decay in Stringers and Caps. Failure of stringers is one of the most costly forms of damage to waterfront structures because these timbers are a major load-bearing component. To replace stringers necessitates removal of all that they support. Most decay in stringers begins along the upper edge, and even at early stages may cause trouble by causing deck spikes to become loose. Stringer decay generally originates in checks and splits caused by plank spikes and alongside driftpins.

(1) Checks and Splits Made by Deck Spikes. Driving deck spikes without boring a receiving hole generally makes at least a small split in the stringer. The splits may be quite small and inconspicuous, but even so they furnish a place in which water can collect. They are likely to be largest near the ends of the stringers. The tendency to splitting is aggravated by driving the spikes in line along the grain of the stringers and by using larger spikes than are needed. Cases were noted where oversized spikes had been used, presumably as a matter of convenience.

(2) Water Entry Alongside Driftpins. Although holes are drilled for driftpins, thus precluding splitting of the stringer, water nevertheless enters the stringer alongside the pin. The hole enlarges somewhat with time as the wood shrinks and swells with changes in climate. This increasingly adds to the space between pier and wood, thereby creating more and more opportunity for wetting deep in the stringer (around the driftpin).

(3) Serious Decay of Caps. This usually begins at untreated driftpin holes and at end cut-offs. While this is a little less common than stringer decay, it can be even more expensive when it occurs.

(4) Subterranean Termites. In moisture-trapping areas such as checks in stringers, subterranean termites as well as decay are sometimes found. There is adequate moisture to support them, and they are as well insulated from extremes of temperature as they would be in the soil. This association is not as common with species of Reticulotermes as it is where Coptotermes formosanus is found.

4.5.1.4 Decay in Curbs, Chocks and Wales. Although they are not supporting members, curbs, chocks, and wales are larger and relatively expensive timbers, fully deserving protective measures. Further justification for their protection is the high labor cost for replacing them. Although comparatively accessible, they resist removal because they are strongly attached and also commonly carry a heavy complement of cables and pipes which also are firmly attached. Low wales are sometimes found in the tide zones. Decay is of little concern where the wood is covered with salt water twice each day, but the many field cuts during construction which expose untreated wood lead to marine borer damage.

Conditions contributing to decay of curbs, chocks, and wales can be nullified by deep preservative treatment, as is common in pressure-treated pine sapwood. Decay in treated pine items is thus usually well controlled irrespective of construction practices, mishandling, or long exposures. Where there is no treatment, or where the treatment is not very deep--as is typical in Douglas fir--various conditions can lead to serious decay.

(1) Seasoning and Weather Checks. As with deck planking, checks developing in the upper portion are the main cause of wetting and decay infection in these heavier members. Seasoning as well as weather checks are prevalent since the items, because of their large size (at least 10 inches on a side), are usually not fully air dry before they are placed in service. The large size of the items, moreover, favors the development of especially deep checks.

(2) Lack of Supplementary Preservative Treatment at Ends. Some severe rot can be found at the ends of Douglas fir curbs, chocks, and wales, but it seems to be less frequent than that occurring through checks. The rot enters through the ends of pressure-treated timbers where untreated wood is exposed by cutting the timbers to length.

(3) Lap-Joint Construction at Ends of Curbs and Wales. The common lap-type joining of ends favors decay in curbs and wales. The joint of this kind, most frequently seen, is the half lap. A similar connection occasionally seen is the oblique-scarf joint. The lap-type joint accentuates the decay hazard at the ends of the timbers in two ways: (a) exposes an excessive amount of untreated interior wood in initially treated Douglas fir timber, and (b) creates a relatively large interfacial zone where water can be trapped. It is further objectionable because effective supplementary treating of the newly exposed wood in such a joint is especially difficult since much of the new surface is side grain, where penetration of preservative solution applied by brushing or spraying tends to be very shallow.

(4) Splits in Curbs Caused by Twisting of Mooring Cleats. Occasionally splits are formed in curbs as the result of stresses on mooring cleats. These, of course, favor decay in the same way as splits developing from seasoning or weathering.

(5) Bolt holes. Bolt holes are a common source of decay-supporting moisture in large timbers.

4.5.1.5 Decay in Fender Piles. Decay of fender piles is strictly a problem of treated piling, since untreated piles will fail from marine-borer attack before there is opportunity for significant decay. The principal woods used for fender piles are Douglas fir and southern pine; oak is used in moderate quantity. Southern pine, being mostly sapwood, treats deeply, consequently southern pine fender piles treated according to recognized standards present comparatively little difficulty from decay. The problem is with the other species (especially Douglas fir); they have relatively narrow sapwood and therefore do not treat deeply.

The dimensional stability of wood can depend on the moisture content (2.5.3). When Douglas fir dries, the tangential shrinkage is approximately twice the radial shrinkage. Because of this, Douglas fir poles and piles must check or split when shrinking in drying. There may be many small checks or only a few which may be wide and deep. Often when a fender pile is cut off at the appropriate height, some preservative is applied to the exposed top. Most preservatives applied to the surface will protect the wood to some extent where it dries quickly after rains. Water is trapped in deep checks, and contributes to the speed of decay within the pile while the pile top may appear to be only checked.

Decay in Douglas fir fender piles starts at the top and progresses downward into the central column of untreated wood. The rate of downward progress is about 1/2 foot per year. Pile decay eventually will extend to the high-water level, where water-soaking of the wood inhibits further progress of the causal fungus. Practically all of the above-water portion of the pile can become decayed on the inside without being apparent on the exterior shell of treated wood. The resultant lack of interior strength is responsible for much pile breakage; yet this indirect but seriously damaging effect of the decay seems to be largely unrecognized. The principal condition leading to infection of the pile top is exposure of untreated wood when the pile is cut to suitable length after driving.

(1) Improperly Treated Pile Cutoff. Although it is universally recognized that untreated wood exposed in cutting or boring on the construction site should be at least brush treated, the limitations of this form of treatment and the need for a pile-top cover to supplement the preservative treatment have not always been recognized by many who are responsible for maintaining fender piles. Moreover, even those who are aware of the need for both preservative and pile cover overlook certain requirements for their effective application.

It follows from what has been said that a cover added after decay has gotten started will not be effective. Many covers have been applied far too late, under the mistaken idea that "better late than never" should apply. This has been coupled with the idea that by covering the pile, further rain wetting would be excluded, so that decay could not continue. Excluding rainwater from fender piles after decay has gotten underway will not help because by that time moisture in the pile is usually sufficient to support decay indefinitely.

(2) Notching Piles. At some structures the fender piles have been notched to receive the ends of the chocks more snugly than if they were simply butted against the pile. This practice has no real merit. Therefore it would be better to avoid it, at least with Douglas fir or oak piles, because in these species the notching generally will expose untreated wood. Moreover, the untreated wood cannot be easily protected by superficial supplementary treating because the surface consists of side grain, which as noted, is penetrated very little by a preservative solution applied by brushing or spraying. Essentially the same decay hazard and problem of supplementary preservative protection is created when the pile top is notched on opposite sides to form ledges on which clamps can rest.

4.5.1.6 Decay in Support Piles. As with fender piles, southern pine support piles are almost never seriously damaged by decay. If they are not properly preservative treated they will be destroyed by marine borers before decay can become serious. However, because of the shallow penetration in Douglas fir and the end grain exposure when cut off, decay in these piles can begin and can progress rapidly and unseen if the pile top is not properly protected during construction. The water which supports the decay may be wind-driven rain for piles in the outer rows; but usually the water is from seepage through the structure. This decay, where it occurs, can be the most expensive of all decay at waterfront structures.

4.5.2 CONSTRUCTION TO PREVENT DECAY IN WATERFRONT STRUCTURES

4.5.2.1 Construction and Decking Decay. There are positive steps that can be taken before and during construction to help prevent decay in wooden decking.

(1) Procurement of Wood. In the planning stages, assure that the preservative-treated wood procured will be the dimensions required without any on-the-job cutting. This is especially important with Douglas fir decking.

(2) Heart Face Down. Southern pine decking delivered to the job will have a number of planks containing some heartwood faces. This heartwood will not accept preservative treatment. Parts of it (the pith areas) check easily and are subject to rapid physical failure under traffic. Pine heart faces should always be placed down.

(3) Spacing for Drainage. Assure that deck planks are laid with spaces of approximately 1/2 inch between them.

(4) Spike Holes. Holes should be drilled for spiking. In southern pine, the drilling helps prevent splitting and assures alignment. It is even more important in Douglas fir. If drilled two-or-more hours prior to spiking, the holes may be treated with a preservative grease which will help prevent decay of the untreated centers of the planks.

(5) Double Decks. Avoid multiple-layered wooden decks even if the wood is pressure-treated.

(6) Blacktop Decks. The wooden subdecking for use under blacktop decking not only must be pressure-treated but must be coated with hot bitumen which is allowed to cool prior to placing the blacktop decking. The same hot bitumen coating should be used at all places where wood contacts wood below a blacktop deck.

4.5.2.2 Construction for Stringers and Caps. The financial losses due to decay in stringers and caps can be prevented if pressure-treated wood of the right lengths is used and if it is installed properly using those few construction techniques that will help prevent the wetting of the interior untreated wood.

(1) Procurement. Assure that only pressure-treated wood of the required lengths are delivered to the job. If any cutting-to-length is required, place the cut end where it will get the least exposure to moisture, and assure that cut ends are heavily coated with a preservative grease.

(2) Prevention of Splitting. For the spiking of decking, always drill spike holes, ideally slightly undersized. Also, avoid use of truly oversized spikes. Stagger the spike holes in the stringers to avoid having spikes in straight lines along the grain of a stringer. These simple precautions will prevent most of the stringer splitting and cracking occurring at construction, and so will materially aid in prolonging the life of the structure.

(3) Protection of Drilled Holes. All spike holes drilled into stringers, all driftpin holes drilled into stringers and caps, and all bolt holes drilled into stringers, caps, and splicing timbers should be heavily treated with grease-type preservatives two-to-four hours or more prior to the placing of spikes, drift pins and bolts.

(4) Bitumen and Felts. Placing a strip of bitumastic felt along the top of the stringer was a practice used to help keep water out of the splits and checks caused by spiking decking to untreated stringers or to Douglas-fir stringers without pre-drilling spike holes in stringers. Strips used were somewhat wider than the stringers. They were thought to serve as a water shed, keeping water from running into splits and cracks and splices and also to fit so tightly around the spikes that water could not move down around them. However, the extensive decay found under felt strips in Douglas fir or untreated southern pine stringers points to the lack of real protection having been provided by the bitumastic felt strips. Pre-drilling spike holes in decking and stringers at the same time, and then treating the drilled holes prevents the splits which the felt was to have protected. Even further protection may then be had by coating the drilled top surface of the stringers with hot bitumen (without felt) just before spiking-down the decking. This provides additional protection where water would accumulate at the wood-to-wood joint.

Bitumastic felts are used under caps at the pile tops and above caps at the stringers. This is good practice if done after the applied preservative has had time to penetrate the wood and if the felt is placed on hot bitumen and then covered with hot bitumen.

4.5.2.3 Decay-Preventing Construction for Curbs, Chocks and Wales. As previously explained (4.5.1.4) there is a group of problems which lead to decay in exposed superstructure timbers. These are seasoning and weather checks, splits caused mechanically, exposure of untreated wood by on-the-job cutting, and the holding of moisture in joints. Bolt holes should be added to this list. By the use of modern construction and maintenance procedures, the decay in curbs, wales and chocks can be reduced materially.

(1) Procurement. Occasionally, the long timbers used for wales and curbs can be obtained, pressure-treated, in the lengths required. Whenever possible, this should be taken advantage of to avoid the need for on-the-job cutting-to-length which exposes untreated centers. However, this is rare, and cutting is usually required for both wales and curbs. If a curb and an upperwale are above and below each other with just the deck between they are sometimes called "string pieces" as their roles in relationship to decking is somewhat similar to that of the stringers which support the decking. The chocks attached to the upper wales (often there are no lower wales), and sometimes to curbs, are used as spacers between fender piles. They must be cut to size on the job exposing the timber interiors.

(2) Keep Heartfaces Down. The same recommendation as for deck planks regarding placement of a heartwood face in pine timbers is valid for pine curbs, chocks, and wales. It was mentioned in discussing deck decay that pine planks commonly had heartwood on one face and that the heartwood does not receive much preservative; consequently, such planks should be positioned with the heartwood-containing face downward, where weather checks develop the least.

(3) Use Butt-Type Joints. Lap-type joints are often used because when carefully made they present a trim appearance while new, and they require a minimum of hardware. They amount to a splice at the point of attachment to the structure. However, they should be avoided as they add materially to structural decay. The preferred joint from the standpoint of a lesser decay hazard, and it would seem in other respects also, is the simple butt joint with a separate bolt fastener in each of the adjoining timbers. With this type of joint the ends of the timbers can be separated 1/2 inch or so; thus a water-trapping situation is avoided. Also, in supplementary treating on the construction site, only end grain need be treated, thereby increasing the likelihood of successful treatment.

(4) Separate Curbs and Wales from Decks. The practice of separating curbs and wales from the deck by means of filler blocks should be a standard practice. This is very commendable construction for it avoids the large water-trapping zone that would exist if the timbers were in direct contact with the deck.

4.5.2.4. Protective Construction for Pile Tops.

4.5.2.4.1 Support Piles. Piles must be cut to proper height after driving. They should never be cut again for any reason except to be drilled for drift-pin holes and for bolt holes. Countersinking of bolt heads can be avoided by redesigning as required. All drilled holes should be treated, usually with a grease-type preservative. Pile top treatment for support piles is described with protective measures for pile caps (4.5.2.4.2.(3)).

4.5.2.4.2 Fender Piles. The protection required for fender pile cutoffs differs from that needed for the tops of support piles. The fender pile top has maximum exposure to weather, and the sides are usually heated by the sun and so dry quickly enough to check.

(1) Southern Pine. Deeply treated pine piles have only a small area of wood that can decay. This can be given some protective applications of hot creosote followed by hot coat tar mastic or by application of a penetrating grease-type preservative.

(2) Douglas Fir. This species requires more protection than does pine due to the lack of treatment beyond the thin sapwood zone and because of the severe checking on drying (4.5.1.5). Pile-top preservatives must certainly be applied at the time of construction, but still additional pile-top protection is required. This may be in the form of attaching pile caps after initial treatment or in the form of scheduling routine supplementary treatments, or both.

(3) Pile Caps. Caps of a considerable variety have been used. Most bitumastic coatings will dry, shrink, and flake-off, leaving a bare surface which is checked. Used with various cloths, including fiberglass cloths, bitumastic coatings will usually last longer--particularly if the cloth has considerable overhang. But drying and fine checking of the bitumen can result in the trapping of water which will enter the wood checks. Epoxy resins have been used following wood sterilization. Even with imbedded fiberglass cloth, these have failed. This failure is due in part, at least, to the stresses set up by the shrinkage of the wood.

Pile caps have been made of lead, of copper, of aluminum, of iron, and of galvanized sheet steel. Any cap that can be kept in place, puncture-free, which has enough tight-fitting overhang to exclude storm-driven rain from the pile top can considerably prolong the useful life of a fender pile if it is installed over a layer of grease-type preservative or over a pad saturated with a non-volatile liquid preservative. If pile caps cannot be kept in place, or if their installation is considered excessively expensive, the firm decision must be made to apply preservatives to the Douglas fir pile tops annually.

Because the top surface of a Douglas fir pile has been given some initial treatment when installed, and because the surface dries quickly after a rain, the well checked top of a pile may appear quite sound on casual observation. A sharp blow from a hammer may show that the upper portion of the pile is nearly hollow. In addition to protecting the surface of the pile cut-off it is important to remember to treat all bolt holes. Untreated bolt holes can lead to extensive internal decay beneath a protected top.

4.5.3 PRESERVATIVE TREATMENT FOR WATERFRONT STRUCTURES. As has been discussed (4.5.1), all wood members of waterfront structures are exposed to decay hazards, most of which are quite severe. They require protection through proper construction and through preservative treatment. It has also been explained (4.5.2) how on-the-job application of preservatives can help prolong the life of the structures when applied to untreated interior wood exposed by cutting or drilling. However, no amount of protective construction or on-the-job treatment can protect wooden members which were not first given preservative treatments. Various treatments are required for different structural members. The preservatives and the treatment methods are discussed in Chapter 5, and Chapter 6 provides guidance on selection and procurement.

SECTION 4.6 INSECT CONTROL

4.6.1 CARPENTER ANTS AND BEES

4.6.1.1 Carpenter Ants.

(1) Nest Treatment. For the quickest and most thorough control, short of removal of the infected wood, the nest must be located. Both liquid and dust formulations of appropriate insecticides can be highly effective if injected into the nest. Liquids should be avoided if there are wood finishes they can damage as even the most experienced and knowledgeable personnel cannot determine the true extent of the galleries of an occupied nest in structural timbers.

(2) Tracking Powders. In some cases, carpenter ant nests cannot be found; or if they are found are so located that nest treatment cannot be used. In some such cases, approved insecticidal dusts may be used as tracking powders. This may be appropriate in some cases where ants are seen coming from joints or cracks in a structure. The dust is carried to the nest by the ants walking through it, and this tends to contaminate the active galleries and destroy the colony. But this is not as quick and as certain as is nest treatment.

(3) Ant Baits. Carpenter ants do not eat wood. They use it only as a secure substance for their nests. Other species in the genus Campanotus which are not carpenter ants will nest in soil or in rotten wood. Most of these are primarily feeders on sweet materials, while both Eastern and Western Carpenter ants are truly omnivorous. When nesting in a tree they may tend aphids for their honeydew and eat most other insects on their tree. Because they will eat a wide variety of foods, it is relatively easy to control them with almost any ant baits manufactured. The poisoned food materials are taken to the nest and fed to the developing larvae and to the egg-laying queen, but not, of course, to the pupae from which will emerge new ants. Control through the use of baits can seem to be slow, but it can be highly effective. A few days after the last ant is seen, the bait should be removed. If carpenter ants are seen again in a few days or a few weeks, the bait should again be used. By baiting, complete control can be obtained with the least possible use of pesticidal chemicals.

4.6.1.2 Carpenter Bees

(1) Preventive Controls. There are no truly specific preventive controls that have been developed just for carpenter bees. A coat of paint or a surface treatment with a persistent pesticide will prevent attack by carpenter bees.

(2) Corrective Controls. Dusting partly completed tunnels with insecticide powder will kill the adult bees. After insecticide application and the

death of adult bees, the holes should be sealed with putty. This is an appropriate time to add future prevention through application of a coat of paint. If on close inspection it is found that some brood chambers have been completed and the holes capped off, the holes should be cleaned out to a depth of about one inch, and then treated with dust and filled with putty just like a partially completed tunnel.

4.6.2 WOOD-DESTROYING BEETLES

4.6.2.1 Powder-Post Beetles. Inspection is the first aspect of control. Seasoned lumber and manufactured products that are held in storage are subject to attack by various power-post beetles. Materials in or intended for storage should be inspected at regular intervals. A careful check should be made for signs of infestation such as wood dust. Infested materials should be destroyed or treated to destroy the beetles. To facilitate inspection, as well as control infestation, it is advisable to classify all wood stock, as far as possible, by species or kinds, by quality, and by length of time the wood has been seasoned and the time the wood may remain in storage.

(1) Preventive Control. One approach to prevention of attack is to plug up the wood pores in which eggs might be laid. Solutions of various resins, waxes and oils appropriate to the end use of the wood are used for this purpose. If this treatment is delayed until the eggs have hatched and the larvae have penetrated the wood it will do little good. Wood for outdoor exposure, such as pallets may be protected from decay as well as from insect attack by dipping in a 5% water-repellent pentachlorophenol solution.

(2) Corrective Control. Active infestations of Lyctus in small dimension material and tool handles can be controlled by dip-treatment in approved insecticide solutions. On smaller items, brush or spray treatments have been satisfactory. Repeated flooding treatments of flooring, which has been cleared of heavy timbers, have been used. Fumigation of structures under tarps or of infested materials can provide effective corrective controls. For specific pesticide recommendations, the advice of the appropriate entomologist should be followed.

4.6.2.2 Powder-Post Borers.

(1) Preventive Control. By the time lumber and wood products reach the construction site, the time for real preventive control of, and for the prevention of attack by most powder-post borers has passed. However, because the old house borer can infest seasoned wood, preventive treatment for its control may be needed where infestations are found. The preventive controls for powder-post beetles are generally satisfactory. A residual insecticide treatment has the advantage of killing egg-laying females. The depositing of eggs can be prevented by painting.

(2) Corrective Control. Corrective treatment is the same as for powder-post beetles. Fumigation or kiln heat treatment may be used to control the bamboo borer. The infested stock must be brought to a temperature of 125°F or higher and held there for an hour or longer to kill the insects. The exact time required depends upon the temperature and humidity of the kiln, and the thickness of the stock being treated. This treatment destroys all insects present but does not prevent subsequent attack.

4.6.2.3 Other Wood-Destroying Beetles. For the most part, the other wood-destroying beetles (3.3.2.3), while relatively rare, are found mostly in situations where untreated wood is placed where it will be continuously damp. The preventive control is preservative treatment for all wood which is to be so used that it will frequently be damp. The corrective control usually is replacement of the infected wood with treated wood.

4.6.3 NON-SUBTERRANEAN TERMITES

4.6.3.1 Preventive Controls.

4.6.3.1.1 Stored Materials and Furniture. Because they normally seek the shelter of cracks and crevices to start a new colony (3.3.3.2.3), a mated pair of dry-wood termites begin their destructive work where it is least evident. The interior of items such as pianos, cabinets, cupboards, dressers, chests of drawers and other items of furniture with some surfaces normally not given a finished coating, such as joints, in otherwise finished pieces, "hidden" surfaces, and even the bottoms of furniture legs partially covered by metal feet or frogs are all locations where dry-wood termite nests are started. Items of furniture to be used in geographical areas of heavy termite attack require the protection that can be provided by finishing all surfaces or by coating unfinished surfaces with a residual insecticide. Many items in storage may be damaged by dry-wood termites. Lumber and plywood held in storage are particularly vulnerable to unseen attack; and the damage may become extensive before it is seen. The best preventive control is a dip treatment in an insecticidal wood-preservative solution prior to storage.

4.6.3.1.2 Structures. Because of the greater complexity of structures as compared to furniture and stored materials, there are more preventive measures that can be used to control dry-wood termites.

(1) Wood Preservatives. The preservative treatment of wood is required to protect some parts of buildings against decay and against subterranean termites. This protection can be provided only by pressure treatment. In contrast to this, effective protection against dry-wood termites can be obtained by surface treatment with residual pesticidal materials; but all wood in the structure should be dip-treated prior to delivery to the job site. It is most important that every cut surface be dipped or given a brushed-on treatment. If this is done, dry-wood termites will never damage any part of the structure as long as the protection provided by the dip-treatment remains.

(2) Screening. An 18 x 18 noncorrodible screening, in tight-fitting frames, covering all possible points of termite entry can greatly reduce hidden structural damage by dry-wood termites. Particular attention should be given to the screening of louvers, eaves, apron ventings, and field strips under tile.

(3) Exterior Surfaces. Penetration and attack of outer surfaces by dry-wood termites can be prevented by maintaining smooth exterior surfaces on buildings. While a preservative dip-treatment can protect against dry-wood termites in interior areas for the life of the building, the weathering of exterior wood can remove this protection and leave the wood vulnerable to attack. Grooves and joints should be well filled before painting. A good coat of paint, with careful application at points of vulnerability, will maintain the protective dip-treatment and will aid in warding off attack.

(4) Desiccating Dusts. Effective preventive treatments for some parts of wooden buildings have been obtained by dusting spaces such as hollow walls, attics, and the under surfaces of buildings with crawl spaces with specially formulated dusts which may or may not contain any chemical insecticide but which, on contact, removes the moisture-proofing waxes from the surface of insects walking over the dusted areas.

4.6.3.2 Corrective Controls for Dry-Wood Termites. The corrective controls for dry-wood termites that are effective for furniture and stored materials are also effective for buildings.

(1) Insecticidal Dusts. These may be blown into holes punched or drilled into the termite galleries. Only very small quantities of dust are needed.

(2) Liquids. Insecticidal liquids may be squirted through holes into the termite nests. Oil formulations which will stain or prevent painting should be avoided.

(3) Fumigation. Items of furniture or stored materials may be fumigated under tarps or in fumigation chambers. Buildings require tarps. Fumigation can completely eliminate dry-wood termites. It is expensive, and it provides no residual effect to prevent future infestations.

4.6.4 SUBTERRANEAN TERMITE CONTROL

4.6.4.1 Preventive Controls. The best time to provide protection from subterranean termites is during the planning and construction of a building. Many common design and construction practices are favorable for infestation. Some preventive control measures can be applied after construction and during the use of the buildings.

(1) Construction. Military buildings should be planned and constructed to provide protection against termites. Recommendations regarding design and construction and the use of wood preservatives should be followed without deviation regardless of the urgency to complete construction by a specified date. Some common errors of design and construction are: burial of stumps, logs, boards, stakes, form lumber and wood scraps beneath buildings or next to the foundations; improper grading and drainage; insufficient air circulation and cross-ventilation; failure to use chemically preserved wood.

(2) Site Sanitation. All surplus wood including stumps, tree roots, logs and other wood debris should be removed from the building site before construction work is started. All form lumber, grade stakes, and wood scraps should be removed by the time construction work has been completed.

(3) Foundation Construction. It is important that building foundations be impervious to subterranean termites and that woodwork resting on the foundation be protected against attack. Foundation types may be rated by their relative resistance to penetration as follows:

(a) Poured concrete, reinforced to prevent cracks, with the expansion joints properly filled.

(b) Masonry walls capped with a minimum of 4 inches of reinforced concrete or its equivalent.

(c) Hollow blocks with all of the top rows and joints between blocks filled with concrete.

(d) Wood posts, piers, steps, or braces pressure-treated with an approved chemical preservative and capped, when recommended.

(4) Ventilation and Drainage. It is necessary to provide adequate ventilation and drainage to prevent termite attack. The number and size of openings should be determined by the soil moisture, air movement, and humidity. Areas beneath buildings should be well drained. The soil adjacent to foundation walls should be graded to permit the drainage of surface water away from the buildings.

(5) Clearance Beneath Buildings. In order that periodic inspections can be made for subterranean termites, adequate crawl space should be provided beneath buildings. The minimum clearance for effective inspection is 18 inches from ground to bottom of lowest joist, beam, or girder.

(6) Skirting. When skirting is used, a clearance of three to six inches between it and the ground is needed. If this space is closed in winter, it should be reestablished early each spring.

(7) Miscellaneous Appendages. All miscellaneous building appendages including porches, steps, terraces, platforms, and fire escape ladders should be installed with an unbridged clearance of effective barrier so as to prevent entry of termites into buildings. All wood used in contact with the soil should be pressure-treated with approved wood preservatives. Only treated wood should be used for construction timbers placed on concrete or masonry foundations. Pipes and conduits often provide entrance points for termites. Plumbing, electrical conduits, and other piping should be installed clear of the ground and should not be supported by wood braces or other appendages that touch the ground. At the point where piping enters the floor or wall from below ground, a funnel type shield caulked with a coal-tar type mastic provides a barrier.

(8) Chemical Soil Barriers. Residual insecticides may be added to the soil. When properly applied, they will provide long-lasting barriers of poisoned soil adjacent to foundation walls and piers and under concrete slabs. The formulations and application rates should be as recommended by an entomologist. Water emulsions are normally used. Oil solutions should not be used against surfaces which have been waterproofed or damp-proofed with asphaltic or other materials subject to deterioration by oil. Oil may "burn" the roots of ornamental plants.

(9) Wood Preservatives. Lumber and other forest products which are exposed to excessive moisture, to fungi, and to wood destroying insects such as termites should be treated with wood preservatives to prolong their useful life. The type of treatment and the preservatives to be applied will depend upon the type and severity of exposure and upon the desired life of the material treated. Surface treatments, as well as dip or soak treatments, which provide shallow penetration will protect wood against dry-wood termites.

However, the deeper penetration provided by pressure treatment is required for protection against subterranean termites. Only the wood actually treated is protected. Termites will "bridge over" treated wood with their shelter tubes just as they will bypass other nonedible structural materials.

4.6.4.2 Corrective Controls. The corrective control of termites involves the same basic principles as does preventive control, and many of the same procedures are used. However, because in this case the control is applied at existing structures, some different techniques are used for the application of chemicals.

(1) Perimeter Treatment. Though insecticides applied to soils may kill-out existing colonies, the creation of a barrier of impenetrable soil is still the aim of soil poisoning. But because of the combination of certain types of structures and soils and of the labor costs involved, limited "spot treatment" of the most vulnerable areas may be justified in some cases. Because of the great variations in soil types and in termite species, such limited spot treatment should be considered only if recommended by the an entomologist.

(2) Treatment Under Concrete Slab. Soil beneath a concrete slab may be treated either from above the slab or from outside the building.

(a) Pressure Treating. Holes are drilled through the slab on 12- to 18-inch centers six to eight inches from cracks and expansion joints. The insecticide is pumped through these holes to provide quick even distribution. A plumber's test-plug or similar device with an expandable rubber ring is used to seal the hole and prevent back flow of the emulsion under pressure.

(b) Rodding. Holes are drilled through the foundation wall beneath the slab, and long, perforated pipe, pointed at the end, is driven between the slab and the soil. The insecticide is then pumped through the rod, under pressure, as the rod is withdrawn.

(3) Termite Baits. A new concept in termite control, the use of poisoned baits, has proved effective in extensive field tests. A word of warning must now be provided. Although the baits block decay where placed in the soil, they can NOT be substituted for the preventive controls previously described. They can be used ONLY FOR CORRECTIVE CONTROL.

SECTION 4.7 PREVENTIVE MARINE BORER CONTROL

4.7.1 BIOLOGICAL CONSIDERATIONS FOR PLANNING

During the planning stages for new construction or for major rehabilitation, the biological characteristics of the area under consideration should be investigated. Attempts should be made to find sites at which marine borers and fouling will be at a minimum.

4.7.1.1 Ecological Factors and Area Types. Each of several topographical conditions falling in the category of waterfront environment presents both advantages and disadvantages as far as structures are concerned.

(1) Harbor Conditions. A harbor is usually a body of water connected to the sea by navigable channels and largely enclosed by land. By far most waterfront structures are found in or at the entrances to harbors. As a result marine borers are more consistently found in harbors than in other environments. The incidence of attack can be relatively high because of the presence of large numbers of breeding adults in the vicinity. On the other hand, harbors in highly industrial areas may be so polluted by industrial wastes that marine life is impossible.

(2) Estuarine Considerations. An estuarine environment is the tidal portion of a fresh water river, having at least some measurable salinity. During periods of high rainfall with the consequent runoff into rivers, the salinity is lowered and animals normally found in full sea water disappear if the condition persists for a sufficient length of time. During periods of low rainfall sea water characteristics may ingress some distance up the river. As a result of these fluctuations, most of the organisms present tend to be those preferring brackish water. Unfortunately some of these organisms are among the more severe destructors. Many locations in the estuary are threatened from time to time by marine borer activity when the water conditions reach salinity levels suitable for the existence of these organisms. For the purpose of protection against marine organisms, estuarine waters generally should be considered the same as harbor waters.

(3) River Conditions. A true river condition usually implies that the waters are fresh and that no salinity exists with the exception of minute quantities at widely separated intervals of time. Many organisms thrive on extremely low salinity water if the salinity persists. Biologically speaking, the underwater portions of structures in river conditions are in ideal circumstances. There are no known destructive organisms active in wood completely saturated with fresh water. In fact, the practice of submerging timbers in fresh water has been used for many years as a means of safe storage. The normal hazard from the activities of insects and fungi exists in the area above the water line.

4.7.1.2 Previous Local Experience. When a location is being considered for waterfront construction, it is advisable to investigate the previous local experience of other structures in that area. However, these experiences should only be used as additional data since biological conditions may change over a period of years, and also the reliability of past records can sometimes be challenged. Local traditions often are scientifically misleading.

(1) Other Structures. The history and service records of neighboring structures should be investigated. If possible, the cursory examination of neighboring structures can be helpful if satisfactory records of previous inspections are not available. A chronological record of replacements and major structural repairs, together with specifications for the original preservatives and construction materials, is often valuable. The absence of destructive marine organisms in wood found in undeveloped areas does not mean that the area is immune to future attack. Once susceptible material is installed in a suitable environment, attack will occur upon introduction of the organisms.

(2) Hydrology Records. A study of any records dealing with past and present water analysis and temperature data of the area is very helpful in

judging the suitability of the water for the support of destructive marine organisms. These data are sometimes available from industrial and public utility establishments. Since the environmental requirements of most organisms are limited, it is often possible to predict the approximate intensity of activity and deterioration to be expected. Although accurate pollution data are not always available, knowledge of such abnormal constituents of the sea water can be important.

(3) Historical Records. It is often valuable to investigate the service records of structures of classic design as well as service records of improved design; which are often described in engineering journals. However, service records of structures in the immediate area are of more value since different locations have individual variations.

4.7.2 WOOD AS A WATERFRONT STRUCTURAL MATERIAL. The most important factors influencing the length of effective service life of a structure are a satisfactory design and the correct selection of structural materials. In most instances a compatibility between several materials used is necessary and a final selection should be based on the protection required under the circumstances of the environment. Since many structures are called upon for a longer effective life than anticipated in the original planning, it is good to design for the most severe conditions which could be expected at the location in question. Adequate control measures usually represent only a very small portion of the original cost and a small portion of maintenance costs.

One of the most common materials used in waterfront structures is wood. It is readily obtained, resilient to approaching craft, economical, easily fabricated and lends itself particularly well to the engineering requirements of all parts of waterfront structures, from piling to decking.

4.7.2.1 Wood Species. A great variety of wood species are available from all parts of the world. They have various degrees of resistance to deterioration by destructive organisms, and a variety of receptiveness to preservative treatments.

(1) Native. Native species are those originating within the continental limits of the United States. Similar species are often found in other countries having the same general climate.

(a) Pine. The term "Pine" includes several of the following species: Southern Pine, both long and short leaf; Jack Pine; Red Pine; Lodgepole; and Ponderosa Pine. These have a fairly rapid rate of growth with a large proportion of sapwood. Of these, Southern Pine is used most and is commonly obtained from the southeastern area of the United States. Southern Pine grows tall enough to provide piles up to approximately 80 feet. It can be treated satisfactorily with most preservatives by standard commercial methods. Red or Norway Pine grown in the northeast is often used. It also is readily treated. Ponderosa Pine, Jack Pine and Lodgepole Pine are used to some extent for marine piling.

(b) Douglas-Fir. Intermountain Douglas-Fir and Pacific Coast Douglas Fir are probably the second most commonly used species for marine piling. Douglas Fir is obtained wholly from the northwestern and western parts of the country. An advantage is that it grows in straight lengths well over one hundred (100) feet. The sapwood of coastal Douglas Fir is relatively treatable although susceptible to structural damage during the treating process if subjected to abnormally high temperature and pressures. The sapwood ring is narrower than that in pine but when properly treated, a very satisfactory wooden pile results. Intermountain Douglas Fir is difficult to treat, particularly with the retentions required for use in coastal waters.

(c) Oak. Oak was very commonly used in the past when piling demands were for shorter lengths. The types, Red Oak and White Oak, are used. Oak piling is not as straight as Fir and Pine. Red OaK can be easily treated when proper techniques are used. However, White OaK resists treatment and should not be specified when treated wood is needed. The density of Oak is considerably higher than that of Pine or Fir and lends itself well when high impact strength or abrasion resistance is required. It is widely used in the construction of fender systems.

(d) Miscellaneous. During the history of marine construction small numbers of various species such as Chestnut have been used for marine piling, when available. Commercial quantities of these species have decreased so that few are used today.

(2) Tropical. A large number of wood species grown in tropical and subtropical climates have been used in marine construction. These species are widely used in their native localities, both as a matter of economics and because some species show limited natural resistance to the activities of some marine borers. However, experience has shown that no reliance can be placed in the natural resistance of tropical woods to marine borer attack.

(a) General Types. The various species differ widely from each other in some categories ranging from very light woods to those of very high density. A large number have been investigated in this country, but except for a few species they have not been available in commercial quantities in the United States. The three most commonly known and available are Greenheart, Manbarklac and Angelique. Several varieties of each of these are found in commercial practice. The detailed identification of species requires highly specialized knowledge and skills. The high density woods have been used to advantage where a high strength to volume ratio is needed in fender systems and ferry slips, and in structures where high load capacity in limited space is necessary. Practically all of the hard woods, classified as "tropical" woods, are subject to cracking unless given special handling. It is usually necessary to use restraining encircling steel bands at the top during driving to prevent mechanical damage. Very few, if any, tropical species can be adequately treated with preservatives.

(b) Classification Based on Resistance to Marine Borer Activity. Since the major advantage furnished by the use of tropical woods in this country appears to depend on their resistance to marine borer activity, the broad classification of the types is often made on this basis. Research studies to date show that there is no wood which is suitable for marine construction and which is completely immune to marine borers in locations where borer activity is high. The position in the scale of classification of any species is determined by its relative resistance to attack. There are many conflicting data regarding service records throughout the world. While most of these are based on accurate reporting, the discrepancies are probably caused by variation in the organisms present, the local water conditions, and improper identification of the wood. Many species are highly resistant to one group of borers while readily attacked by another. The palm group is an example of this situation. While rarely entered by teredine borers, palm wood is readily attacked by pholads. The natural resistance of any foreign wood species cannot be relied upon for protection against marine borer attack where the activity of these destructive organisms is high.

4.7.2.2 General Biological Considerations. The resistance to destructive organisms is one of the major aspects concerning the selection of wooden piling. Very few conditions warrant the use of wood without preservative treatment.

(1) Marine Borer Activity. No untreated wood native to the United States appears to exhibit other than a temporary resistance to marine borer activity. Exposure studies have shown that, where the attack is even moderate, all the species which could be considered for use as piling are totally destroyed in a period of a very few years. Any resistance existing in native species is minor and of little practical significance. Often so-called immunity to attack is the result of a low rate of biological activity. If it is found necessary to use untreated piling of any native species, it is preferable not to remove the bark, as this layer is naturally impervious to some marine borer activity while it remains in place. However, Bankia penetrate it. The aspects of marine borer activity in foreign woods is discussed in paragraph 4.7.2.1.

(2) Fungus Activity. The activity of destructive fungi in the tops of wooden piling or other structural timbers can result in very expensive damage and repair. Although native woods exhibit more variation in resistance to the activity of fungi, the relatively few species of wood available for wooden piling are not in the highly resistant category. Unless careful precautions are taken, conditions in a pile top are extremely favorable for the existence of destructive fungi (4.5.1.5 and 4.5.1.6).

4.7.2.3 Wood Preservation for Marine Borer Control. Wood preservation is the combination of materials and methods to prevent attack and destruction of wood by decay fungi, by insects, and by marine borers. Of all of these, marine borers are the most difficult to control. Preservative treatment is required for piles and timbers in the water; but there have been situations in which treatment has not satisfactorily prevented attack and destruction (3.4.3.3). The preservative treatment of wood for marine use is discussed later (6.1.2.3). The protection given by even the most effective treatments is negated by some common construction practices which broach the protective shell of treated wood. Preventive and corrective protective physical measures are described (4.7.4 and 10.4.2).

4.7.3 ALTERNATE STRUCTURAL MATERIALS. Materials other than wood are used for construction of waterfront facilities. Because it can be designed to meet specific needs of a particular structure, reinforced concrete is widely used. While its cost is high, it is well suited to large structures which carry heavy loads. But metals and concrete as well as wood, are subject to degradation.

4.7.3.1 Chemical and Biological Considerations. When wood is selected for portions of waterfront structure, the primary concern is with biodegradation even though chemical degradation can occur (2.6.3.2). Both chemical degradation and biodegradation effect the alternate structural materials.

4.7.3.1.1 Metals. Modern metallurgical research has produced numerous varieties of alloys, each particularly suitable for specific water conditions found in various locations. The choice depends upon the nature of the environment. The detailed composition of steel can vary considerably depending on the structural characteristics required. Various percentages of alloying elements are added to steel to reduce the rate of corrosion which is probably the most important factor affecting the life of metal piles. Competitive economic considerations limit the extent to which the more expensive corrosion resistant metals may be used. High costs generally prohibit the use of materials with extremely low corrosion rates. The addition of small amounts of copper and nickel to steel has improved service life under some conditions.

(1) Chemical Corrosion. Because a typical marine pile is exposed to different environments extending from the atmosphere at the superstructure level down through the tidal and water areas into the soil, these protective methods vary from elevation to elevation. Atmospheric corrosion in marine environments is usually severe. The action of salt spray in the presence of a plentiful supply of oxygen furnishes conditions extremely favorable to corrosion. Tidal areas can be exceedingly troublesome because of wetting and drying cycles. Corrosion rates in the continuously submerged portion are usually somewhat less than in the tidal portion where periodic exposure to air is found. Because corrosion is primarily caused by difference of electro-chemical potential in adjacent areas, most deterioration takes place when the environmental conditions change abruptly. Examples of this are the mud line, the water surface, the tidal zones and the spray zone.

(2) Biodegradation.

(a) Microorganisms and Primary Films. When a solid object is placed in sea water, a biological "primary film" is quickly formed on the surface. With most materials in most waters, the first organisms to settle on the surface are microorganisms such as bacteria which are soon followed by aquatic fungi and by diatoms. Bacteria establish hydrogen-ion-potential cells at the surface which initiates pitting. As a bacterial colony develops, the pitting increases in width and depth. The action of anaerobic bacteria below the mud line may have considerable influence on corrosion. The most common group is the sulphur reducing bacteria which derive their oxygen from compounds containing sulphur such as sulphates, sulphites or other organic substances. They liberate hydrogen sulphide which is corrosive to iron. These organisms are frequently found in large numbers beneath corrosion products on the pile surface, an area devoid of oxygen. The complete role of these organisms is not completely known. Corrosion below the mud line depends upon the characteristics of the soil but ordinarily the corrosion rate is not high in this area.

(b) Visible Macroorganisms. Larval forms of macroorganisms normally attach only in the later stages of development of a primary film coating. If, as they grow, the macroorganisms are not cemented tightly to the surface but are temporarily or semi-temporarily attached as are limpets and abalones, a hydrogen-ion-potential cell of large diameter can be formed which can dissolve most metals. In death, most macroorganisms adhere at least in part to the surface to which they attached in life. Bacterial decomposition usually produces acids which etch the metals. Heavy coatings of healthy fouling organisms can provide some protection for metals in the patches that they cover; but in between these patches, corrosion occurs.

4.7.3.1.2 Concrete.

(1) Utilization. Concrete is used in various ways in the production of piles which may be either precast or cast-in-place. Concrete is also used in composite piles where the lower portion, to be completely buried, is wood. Piles may be cast-in-place. Steel forms used for this may be left in place to exclude salt water and to add to the strength of the internal reinforcing steel. Precast piles can carry substantial loads through relatively long distances of soft material down to a firm foundation. Internal prestressed reinforcing provides stability and minimizes cracking. Precasting permits inspection before driving. The use of air-entrained concrete provides some protection against marine damage. Waterproofing coatings also extend the life of the pile.

(2) Degradation. If the correct concrete mix is selected, the salt in harbor waters will have no measurable direct detrimental effect on the concrete in waterfront structures. But other features of the environment can severely damage it. In northern waters, tide-zone freezing and thawing of contained moisture can produce extensive damage. The life and death processes in the primary film and the later fouling release acids which penetrate and damage the concrete. Where heavy masses of fouling are firmly attached, they place great stresses on the surface and the near-surface part of the concrete in strong currents and turbulent waters, and often produce repeated spalling where fouling attaches. However, spalling is sometimes due almost entirely to the fact that reinforcing steel is too close to the concrete surface so that salt and oxygen may attack it. In tropical and semitropical waters where pholads (3.4.2.3) are active they can destroy concrete made with limestone sand and aggregate.

4.7.3.1.3 Plastics. Some plastic materials withstand exposure in the marine environment for many years. While none are normally used as primary structural materials, some serve well as supplemental materials to bond, to strengthen, or to extend the life of the structures. Water-proofing compounds can considerably extend the life of concrete piling; and in some cases can extend the life of concrete superstructures. Some epoxies are used in adhesives to attach main structural members. The use of flexible plastic wraps to protect piles and the use of epoxies for repair work are later described (7.4.2, and briefly in 4.7.3.2).

4.7.3.2 Protective Procedures and Materials.

(1) Cathodic Protection. Actively corroding metal assumes a positive or anodic electrical potential, and the non-corroding area of materials become negative or cathodic. Basically this condition constitutes part of an electrical cell. Corrosion may be reduced or eliminated by the process of making the steel pile cathodic. This can be accomplished by an outside current or by the connection of the pile to a less noble metal placed in the water nearby.

The less noble material thus becomes the anode and is sacrificially corroded during the process by which the pile is protected. Sacrificial anodes can be made of magnesium, zinc or aluminum. These are suspended at carefully selected locations in the structure. In large, complicated structures, the design and successful operation of a cathodic protection system usually requires special knowledge to obtain efficient results. Where the structure is relatively close to a cheap source of electrical power, it is often an advantage to use currents from this source. In such cases carbon electrodes are used instead of sacrificial anodes. Satisfactory results are obtained only when the electrodes and the piling are both continually submerged since the sea water serves as the electrolyte. Reduction in salinity reduces the effectiveness of the electrolyte and consequently the efficiency of the protective method. Some degree of protection can be obtained for some distance above the low water mark because conductivity exists a considerable percentage of the time within tidal variation due to the wet surface. This method is widely used in the underwater portion of structures.

(2) Coatings. Protective coatings of various types are used to prevent corrosion. In the underwater portions of structures, the longevity of the coatings selected is of considerable importance. Recoating underwater is quite expensive due to the extensive time required for surface preparation of submerged structures. If coatings containing a metallic pigment are used, these layers should be separated from the base metal by sufficient thickness of insulating barrier coating in order to prevent galvanic corrosion. Coatings are almost entirely depended upon in the atmospheric areas.

The coatings vary from easily applied, specially designed paints, to more complicated systems which involve the application of metallic pigments in highly specialized vehicles. The severity of the anticipated deterioration determines the choice of coating. Each manufacturer provides specification for the application of his product. It is important that these be carefully followed, since adequate performance is dependent upon careful surface preparation and coating application. Special attention should be given to conditions of temperature and humidity. Sand blasting of the steel, or chemical cleaning is usually recommended. Coatings should be carried below the mud line and should be without holidays.

When no coating is present on the pile, the corrosion is more or less evenly distributed over the entire surface. In the case of coating voids, the corrosion is heavily concentrated in the bare areas. When soft coatings are used, some calcareous (Balanus) organisms and oysters can, by the physical action of their growth, bury themselves in the coating. Eventually they will reach the bare metal. Their death and decomposition result in the formation of products which accelerate corrosion. Tightly adherent organisms prevent the access of oxygen to the metal surface beneath them so that galvanic cells are created, causing pitting. Some organisms such as sea urchins and boring pholads may penetrate coatings or accumulated layers of other organisms. When they reach the metal the action of their appendages or other body parts results in the continuous removal of blanketing corrosion products. Normal corrosion rates are thus accelerated. One half inch thick steel has been penetrated in a few years by these actions. Mechanical barriers, such as sand or metallic skins, are sometimes used to prevent these penetrations.

(3) Sheathing. It is good practice to cover tide-zone portions of piling with layers of various materials to protect against tide-zone corrosion and abrasion. Preservative-treated wood has been used to protect both steel and concrete against abrasion; while steel and concrete have each been used to protect the other against both abrasion and corrosion in the tide zone and the splash zone. Plastic wraps which fit quite tightly and are sealed at the ends will prevent fouling, marine borers, and corrosion of metals. What little water remains at the surface under the sheathing quickly becomes stagnant and deoxygenated, and there can be no life and no rust there. This is discussed in more detail later (7.6.2.4).

4.7.3.3 Compatibility of Materials. In the marine environment, some materials adversely affect each other. A good general rule to follow is that, except for fastenings and hardware, direct contact of different materials should be avoided. But this rule should not be followed blindly because there are some beneficial effects.

(1) Adverse Effects.

(a) Treated and Untreated Wood. As borers and destructive fungi may move from untreated wood into treated wood, untreated wood must never be placed in contact with treated wood.

(b) Preservatives and Sea Water. Pentachlorophenol, and the low boiling point fractions of creosote, for example, are readily leached from wood by sea water. Only creosotes having a high percentage of high boiling point fractions or non-leaching metalic salts should be used where long-lasting protection is needed.

(c) Preservatives and Solvents. Paints or other coatings may act as solvents, and remove preservatives from treated wood.

(d) Preservatives and Pollution. Industrial pollution in sea water, particularly oil, may accelerate the leaching of preservatives from wood.

(e) Preservatives and Metals. Certain preservatives, particularly those containing water-borne salts, may corrode metals.

(f) Wood Constituents and Metals. Some species of wood contain natural chemicals which may accelerate corrosion of metal fastenings.

(g) Dissimilar Metals. Dissimilar metals placed together may create galvanic cells, resulting in accelerated corrosion.

(h) Pollution and Metals. Industrial polluted sea water may contain chemicals which will attack and destroy metals.

(2) Beneficial Effects. Not all contact between different materials and chemicals is detrimental.

(a) Creosote and Metals. Demonstrations show that some oil preservatives, such as creosote, protect most metals.

(b) Industrial Pollution and Marine Borers. The continued presence of some types of industrial pollution may prevent the establishment of, or eliminate existing populations of, marine borers. However, because of the requirements for pollution control, this cannot be used in determining the future need for degrees of protection.

4.7.4 STRUCTURAL DESIGN AND MARINE BORER CONTROL. Once the general habits and characteristic activities of destructive marine organisms are known, proper design can minimize or prevent damage. One of the fundamental factors in this respect is the location of structural members.

4.7.4.1 Bracing and Lower Wales. Other than piling, bracing timbers attached to piling are perhaps the most frequently attacked structural members in a wharf or pier. These are ordinarily sawn timbers of fairly large dimensions. As such they originate in the heartwood areas of the tree, and adequate treatment with a preservative is difficult. This is true of diagonal bracing, cross bracing, and lower wales. Where these must be cut to length, untreated end grain is exposed, as it is with drilled holes, and the timbers can be hollowed out by Limnoria if in or below the tide zone. Some newly available materials such as expoxy coatings can provide some protection.

(1) Design. Structures should be designed so that all bracing is located as high as possible above the low water mark. In areas where tidal variations are great the lowest point of attachment should be at the mid-tide level. The removal of these members from areas of possible attack, greatly adds to the life of the structure and reduces the need for replacement.

(2) Relationship to Piling. Particular attention should be given to the means of fastening bracing to the piles. Because of the variation in the shape and diameter of piles, it is seldom possible to achieve perfect alignment of the pile bents during driving. Projecting or misaligned piles should never be topped or trimmed to provide clearance during the installation of the braces. The proper procedure is to fasten the timbers to the outermost piles and fill the spaces between the bracing timber and the non-aligned piles with treated wooden blocks. This prevents the exposure of untreated portions of wood. Unpreserved wood should never be used in contact with treated wood since few chemical treatments are completely immune from entrance by some adult borers. All bored bolt holes in the wood and all timber cuts which expose untreated wood should be given protective epoxy coatings. This is later described in detail (7.4.2.2).

4.7.4.2 Fender Systems. Fender systems are placed at piers, wharves and bridges to protect both these structures and ships from mechanical damage. To function properly, they must absorb impact shock. On some facilities, fenders are frequently broken by impact due to underdesign of the fender system or due to decay and marine borer damage.

(1) Hung Fenders. These are designed to absorb considerable energy from berthing ships, and so are often used where repeated heavy impact is expected. They are composite structures having wooden or rubber contact pads or rubbing strips. Wood can serve well here if it is pressure-treated. As field cutting is a normal requirement of fabrication, the wood species must be selected for its ability to accept deep penetration.

(2) Fender Piles. The most common fender systems consist primarily of side rows and end clusters of fender piles. Attached to the main structure only at upper wales, their flexibility absorbs the energy of impact. Tethered camels help distribute the initial load to rows of piles. By contrast, when the fender piles are additionally secured by extension of bracings and by lower wales, they become part of the rigid structure they are intended to protect. This permits direct transfer of shock to the primary structure, and it is blamed for excessive pile breakage.

(3) Rubbing Strips. The tethered camel rides up and down with the tide, rubbing against the fender piles. In thin-sapwood species such as Douglas fir, this rubbing erodes to the extent that untreated wood is exposed to marine borer attack. This damage can be prevented by the use of metal or plastic rubbing strips attached to the outer face of the piles in the area where abrasion can take place - just beyond the range of the highest and lowest tides. The tethered camel is expendable; and its replacement cost is much less than the cost of any of the several piles against which it rubs. As rubbing strips are considered even more expendable than large camels, they are sometimes placed on the camels as well as on the fender piles.

4.7.4.3 Bulkhead Systems. Bulkheads are those vertical walls serving to support fill, either at the shore end of the structure, along the shore itself, or as partitions to deflect undesirable water currents. The design varies somewhat from wharf construction because of different stresses encountered. Most bulkheads are primarily subjected to lateral forces. In wooden construction, it is customary to fortify the sheet piling wall at regular intervals with vertical wooden piles. Because of the stresses present, relatively small losses of wood by marine borer attack materially affect the strength of the bulkhead. Thus, well treated piling should be stipulated for this use.

4.7.4.3.1 Bulkhead Materials. Bulkheads may be constructed of wood sheet piling, metal sheet piling or masonry. The design may be linear, serpentine or cellular, depending on the service requirements.

4.7.4.3.2 Bulkhead Protection. Wood should be given maximum preservative treatment. Cut surfaces should be given the same protection as piles and timbers for piers and wharves (4.7.3 and 7.4.2). In the case of concrete and steel, precautions should be taken so that the chemical characteristics of the fill material do not cause accelerated deterioration along the inner face of the bulkhead. Such deterioration can be caused by high sulphur content of cinders or chemical waste drainage. Be sure that any tie rods or buried anchor structures are adequately protected against corrosion and decay. This can be done through the use of coatings, cathodic protection or preservative treatment. Steel, wood, concrete or masonry are all quite suitable for bulkhead construction. Economics and service requirements usually dictate the choice of materials. Since the open face of bulkheads are subjected to the same destructive influences as marine piles, similar preservation precautions should be taken. When soft, loose fill is not available, bulkheads may be constructed of large pieces of irregularly shaped stone.

Adequate preservative treatment of wooden sheet piling is particularly important in bulkhead construction where marine borer activity is a factor. Relatively light borer activity along the joints may result in the formation of voids through which fill may be lost. Timbers with a maximum amount of sapwood should be used so that heavy retentions of preservatives will be obtained. As marine growth on the surface of metal sheet piling may cause corrosion, protective coatings are customarily specified.

In recent years, various systems have been developed to provide prolonged protection to bulkhead materials. These are discussed later (7.4.2) under the subject of preventive maintenance though they are applicable at the time of new construction.

SECTION 4.8 PRESERVATIVE TREATMENT FOR MARINE BORER CONTROL

Experience has proven that, without proper protection, wood exposed in salt water and in brackish water can be destroyed by marine borers. The selection of the correct preservative treatments for the various exposure conditions is previously mentioned (4.5.3). Wood preservatives and treatment methods are discussed in Chapter 5; and Chapter 6 provides guidance on selection and procurement to meet specific needs.

CHAPTER 5. PRESERVATIVE TREATMENT OF WOOD: MATERIALS AND METHODS

SECTION 5.1 NEED AND ABILITY TO TREAT WOOD

While wood is a highly valuable structural material and the only renewable natural resource that can be used for modern construction, there are many situations in which it cannot serve well or long unless it is given preservative treatment to protect it from biological degradation. However, for many other uses, no preservation is required. For economic reasons, it is very important to know why, when, and how to treat wood.

5.1.1 WHY AND WHEN TO TREAT WOOD. Whenever a wooden part of a structure, or a completely wooden structure, is required to be relatively permanent but may be exposed to moisture and wood-decay fungi, or to wood-destroying insects, or to marine borers, it requires the protection that can be provided only by the most effective preservative treatments. The extent to which wood is subject to biodegradation and therefore its need for protection depends on the amounts and types of exposure to wood destroying organisms, and on the ways in which these organisms cause economic losses. Some detailed information is provided in Chapter 3.

If permanence of the wooden structure or of the structural part is not an important consideration and a short life is planned, then wood preservation is not needed. Neglecting consideration of wood treatment in the planning stages is the same as making a decision to omit it. The omission should always follow thoughtful consideration of all alternatives rather than result from neglect. The question of whether to use treated wood or to use untreated wood should be answered by economic considerations. Will the increase in the cost of wood due to protective treatment be more or less than the costs of repair or replacement in a time period dictated by the exposure hazard? Throughout Chapter 4 there are explanations of when preservative treated wood should be selected and when in-place or on-the-job supplemental treatment is required. Chapter 6 provides guidance in the selection of treatments for various exposure conditions.

5.1.2 PENETRABILITY OF WOOD.

5.1.2.1 Effects of Wood Structure. Woods of different timber species do not treat with equal ease. Moreover, in most species heartwood is more difficult to treat than sapwood. Differences in treatability are correlated with the penetrability of porosity of the wood. Dry southern pine sapwood, for example, is relatively porous and will take up preservative solutions without much difficulty; but the heartwood is moderately difficult to penetrate. In a species like western redcedar, both sapwood and heartwood are difficult to treat. The variability of wood structure with differences in wood species, and some of the effects that these differences have on the penetrability of wood, is previously explained (2.5.4.2). Poles and round posts are seldom treated deeper than the sapwood. Thus, the thickness of the sapwood, as well

TABLE 5-1

Penetrability of Woods

Recognizing that considerable variability exists in a particular wood, the relative ease of getting preservative penetration into dry lumber of common building woods can be summarized as follows, using E for easy, M for moderate, and D for difficult:

Relative ease of getting penetration into:

Species	Sapwood	Heartwood
Pines (most species)	E	M to D
Ponderosa pine	E	M
White fir	M	M
Most other true firs	E to M	D
Eastern hemlock	M	D
Western hemlock	E	E to M
Redwood	M to D	M to D
Douglas-fir (Coast)	E to M	M to D
Douglas-fir (Rocky Mountain)	D	D
Western larch	E	D
Sitka spruce	M	M
Most other spruces	D	D
Western redcedar	D	D
White oak	E	D
Selected red oaks	E	E

as the quality of the preservative, can be very important in determining the effectiveness of treatment.

5.1.2.2. Incising. In nearly all species of wood, the longitudinal or end-grain penetration is much better than either radial or tangential penetration. In some species the longitudinal penetration is quite good, but the tangential and radial are still relatively poor. In the treatment of wood, advantage can be taken of the longitudinal penetration by puncturing or perforating the surface to a pre-determined depth in a pattern, commonly a diamond pattern, such that in the species to be treated the penetration will permit treatment between perforations both radially and longitudinally. This provides a treated layer of wood at least as deep as the perforations. The mechanical operation of making small longitudinal cuts is called incising. It is usually performed with rollers equipped with cutting teeth which make the cuts further apart longitudinally than radially, and further apart at their deepest points than at the surface.

In some species, very even penetration can be obtained to and beyond the depth of incising. In other species, radial penetration is nearly impossible and treatment seems to be limited to the interior surfaces of the cuts. It is common practice to incise sawn timbers of resistant woods prior to treatment. Machines for incising round materials are much less common than those for sawn timbers. They are most often used for incising the butts of difficult-to-treat species.

5.1.3 MEASUREMENT OF PRESERVATIVE PENETRATION AND RETENTION

5.1.3.1 Preservative Penetration. As penetration of the preservative is a major factor in the effectiveness of treatment, measurements of penetration are highly important is assessing the quality of a treatment. Where the preservative is applied commercially by pressure, penetrations are commonly checked against specifications. For the purpose, a slender, cylindrical sample is extracted from the wood with a Swedish increment borer. A dark-colored preservative, such as creosote, is easily observed on the sample. The observations should be made immediately after extracting the boring, before the preservative oil has time to spread significantly on the surface. To further avoid error from this source, it sometimes is helpful to split the boring with a razor blade.

To ascertain the penetration of a preservative having no pronounced color may require a laboratory test. This might be necessary in the case of pentachlorophenol dissolved in a light colored oil. One can obtain a good approximation of the penetration of such a preservative, however, during a limited period following treatment when a substantial amount of the oil carrier is still present in the wood. Then if a suitable oil-soluble dye is dusted on the sample, the dye will dissolve and show its color on areas reached by the oil. A quick and easy determination of the depth of penetration by pentachlorophenol is given in the American Wood Preservers' Association (AWPA) Standard A3. In discussing measurement of penetration, AWPA Standard M2-74 states that "an annual ring shall be considered penetrated if any portion of the ring is penetrated," and that "the measurement shall be made to the nearest one tenth inch."

5.1.3.2 Retention of Preservatives. For the procurement of preservative-treated wood, contracts made cite standards which specify not only the required depth of preservative penetration but also the amount of preservative retained after treatment in a stated area (assay zone) of the wood. This is normally stated as pounds of preservative per cubic foot of wood in the assay zone. If the preservative is creosote or a creosote solution, the total amount of creosote or solution per cubic foot is specified and the wood assayed for it. If it is an oil-borne preservative, such as pentachlorophenol, it is the pounds per cubic foot of the actual preservative chemical that is specified and for which the wood is assayed. The solvent is not considered. When water-borne preservative salts are used, only the metallic content (equated to an oxide basis) is used for specifications and for determining compliance. In order to determine preservative retention, borings which form representative samples of a cylinder charge of treated wood are assayed in accordance with the laboratory procedures set forth in the Standards of the American Wood Preservers Association.

SECTION 5.2 PRESERVATIVE MATERIALS

5.2.1 IMPORTANT PROPERTIES OF PRESERVATIVES. A few requirements of wood preservatives are basic in that they apply to all treated wood. Other properties may be essential for some wood items or some conditions of use but relatively unimportant in other cases.

(1) Toxicity to Wood-Destroying Organisms. All preservatives that are now in commercial use owe their effect to a toxic action on the wood-attacking organisms. Toxicity is therefore listed first as a prime requirement.

(2) Penetrability. Various materials are used to protect wood by providing protective coatings. These are not wood preservatives. The true preservatives must be able to penetrate the wood of treatable species (5.1.2). Some preservatives and solutions must be heated to become fluid enough to penetrate the wood structure. Solid materials must be used in appropriate solvents.

(3) Permanence. The permanence of a preservative is inversely related to the rates at which it is removed from wood by surrounding air (evaporation) and contacting water (leaching). This determines the length of time that the wood is protected and--along with the initial cost--determines the annual in-place cost of the wood. Low volatility of a preservative is always a virtue. Low leach-ability is important under some conditions of use but not under others.

(4) Availability and Cost. A preservative must be available in adequate quantity and at a cost that is commensurate with its performance.

(5) Freedom from Injurious Effects on the Strength of Wood. The chemicals used to preserve wood should remain within the wood for long periods of time without weakening the structure of the wood. Tensile and compressive strength as well as resistance to impact should be as great after treatment as before.

(6) Freedom from Undue Health Hazard. This requirement is more important with some treating methods than with others. It requires careful consideration under all circumstances but especially when treatment is by a simple non-pressure method. Only one preservative (TBTU) is registered with the EPA for treatment of wood which is to be used in direct contact with food for humans.

(7) Effect on Cleanliness of Wood Surface. Wood that is to be painted or glued should not be impregnated with a heavy oil-type preservative. A related disadvantage of such preservatives when applied to framing lumber, floor joists, or sleepers, lies in their tendency to creep along nails and appear on finish flooring and wall surfaces.

When cleanliness is essential and conditions of use are conducive to decay or termite attack, the choice of treatment lies between a water-borne preservative or pentachlorophenol in a volatile carrier with either preservative being applied by a pressure method.

(8) Freedom From Objectionable Odors. Odor is of negligible importance in the treatment of wood items for outdoor use. It becomes of critical importance when treated lumber is to be used in a confined space, especially in proximity to foods.

(9) Effects on Metals. Some chemicals that might be acceptable in other respects cannot be used because of their corrosiveness to metallic fastenings and also to treating equipment.

(10) Effects on Dimensions. The importance of this property varies with the nature of the wood item being treated. For example, the swelling of structural lumber caused by a water solution of a preservative presents no serious problem other than care in post-treatment seasoning to minimize warping and splitting. However, where precise carpentry along with cleanliness is called for, as in interior woodwork, only clean oil-type preservatives may be used satisfactorily, unless the salt-treated wood is dried to a moisture content equal to the normal relative humidity where it is to be used. This is especially true when items such as window sash are treated after assembly.

(11) Water Repellency. Water repellency is a built-in virtue of the heavy oil-type preservatives. It is easy to understand the almost universal selection of such preservatives for crossties when it is recalled that the ultimate replacement of a crosstie generally becomes necessary not because of biological attack but a mechanical breakdown that is accelerated by splitting and checking. Water repellents increase the effectiveness of penta in light solvents and should always be added to such solutions when used in marginal treatments such as short dips. Depending on the material added to provide water repellency, the wood may or may not be painted satisfactorily. When relatively low retentions are absorbed, as in non-pressure treatments, the water repellent material does not normally cause painting problems. On the contrary, it helps to keep the paint intact.

(12) Fire Retardance. Certain chemicals, called fire retardants, modify the burning characteristics of wood. Their principal effects are to (a) decrease the amount of flammable gases released, (b) decrease rate of flame spread, and (c) decrease the rate of initial heat release. Some render the wood self-extinguishing after flaming and glowing. The most widely used formulations are subject to leaching when the wood is used in wet situations; in recent years, however, systems with increased resistance to leaching have been developed. A few commercial formulations include preservative chemicals.

(13) Ease of Handling and Application. Composition of preservative formulations can create problems in effectiveness and in use for on-the-job applications. Liquid formulations may be brushed or sprayed on horizontal surfaces for flooding treatments with considerably more effectiveness than on vertical surfaces. Bodied formulations (greases, pastes, gels, invert emulsions) can often adhere quite well to vertical surfaces where they can penetrate to depth.

(14) Effect on the Environment. For all external uses of treated wood, the possibility of harmful effects on the environment should be considered and only non-harmful preservatives should be selected if they can leach from the wood.

5.2.2 TYPES AND USEFULNESS OF PRESERVATIVES

5.2.2.1 Creosote and Creosote Solutions. Creosotes are liquids, or combinations of liquids with dissolved solids, which are produced by the fractional distillation of tars. Creosotes produced from various tars differ greatly in their physical qualities and their chemical composition; and they differ in their usefulness for the preservative treatment of wood. Not all of the major categories of tars yield creosote of value as wood preservatives, but they are briefly presented here in order to prevent any later misunderstanding of discussions of creosote uses. It is here noted that the seven preservative standards of the American Wood Preservers Association (AWPA) that are concerned with creosotes and creosote solutions all require that the creosotes be coal tar derivatives. Treating companies using the AWPA Standards are thus limited in the selection of creosote. However, other creosotes may find their way to market packaged for the home owner. For surface treatments of items of limited value, they may serve well.

5.2.2.1.1 Various Tar Sources and the Creosotes Produced

(1) Oil-Tar Creosote. In the production of commercially useful gas from petroleum, the oil is sprayed into generators heated to approximately 1800°F. This process, which is similar in many respects to the coking of coal, yields a tar residue in addition to the gas; and the tar has some properties in common with coal tar. Distillation of the oil tar will produce oil-tar creosote. This material, like coal-tar creosote, is a combination of many chemical compounds. It has not been in use long enough to have been thoroughly evaluated as a wood preservative, but research studies indicate that it is highly effective against fungi.

(2) Wood-Tar Creosotes. When heated in the absence of free air, wood is converted into charcoal and volatile materials. If the volatile materials are collected and cooled, a material called pyroligneous acid is formed. The initial distillation of this "acid" produces gases, oils, and tars. This "destructive distillation" of wood was for years the primary source of acetic acid, acetone, and methyl (wood) alcohol. Hardwoods produce the most valuable by-products. When softwood lumbering scrap is distilled, low grade turpentines and resins are obtained. The heavy tars produced by the destructive distillation of wood may be further distilled to produce wood-tar creosotes. As with all other types of creosotes, wood-tar creosotes vary in their composition with the original materials and with the rendering processes used. No satisfactory specifications for wood-tar creosotes have been prepared. Hardwood tars are decidedly acid in character. In this respect they differ from the "acid" coal tars. The "tar acids" of coal tars are not true acids in a chemical sense, but are phenols and hence not corrosive to iron and steel. The acids of hardwood tars are chiefly acetic and formic acids, and their presence in wood-tar creosotes makes these creosotes objectionable for the preservation of wood to be used in contact with metals.

(3) Water-Gas-Tar Creosote. When steam is passed over hot coke, a mixture of carbon monoxide and hydrogen is formed. This is called water-gas. The flame from this gas is hot, but is non-luminous. It is often enriched by the addition of hydrocarbons from petroleum. The hot gas is passed up through a brick filled tower into the top of which petroleum oil is sprayed. The petroleum vapors mixed with the gas then pass into a cracking chamber where final enrichment takes place. In the first tower, the heat produces water-gas-tar as a by-product of the thermal decomposition of the petroleum. The hydrocarbons are chiefly aromatic and are similar to many of those of coal tar. Like coal tar, water-gas tar may or may not contain aliphatic hydrocarbons. The composition of the water-gas tar will vary with the character of

the petroleum used and with the conditions under which produced. These tars contain less free carbon than do coal tars, and in some cases can be made to penetrate well. Some water-gas tars are sufficiently clean, fluid, and toxic to be used for wood preservation, but others are not. There are no standard specifications for water-gas tars for wood preserving.

This creosote is distilled from water-gas tar in much the same way as coal-tar creosote is made from coal tar. Water-gas-tar creosotes differ from coal-tar creosotes mainly in that they have almost no tar acids or tar bases, and so are comparable to those coal tar preservatives from which these materials have been removed. The presence of tar acids and bases is no assurance that a creosote is a pure coal tar product, since it may be a mixture of coal-tar and water-gas-tar creosotes. The toxicity of water-gas-tar creosotes varies with the percentages of constituent chemical compounds present. These creosotes have, in general, much lower toxicities than those derived from coal tars. Though most of the water-gas-tar creosotes are toxic enough to be very good preservatives, they are almost never sold as such but reach the market in other forms.

(4) Coal-Tar Creosote. This is the creosote used almost exclusively for the pressure treatment of wood in the United States.

5.2.2.1.2 Coal-Tar and Coal-Tar Creosote Production. In the production of coke for use in the metallurgical industries, coal is heated in retorts in the absence of free air. The coal is coked until there is left only a residue composed mostly of carbon and containing some ash. The primary by-products of coke production are ammonia, coal gas, and coal tars. The value of the coke produced depends upon the type of coal used and the temperatures employed in the ovens. The coal tars produced are mixtures of many chemical compounds, quite a few of which are of considerable value in the technological age in which we live. Many of these compounds are highly toxic to most forms of life, and so hold forth promise as wood preservatives. Crude coal tars, when a suitable quality and of a viscosity permitting satisfactory penetration of wood have proven to be fairly effective wood preservatives. Their use, alone and unmixed with other preservatives, was largely limited to the pressure treating of railroad ties. Distillation of these tars yields coal-tar creosotes as well as many other useful materials.

The AWPA Standard M5 defines coal-tar creosote as follows: "A distillate of coal tar. As used in the wood-preserving industry, coal-tar creosote, or 'creosote' denotes a distillate of coal tar produced by high temperature carbonization of bituminous coal; it consists principally of liquid and solid aromatic hydrocarbons and contains appreciable quantities of tar acids and tar bases; it is heavier than water and has a continuous boiling range of at least 125°C beginning at about 200°C."

The "high temperature carbonization of bituminous coal" is the most common method of coke production in the United States. The coal tars are produced by the coking of coal at temperatures ranging from 1600°F to 2000°F. Low temperature carbonization produces coke and coal tars at temperatures ranging from 1000°F to 1400°F. The low temperature coal tars so produced differ from the usual coal tars, and their creosotes also differ. Very little of the low-temperature coal-tar creosotes have been used for wood preservation. They are characterized by lower specific gravity, lower content of cyclic hydrocarbons such as naphthalene, and much higher content of tar acids than the standard coal-tar creosotes. They have not been adequately tested against all types of destructive organisms. Both the high-temperature and low-temperature coal-tar creosotes are produced from bituminous coal. The coking of lignite coal produces a lignite coal tar commonly known as lignite tar. The creosote produced by the distillation of lignite tar is known as lignite-tar creosote. Most lignite-tar creosotes have a specific gravity slightly lower than that of water, a high tar-acid content, and a low distillation residue above 355°C. Lignite-tar creosote has been produced in relatively small quantities, and has been used almost entirely in mixtures with coal-tar creosote or in creosote-petroleum mixtures.

Coal-tar creosote (high temperature, bituminous) is composed of many organic chemical compounds of varying amounts. Most of these compounds belong to one or another of the three major groups of compounds present in coal-tar creosotes. The tar acids (not acids as commonly thought of) include various phenols, cresols, xylenols, and naphthols, all of which are toxic. The tar bases include pyridines, quinolines, and acridines, most of which are toxic. The hydrocarbons, which make up most of the volume of coal-tar creosotes, include benzene, toluene, xylene, naphthalene, acenaphthalene, penanthrene, anthracene, and fluorene. Specifications for coal-tar creosotes cannot name the various chemical compounds or designate the proportions of each that should be present. Instead, they stipulate that the preservative shall be a derivative of coal-tar, provide definite restrictions as to its specific gravity and its distillation range, and carefully limit the amounts of undesirable impurities it may contain. The various Federal Specifications are similar in these respects to those of the AWPA.

5.2.2.1.3 Creosote Solutions. The American Wood Preservers Association (AWPA) publishes eleven standards pertaining to preservatives and solvents for preservatives. Of these eleven, seven involve creosote as either the single preservative or as one of two preservatives in a creosote solution.

(1) Creosote-Petroleum Solutions. AWPA Standard P3 requires that the treating solution contain at least 50% creosote meeting AWPA Standard P1. The principal use of this solution has been for the preservative treatment of railroad crossties. Rock ballast normally supports the crossties above the soil and provides for good drainage. The heavy petroleum helps to retain within the wood some of the more volatile and leachable creosote constituents; and it helps to provide weather-proofing and dimensional stability. These solutions have been the choice of various railroads for many years. However, creosote-coal tar solutions can be used for crosstie treatment and can perform at least as well.

(2) Creosote-Coal Tar Solutions. Coal tar in a crosstie will perform physically as will a heavy petroleum oil, and it adds some chemical protection. Various creosote-coal tar solutions have been used for the treatment of crossties, utility poles, and bridge timbers and piles. Some railroads that had traditionally required creosote-oil solutions were easily convinced of the advantages of creosote-coal tar solutions when the price of petroleum increased sharply in the early 1970's. AWPA Standard P2 defines four grades of solutions ranging from 20% to 50% coal tar in creosote. Standard P12 defines a creosote-coal tar solution intended for piling to be driven in coastal waters.

(3) Creosote-Pentachlorophenol Solution. The AWPA Standard P11 defines a creosote solution which has a minimum of 2% pentachlorophenol. This is used primarily for the treatment of utility poles to increase decay resistance in the high-hazard groundline area.

5.2.2.2 Oil-Borne Preservatives. Of all of the oil-soluble materials which may be used for the preservative treatment of wood, four are recognized by the AWPA in its Standard P8: Pentachlorophenol, Copper Naphthenate, Copper-8-Quinolinolate, and Tributyltin Oxide. These can be used in oil solutions, sometimes with special auxiliary solvents, for the treatment of wood. But these preservatives may also be used with solvents that are definitely not "oils" in the common, every-day meaning of the word. Any discussion of the highly useful "oil-borne" preservatives should begin with some explanations of the solvents used.

5.2.2.2.1 Solvents for Oil-Borne Preservative. A considerable variety of solvents may be used for preservatives packaged for over-the-counter sales or formulated for dip-treatment or vacuum treatments. Those for use in the pressure-treating of wood are specified in AWPA Standard P9. As not all are "oils" but all are hydrocarbons, they are so named.

(1) Hydrocarbon Solvent Type A. "for preparing solutions of oil-borne preservatives such as pentachlorophenol and copper naphthenate shall be composed of petroleum distillates and co-solvents provided that the blended solvent meets the following requirements..." This is the solvent type used for the treatment of wood where paintability, color, and odor are not real problems. Volatility of the solvent may be quite low, and so it can provide some degree of "weather proofing" of the treated wood. Co-solvents may be used with Type A to help assure complete solution of the preservative throughout the treating cycle.

(2) Hydrocarbon Solvent Type C. This is a light petroleum solvent intended for production of reasonably dry and clean wood. Auxiliary solvents must be such that they will not cause "blooming" (surface deposits of preservative) during the drying of the treated wood.

(3) Hydrocarbon Solvent Type B (Volatile Petroleum Solvent--LPG). "for preparing solutions of pentachlorophenol, copper naphthenate, and copper-8-quinolinolate..." The letters "LPG" stand for "liquified petroleum gas." This is the "Cellon" treatment developed by the Koppers Company in the early 1950's. The solvent may have an auxiliary solvent added; and water-repellent materials may also be used. Almost 100% of the LPG is removed from the wood during the treating cycle and is recovered for reuse. This treatment can leave the wood very clean and dry and with the appearance of having not been treated. The LPG is highly flammable, and the vapors are explosive. But while this can cause a problem at the treating plant, there is no problem with the treated wood.

(4) Hydrocarbon Solvent Type D (Chlorinated Hydrocarbon Solvent--Inhibited Grade of Methylene Chloride). "for preparing solutions of pentachlorophenol." This is much like the Type B, or LPG solvent in that it is recovered during the treating cycle, and the wood is clean and appears to be untreated. This treating process was developed by the Dow Chemical Company and is often referred to as "the Dow process." For the users of pentachlorophenol-treated

wood, solvent types B and D are equivalent. However, there is a difference at the treating plant as the methylene chloride is non-flammable.

5.2.2.2.2 Preservatives for Hydrocarbon Solvents. The American Wood Preservers Association (AWPA) in its Standard P8, recognizes only four "oil-borne" preservatives. There are others which range from just fair to very effective but which for any one or more various good reasons are not in commercial use. Near the turn of the century, numerous materials which were both toxic and reasonably available were tested as wood preservatives. These were mostly water-soluble metallic salts and oil-soluble organo-metallic compounds. Only one of the early oil-soluble materials remains in commercial use today. That is copper naphthenate, and very little of this is used. By the early 1940s, the Federal Government was performing true research studies on wood preservatives in contrast to the directly empirical testing that had been standard procedure. The most valuable compound to result from the research was pentachlorophenol. Empirical testing, which can often open doors for pure research, has been continuing; and a great many materials have been tested. The search today is not for just an effective preservative available at a reasonably low cost, but for one which will create no environmental insult while performing its intended function. Fortunately, the four oil-borne preservatives in commercial use today are all environmentally safe when properly selected and used.

(1) Pentachlorophenol. The most popular of the chlorinated phenols is pentachlorophenol. It is a crystalline chemical compound formed by the reaction of chlorine and phenol under controlled conditions. It can be irritating to the skin and mucous membranes of some sensitive people; but finished wooden products treated with this preservative produce no hazard. Pentachlorophenol is completely chlorinated phenol. Tetrachlorophenol has one less chlorine atom in the molecule. The tetra is generally less effective in controlling decay fungi than is penta, but it is a little more effective against various mold fungi. Some tetra is formed in the production of penta, and this has been considered to be good. However, various other compounds have been formed, and some of these present hazards. A new process for production of penta provides a clean and environmentally safe compound which is still a very effective wood preservative.

Pentachlorophenol is not only the most widely used oil-borne preservative, but in recent years it has accounted for approximately 70% of all solid preservation including all of the water-borne salts. It is used in all four of the hydrocarbon solvent types previously discussed (5.2.2.2.1), and in creosote. Wood treated with penta in either the LPG solvent or in methylene chloride can be so clean in appearance that chemical stains are needed to show penetration depth. It is used for vacuum treatment of millwork, as well as for dip treatment and in-place treatment by brushing and spraying. It is sold in bodied or grease-type formulations for surface application. It is never used to treat wood for use in salt water.

(2) Copper Naphthenate. This is usually spoken of in the singular, but in reality is plural. Copper naphthenates are dark green, waxy materials which have slightly pronounced odors. These are mixtures of several copper naphthenates. Oil solutions have been used for many years, chiefly for brush, spray, or dip treatments for wood, fabrics, and cordage. For surface treatments of wood, oil solutions are usually used at from 10% to 30% (1% to 3%

copper). When used for impregnation treatments, it is usually used at a strength of not less than 5% (0.5% copper). Wood treated with this material will tend to be green, and may not be adaptable to transparent finishes or paints. As the various copper naphthenates produced from the seven (7) different naphthenic acids do not have the same toxicity to decay fungi, AWPA Standard P8 attempts to sharply limit variations in effectiveness. It requires that "The naphthenic acid used in the manufacture of copper napthenate shall be of the group of cyclopentane carboxylic acids occurring in petroleum and shall have an acid number of not less than 180, on an oil-free basis" "The copper naphthenate concentrate used to prepare wood-preserving solutions shall have not less than 6 percent nor more than 8 percent copper in the form of copper naphthenate." However, it must be noted that these requirements in no way call for a standardized copper naphthenate because of the variety of "cyclopentane carboxylic acids." AWPA Standards A3 and A5 provide tests for penetration and retention of copper; but none of the commodity standards now include the use of copper naphthenate treatment.

(3) Solubilized Copper-8-Quinolinolate. This preservative has an equal amount of nickel-2-ethylhexoate, and is 1.8% each copper and nickel as metals. It is soluble in the aliphatic and aromatic solvents which comply with AWPA standards. This is not a good preservative for use in continuing ground or water contact. However, it has a reasonably low human toxicity, and so is the only preservative for use for woods to be in frequent or continuing contact with human foods. It is used primarily for wood for fruit and vegetable-picking boxes and for wood for construction of cold storage rooms.

(4) Bis(Tri-n-Butyltin) Oxide. This preservative has been in limited use in Europe for a number of years but is not yet widely used in America. It is a member of a family of compounds many of which are too dangerous to consider as preservatives. This is one of the safest of these from the standpoint of human toxicity; yet it is so toxic to fungi and to insects that very small amounts can be satisfactorily used, and the treated wood (for indoor exposure) has a lower human toxicity than even wood treated with pentachlorophenol. AWPA Standard C29 covers the use of this preservative for the treatment of lumber to be used for the harvesting, storage and transportation of foodstuffs. The scope of the treatment includes the interior areas of refrigerator and box cars, food processing plants and warehouses, greenhouses and milkhouses, fruit, vegetable and grain storage and harvesting containers which require a low human toxicity fungicide.

5.2.2.3 <u>Water-Borne Preservatives</u>. Many hundreds of chemical compounds and even more hundreds of mixtures of compounds have been tested as "water-borne" wood preservatives. Some were ineffective. Some were excessively expensive. Some were so highly toxic that they would pose a continuing threat to all who treated or used the wood. Some are not permanent, even though leaching very slowly. Some pose the threat of causing highly detrimental environmental imbalance under some use conditions. Environmental hazard is generally related to both the toxicity and the leachability; for no matter how toxic a compound is, if it is irreversibly bound to the wood fibers it does not separately enter the environment, and within the wood will prohibit damage by decay fungi, insects and marine borers. Of all of those that have been tested and have been used commercially to some extent, only seven remain in recognizable commercial use, and three of these are nearly identical. Two of the seven will leach from the wood to the extent that they are not recommended for direct ground or water contact. One leaches but very little, and while recommended for above-ground use at approximately the same retention as the non-leaching salts, it must be used at higher retentions for ground or water contact. Only two water-borne salt preservatives are generally recognized as completely non-leaching. One of these is described in AWPA Standard P5 as three different preservatives.

(1) CZC--Chromated Zinc Chloride. AWPA Commodity Standards permit this water-borne salt for treatment of millwork, lumber and plywood for above ground use. It is a mixture of a zinc salt (e.g. zinc chloride) and hexavalent chromium (e.g. chromium trioxide, sodium dichromate) in an acid solution (pH limits 2.8-4.0). Its annual use represents only about 0.5% of all solid wood preservatives.

(2) FCAP--Fluor Chrome Arsenate Phenol. This treatment is sold under the trade names: (a) Osmosalts (Osmosar) (b) Tanalith (c) Wolman Salts FCAP, (d) Wolman Salts FMP. It contains Fluorides (e.g. sodium or potassium fluoride), Hexavalent Chromium (e.g. sodium or potassium chromate or dichromate), Pentavalent Arsenic (e.g. sodium arsenate) and Dinitrophenol. It is used at a pH range of 5.5-7.8 and so causes no acid damage to the wood. The annual use of FCAP represents about 2.5% of all solid wood preservatives. AWPA Commodity Standards permit the use of this preservative for treatment of millwork, lumber and plywood for above-ground use. This is considered to be an excellent preservative for pier and bridge decking and timbers as it has a tendency to slowly migrate deeper into the wood from the initial treated zone and so to minimize decay in checks.

(3) ACC-Acid Copper Chromate. The tradename for ACC is Celcure. It consists of bivalent Copper (e.g. copper sulfate) and hexavalent Chromium (e.g. sodium or Potassium DiChromate or Chromium trioxide). It is used in an acid solution at a pH range of 2.0-3.9. Like FCAP, its annual use represents about 2.5% of all solid preservatives. AWPA Commodity Standards permit ACC for treatment of lumber, millwork, plywood, and posts. For some above-ground uses, higher ACC retentions are required than for the non-leaching ACA and CCA. Where ground contact is permitted, still higher retentions are required.

(4) ACA--Ammoniacal Copper Arsenite. The tradename for this material is Chemonite. It consists of bivalent Copper (e.g. cupric hydroxide) and trivalent Arsenic (e.g. arsenic trioxide) in a solution of Ammonia (NH_3) in water. There is no acid in the solution. It is completely non-leaching after a short drying or curing period following treatment. It is price-competitive with other materials; and it is used for a very wide range of commodities. It will not leach, not even in salt water.

(5) CCA--Chromated Copper Arsenate. There are three forms of this preservative. Each has nearly the same amount of Copper. The greatest differences are that type "A" is heavy on the Chromium and light on the Arsenic, type "B" is light on the chromium and heavy on the arsenic, and type "C" is a reasonable balance between "A" and "B" on both arsenic and chromium. There have been many technical papers on these materials presented at annual meetings of the American Wood Preservers Association. These have not all been in agreement as to the relative qualities or the three forms of CCA. Enough data have been presented to show that type "A" contains more chromium than is effectively used as a biocide and that type "A" could benefit from a little

more arsenic. There is evidence that type "B" could benefit from more chromium, and that some of the arsenic may leach from the wood in continuing salt water exposure. If it is true that a very slight amount of arsenic can leach from wood treated with CCA type "B" in salt-water exposure, this is all that can leach from wood treated with any one type of CCA, provided that the treated wood has had a chance to dry, or cure, prior to exposure. Leaching of Arsenic from CCA type "B"-treated wood is questionable in light of inadequate data on curing time.

Anyone planning to use CCA-treated wood in salt water where marine borers are active should expect to lose the piling to marine borer attack if the piles are driven prior to thorough drying to curing. The metallic salts will leach out under these conditions. After once drying, the salts have formed metallic complexes that cannot leach from the wood, and they can create no harm to the environment. CCA type "A" has the following tradenames: (a) Green salt, and (b) Langwood. CCA type "B" is known as: (a) Boliden CCA, (b) Koppers CCA-B, and (c) Osmose K-33. CCA type "C" is known as: (a) Chrom-Ar-Cu (CCA), (b) Wolman CCA, and (c) Wolmanac CCA.

5.2.2.4 Bodied Preservatives for In-Place Treatment. On-the-job applications of preservatives are often needed where pressure-treated wood must be cut and where this exposes untreated interior wood. Where a slow diffusion to depth is needed, liquids are often unsatisfactory, particularly on vertical surfaces. Bodied or thickened preservatives will often leave wood unpaintable; but for many exposure conditions, paintability is unimportant. Some of the earliest bodied preservatives for use on exposed wood surfaces above water were mixtures of tar and creosote. Some must be applied hot, but others can be trowelled onto the wood cold. Many different types of mixtures have been made and marketed. Some are water-soluble pastes of metallic salts. Some are tar-creosote mixtures with metallic compounds added. Pentachlorophenol has been used in most brands of bodied preservatives marketed since the mid-1950s. Most of the formulations of penta have been greases or invert emulsions. "Penta grease" formulations were extensively tested by the U. S. Forest Service for application to exposed heavy-timber joints such as those found on waterfront structures. Application of such materials by caulking gun along all edges of all above-water joints is recommended. Most of these greases have a tendency to "creep" and so to penetrate joints and to coat and penetrate the cut surfaces of the joints. Early applications can add several years of life to the wooden structural members.

SECTION 5.3 TREATING PROCESSES

Various approaches have been taken to the penetration of wood by preservatives. Most woods that can be preservatively treated can be penetrated by some preservative process involving slow diffusion. However, this generally is uneconomical for large-scale production; and it is effective with only a few species, and then only when liquids, pastes or greases are used which are more or less fluid under ambient temperatures and humidity conditions. The vast majority of preservative-treated wood used in the United States is treated by pressure processes though some is commercially treated by vacuum processes or steeping.

5.3.1 PRESSURE TREATMENT. Wood that still contains natural moisture, above the fiber saturation point, or moisture later acquired, must have most of that moisture removed in order that preservatives can be introduced. Heating the wood is often required as part of the pre-treatment conditioning. Conditioning may begin considerably in advance of the beginning of the treating process and outside of the treating cylinder, or it may begin as part of the treating cycle.

5.3.1.1 Conditioning the Wood for Treatment. As previously explained (5.1.2.2) some woods are incised to permit penetration by preservatives. Other than incising, and other than air-seasoning and kiln-drying, the conditioning of wood for treatment takes place in the treating cylinder as early steps in the treating cycle. Like kiln-drying, the in-cylinder conditioning processes use heat, but in these processes the heat serves not only to reduce the moisture content, but also to warm the wood to depth to more readily accept preservative penetration. The six standard conditioning methods are:

(1) Air Seasoning. Depending on the geographical location, on the season of the year, and on the wood species and dimensions, from one to 16 months may be required for air seasoning to prepare wood for treatment. This should always be considered when planning procurement of large dimension materials. Federal Specification TT-W-571 requires that "green material shall be adequately seasoned or conditioned before impregnation with preservatives." The American Wood Preservers Association Standard M1 states that "When circumstances permit, material should be air-seasoned. When there is not sufficient time for proper air-seasoning, or in cases of large material which in some localities during all seasons of the year will not air-season successfully without deterioration, artificial conditioning should be used." Standard M1 then continues for four more paragraphs explaining proper air seasoning procedures and providing guidance on time periods required for air seasoning various species.

(2) Kiln-Drying. This is a process of drying wood in a kiln or oven. Kilns designed for drying wood provide for the movement of warm air past the wood to continually remove moisture at a constant rate. If the species of wood, its dimensions, its initial moisture content, and its loading configuration remain the same, the time required for drying to a given moisture content depends on air temperature and air movement; and these are both controlled. Most modern kilns are designed to permit high temperature and high volume air movement for the high-speed drying of small dimension lumber. Such material will quickly lose its moisture and then be removed from the heat of the kiln. With larger dimension material, more time is required to move larger volumes of water further through the wood. Long exposures to high temperatures cause loss of strength, or embrittlement, as well as produce visible seasoning degrade. The embrittlement of wood due to pre-treatment and treatment procedures takes on particular significance with large diameter piling which might break easily on impact. The amount of damage done is a function of the wood species and of the temperature and time of kilning. While upper temperature and time limits are cited in AWPA Standards for in-cylinder conditioning of wood, there are no such limitations placed on kiln drying.

(3) Steaming and Vacuum. Steaming is used to condition some woods for preservative treatment. The interior of the wood must be as warm as the preservative needs to be to flow properly. Steaming is used not only to warm wood, but also to help remove moisture prior to treatment. However, a vacuum must

be used to remove the moisture that the steaming prepares for release. During the steaming period, a temperature gradient is set up from the surface to the interior of the wood and the temperature at any given distance from the surface will depend upon a number of variables such as steam temperature, length of steaming period, cross-sectional dimensions, and density of the wood.

In applying the steaming-and-vacuum process, the charge of timber is first steamed for several hours in the treating cylinder, the time depending on the size of the timber and the steam temperature. At the end of the steaming period, the steam pressure is released and a vacuum is applied as quickly as possible in order to use the maximum amount of heat available for moisture removal. When the steaming is discontinued and a vacuum is applied, the boiling point is lowered and part of the water in the wood, especially that near the surface, is forced out mechanically by the steam generated in the wood cells or is evaporated during the vacuum period.

AWPA Standard M1 states that "the conditioning of material in steam is particularly adapted for woods which do not check materially, split or warp when subjected to high temperatures, such as southern yellow pine. Steaming periods should be no longer than necessary to assure the required penetration, and in no case should they exceed that allowed in the specifications for individual species. Steaming is applied to Douglas fir and to hardwoods only when the material is to be given water-borne preservative treatment."

(4) Heating in Preservative. Wood to be treated with creosote or oil-borne preservatives can be partly conditioned for pressure treatment by being heated in the preservative. This technique is used primarily for conditioning Douglas fir and hardwoods. However, these woods may split, check, or warp if subjected to high temperatures during the seasoning process. To reduce the temperatures in the wood, and to remove moisture, vacuum may be applied during heating. This heating in "oil" under vacuum is known as the "Boulton process" or as "boultonizing." It was first used in England where it was patented by S. B. Boulton in 1879. A U.S. patent was issued in 1881. Sixty one years later, a U.S. patent was granted on the "vapor-drying process."

(5) Vapor-Drying. This conditioning method is a little like steam conditioning; but in place of water vapor it uses vapors of organic liquids. Evaporation of water from the green wood during the heating period tends to keep its temperature down sufficiently to prevent detrimental effects from the temperatures of the vapors of the organic liquids. The time required to condition the timbers for treatment is relatively short because the vapors can be maintained at a fairly high temperature while the water is being removed; deep checking is considerably less than in air-seasoned wood, especially in species like red oak that have tendency to develop large checks; it gives good results both in removing moisture and in heating the wood to a favorable treating temperature.

5.3.1.2 Commercial Processes; and Steps in Treatment. The most thorough and effective methods of treating wood with preservatives are those in which pressure is employed. There are a number of pressure processes, all of which employ the same general principles, but which differ in the details of application and in the overall results. The timbers to be treated are loaded on specially designed tramcars which are moved on steel tracks from the yard into large cylinders or retorts. These cylinders are usually from 6 to 9 feet in diameter and up to 150 feet or more in length, and are built to withstand working pressures of up to 250 pounds per square inch. After the cylinder door is bolted closed, the preservative is admitted and the pressure applied until the required absorption is obtained. Two principal types of pressure treatments are used: the full-cell, and the empty-cell processes. There is frequently some misunderstanding as to the relative merits of these processes. The effectiveness of treatment depends primarily upon the preservative and upon the penetration and retention, and not upon the process except as the process used may effect the penetration and retention desired and specified. The terms "full-cell" and "empty-cell," as applied to treating processes, tend to be misleading, as the full-cell processes do not leave all the cells completely full, nor do the empty-cell processes leave them empty. In selecting the treating process, the object in all cases should be to obtain the desired penetration and retention with the preservative chemical selected.

(1) Full-Cell Processes. Various full-cell processes for treating wood have been devised. Those in common usage today are all based upon the Bethell process which originally was used for creosote treatments. After the treating cylinder has been bolted closed, a preliminary vacuum is first applied to remove as much air as is practicable from the wood cells. The preservative is then admitted into the treating cylinder. After the cylinder has been filled with solution, pressure is applied until the desired absorption is obtained. After the preservative has been drained, a final vacuum may be applied to free the charge of dripping preservative solution. This system is usually followed whether or not the charge is given a preliminary steaming-and-vacuum treatment, the preservative being injected immediately following the final vacuum after steaming. If the charge is conditioned by the Boulton process (boiling under vacuum), the space at the top of the tank is filled and pressure applied just as soon as the processing treatment is completed. The pressures used in treating may range up to 250 psi (AWPA standards permit this much pressure only for treating oak) and solution temperatures, for conditioning and final steaming, are permitted to be as high as 250°F for a few items. Treatment with water-borne salts normally requires lower temperatures than those usually used for treatment with creosote and with oil solution.

(2) Empty-Cell Processes. The empty-cell treatment processes differ in results from the full-cell processes in that part of the preservative solution forced into the wood under pressure is subsequently recovered so that the interior of the wood cells tend to be coated with the solution rather than filled with it. This is required when maximum penetration of the wood with preservative and limited retention of the solvent are desired. There are three currently accepted processes: the Lowry, the Rueping, and the Solvent Recovery; all of which depend upon compressed air within the wood to force part of the solution out of the cell cavities after the pressure has been released.

(a) Lowry Process. In the Lowry process, which is also known as the "empty-cell process without initial air," the preservative is admitted to the treating cylinder at atmospheric pressure. When the cylinder is filled, pressure is applied and the preservative is forced into the wood against the air originally in the cell cavities. After the required absorption has been obtained, pressure is released, a vacuum drawn, and the air under pressure in the wood forces out part of the preservative absorbed during the pressure period.

(b) Rueping Process. In this process, which is also known as the "empty-cell process with initial air," air pressure is built up within the cylinder before the preservative solution is injected, and this air pressure is maintained while the cylinder is filled. In some woods resistant to treatment, the air under pressure may penetrate only a short distance from the surface; while in woods that are fairly pervious to the penetration of air, such as the sapwood of many species, the air pressure will be developed in a larger percentage of the cells. The recovery of preservative can be greater with the Rueping than with the Lowery process, so greater penetrations at equal retentions are possible.

(c) Solvent Recovery Process. This process is similar to the Rueping process up to the point at which the preservative solution is drained from the tank, except in that light weight and highly volatile solvents are used for the preservative. In the Solvent Recovery process, fresh solvent is pumped into the treating cylinders to a level at which it covers the heating coils at the bottom of the tank but is still below the lowest level of the wood charge. As the solvent is heated it vaporizes, and in condensing on the cooler wood, it washes off excess preservative from the surface. The vapor gradually heats the wood; and the solvent within the wood is evaporated. The final vacuum is applied after this vapor-drying step in the process. This treatment results in wood which is impregnated with the preservative chemical, but is almost completely free of all solvent. Wood treated in this way is clean, dry, and often paintable. Another advantage of this process is that the preservative chemicals will stay where placed in the wood. Pentachlorophenol is often preferred to the by-product oils because it is not inherently unpaintable. When heavy oil solvents are used with pentachlorophenol, the wood is rendered unpaintable by the oils. If light-weight, volatile solvents, such as xylene or mineral spirits, are used with pressure processes other than the Solvent Recovery process, the solvent will slowly evaporate from the surface, and so will cause the pentachlorophenol to migrate to the surface rather than leaving it where placed.

(d) LPG Process. This process was developed and patented by the Koppers Company, and has been used under the trade name "Cellon Process" (see 5.2.2.2.1.(3)). Wood treated with pentachlorophenol or Copper-8-quinolinolate by the LPG process is clean, dry, odor-free, and paintable after treatment. It may include the use of additional materials to provide some water repellency to the treated wood when this is specified.

(e) Methylene Chloride Process. This process was developed by the Dow Chemical Company. It is the newest of the treating processes in commercial use. It uses methylene chloride as the solvent (see 5.2.2.2.1(4)); and like the LPG treatment, it leaves the wood clean, dry, odor-free, and paintable.

(3) Dual-Treatment Process. This consists of two successive (dual) treatments with different preservatives. After initial conditioning, the wood is given full-cell treatment with a non-leaching water-borne preservative (ACA or CCA). It is again seasoned to remove water and to condition the wood to receive a full-cell treatment with creosote or a creosote-coal tar solution.

5.3.2 NON-PRESSURE TREATING METHODS

5.3.2.1 Types of Non-Pressure Treatments.

(1) Tank Type, or Submersion Treatments. There are four generally recognized submersion or tank-type preservation processes that do not involve the use of pressure above normal atmospheric pressure. The penetrations obtainable depend upon a number of variable factors. These four processes are herein discussed in the order of increasing expense of plant construction, operation, and maintenance, and in the order of decreasing general usefulness.

(a) Dipping Process. In this process, the wood is dipped in preservative solutions for very limited periods of time. Neither the retention nor penetration are suitable for prolonged preservation under severe exposure conditions, but the preservative dipping of certain items should be considered as an expected and even required part of the preventive maintenance program at certain types of activities. This type of treatment, when employing the water-repellent preservative meeting the requirements of Federal Specification TT-W-572, is ideally suited for the inexpensive preservation of wooden items such as pallets and crates exposed to conditions of outdoor use; of materials such as lumber, pallets, tool handles, ladders, etc., during storage; and of lumber for use under only moderate conditions of exposure in structures where it is to be further protected by painting, such as siding where protection is needed against dry-wood termites.

(b) Steeping Process. The steeping process, often referred to as the "cold-soaking process" can be and often is the simplest and most versatile preservation process employing tanks to hold both the wood and the preservative solution. The penetrations and retentions are not equal to those obtainable with the hot-cold process, but are superior to those of quick dips. This process involves simply the prolonged soaking of wood in preservative solutions at atmospheric pressures and temperatures. Both water-borne and oil-borne solutions can be used. The time required for treatment will depend upon the type of wood treated, upon the moisture content of the wood, upon atmospheric temperatures, and upon the solvent and preservative chemical used. If 5% pentachlorophenol solutions in light weight and volatile solvents are used at moderate temperatures, and if the wood is reasonably dry (approximately 20% or below), items such as pallets, window screen frames, window frames, sash and sills, etc., will receive adequate protection with a 3-minute dip. In a 3-minute dip, wood will absorb approximately 1/3 as much material as with a 24-hour immersion. During the first 2-hour period, at 80°F, approximately 2/3 as much will be absorbed as during a 24-hour period. Absorption proceeds slowly after the first two hours, never approaching that obtainable with the hot-cold process.

(c) Hot-Cold Process. The hot-cold process is probably the most effective of the non-pressure processes for some large-dimension materials of some species of wood, and the thoroughness of the treatment obtainable with heavy oil-borne preservatives most nearly approaches that of the pressure processes. As the name implies, the process consists essentially of heating the wood and then covering it with a cold preservative solution. A number of variations are possible. One technique consists of heating the wood in the preservative solutions or in an oil bath, then quickly transferring it to a tank of cold solution and allowing it to remain there for a few hours. Another technique involves heating the wood in the tank, and quickly draining the hot solution and replacing it with a cold solution. The simplest technique involves heating the solution, then shutting off the heat at the proper time, and allowing the wood and the preservative solution to cool together.

(d) Vacuum Process. This process consists of the use of a vacuum to lower the air pressure within the wood cells to below that of atmospheric air pressure. Either before or just after the vacuum is created, the wood is covered with the preservative solution. When the vacuum is released, the preservative is forced into the wood by the atmospheric air pressure. With easily treatable wood, and with preservative solutions of low viscosity, appreciable absorption can be obtained in this way. This process, however, permits very little of the control over either penetration or retention that the pressure processes allow. The vacuum tank, though not as expensive as a pressure cylinder, must be made of heavy-gauge metal and must have a tightly fitting lid. This is the process most used by the sash-and-trim industry to provide both dimensional stability (through water repellency) and protection against decay. Much of the sash and trim in the United States is made of ponderosa pine; and this species very readily accepts treatment with TT-W-572 material (water-repellent pentachlorophenol in a volatile solvent). The National Woodwork Manufacturers Association assures uniformity of quality of treatment through use of "NWMA Industry Standard for Water-Repellent Preservative Non-Pressure Treatment for Millwork" which defines methods and results. The NWMA also provides for test methods, a licensing program, a seal of approval, and a certificate of approval.

(2) Non-Tank (Non-Submersion) Treatments. The non-submersion wood preserving processes, or those not employing tanks of preservative solutions into which the wood is placed, are normally limited to the treatment of structural wood in place where they may be of considerable value. They may be strictly surface treatments, or they may involve relatively deep penetration through slow diffusion. Because of the handling and labor costs involved, the surface treatments are normally as expensive as the more effective pressure treatments, while the slower diffusion treatments are so expensive as to be applicable only to wood which cannot be treated by submersion. They are herein discussed primarily from the standpoint of the treatment techniques employed rather than from the penetration obtainable.

(a) Brushing and Spraying. Exposed and reasonably dry wood in place can be easily treated by brushed-on applications of preservatives such as pentachlorophenol in readily penetrating volatile solvents such as mineral spirits. This type of treatment is often required during repairs to structures necessitated by insect and fungus damage. All wood remaining in place and adjacent to new and treated wood used as replacement for damaged wood should be treated. Whenever wooden siding and trim are to be repaired, consideration should be given to brush treatments with wood preservatives if pressure treatment is not required. As the preservative solutions will not readily penetrate existing coats of paint, they are most satisfactorily used where the paint is missing due to either biological or moisture damage or because it has been removed to expose a paintable surface. An ideally suitable material for this type of treatment is the water-repellent 5% pentachlorophenol meeting Federal Specification TT-W-572. The use of this material before painting will often obviate the need for a primer coat of paint.

The spraying of preservatives on surfaces will prove as satisfactory from the standpoint of preservation as will brushing. Under some conditions, it will be more advantageous. If considerable amounts of surface are to be treated, the use of paint-spraying equipment may be required. With both brushing and spraying, each repeat treatment should be applied after the solution of the preceding treatment has been absorbed, and before the solution has evaporated. This is the only way by which satisfactory penetration can be obtained.

(b) Diffusion Treatments. The bodied preservative, or preservatives greases, are previously described (5.2.2.4). Because they will adhere to vertical as well as to horizontal surfaces, and because most will "creep" into joints and diffuse over surfaces as well as penetrate surfaces and diffuse to depth, they are used on cut surfaces where painting will not be required. At the time of construction or rehabilitation of the above-water portions of waterfront structures and of other structures with exposed timbers, all cut surfaces of pressure-treated wood should be liberally coated with bodied preservatives. All joints involving cut surfaces should be given treatment by the application of a "bead" of the grease applied to the edge of the joint to permit diffusion down into the joint, and over and into the surfaces. This also applies, of course, to cut ends which are not at joints. This preventive maintenance should be planned for five year intervals for all exposed, non-painted structural members. Utility pole maintenance programs employ bodied preservatives for the ground-line treatment of poles in place. The preservative formulations are held against the pole by sheet plastic "bandages" which prevent absorption by the soil while they slowly diffuse to depth into the decay-hazard area of the pole.

(c) Wood Fumigation. This differs from structural fumigation which is the fumigation of a structure (a more complex structure than a utility pole, which is a "ground structure") to control pests of items or materials within the structure or for control of structural pests such as dry-wood termites. Structural fumigation usually requires covering the structure with a gas-tight tarpaulin to retain the fumigant for the required time. In contrast to this, wood fumigation is quite simple. It is the fumigation of individual pieces of wood, such as poles, piles and timbers by the introduction of liquid fumigants into holes bored into the wood and then plugged to retain the fumigant in the wood. The fumigant slowly diffuses through the wood as a gas to kill decay fungi at depths normally beyond the reach of liquid or grease-type preservatives. Some of the fumigants undergo chemical changes within the wood to deposit materials which remain toxic to fungi for prolonged periods. Wood fumigation techniques were developed at Oregon State University for protection of large Douglas fir transmission poles and have quickly gained wide acceptance. Research has proven these techniques to be generally applicable to piling and large timbers, and of value in protecting waterfront structures.

5.3.2.2 Limitations and Precautions for Non-Pressure Treatments. While properly applied non-pressure treatments for wood can greatly reduce maintenance costs, these treatments have very definite limitations, and certain precautions must be observed. The following comments are generally applicable to pre-installation treatment away from the area of wood use or at the work site and to on-site application for maintenance treatments of existing structures. While generally applicable, they are separately listed here for special emphasis. The safety precautions apply across the board.

(1) Pre-Installation Treatment Limitations

(a) Limit to wood for above-ground use. Non-pressure preservative treatments are generally unsatisfactory for the protection of wood to be placed in ground contact or in the water, and they should never be used in lieu of pressure treatment for such exposure. The single exception to this rule is the thermal process treatment of some thin sapwood poles for exposure in northern areas.

(b) Pre-Cut, Shape, and Bore. All cutting and boring must be done prior to pre-installation non-pressure preservative treatment. If not, what treatment is provided is probably wasted.

(c) Treat Only Dry Wood. Damp wood will not accept penetration by oil-borne materials.

(2) On-Site Treatment Requirements.

(a) Selection for Effectiveness and Longevity. When materials are selected for application to wood in existing structures, their effectiveness will be due in large part to their ability to be so applied that they have a very good chance to penetrate deeply into the wood. In connection with this must be considered the persistence of effectiveness provided. A fumigant may penetrate to greater depth than a penta-grease, but it will normally not be effective for as long a time.

(b) Selection for Cost of Materials and of Application. For almost any on-site treatment, labor costs will be greater than material costs. The use of hand caulking guns may permit faster application of grease-type preservatives than will a spatula, but in the long run, the spatula may be more cost effective due to buying materials in bulk. However, for large jobs, a pressurized grease gun with a long hose will be most economical.

(c) Appearance. For many structures, appearance will play no role in the selection of preservatives for on-site treatment. However, for some structures this will be an important consideration.

(3) Safety Precautions. All wood preservatives are, legally and factually, pesticides; and they are toxic in varying degrees to man. There are many people trained and certified in the use of this class of pesticides. Consult them. When wood preservatives are used, certain precautions are required.

(a) Ventilation. Concentrations of vapors of the volatile solvents used in most off-the-shelf penta solutions should be considered to be hazardous. The same precautions should apply here as apply to industrial solvents and paint thinners.

(b) Avoiding Skin Contact. The preservative formulations available to shops personnel will normally do little harm on a single contact other than to partially de-fat the skin. Repeated skin contact should be avoided. Repeated defatting of the skin can lead to serious dermatitis.

(c) Washing. Whenever any of the wood preservatives come into direct contact with the skin, the skin should be washed with soap and water.

(d) Special Sensitivity. Some people, after repeated skin contact with various organic compounds, will develop a high degree of sensitivity to the compounds and can not stay in an area where they are exposed to the vapors. This sensitivity may be expressed as violent sneezing in the presence of pentachlorophenol, or development of raised, red, tender blotches on exposed skin surfaces when in the presence of warm creosote, or any of a wide variety of symptoms.

(e) Environmental Protection. Care must always be exercised to prevent contamination of the environment with biocidal preservatives while protecting the wooden structures. This depends to some extent on the avoidance of spillage, but it is effected even more by the proper selection and application of materials.

CHAPTER 6. SELECTION OF TREATMENT FOR WOOD USE

PART 6.1 CONDITIONS LEADING TO WOOD DETERIORATION

The structure of wood and the usefulness of wood are explained in Chapter 2. The causes of wood deterioration are detailed in Chapter 3, and the exposure conditions which tend to invite biological deterioration are explained in Chapter 4. Chapter 5 speaks in detail of wood preservatives and treatment methods. With the background of these four chapters (2 through 5) preceding it, Chapter 6 will now provide guidance on the selection of preservative treatment for wood to be exposed in various ways to the most common destructive organisms. This chapter makes heavy use of referencing material from these previous chapters by paragraph number to avoid considerable repetition. The reader is urged to use this internal referencing provided for quick reviews of problem descriptions and treatment effectiveness when considering the selection of preservative-treated wood. In this treatment of subject matter, it has been necessary to first provide a brief review of climate and of structural pests and their interrelationships, and second to discuss situations of structural exposure. The economic impact of the choices is explained, and guidance is offered on the procurement of pressure-treated wood.

6.1.1 CLIMATE AND STRUCTURAL PESTS

Climate has a direct relationship to the distribution of some structural pests, and it has some influence on the destructiveness of most of them.

6.1.1.1 <u>Presence of Structural Pests and Severity of Attack.</u>

6.1.1.1.1 Decay Fungi. These plants can survive periods of severe cold as well as temperatures above those normal to man's environment (3.2.4.3). But, while they may be most destructive in areas of high humidity, they must have free moisture available to them in the wood or, in the case of water-conducting fungi, at a location near the structural wood (3.2.4.4). Climate, along with structural design, is important in the way it creates requirements for preservative treatment, but not just because of rainfall. Most, but not all, of the many sources of water in structures previously discussed are directly related to climate (Rainwater-4.1.2.1; Ground Moisture-4.1.2.2; Condensation-4.1.2.3; and Plumbing Leaks, Seepage, and Sprinklers-4.1.2.4).

All preservatives in commercial use have the potential for preventing most decay. However, there are some unusual exceptions such as utility poles treated with copper salts being destroyed in some areas by copper-tolerant fungi. In geographical areas where this or other unusual conditions exist, experience should determine which treatments to avoid. In general, the preservative and the treatment method should be selected on the basis of the suitability to the type of structure or structural component (to be discussed in 6.2.1) as well as for the protection provided.

6.1.1.1.2 Insects.

(1) Carpenter Bees and Ants. There are no specific preventive treatments for these wood-destroying hymenopterous insects (4.6.1), but any persistent pesticides will normally prevent all damage. The selection of preservative materials and methods can be based on factors other than relative effectiveness, such as appearance, environmental quality, and cost.

(2) Termites.

(a) Dry-Wood Termites (4.6.3.1). In most of the United States and its territories, the dry-wood termites are limited to those areas where the weather tends to remain both warm and humid throughout the year, though year-round temperature is more important than humidity. In the southwest the drywood termites are active in areas classed as arid and semi-arid. In the continental United States they are limited to the area including coastal portions of Southeastern and Gulf States (all of Florida) southern Texas and New Mexico, most of Arizona, and southern California and coastal California up to and past the San Francisco Bay area.

Any permanent insecticidal surface treatment can be satisfactory for protection if it provides a "clean" treatment. If a surface treatment, such as a dip treatment, is used, special care must be taken to assure on-the-job treatment of all field cuts. All wood should be treated, including siding and trim as well as principal structural timbers. Pressure treatment can, of course, be used. A clean oil-borne treatment or a water-borne salt treatment should be used. TBTO treatment is satisfactory. Even though pressure treatment is used, all cut ends of framing and other structural timbers should be given on-the-job treatment. Because of the importance of structural timbers and because they can check deeply after surface treatment, only pressure treatment of seasoned wood can assure protection.

(b) Subterranean Termites (4.6.4.1). Deep pressure treatments are generally satisfactory for main structural timbers and should be called for in subterranean termite damage areas if chemical soil treatment is not being used. For most structures that are to be inhabited, creosote and heavy oil solutions should be avoided even though treated timber will not be visible (5.2.1). Preservative treatments do not keep termites from building runways over the wood. If only the timbers resting on masonry foundations are treated, they can resist direct attack, but they will not keep timbers above them from being destroyed. The bridging-over of treated wood is of particular significance in large round or sawn items, as checking can expose untreated heartwood of thin-sapwood species. Such checks require in-place treatment.

(c) Carton-Building Termites. These are types of subterranean termites which build additional nests (subnests) above the soil. Depending on the species of termites that build them, these nests may be hidden within some part of the structure under attack, or they may be typically exposed to the weather. These carton-builders are generally much more quickly destructive where they are found than are other forms of termites, but their attack can be prevented by the use of pressure-treated wood. There have been reports that creosotes have been less effective than water-borne salts in stopping attack on utility poles. But in the thin-sapwood species of poles involved, checking exposes the large area of untreated heartwood. Regardless of the preservative used for initial treatment, the heartwood must be protected by supplemental treatment. Pole fumigation by injection of liquid fumigant into bored holes (5.3.2.1 (2)) has been effective, and it is later explained (7.5.3.2) as part of continuing pole maintenance programs.

(3) Beetles. Wood-destroying beetles and their life histories are thoroughly covered earlier (3.3.2).

(a) Powder-Post Beetles. Almost all species that can be called powder-post beetles place their eggs in the wood pores, though some that are given this name chew into the wood to prepare a place to oviposit. With both of these types, attack can be prevented by dip-treatment just as it can by painting. However, as some species attack freshly-cut timbers at the mills, dip-treatments may not provide sufficient penetration to eliminate unseen, early infestations. Pressure treatment can provide complete assurance of control as can fumigation followed by dip treatment.

(b) Powder-Post Borers. Dip treatment with permanent materials can be highly satisfactory for some roundheaded borers such as the Old House Borer which primarily attacks only dry wood; but others normally initiate attack in lumber mills and storage yards and would require the deep penetration of pressure treatment or fumigation followed by dip treatment for assurance of freedom from destruction.

(c) Other Beetles. In some parts of the country, attack on untreated wood by powder-post beetles and powder-post borers is to be expected a given amount of the time. This is generally not true with other wood destroying beetles, except for certain species in limited areas. Because of this, preservative treatment of wood as a preventive control for these other beetles is not recommended as a normal procedure.

(4) Insect Distinction. Some insects have very broad distribution. The housefly, Musca domestica, is found in most areas inhabited by man; and the oriental rat flea, Xenopsylla cheopis, is found almost everywhere the Norway rat and the roof rat are established. Often, a single insect species will be found to have a very limited geographical range. Some attack dry wood, some damp wood, some heartwood, and some sapwood. Some have species requirements. Some insects, such as subterranean termites, are found in all 15 U.S. climate zones (though no single termite species is found in them all), while the ranges for dry wood and damp wood termites are limited.

A zone map must be used with some judgement. The zones are intended to indicate those wood-destroying insects which will almost certainly be found in the proper ecological location in each zone. The lines drawn on paper do not prevent the movement of insects. They do not exclude a particular species from entering an arbitrarily demarcated area. If another insect is found damaging wood, those species in the adjoining zones should be considered. It should be remembered that many insects are good hitch hikers and are readily moved by commerce. Care should be taken to differentiate between well-established infestations and a few introduced individuals.

6.1.1.1.3 Marine Borers. All of the various types of marine borers, and the damage they cause under various conditions are detailed earlier (3.4), and the biological considerations for the planning of waterfront structures are also explained (4.7.1). Wood preservatives for marine borer control is briefly mentioned in 4.7.2.3 and more fully worded in 6.1.2.3.

(1) Cold-Water Harbors and Teredine Borers. In cold-water harbors, the crustacean borers such as Limnoria are often thought of as being of little importance because the species in such harbors are easily controlled by the preservative treatments used to control the mulluscan borers such as Teredo and Bankia. Treatment with a marine grade creosote or creosote-coal tar solution at 20 pounds retention (AWPB Standard MP-2, AWPA Standard C3, or Federal Specification TT-W-571) will provide protection against shipworms for many years as well as against any crustacean borers which may be present.

(2) Warm-Water Harbors that are Free of Pholads. The crustacean borer Limnoria tripunctata is now present in all of our warm-water harbors and in many of our temperate harbors. As our pollution-control efforts continue, this species is expected to occupy all of our temperate harbors. Where this species is active, the standard marine-grade creosote has failed to give protection. Either of two other treatments is required. One is the heavy salt treatment (2.5 lb/cu ft in outer assay zone) which will stop both Limnoria and shipworms (AWPB Standard MP-4, AWPA Standard C3, Federal Specification TT-W-571). The other is the dual treatment in which a salt treatment is 1 lb/cu ft is followed by a 20 lb/cu ft creosote treatment (5.3.1.2 (3)) (AWPB Standard Mp-1, AWPA Standard C3, Federal Specification TT-W-571).

(3) Warm-Water Harbors with Pholads. The pholads (3.4.2.3) are rock borers, some species of which will bore into wood as well as into rock. In some warm-water harbors, a heavy treatment with creosote or with creosote coal-tar solution is the best protection against this borer. But the pholads do not occur alone. Limnoria tripunctata is almost always present in waters in which pholads are destructive, and these crustaceans require the heavy salt treatment or the dual treatment. Because of this, the dual treatment should be specified for harbors where pholads attack wood.

6.1.1.2 Climate and Wood Deterioration. As previously mentioned (6.1.1.1.1 and 6.1.1.1.2), climate has a direct relationship to the distribution and to the destructiveness of insects that damage wood as well as to most sources of decay-supporting moisture in structures. For most exposed structural wood, climate is the most important single factor affecting the life of untreated wood, and therefore affecting the need for preservative treatment for exposed wood. Temperature and rainfall and relative humidity are all important in the destruction of wood. The weather averages are much more important to decay and insect damage than are the extremes, and so are the seasonal effects. In most studies of the effects of climate on the decay of structural wood, the effects of relative humidity have not been given sufficient consideration. This is important because the diurnal changes in relative humidity play an important part in the evaporation of moisture, in the length of time it remains on and in structural wood, and therefore in the overall decay hazard.

6.1.1.2.1 The Basis for Defining Types of Climate. Though relative humidity is a feature of climate important to wood protection, it is temperature and precipitation that come first to mind when man begins to define and classify climates typical of the world's various areas. It requires no science to begin a simple system for categorizing areas by their climates. Polar regions and high-mountain glaciers have much in common. The various types of deserts, though different, have in common their high temperatures and infrequent, if any, precipitation. Like the deserts, tropical rain forests wherever found share the features of high temperatures and heavy rainfall. In between the very cold areas on the one hand and the deserts and the rain forests on the other, are the temperate zones within which are found considerable variations in temperature, precipitation and humidity.

The measuring and recording of temperature and precipitation in many locations made possible the application of both art and science to the defining of types of climate and to the classification of terrestrial areas by their climate types. The first truly scientific system applied to the climates of the world was developed by Wladimir Koppen and first published in 1918. In his system of categorizing climates, Koppen used both temperature and precipitation to devise five primary types of climate having a total of eleven subtypes. Koppen continued to modify and expand this system until 1936; but it had inherent faults which were later overcome by others. For example, it placed the wet coastal range of the Pacific Northwest in the same category as semi-arid coastal southern California.

In 1931, C. Warren Thornthwaite published his newly developed system for classifying types of climate. Like Koppen, Thornthwaite considered simple temperature readings and precipitation values. But he added "temperature efficiency" and "precipitation effectiveness." These, with seasonal distribution of precipitation, are the basis of the Thornthwaite system. He used five humidity zones, six temperature zones, and four types of seasonal distribution of precipitation effectiveness. This provides a theoretically possible 120 climate types; but only 32 of all these actually exist as real climate types, and of these only 19 are found in the contiguous 48 States. Thorthwaite's "climatic provinces" represent a very close approximation to actual areas of decay hazard. When an adjustment is made for diurnal shifts in relative humidity in coastal areas, a map representing decay-hazard areas can be prepared which might be used in providing guidance on the protection of wood. However, there would be no logic in attempting to provide 19 different sets of recommendations for protecting wood from biodegradation.

It must be realized that all maps showing zones of climate are inherently inaccurate. Weather data is collected at, and recorded for discrete sites. A line drawn on a map to differentiate regions of climate will tell the user of the map that data from one or more weather stations on one side of the line differ from the data for stations on the other side of the line. The locations of the lines must be somewhat arbitrary except for locations where certain geographical features clearly define the separation of zones. An example of this would be mountains in coastal areas which have heavy precipitation on the seaward side and very little precipitation in the "rain shadow" on the other side. On a small map, no allowances can be made for differences in the "micro-climate" found in specific areas. For instance, cities almost always have higher winter temperatures than do nearby open areas except during heavy winds. Structures located on or very near zone lines would find that recommendations for both areas might be appropriate. Unless a well-known local anomaly exists, the recommendations for the greatest protective action should be taken.

6.1.1.2.2 Features of Climate and Wood Protection. Chapter 4 addressed the subject of various structural features and their potential for biodegradation. There now follows a series of discussions of various structures and structural elements and the types of protection required for each of them in the various climate zones, or Decay Hazard Zones (See Appendix II to determine your building's zone). Because these structures and structural elements differ greatly from one another, just as do the various types of climate, there can be no all-encompassing recommendations applicable to all structures in a single type of climate any more than there can be a single recommendation pertaining to a single structural element in all types of climate. In the following material, structural types and elements are discussed, and for each of these the recommendations applicable to protection in various types of climate are provided.

Some of the comments and recommendations that follow will speak of "high rainfall areas," of "wind-driven rain" and storms, and of "very cold" areas rather than speaking of one or several of the five basic Decay Hazard Zones. This is intentional, not oversight. It is done to make the application of these recommendations as simple and as easy as possible.

6.1.1.2.3 Some Useful Definitions. While the following definitions may seem somewhat arbitrary, they have been useful to many people for many years.

(1) Rainfall (including snow and ice).

(a) Low Rainfall Areas: Never over 20 inches of rain (or other precipitation equated to inches of rain) per year; and never over 10-12 inches in the "rainy season."

(b) High Rainfall Areas: Over 40 inches per year.

(c) Moderate Rainfall Areas: Between 20 and 40 inches of rain per year.

(2) Storms. These are of particular interest, as winds of over 40 mph drive rain deeply into relatively tight joints in walls and other structures.

(a) Cyclonic Storms: Rain (or other precipitation) and winds up to and above 75 mph. These are systems of winds with heavy rainfall circulating in a counterclockwise direction (northern hemisphere, clockwise in the southern hemisphere) about low pressure centers while the whole system advances across the globe.

(b) Hurricanes: These are a type of cyclonic storm. They are infrequent enough in any one location that they aren't considered a major source of water that wets wood in the interior of walls; but in those areas where other precautions are taken in designing for hurricane force winds, the effects of wind-driven water should also be considered in designs.

(c) Thunderstorms:

(i) Zone I (coastal central-south eastern United States) contains the area with weather stations recording an average of 70 or more days per year with thunderstorms (the New Orleans region and most of Florida).

(ii) Areas with stations recording averages of between 50 and 70 thunderstorm-days per year are almost all within Zones I and II of the Map of Decay Hazard Areas. A small area outside Zones I and II, and having 50 or more days per year with thunderstorms is a narrow band extending from south-central Wyoming through northwest to south-central Colorado, and into north-central New Mexico. This is mountainous land on the continental divide.

(iii) An area averaging less than ten thunderstorm days per year per recording station contains most of California, most of Washington, and the western half of Oregon.

(iv) Even in areas averaging only a few thunderstorms per year, it should be remembered that winds of over 40 mph drive rain deeply into structural joints. Winds developed by thunderstorm systems are almost always as strong as winds of a fresh gale (39-46 mph, on the Beaufort wind scale) and may often reach hurricane force. Because of this, a few thunderstorms present the potential for more serious deep structural wetting than do many days of gentle, windless rain.

6.1.1.2.4.1 Roof Edge Problems in Zones I and II

a. Gutters. Gutters overflow during heavy rains. If the roof edge is not protected by high flashing, roof sheathing will be wet; and unless preservative treated, it will decay. Where gutters are absent, flashing must extend out and down at roof edge to protect sheathing and fascia.

b. Tile. Tile joints can overflow during heavy rains, particularly at inside corners of the roof. If the roof sheathing is not protected by high flashing, it must be preservative treated to prevent decay.

c. Fascia. Fascia is vulnerable (4.3.4.1.1). Expect decay if roll roofing is nailed to top of roof edges with or without nailing strips.

d. Roof Sheathing. Roof Sheathing Edges (4.2.4.1.3). If they are not well flashed, and if fascia is absent, sheathing that is not preservative treated can be expected to decay, and require replacement prior to the shingles.

e. Moldings. Roof-edge Moldings (4.2.1.4) are vulnerable to the same extent as fascia. They can last for many years in Zones I and II if protected against decay.

f. Rafters. Rafter Ends at roof edges (4.2.1.5) are highly vulnerable to decay; and the probability of decay of unprotected rafter ends progresses from a fair probability in some of the drier parts of Zone V up through a certainty in most of Zone III. From parts of Zone IV up through III, II, and I, it is more a question of how soon and how extensive the decay rather than whether decay. Flashing, if thorough, can provide a reasonable degree of protection for Zones IV and III if preservative dip treatment is used; but pressure preservative treatment is required in Zones II and I. In theory, flashing and dip treatment should be enough protection in Zone II if adequate inspection and maintenance programs for roof edges could be assured. But no designer or builder today can assure a given level of maintenance tomorrow.

g. Beams. Beam Ends at roof edges are vulnerable to the same extent as rafter ends; and they require the same types of protection in the various climate areas.

6.1.1.2.4.2 Roof Edge Problems in Cold Areas. In periods of prolonged cold weather, ice dams do not normally form. They are most often formed at times of moderate thawing with some snow melting on roofs, or melting due to inadequate insulation, followed by freezing at roof edge. Only high flashing can protect sheathing and rafters from water trapped behind roof-edge ice dams when some thawing occurs. The extensive decay that takes place can be prevented by preservative treatment, but only high flashing can protect interior wall surfaces from water-marking and wall insulation from water-soaking.

6.1.1.2.5 Rainfall and Siding

6.1.1.2.5.1 Basic Considerations of Wall Wetting and Drying.

(1) Wall Wetting. This is a function of:

(a) The amount and frequency of rainfall,
(b) The force of the wind accompanying the rain, and
(c) Building design as it affects both roof run-off and wall splashing.

(2) Building Design. Only building design is controllable.

(3) Rates of Drying. These are governed by:

(a) Relative humidity;
(b) Ability of moisture to move;
(c) Construction details, such as type of sheathing paper used (if vapor permeable, it will let some of the moisture move on into wall as vapor); and
(d) Wall surface type (paint type). This will influence movement through the surface. A film of water on the backside of siding puts large stresses on surface paint films.

6.1.1.2.5.2 Siding - Splash-Wetting vs. Direct Wetting. Building siding can be seriously wet by rainwater in two different ways; by direct wetting and by rain-splash. Direct wetting and its control will be discussed first. Most of the measures that apply to reduction of direct wetting also apply to the reduction of splash.

(1) Direct Wetting. Roof overhang, intermediate or canopy roof, roof drains (gutters), and flashing (with proper drip edges) are design and construction features used to protect siding from direct rain wetting. Of these, overhang is the most important single factor for any climate type. The amount of roof overhang required for good protection varies from one Decay Hazard Zone to another. The figures given here are for single-story buildings. For two or more stories, add six inches overhang for each story above the first, and use the figures given here for first floor intermediate or canopy roofs:

(a) Zone I; two feet with gutter
(b) Zone II; one and one half (1½) feet with gutter
(c) Zone III; one foot with gutter

(d) Zones IV and V; one foot, gutter optional if good flashing is used (and if splash zone area is reduced by a high foundation wall and a natural (grass) or textured (gravel) splash area).

(2) Splash Wetting. The wetting of siding, and wood beneath it, by water splashed up from the ground can be just as serious as direct wetting. Splash wetting is sometimes caused by the watering of lawns and other plantings, but in most climatic areas it can be more serious when caused by rain. Splash wetting can be considerably reduced by adhering to the roof-overhang recommendations for reducing the effects of direct rain wetting in the Decay Hazard Areas. Also, additional precautions are called for. To help prevent splashing, roof-edge guttering must be provided with functioning down-spouts. During heavy rains, guttering can be inadequate to prevent splash. However, the force of splash can be reduced by assuring that the area where run-off will fall is covered with vegetation (most often grass) or with crushed stone. The worst surface is a flat, paved surface.

In addition to roof-overhang and guttering, a design feature important in protecting the siding and the wood beneath from splash wetting is the above-grade foundation height (or above-grade basement wall height). The heights required for protection in the different Decay Hazard Areas are as follows:

(a) Zone I; at least 12 inches of foundation wall exposed below siding and above grade where soil or other material meets the wall.
(b) Zone II; at least 10 inches of foundation wall exposed.
(c) Zone III; at least eight inches of foundation wall exposed.
(d) Zone IV and V; at least six inches of foundation wall exposed.

While this much might not be required in most of Zone V for decay prevention, it should not be reduced to less than six inches as this forces any subterranean termites attacking the building from the outside to build tubes which are visible.

It is important to maintain these exposed foundation wall heights. Dirt can splash up onto a wall, and building occupants will often build it up in accordance with their esthetic concepts of the way a building should look. Maintenance inspections are important.

6.1.1.2.5.3 Siding Wetting and Preservative Treatment. Only where important design features are completely neglected or where a most unusual type of siding is being used would pressure preservative treatment normally be required. However, in high rainfall areas dip or soak treatment with a penetrating water-repellent preservative can considerably prolong the useful life of a given building and can save materially in the costs of maintenance painting. The inches of measured rainfall are less important to the life of siding than the frequency of wind-driven rains. Zones I, II, and III have rain in all seasons. In all three of these Decay Hazard Zones, siding and its paint film should be protected by water-repellent preservative treatment. It is important to remember that wherever dip-treated siding is used, on-the-job cutting will expose untreated ends to quick water pick-up and thus undo much of the value of the dip treatment unless on-the-job treatment of cut ends is carried out. This should be required even if there is good roof overhang because of the damage to surface painting that can be done by end-grain soaking up of a single wind-driven rain. This is of particular importance around doors and windows. If the recommended roof overhang is omitted, water-repellent preservative treatment should be used in Zones IV and V as well as in Zones I, II and III.

6.1.1.2.5.4 Plywood Siding and Special Precautions. Under the proper conditions, plywood can be a satisfactory siding material provided it is not cut or "textured" except at the edges of large sheets, provided the sheet edges are sealed against water uptake, and provided that only exterior grade plywood with waterproof glues are used. However, even the best exterior grades with waterproof glues can delaminate between glue lines due to the internal stresses placed on the laminae when wetted from the edges or from texturing cuts through two or more plies. In addition to the need to observe these precautions for the use of all plywood siding, there are additional precautions based on the Decay Hazard Zone in which it is to be used.

(1) Treatment of Siding. In Zones I, II, and III, pressure treat all plywood siding (after any texturizing) with water-borne salts, and when dry, dip or soak in water-repellent preservative. For Zones IV and V, the pressure treatment can normally be omitted if the soak in water-repellent preservative is extended to 10 minutes or more.

(2) Design and Construction. In Zones I and II, caulk all joints and use battons on all vertical joints. In Zones III, IV, and V, caulk all joints.

6.1.1.2.5.5 Requirements for Flashing. Some requirements for flashing, particularly at roof edges, have been discussed. A listing of general requirements now follows:

(1) Roof edges. Flashing is required at all roof edges where there are no gutters to provide drip edges and to protect fascia.

(2) Flat Roof. For flat roofs, and for some others, flashing may be an extension of the gravel stop.

(3) Joins. Where siding joins the roof, as at a dormer, leave a 3-inch clearance between siding and shingles for Zone I, 2½ inches for Zone II, 2 inches for Zone III, 1½ inches for Zone IV, and 1 inch for Zone V.

(4) Projections. Use flashing wherever any horizontal projection from a wall occurs in exposed locations such as windows, and over doors which are not protected by porch roofing. Such flashing should extend beyond drip caps to provide drip edges and so protect the structural wood of the wall.

6.1.1.2.6 Rainfall and Building Appendages. There are many things that can and should be done to protect building appendages.

(1) In High Rainfall Areas (Decay Hazard Areas I and II). Construct to resist wetting (and decay). Follow all six of these recommendations and all of those for both moderate and low rainfall areas.

(a) Provide cover and wide eaves.
(b) Slope deck to drain off water.

(c) Minimize joints and contacting surfaces.

(d) Flash and caulk all horizontal joints; caulk vertical joints.

(e) Pressure treat all steps and fire ladders, as well as railings and structural supports (columns).

(f) For all framing and other items not to be painted, creosote treatment or penta in heavy oil can provide protection. But beware of odors and of oils that creep along nails to discolor paints. Penta in volatile oils and waterborne salt treatments overcome the odor and paint-staining problems.

(2) In Moderate Rainfall Areas (Decay Hazard Zone III). Follow all six of these following recommendations and all of those for low rainfall areas.

(a) Provide cover and eaves.

(b) Slope decks to drain off water.

(c) Minimize joints and contacting surfaces.

(d) Flash and caulk all horizontal joints, and caulk all vertical joints.

(e) Pressure treat all fire ladders, structural supports (columns and supporting members) and decking if double layered.

(f) Give all other wood water-repellent Penta dip (or use pressure treatment). Dip or soak 3-15 minutes, depending on size.

(3) In Low Rainfall Areas (Decay Hazard Zones IV and V).

(a) Don't use double flooring unless preservative treated.

(b) Drain water away from building.

(c) Provide drain holes through porch screen rails and other obstructions to fast permit drainage.

(d) Reduce molding and trim to a minimum.

(e) Extend fascia below the soffit.

(f) Use gutters with downspouts to protect porches and decks.

(g) Pressure treat main supporting members unless completely protected in Zones III and IV by design and construction to assure no wetting.

6.1.1.2.7 Rainfall and Exposed Structural Members. Some of the problems with exposed structural members are similar to those with building appendages. However, principal structural members are financially much more important than are most appendages and therefore deserve the best protection.

(1) High rainfall areas (Zones I and II).

(a) Supporting arches, laminated or solid, extending beyond the building wall. This is extremely poor design for all but Decay Hazard Area V, and is not economically justified there. For the benefit of all concerned, it is hoped that the fad that fostered this architectural mistake has ended.

(b) Rafters and beams extending beyond the roof decking. This construction is almost as bad as exposed arches; whereas decay in the ends of the arches can result in complete loss of a building, loss of rafters and beams usually results only in replacement of the entire roof structure.

(c) Sides of heavy rafters and beams exposed at ends of buildings. This is very poor construction practice and should be avoided.

(d) Pressure treatment for all exposed members should be required for these two decay hazard zones. This should be followed with water-repellent soak treatment for paint protection.

(2) Moderate Rainfall Areas (Decay Hazard Zone III). Metal caps and flashings are of some help in delaying replacement of, or major repair to, exposed structural members; but these alone <u>will not</u> provide long-time protection where preservative treatment has not been used.

(3) Low Rainfall Areas (Decay Hazard Zone IV).

(a) Use pressure treatment and metal flashings.

(b) Metal sockets for exposed arches can be satisfactory, provided that wood is pressure treated and provided that only non-leaching salt treatments are used.

(4) Dry Areas (Decay Hazard Zone V).

(a) Use water repellent treatment under all caps and flashing. Penta-grease helps here, but is usually not good for painting.

(b) <u>All</u> exposed arches must be pressure treated.

6.1.1.2.8 Condensation and Dewpoint Isotherm. A dewpoint temperature is the temperature of an object (or a substance) at which moisture from the air will condense on that object--will form dew on the object. This is a function of the humidity of the air (the relative humidity rather than the actual humidity). In air of nearly 100% relative humidity, an object needs to be only a few degrees cooler than the air to become wet with dew. In very dry air, the same object must be many degrees below the temperature of the air, low enough for frost to form rather than liquid dew. Even though it is frost that forms, the temperature at which this happens is the dewpoint temperature.

A dewpoint isotherm is a dewpoint line, or in relation to the interiors of structural units, it may be an infinite number of lines, or a "sheet." It is the location of the dewpoint in a wall, in a ceiling, or in a floor or a roof. The dewpoint isotherm in a structural unit such as a wall is not constant, but moves with changes in the temperatures and relative humidities on its sides or faces. It moves toward the cooler (and drier) side. Where the dewpoint isotherm goes, moisture vapor goes unless prevented by a vapor barrier. This creates condensation problems which can lead to structural decay.

6.1.1.2.9 Air Conditioning and Condensation. In humid climates, dewpoint temperatures (a dewpoint isotherm) will exist at least part of the time when indoor temperatures are in the low 70's, and almost all of the time if indoor temperatures are at or below 70°F.

Where crawl spaces are damp, low room temperatures will pull moisture up into the flooring. If the crawl spaces must remain damp, the flooring can be saved by attaching insulation board beneath the joists. It must have a vapor barrier on the lower surface. However, it is usually easier and cheaper to use a soil cover vapor barrier. Gravel or sand fill is sometimes needed under the barrier. Even with a dry crawl space in Zones I and II, don't cool interior spaces below 70°F except for brief periods in rooms with crowds (such as mess halls and theaters). In the humid areas, if air conditioning is used for only eight or nine hours per day, temperatures in the low 70's are normally safe, and if the crawl space is dry, 70°F is safe for daytime use.

6.1.1.2.10 Cold Weather Condensation. If a crawl space is kept ventilated to prevent build-up of water vapor that can condense on structural members, outside winter air will enter. The results can be cold floors and frozen pipes. A vapor barrier soil cover will normally solve the problem and permit safe closing of the crawl space vent openings for the winter. If the floors remain cold, they will contain a dewpoint isotherm and will become wet from moisture generated within the building. Condensation can occur under an unheated building if the ground is damp, but not frozen. This condensation tends more to be in the subflooring than on the joists because of the cold air in the building. With outdoor temperatures of 50°F and below, sills, plates, and joists become cool enough for condensation.

Most cold weather condensation is due to moisture vapor moving outward through walls, ceilings, roofs, and floors. It stops at the dewpoint isotherm to condense as liquid water. It also stops at a vapor barrier. The vapor barrier should be on the warm side of the wall. On the cool side of the wall, under the siding, there should be "breathing" sheathing paper which is a barrier to liquid water but not to vapor. It lets moisture escape but not enter. If vapor gets into a wall and freezes, the wetting (with following decay) will occur in the spring. Preservative treatment of all structural framing is the best assurance of prolonged structural life.

6.1.1.2.11 Condensation and Slab Foundations. In the construction of slab-on-grade buildings, the slab may be built as a unit with the foundation walls, or it may be a "floating slab" poured within the boundaries of the perimeter wall. In the winter, even in "warm" climates, the perimeter of the slab (or the foundation wall) will collect moisture. In humid areas, the slab is normally cooled by the ground to the dewpoint temperature. This can result in condensation on the concrete and in absorption of moisture by the wood in contact with the masonary. In cold areas it is desirable to insulate the perimeter of the slab as well as to provide a gravel layer under the slab. All wood in contact with slab foundations or with other structural masonry must be preservative treated.

6.1.1.2.12 Waterfront Structures and Climate. The effects of rain on unprotected parts of waterfront structures has been well covered (4.5). However, the effects of condensation can be equally devastating. In the "arid southwest" (technically semi-arid) piers and wharves have required replacement due to decay of pile tops, caps, stringers, bracing and decking timbers. The decay results from condensation wetting of untreated wood and of cuts and checks through the treated zone of wood. Other damaging condensation occurs on metal items such as bolts and enters bolt holes to depths beyond the treated zone of the wood. This decay of waterfront structures can be prevented by pressure treatment of all timbers, and by on-the-job treatment for all cuts, including drilled holes. This applies to all wood in waterfront structures in Decay Hazard Zones I, II, and III.

6.1.1.2.13 Grounds Structures and Climate. The effects of climate and of various soil types on utility poles is previously discussed (4.4.1.1.3 and 4.4.1.1.4). Maintenance programs for poles are covered in detail later

(7.5.3). Maps of decay hazard areas, useful in predetermining the needs for various measures to protect wood, sometimes attempt to define decay hazards for particular wood projects. It should be a relatively simple matter to prepare a decay hazard map for a single commodity. If railroad ties only are of concern, for instance, and if it is assumed that all are set in well-draining ballast, the features of weather that are of concern are: temperature, precipitation, relative humidity, hours of sunshine, wind velocity-hours, and the freeze-thaw cycle. These are all of the variables of climate that will affect the moisture content, the loss of preservative, deep checking, and rate of decay. A map of decay hazard areas for railroad ties would find but limited use as the railroad companies keep good records, and they rely on experience in the areas they serve. On the other hand, maps have been prepared to show how the various areas differ from each other in degree of pole decay hazard.

At the 1974 annual meeting of the American Wood Preservers Association, the report of Committee T-4 (Poles) presented two maps concerning pole decay in appendices to the report to the Association. The first of these maps was presented in Appendix A to the Committee T-4 report. Developed by a Committee Task Force, it is intended to provide some general guidance on recommended time intervals between in-place pole inspections. It is based on average monthly temperature and precipitation figures; and it considers no other features of climate that affect pole service life. Appendix C of the 1974 Committee T-4 report to the AWPA presented a report of "Performance of Creosoted Southern Pine Distribution Poles in Decay Zones in the United States."

In the eastern United States, this four-zone map can provide some general guidance on the frequencies needed for inspections, but it lacks some of the validity of a map based on service records. More about its location than just precipitation and temperature determine the longevity of a utility pole in place. To all of the features of climate previously listed as affecting the service life of a railroad crosstie must be added the characteristics of the soil in which the pole is placed.

In Zone I untreated poles may last as long as three or more years in some locations. The average life of untreated poles becomes longer as one goes from Zone II through Zone V. Given the same treatment, the poles in Zone V will outlast those in Zone I. Regardless of the decay hazard zone where poles are to be placed, it is incumbent upon everyone concerned to assure that only those poles with the best preservative treatment possible are purchased and used. This subject is further discussed (6.2.3.5 and 7.5.3).

6.1.2 STRUCTURAL EXPOSURE AND WOOD DETERIORATION.

6.1.2.1 Above-Ground Exposure Treating Requirements.

6.1.2.1.1 Load-Bearing Importance of Structural Members. The best possible treatment can be justified for items in which decay could be more than ordinarily disastrous. This can be well illustrated by considering load-bearing items. Clearly an item such as a girder, a sill plate, or a stud would entail more damage if it failed on account of decay than would a nonload-bearing item such as a railing or window frame. Decay in the former items may result in serious deflections and possibly even breakage of a structure depending on it for support.

For important load-bearing structures, therefore, the manner of treating should be as thorough as practicable even though less thorough preservation, as by dip treating, might be good enough to take care of the situation generally. While the most permanent treatment should be selected, other factors such as a requirement for paintability must be considered.

6.1.2.1.2 Appearance and Paintability. In many exterior locations, lumber appearance and paintability are prominently considered in deciding whether preservative treatment should be made, or what treatment to use. The heavier oil-type preservatives discolor the wood and tend to make the wood surface unpaintable for periods. Fortunately, there are preservatives and methods of application that do not interfere with painting.

Where a natural finish or a painted surface is desired, a clean treatment is necessary. One oil-type preservative meeting the requirement of nondiscoloration and paintability (if applied without pressure) is five percent pentachlorophenol, plus water-repellent ingredients, in a light oil (5.2.2.2.1(2)). Such a preservative can be purchased under Federal Specification TT-W-572. It is widely used and is often referred to as "water-repellent penta." A pigment can be added to the preservative if a stain is desired.

Good paintability can be generally assured if the water-repellent preservative is applied simply by short soaking or equivalent vacuum treatment. It is common in the industry to soak exterior woodwork such as window sash, frames, and doors for three minutes. Such treatment or its equivalent is covered by Commercial Specifications CS 262-63 (5.3.2.1(1)(a) and (d)).

For good paintability of an item requiring pressure treatment with pentachlorophenol, the liquefied-gas process or the methylene chloride process should be used (5.3.1.2.(2)(d) & (e)). Also, pressure treatment with most of the conventional waterborne preservatives (5.2.2.3) will satisfy the objective of a clean, paintable surface. Wood treated with a waterborne preservative generally will receive paint about as well as untreated wood.

6.1.2.1.3 End Grain Versus Side Grain. A choice of pressure treating versus simple, on-site dip treating for small-dimension material that is not structurally critical depends partly on whether the wetting and decay normally would occur through the end grain of the wood or through the face or side grain. What is involved here is the difference in depth of penetration through end grain and face grain obtained by dipping.

In general, it is much easier to get preservative solution into wood through the end grain than through the side or face grain. This effect on penetrability is of great importance in choosing the method of treating building lumber. A light treatment, such as by dipping or short soaking, for example, penetrates so little into face grain that the wood beneath is given only shallow protection. The same treatment, however, will enter deeply enough into the end grain of most woods to provide considerable protection against decay infection at this point. Inasmuch as grain direction affects penetration of rain water in the same ways as it does a treating solution, the preservative tends to reach wood that gets the wettest and, therefore, needs protection most.

(1) Treatment for Decay Occuring Predominantly Through End Grain. Because the treating solution is as able as water to penetrate into end grain, dipping or soaking small-dimension material such as trim often will be adequate for items likely to decay near the ends. For example, where one or more ends of lumber form a joint, it is the wetting of the end grain that will result in sufficient moisture pickup for decay; consequently, if the end grain can be protected, the possibility of decay will be largely eliminated. Typical joints of this kind are those in window sash and frames, the attachment of porch or stair railing to post, the attachment of stair carriage to header, and the junction of a column with its base. Except in the wettest climates and maximum exposures, joints of this kind can generally be protected by soaking for 3 to 15 minutes in a 5 per cent solution of pentachlorophenol with water repellents.

(2) Treatment for Decay Occuring Predominantly Through Side Grain. If decay is most likely to occur through the face or side grain, dip or soak treating will not be very effective. Penetration of the treating solution through side grain is usually very slight, perhaps not more than a sixteenth of an inch. Such shallow penetration offers little protection against infection through weather checks, which commonly go much deeper.

Items in which decay infection is as likely or more likely to occur through the side grain as through the end grain would include sleepers on concrete, sills or plates on concrete, fascia boards, and step treads. Exterior step treads are especially subject to weather checking because of the alternate wetting and drying they receive. The checks provide not only entrance ways for infection, but also points for water collection; thus they are the zones most vulnerable to decay. To get a preservative through the side grain of lumber to a depth greater than that reached by weather checks requires pressure treating.

6.1.2.1.4 Structural Design and Water Trapping. The desirability of designing and building structures to provide for water-shedding and to avoid water trapping are earlier discussed (4.1.2.1.2 and 4.1.2.1.3). While such construction is desirable, it is not always practicable.

Decay of wood in above-ground service varies according to the detail of construction. If the construction brings two or more surfaces together, forming joints, more opportunity is provided for trapping rainwater than in the case of open construction. Also, if the item is vertically oriented or sloping, it is less likely to accumulate water than if its position is horizontal. Siding is not as subject to wetting and decay--even if of a decay-susceptible wood--as are building appendages. This explains why siding does not normally need treatment for protection against decay, except in the wetter climates, and then dip treatment is usually adequate. Conversely, building appendages in wet climates generally will benefit from more thorough treatment. Paint maintenance may be improved by dipping the siding in pentachlorophenol solution containing water-repellent ingredients. The water repellency provided is the important factor in this case.

6.1.2.1.5 Opportunities for Condensation. Wetting sufficient to support decay may be caused by condensation in damp crawl spaces (4.2.2.3), in the walls of cold-storage rooms having inadequate vapor barriers (4.3.2.1), in the floor of air-conditioned rooms over a damp crawl space (4.3.3.1), and in swimming-pool areas (4.3.4.2). The crawl space can usually be made dry enough, by use of a vapor-retarding ground cover, to prevent its contributing significantly to condensation problems. Wood in the walls, ceiling, and floor of cold-storage rooms, and in some cases in the roof members of swimming pools, should be pressure treated.

6.1.2.1.6 Future Plumbing Leaks and Other Wood Wetting. Besides rain wetting, the water supply in the building may occasionally cause hazardous wetting. Wetting of this sort occurs beneath shower rooms and adjacent areas (4.3.1), but occasionally from plumbing leaks in kitchens (4.3.5) and careless lawn sprinkling (4.2.3.1.4). It seems to be difficult to prevent leaks in the shower room, at least for long periods. Therefore, framing and sheathing of shower walls and floors should be pressure treated (4.3.5).

For protection of the interior structural members, either a water-borne salt (5.2.2.3) or pentachlorophenol (5.2.2.2.2(1)) in a volatile solvent (5.2.2.2.1) should be selected for preservative treatment.

6.1.2.1.7 Foundation Contact and Moisture Movement. Structural wood to be used in direct contact with structural steel or concrete should be preservative treated because of the potential for condensation on the steel or concrete to wet the wood and lead to decay. Not only does concrete in contact with cold soil or exposed to cold air increase this risk, but direct migration at the surface adds further hazard. All wood contacting foundation materials should be treated with a non-leaching water-borne preservative (5.2.2.3) or with pentachlorophenol (5.2.2.2.2) in a volatile solvent (5.2.2.2.1).

6.1.2.2 Treating Requirements for Wood in Ground Contact. The most severe service condition of all in regard to decay is imposed by contact between the wood and the ground. As a general rule, except for poles, posts, cribbing, bulkhead walls, and foundation piling, ground contact is unnecessary and should be strictly avoided in building construction for most purposes. Wood that must be placed in contact with the ground permanently should be pressure treated according to recognized standards (5.2 and 5.3). Moreover, special care should be taken to avoid cutting the wood after treating.

The need for these precautions stems from the fact that wood in contact with the ground is doubly threatened by decay: (1) the ground itself tends to be prevalently wet or damp and, therefore, may act as a reservoir of water that can keep the wood wet for long periods; and (2) most soils harbor decay fungi and thus constitute a dangerous source of infection.

The need for any given penetration and retention of a particular preservative will vary on an item-by-item basis. These needs are reflected in the tables of Federal Specification TT-W-571 and in standards of the American Wood Preservers Association and of the American Wood Preservers Bureau.

6.1.2.3 Preservative Treatment for Wood in Marine Structures. In all of man's uses of wood, there are none which normally expose wood to more severe conditions of biodegredation than does its use in waterfront structures.

Typically, wood at the shore end (or side) of the structure is exposed to direct ground contact with all of its problems of decay and termites. Most of its foundation and its fender system are exposed to marine borers (3.4) and decay, and all of the above-water wood is exposed to decay (4.5.1). Even wood beneath deck pavement decays due to condensation and to leakage (4.5.1.2) if not protected by treatment.

6.1.2.3.1 Above-Water Exposure and Preservation. The decay hazard due to exposure of wood in the above-water portions of marine structures is previously described in detail (4.5.1). This covers wooden decks, deck foundations, stringers, caps, curbs, chocks and wales, and the tops of both fender and foundation piles. Preservatives and treating methods are detailed in Chapter 5.

Preservative treatment standards differentiate between the treatments required for wood in ground contact and for wood above ground. In general, wood used in waterfront structures should be given the heavier treatment for ground contact because the severity of exposure is greater than for most above-ground use, and because of the high replacement costs (6.2.1 and 6.2.2) or in-place value of many items such as caps and stringers. Most preservatives can do a satisfactory job in the above water members of marine structures, but there are exceptions and precautions. Creosote (5.2.2.1) has long been used for protection of caps, stringers, wales, braces, and other items. It is a good preservative for these members. Filler under decking pavement can be creosote treated; but decking should never be creosoted. If it receives satisfactory treatment to withstand the exposure which it will receive, it will bleed. When new, it will be very dark and will become hot in the bright sunlight. The air trapped in the inner-most wood cells will expand and push the warm creosote to the top of the decking. This can make the decking dangerously slippery; and the liquid creosote will penetrate shoe leather and be tracked aboard ship where its odor in confined spaces is objectionable.

Pentachlorophenol (5.2.2.2) in a heavy oil can act in a manner similar to creosote in treated decking. For this particular use, it must be in a volatile solvent for treatment (5.2.2.2.1). Penta can serve very well when exposed to fresh water. However, it should never be used in salt water or even above the water-level in locations where it would be subjected to frequent salt water splash. In the continuing presence of salt in the water, the pentachlorophenol slowly changes to sodium pentachlorophenate which is water-soluble and leaches out of the wood. Most decking is far enough above the water as to be exposed to salt water only during storms so that the penta can provide lasting protection.

With the exception of CZC, the water-borne salts (5.2.2.3) are satisfactory for treatment of above-water members of waterfront structures. As with penta and creosote, the deep penetrations and heavy retentions normal to treatment for ground contact, rather than the lighter treatments normally specified for above-ground use, should be specified. A long term research study has shown that FCAP (5.2.2.3) (Fluor Chrome Arsenate Phenol) tends to migrate to depth in wood exposed to the sun and rain, such as decking. In doing this, it often moves to a depth below the checks and thus functions well to prevent the decay which starts in checks.

6.1.2.3.2 Marine Exposure. In salt water, piling is exposed to marine borers. The various types of borers and the damage they can do are explained earlier (3.4). In Chapter 6, under the discussion of the presence of structural pests, the severity of marine borer attack (6.1.1.1) is considered, and the treatment required for control of various types of borers in differing areas is explained (6.1.1.1.3). This material reflects that provided in Federal Specification TT-W-571 and in the Standards of both the AWPA and AWPB.

SECTION 6.2 COST CONSIDERATIONS IN THE SELECTION OF PROTECTIVE MEASURES FOR STRUCTURAL WOOD

The need for the protection of some wooden items such as utility poles and marine piling seems obvious to nearly everyone. But not all structural wood requires special protective measures such as preservative treatment of the wood (5.1), soil treatment to prevent subterranean termite attack (4.6.4), and special design considerations to prevent decay (4.2, 4.3, and 4.5.2). It must be remembered that a principal reason for selecting wood for structural members is the economy of its use; and cost considerations must play a part in the selection of any measures to prolong the life of the structural wood. Meaningful cost considerations must involve evaluations of the planned life-span of a structure, of maintenance costs during this planned useful life, and of costs of major rehabilitation or of demolition and replacement as required if maintenance is neglected. In addition to the economics of construction, maintenance, and future replacement, it is essential to consider the cost of structural down-time from the standpoint of lost opportunity costs.

6.2.1 PROJECTED STRUCTURAL LIFE. During the emergency periods of WW I and WW II, design and construction shortcuts were often taken in structures which were intended to serve for only the duration of a short war and the following demobilization period. Because of the need for haste to build, combined with the planning for very short structural lives, protection against decay and termites was often omitted. At the beginning of the Korean War, many deactivated and empty but still standing buildings required speedy rehabilitation for occupancy. In a majority of cases, the costs of this rehabilitation in 1950 were considerably more than would have been the costs of added termite and decay control during early wartime conditions.

The shortcuts were not taken in all wartime construction; and many buildings erected in the early 1940's were still in use in the late 1970's. Some structures built to resist termites and decay were later determined to be in excess of military needs and were sold on the open market rather than being demolished at a cost. This returned a cash profit of a few hundred to a few thousand percent on the expenditures for decay and termite control measures taken at the time of construction.

Some piers and wharves constructed in wartime not only were considered expendable, but were planned to last for only two-to-three years. Neglect of protection of the superstructure against decay was perhaps logical under such conditions, but neglecting protection of support piling in all but heavily polluted waters was a serious error. Because of a bad guess that some Alaskan waters were too cold for marine borers to be active, an attempt was made to build a very large military supply pier on untreated wooden piling. In approximately six months from the beginning of pile-driving, piles were being completely destroyed by Bankia attacking from the mud-line upward. The replacement pier remained in service beyond the end of the war.

Obsolescence should be considered whenever possible in the projection of structural life. If a structure is of use only in connection with an item of hardware with a very short planned life span due to replacement by more effective and sophisticated hardware, protective design and preservative treatment for wooden items would not normally be considered except for wood in direct ground contact. However, it must be noted that it became necessary to provide preservative-treated wood for use in the construction of bunkers in Vietnam due to the very rapid decay of wood in ground contact in that warm, moist area.

Projecting the true requirements for structural life can often be quite difficult when considering obsolescence. Even "permanent" structures of steel and concrete, such as pre-WW II revetments for coastal defense artillery and abandoned Navy seaplane ramps provide examples of obsolescence due to technical advances. However, when obsolescence is not anticipated, and when its useful life is expected to be protracted, wooden structural members should be given such protection as required for long service life in order to reduce the later costs of repair or replacement.

6.2.2 COSTS OF REPLACEMENT AND REPAIR. The initial costs of treating are often given undue weight in deciding whether or not the protection provided is worth the cost. Consideration must be given to more than the treatment cost. If it would cost a great deal to replace or repair a particular item, it should get better protection against decay than one that can be returned to service or replaced at relatively small expense.

Obviously, there usually will be more concern about the possibility of decay if the part in question would be comparatively expensive to replace. Generally, replacement costs consist largely of expensive labor, the cost of the material itself being comparatively nominal. This fact is often overlooked in deciding whether it is worthwhile to treat. Wood in steps, for example, although entailing a relatively small cost for lumber, usually will cost considerably more when the carpenters' charges are added on. The labor charge can be especially formidable if the part to be replaced is not easily accessible.

To demonstrate an effective method for determining the cost effectiveness of preservative treatment for wood, an exemplary case has been prepared. In this example, porch units on permanent buildings are being considered as they are typically exposed to the weather. The wood selected for this example is southern pine. In relatively high decay hazard areas (Decay Hazard Zone I) untreated southern pine in this exposure situation can be expected to be serviceable for from 3½ to 5 years. After this period, the porch units must be rehabilitated (replaced or given major repairs).

Replacement costs are higher than the original building costs, even without considering future inflation, because of the added labor of removing and disposing of the structural wood prior to replacing it. For new construction, the average cost ratio for labor and materials is very close to 50/50. But for rehabilitation or replacement the labor-to-materials cost ratio jumps up to 70/30.. This makes long-range protection even more appealing. In moderate climates (Decay Hazard Zone III) the southern pine could be expected to have an average useful life of 8 to 10 years in exposed porches if not in direct ground contact. In contrast to untreated wood, pressure treated southern pine can serve well for over 30 years of exposure under severe conditions.

The costs used in these examples are the following: (1) Untreated southern pine lumber per 1000 FBM = $225; (2) New installation costs = $225 (the 50/50 ratio. Note that the labor required remains the same if the lumber is treated or untreated.); (3) Preservative treatment per 1000 FBM - $75; Replacement labor costs - $525 (the 70/30 ratio. The additional labor costs due to requirements for removal and disposal of damaged wood which is being replaced.) New installation with treated wood costs $525. Of this, $75 can be "saved" if untreated wood is used, thus dropping the new installation costs down from $525 to $450.

However, in Decay Hazard Zone I, it will be necessary to replace the porch units at the end of five years if not sooner at a cost of $825 using treated wood, or, if the lesson hasn't yet been learned, using untreated wood at an installed cost of $750. Failure to use the treated wood the first time saved the initial $75, but the rehabilitation cost the difference between an initial cost for building with treated wood of $525 and the total cost so far of the first and second construction jobs of $1,275. This is $750--the cost of rehabilitating with untreated wood. These losses will continue at five-year intervals in a high hazard area.

Adding in the nearly certain costs of future inflation provides a financially more realistic approach to the true losses because it considers the costs of the use of money over the years for both the original construction and the repeated rehabilitation. In this, the cost of money is based on unearned interest on money not saved but spent for construction; and the interest rate used is an extremely conservative 5% compounded annually. The $525 spent to build the porch units with 1000 FBM of pressure treated southern pine would have earned $1,852 to return a total of $2,377 at the end of 30 years. By comparison, the initial savings of $75 made possible by using untreated rather than treated wood if invested for 30 years at 5% compound would return a profit of $214. This initial $75 savings, when repeated for the rehabilitations required over the 30 year period, cost the difference between $2,377 and $10,213, or a loss of $7,836 to save $75.

6.2.3 IMPORTANCE OF STRUCTURAL DOWN-TIME. Throughout American industry, the costs of mechanical and structural down-time are recognized as being high. The inoperability of a single item of production plant equipment may idle one or many workers and produce considerable financial loss. Structural down-time can be even more disruptive and costly than mechanical down-time. Industry suffers financially due to down-time, but of much greater importance than all economic losses could ever be is the temporary loss of military readiness when military structures fail. A problem at first as seemingly simple as a lack of maintenance of a fendering system on a pier or wharf can make unavailable to ships of the fleet the berthing required for refueling, refitting, and resupplying. Military telephonic communication systems and some radio communications and intelligence gathering are dependent on the ability of wooden poles to continue to support their loads. In the procurement of these poles there must be assurance of proper treatment for long life (6.3.2), and to this must be added the additional safety factor provided by programs for routine maintenance inspections (7.5.3).

Electrical generators are located at many critical sites where they wait, in stand-by capacity, for a failure in the normal transmission of electrical power. Detection and alarm systems capability, airfield operations, electronic and electromechanical equipment functioning, maintenance of required temperatures in critical areas, and some aspects of munitions production are examples of requirements for interruption- free distribution of electrical power. As with communication systems poles, caution must be exercised to assure that only the best treated materials are procured and used if the Nation's military readiness is not to be weakened in times of need.

SECTION 6.3 PROCUREMENT OF TREATED WOOD

6.3.1 MILLWORK TREATED BY NON-PRESSURE METHODS. The National Woodwork Manufacturers Association (NWMA) maintains a quality control program for the production of millwork treated with water-repellent preservative solutions (5.3.2.1(1)(d)). All wood products procured as windows, window frames, doors, doorways, and other millwork items require the protection of the water-repellent pentachlorophenol treatment (5.2.2.2.2.(1)). This is true in areas that have only occasional rains which can lead to decay. The water-repellency does not provide for true water-proofing, but it does prevent quick pick-up of moisture by the wood and so provides for the dimensional stability which is so important in most millwork items. In areas of moderate-to-high decay hazard, the protection against decay is of at least equal importance to dimensional stability and so provides even more reason to require the water-repellent preservative treatment for all millwork items.

Other than paying for extensive testing on each procurement, there is only one way to assure the quality of treatment for the mill work items given the non-pressure, water-repellent preservative treatment. This is to place in the procurement document a firm requirement that their mill work be treated in accordance with the appropriate standard (NWMA Industry Standard for Water Repellent Preservative Non-Pressure Treatment for Millwork) and that the millwork items bear the NWMA Seal of Approval which is stamped on wood treated under this program.

6.3.2 PROCUREMENT OF PRESSURE-TREATED WOOD. Theoretically, there are four quite different approaches to procurement of pressure-treated wood briefly discussed below. However, it must be clearly stated at both the beginning and end of this discussion that a true understanding of the use of any of these four approaches to procurement requires an appreciation of three simple but basic truths. Without this understanding, procurement becomes a game of chance. These three realities are:

(1) Preservative treatment, properly selected and applied, can prevent or delay biodegradation of wood, but (except for water-repellency added by some treatments) the physical features of the wood are not improved by treatment and may be degraded to some extent. There is no way that preservative treatment can change the existence of excessive sweep, crook, wane, spiral grain, checks, splits, shakes, dote, knot clusters, knot swells, and twist. If these

and other defects exist in the white stock, they will continue to exist in the treated wood. Treatment will not up-grade the physical quality, but it may partially hide some defects. The physical quality of the wood must be specified in order that the proper white stock be selected for treatment.

(2) The second basis noted is that no two pieces of wood will be exactly the same in their physical characteristics or accept preservative treatment exactly to the same depth and retention. Recent genetic work on southern pine is resulting in some remarkable uniformity of growth on level land. But though this wood is almost the exception to the rule, the existence of differences in the reception of treatment by wood must be remembered.

(3) The third basic truth is that, as long as one buys from the lowest bidder, citation of requirements can be nearly meaningless without either an effective independent quality control program or very tight inspection procedures.

6.3.2.1 Standard Stock Items. Standard stock items of equipment are required for maintenance. A standard stock system provides for lower prices and higher quality of some items and of some bulk materials. Such a system can greatly simplify procurement through citation of stock numbers. Procurement in quantity, and maintenance of supplies for ready issue, can afford considerable savings but require standardization to assure demand for items stored. During periods of shortages and delayed deliveries, on-hand supplies of standardized items may be a necessity. Before, during and after WW II, military supply centers stocked many items of forest products, and many large installations maintained large supplies of lumber. Unfortunately, the storage procedures often led to considerable degradation due to insect and decay damage.

Today, large supplies of forest products at military installations are the exception rather than the rule. Most installations maintain supplies of only enough lumber to satisfy normal maintenance needs until the next resupply, and delivery is normally directly from the producer rather than from a military supply yard. These changes have made the listing of military stock numbers for various forest products nearly meaningless, particularly so for preservative-treated forest products. Ordering by stock number has one small advantage in that with the listed numbers there is descriptive material which gives the catalog user some idea of the items theoretically available through the catalog system and commonly purchased. But this system limits availability of treated wood.

The treated wood items listed as standard stock are not procured under an independent quality control program, and their condition on delivery often offers conclusive proof of inadequate inspection and lack of adherence to the standards cited in the stock catalog. This is an example of the third of the three basic truths that must be understood for satisfactory procurement (6.3.2.(3)).

6.3.2.2 Federal Specification TT-W-571. The title of this specification is "Wood Preservation: Treating Practices." This specification is often quoted in military procurement of pressure-treated forest products. There are questions occasionally asked about the legality of using this specification because of the possibility of its internal conflicts and the resultant possible inability of bidding treaters to follow the requirements of TT-W-571.

This is in the area of internal references. It cites various Federal specifications for wood preservatives, and it cites the American Wood Preservers' Association (AWPA) commodity standards for treatment; and these, in turn cite AWPA preservative standards rather than the Federal specifications for preservatives. TT-W-571 specifies the quality of the wood as well as the treatment:

> "6.2 Ordering data. Purchasers should select the preferred options permitted herein, and include the following information in procurement documents:
>
> "(a) Title, number, and date of this specification.
> (b) Moisture content required at acceptance (see 3.4).
> (c) Minimum information required in the branding or marking (see 3.6).
> (d) Treatment other than normally required (see 3.1)
> (e) Condition of surface following treatment (see 6.1.2 and 6.1.3)."
>
> "6.3 Invitation for bids. Invitations for bids should state the quantity, form, species, grade, the fabrication of the wood, the preservatives and retentions required, the corresponding treatment specifications to be complied with, and also any special requirements, such as cleanliness, paintability, water repellency, and drying of timbers after treatment with waterborne preservatives." It provides guidance as to the information that should be provided when purchasing wood.

Under the heading of "Quality Assurance Provisions," paragraph 4.1 of TT-W-571 makes the following statements about inspections and independent quality control agencies and about destination inspection. The underlining is added.

> "4.1 The Government reserves the right to perform and/or retain services for any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements. Tests to verify the accuracy of inspection reports furnished by the supplier shall be made either by employees of the purchaser or by commercial inspection companies retained by the purchaser. The purchaser may elect to employ the services and accept the stamp of an independent quality control agency. When treated wood, as specified by a Government agency, is procured by a contractor for the construction of a building or other facility for that agency, the contractor shall submit to that agency an inspection report from an independent commercial inspection company acceptable to the purchaser. An omission of this inspection report is permissible if the treated wood bears the brand or stamp of an independent quality control agency acceptable to the purchaser. In the invitation for bids, the purchaser will designate the general procedure to be used in confirming the quality of the produce."
>
> "4.1.4 The Government reserves the right to conduct or retain services for inspections at destination. When the results obtained at destination disagree with those obtained at origin, the results of the destination inspection shall be binding." Please note that this inspection will be of no legal value unless the procurement contract clearly states the treatment results which will be accepted.
>
> "4.1.5 When inspection is made at destination, it will be made within 30 days of delivery. AWPA methods of assay will be used and an assay retention of 90 percent of the stipulated assay retention will be accepted as conforming."

In regard to planning procurement in accordance with the above quoted concepts, three points must be made:

(1) Basic concept number two previously stated that no two pieces of treated wood are precisely alike. Variations in penetrations and retentions in a single cylinder charge of treated poles or lumber will exist. A quality control program of the right type will help assure that the overall level of quality of treatment is sufficiently high that most of the lower variations from a norm are still above the specified requirements. This is further explained (6.3.2.4).

(2) The threat of destination inspection has an effect on the average quality of treatment like that of a quality control program.

(3) Citing these statements in TT-W-571 may be of little or no use if the user agency is forced to accept and to pay for material "inspected" and accepted at the treating plant by another Government agency (6.3.2.5).

6.3.2.3 Basic Industry Standards. The standards published by the American Wood Preservers Association (AWPA) are the basis for nearly every standard and specification for pressure-treated wood.

The AWPA is a non-profit organization with membership open to all those with interests in the preservative treatment of wood. Its articles of incorporation list four "objects and purposes," one of which is "the standardization of specifications for wood preservatives and their introduction into the materials to be preserved." In keeping with this purpose, the AWPA maintains standards which are listed in four major groups: (1) Preservative Standards; (2) Commodity Standards; (3) Analysis Methods; and (4) Miscellaneous Standards.

Early in its history, the AWPA developed its Service Bureau to provide guidance in the use of treated wood. When the AWPA Service Bureau eventually became primarily promotional, it was separated from the AWPA and in 1960 became the American Wood Preservers Institute. Unlike the AWPA, the AWPI is entirely supported by the treating industry. The first quality control programs (QCP's) for industry-wide use were developed cooperatively by the AWPI, the Navy, and the Department of Commerce in 1962, and the AWPI established the American Wood Preservers Bureau (AWPB) as a wholly owned subsidiary to manage the AWPI QCP's. In 1971, the AWPB became a completely independent, non-profit quality control agency, and it acquired all rights to the AWPI-developed QCP's (6.3.2.4).

The AWPA standards are the basic standards for the wood-treating industry in the United States and in Canada. They cover almost all treated commodities. These are the standards cited in Federal Specification TT-W-571 (6.3.2.2) and, through TT-W-571, cited in standard stock item descriptions. These AWPA standards are continually being revised and improved to keep up with developing technology. These are the standards that were cited directly or through TT-W-571 by all Federal agencies prior to the development of the AWPI/AWPB QCP's. When citing an AWPA commodity standard in any procurement, it is necessary for these agencies to also list some of the requirements found in TT-W-571 pertaining to ordering data and to inspection or QCP procedures (6.3.2.2).

6.3.2.4 Quality Control Standards. The quality control standards are the American Wood Preservers Bureau (AWPB) standards. They have treating requirements for preservative penetrations and retentions which are always equal to or more stringent than the requirements of the AWPA standards and of TT-W-571. They provide assurance of the highest level of quality of treatment available; and their use cost less than Government inspection, and much less than the extensive and detailed inspections which would be required to assure an equal quality level of commodities procured. They carry the continuing threat of, and from time to time do carry out, destination and in-shipment inspection. In this program, seven commercial inspection and quality control companies (agencies) are licensed by the AWPB to work directly with over 145 commercial treating plants to provide QCP technical guidance and QCP inspections. In turn, the AWPB inspects to determine effectiveness of work by the seven agencies. The published AWPB standards provide the following information on these quality control agencies and their responsibilities:

> "Quality Control Agency (hereinafter called the control agency). An organization certified by the AWPB to continuously sample and test quality marked products treated in accordance with this standard. These samples may be obtained at the treating plant, at storage points and/or points of use. The control agency shall initially and continuously thereafter determine that the manufacturing equipment meets the minimum requirements described in this standard. The control agency shall initially and annually thereafter determine that the resident quality supervisor can demonstrate satisfactory knowledge of all manufacturing, sampling and testing requirements described in this standard. The control agency shall have no financial interest in any company producing any portion of the products inspected and tested. The agency shall not be owned, operated, or controlled by any such company."
>
> "Control Agency Duties. A Quality Control Agency described in Paragraph 2.6 shall check and approve the plant equipment, resident quality supervisor, and the first charge and shall thereafter perform continued checking and testing as specified by this Standard. The Control Agency shall:
>
> "(a) Initially and continuingly thereafter determine that procedures and requirements of this Standard are being adhered to by the treater.
>
> "(b) Check plant equipment for compliance with Paragraph 3.4.1 at least once each six (6) months.
>
> "(c) (For lumber and plywood) Perform the sampling and testing described in Section 4, at the frequency shown in Table 1. The samples collected as required in this section shall be submitted to the AWPB for analysis to determine if the preservatives retained conform to the requirements of 3.2.3 and 3.2.4.
>
> "(c) (For marine piles) Perform the sampling and testing described in Section 4 on a 100 percent Lot Inspection basis. The samples collected as required in this section shall be submitted to AWPB for analysis to determine if the preservatives retained conform to the requirements of 3.2.3."

If the treatment is found to be less than that required by the standards, it is a situation of non-conformance, and the following is required:

"(a) Under Treater's Jurisdiction. When results of the original treatment do not meet the minimum requirements specified, material may be retreated and may be reoffered for acceptance, subject to the limitations specified by AWPA C1 under Section 6, Retreatment.

"(b) At Locations Other Than the Treating Plant. If product non-conformance is discovered at locations other than the treating plant by the Control Agency, the Control Agency must determine whether the lot being inspected would be acceptable under the provisions of Paragraph 6 of this Standard (Reinspection). If the material is not acceptable under Paragraph 6, the Control Agency must notify the owner of its findings and request that the Quality Mark be removed. A treating plant suspended for cause from applying the Quality Mark to its products while under license of one Control Agency shall not apply the Quality Mark under license of another Control Agency."

In a case of non-conformance discovered within 30 days after delivery, ownership of the improperly treated product with the quality mark removed reverts to the supplier who must replace it with properly treated material at no expense to the buyer/user. In any case where the user may have reason to believe that materials delivered do not meet the treating requirements, he has direct recourse to the AWPB, and he should contact this organization without delay. Samples taken at plants or other locations are sent by the quality control agencies to the AWPB laboratories for quantitative and qualitative analysis.

As a wholly independent, non-profit organization, the AWPB continually strives to maintain a posture of helpful service to Federal agencies as well as to all other users of its standards and to assist treaters in the improvement of product quality. To these ends, the AWPB has on its Board of Governors three Federal agency employees (Navy, Federal Housing Authority, and Department of Transportation. The Standards Committee of the AWPB consists of highly knowledgeable members from the Forest Service, several universities, various inspection and quality control agencies, and several preservative producers and wood treaters. The quantity of treated lumber and plywood satisfactorily produced under the AWPB QCP's has risen steadily to its present level of nearly 3/4 billion board feet per year as more and more users discover that there is one system for inexpensively assuring high quality of treatment.

6.3.2.5 The Meaning of "Inspection". It is of very real importance that those who plan to use treated wood and those who purchase it understand the true meaning of the term "inspection" as it applies to materials procured in accordance with the American Wood Preservers Association commodity standards and with Federal Specification TT-W-571 which quotes the AWPA. The previously mentioned (6.3.2(2)) basic truth number two which states that no two pieces of wood accept treatment exactly alike can be extended to include the statement that within a single large piece of wood there will be variations, and that the larger the piece of wood, up to the size of a large pile or pole, the greater will be the variations.

Not all of the areas of minimal treatment are easily avoided in boring to determine penetration and retention, as are knot swells and clusters. For example, a tree growing on the east side of a steep north-south hill is quite likely to have an off-center heart due to the years of more rapid growth on the sunny, east side of the tree than on the shaded west side. The annual rings will all be thinner on the west side; and the wood on this side will normally not accept penetration as well as will the wood on the east side. If four borings are taken at midpoint on the length of the pole and at 90 degrees apart around the pole, the results might show two opposing (180 degrees apart) borings just meeting the penetration requirement, one boring with penetration a good bit deeper than required, and one with penetration inadequate to meet the requirements of the specifications and inadequate to meet the requirements of the environment where it will be exposed. From this it is easy to see that taking a single boring at midpoint from poles spread out in a treating plant yard might or might not indicate the true condition of the poles.

In regard to inspecting poles, paragraph 4.2.1 of TT-W-571 states, in part, "In determining the penetration in Group A utility poles (less than 37.5 in. in circumference 6 ft. from the butt), 20 representative poles in charge shall be bored at the approximate midpoint. If 18 of the borings meet penetration requirements, the Group A poles in the charge as a whole shall be accepted, but the nonconforming poles shall be rejected. If 16 or 17 of the borings meet penetration requirements, each Group A pole in the charge shall be bored and only those meeting penetration requirements shall be accepted. If less than 16 of the borings meet penetration requirements, the charge shall be rejected."

The AWPA standard "C4-Poles" poses the same requirements. Following these directions for inspection can result in procurement of some very poor material.

At the 1974 annual meeting of the American Wood Preservers Association, Committee "T-3-Piles" reported on "A Study of Penetration in Pressure Treated Poles and Piles." Several treating companies cooperated in the study by taking extra borings on charges of poles and piles treated, and by submitting the data collected to a subcommittee. The intent of the study was to determine whether there is any real significance in multiple borings or if one boring per pole is adequate to determine overall treatment quality.

In the study, 10 charges of 20 piles each were bored in a circular pattern three times (120 degrees apart) at midpoint (seven of the charges) and at planned groundline point (three charges). The first, second, and third borings are designated "A", "B" and "C". In consideration of the statements in both AWPA Standard C4 and Federal Specification TT-W-571, the 40 piles of charges numbers 1 and 2 would have been rejected (retreated), and that the 160 poles of charges numbers 3 through 10 would have been accepted except for the 11 poles found in boring "A" to have inadequate penetration. That would have meant acceptance of 149 poles on the basis of one boring per pole.

If the poles are rolled approximately 120 degrees and bored a second time (boring "B"), more of them are found to have inadequate penetration. On the basis of having taken two borings, a total of 60 poles of charges number 1, 2 and 3 are rejected as well as four more poles from the remaining seven charges. This leaves only 128 acceptable poles remaining from the 149 that would have been accepted on the basis of a single boring. Then, if the poles are again rolled 120 degrees and bored the third time, all of the first seven charges (140 poles) are rejected as are four poles from the last three charges (8, 9 and 10), leaving a total of only 56 acceptable poles rather than the original 149.

The ability of the pole to accept treatment in one place but not in another can be due to several physical variables. It is important to realize that the laws of probability would show that it would be possible at some time to have taken boring "A" in just the right place on each pile or pole to have rejected all poles with poorly treated areas with a single boring system. But those same laws of probability show that this is unlikely to happen in the lifetime of any one inspector. The data presented above are factual data and give a realistic view of normal treated material.

If it can be assumed that taking three borings 120 degrees apart in a ring around the center of a pole or pile will with certainty identify all poles and piles with inadequate treatment at any place, it can be shown that using a simple three-boring inspection system rather than the system cited in AWPA C4 and in TT-W-571 will be of greater benefit to both the treater and the user of the treated product. It is seen that of the total 200 poles in the 10 charges, only 46 poles actually failed on the basis of what the penetrations found on a three-boring system and required retreatment for this reason. This is a considerable contrast to the unrealistic requirement for retreating 18 perfectly good poles (45%) of the sum of only charges 1 and 2 when only the 22 (55%) nonconforming poles should have been retreated.

Along with the retreatment of 18 already well-treated poles, the inspection system of AWPA C4 and TT-W-571 based on single borings would have meant acceptance of 13 poles which, with a three-boring system, were found to have inadequate penetration. With 18 poles retreated without real need and 13 future failures accepted, the presently used "inspection" system has a total failure rate of 15.5% if the poles and piles in AWPA study were typical. Another fault of the present procurement and inspection system citing AWPA C4 and TT-W-571 is much more serious than those just explained in that it can result in procurement of 100% of inadequately treated poles and piles, as herein explained.

Basic truth number 3 (6.3.2(3)) related to the low-bidder system in most procurement and the requirement for use of either an effective quality control system (with some destination inspection) or a very tight inspection system. Referring again to the real-life study detailed above, assume that all 200 piles have been inspected by an independent inspection company in accordance with the AWPA C4 requirements. The 40 piles or poles of charges one and two and the 11 nonconforming piles or poles of charges three to ten are set aside for retreatment; but the remaining 149 piles or poles (including the 13 future failures that would be picked up with a three-boring system) are branded by hammer stamping on each end to show that they passed the inspection.

Before any retreatment takes place, a buyer from a utility company inspects the 149 branded poles using the three-boring system. The utility buys 135 of the 136 poles that pass the three-boring test. The one that passed the utility inspection and the 13 that failed on the second or third boring are in the treaters yard bearing the hammer stamp of an independent inspector showing that these poles did, in fact, meet the AWPA and Federal Specification requirements. Without either an effective quality control program or a very tight inspection system, another agency buys the 14 poles with 13 future early failures as replacements for 14 other early failures.

While paragraph 4.2.1 of TT-W-571 quoted earlier, follows the AWPA C4 procedure for pole inspection, paragraph 6.1.1 of TT-W-571 addresses the subjects of quality control and destination inspections as follows:

> "It is recommended that observations of penetration be made on a number of pieces selected at random from each shipment received at destination. The presence or absence of the mark of a quality control agency or independent inspection agency acceptable to the purchaser should also be noted. When the wood contains such a mark and the penetration observed conforms to the specification, the shipment may be accepted. When the penetration observed casts doubt on the quality of the treatment, a thorough inspection by either the Government, a quality control agency, or an independent inspection agency should be made and any nonconforming shipment or lot should be rejected."

It is incumbent upon the end users of treated wood products to assure that the procurement system used is one which will provide products of an acceptable quality level.

CHAPTER 7. PREVENTIVE MAINTENANCE AND CORRECTIVE CONTROLS

SECTION 7.1 MAINTENANCE NEEDS FOR A SHORE ESTABLISHMENT

Shore installations must be in a continuing state of readiness and must be physically well-maintained. Effective support, responsive to fleet needs, requires vigorous programs of preventive maintenance and corrective controls. Such programs, properly established and managed, not only permit the most effective service to their fleets, but they can also save considerable sums of money. The financial significance of effective maintenance programs - and, on the other hand, of the lack of maintenance followed by replacements - becomes meaningful if one considers some of the existing investment in wooden structures or structural elements of just the U.S. Navy.

The Navy holds in trust for the American public approximately one thousand piers and wharves constructed, at least in part, of wood and having over 180 miles of wooden fender systems and well over 50 million square yards of wooden decking. There are 130 miles of sea walls, some of wood. The Navy has in use over 1.5 million utility poles and 6.3 million railway crossties. There are over 100,000 buildings of partial to nearly complete wooden construction. No one has totalled the numbers of the many miscellaneous wooden structures such as antenna systems, bridges, cooling towers, fences, firing ranges, guardrail posts, ladders, loading ramps, sign posts, training facilities, and various recreational facilities.

Like the elements of the Fleets, each of the structures of the Shore Establishment have anticipated or established useful lives. The estimates are based on various considerations which include the structural material, its exposure to natural destructive forces, the protection initially given to the material, the need for periodically providing additional protection, and the chances that periodic preventive maintenance will become "deferred maintenance" for the time remaining until the structure fails and requires replacement. Most structural elements in most geographical areas, whether of wood, metal, or concrete, can outlive the "anticipated useful life" if given routine preventive maintenance. Without this maintenance, early failure and excessive replacement costs can be the certain results of neglect. For discussions of projected useful structural life and of costs of replacement and repair, the reader is referred to 6.2.1 and 6.2.2. In 6.2.3 the importance of structural downtime is discussed.

The purpose of Chapter 7 is to provide guidance in the preventive maintenance of the wooden structures of the Shore Establishment. While originally written for the U.S. Navy, the procedures outlined here should be followed by all owners of wooden structures or structural supports.

SECTION 7.2 INSPECTION PROGRAMS AND POLICIES

7.2.1 NECESSITY FOR INSPECTIONS

7.2.1.1 <u>Maintenance Requirements</u>. Inspection programs are essential parts of programs of preventive maintenance and of corrective maintenance and repair. The basic policies for the management of inspection programs for facilities of naval shore activities are set forth in NAVFAC MO-322. This publication states that the shore activity Commanding Officer is responsible for ensuring that an effective Shore Facilities Inspection System is maintained and that corrective action on facility deficiencies is initiated. It further states that since the basis of good maintenance management is "continuous inspection", the Inspection Branch of the Public Works Department (PWD) should be adequately staffed to properly perform the inspection functions.

7.2.1.2 Types of Damage Encountered. The three categories of damage to wood in use are previously discussed at length. They are: mechanical damage (3.1.2), chemical damage (2.6.3, 3.1.1), and biological damage (2.5.2.7 and Sections 3.2, 3.3, and 3.4). For orientation purposes, these three categories will be mentioned briefly here in discussions of inspection programs for various types of structural elements. Mechanical damage and chemical damage can be expected to be found during many inspections, but, except for collision, fire, or storm, chemical and mechanical damage are not normally the reason behind the need for inspection programs for wooden structures or wooden structural members. In most cases, inspection discloses that any existing deterioration is due to biological damage caused by decay fungi, by any of several types of wood-destroying insects, or by marine borers.

7.2.2 INSPECTION PROGRAMS AND REQUIREMENTS

7.2.2.1 Specific Incidents Necessitating Inspection. Orderly management policies dictate that there be some logically based periodicity for inspection of structures and structural components at shore facilities. However, there are situations caused by events such as collision, fire, storm, or attack which necessitate the reordering of usual priorities to permit immediate initiation of inspection to determine the extent of damage to, and the safety or hazard in the continued use of some structures and structural elements. Consideration of a change of primary mission for a particular structure can also necessitate early inspection.

7.2.2.2 Routine Periodic Inspections. NAVFAC MO-322 addresses inspection and provides broad guidance on the scheduling of inspections. In its Appendix B it suggests some minimum frequencies to apply Navy-wide. In its Section 3.5 it states that inspection frequencies must be established as based on experience and engineering judgment. It specifically considers climate. While there are many variables that affect the in-place life of wooden structures and structural components and that therefore affect the need for maintenance inspections, the establishment of the frequencies recommended in MO-322 takes these into consideration. The suggested minimum frequencies are valid.

7.2.3 INSPECTOR TRAINING

7.2.3.1 Understanding the Evidence. There are many misconceptions as to the causes and seriousness of various types of degradation of wooden structural elements observed during a moderately extensive inspection. Many thousands of dollars can be spent unnecessarily, and a required rehabilitation of a vital facility may be neglected due to misunderstanding of an observed situation by an inadequately trained inspector. There are so many technologies involved in some structures that it seems almost inevitable that inspection errors occur even though inspectors are normally very conscientious. It is incumbent upon activity Public Works Officers (PWO's) to assure that their structural inspectors have all the basic training needed, that they are periodically updated on the latest techniques for structural inspection, and that they receive specialty training as available.

7.2.3.2 Availability of Special Training. The Naval Facilities Engineering Command has issued four training films concerned with the biodegradation and the protection of wood in storage and in use. They show and explain procedures, techniques, and equipment for inspection of wooden structures and structural components. NAVFAC Engineering Field Divisions (EFD's) periodically sponsor training seminars in structural pest control, stressing structural inspection. PWO's should assure that their structural inspectors receive the periodic updating and specialty training at these seminars.

7.2.3.3 Availability of Specialty Skills. Often a facility may not have personnel with some of the highly specialized skills required for some inspections. Inspection of a utility distribution system requires use of a trained lineman inspector who not only has the climbing skills and equipment needed, but who quickly recognizes all the various signs of pole degradation to be encountered. For almost all waterfront structures, complete inspection requires divers, either scuba or hardhat, depending on local conditions. Even good divers need special instruction in inspection of waterfront structures for some marine borer attacks. Not all PWD's can justify full-time employment of these specialty skills. However, the lack of trained personnel in the PWD is not a valid excuse for failure to perform certain critical elements of inspection such as those requiring climbing or diving. Trained and equipped personnel are often available from nearby facilities. Competent and reliable commercial inspection companies are also available to inspect under contract to any facility as well as to utility companies and harbor authorities. On request, the appropriate NAVFAC EFD will supply lists of inspection companies specializing in utility systems and in waterfront structures.

7.2.4 INSPECTION RECORDS

7.2.4.1 Historical Records and Plans. These are data available prior to the beginning of a particular inspection to develop new ("current") data (See 7.2.4.2). Short of a sudden structural breakdown, there can normally be no justification for funding and performing previously unplanned maintenance, whether preventive or corrective in nature. There must be inspection records which show the true condition of a structure at one or more points in time. NAVFAC MO-322 covers forms and records in Section 4 of its Chapter 2, and then devotes all of its Chapters 6 and 7 to this most important subject of inspection records. It may occasionally appear adequate or expedient to recommend corrective action upon locating a structural deficiency. Unfortunately, this is sometimes done without reference to previous inspection records which may be required to logically determine the most effective and economical action.

(1) Records. It is as true in the maintenance and repair of wooden structures as elsewhere that to forget or neglect history is to have to repeat it. If we now cover up the problems of the past with the gloss of today, tomorrow we will most surely suffer. The keeping of records is as vital to the effective maintenance of the structures of a shore facility as are proper inspection procedures. Records of other inspections and of maintenance performed and repairs made should be available for detailed review.

(a) Inspection Records. A trained inspector can determine the cause or causes and the extent of structural damage; but without records of previous conditions, no one can determine the rate of progress of degradation up to the time of the inspection. Without records of previous inspections, no one can determine the urgency of initiating pest control and physical repairs for a structure that has undergone some biological damage but can still be used.

(b) Records of Maintenance and Repair. These are as important as inspection records in their usefulness to an inspector. They tell what has been done to a structure since the last inspection. In some situations, past repairs will be obvious, but confusion is the normal result of reviewing only previous inspection records but not maintenance and repair records prior to inspecting a structure.

(2) Drawings, Plans, and Maps. Depending on the type of inspection to be made, plans, drawings or plots, and maps may be needed. Most Navy pest control shops keep records of attack by wood-destroying insects on file cards, one for each building or structure attacked. On the back of each card is a line drawing of the building showing the extent of infestation at a given date, and the extent and date of treatment. Plot plans of waterfront structures must show the locations of all piles and other principal parts of the structure to permit proper orientation of both inspectors and repair crews. Maps are essential to the proper inspections of utility pole systems and to recording observations made. After performance of maintenance or repair, the drawings, plans, and maps should be properly marked to show what was done, and when. They then become part of the shore activity records.

7.2.4.2 Current Records. These contain data just obtained by a particular current inspection, either in progress or just completed.

(1) Plans and Records. The plans and records of the structure (See 7.2.4.1 preceding) provide the baseline data for any current inspection. They must be reviewed prior to beginning physical inspection.

(2) Inspection Checklists. The on-site phase of the inspection should follow the office review of baseline data as soon as possible. A checklist should be made during the review of plans and records and should be used to assure that none of the inspection points are overlooked.

(3) Inspection Report. Complete detailed data from the current inspection should be incorporated into the records. These data allow the progress and extent of deterioration to be determined over a period of time. It is important that data be accompanied by proper plan identifications so that uniform comparisons can be made for each inspection. All evidence of damage should be accurately located to facilitate remedial measures. Whenever possible all applicable remarks and observations should be noted.

(4) Data from Neighboring Structures. Many valuable data can often be obtained from a review of records of nearby structures of similar-type construction. A single structural design fault will often be repeated in a series of structures. If, in one set of quarters, termites gain access to structural wood at the site of a back-filled porch, then in similarly designed quarters, termite damage is to be expected at the same place. If Limnoria enter marine piling in one pier through tide-zone bolt holes, they are to be

expected in a nearby pier if it has bolt holes in the tide zone. Decay in one unventilated crawl-space can be expected to be repeated in all nearby buildings of similar construction. Obtained and studied in advance, the data from neighboring structures can aid an inspector.

SECTION 7.3 BUILDING INSPECTION AND MAINTENANCE

To be thorough, inspections of buildings for biodegradation of wooden structural members or for the potential for such biodegradation must consider all relevant portions of the material previously presented in Chapter 3 pertaining to fungus and insect damage to wood. Equally important are Parts 1, 2, and 3 of Chapter 4. Chapter 6 provides information on the effects of climate on the distribution and destructiveness of various structural pests and on both preventive and corrective action to protect various structural elements.

Each structural inspector should have an in-depth understanding of the contents of Chapters 3, 4, and 6. It can help him trace moisture damage to its source and then recommend the most effective and economical controls. He will know what to look for in walls and trim if there is inadequate roof overhang. He will know that where true water damage exists, such as board cupping or paint peeling or blistering, there may be sufficient moisture to support decay fungi. If he sees poor drainage around basementless buildings, he will recognize that there may be a serious decay problem in the crawlspace area. If he sees rusty boltheads in buildings, particularly in areas near the roofs of buildings, he will know that some of the repeated condensation on the bolts probably soaked into the timbers which may now have serious decay. He will recognize the splash marks on the soil around some buildings and on their lower walls, and realize the potential for decay. He will recognize insect attack as being insect attack rather than mechanical or weather damage or decay. With a little training he will differentiate between attack by termites and by carpenter ants, carpenter bees, and various beetles.

It is normally not necessary for the structural inspector to be highly skilled in the identification of various wood-destroying insects, as he has available the services of a trained and certified pest control supervisor who has a thorough understanding of all structural pests common to his geographical area. Further, if the content of this technical manual appears not to apply to a particular problem, or if a problem solution and other guidance given seem less than adequate, the assistance of a professional biologist should be requested. Guidance in the identification and control of pests is always readily available. Training in this area is also available.

SECTION 7.4 STORAGE AND INSPECTION OF WOOD

7.4.1 BRIEF HISTORY OF NAVY WOOD USAGE. The U.S. Navy has the very best reasons to store and to protect timber and lumber of many species of wood. Initially, the procurement and storage of wood was primarily for the construction and repair of ships and boats. Later, large percentages of the stored material were for the maintenance of shore facilities. A brief historical sketch of events leading to the present storage situation follows.

(a) Early Colonial Period. A principal reason for the early settlement of eastern North America was the abundance of native materials of value in shipbuilding and in commerce. Vast expanses of forest were at hand to provide timber, lumber, and naval stores. In the deep virgin forests, trees grew slowly as they reached for a place in the sun. The southern yellow pine was straight and tall. Its wood was nearly all dense heartwood with closely spaced annual rings and nearly complete resistance to decay. No other of the world's woods then available could surpass its usefulness as spars for masts, and for yards and booms. It could also serve well for ship and boat framing and planking, but some other American woods were even better for these uses. White oak was also available in large stands of tall, straight trees. Dense, strong, impenetrable to water, and therefore nearly decay-proof, it was highly prized for shipbuilding. Another oak, the live oak of the Southeast, is also quite dense and strong. Because of this tree's tendency to branch early and low, and because of the valuable characteristics of the wood, it was used not only for keels and for stem-and-stern posts but was also highly prized for use as knees (natural unions of keels with stem-and-stern posts) for ships and boats. Tamarack was also a valuable wood for keels and knees, as well as for general framing. Black locust was used mostly as a specialty wood where high strength, weight, and durability were important for items such as belaying pins and wheel pins. Naval stores production development paralleled that of timbering. Distillation of pine stumps and slash yielded the resin from which rosin and turpentine were produced. By destructive distillation of pinewood, tars and creosotes were produced. The tapping, or turpentining, of large stands of pine began then and continues today.

(b) Up to the Early 1900's. With the advent of steel ships, smaller and smaller amounts of wood went into new construction and maintenance of ships. This was important to America, as the virgin stands of some species were disappearing, and the faster-growing second growth stands lacked some of the more desirable qualities of the trees they replaced. Not only was America exporting diminishing quantities of shipbuilding timbers, but foreign woods were being imported for use in American shipbuilding. Teak (Tecona grandis) was prized for panelling and decking, even over steel decks. Large amounts of the very heavy greenheart (Octer rodiei) were used for keel blocks and lock facings in dry docks because most greenheart timbers of all heartwood are highly resistant to decay, dimensionally stable, and tough. However, when used for some ship and boat parts, greenheart failed due to destruction by Teredine borers and pholads. It has been used for piling, but is not as good as properly treated pine or Douglas fir. Ligum vitae (Guaiacum officinale) is one of the densest and hardest woods in the world, and is resistant to wear, to dimensional changes, and to biological attack. It finds specialty uses such as in propeller shaft bearings. Ebony (Diospirus ebenum) has been used interchangeably with Lignum vitae for some uses.

(c) After the First World War. Shipyards were stocking not only the commonly used native species but also the more useful imported woods, as these always had to be readily available for ship and boat repairs. After the first World War, large quantities of some specialty woods were stored at naval shipyards, but lack of funds stopped procurement early in the Depression years. The Navy had inadequate funds for its ships' fuel and for ships' crews' pay. At this time international events had considerable impact on the Navy's need for procurement and storage of a variety of woods for many different uses.

After the fall of Manchuria, Ethiopia, and the Rhineland, and after the Spanish Civil War, the German Navy began to grow so rapidly that Britain recognized "the inevitability of war" with Germany. The United States began to update its Navy. Then came the fall of Beijing, Nanking, Austria, and the Sudetenland; and the United States began actively building ships for its Navy. In 1939, Germany and Italy established the Axis, and Albania, Czechoslovakia, and Poland fell. Britain declared war on Germany; and the German U-boats began sinking Allied ships. France declared war on Germany, but waited at its Maginot line. The U.S. Navy manned new ships, and retired some older ones. In 1940 Indochina, the Netherlands, Belgium, Luxembourg, and France capitulated. The United States inducted its first draftees since WWI and gave England 50 of its WWI destroyers. By July 1941 we were arming rapidly; and we had 800,000 draftees in uniform, but we had a shortage of facilities for them.

WWII and Korea. Just before and during WWII, many military installations' facilities were quickly enlarged, and new military installations were created. Wood was in great demand as an important structural material by military agencies and industries in support of the war effort. Further, it was considered essential for packing and crating much that moved by rail or truck. Wood had become a critical war material, and procurement was often delayed by the unavailability of needed grades and sizes. Consequently, military agencies began to increase the supplies of wood on hand, and Navy shipyards and supply centers greatly increased their storage facilities for wood.

Then, in 1946, some military installations were closed. Many wooden buildings were sold, some moved away in sections, and some taken apart to salvage their well-seasoned high quality lumber. The post-war home construction boom led to a greater demand for lumber than could be supplied by timbering, so some military supplies were released to civilian wholesale dealers. The number of personnel maintaining installations and goods dropped dramatically. In many places wood in storage and in many quickly built WWII structures was neglected due to lack of personnel, money, and general knowledge of wood protection.

Many military facilities were reactivated on an emergency basis 4½ years later. By then many of the previously abandoned WWII buildings had been seriously damaged by termites and decay, and lumber neglected in outdoor storage often had to be burned as it could not be used or sold due to decay. The importance of preventive maintenance of materials in storage as well as of military structures had been dramatically proven. But at some Navy lumber storage yards there were many misconceptions about the cause and prevention of losses in storage. It was rare that Navy installations took advantage of the lumber-saving techniques developed by the U.S. Forest Service in which all lumber received was restacked, stickered and strapped, covered until dry, and then given a protective dip in a water-repellent solution of pentachlorophenol for long-term protection in storage. Lumber received for storage was often neglected until required. But in the early and mid-1950's the District Public Works Office began to hire biologists who advised shore facilities of the need and methods for wood protection.

In general, wood stored in shipyards for the maintenance and repair of ships and boats received much better protection than did wood stored by supply centers and depots. This was due largely to a basic difference in attitudes toward wood. In the supply system, wood was something to order, store, and issue. In a shipyard it had always been something to use and to protect. During WWII and the Korean War, more than 40,000 wooden ships, boats, and landing craft were added to the fleet, and during the decades following the Korean War many additional wooden ships and boats were put into service.

Lumber, timber, poles, and piles for the maintenance of a shore facility can be procured in advance of demand and can be economically protected in outdoor storage to be ready as needed. If the guidance herein provided is followed, there will be no storage degradation due to weathering, to termites and other insects, or to decay.

7.4.2 INSPECTION OF WOOD IN STORAGE

7.4.2.1 Inspection of Stored Lumber, Timber, and Plywood. Too often when stored wood products are readied for use, they are found to have been seriously degraded or completely destroyed in storage. Any material worth placing in storage is worth protection, and protection begins with inspection. Lumber, timber, and plywood should be inspected at two-month intervals. These inspections should be thorough in both their physical and technical coverage.

(a) Indoor Storage. Unfortunately, indoor storage is too often reserved for only the most expensive forest products such as plywood and lumber procured for special uses. However, it is often advisable to store lumber under cover when available to avoid rain erosion and frost damage. In a drywood termite area, a casual glance at a load of plywood neatly stacked above the deck on risers may yield no evidence of damage. A very careful visual inspection might possibly reveal some very small, peculiar spots on the edges but these would probably not be noticed. If the deck were not cleaned often, there might be widely scattered drywood termite pellets. But these could easily be overlooked unless the inspector had a strong flashlight. However, if some sheets are lifted occasionally, drywood termite damage would be detected and stopped while the damage is still negligible rather than total. Other wood stored indoors should be carefully inspected for signs of beetle or termite damage. Both hardwoods and softwoods may be attacked in storage by various beetles; or they may have been infested when placed in storage (See 7.4.2.3).

(b) Shed Storage. From the standpoint of inspection for biological degradation of lumber and timber, shed storage is closer to indoor than outdoor storage. If it is not wet by driven rain, procedures for inspecting and handling lumber and timber in shed storage are essentially the same as for indoor storage, except for the lack of a paved deck to more readily permit viewing insect frass and for the readier access to stored wood by subterranean termites. The attention paid to lumber pile construction should be as thorough as in outdoor storage to assure adequate elevation above ground for the inspection and stickering of each stack. However, bundles for shed storage need not be sloped to provide for rain run-off, and individual stacks need not have roofs attached. However, where there are no shed walls, horizontal stacking in stacks nearest to the shed perimeter can lead to decay unless the shed roof overhang is considerable.

Knowing the potential for decay in some shed storage, the inspector should be particularly alert for softening or discoloration of wood stored near the perimeter of the shed for 6 to 9 months or more. Tightly bailed lumber in shed storage for 3 months or longer should be suspected of decay; and the bales should be broken to permit inspection, including use of a moisture meter to help speed the inspection of the wood. If the wood both inside a stack and at its outside has similar moisture readings (less than 30% on an oven-dry basis - See 3.2.4.4) the potential for decay is near zero. But the potential for insect damage is still present, and frass will not be as evident as on a concrete deck in a warehouse. Unless the soil under the shed has been treated for termite control, constant vigilance must be maintained. A two-month inspection cycle will permit detection of subterranean termite attacks before much real damage is done, if concrete pile foundations are used.

(c) Outdoor Storage. In some geographical areas, lumber and timber are as safe in storage outdoors as indoors. Infrequent rains and little or no dew preclude all chance for decay in properly stacked lumber. In areas of frequent rains, lumber and timber in outdoor storage is almost certain to decay unless protected by a preservative dip treatment and proper stack construction. Between the extremes are climates with all possible degrees of hazards.

Providing air circulation by stickering lumber stacks and by stacking timber in open stacks with slopes are as important as the roofs placed on all lumber and timber stacks. Where wind blown rains are frequent, lumber and timbers in even the best-built stacks need protective of dip treatments. The two-month inspection interval for stored lumber and timber should be considered mandatory. In two monthw, weeds can cut off air circulation under and around stacks, and termites can tube over concrete pile foundations. Stain fungi will degrade the lumber, and their presence indicates ideal conditions for the growth of highly destructive decay fungi. Hidden white rot damage may become evident when an inspector pokes his finger into the softened wood. White rot can very easily be detected in wood by the pick test described in 3.2.3.2.

Tight stacking looks neat and saves space, but also usually assures loss of lumber. Some tightly stacked lumber that is heavily decayed would have been safe from decay for many years if first dip-treated and then open-stacked. Outer timbers in the stack do not show evidence of brown rot. An inspection of tightly-stacked lumber requires that the lumber be moved. This provides a good time to change to open stacking which permits considerable ventilation. However, in one case some expensive tongue-and-groove flooring that had been restacked stickered, was then placed in horizontal open storage and neglected. The wetting-drying cycle in the area was well suited to the growth of the brown rot ("dry-rot") fungus which then still destroyed the lumber.

7.4.2.2 Inspection of Piles and Poles in Storage. Piles and poles for Navy use are pressure-treated prior to procurement. In theory, they should accept long-term storage without damage. In fact, storage can often be detrimental. Because poles and piles are stored horizontally, and because the creosote used in treatment, like the oil solvent for penta, will migrate downward (toward the lower side in storage), there can be substantial preservative loss on one side. In very cold weather, there is minimal movement. But on bright, sunny days the very dark wood surface will absorb heat. All poles and piles in storage should be inspected at four-month intervals. At this time they should be rolled 180°. The inspector should note the presence of checks and splits; and he should measure them and check the records of the last inspection to note changes. Termites attack the hearts of treated poles and piles in storage, particularly in thin-sapwood species, by penetrating the checks that have developed since treatment. Rolling the piles and poles will help locate such attacks. It will also permit more even distribution of preservative oils than is normally found after a few months in horizontal storage.

7.4.2.3 Other Wood in Storage. Like lumber and timber, other stored wood is subject to biological degrade. All hardwood items should be inspected at least every six months. It is important to inspect not only hardwood pallets in storage awaiting use, but also pallets in use. Even though pallets with powder-post beetles are deep within a stack of materials, they should be removed from the storage area. The spread of powder-post beetles throughout a supply depot by infested pallets can be stopped if inspection is vigilant and if control measures quickly follow. Tool handles are sometimes heavily infested where produced and packaged. Heavy infestations with complete loss of tool handles may sometimes be found on opening shipping containers after long storage periods. Shipments of hardwood products should be inspected on arrival, and then with routine six-month inspections. Any holes, frass, or undermining of the surface should alert the inspector. Piles of frass may be found below or beside tool handles or hardwood ladder rungs as easily as on or below pallets. Possible termite penetration of storage buildings should also be checked. Where pre-construction soil treatment was not used, hairline cracks give termites access to stored materials. If periodic inspections are not scheduled and performed, damage can be extensive when found.

SECTION 7.5 INSPECTION AND MAINTENANCE OF GROUNDS STRUCTURES

7.5.1 TYPES OF GROUNDS STRUCTURES. In the broadest sense, the term "grounds structures" includes all permanent and temporary structures in or on the ground. In this sense, the term includes roads, runways, culverts, sewers, and even large buildings. This section is not concerned with buildings, but with other predominantly wooden, more or less permanent grounds structures. Decay hazards in grounds structures, and the need for pre-construction preservative treatment are discussed in Section 4.4. This section is concerned with inspection and maintenance for the prolongation of the useful service life of such structures as wooden bridges, retaining walls, antenna systems, roadside guardrail systems, lighting standards, utility systems, railroad ties and crossings, sign posts, and fence posts. Items such as tool sheds and storage sheds are not included here as they are more properly considered buildings from the standpoint of inspection and maintenance.

7.5.2 GENERAL INSPECTION AND MAINTENANCE PROGRAMS FOR GROUNDS STRUCTURES

7.5.2.1 Antenna Systems. The major supporting structural elements of some very large and very important antenna systems are constructed almost entirely of wood. These structures are expensive, and are continuously exposed to the threat of biodegradation. Antenna poles are likely to be purchased as are utility poles, and so are likely to be inadequately inspected (6.3.2.5 - The Meaning of "Inspection"). They are not normally inspected for preservative penetration and retention after procurement and prior to installation. In place, they all too often receive only infrequent and cursory inspections at best. Inspection at five-year intervals reveals incipient decay, and in-place treatment prevents further decay. The lack of inspection and maintenance results in considerable financial waste. Of much greater importance is the operational downtime of affected antenna systems. Antenna poles should receive the same groundline inspection and supplemental treatment as utility poles, as well as full-length inspection and treatment as needed (7.5.3).

Some antenna systems consist of a ring of vertical wires suspended from a horizontal circle of large, composite booms held up by tall wooden poles. The design of the booms may allow water to be trapped internally. On hot days, dark oil-type preservatives migrate to the surface where they are washed away by rains. Without maintenance, these structures decay. This is preventable waste. These structures can be inspected in place, and their useful lives can be extended many years through the periodic application of penetrating preservatives designed for in-place treatment (5.2.2.4).

7.5.2.2 Posts: Fence, Guardrail System, and Sign. Posts are necessary, but often neglected parts of a shore facility. Individually they represent very small investments of time and money. Collectively they are quite valuable. As mentioned earlier (4.4.1.2), sign posts are usually less expensive to replace than fence or guardrail posts because each usually stands alone with its sign while the others are parts of larger systems. Decay in a sign post may occur at the top if the post is untreated and unpainted, or at points of connection to the sign if the post is untreated. However, nearly all really destructive decay of sign posts is groundline decay. Because of the small diameter of the usual sign post, groundline treatment, applied on a routine basis, can help provide a long service life. But the repeated expense could be more than the replacement cost. If posts are treated with one of the non-leaching waterborne salts (5.2.2.3) to the high retentions recommended for ground contact, and then painted, they will retain their strength and attractiveness for many years without any need for supplemental treatment. Inspection on a spot-check basis can assist work-load scheduling by indicating the number of posts that may soon require replacement. Pressure-treated posts can be kept in outdoor storage for long periods if treated with a non-leaching waterborne preservative salt.

Fence posts and guardrail posts are parts of ground structures which have other structural elements in addition to many posts. If some of the wooden posts in a fence are known to be under attack by decay or termites, it is probable that most of the others are or soon will be under attack. Plans should be made for replacement with posts protected by heavy treatment of a non-leaching waterborne preservative salt formulation (5.2.2.3). In some cases it may be desirable, due to labor shortages, to replace only a few posts at a time on a particular fence. In these situations, it is economically advisable to procure all of the pressure-treated posts for the fence at one time, and to then put them into service when most convenient.

At some shore facilities, personnel occupying government quarters are allowed to fence their yards if they supply both materials and labor. In all such cases, a source of pressure-treated fence posts should be provided either free or at cost and only these posts should be permitted. Cheap untreated posts have short lives and so detract from the appearance of the quarters area, and they can greatly increase the termite population in the area.

Posts in guardrail systems are typically the largest and heaviest posts at most shore activities. They may stand for many years almost hidden behind roadside rail barriers without ever restraining a high-speed vehicle; or they could reduce the potential seriousness of an accident the day after their installation. Because of their importance, guardrail posts should be inspected on 2 to 3 year intervals beginning 6 to 8 years after original installation. Inspection should include hammer-sounding, probing around attachments, and a digging groundline inspection on a 20% to 30% basis. Any digging inspection should include groundline treatment as with utility poles

(7.5.3.2). There are many types of guardrail systems, and a variety of wood species, shapes, and sizes have been given all the various types of treatment available. Some of the "posts" for guardrail systems have been locally made by sectioning long poles, thus leaving an untreated center exposed at the top and bottom of most posts. In-place treatment may be economically desirable in some situations (beyond the treatment given during digging inspections). If this is being considered, the advice of a biologist should be requested. Replacement posts should always be pressure-treated with the high retentions of preservatives recommended for ground contact use.

7.5.2.3 Railroad Ties. Scattered throughout the Naval Shore Establishment are approximately 6.3 million ties supporting and anchoring the Navy's rails. Their numbers certainly include most of the more than 21 species of wood in the Standards of the American Wood Preservers Association for crosstie treatment. All the preservatives used for tie treatment in this country in over 50 years are in these millions of ties; and the penetrations and retentions range from the maximum possible to only surface coatings. These ties' present condition is somewhat representative of the original quality of treatment. It ranges from very good to long overdue for replacement. Much has been written on the maintenance of railroad lines. Attention is given to the maintenance of the road bed up to and including such actions as controlling weeds and reballasting. Rail spacing and wear are given critical attention. Plate movement and the spike pulling that permit it are important. Internal decay, splitting, and crushing of ties are considered important. Quite logically, line inspection considers the ties as integral parts of the rail system. Tie replacement and road reballasting are often performed together.

Most railroads have experimented with techniques for the preservative maintenance of ties in service, but little has been really proven to be effective in extending useful tie life in more than a few limited situations. A great many ties have boxed hearts. After shaping, they have end irons attached to prevent excessive splitting during seasoning and in service. Many of the woods used are mostly heartwood that just will not accept preservative penetration beyond a shallow outer layer of the tie and a shallow layer on the inner faces of the checks and the pre-bored spike holes. In the hot sun, creosote-coal tar solutions tend to bleed a little less than the more fluid creosote. The added tar helps prevent rain erosion of surface deposits. Crossties typically decay at depth rather than at the surface. Splits and checks deeper than the treated zone hold the moisture required for fungus growth. Because of the wetting-drying cycle, most tie decay is brown rot (dry-rot) rather than white rot. Spike pulling in ties can be one of the earliest signs of decay. It can also indicate rust damage to acidic woods.

One of the quickest methods of "inspecting" railroad ties is to walk the line with a steel pike-pole. Thumping with the solid end of the pike-pole will usually disclose central decay and loose spikes. Probing into checks and splits can disclose decay. These procedures can indicate which ties are non-supportive and so require replacement.

Various procedures have been developed to extend the life of crossties in service. Good drainage is important, of course, so attention to ballast condition is important. Also, spike pulling due to tier rocking can rub through the treated zone of the wood, leading to decay. Spike pulling can usually be corrected by tamping if complete reballasting is not to be provided soon.

Because checking and splitting can extend beyond the treated zone of ties in service, various in-place treatments have been used. Some have used lightweight "penetrating" solvents for preservatives, expecting that they would reach the extreme internal ends of checks and splits and then, hopefully, penetrate the wood to some degree. Others have been hot solutions of coal tar and creosote used to coat the outer surface of the ties to keep out water and to permit moisture evaporation from the lower tie surface. Still others have involved the use of heavy grease formulations containing preservatives and penetrating surfactants.

Considerable differences of opinion exist within the railroad industry as to the most effective maintenance procedures for protecting ties in place. In consideration of their known effectiveness in protecting other structures, it is believed that the penetrating grease-type preservative formulations will be the most effective in extending useful tie life at considerable financial savings. However, no in-place treatment can save an already hollow tie. Action is needed early on to nip decay in the bud. For specific recommendations most appropriate to tie maintenance in a given area, the advice of a biologist should be requested.

7.5.2.4 Miscellaneous Grounds Structures. The term "miscellaneous" as used here includes all the wooden grounds structures not yet discussed. They are of many different types and serve varied functions such as cooling and lifeguard towers, bridges, boardwalks, bleachers and benches, handball courts; firing ranges, retaining walls and drainage spillways, loading ramps, and tide gates. These structures can have long and useful lives if protected from decay and termites. This requires proper preservative treatment of the wood to be in ground contact. It also usually calls for pressure treatment of all wood for above ground use. For example, bridge rails given no preservative treatment will rot and will have to be replaced. If the rails are of small cross section of an easily penetrated species, they can be given a reasonable service life by a two-hour soak in a water-repellent penta solution. However, such treatment would not save a bridge's heavy timber which requires pressure treatment. Some protection can be provided to structural members that are not painted by laying a penta-grease bead at the joints at during each inspection, or about every two years. The penta grease can be easily applied by a caulking gun. It stays where placed until the wood is dry enough to receive it and can creep well into joints. At the end of a bridge, wood piles may serve to both support the structure and retain the bulkhead timbers. A procurement system with inadequate inspection (6.3.2.5), and lack of further inspection at the construction site may permit the installation of piles with almost no preservative penetration into the wood.

Such possibilities point to the need for periodic inspections of all grounds structures. If detected early, decay in bridge rails can be stopped by saturating with water-repellent penta solution flooded into boltholes. Insecticidal soil treatment will stop termite attack in piles, and heavy applications of penta-grease will give protection from decay to a substantially thick shell of wood. Pouring liquid fumigant into drilled holes stops all decay in piles. Treated wood must be used in the construction of all grounds structures; and periodic thorough inspections and maintenance controls must be made. For the best technical advice in any particular situation, consult a biologist.

7.5.3 UTILITY POLE PROTECTION PROGRAMS

7.5.3.1 Inspection and In-Place Treatment. One large naval shore activity with many miles of communication lines and power distribution lines has so many utility poles in service that one man-year is required for a non-climbing above-ground inspection of all poles with some groundline inspection on a sampling basis. Because of the importance of these poles to the primary mission of this installation, the inspection is made annually. For a number of years, all poles found to be deficient were replaced. It was essential that there be no outages of either power or communications. By using recently developed technologies, this facility can save many utility poles now that previously would have been changed-out. Some work is performed inhouse and some under contract. Through it, the shore facility can now extend for several years the safe and useful life of most of its poles in plant. The annual financial savings are considerable. It is recognized that without an inspection program, the financial savings obtained now by the extension of safe pole life could not be realized. It is also recognized that without the inspection program, power outages could result in severe and sudden material losses, and even in the loss of life, and that communication outages could increase the seriousness of the power outages.

7.5.3.1.1 Inspection Frequency. The average shore facility should have a complete inspection of its utility poles at least every second or third year; but this inspection, while "complete" need not be "thorough." Much has been written about economically desirable frequencies for utility pole inspection programs. There are many variables involved in useful service life, and these variables have very real relationships to the establishment and maintenance of an inspection frequency for the poles at a particular plant. A typical military installation can be expected to have a wider variety of pole species than will the usual utility. But a large company may have several wood pole species in plant, and due to size alone, many large utilities will experience wider variations in climate and in soil types than will military installations. Most naval shore facilities are located in low-lying areas which usually have poor soil drainage, while few utilities average such poor soil conditions. Most utility companies have been forced by the economics of plant maintenance to have complete and thorough inspections at five-year intervals, though some require more frequent inspections for poles in heavy soils in wet climates. In addition to differences in climates and soils, pole species and age of the existing plant are also variables that affect inspection frequency. The one thing that sometimes is, but never should be, considered in establishing inspection frequencies for utility pole systems is the availability of trained manpower. There are many reliable inspection contractors.

7.5.3.1.2 Types of Inspections. Whether performed in house or by contract, the three primary types of inspections would be: (1) visual, with sounding, (2) groundline, and (3) climbing. In addition, other types of inspection can be made such as: (4) scanning, (5) percentage, (6) pole enumeration and description, and (7) infrared. Each serves a particular need. All are available by contract.

(1) Visual and Sounding Inspections. These are two distinctly different types of inspections, but, except for the visual aspects of a scanning inspection (See paragraph (4) below) they are normally conducted together. After the pole plant pole number, the location, and the pole brand data have

been checked (this may have been done earlier as a pole enumeration and description inspection), a non-climbing, visual inspection of all of the above-ground portion of the pole and attachments is made from the ground both with and without binoculars. All defects seen or suspected are recorded. It is noted that the use of a lineman's insulated bucket for examining the upper portion of poles provides data like that provided by climbing, and such inspection from a bucket is not part of a typical "visual" inspection which is normally made from the ground.

The type of damage found by visual inspection will include all types of non-biological damage such as storm damage, vehicle impact damage, loose connectors, and excessive weathering as well as biological damage like woodpecker holes and surface evidence of insect attack. After the visually evident damage to a pole is noted, the above-ground sounding inspection begins. When struck squarely with a hammer, a pole without internal voids or soft spots in that area will ring true with a typically reverberatory sound which indicates that the wood in that area of the pole is without voids. If a dull thud is heard, this is reasonable assurance of a soft spot, while a hollow drum sound indicates a hollow area which might be due to insects (termites, carpenter ants) or to ring shakes (internal separations at annual rings). When the hammer sounding indicates other than normal wood, borings are taken to determine the true condition. Hammer soundings are usually made around the pole from the groundline to approximately seven feet above ground.

(2) Groundline or Digging Inspection. This type of inspection is normally made in conjunction with the previously described visual and sounding inspection. Soil around the pole is removed to a depth of 18 to 24 inches (depending on soil type and usual moisture content), and the exposed portion of the pole is inspected. In almost all situations this is the area of most severe exposure and so should receive the most critical inspection. Several steps need to be taken here. The soil removed is placed on a tarpaulin. The pole is cleaned with a wire brush. It is sounded with a hammer as in above-ground hammer sounding. Groundline boring is usually used to confirm suspected damage and to determine the extent of known damage which may be first found at the time of digging or brushing. Bored holes are always filled with treated wooden plugs, and may first be treated with a fungicide to sterilize the hole.

If the pole is to receive the groundline preservative treatment normally provided with groundline inspection for all poles to be left in place, any soft wood at the surface is usually removed first. It does not support the pole, and it prevents direct penetration of the sound wood by the preservative used for in-place treatment. After the soft wood has been removed, the surface is heavily coated with a "bodied" preservative. This preservative is prevented from soaking into the backfill soil by an oil-and-water impermeable wrap which is attached over the treated area. After the backfilling and tamping, a metal tag is attached to the pole to show the date of groundline inspection and treatment. When a groundline inspection reveals such serious damage that the pole is considered a danger pole and the attached tag should indicate this. The arrow on the tag points to the hazardous end of the pole.

(3) Climbing Inspection. This is a "hands-on" inspection of the pole and its attachments from the pole roof down to the area covered by the earlier sounding inspection. While a lineman's bucket may sometimes be used, particularly on suspect poles, a set of lineman's spikes and belt are usually preferred as

this normally permits a more careful and detailed inspection. A climbing inspection is usually, but not always, followed by in-place preservative treatment. Exceptions to this would be pole plants of approximately ten years of age and consisting of all pressure treated poles which were procured under quality control programs (See 6.3.2.4). Depending on the species of wood, the pole roof may well be most vulnerable to decay above ground. Fortunately, protective treatments and covers are available. Lack of pole top inspection can result in pole loss. Below the pole roof, the areas of attachments should be inspected carefully and should usually be given in-place treatment. Checks typically present the greatest potential for decay of a pole between the upper area of attachments and the groundline because wind-borne fungus spores are easily trapped in the checks which retain rain water long after the pole surface is dry. Depending on the pole species and the type of original treatment, surface flooding with preservative is often advisable. If butt-treated poles rather than full-length-treated poles are installed in drywood termite areas, in-place flooding treatment are an absolute requirement. Further, all thin-sapwood species in drywood termite areas require full-length in-place treatment by flooding after checking has progressed beyond the treated zone regardless of the type of original treatment.

(4) Scanning Inspection. A scanning inspection is a cursory check of poles in plant. It will usually include all or most areas involved rather than be limited in area. A pre-selected number of poles will be checked against property data sheets and checked for presence of species, treatment, and age data branded on the poles. Most of the poles in plant will be "visually inspected" by a passenger in a moving car. A properly performed scanning inspection can be of considerable value where no valid data on pole condition exists, as it provides a sound basis for determining the type and the urgency of the more detailed inspection to follow. In this way it can provide data of value in establishing requirements for contract operations or of use in planning extensive in-house inspections.

(5) Percentage Inspections. A percentage inspection is much like a scanning inspection in its purpose and in the value of the data it can provide, but it differs in method. It involves a detailed inspection of a given percentage of the poles in plant. If there are known differences in age, species, and treatment as well as in value, these factors may be considered in the selection of poles to be inspected; or the poles may be randomly selected. This is a sampling type inspection. Like a scanning inspection, a percentage inspection can give a good estimate of the condition of the average pole in plant.

(6) Pole Enumeration Inspection. In a pole enumeration inspection all poles are checked against station records to determine the validity of the records. It may be rather cursory and involve only counting and checking map locations, if made as part of a scanning inspection. However, a thorough enumeration and descriptive inspection will assure that all plant records are consistent with pole brand data. Such an inspection may supplement data from a percentage inspection to permit the percentage data to more accurately reflect the condition of all poles in plant. If not made at other times, a pole enumeration inspection is usually part of a complete plant inspection.

(7) Infrared Inspection. These inspections are not of the poles but of items on the poles. They easily detect hot spots in lines, connectors, transformers, and substations. They use the thermal image system of thermal differentiation and may be incorporated in a pole plant inspection program.

7.5.3.2 New In-Place Pole-Treatment Procedures. A very extensive research study was conducted over a period of several years to determine the effectiveness of "agricultural" fumigants in the in-place protection of poles and other structures. Conceived and conducted primarily by researchers at Oregon State University, ten power companies and various chemical companies, lumber companies, and pole-treating companies contributed to it. The U.S. Navy also cooperated in the studies, particularly as they apply to waterfront timbers and pile tops. What might have been a relatively simple study was made very complex by the multiplicity of both the species of decay fungi in the different species of wood used for poles and the much larger numbers of non-decay mold fungi species in the wood which can respond differently to the fumigants and which in laboratory cultures can mask the presence of decay organisms.

One technique for pole fumigation involves boring holes into utility poles, putting liquid fumigant into the holes, and plugging them with preservative-treated wooden plugs. Because of the many wood species and use conditions involved, the techniques of this maintenance procedure cannot be given here for the very many potential use situations other than pole fumigation and pile-top fumigation. Because of the considerable financial savings possible from pole fumigation compared to other in-place treatments in some circumstances, pole plant maintenance personnel should contact a biologist to obtain the latest information on this method for prolonging the life of structures in-place, thereby saving considerable maintenance funds.

7.5.3.3 Structural Repairs to Poles. Just as the useful service life of utility poles can be prolonged by the application of chemical preservatives, so can mechanical means extend the useful life of some poles. Because decay at the groundline is more common than decay above ground, there is more need for restrengthening this area. Because the pole structure is normally more simple near the groundline area than in the area of attachments near the top, restrengthing the groundline area is usually much easier than near the top.

7.5.3.3.1 Pole Stubbing. This is the oldest technique in common use today for strengthening the lower end of a pole. In its simplest form a short pole is planted upright next to an in-line pole and bolting or binding the new stub pole to the older pole. The pole stub then supports the older pole and its attachments. Because of the labor costs involved, pole stubbing is usually not considered for poles carrying only limited hardware. However, it has been economically justifiable for large poles, particularly those with transformers or many lines and for those in highly congested areas. Some of the disadvantages to stubbing are the need to place the base of the new stub pole in the ground beside the existing pole with all the immediate physical problems and the later biological problems. Reinforced concrete stubs have been used to prevent decay and insect attack from spreading from pole butts to stubs.

7.5.3.3.2 Trussing. This system of restrengthening and supporting utility poles with groundline damage is usually less expensive and less time-consuming than stubbing, and can be more effective. Galvanized steel sections, usually C-shaped in cross section, are used. A C-truss is secured to the pole and driven to depth beside it. It is then bound securely in place with stainless steel bands. Liquid fumigants (7.5.3.2) can stop the decay in the pole so that it cannot progress upward to where the steel bands secure the pole to the C-truss. From the standpoint of prevention of further biodegradation of standing poles, this use of the C-truss is more effective than is stubbing.

7.5.3.3.3 Woodpecker Damage. In some geographical areas, woodpeckers can seriously damage wooden poles. After making a small entrance hole, a woodpecker can quickly create a large nesting area. An average woodpecker nest can destroy a considerable amount of the needed cross section of a pole. Where woodpecker attack to poles is common, it can be prevented by wrapping the vulnerable areas of the poles with hardware cloth. Where excavations have been made, the pole must be restrengthened or replaced. Before restrengthening begins, the interior wood must be sterilized to destroy any fungus spores. A good way to restrengthen a pole in the area of woodpecker damage is to clean out the nest and cut a drain to assure that any water that gets into the hole can get out. Then, the inside surface must be thickly coated with a preservative grease. After this is done, the reinforcing can be attached.

Another good way to correct woodpecker damage is to fill the hole with epoxy resins--but only after some initial preparation. In this method the full length of the nest is opened up, usually with a hand axe. It is cleaned out, then partially filled with wooden spacer blocks. The area of the pole with the damage is wrapped with a plastic cover which is stapled in place. A highly fluid but quick-setting epoxy cement is pumped into a hole previously drilled down at an angle into the nest area. Within a day, the pole will have regained all of the load carrying ability that it had before the woodpecker attack. However, if wood around the hole was thin, it is advisable to place several drift pins on angles from the sound wood above the hole to the sound wood below it prior to using the filler blocks and epoxy.

7.5.3.3.4 Pole Tops. Because of poor initial treatment; poor inspection, if any, at the time of procurement; and a lack of a maintenance inspection program, some poles are certain to fail. However, many poles with pole-top decay problems can be saved if the decay is not extensive. Paragraph 7.5.3.1.2(3) describes how to protect pole tops by applying supplemental in-place preservative treatments and using protective covers at the pole top. Techniques for the actual restrengthening of damaged pole tops depend on the specific damage situations. Some of the systems in use are:

(1) Posting. In this method a new top replaces the old one, using steel drift pins and epoxy cement. This system is little used and can be justified for only the most expensive poles.

(2) Splicing. Treated wooden reinforcement is bound to or bolted to the pole to strengthen it. This provides only temporary relief.

(3) Reinforcement with Metal Strips. This has been done, but it is no better than reinforcement with wooden strips.

(4) Shortening. If the damage is limited to only a short section of the uppermost part of the pole, and if the attached utilities can be lowered a few feet without strain, the upper section of softened wood can be removed, the remaining wood sterilized and capped, and the utility attachments lowered.

SECTION 7.6 WATERFRONT STRUCTURES INSPECTION AND MAINTENANCE

7.6.1 INSPECTION OF WATERFRONT STRUCTURES. The following material is limited to the inspection of wooden waterfront structures and to the inspection of wooden components of those waterfront structures which are partially or primarily steel and concrete structures. This section is not concerned with inspection of materials other than wood.

7.6.1.1 Inspection Necessity, Policy, and Frequency. Periodic inspection of waterfront structures is an absolute necessity (7.2.1.1). While annual inspections for various waterfront structures are the norm, eight-month intervals would be better for some structures in some geographical areas, and 18 months might be adequate for a few in some other areas. However, the one-year interval is as near to an ideal period as possible for both managerial and technical reasons. Depending on the location of the shore facility, there may be a difference of several feet or only a few inches between high and low water. The time of day, month, and year will all affect the selection of the most suitable periods for inspection in the intertidal zone. Seasonal weather severity can also be important in selecting the time to inspect waterfront structures. In many areas, attack-and-destruction rates are seasonal due to seasonal changes in the weather. However, the actual speed of fungus spread through wood, or the rate of destruction by various marine borers are factors that cannot usually be determined from a single inspection and so should not enter into selecting times for annual inspections. Extraordinary inspections should be made immediately when special situations have been noted such as large numbers of flying insects (i.e., termites, ants, or beetles) near a pier or wharf in emergence and mating flights, or evidence of insect or marine borer attack, e.g., easy destruction by man or machine of thin wood surfaces over damaged areas.

7.6.1.2 Inspector Requirements

7.6.1.2.1 Inspector Training

(1) Previous Material. Paragraph 7.2.3 addresses inspector training in some depth, but this discussion assumes that the facility inspectors are adequately trained to inspect waterfront structures or that inspection will be done by contract. As previously explained (7.2.3.1 and 7.2.3.2), special training to periodically update inspection skills is readily available and should be exploited. Paragraph 7.2.3.2 explains the availability of specialty skills, such as those required for underwater inspection, and this material should be reviewed when considering inspection of waterfront structures. Paragraph 7.2.4 covers historical and current records and plans, and the need for their review prior to, as well as during an inspection, and stresses the importance of detailed and accurate recording of all substandard conditions. This material will not be repeated here, but will be expanded.

(2) Training Films. Four Navy training films describe wood-destroying organisms and demonstrate methods for inspecting and protecting structures from them. They are: MN-8167A, "Inspection for Wood- Destroying Organisms"; MN-8167B, "Control of Wood-Destroying Organisms"; MN-8167C, "Effects of Marine Organisms"; and MN-8167D, "Control of Marine Organisms". The latter two are devoted entirely to problems of waterfront structures and the need to protect them from biodegradation. Film "C" shows and explains the life history of

each of various types of organisms that destroy waterfront structures. Film "D" provides step-by-step training in the inspection and maintenance of these structures for the various organisms and their damage. This manual does not repeat the material provided by these Navy training films and so does not detail an inspection step-by-step. Rather, it gives listings, reminders, and information on how to best determine the presence and activities of some of the organisms previously described (3.2, 3.3, 3.4, 4.5, 4.6 and 4.7).

(3) Special Inspection Skills. Thorough structural inspections of almost all waterfront structures require diving inspections. A highly-skilled inspector could become proficient at SCUBA diving for this purpose; the cost of lessons are reasonable. However, hard hat diving is required to inspect most Navy structures, and the costs of training an inspector for hard hat diving would never be recovered unless there is a nearly continuous, year-round need for diving inspection at a complex of structures. On the other hand, a professional diver can be trained in a short time to recognize and identify biological damage. It is normally much more economical for a diver to become an underwater inspector than for an inspector to become a professional diver.

7.6.1.2.2 Inspector Availability. The various requirements for inspector training have been discussed. Equally critical is inspector availability. NAVFAC MO-322 discusses availability of inspectors and mentions contract inspections. If the Inspection Branch is not staffed to perform all required inspections, neglecting or postponing some inspections is not an acceptable substitute for maintaining the established inspection schedule. There are competent inspection contractors to perform the required evaluation of waterfront structures. In some cases, it may be desirable to have the contractor perform all inspection below the high tide line, and to have the facility's inspectors concentrate on the above-water portions of the structure. However, this type of split responsibility requires careful coordination.

7.6.1.3 Inspection Planning.

7.6.1.3.1 Natural Conditions. Tides and weather must be considered in long-range planning for inspections of waterfront structures. Inspectors are outdoors and exposed to the weather. Some above-water inspection requires working from a boat or floating platform to inspect the underside. To be thorough, the intertidal inspection, often made in conjunction with the above-water inspection, requires considerable exposure to the water. The diving inspection requires not only that the diver spend long periods in the water, but that his tenders and recorders be exposed to the weather. In northern climates, the period from late Spring to early Fall is usually chosen because of air and water temperatures. In locations with very little tidal range, planning for spring or neap tides can usually be neglected. But, for most areas, attention is given to the phase of the moon, because the intertidal zone inspection can be made only during the extreme ranges of the spring tides occurring at or shortly after new moons and full moons. For a diving inspection, the neap tides of quarter moons are often the best where the tidal range of spring tides is considerable. Since storms are not yet subject to long-range forecasting, and since they can delay the start or prevent the continuation of waterfront structure inspections, contingency planning should always provide for alternative inspection times.

7.6.1.3.2 Availability of Structures. Waterfront structures exist to be used, and when they are in use, inspection of all but top-side structural elements may be prevented. Even then, much of the deck may be in use. Advance planning for annual inspections of waterfront structures must consider planning for use of these structures.

7.6.1.3.3 Personnel Availability. Annual inspection planning must always include planning for the presence of the inspection team at the selected time. This is particularly true for diving inspections. Navy diving teams and contractor divers usually make their plans many months in advance, and they will adhere to their advance plans except for emergency situations. After natural conditions and the availability of the structure are considered, firm commitments must be made to have the required specialists present.

7.6.1.3.4 Assembling Equipment. If planned far enough in advance, assembling inspection equipment is not difficult. The items most commonly required are listed below. Not included are special items required for diving inspections.

(1) Hammer, straight claw
(2) Hatchet
(3) Paint scraper, heavy duty
(4) Scrub brush, small, kitchen type
(5) Increment borer or auger
(6) Container for specimens
(7) Treated wooden plugs
(8) Prybar or wrecking bar
(9) Saw
(10) Sharp probe (ice pick or sharpened screwdriver)
(11) String level and cord (with nails)
(12) Steel tape measure
(13) Folding carpenter's rule
(14) Measuring calipers
(15) Sounding line
(16) Flashlight
(17) Low-power hand lens
(18) Camera
(19) Notebook or covered clipboard
(20) Boat or platform, with lines and locomotion
(21) Divers special needs

During waterfront structure inspections, tools have often been lost, most over the side. One hammer was lost when it fell deep within the hollow center of a fender pile when the inspector struck the weathered and checked pile top which shattered and fell into the hole resulting from complete decay of all of the wood above high water except for the treated shell and the top which had been given in-place treatment after cut-off and before checking. Inspectors crawling around and under structures or working from a dinghy where subjected to wave action will occasionally drop tools. If a dropped tool is attached by cord to the inspector's wrist, it will not be lost. Holes should be drilled or deep notches cut into the tools to attach the security cords. If this is not done, there must be a complete set of standby tools, or the inspection team will be idled while awaiting tool replacement.

7.6.1.4 Above-Water Inspection.

7.6.1.4.1 The Structural Elements Involved. An above-water inspection determines in detail the condition of wooden structural members above the high tide line. It involves working from the deck, sometimes on a ladder; working over the side, either suspended or on a platform; and working on a floating platform under open (not filled) structures. The annual inspection must include a detailed determination of the condition of each support, batter, and fender pile, of all understructure timber cross-bracing and diagonal bracing, of all wooden fire walls, and of all pile caps. Depending on previous experience with a particular structure, stringers may be inspected every other year; but if this is done, it should be on the basis of every other stringer in line rather than on one half the pier. If there is solid fill or pavement above the planking on the stringers, then it is most important that all stringers and the planking above them be very carefully inspected each year since they are particularly vulnerable to decay in such positions.

Depending on the conditions reported one year prior to the current inspection, it may or may not be necessary to inspect all curbs, wales, and chocks, and all curb blocks. However, special bollard support timbers should be inspected every year as should all hatchways and covers. For most structures it is sufficient to carefully inspect 25% of the timbers and give a cursory check to the others. However, when the extent of damage noted on a sampling inspection indicates a need for maintenance or repair, each plank should be inspected. If there is patching, or if there has been some replacement, complete and careful inspection should be made. Double decking, such as two layers of planking or treads over planking traps water and so creates a particularly high decay hazard. Where probing and drilling can be used to determine the condition of the sub-decking, this should be done from above and also from under the structure where the spacing of stringers permits. Where probing and drilling cannot satisfactorily indicate the extent of decay, the subdecking can be accessed by removal of some top-decking pieces on a sampling basis.

7.6.1.4.2 Determining the Structural Condition Above the Tide Level. Inspection frequencies and timing, training for inspections, required inspection tools, and the structural members to be inspected have all been explained. Guidance on finding biologically-caused deterioration conditions now follows.

(1) Insect Damage. Above the waterline, insect attack to waterfront structures can be quite destructive, and its repair can be expensive. Most wood-destroying insects discussed earlier (3.3 and 4.6) either do not attack wood used in waterfront structures or attack only rarely, and then, do little total damage. In contrast, individual nests of carpenter ants are occasionally found in some of the heavier timbers of waterfront structures when the wood is hammer-sounded by the inspector. More often, carpenter ant activity would be noted by someone working at the pier or wharf, and the Pest Control Supervisor would be notified. He would then control the ants and would tell the Inspection Branch Manager where the damage was done and whether, in his opinion, the damage was extensive enough to warrant a careful inspection. The decision to inspect now or to wait for the next annual inspection would then be the responsibility of the Inspection Branch Manager. These situations are quite rare. There is no one particular part of a structure to which an inspector should give particular attention in consideration of carpenter ant damage.

Like carpenter ants, carpenter bees normally do not single out particular parts of a structure and so are not usually sought during inspections. Carpenter bees occasionally have been troublesome when their population in a given waterfront area has increased significantly. A single female carpenter bee will excavate only a few brood chambers to stock with food for the larvae that will hatch from the eggs she places there. However, several thousand of these bees all boring their typically deep and large diameter holes in the same area can seriously weaken wood. This may be noticed first by the inspection team if they are on-site at the right time, or people who fear bumblebees may report a heavy infestation. Pest control personnel would recognize the pest as a carpenter bee rather than as a bumblebee.

Not very many of the wood-destroying beetles damage waterfront structures much. The Old House Borer can do extensive damage to the sapwood of large pine timbers if they are not preservative treated. Various other beetles are occasionally destructive to a limited extent. The one beetle most often found damaging waterfront timbers is the wharf borer, Nacerda mezanura. Wharfborers and wharfborer damage may occasionally be found in wood that does not appear to be particularly moist. However, they are most often found in wood which is frequently wetted and so remains moist. Nacerda damage will rarely be recognized for what is because it has the appearance of decay. When the surface of Nacerda damaged wood is scraped away, the material beneath it may be a pasty, brownish layer in which creamy white larvae and pupae are found. All wood at and near the water line should be probed to find any softening which might indicate Nacerda attack. If the wood is soft, and if it seems almost muddy when wet, Nacerda damage should be suspected. Active larvae should be sought, and any insects found should be preserved and held for identification.

Of all insects, termites are the most destructive to waterfront structures (3.3.3.2.3). Drywood termites have only small colonies with few active members, but where these colonies are numerous, they do extensive damage. The Formosan termite, Coptotermes formosaraus, is extremely destructive wherever found. In the United States this termite is limited to Hawaii and to the New Orleans area. The reproductives, workers, and soldiers are larger than those of most other species. This species reproduces rapidly and its colonies become very large. They construct underground tunnels many yards long which have very hard, waterproof walls. A single colony can extensively damage a wooden pier. While the Formosan termite is categorized as a subterranean termite, it will establish colonies wherever wood and moisture are close, and there are all too many water-trapping locations on most waterfront structures. Coptotermes has initiated attack on parts of waterfront structures at some distance from the shore. Unlike the larger Coptotermes, the more common true subterranean termite, Reticulitermes sp., is almost always found nesting in the soil, but even these true subterranean species found in our coastal areas are not always truly subterranean. They are occasionally found on piers with no soil connection. Often when pier stringers must be replaced, the damage should have been found during inspection several years earlier while termite controls could have been used to save the timbers. This is one of the reasons why hammer-sounding and probing are important parts of an inspection.

(2) Finding Decay and Evaluating Damage.

(a) Unpaved Decking. On a structure with unpaved decking, the wooden decking is the most natural place to begin the annual inspection. The inspector must look for various conditions to evaluate the decking. Poor construction practice leaves no spacing between the deck planks to permit rapid water runoff. The small spaces inadvertently left soon fill with debris and other dirt. The temporary ponding of water on parts of the deck greatly speeds surface decay, though in keeping the planking from drying between rains, it may reduce the deep checking which leads to early internal decay. If an inspector understands the nature of decay in decking, he may realize that while the decking "doesn't look bad" from above, further delay in the in-place flooding application of preservative materials would certainly result in the early need to replace a pier deck.

The decay hazard inherent in double-decking was mentioned earlier (7.6.1.4.1). This type of construction requires dedication, diligence, and physical effort from the inspection team, for it is often necessary to remove portions of the upper layer to determine the presence and extent of decay. Where decking prevents determination of the physical integrity of the structure, at least some of the decking must be removed for a sampling inspection.

(b) Paved Decking Over Wooden Planking. An Inspector may be reluctant to remove paving to inspect timbers, ties, or deck planking beneath it, but this must be done at times. Deck paving cracks when the supporting material is failing. Unless some heavy load such as a locomotive or a crane is placed on the structure, there will normally not be large cracks, and only fine hairline crazing of the paving may exist for the inspector to see. Since the hairline cracks easily become filled with dirt, they are often not seen unless the pavement is washed on a sunny day; then the cracking is easily seen as the pavement dries. In one case of long-delayed inspection of deck planking, early detection of the decay would have allowed removing the paving and applying preservative in-place. The paving contributed no structural strength, so it could have been left off after the in-place treatment of the wood. Its purpose had been to protect the wood from wear, but it was a principal reason for the loss of the entire deck. Since the decking beneath the pavement had not been inspected until most of the structure began to fail, this pier could not be used until new construction could be funded and completed. This may be blamed on decay fungi, but it was the result of poor construction practice followed by a complete lack of inspection by trained personnel. Another case of failure to inspect beneath paved decking until after failure of the structure required that the very heavy stringers as well as the heavy planking above them be replaced. Removal and replacement of some pavement annually at the time of the thorough structural inspection would have been an extremely small cost compared to the required structural rehabilitation.

(c) Stringers, Pile Caps, and Bracing Timbers. In all cases where deck planking has been spaced sufficiently to permit rapid rainwater runoff, the tops of stringers in the spaces between the planking can be inspected with sharp probes and increment borers. The holes should be filled with treated plugs or hot tar. This area of most stringers can also be inspected by boring at an upward angle in the upper 1/3-to-1/2 of the stringer. Upward boring is usually safe in most structural members because a hole so bored does not hold water. So, though it has penetrated the treated zone of the wood and the untreated interior, the good drainage means no decay. However, holes drilled upward to the top will open up the interior to moisture. As a decking spike can ruin an increment borer, the inspector drilling upward into stringers will need guidance from an assistant topside to locate and avoid spikes. If an adequate inspection is made annually, extensive and expensive decay damage can be prevented. Some species of wood (Table 5-1) which provide timbers with excellent physical characteristics are quite difficult to penetrate with preservatives (5.1.2). In general, these species can all be satisfactorily used for waterfront structures if proper construction practices are followed and if the needed inspections are made. Preventive and corrective measures are explained in Part 7.6.2 of this manual. However, timely corrective action can be taken only following a routine annual inspection at which time the earliest stages of the damage can be reported.

(d) Curbs, Wales, and Chocks. As a general rule curbs, wales, and chocks will begin to decay at checks and where cut and drilled. In some wood species, checking will rather quickly penetrate the treated zone. Deep checks and splitting often originate where mooring cleats are attached due to the twisting stresses caused by the mooring lines. During annual inspections, occasional borings should be taken to determine depths of preservative penetration, and probes should be used to determine depths of checks. When checking extends into untreated wood, this should be reported at once so that treatment may be applied before the hyphal threads of decay fungi starting at or near the bottom of a check have extended into the wood further than the fungicide for in-place treatment can penetrate to kill them. A lap-joint will rot out quickly. During an annual inspection, this type of joint should be recorded for in-place application of preservative to be made to prevent the otherwise inevitable loss. When a timber, reasonably well-penetrated with preservative, is cut on the job, supplemental treatment must be provided for the cut end. Lack of this supplemental treatment should be apparent at the first annual inspection. If the lack of in-place treatment is reported then, the life of the timber could be extended for many years at almost no cost.

(e) Fender Pile Tops. Neglect of pile tops is common. Good practice can prolong the life of the piles for many years (4.5.1.5). All fender pile tops should be vigorously struck by hammer to locate any softening beneath the top. If this test indicates that the wood is less than sound, borings should be taken to determine the extent of soft wood. (Note: Do not attempt to use an increment borer lengthwise with the grain of the wood - as from the top down.) Even hollowed-out piles can now quite often be saved and restrengthened in place, but inspections must be thorough to provide the details required to plan piling rehabilitation.

(f) Under the Pier. Inspecting above the waterline under a pier or wharf is at least as important as inspecting topside, but is often much more difficult. Considerable agility is often required for hammer-sounding, probing, and boring the support and batter piles near their tops as well as the pile caps, stringers, and bracing timbers. Movable scaffolding is often required. The specific location of any softening of wood as well as any more obvious signs of decay should be reported. Usually, the pile bent number and its location within the bent are recorded as well as the particular or individual items and the elevations measured above or below an established datum line.

7.6.1.5 Tide-Zone Inspection. Since diving equipment is not required, this inspection is usually made in conjunction with the above-water inspection.

7.6.1.5.1 Insect Damage. Insect damage may be found in the upper end of the tide zone and in the splash zone above it. Whenever soft wood is found in this area it should be removed. Soft wood supports nothing but trouble, and it can hide the cause of some trouble. Scraping away soft brown wood of an almost muddy appearance and texture can often uncover Nacerda larvae.

7.6.1.5.2 Marine Borers. In cold-water harbors or in polluted waters, softening of wood in the tide zone and the splash zone may be caused by soft-rot fungi. But in areas where crustacean borers are active (3.4.3) they will destroy the surface of untreated wood so quickly that an inspector will normally not find any soft-rot. Molluscan borers (3.4.2) may be found in the lower third or half of the tidal range in cold waters that do not support the very active crustacean borer Limnoria tripunctata (3.4.3).

7.6.1.5.3 Limnoria Damage Pattern. In most areas where Limnoria are active, they will be found in the tide zone. They may also be found from the splash zone clear down to the mud line. In only very unusual water conditions will Limnoria be found only below the low tide line. Generally, two basically different types of Limnoria attack are found in and near the tide zone. One is the very evident attack from the surface inward which causes the so-called "typical" Limnoria attack. However, "typical" means different things in different areas. Where the tidal range is very limited (often the case in tropical waters), and where limited water exchange in a given harbor makes the oxygen content of the water most suitable near the surface, Limnoria damage to a pile may be limited to the tide zone and heaviest where the water surface remains longest each day. The damage may closely resemble beaver damage to a tree at water's edge. However, where the tidal range is considerable, the length of the "hourglass" area is longer than usual.

Much that has been learned about what permits one Limnoria species to attack and destroy heavily-creosoted wood in some warm-water harbors is being used. In some areas, this borer cannot attack creosoted wood from the surface inward and so does not produce "typical" hourglassing. Instead, it destroys piles in the tide zone by entering bolt holes beside the bolt (that should never have been placed in the tide zone), hollowing out the pile's interior untreated wood, and then working outward toward the surface. This is the case with many well-treated Douglas fir piles with heavy retentions of good quality creosote in the treated sapwood zones. The creosote apparently won't leach outward from the pile's surface where the concentration of creosote is heaviest in the wood cell structure; but it does slowly leach inward into the less heavily treated areas and is "pumped" out of the cavity with the tidal changes. As the preservative in the wood diminishes and the Limnoria remain active, the interior cavity grows. Finally, there is no wood left. It is not just bolt holes that provide access to untreated interior wood; any cutting of the wood for inletting bracings have the same destructive result, and the inspector should be alert for this. The development of large Limnoria populations considerably speed the attack at bolt holes and dapping in the ends of diagonal and crossbracing timbers in the tide zone. The cut ends of these timbers are usually in the tide zone; and though they were very well treated for their wood species, they have untreated centers. These centers are quickly hollowed out, and the borers follow the bolt holes to the pile interiors. The inspector should probe all braces with hollowed-out ends to determine the extent of the damage. It may be necessary to bore the wood in two or more places. The penetration into the timbers is certainly worth recording carefully because there are relatively inexpensive corrective controls available to replace the lost strength of the structural members and stop Limnoria damage.

Sometimes the attack on a pile is uneven, covering patches of the surface and working inward from them, indicating very poor and uneven treatment. This pattern is typical of incomplete removal of the cambium layer from the logs when they were barked, revealing a lack of quality control or user inspection of the piling. In contrast, an inspector may find new attack by Limnoria covering large amounts of the surface but not yet extending to any real depth. This usually indicates a relatively even treatment of seasoned piles, but too low retentions of a poor preservative. The inspector should carefully note and record the type and degree of damage to each pile and to each bracing timber. Maintenance procedures, explained later in this chapter, make it quite economical to rehabilitate a pile rather than to pull and replace it.

7.6.1.5.4 The Difficult Basis for Decision. The inspector may find many bad piles and timbers; but some or all of them may be rehabilitated at much less cost than replacement. Sometimes most piles of a pile bent may be destroyed by Limnoria in the low tide zone, but from the high tide line up they are in good condition. If the piles are to be replaced, the rock fill must be removed to permit removal of the buried pile stubs and the driving of new piles. Depending on what preparatory work must be done topside for driving, it might be less costly after removal of the stone to expose the stubs and post the piles, replacing the destroyed section (7.6.2). The inspector will not decide which is the most economical action, but a logical decison requires his report. A Limnoria attack in the tide zone may also severely damage and cause failure of sheet piling, or fill may wash out from under the pavement at the shore end of a pier. Early action is needed. These situations must be corrected and can be handled by any one of several methods. As with the first situation, the inspector plays the most important part in selecting the best and most economical corrective measures because the selection must be based on his report.

Sometimes an inspector must work in hazardous conditions to get the needed information. Over a period of years, floating oil has been carried by the tides to wash against and coat the stones, the piles, the bulkhead, and debris. What would be poor footing if dry now has both oil and water to increase the hazards in both walking and crawling. Portable lights, inspecting equipment, and notebook must all accompany the inspector.

7.6.1.6 Diving Inspection.

7.6.1.6.1 The Diver's Job. An in house or a contract diving team may inspect wooden structures below water. They seek the same type of molluscan and crustacean biological attack and degradation that is sought in the tide zone. The teredine damage may be much greater than in the tide zone, and the crustacean damage may well be much less. In one case a diver saw Limnoria damage in the tide zone initiated by a camel-log rubbing against fender piles. The zone of preserved wood was finally worn through, and the Limnoria attack began, hollowing out the untreated wood in the tide zone. There was good preservative treatment but the piles were neglected in place when they could have been inexpensively protected.

A diver determines and reports the extent of damage to each pile from the waterline to the mudline to facilitate logical repair and replacement decisions. To inspect for the presence of teredine borers, it is often necessary to scrape off their heavy fouling and to wait for emergence of the siphons. Sometimes, when there is little fouling, teredine holes can be seen because of a ring-like, whitish calcium carbonate deposit on the darker wood surface around the hole. The diver should pay particular attention to areas around wood knots. If some large knot swells on Douglas fir were shaved down prior to treatment, there may be quite a few annual rings of heartwood surrounding the knot at the pile surface. As the heartwood is not penetrated by the preservative, the surface coating around the knots will soon wash out. It is here that Bankia can do serious damage. Bankia setacea entering at a knot area can encircle the pile beneath the surface rather than moving vertically and so can greatly weaken the pile. Pholad holes usually will be more readily visible than teredine holes because of their larger diameter, but removal of fouling will often be necessary for a diver to find pholads. Small wood chips cut from the pile surface can help confirm suspected teredine holes when they are seen better above water. In addition to scraping, brushing, and chipping, taking borings is sometimes advised. For borings the diver will need a power drill and treated wooden plugs or an epoxy resin mix to fill the boring holes.

7.6.1.6.2 Sonic Inspection Equipment. Probably the most effective method for inspecting marine piling for teredine damage underwater is sonic testing. A transducer introduces high frequency sound into a pile. The sound travels vertically and reverberates at points, leaving the pile to be detected by a transponder at a fixed distance. Since the speed of sound in water and in wet wood differ, voids in the wood are quickly detected and accurately located. The unit is moved around the pile while the diver and recorder are in constant communication. The technique is so sensitive that it has detected simple Bankia holes in piling. Use of the equipment requires a team of two men. A diver must tend the equipment in the water and a recorder is required on a floating platform. Sonic inspection team services are available.

7.6.2 MAINTENANCE AND REPAIR OF WATERFRONT STRUCTURES. Considerable information on preventing decay in various parts of waterfront structures was given in Sections 4.5 and 4.7. This section covers only maintenance and repair, and presents materials and methods developed and proven within the last thirty years. There has been some repetition of statements made earlier in this manual; avoiding all repetition would require such excessive referencing of previous paragraphs as to burden the reader seeking information. Paragraph referencing will be used at times to remind the reader of broader coverage of a particular subject in previous sections.

7.6.2.1 Topside Maintenance. The Navy's financial losses due to deterioration of waterfront structures are considerably greater for above-water damage than for damage to the supporting piling. These losses are preventable.

7.6.2.1.1 The Timber Deck. There is no reason for timber decking to ever decay if it is properly constructed and maintained. Briefly, proper construction requires pressure-treated wood (NOT treated with creosote or heavy oils for decking), proper design (spacing to prevent water-trapping), and on-the-job treatment of all cuts (including drilled holes) with deeply penetrating preservatives. Maintenance, normally to be based on the results of thorough annual inspections, should always include flooding treatment of decking on a schedule that will keep up with the depths of checking and stay ahead of soft-rot damage at the top surface as this surface is worn away by traffic. Pentachlorophenol solutions with penetrating solvents are usually as suitable for this as any other materials. An exception is a pier deck subject to considerable salt spray. Salt can react with pentachlorophenol to produce sodium pentachlorophenate which, though an effective fungicide, is water- rather than oil-soluble and so can leach from the wood if it is washed often with water.

It is very economical to provide penta flooding treatment for deck planking. Penta soaks into checks to help prevent deep decay, and it stops the softening caused by surface soft-rot fungi where the original treatment has been worn away. However, there is no economy in treating dirty, debris-strewn planking. The decking must be cleaned in advance of treatment. Often the best cleaner is high-pressure water, but the wood must be allowed to dry thoroughly prior to treatment, even deep down in the checks. Heavy flooding of deck timbers with a penetrating penta formulation can produce very desirable results, but if care is not taken, it can pollute the harbor waters with a potent biocide. Where this treatment is planned, tarpaulins, painters' drop-cloths or other splatter catchers should be suspended under the portion of the pier where the deck is being flooded. Some penta solutions are formulated with resins and waxes to provide water-repellency to dip-treated wood. This will make wood water repellent, but not waterproof. As explained earlier (5.2.1(11)), this is desirable for some wood uses, but such WR formulations should not be used for flooding treatments of pier decking or other places where the treatment is to be repeated. They do not prevent standing water in checks from soaking into the wood, but they do tend to block further penetration of the wood by more preservative formulations.

At all tight joints in decking, such as closely abutting deck timber ends, a bodied preservative should be applied just as it should be applied to the more exposed ends of deck planking. In the interest of saving time, a power grease gun with extension hose and a 12-to-18 inch metal wand should be used to apply the bodied preservative. As explained in the following material, the grease gun for applying bodied preservatives will find many uses on the pier. If the deck had been constructed properly with well-treated wood and given on-the-job treatment of cuts, the annual maintenance flooding and grease gun treatment should ensure many long and useful years of service at low cost. If the deck was improperly designed, incorrectly built, and contains poorly-treated wood, the maintenance treatments described here are absolute necessities; and in such cases, the costs of these maintenance treatments will be returned many times over in extending the useful life of the pier deck.

7.6.2.1.2 Curbs, Wales, and Chocks. Part 3.2.3 covers decay generally, and 4.5.1.4 explains the need to protect curbs, wales, and chocks. 7.6.1.4.2 explains the decay pattern in these structural elements, and mentions in-place treatment. As with deck timbers, the service lives of these other topside timbers can be extended with financial returns greater than the cost of the maintenance treatments. There is no secret--no magic. All that is required is the proper application of preservatives, and their reapplication on a maintenance basis. Even pressure-treated timbers probably have untreated interiors which decay, leaving only hollow shells of treated surface wood. Whenever, wherever, and however these timbers are cut on the job, they should be treated. In-place treatment of some well-weathered and treatable sapwood can show some remarkable penetration, but the heartwood of some species that is difficult to treat with heat and pressure is not easy to penetrate when it is part of a pier or wharf. However, surface flooding of cuts helps, particularly when repeated; and some of the bodied formulations on dry and sun-warmed wood can very slowly penetrate to depths equal to some pressure treatments. Some of these, when applied at the edges and corners of structural joints, show remarkably good creep into the intrajoint space and so into the wood.

Sometimes for the treatment of the tops of curbs, grease-type materials should be avoided for safety because people sometimes step up on curbs. Where a real safety hazard exists in using grease-type preservatives, the tops of the curbs should be heavily flooded to fill all checks and to continue to refill them as long as they accept the fluid unless the check joins a bolthole or a split and so lets the liquid escape. As with flooding checks in deck planking, water-repellent preservative formulations should be avoided. Wide checks, splits, cuts, and holes should be filled with a bodied preservative, but not so over-filled as to create safety hazards. Checks on the sides of curbs should also be filled. If the curb is directly atop the deck planking, a heavy bead of bodied preservative should be placed wherever possible. If the curb is supported above the decking by blocks, the joints between the curb and the block and between the block and the deck timber must be treated. The edges of the block also need to be treated. Where the curb is bolted, the boltholes require treatment. They may seem inaccessible, but a ring bead on the wood at the bolthead will creep. If replaced often enough until creep stops, grease-type formulations can preserve the wood. Beads repeatedly placed around the bases of bollards and cleats will creep under them and into the boltholes in the curbing timbers and so help to provide long and useful curb life.

On small wooden piers there may be timbers comparable to curbs, but directly below the timber decking and in line with the curbs. These timbers are usually bolted to the curb timbers through the decking. In this type of construction, the curb timber may be called the upper string piece, and the corresponding below-deck timber may be called the lower string piece. This lower timber, not exposed to the sun on its topside, will have less checking. It cannot be flooded as can the curb top, but its life can be extended by placing beads of bodied preservatives at all cuts and joints.

Wales, or walers, are horizontal timbers usually, but not always, related in some way to berthing. A wooden bulkhead wall may have as many as two upper and two lower wales. In this case only the outer two would be seen after filling behind the wall. Mechanical fender systems may use one or more wooden wales as expendable rubbing strips. Depending on their construction and intended function, piers may have from one to four wales on each side of the pier. There may be two upper and two lower wales. Where this is true, one upper will be inboard of the fender pile and one outboard. At the upper waterline or in the tide zone there may be one inboard and one outboard wale bolted through the fender piles. There may be only one wale, an upper inboard timber which is sometimes called a bull-rail or a bull-timber if it is the primary upper attachment for the fender piling. Like lower string pieces, upper wales, both inner and outer, should be given the same maintenance treatment as upper string pieces or curbs. Top surfaces should be flooded. All checks, joints, cuts, and boltholes should be treated with slowly penetrating bodied preservative formulations. Lower wales should be given protective, on-the-job treatment during construction (not with pentachlorophenol). After the wood has become water-saturated it will not absorb any preservatives now in use for maintenance treatments.

Chocks are short horizontal timbers cut to fit between fender piles. They help prevent lateral motion of a pile during berthing. Many waterfront structures have upper chocks. Some have lower chocks attached to one or two lower wales. Individually these are the least expensive timbers to replace. Collectively they have considerable in-place monetary value that can be protected by in-place treatment. The procedures used for all of the other topside timbers will work well to extend the lives of chocks. Per linear foot of timber, chocks require more total bodied preservative than other timbers because they have a higher ratio of cut surfaces and drilled holes.

7.6.2.2 Upper Fender Pile Maintenance and Repair. This concerns protective maintenance, repair, and rehabilitation of the above-water portion of fender piles exposed to decay. The maintenance of the fender pile portion exposed to marine borer damage is presented later (7.6.2.4). Paragraph 7.6.1.3.4, mentions the loss of the interior of fender piles to decay from the top downward.

7.6.2.2.1 Pile Top Decay Patterns. Southern pine and Douglas fir have differing typical decay patterns.

(1) Decay in Southern Pine Pile Tops. Southern pine is nearly all sapwood which differs greatly from its heartwood. In the sapwood, some of the soft springwood in each annual ring is washed away by rains while the denser summerwood in each ring resists rain erosion, creating a rain erosion pattern. When the heartwood changes from sapwood to heartwood, the springwood becomes almost as resistant to erosion as the summerwood. The fact that rain erosion can be speeded up by surface soft rot is also evident here, as the heartwood has a much higher resistance to decay than does the sapwood further from the center. This is due to the original penetration of creosote during pressure treatment as later modified by internal movement. There is a retention gradient--the retention being greatest at the surface and eventually reaching a zero point at depth. The preservative value of the original hot creosote surface treatment applied to the pile after it was cut off to grade and trimmed is eventually lost. It protects from early decay the untreated sapwood nearest to the heartwood and the lightly treated sapwood further away. The pile top at first dries out too quickly to be damaged by other than surface soft rots, but the springwood erosion in the annual rings results in water trapping for periods long enough to support some brown-rot decay fungi.

Southern pine does not exhibit the same severe checking typical of Douglas fir, but it does check. Many small checks may be evident on the pile side and top. Wind-borne fungus spores lodge in these checks and rainwater enters. Decay begins where treatment is inadequate to prevent it, and continues where occasionally supplied with rainwater long enough for the fungus to grow. In most areas where southern pine is used, the top dries too quickly for surface decay. But an inch or two down there may be adequate moisture to support fungus growth for several days. Eventually, the sapwood below the top and nearest the heartwood center goes completely. It is then that the treatment gradient in the sapwood becomes most apparent. The heavy decay on the inside slowly moves outward as the more volatile and most water-soluble fractions of the creosote are lost. In well-treated pine this outward progression of preservative loss and decay is quite slow and so takes many years. However, all this decay can be prevented with techniques now available.

(2) Douglas Fir Pile Top Decay. The top center of a Douglas fir pile may collapse. In comparison with the many small checks in pine, there are numerous large checks in Douglas fir. Before it collapses, the center of the top is crisscrossed with a pattern of checking that is somewhat evident in the remaining surface wood. The tangential shrinkage in this species is approximately twice that of the radial shrinkage. When Douglas fir dries, it checks.

Materials can be placed in the wood to prevent shrinkage, but they are not compatible with the preservatives. They are also water soluble, and so will wash out of the wood exposed to frequent, heavy rains, and they are very expensive. There are many less expensive ways to protect piles from internal decay than to prevent checking. Where decay now exists it can be stopped quite easily and inexpensively, and the damage that the decay has done can be corrected. While all the decay in a pile can be stopped inexpensively, the costs of repair will depend on the extent of damage at the time the decay has been stopped. When the decay is truly extensive, it may well cost less to pull the pile and drive a new one. Pulling and driving costs are variable, and one of the biggest variables is availability of equipment.

7.6.2.2.2 Pile Top Rehabilitation.

(1) Pile Fumigation. The fumigation techniques developed for utility poles described earlier (7.5.3.2) are applicable to fender piles. In one Douglas fir pile top, dryrot had progressed downward about four feet. By that time, the top was checked but otherwise appeared to be sound until the inspector gave it a hard hammer blow. The brown-rotted wood was scraped and reamed out. It was easy to remove from the treated sapwood; but at the bottom of the cavity relatively solid wood had to be exposed. Debris was blown out and vacuumed out, and the checks were caulked. Fumigant was placed in bored holes below the hollowed-out area to kill all fungus below that point, and some was placed in the top cavity which was then covered and sealed. After the fumigant placed in the upper cavity penetrated the wooden shell, the top seal was removed and the pile was ready to be restrengthened and sealed against further moisture penetration from the pile top downward.

(2) Pile Restrengthening. Fender pile tops are not normally required to support heavy loads, but they are expected to withstand crushing and snapping under lateral loading. There are two time-saving and money-saving techniques to restore a pile. Instead of caulking all the checks around the pile with hand tools, a plastic sheet is coated with epoxy resin, wrapped around the pile, and stapled in place. After the stapling has started, the sheet is rubbed against the pile and pulled around tightly to work the epoxy into the checks. The sheet need not be of greater vertical length than is convenient to handle under local working conditions as a number of them can be used to seal the checks from the pile top to the waterline. In some situations it will be necessary to remove attached hardware to accomplish the caulking. There will be some situations in which it will be completely impractical to caulk all checks. In these cases, if only small spaces are left and are in such locations that absolutely no fumigant in liquid form could get into the uncaulked sections of the checks, these small spaces may be left uncaulked.

The second time-saving method to restrengthen the area of a pile destroyed by decay is to use wooden blocks as cheap space fillers embedded in a column of epoxy resin. Clean crushed stone is equally effective, and for large jobs involving many piles, stone filler might be much cheaper than wood. But wood filler can be drilled for bolts and other fasteners. Cheaper cement and stone fillers can be used in place of epoxy resins, but eventual decay below the cement is to be expected, while epoxy seals out further moisture.

7.6.2.3 Below-the-Deck Maintenance.

7.6.2.3.1 Pile Caps, Stringers, and Bracing Timbers.

(1) Maintenance. Pile caps are the heavy timber horizontal beams which, singly or spliced as dictated by the width of a pier or wharf, lie atop the piles joining together all piles in a single bent across the width of the pier or wharf. With the support piles beneath them and the stringers and deck above them, they are important structural elements in a pier or a wharf. Also, once in place, they are difficult and expensive to remove and replace. Wherever these can be saved in-place, they should be saved. Because of their value and potential for loss, they are worth the expenditure of maintenance manpower and money.

Stringers are the horizontal timbers which run lengthwise with the pier or wharf, above, and at right angles to, the pile caps. The timber deck is fastened to these stringers. Individually, stringers are smaller timbers than pile caps. They are not as securely fastened to the pile caps as the pile caps are fastened to the tops of support piles, so they are not quite as difficult to remove individually. Collectively they may represent a larger mass of wood and a larger financial investment than the pile caps.

Above-water bracing timbers vary greatly from pier to pier. Few specific statements can be made about their required maintenance other than that their value in-place is usually equal to or greater than that of the caps and stringers. Their problems are like those of caps and stringers, and the measures for economically prolonging their useful lives are also the same.

The decay hazard in all of these below-the-deck timbers is not quite the same as in upper decking timbers. They are not subject to the surface erosion caused by traffic on the decks, nor are they subject to the frequent showers followed by bright sunshine and rapid surface drying and subsequent checking. Rather, these below-decks timbers are exposed to the very real threat of decay due to water getting trapped in joints.

Spiking decks to stringers, and water collecting between deck plank and stringer is responsible for more stringer decay than any other single cause. However, this is standard construction practice, and except for the decay hazard, is most logical. This simple and effective construction technique should continue, but with slight changes to prevent decay and loss of the stringers. Stringers which are in-place with decking above them cannot be flooded with preservative to extend their life. But bodied preservatives can be of value if they are applied as beads at the contact edges of deck planks and stringers, and pile caps and stringers. They should be repeatedly applied until no more will creep into the joints. Ideally, the deck plank and stringer should be drilled together for spikeholes which are not quite large enough for the spikes. The holes in both plank and stringer should be swabbed with a hot coal tar pitch, the plank returned to its position, aligned by spacers, and the spikes driven. A similar procedure for protecting both stringer and pile cap from decay due to water entering holes for the spikes and bolts which join them can be highly effective. For maintenance, repeated application of beads of bodied preservative can help materially unless these structural elements are so arranged that they are often saturated with moisture.

Testing of liquid fumigants on large round timbers such as poles and piles has shown considerable promise where excessive checking has not been a problem. Because the liquids are placed in bored holes which must slope downward to hold the liquid, stringers and pile caps could normally be given this fumigation treatment only with the decking removed. When so applied, this technique should be as effective with these timbers as with piles and poles.

The wide variety of vertical, horizontal, and angled bracing timber used below decks to strengthen a pier or wharf suffer all the problems of the timbers mentioned by name above. The procedures for prolonging the life of these other bracing timbers are the same as those used for stringers and pile caps. In many situations, bodied preservatives can be applied economically. In some cases, liquid fumigants should be considered.

(2) Rehabilitation. The techniques of physical rehabilitation, such as fish-plating, scabbing, bracing, splinting, splicing, posting, stubbing, and complete replacement, in all of their possible variations, seem to be no more limited than an engineer's constructive imagination. The subject of rehabilitation versus replacement of below-the-deck timbers is mentioned only for the purpose of pointing out that, where a timber with decay in one part often had to be replaced or more-or-less temporarily restrengthened until it completely rotted away, the decay can now be stopped, and the use of epoxy mixtures can now rebuild the decayed portions of individual structural members and structural joints. Such rebuilding may require the use of steel drift pins and bolts as well as various epoxy formulations. It may often cost much less than replacement. Chemical wood protection and restrengthening jointly provide low-cost maintenance and rehabilitation procedures not previously available.

7.6.2.3.2 Support Piles and Batter Piles Above Water. Support pile and batter pile decay above water is usually not as extensive as that in fender piles; and it is certainly not as readily visible. But, when it exists, it can be much more expensive. A number of techniques have been developed to protect pile cut-offs prior to attaching the pile-cap timbers. Perhaps the most effective is flooding the top surface and drift-pin holes with hot creosote, then coating the pile top with hot pitch. However, the normal "working" of the structure eventually lets water into untreated upper portions of the piles, and this is followed by decay. Where space above pile tops permits, liquid fumigants can be used to destroy and prevent decay above water. As with the other above-water structural members, repeated application of beads of bodied preservatives to piles can help prevent decay.

When annual inspections discover pockets of decay in piles, there are several choices of corrective techniques. If only the interior of a pile is decayed, it may be handled like the decayed upper portion of a fender pile. It may be replaced by a new section held in place with drift pins and epoxy cements. It may then be as good as new if the wood is protected from further decay.

7.6.2.4 Maintenance and Rehabilitation In-and-Below the Tide Zone.

7.6.2.4.1 Pile Barrier Wraps. In warm-water harbors, Limnoria tripunctata has often penetrated and destroyed creosoted marine piles, costing the Navy many millions of dollars in structural losses. Navy laboratory and field research on this problem has determined how these piles are destroyed, at least in part. A new preservative treatment has proven itself in extensive testing and has been used to treat over 450 fender piles for a Navy pier in a tropical harbor. The new preservative treatment will not protect-in-place the existing financial investment in piles, but there are maintenance techniques which can extend the useful service life of many piles for many years without any structural rehabilitation. These techniques all involve placing barriers between the piles and the destructive crustacean borer.

Many variations on the barrier theme have been developed and tested. One was to place a plastic bag around a scraped pile, with or without an inside wire mesh frame, and to pump the bag full of cement. These have seldom effectively prevented damage, entering through cracks, Limnoria are hidden from view while they destroy the pile. Metallic copper dissolves slowly in seawater, so it was used many years ago as a protective skin for wooden ships. Copper alloy nails with wide heads were driven into wooden hulls to prevent borer attack. Various copper alloys have been extensively tested as sheathing to stop marine borer attack on piling. A reasonable balance between toxicity and permanence was developed, but the cost in-place was quite high. They were rather fragile compared to other structural elements of a pier or wharf, and could not be used on fender piles on most structures. Other systems were developed.

With a multiplicity of pile barrier wraps being touted, the Naval Civil Engineering Laboratory conducted extensive tests on all available systems. One system was found to be considerably better than the others, and is now widely used in commercial installations because of its effectiveness, simplicity, and relatively low cost installed. It is a patented system sold under the registered trade name "Pile-Gard." The basic principle by which it works is the suffocation and death of all animal life between the plastic wrap and the pile due to stagnation of the water trapped in it. A PVC sheet is wrapped around the pile, secured in place, and sealed top and bottom to prevent water movement. NAVFAC SPECIFICATION TSM-B10 describes this method to protect piles, and recommends that the pile wrap be applied before 10% to 15% of the cross-sectional area of the pile has been destroyed. A 10% to 15% loss at the heart of the pile has little effect on the strength of the pile. A 15% loss at the periphery of the pile causes greater strength loss. As soon as a general attack by Limnoria is confirmed, planning for pile wrapping should begin.

Because so many unsatisfactory pile coverings were marketed prior to the Pile-Gard PVC wrap, there was logical skepticism as to its possible effectiveness. When the results of the Navy comparative testing began to prove its superiority to other systems, Naval shore facilities began to use it. In one test nearly all the piles were protected by the PVC wrap at the time of about 10% reduction in pile diameter. One pile in the pile bent was not given the protective wrap with the others less than two years earlier but was saved to serve as a control example for demonstration purposes; it completely rotted.

PVC wraps are quite tough and securely fastened in place, but they can be damaged. The potential for damage is greatest where camel logs or other camel structures rub against the piles, often wearing through the treated zone of thin-sapwood species such as Douglas fir, and exposing the untreated interior heartwood of the piles to marine borer attack. Camels not only move up and down with the tides, but also have some longitudinal movement, resulting in the camels' arc of abrasion being greater than the arc in the fender pile. Such camel log rubbing could quickly destroy unprotected Pile-Gard. Rubbing strips can be used over a PVC pile wrap to protect it and the fender pile from the abrasion of a camel log, and probably save the pile.

7.6.2.4.2 Pile Repairs. Because some waterfront structures are not thoroughly inspected annually, the failure of support piling can come as a shock when the pier or wharf must be used. There are many satisfactory methods of restrengthening, but occasionally, panic decisions are based on expediency rather than on knowledge and logic. A real repair job could be done for about the same cost as the expedient job, and it will last.

Many systems have been developed to provide forms into which to pour concrete. Some of these involve a new pile diameter not much larger than the original. Even when the piles so jacketed are support piles and so are not exposed to the lateral loading given fender piles, the concrete often checks and provides access to the wood by Limnoria. When concrete is to be used, it should be heavily reinforced. The reinforcing may be in the form of a permanent jacket such as welded steel drums.

Epoxy grouts, with and without stone fillers, may be pumped into forms to rebuild many structures. One of the easiest ways to do this is to use self-sealing snap-around plastic-fiberglass forms which become a permanent part of the repaired pile after the epoxy grout is poured. Material costs are higher than when temporary forms and concrete are used, but when repaired this way, the piles are at least as strong as when installed, and they are permanent. Such repairs on fender piles will not break due to impact.

In another system, plastic sheeting is cut to a size that will cover the damaged area with some overlap. This is spread out on the deck and "buttered" with epoxy resin to a thickness of between ¼ and ½ in. It is then passed over the side, the top and bottom rubbed against the pile, stapled around the top, smoothed out, and stapled around the bottom. A day later it is the permanent form into which epoxy grout is poured. Depending on its length, one or more vertical rods may have to be placed on the pile to help shape the form; but this is not often the case. Two holes are cut into the hardened form. One is for the funnel into which the fluid epoxy grout is poured. The other hole is part way around the pile and at the top of the air space under the form. This lets air and water escape. When the system is used to repair fender piles, care should be taken to have as smooth a surface as possible top and bottom on the outboard face to prevent camel log hang up.

Spacer blocks can also be used to cut down on the use of the more expensive epoxy. A non-slumping mixture is described in Military Specification MIL-P-28579(YD), "Plastic Compound, Epoxy-Polyamide, Marine Splash-Zone Application." This material can be patted and pushed into place. It sticks to wet surfaces and has almost no slump, so it stays where put. Attention must be given to providing a smooth surface on the outboard face of a fender pile. A flexible plastic sheet can be used to cover and smooth the surface.

Bolthole area damage to a pile can be repaired with epoxy resin grouts and spacer blocks. An opening is made into the pile, 90° from the bolthole and the length of the damaged area. If the opening is made carefully, the piece removed can later be cemented back into place. The cavity is filled with the non-slumping epoxy material described above. Small wooden spacer blocks may be used. When the bolthole is redrilled through the epoxy, large spacer blocks in the middle of the pile would be exposed to Limnoria and could be completely removed. The volume in the small blocks, separated by epoxy and exposed to attack by drilling would be small. Rather than to go to the trouble of opening and packing the cavity, the repair could be made by drilling into the top of cavity and pouring in a fluid epoxy grout. This would save a little labor, but it will forever bind the bolt in place and prohibit its eventual reuse.

As with the piles to which they are attached, timbers in the water can be hollowed out and destroyed by Limnoria. If the damage has not progressed far, it may be stopped and repaired with epoxy materials. When the cut ends of timbers must be placed in the tide zone, there is no known way to give them in-place preservative treatment. However, they can be coated when dry with epoxy materials which will last indefinitely.

Acacia. Trees and shrubs (about 550 species) of the Subfamily Mimosoideae of Family Leguminoseae of tropical, subtropical, and temperate regions. Acacia seyal is an excellent timber tree and is quite resistant to decay. It is thought to be the Shittah tree producing the Shittim wood used by Noah to build his ark.

Advanced Decay. See Decay.

Aerobic Corrosion. See Corrosion, Aerobic

Air-Dried. See Seasoning.

Aliphatic Hydrocarbons. Saturated and unsaturated compounds of open-chain formation, including alkanes, alkenes, and alkynes. (Note: Compare this with Aromatic Hydrocarbons).

Ambrosia Beetle. See Beetle, Ambrosia.

Amphipoda. Within the class of crustacean animals is the Order of Amphipods which contains a single genus of marine wood borers, Chelura.

Anaerobic Corrosion. See Corrosion, Anaerobic.

Angelique, Dicorynia paraensis, also called basra locus. This is a tropical wood from Surinam, sold for use in marine construction. In U.S. Naval Research Laboratory studies, this species was given high ratings for resistance to marine borers (14 months exposure) and to termites (18 months exposure), but it had only moderate resistance to decay in an 18-month exposure.

Annual Growth Ring (Annual Ring). The layer of growth of a tree added to the tree in a single growth year, including springwood and summerwood (earlywood and latewood).

Antenna (pl. antennae). In arthropods, a segmented sensory appendage on the head.

Aromatic Hydrocarbons. Compounds having, or incorporating, the closed ring structure of benzene. (Note: compare this with Aliphatic Hydrocarbons).

Arthropod. A member of the Phylum Arthropoda which is one of the eleven main divisions (phyla) used in the classification of members of the Animal Kingdom. The arthropods have bilateral symmetry, bodies usually segmented and jointed externally, one or no paired appendages per body segment, a hardened exoskeleton containing chitin secreted by the epidermis and molted at intervals. It contains the following classes: (1) Crustacea (crustaceans), (2) Insecta (insects), (3) Arachnoidea (spiders, etc), (4) Chilopoda (centipedes), and (5) Diplopoda (millipedes).

Assay. Determination, by appropriate physical and chemical means, of the amount of preservative or fire-retardant in a sample of treated wood. It is usually expressed in pounds per cubic foot (pcf) or kilograms per cubic meter (kg/m^3).

Bark. The outer layer of a tree, consisting of the inner bark, the thin, inner, living portion (phloem), and the outer bark, or corky layer, composed of dead, dry tissue.

Bastard Sawn. Hardwood lumber in which the annual rings make angles of 30-to-60 degrees with the surface of the piece.

Batter Piles. Piles which are driven at a sufficient angle from the vertical that when attached to a structure they provide resistance to horizontal forces such as may be imparted to a pier by a ship.

Beams and Stringers. Large pieces (nominal dimensions 5x8 inches and up) of rectangular cross section graded with respect to their strength in bending when loaded on the narrow face.

Bearing Partition. A partition that supports any vertical load in addition to its own weight.

Bearing Pile. One of the piles in a structure that support the load.

Bearing Wall. A wall that supports any vertical load in addition to its own weight.

Beetle, Ambrosia. These are members of the Family Scolytidae (see below). They tunnel through bark into sapwood (one type into heartwood) where they cultivate ambrosial fungi on which they feed exclusively as both larvae and adults. These are often called "pin-hole" borers because of the small, round entrance holes in the bark. Another family of ambrosia beetles, Platypodidae, is limited to the tropics and the subtropics.

Bent. Transverse pile framing in the structure of a pier.

Bethel Process. A full-cell process (see below), for wood treating patented in 1838 by John Bethel. Under pressure, creosote was pumped into a closed cylinder containing wood.

Biodegradation; Biodeterioration. This is the degrading or the deteriorating of materials as caused by the physical, chemical activities of living organisms, or by electrochemical changes in materials due to the otherwise passive presence of some organisms.

Birds-eye. A small central spot with the wood fibers arranged around it in the form of an ellipse so as to give the appearance of an eye.

Bitumen. Any of a variety of mixtures of solid and semi-solid aliphatic and aromatic hydrocarbons. The term includes various types of tars of various origins and consistencies.

Bitumastic. (a) Compounds produced or extracted from bitumen; (b) construction materials such as roofing felts and vapor barriers which contain bitumen as an essential element.

Bituminous. A type of coal which contains little free carbon, having most of its carbon forming parts of numerous organic compounds. It is sometimes called "soft coal" in contrast to anthracite, which is called "hard coal," and consists primarily of carbon, and with lignite, which is called "brown coal."

Bivalve. A mollusc possessing a pair of shells. Members of the Class Pelecypoda. The body is enclosed in a shell of two lateral valves with dorsal hinge; no head or jaws; foot often hatchet-shaped, extends between valves for locomotion. Some members are (a) *Ostrea* (oyster), (b) *Mya* (clam), (c) *Teredo* (shipworm).

Bleeding. The exudation of liquid preservative from treated wood. The exudate may evaporate, remain liquid, or harden into a solid or semi-solid state.

Blemish. Anything, not necessarily a defect, marring the appearance of wood.

Blooming. The formation of crystals on the surface of treated wood as a result of exudation and evaporation of the solvent or water component of the preservative or the fire-retardant solution.

Blue Stain. See Stain.

Boards. See Lumber.

Boardered Pit. See Pit.

Bore Holes. These are holes in wood cell walls resulting from infection by decay fungi. Acids and enzymes are produced at the tops of the growing hyphal threads. As a single hypha nears a cell wall, a hole is produced as the wall is dissolved. Just behind the liquid-secreting tips is a liquid-absorbing area which brings the digested wood into the fungus structure. Bore holes are often made in the areas of cell-wall pits, and so destroy the pit membranes.

Borer, Increment. An auger-like instrument with a hollow bit, and equipped with an extractor, used to sample wood internally without destroying the piece. The core obtained serves to measure sapwood thickness and depth of penetration. Likewise, the borer is used to obtain sample cores of treated wood at specified depths (zones) for the determination of preservative retention by assay or by volume extraction.

Borers, Marine. Marine organisms which attack wood in the submerged or intertidal portions of structures placed in salt or brackish waters. Two general groups of borers are recognized: the crustacean (*Limnoria*, *Sphaeroma*, and *Chelura*) and the molluscan (*Teredo*, *Bankia*, *Martesia*).

Borers, Rock. These are bivalve molluscs, such as *Pholas* and *Martesia* in the family Pholadidae of the order Teleodesmacea (along with the teredine borers) of the class Pelycypoda. These usually bore into clay and rock. Where numerous in some warm-water harbors, *Martesia* can seriously damage wood in structures. Unlike the teredine borers, it is protected within its shell, and so has less close contact with toxic materials in the wood.

Boucherie Process. A process for treating wood in which water-borne preservative is applied to the end surface of green wood through a suitable chamber and either forced through the wood by hydrostatic or other pressure or drawn into the wood by the evaporation of moisture from the tree leaves. This process has given some excellent results; but these are inconsistent to the extent that they are not reliable when long-term exposure is required.

Boulton Drying Process. A process for drying wood by removing moisture from it by boiling in preservative under sufficient intensity of vacuum to evaporate water from the material at the temperature of the preservative used.

Bow. The distortion of a board that deviates from flatness lengthwise but not across its face transversely as in cup (see below).

Boxed Heart. The term used when the pith center falls entirely within the four faces of a piece of wood anywhere within its length. Also, boxed pith.

Bracing. Timber supports supplying additional strength to a structure.

Brackish. Water which is somewhat saline, neither saltly nor fresh, but which is a mixture of the two and which has some characteristics of each.

Brashness. A condition that causes some pieces of wood to be relatively low in shock resistance for the species and, when broken in bending, to fail abruptly without splintering at comparatively small deflections.

Brood-Leaved Trees. See Hardwoods.

Brown Rot. A decay of wood caused by various fungi; which remove cellulose from the wood cell walls, but which leave the lignin in place. When drying, brown-rotted wood tends to shrink and to crack - hence the term "cube-rot." When dry, brown-rotted wood is easily powdered, this is sometimes called "dry-rot" (see below).

Brown Stain. See Stain.

Brush Treatment. See Treatment, Brush.

Built-up Timbers. Assemblies made by joining layers of lumber together with mechanical fastenings so that the grain of all laminations is essentially parallel.

Bulkhead. A structure used in waterfront construction to retain earth fill.

Burl. A swirl or twist in the grain of wood that usually occurs near a knot but does not contain a knot.

Butt Treatment. See Treatment, Butt.

Byssal Thread, Byssus (pl byssi). Silky thread(s) secreted by the foot of some stationary bivalve molluscs, such as mussels, which attach the mollusc to an object.

Cambium. The one-cell thick layer of tissue between the bark and the wood that repeatedly subdivides to form new wood cells and new bark cells.

Camel, Camel Log. A floating log or a timber structure tethered to a pier or wharf outboard of the rest of the fender system to absorb both berthing shocks and continuing abrasion and to redistribute these among a number of fender piles.

Cant. A thick piece of lumber, with or without squared edges, sawed from a flitch or log and intended for remanufacture into lumber.

Carapace. The hard covering of the thorax in Crustacea; the shell of crabs, etc.

Casehardening. A stressed condition in a board or timber characterized by compression in the outer layers accompanied by tension in the center or core, the result of too severe drying conditions.

Cathodic Protection. Protection of a metal object or structure by making it cathodic in relation to another material (i.e., a less mobile metal) which serves as the sacrificial anode.

Cell. A general term for microscopic structural units of a plant or animal body; in wood, including wood fibers, vessel segments and other elements of diverse structure and function enclosed by a cell wall.

Cellulose. The carbohydrate that is the principal constituent of wood and forms the framework of the wood cells. It is a mixture of complex polysaccharides (alpha and beta cellulose) which with hemicellulose and lignin (a non-polysaccharide) form the wood cell walls.

Chafing. Abrasion caused by material rubbing against a structure.

Check. A lengthwise separation of the wood that usually extends across the rings of annual growth and commonly results from stresses set up in the wood during seasoning. (See split.)

Chemical Brown Stain. See Stain.

Chock. A block of wood to steady or hold motionless a boat, or to fill an unwanted space as between wales.

Class. A subdivision of a larger group (phylum) used in the system of classification of all animals and plants. A class typically has several divisions called orders, and these inturn have divisions call families.

Close-grained Wood. See Grain.

Coal tar. See Tar, Coal.

Coarse-grained Wood. See Grain.

Cold Soak Treatment. See Treatment, Cold Soak.

Collapse. The flattening of single cells or rows of cells in a heartwood during the drying or pressure treatment of wood, characterized externally by a caved-in or corrugated appearance.

Compression Failure. Deterioration of wood fibers resulting from excessive compression along the grain either in direct end compression or in bending. It may develop in standing trees due to bending by wind or snow or due to internal longitudinal stresses developed in growth, or it may result from stresses imposed after the tree is cut. In surfaced lumber, compression failures appear as fine wrinkles across the face of the piece.

Compression Set. Permanent compression of a group of wood fibers resulting from restraint from swelling while taking on moisture, or compressive stresses on the wetter core of wood during drying imposed by adjoining fibers or an external mechanical agency.

Compression Wood. Abnormal wood formed on the lower sides of branches and inclined trunks of softwood trees. It is identified by (a) its relatively wide annual rings, usually eccentric, (b) its relatively large amount of summerwood, sometimes more than 50% of the width in which it occurs, and (c) its lack of demarcation between springwood and summerwood in the same annual rings. Compression wood shrinks excessively lengthwise as compared with normal wood. (See Tension Wood).

Conditioning. The heating of, or removal of moisture from, unseasoned or partially seasoned wood as a preliminary to preservative treatment and as a means of improving the penetrability and absorptive properties of the wood.

Conifer. See Softwoods.

Corrosion. Destruction of a metal by chemical or electrochemical reaction with its environment.

Crawl Space. The shallow space below the living quarters of a basementless house, normally enclosed by the foundation wall.

Creosote. A generic term applied to certain distillates of tars. As the term is used in the wood-preserving industry, the unmodified term "creosote" denotes coal-tar creosote (see next entry).

Creosote, Coal Tar. A distillate of tar. As the term is used in the wood-preserving industry, coal-tar creosote, or "creosote," denotes a distillate of coal tar produced by high temperature carbonization of bituminous coal, consisting principally of liquid and solid aromatic hydrocarbons and containing appreciable quantities of tar acids and tar bases. It is heavier than water, and has a continuous boiling range of at least 125°C, beginning at above 200°C.

Crevice Corrosion. Corrosion of a metal at an area where contact is made with a non-metallic material.

Crook. A distortion of a board in which there is a deviation from a straight line from the edge at one end of a board to the corresponding edge at the other end of the board. This occurs after boards are cut from logs. A similar curve in a round pole is called sweep. See also - twist, warp, bow, and cup.

Cross Grain. See Grain.

Cup. A distortion of a board in which the face is concave or convex transversely.

Corrosion, Aerobic. Corrosion which can occur only in the presence of oxygen which enters into the chemical reactions producing the corrosion.

Corrosion, Anaerobic. Corrosion which can occur only in the absence of oxygen which could otherwise enter into chemical reactions which could prevent the corrosion.

Curb. A stringer (see below) on top of, and at the sides of a pier deck.

Deathwatch Beetles. Anobiid Powder-Post Beetles. The sound of larvae snapping individual wood fibers can reverberate through a timber, and in an otherwise quiet building, can be easily heard as during a wake or deathwatch.

Decay. The decomposition of wood by fungi.

> Advanced Decay (typical decay). The older stage of decay in which the destruction is readily recognized because the wood has become punky, soft or spongy, stringy, ring shaked, pitted or crumbly. Decided discoloration or bleaching of the rotted area is often apparent.
>
> Incipient Decay. The early stage of decay that has not proceeded far enough to soften or otherwise perceptibly impair hardness of the wood. It is usually accompanied by slight discoloration or bleaching of the wood. See also dote, doze, rot, dry rot.

Decay Fungi. All of the many species of wood-destroying fungi, some of which are parasitic on growing wood, but most of which attack only dead wood and in so doing produce either white rot or brown rot conditions. In very limited situations, some produce soft rot conditions.

Decayed Knot. See Knot.

Deciduous Tree. A tree which sheds its leaves seasonally, as in the fall, in contrast to an evergreen which replaces its leaves, needles or bracts throughout the year and nearly always has green leaves available for photosynthesis. See Evergreens.

Defect. Any irregularity occurring in or on wood that may lower its strength.

Delamination. Separation of plywood plies through failure of adhesive; often used in reference to the durability of the glue line.

Density. The weight of a body per unit volume. The concentration of matter, measured by the mass per unit volume. The specific gravity.

Density Rules. Rules for estimating the density of wood based on percentage of summerwood and rate of growth.

Dewpoint. Temperature at which a vapor begins to deposit as a liquid.

Dewpoint Isotherm. The location of a dewpoint in a wall, ceiling, floor, or roof. It moves within a structural unit, such as a wall, with changes in the temperatures and relative humidities on its sides or faces. It moves toward the cooler (and drier) side. The moisture vapor goes to the dewpoint isotherm where it becomes liquid unless prevented by a vapor barrier on the warm, humid side.

Diagonal Grain. See Grain.

Diffusion Treatment. See Treatment, Diffusion.

Dimension. See Lumber.

Dimension Stabilization. Reduction of swelling and shrinking of wood, caused by changes in its moisture content with changes in the relative humidity, through special treatments.

Dimension Stock. Squares or flat stock, usually in pieces under the minimum size admitted in standard lumber grades. They are supplied rough or dressed, green or dry, and cut to the approximate dimensions required for the various products of wood working factories.

Dip Treatment. See Treatment, Dip.

Dorsal. On or toward the back of any animal with adequate structural organization for there to be a front and a back of the animal.

Dote. "Dote," "doze," and "rot" are synonymous with "decay" and are any form of decay that may be evident as either a discoloration or a softening of the wood. See also Decay.

Doze. See Dote, see also Decay, Rot, Dry Rot.

Dressed Size. See Lumber.

Dry Rot. A term loosely applied to any dry, crumbly rot but especially to that which when in an advanced stage, permits the wood to be crushed easily to a dry powder. The term is actually a misnomer for decay. All of the wood-rotting or wood-decaying fungi require moisture for growth. It is also called Brown Rot (see above).

Dual Treatment. See Treatment, Dual.

Durability. A general term for performance or lastingness. Frequently used to refer to the degree of resistance of a species or of an individual piece of wood to attack by wood-destroying fungi under conditions that favor such attack. In this connection, the term "resistance to decay" is more specific.

Double Treatment. See Treatment, Double.

Douglas fir, Pacific Coast. This is Douglas fir growing between the Pacific Ocean and the summit of the coastal mountains. Also called coastal Douglas fir.

Douglas fir, Interior. Douglas fir growing east of the summit of the Cascade Mountains. When growing above 42° North (California - Oregon Border) in Oregon, Washington, Idaho, Montana, and Wyoming, it is called Intermountain Douglas fir.

Earlywood. This is the first part of an annual ring to be formed from the cambium in the spring. It is later covered by the latewood or summerwood which remains next to the cambium throughout the winter.

Edge Grain. See Grain.

Empty-Cell Process. Any process for impregnating wood with preservatives or other materials in which air, imprisoned within the wood under pressure, expands when pressure is released to drive out part of the introduced liquid. The distinguishing characteristic of the empty-cell process is that no vacuum is drawn before applying the preservative. The aim is to obtain good preservative distribution within the wood and to leave the cell cavities only partly filled. See Full-Cell Process.

Empty-Cell Treatment. See Treatment, Empty Cell.

Encased Knot. See Knot.

Enzyme: (a) an organic catalyst; (b) a substance that changes insoluble foods into soluble forms during digestion; (c) a protein produced by cells, and having the power to initiate or accelerate specific chemical reactions in the metabolism of plants and animals.

Equilibrium Moisture Content. The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature. See Moisture Content of Wood.

Evergreens. The species of trees that typically are coniferous, non-deciduous types. In contrast to the deciduous trees which typically shed all of their leaves in the Fall (except for a few like some oaks which retain dead leaves all winter to shed them in the Spring), the evergreens drop and replace their leaves (often needles or bracts) throughout the year. A few non-coniferous trees, such as the magnolia, are "evergreen" in that they shed all year and typically retain green leaves all year in most of their range.

Extractives. Substances in wood, not integral parts of the cellular structure, that can be removed by solution in cold or hot water, ether, benzene, or other solvents that do not react chemically with wood components.

Facia (Fascia, Faschia). A flat, horizontal board, member, band, or face, used sometimes by itself but usually with moldings, often located at the outer face of the cornice. When covering and extending below the soffit (see below) it prevents entrance of wind-driven rain and it provides a drip line. It should never rest on the soffit.

Factory and Shop Lumber. See Lumber.

Family. A grouping of similar genera within a biological order; a logical subdivision of an order into subgroups each of which can logically be further divided into genera each of which contain one or more species.

Fender. A device or a framed system placed against the edge of a pier, dock, etc., to take the impact from the berthing of vessels and repeated lesser impacts and chafing from berthed vessels.

Fiber. A wood fiber is a comparatively long (one-twentyfifth or less to one-third inch), narrow, tapering wood cell closed at both ends. See Tracheid.

Fiber Saturation Point. The stage of the drying or the wetting of wood at which the cell walls are saturated and the cell cavities are free of water. It is usually taken as approximately 30 percent moisture content as based on weight when oven-dry.

Figure. The pattern produced in a wood surface by irregular coloration and by annual growth rings, rays, knots, and such deviations from regular grain as interlocked and wavy grain.

Fireproofing. Making wood resistant to fire. Wood cannot be treated chemically so that it will not char or decompose at high temperatures (280°F. and above). What effective fireproofing does is to make the wood difficult to ignite, keep it from supporting its own combustion, and delay the spread of flame over the wood surface.

Fire-Retardant Chemical. A chemical or a preparation of chemicals used to reduce flammability or to retard spread of fire.

Fishplate. In light frame construction, a wood or plywood piece used to fasten together the ends of two members at a butt joint with nails or bolts. Sometimes used at the junction of opposite rafters at the ridge line. In heavy construction, such as with waterfront structures, fishplating is relatively common; but in contrast with light frame construction it requires the use of heavy-gauge steel plate.

Flakes. See Rays, Wood.

Flashing. Sheet metal or other material used in roof and wall construction to protect a building from water seepage.

Flat Grain. See Grain.

Flitch. A longitudinal section of a log, usually for further working. Also a section of veneer.

Foot. A muscular mass by means of which some molluscs are able to move.

Fouling. Living organisms growing at the surface of submerged objects.

Frass. Feeding wastes, wood fibers, and wood scraps produced by wood-destroying insects. May remain packed tightly in galleries or be expelled from them. As most commonly used, the term does not include fecal pellets of drywood termites or fecal spotting of wood galleries by subterranean termites.

Fruiting Body. A term sometimes used for a sporophore, which is that part of a fungus differentiated from the thallus, or main body, and which produces reproductive spores. A mushroom is an example.

Full-Cell Process. Any process for impregnating wood with preservatives or other chemicals in which a vacuum is drawn to remove oil from the wood before admitting the preservative. This favors heavy absorption and retention of preservative in the treated portions. See Empty-Cell Process.

Full-Cell Treatment. See Treatment, Full-Cell.

Fungi, Mold. See Mold Fungi.

Fungi, Parasitic. Fungi which live on and/or in and at the expense of living plants or animals. Numerous parasitic fungi cause diseases of trees. When a tree is felled, and the lumber and timber are seasoned, a parasitic fungus ceases all metabolic function. It does not function saprophytically to destroy dead wood. See Parasite and Saprophyte.

Fungi, Soft Rot. Fungi which cause a condition in wood known as Soft Rot (see below).

Genus (pl. Genera). A group in the system of classification of plants and animals between the family and the species. A family will normally have several genera; and most genera, but not all, have more than one species.

Germination. The beginning of growth, or change from the resting stage to the active and developmental stage, of a seed or a spore.

Grade. The designation of the quality of a manufactured piece of wood.

Grade Mark. Identification of lumber with symbols or lettering to certify its quality or grade, which is based on the presence or absence of defects such as knots, checks, decay, etc.

Grain. The direction, size, arrangement, appearance, or quality of the fibers in wood.

Grain: Close-Grained Wood. Wood with narrow and inconspicuous annual rings. The term is sometimes used to designate wood having small and closely-spaced pores, but in this sense, the term "fine-textured" is more often used.

Grain: Coarse-Grained Wood. Wood with wide and conspicuous annual rings; that is, rings in which there is considerable difference between springwood and summerwood. The term is sometimes used to designate wood with large pores, such as oak, ash, chestnut, and walnut, but in this sense the term "coarse-textured" is more often used.

Grain: Cross Grain. Grain not parallel with the axis of a piece. It may be either diagonal grain or spiral grain or a combination of the two.

Grain: Diagonal Grain. Annual rings at an angle with the axis of a piece as a result of sawing at an angle with the bark of the tree.

Grain: Edge Grain. Edge-grain lumber has been sawed parallel with the pith of the log and approximately at right angles to the growth rings; that is, the rings form an angle of 45° or more with the surface of the piece.

Grain: Flat Grain. Flat-Grained lumber has been sawed parallel with the pith of the log and approximately tangent to the growth rings; that is, the rings form an angle of less than 45° with the surface of the piece.

Grain: Interlocked-Grained Wood. Wood in which the fibers are inclined in one direction in a number of annual rings, then gradually reverse and are inclined in an opposite direction in succeeding growth rings, then reverse again.

Grain: Open-Grained Wood. Common classification, used by painters, for woods with large pores, such as oak, ash, chestnut and walnut. Also known as "coarse-textured."

Grain: Plain-Sawed. Another term for "flat-grained" (see above).

Grain: Quarter-Sawed. Another term for "edge-grained" (see above).

Grain: Spiral Grain. A type of growth in which the fibers take a spiral course about the bole of a tree instead of the normal vertical course. The spiral may extend right-handed or left-handed around the tree trunk.

Grain: Vertical Grain. Another term for "edge-grain" (see above).

Grain: Wavy-Grained Wood. Wood in which the fibers collectively take the form of waves or undulations.

Green. Wood that is unseasoned, wet.

Gribble. A small marine isopod that bores into and destroys submerged wood and tide-zone wood. This is the common name for any of the species of the genus Limnoria.

Growth Layer. The layer of wood produced in one growing season including both earlywood and latewood. See Annual Growth Ring.

Growth Ring. See Annual Growth Ring.

Hardwoods. The botanical group of trees having broad leaves in contrast to the conifers or softwoods. This term has no reference to the actual hardness of the wood. See also softwoods.

Heartwood. The wood extending from the pith to the sapwood, the cells of which no longer participate in the life process of the tree. Heartwood may be infiltrated with gums, resins, and other materials that usually make it darker and more decay resistant than sapwood (see below).

Hemicellulose. A cellulose-like material in the wood that is easily decomposable, as by dilute acid, yielding several different simple sugars.

Hollow-Heart. This is a void in the heartwood of a pole caused by decay or insect attack.

Honeycomb. Checks, often not visible at the surface, that occur in the interior of a piece, usually along the wood rays.

Hypha (pl. Hyphae). One of the thread-like filaments which collectively compose the body of a fungus.

Incipient Decay. See Decay.

Incising. The operation of puncturing the lateral surfaces of wood as an aid in securing more uniform penetration of preservative.

Incising Machine. Power-driven equipment used for incising square or round timbers.

Increment Borer. See Borer, Increment.

Interlocked-Grained Wood. See Grain.

Intergrown Knot. See Knot.

Internal Treatment. See Treatment, Internal.

Invertebrates. Animals without backbones.

Ion. An electrically charged particle, radical, atom or molecule.

Isopoda. A subdivision (order) of the class Crustacea. It includes Limnoria and Sphaeroma.

Isotherm, Dew-point. See Dewpoint Isotherm.

Joint: Butt Joint. An end joint formed by abutting the square ends of two pieces. Because of the inadequacy of and variability in strength of butt joints when glued, glue is not usually used.

Joint: Edge Joint. The place where two pieces of wood are joined together edge-to-edge, commonly by gluing. The joints may be made by gluing two squared edges as in a plane edge joint, or by using machined joints of various kinds, such a tongue-and-grooved joints.

Joint: End Joint. The place where two pieces of wood are joined together end-to-end, commonly by scarfing or gluing.

Joint. Lap Joint. A joint made by placing one adherend partly over another and bending the overlap portions.

Joint: Scarf Joint. An end joint formed by uniting with glue the ends of two pieces that have been tapered or beveled to form sloping plane surfaces, usually to a feather edge, and with the same slope of the plane with respect to the length in both pieces. In some cases, a step or a hook may be machined into the scarf to facilitate alignment of two ends in which case the plane is discontinuous and the joint is known as a stepped or hooked scarf joint.

Joint: Starved Joint. A glue joint that is poorly bonded because of an insufficient quantity of glue remaining in the joint. Starved joints are caused by the use of excess pressure or insufficient viscosity of the glue, or a combination of these, which results in the glue being forced out from between the surfaces to be joined.

Joist. One of a series of parallel beams used to support floor and ceiling loads, and supported in turn by larger beams, girders, or bearing walls.

Juvenile Wood. This wood occurs next to the pith of a tree and is characterized by indistinct growth rings. Along with compression wood and tension wood, it is one of the types of abnormal wood which are subject to early failure under stress.

Kiln. A heated chamber for drying lumber, veneer, timbers, and other wood products.

Kiln-Dried. See Seasoning.

Knot. That portion of a branch or limb which has been surrounded by subsequent growth of the wood of the trunk or other portions of the tree. As a knot appears on the sawed surface it is merely a section of the entire knot, its shape depending on the direction of the cut.

Knot: Decayed Knot. A knot that, due to advanced decay, is softer than the surrounding wood.

Knot: Encased Knot. A knot whose rings of annual growth are not intergrown with those of the surrounding wood.

Knot: Intergrown Knot. A knot whose rings of annual growth are completely intergrown with those of the surrounding wood.

Knot: Loose Knot. A knot that is not held firmly in place by growth or position and that cannot be relied upon to remain in place.

Knot: Round Knot. A knot whose sawed section is circular or oval.

Knot: Sound Knot. A knot that is solid across its face, at least as hard as the surrounding wood, and shows no indication of decay.

Knot: Spike Knot. A knot cut approximately parallel to its long axis so that the exposed section is definitely elongated.

Knot Cluster. Three or more knots in a compact, roughly circular group, with the grain between them highly contorted, originating from adventitious buds.

In contrast, two or more knots laterally arranged and without contortion of fibers between them do not constitute a knot cluster.

Latewood. The denser, smaller-celled, later-formed part of a growth layer in wood. See Summerwood.

Lignin. The second most abundant constituent of wood, located principally in the middle lamella which is the cementing layer between the wood cells.

Lignite: Lignite coal. Soft coal or brown coal. It is a compact, carbonized, brownish vegetable substance, often retaining a wood-like structure, forming a fuel intermediate between peat and bituminous coal (see above).

Lignite Coal Tar. A tar produced form lignite coal. This is not normally used for the production of creosotes to be used as wood preservatives, and by definition (see "creosote" and "creosote coal tar") must be excluded.

Loose Knot. See Knot.

Lowry Process. An empty cell process for treating wood, usually with oil, in which there is injected, without a preliminary vacuum, an amount of liquid in excess of the required final retention, this excess being then removed by quick high vacuum. (Patented by C.B. Lowry in 1906).

Lumber. The product of the saw and planing mills, not further manufactured than by sawing, resawing, and passing lengthwise through a standard planing machine, crosscut to length, and worked.

Lumber: Dressed Size. The dimensions of lumber after shrinking from the green dimension and planing, usually 3/8 inch less than the nominal rough size; for example, a 2x4 actually measures 1 5/8 by 3 5/8 inches (see Lumber, Nominal Size).

Lumber: Factory and Shop Lumber. Lumber intended to be cut up for use in further manufacture. It is graded on the basis of the percentage of the area which will produce a limited number of cuttings of a specified, or given minimum size and quality.

Lumber: Matched Lumber. Lumber that is edge dressed and shaped to make a close tongue-and-groove joint at the edges or ends or when laid edge-to-edge or end-to-end.

Lumber: Nominal Size. Applied to timber or lumber, the rough-sawn commercial size by which it is known and sold in the market. (See Lumber, Dressed Size.)

Lumber: Plank. A broad board, usually more than one inch thick, laid with its wide dimensions horizontal and used as a bearing surface.

Lumber: Rough Lumber. Lumber as it comes from the saw.

Lumber: Shiplapped Lumber. Lumber that is edge-dressed to make a close rabbetted or lapped joint.

Lumber: Surfaced Lumber. Lumber that is dressed by running it through a planer.

Lumber: Yard Lumber. Lumber that is less than five inches in thickness and is intended for general building purposes.

Yard Lumber: Boards. Yard lumber less than two inches thick, and one inch or more in thickness.

Yard Lumber. Dimension. All yard lumber except boards, strips, and timbers; that is, yard lumber more than two inches and less than five inches thick, and of any width.

Yard Lumber: Strips. Yard lumber less than two inches thick and less than four inches wide.

Lyctidae. The family of Lyctus powder-post beetles in the order Coleoptera (all beetles) of the class Insecta (all insects). North American species bore into the sapwood of seasoned hardwoods. They can be very destructive, but the damage can be easily prevented.

Mantle. The soft fold of the outer body wall of molluscs. It covers and protects much of the internal body, and secretes and fashions the shell.

Marine Organisms. The living entities to be expected and normally to be found in waters containing measurable salinity. They are members of both the plant and animal kingdoms, and are both microscopic and macroscopic.

Martesia. A genus of boring pholads. These are typically "rock borers", but will bore into soft (or softened) concrete and into preservative-treated wood. Unlike the shipworms (Teredo and Bankia), the pholads are primarily enclosed within their shell and so have little continuing, direct contact with treated wood and with the preservatives that easily deter other borers.

Matched Lumber. See Lumber, Matched.

Metabolism. The sum of all of the processes involved in the building up and the tearing down of the living matter of cells. It is the sum of all of the processes constantly taking place in a living organism, including those that use energy to convert nutritive materials into protoplasm (anabolism) and those that release energy for vital processes in breaking down protoplasm into simpler substances (catabolism).

Microorganism. Any microscopic organism, as a bacterium or protozoon. (See Organism.)

Millwork. Generally, all building materials made of finished wood and manufactured in millwork plants and planing mills are included under the term "millwork." It includes such items as inside and outside doors, window and door frames, blinds, porch work, mantels, panelwork, stairways, moldings, and interior trim. It does not include flooring, ceiling, or siding.

Moisture Content, Equilibrium. See Equilibrium Moisture Content.

Moisture Content of Wood. The amount of water contained in the wood, usually expressed as a percentage of the weight of oven-dry wood. See Equilibrium Moisture Content.

Moisture Gradient. A condition of graduated moisture content between successive thickness zones of wood that may be losing or absorbing moisture. During seasoning, the gradations are between the relatively dry surface zones and the wet zones at the center of the wood.

Moisture, Hygroscopic. Moisture within the cell walls of wood in contrast to free moisture in the cell cavities.

Mold Fungi. On and in wood, these saprophytic fungi metabolize materials in the wood cells (i.e. starches, sugars) but do not directly attack the cellulose and lignin and so do not directly change the wood cell structure. Some, such as blue stain, physically damage cells. All molds indicate sufficient moisture to support decay fungi.

Mollusca. One of the eleven phyla (largest divisions) in the animal kingdom. They have unsegmented bodies usually with limey shells, with typical or modified bilateral symmetry. Respiration is by gills. Marine examples are clams, mussels, and teredine borers.

Molluscan Borers. Marine Borers which are members of the phylum Mollusca. Includes Teredo, Bankia, and pholads. See Borers, Marine; and Borers, Rock.

Mycelium. The thallus or vegetative portion of a fungus, consisting of hyphae (see hypha). It is a mass of hyphal or mycelial fibers which may be un-massed as in hyphal threads in a decaying piece of wood, or may be tightly massed in a thallus as in a mycelial mat on decayed wood, as in the rhizomorph of a water-conducting fungus, or as in a sporophore such as a mushroom or a puff ball.

Nacerda. Nacerda melanura, the wharfborer. This is a wood-destroying beetle in the family Oedemeridae. It attacks damp wood, and it may require that some decay be present. Its larval frass is a dull-rusty-colored, mud-like material packed in the excavations.

Naval Stores. A term applied to the oils, resins, tars, and pitches derived from oleoresins and contained in, exuded by, or extracted from trees chiefly of the pine species (in genus Pinus) or from the wood of such trees.

Nominal Size. See Lumber.

Oil-Borne Preservatives. See Preservatives, Oil Borne.

Oil-type Preservatives. See Preservatives, Oil type.

Open-Grained Wood. See Grain.

Order. A subdivision of plants or animals which ranks below and helps to comprise a class, and which ranks above and consists of families.

Organic Matter. Any substance containing carbon and derived from living or once-living organisms.

Organism. A single plant or animal; one that functions as a unit. However, as a distinct entity, such a unit may be a member of a group of like units.

Oven-Dry Wood. Wood dried to constant weight in an oven (kiln) at or above the temperature of boiling water, usually at 101°C to 105° C.

Oxygen Concentration Cell. A space on a submerged metal surface having two zones with different concentrations of oxygen. Here, the area where the O_2 concentration is the least becomes anodic (the anode), and the metal goes into solution to move to the area of greater O_2 concentration. This is corrosion of the metal occurring at the anode. Such cells are found beneath some living and most dead marine fouling.

Paper, Sheathing. A building material, generally paper or felt, used in wall and roof construction as a protection against the passage of air. Most sheathing papers prevent or reduce the passage of liquid moisture but not of moisture vapor.

Parasitic Fungi. See Fungi, Parasitic.

Parasite. An organism living on or in another living organism (the host) at whose expense it obtains nourishment and shelter without providing any benefit to the host.

Parenchyma. In wood, short cells having simple pits and functioning primarily in the metabolism and storage of plant food materials.

Peck. Pockets or areas of disintegrated wood caused by advanced stages of localized decay in the living tree. It is usually associated with cypress and with incense cedar. There is no further development of peck once the lumber is seasoned.

Penetrant. A liquid used as a carrier for a soluble wood preservative.

Penetration. The depth to which preservative enters the wood.

Penta Preservative. In the wood treating industry, this means a wood-preservative solution mode of pentachlorophenol, C_6Cl_5OH, dissolved in hydrocarbon solvent. Oftentimes, an auxiliary solvent is added to increase the solubility of the "penta." It may have a water-repellent material added. (See Preservative, Water-Repellent). The term "penta" preservative may also be used for bodied formulations (greases, invert emulsions) containing pentachlorophenol.

Perm. A measure of permeability, of water vapor movement through a material (grains per square foot per hour per inch of mercury difference in vapor pressure).

Phloem. The living inner bark. See bark.

Photosynthesis. The process by which green plants make carbohydrates from carbon dioxide and water in the presence of sunlight and chlorophyll.

Pit. A relatively unthickened portion of a cell wall where a thin membrane permits liquids to pass from one cell to another.

Pit: Boardered Pit. A pit that has a portion of the cell wall projecting out over the pit membrane thus reducing the aperture or pit canal. With these, the pit membrane often has a thickened, impervious central portion. See next entry.

Pit Membrane. A pervious membrane between two wood cells at a pit (hole) in the cell walls which separates the cytoplasm of the two cells but which, in sapwood, permits the passage of liquids if not thickened or overgrown. See Pit.

Pitch Pocket. An opening extending parallel to the annual rings of growth usually containing, or which has contained, pitch, either solid or liquid.

Pith. The small, soft core occurring in the structural center of a log.

Pith Fleck. A narrow streak resembling pith on the center of a piece, usually brownish and up to several inches in length, which results from the burrowing of insect larvae in the growing tissue of the tree.

Plain Sawed. See Grain.

Plank. See Lumber.

Plankton. A collective term referring to plant and animal marine organisms that drift or float with currents, waves, etc., unable to materially influence their own course, ranging in size from microorganism to large jelly fish, and including some early stages in the life cycles of some organisms which are non-planctonic in later stages of life.

Plate: Sill Plate. A horizontal member anchored to a masonry wall.

Plate: Sole Plate. The bottom horizontal member of a frame wall.

Plate: Top Plate. The top horizontal member of a frame wall supporting ceiling joists, rafters, and other members.

Pocket Rot. Advanced decay that appears in the form of a hole, pocket or area of soft rot usually surrounded by apparently sound wood.

Pocket, White. See White Pocket.

Pore. See Vessel.

Preservative. Any substance that, for a reasonable length of time, is effective in preventing the development and action of wood-rotting fungi, of borers of various kinds, and of harmful insects that deteriorate wood.

Preservative, Oil-Borne. A preservative that is introduced into wood in the form of a solution in oil.

Preservative, Oil-Type. A preservative such as creosote, creosote coal for solution, and oil-borne preservatives, or other preservatives strictly of an oily nature which are generally insoluble in water.

Preservative, Water-Borne. A wood preservative that is introduced into wood in the form of a solution in water.

Preservative, Water-Repellent. A solution of one or more toxic chemicals and water-repellent materials that preserves wood and retards changes in moisture content and the accompanying changes in dimensions.

Preservative, Wood. The term "preservative" is intended to include such chemicals or combinations thereof as will protect wood against deterioration from any one or combination of the following: decay, insects, marine borers, fire, weathering, absorption of water, and chemical action.

Punk. Decayed wood that is dry and crumbly.

Quarter Sawed. See Grain.

Rays, Wood. Strips of cells extending radially within a tree and varying in height from a few cells in some species to four inches or more in some oaks. The rays serve primarily to store food and to transmit it horizontally in the tree.

Relative Humidity. Ratio of the amount of water vapor present in the air to that which the air would hold at saturation at the same temperature.

Retention by Assay. The determination of preservative retention in a specific zone of treated wood by extraction or analysis of specified samples such as (a) increment borer cores or (b) chips obtained with a wood bit. The principle applies to freshly treated material and to old treated material, and to larger samples if necessary.

Retention by Gauge or Weight. The amount of preservative, in pounds per cubic foot, of the total charge remaining in the wood immediately after completion of the treating operation. Same as Net Absorption.

Rhizomorphs. Branch-like or root-like structures. In fungi, these structures are sometimes found to form dendritic patterns between two pieces of decaying wood or on other wood surfaces when protected from dessication. In the water-conducting fungi, these confluent rope-like or vine-like masses of hyphae may be found within timbers which have been hollowed-out by the fungus, or between timbers, or between masonry and wood. These rhizomorphs conduct moisture from a source, such as damp soil or a plumbing leak throughout the timber framing until two-and-three story buildings are destroyed by the single fungus plant originally involved.

Ring, Annual Growth. See Annual Growth Ring.

Ring-Porous Woods. A group of hardwoods in which pores are comparatively large at the beginning of each annual ring (early wood) and decrease in size more or less abruptly toward the outer portion of the ring (latewood), thus forming a distinct inner zone of pores known as springwood (early wood) and an outer zone of smaller pores known as summerwood (latewood).

Rock Borers. See Borers, Rock.

Rot. See Decay. Also see Dote, Doze, Dry Rot.

Rot, Soft. See Soft Rot.

Rot, White. This is a decay of wood caused by fungi which metabolize the lignin of the wood cell structure but not the cellulose. The wood becomes soft, and is easily compressed, particularly when wet. It is often very light in color--hence the name. In its early or middle stages it may often be noticed due to a dark "zone line" which occurs at its active, growing front. The drywood breaks easily across the grain without slivering.

Rough Lumber. See Lumber.

Round Knot. See Knot.

Rueping Process. An empty cell process for treating wood, usually with oil, in which the following sequence is employed: compressed air; cylinder filled without reducing pressure; pressure increased and held until the required absorption is obtained; final vacuum. (Patented by Max Rueping in 1902).

Sap. All of the fluids in a tree, special secretions and excretions, such as gum, excluded.

Saprophyte. A vegetable organism lacking chlorophyll that lives on dead organic matter, as do certain fungi and bacteria, in contrast to parasites (see above).

Sap Stain. See Stain, Sap.

Sapwood. The living wood of pale color near the outside of the tree or log. Under most conditions the sapwood is more susceptible to decay than is heartwood. See heartwood.

Scolytidae. The family of Bark Beetles in the sub-order Rhynchophora in the Order Coleoptera. They differ from other families in this sub-order in that they are not weevils. The larvae, which are legless, usually have food habits similar to the adults. Nearly all are borers under bark. In the family there are three subgroups which attack wood differently: (1) the true bark beetles burrow only in the bark and cambium; (2) the xylophagous, or wood-eating scolytids, burrow into and spend their lives feeding on the wood tissues in both sapwood and heartwood; and (3) the ambrosia beetles which cut burrows into the sapwood and which feed only on the fungi (ambrosia) which they cultivate within their tunnels. Some of the ambrosia beetles, or pinhole borers, are most destructive of newly cut timber where their tunnels and the fungi they carry quickly cause considerable degradation of wood.

Seasoning. Removing moisture from green wood in order to improve its service ability.

Seasoning: Air Dried. Dried by exposure to air, usually in a yard, without artificial heating.

Seasoning: Kiln Dried. Dried in a kiln with artificial heating.

Second Growth. Timber that has grown after the removal, by any means, of all or a large portion of the previous stand.

Shake. (1) (a defect). A separation along the grain, the greater part of which occurs between the rings of annual growth.

Shake. (2) (an item). A thick, handsplit shingle, usually edge-grained; sometimes resawed to form two shakes.

Sheathing. The structural covering, usually wood boards or plywood, used over studs or rafters of a structure. Structural building boards usually used as wall sheathing.

Sheathing Paper. See Paper, Sheathing.

Shell Rot of Poles. A condition sometimes found in butt-treated or hot-cold-treated poles of thin sapwood species with moderately resistant heartwoods. This is a decay of the inner layers of the sapwood under the outer layers which are protected by treatment or which dry quickly after wetting. With shell rot, the outer, relatively sound shell can easily fall away from the heartwood center of the pole when subjected to stresses such as those imposed by a lineman climbing a pole.

Shiplapped Lumber. See Lumber.

Shipworm. See Borers, Marine.

Shittah Tree; Shittim Wood. See Acacia.

Soffit. In most twentieth-century architecture, the term relates to and includes the underside of an overhanging cornice. Where such a soffit exists, the structure should be protected from rain penetration by a facia (see above) which will extend below the edge of the soffit. The term is broadly used to include the underside of a staircase, entabulature, lintel, archway, or cornice.

Soft Rot. A softening deterioration of wood components, often without visual distortion or apparent damage to the wood, caused by certain molds and other fungi which are not true decay fungi.

Softwoods. Those botanical groups of trees that in most cases have needlelike or scalelike leaves; the conifers; also the wood produced by such trees. The term has no reference to the actual hardness of the wood. See also Hardwoods.

Soil Cover (Ground cover). A light covering of plastic film, roll roofing or similar material used over the soil in crawl-spaces of buildings to minimize permeation of the area by moisture vapor due to evaporation of soil moisture.

Sound Knot. See Knot.

Spalling. The chipping, flaking or other fragmentation of a surface or a surface coating.

Species. The definitive identification of an organism in the system of classification of living organisms. A category of organisms subordinate to a genus, but above a race, strain or variety.

Specific Gravity. The ratio of the weight of a body to the weight of an equal volume of water at some standard temperature.

Spike Knot. See Knot.

Spiral Grain. See Grain.

Split. A lengthwise separation of the wood, due to the tearing apart of the wood cells. See check.

Spore. In fungi, a spore is a single cell which is capable of developing into an independent individual new fungus plant. An asexual spore is one produced by vegetative hyphae when the cell walls thicken to produce a cell which is resistant to desication and which can survive for long periods of time. These can be widely distributed as dust particles and by insects. A sexual spore is produced on sporophores (fruiting bodies), which are branches of the thallus, such a mushrooms, bracket fungi, and puff balls.

Sporophore. That portion of a fungus produced by and often thought of as a part of the plant thallus, and which gives rise to the reproductive spores (see above). It is sometimes called a "fruiting body" (see above), and depending on the fungus species, may be a mushroom, toadstool, bracket, or puff ball.

Spray Treatment. See Treatment, Spray.

Springwood. Earlywood. That portion of the annual growth ring of a tree that is first formed by the cambium during the early part of the season's growth. See also summerwood.

Stain. A discoloration in wood which may be caused by such diverse agencies as microorganisms, metals, or chemicals. The term also applies to materials used to impart color to wood.

Stain, Blue. A bluish or grayish discoloration of the sapwood caused by the growth of certain dark-coloring fungi on the surface and in the interior of wood.

Stain, Brown. A rich brown to deep chocolate-brownish coloration of the sapwood of some pines caused by a fungus that acts much like the blue-stain fungus.

Chemical Brown Stain. A chemical discoloration of the wood, which sometimes occurs during drying of several species, apparently caused by the concentration and modification of extractives.

Sap Stain. Another name for Blue Stain.

Stain, Sticker. A brown or blue stain, caused by fungi, that occurs in air seasoning of lumber where stickers rest on the faces of stock. Also, a brown chemical stain occurring on and beneath the surface of portions of a piece that is in contact with stickers.

Steam Conditioning. Subjecting wood in a closed space to the action of steam at or above atmospheric pressures to prepare it for preservative treatment.

Stickering. The use of stickers in piling or stacking lumber.

Stickers. Strips or boards used to separate the layers of lumber in a pile and thus permit air to circulate between the layers.

Strength. The term in its broader sense embraces collectively all of the properties of wood that enable it to resist different forces or loads. In its more restricted sense, the term "strength" may apply to any one of the mechanical properties; and in this use the name of the property under consideration should be stated, thus: strength in compression parallel to grain, strength in bending, hardness, etc.

Strength ratio. A ratio representing the strength of a piece of wood remaining after allowance is made for the maximum effect of the permitted knots, cross grain, shakes, or other strength-reducing features.

Stress, Force Per Unit Area:

Stress, Basic. The working stress of material free from strength-reducing features such as knots, checks, and cross grain. It has in it all of the factors appropriate to the nature of structural timber and the conditions under which it is used except those that are accounted for in the strength ratio.

Stress, Working. Stress used in the design of a wood member that is appropriate to the species and grade. It is obtained by multiplying the basic stress for the species and strength property by the strength ratio for the grade.

String, Stringer. A timber or other support for cross members in floors and ceilings. In stairs, the support on which the stair treads rest; also, stringboard. In waterfront piers, the longitudinal members that rest atop and at right angles to the pile cap timbers. Timber curbs on piers are also known as stringers. Some people also refer to wales or walers (see above) as stringers, or string pieces, because they run lengthwise with the pier.

Strips. See Lumber.

Structural Timbers. Pieces of wood of relatively large size, the strength of which is the controlling element in their selection and use. Trestle timbers (stringers, caps, posts, sills, bracing, bridge ties, guard rails); car-timbers (car-framing, including upper framing and car sills); framing for buildings (posts, sills, girders, framing joists); ship timbers (ship timbers, ship decking); and crossarms for poles are all examples of structural timbers.

Summerwood. The outer portion of the annual growth ring that is formed by the cambium after the springwood formation has ceased. It is usually denser and mechanically stronger than is springwood (see above).

Surface Hardening. A condition of the surface of timber that appears to be due to improper seasoning and may result in resistance to penetration of preservatives. Sometimes incorrectly called case hardening (see above).

Surfaced Lumber. See Lumber.

Sweep. A distortion of a round pole in which there is a deviation from a straight line from end to end of the pole.

Tangential. Strictly defined, coincident with a tangent at the circumference of a tree or log, or parallel to such a tangent. In practice, however, it often means roughly coincident with a growth ring. A tangential section is a longitudinal section through a tree or limb perpendicular to a radius. Flat-grained lumber (see grain) is sawed tangentially.

Tar. A generic term applied to non-aqueous liquids obtained as residuum in the destructive distillation of organic materials such as coal, lignite, petroleum, wood, etc.

Tar Acids. Weakly acidic compounds, soluble in sodium hydroxide solution and found in coal tars. They consist chiefly of phenols and their homologues.

Tar Bases. Weakly basic compounds found in coal tar. They consist chiefly of heterocyclic nitrogen-containing compounds.

Tar, Coal. The non-aqueous portion of the liquid distillate obtained during the carbonization of bituminous coal.

Taxonomy. The study of the laws and principals of classification, as based upon the structure of organisms; the systematic arrangement of plant and animal organisms according to established criteria that determine their assignment to the following major groups, beginning with the most inclusive: Kingdom, phylum, class, order, family, genus, and species.

Telson. The last abdominal segment of the body of an arthropod, as of a lobster or a scorpion. In the crustacean marine borers of the genus Limnoria, it is used by the borer as an aid to locomotion and by humans as a means of determining the species, Limnoria.

Tension Wood. An abnormal form of wood found in leaning trees of some hardwood species and recognizable by the presence of gelatinous fibers and excessive longitudinal shrinkage. Tension wood fibers hold together tenaciously, so that sawed surfaces usually have projecting fibers, and planed surfaces often are torn or have raised grain. Tension wood may cause warping. (See Compression Wood).

Teredo. A genus of mulluscan borers, in the family Teredinidae, often called shipworms.

Termite Shield. A shield, usually of metal, placed in or on a foundation wall or other mass of masonry or around pipes to force termites to tube over the shield. This allows the otherwise hidden termite tubes to be seen by anyone carefully inspecting a structure. They do not prevent termites' access to structures as termites easily tube over them.

Texture. A term often used interchangeably with grain (see above). Sometimes used to combine the concepts of density and degree of contrast between springwood and summerwood.

Thorax. In arthropods (see above) the division of the body between the head and the abdomen where such a division exists. Note that this division and this structure are not evident in all members.

Timbers. Lumber five inches or larger in the least dimension.

Timber Worms. These are larvae of beetles in the family Brentidae in the order Coleoptera. They attack recently felled oak, where the larvae make meandering tunnels in the wood.

Toxic. Capable of inhibiting growth or causing death when ingested by or contacted by wood-destroying organisms.

Tracheid. The elongated cells that constitute the greater part of the structure of softwoods (frequently referred to as fibers or as fiber tracheids). Also a portion of some hardwoods. (See Fiber).

Translocation. The movement or redistribution of preservative within the structure of treated wood in contrast to the movement of preservative out of the wood by exudation (bleeding), evaporation, blooming, or leaching.

Treatment, Brush. Application of one or more coats of liquid preservative to the surface of timber with a brush.

Treatment, Butt. Preservative treatment applied to the lower or butt ends of posts or poles, usually by the thermal or hot-cold process.

Treatment, Cold Soak. Partial or full length treatment of wood by soaking for varying periods of time in open vats containing unheated, low-viscosity preservative oil at atmospheric temperatures.

Treatment, Diffusion. Treatment in which green wood or water-soaked wood is immersed in an aqueous solution or has applied to it a paste or solid containing water-soluble chemicals to permit the chemicals to diffuse into the water in the wood.

Treatment, Dip. Application of a liquid preservative to a wood by immersing the wood in the liquid for a short time.

Treatment, Double (Double Pressure). Application, during any given treatment (charge), of two distinct pressure phases (e.g. pressure - partial of full release - pressure) to increase penetration of preservative.

Treatment, Dual. Treatment of wood to be used under severe conditions of exposure with two dissimilar synergistic preservatives in two separate treatment cycles, e.g., treatment of marine piles and timbers for areas of extreme borer hazard. Usually, the first treatment is with a waterborne salt preservative, and the second with creosote or creosote coal tar solution.

Treatment, Empty-cell. A treatment in which air imprisoned in the wood is employed to force out part of the preservative when treating pressure is released and the final vacuum is applied.

Treatment, Full-cell. A treatment involving a preliminary vacuum followed by pressure impregnation such that the cell cavities in the treated portion of the wood remain partially or completely filled with preservatives (See Bethel process).

Treatment, Internal. A treatment applied by injecting into a pole or timber, through holes bored for the purpose, sufficient toxic material to control interior infection or infestation by ants or termites.

Treatment, Spray. Application of one or more coats of liquid preservative to the surface of wood with a spraying device.

Twist. A distortion caused by the turning or winding of the edges of a board so that the four corners of any face are no longer in the same plane. See also Warp, Bow, Crook, Cup, and Sweep.

Tyloses. Masses of parenchyma cells appearing somewhat like froth in the pores of some hardwoods, notably white oak and black locust.

Vapor Barrier. Material used to retard the movement of water vapor into walls and so to prevent condensation in them. Usually considered as having a perm value of less than 1.0. Applied separately over the warm side of exposed walls or as part of batt or blanket insulation.

Veliger Larva. This is a free-swimming (and drifting) larva typical of most members of the molluscan class Pelecypoda. Both ova and sperm are discharged directly into the water where fertilization occurs, and the zygote develops into a ciliated veliger larva. This in time develops a shell gland, sinks to the bottom or attaches to another suitable surface, and becomes a miniature bivalve. For most <u>Teredo</u> and <u>Bankia</u>, the surface must be wood in order for the organisms to penetrate and to live.

Velum. A thin membranous covering or partition. In some marine organisms, it is a swimming organ of veliger larvae, and may be ciliated. It permits a degree of positive chemotropism for veliger larvae in contrast to complete drifting.

Ventral. The lower or frontal side of an organism as opposed to the dorsal (see above).

Vertical Grain. See Grain.

Vessels. Wood cells of comparatively large diameter which have open ends and are set one above the other, forming continuous tubes. The openings of the vessels on the surface of a piece of wood are usually referred to as pores.

Wale, Waler. A horizontal, longitudinal timber below the decks in piers. They do not include the stringers (see above) which are placed above and at right angles to the pile cap timbers. They are used variously to provide some rigidity to a pier by tying together rows of piles. They may be inner or outer wales depending on their location on the inner or outer face of the row of piles to which they are attached, and upper or lower wales depending on whether they are near the tops of the piles or near the waterline. Where both inner and outer wales exist parallel, there may also be chocks attached between them and filling the spaces between piles at that elevation. Chocks are often used when only an upper, inner wale is used.

Wane. Bark on the edge or corner of a piece of lumber, or other lack of wood for any other cause on the edge or corner of a piece of lumber.

Warp. Any variation from a true or plane surface. Warp includes bow, crook, cup, and twist, and any combination of these. (See also sweep)

Water-Borne Preservative. See Preservative.

Water-Conducting Fungus. A fungus which, by means of rhizomorphs (see above), conducts moisture from a source to areas of active wood dissolution (digestion). An example is the "building poria," Poria incrassata.

Water-Repellent Preservative. See Preservative, Water-Repellent.

Wavy-Grain Wood. See Grain.

Weathering. The mechanical and chemical disintegration and discoloration of the surface of wood that is caused by exposure to light, the action of dust and sand carried by winds, the action of frost, or the freezing and thawing of moisture at the surface, and the alternate shrinking and swelling of the surface fibers with the continual variation in moisture content brought on by changes in the weather. Weathering does not include decay.

White Ant. A common name for termites. Note that termites are not ants. All ants belong to the insect order Hymenoptera, and all termites belong to the order Isoptera. Worker termites and nymphs are a whitish color and bear a superficial resemblance to ants. Hence the term.

White Pocket. A fungus disease of the heartwood of mature and over-mature Douglas fir trees. It is sometimes called peck (see above). As with the peck (holes) in pecky cypress, there is strength loss, but there is no growth of the fungus after the cutting of the tree.

White Rot. See Rot, White.

Wood Grain. See Grain.

Wood Preservative. See Preservative.

Wood Rays. See Rays, Wood.

Working of wood. Changes in the dimensions of a piece of wood with changes in moisture content.

Xylem. The portion of the tree trunk, branches, and roots that lies between the pith and the cambium.

Xylophaga. A genus of wood-boring pholads.

Yard Lumber. See Lumber.

Appendix I

Wood Destroying Organisms in the Animal Kingdom

Wood-Destroying Organisms in the Animal Kingdom

A Brief Synopsis

Kingdom: Animal. Separated from plants primarily by metabolism and neurology (neural irritability).

Sub-kingdom: Metazoa. Animals whose bodies consist of many cells organized into tissues and structures; as differentiated from Protozoa which typically are single-celled animals.

Phylum: Mollusca. Body unsegmented, soft, usually enclosed by a mantle which usually secretes a limey shell of 1, 2 or 8 parts, typically with a fleshy foot for locomotion, with bilateral symmetry, and a complete digestive tract. Respiration by gills.

Class: Pelycypoda. The bivalve molluscs: clams, oysters, vessels, etc. Body enclosed (usually in a shell of two latteral halves, with dorsal hinge. No head or jaws. Veliger larvae.

Order: Teleodesmacea. Margins of mantle more or less connected vertically and posteriorly. Siphons usually well developed.

Family: Pholadidae. Shells which can enclose the animal. These are "rock borers," typically boring into rock or hard clay. Of the several genera, the two most commonly troublesome in structural wood are *Pholads* and *Martesia*. Of all the Pholadidae destructive of property, *M. Striata* has caused the greatest losses.

Family: Teredinidae. Members of this molluscan family, known as shipworms, have the valves (shell halves) greatly reduced to two small cutting and rasping structures of the growing, internal end of the worm-like body. For protection, and to maintain the hydrostatic pressure required for burrow expansion, the teredine bores its tunnel with calcium carbonate which substitutes for a complete shell housing. At the entrance, the holes provide places for both the incurrent and excurrent siphons. Pallets, characteristic of each species, are used to plug the holes. These pallets provide the quickest way to identify the several destructive species and to tell whether a species belongs in the genus *Teredo* or in the genus *Bankia*.

Phylum: Arthropoda. Animals with exoskeletons and jointed feet.

Class: Crustacea. Animals typically with hard shells, more or less jointed. Two pair of antennae and mandibles; and one pair of appendages per body somite. Respiration by gills or through body surface. Most aquatic, but includes some terrestrial forms such as sowbugs. Some structures typical of this class are found only in early developmental stages of some members; i.e., jointed feet (phylum Arthropoda) are not found in mature barnacles.

Subclass: Cirripedia. These are barnacles. Adults are sessile and attached by a cement gland. The carapace becomes a mantle surrounding the body, and usually has limey plates. These are the goose barnacles (Lepae, Mitella) and the rock barnacles (Bulanus) or ship barnacles. The Cirripedia do not directly damage wooden waterfront structures as they do metal and concrete structures. But, on borer-damaged wood, their weight and their drag can hasten "natural removal" of piles and timbers.

Subclass: Malacostraca. These animals typically have bodies of 19 somites (5 head, 8 thorax, 6 abdomen). The head is usually fused to one of more thoracic somites. There often is a carapace, and an abdomen with appendages. Lobsters, crayfish, crabs, crustacean wood borers, and terrestrial sowbugs are members of this subclass.

Order: Amphipoda. These animals have no carapace. The body is commonly compressed laterally. The abdomen is flexed vertically between the 3rd and 4th somite. The telson is large, with its individual parts divergent. In general, amphipod appendages are often larger than are isopod appendages.

Genus: Chelura. These have pronounced chelipeds, uropods and antennae, all of which, along with other appendages, tend to be "feathery" in appearance. Almost always found with Limnoria rather than alone, while Limnoria is often found without Chelura present. Because of this, it is believed by some to be only a secondary invader rather than a wood destroyer. However, if it does not originate damage, it does enlarge the tunnels made by Limnoria.

Order: Isopoda. These isopod malacostraceans are like the amphipods in that they have no carapace; but they differ from them in that the body is usually compressed dorso-vertically (rather than laterally), and in that the abdomen is short and is fused either partially or completely. The telson is of moderate size. In the wood-boring species, chelipeds and uropods are not highly developed nor do they have a "feathery" appearance.

Family: Limnoridae: The only wood-boring marine Isopods. Two isopod genera have species which tunnel in wood: Limnoria and Sphaeroma.

Genus: Limnoria. Within this genus are some very destructive species. In recent years, L. tripunctata has caused the greatest losses to waterfront structures for two reasons: (1) as a warm-water/temperate-water species, it is active in a wide geographical area throughout the year; and (2) it can not only survive in the presence of creosote, but it can destroy wood which is heavily creosote-treated if the creosote contains very small amounts of oliphatic compound which may have been in the original creosote, which may have come form occasional oil slicks on water washing against the wood between high and low tide, or which were produced from aromatic compounds by the actions of various microorganisms.

Genus: Sphaeroma. These are truly "marine pill bugs" in that they can roll up into a tight ball for protection of their appendages. Their width-to-length ratio is greater than that of the *Limnoria*. The *Sphaeroma* telson is somewhat triangular in shape while that of *Limnoria* is broadly rounded.

Class: Insecta. Members of this group of arthropods, as adults, typically have distinct head, thorax and abdomen, one pair of antennae on the head, and two pair of wings and three pairs of legs on the thorax. In some orders, metamorphosis is complete (egg, larvae, pupa, adult), and in others is incomplete (egg, nymph, adult).

Order: Isoptera. These are the termites, sometimes called white ants because of their size, their superficial resemblance to ants, their colonial existence, and the creamy-white color of most individuals. Termites feed on materials composed of cellulose which is digested by protozoa within the termite gut. Each termite species maintains its own characteristic gut fauna. Termites have a cast system with workers, soldiers and reproductives. Metamorphosis is of the incomplete type: from the eggs hatch nymphs which, after several molts, evolve into one or another of the three adult forms. Termite colonies may range in size from only a very few members in some dry-wood species to many thousands of members in some subterranean species. All termites may be divided into two groups, the soil-inhabiting and the wood-inhabiting. Two families are of economic importance in temperate and subtropical regions of the Western world and some Pacific Ocean and Tropical American areas. Specifically omitted from this discussion are some North American termites, such as some desert soil-dwelling species of little if any economic interest to the U.S. Navy. Also omitted are many foreign species which could be introduced and which could become established.

Family: Kalotermitidae. In this family belong all four genera of American wood-dwelling termites. These are both damp-wood termites and dry-wood termites.

Genus: *Paraneotermes simplicicornis*. This is a desert damp wood termite which can damage property in only a very limited range. It typically feeds on living plants but also destroys below-ground portions of untreated posts and poles. It seems to be a little less of an obligate wood-dweller than are the other kalotermitidae.

Genus: *Zootermopsis*. These are true damp wood termites. They typically are found in old logs or stumps in damp areas. They will enter checks that expose untreated wood in railroad ties; but it is probable that some moisture-holding decay areas exist before a termite colony is established. Once established in damp wood, these termites can extend their area of feeding and damage to sound, dry wood in utility poles and in buildings just as do subterranean termites.

Z. angusticollis is a large termite, the largest native to the Pacific Coast. It is a very primitive type which has a less highly evolved social system than that of most termites. It lacks a worker cast; all nymphs eventually becoming soldiers or reproductives. It is most destructive in the northern part of its range (Northern California, Western Oregon and Washington).

Z. nevadensis. This species is smaller and darker than *Z. angusticollis*. It is not found as far south, but is found in dryer areas and at higher altitudes. Its economic importance is about equal to that of *Z. angusticollis*.

Genus: *Cryptotermes*. These are the Powder-Post termite. They are able to live indefinitely in dry, seasoned wood having no moisture contacts. The soldiers have high, short, dished-out or truncated heads used to plug up runways in case of attack.

C. brevis. This is the common powder-post termite of the Gulf Coast. It is found only in very dry wood, and typically is not found in nature but only in woodwork and furniture. Because of infestations in the furniture of military personnel shipped to a variety of places, *C. brevis* has been found in buildings considerably north of its normal range years after the last occupancy by a military family moving furniture north from tropical areas.

C. piceatus. This is the Hawaiian Powder-Post termite. It is a considerable pest in Hawaii. This powder-post termite has been found in many places in the Pacific Ocean area and the Orient. As it must be a good traveler to have become so widely distributed, it can certainly be expected to be introduced to west coast ports. Like *C. brevis*, it can be highly destructive.

Genus: *Kalotermes*. Members of this genus are the true dry-wood termites. With most species, the severe damage to structures is not due to large colonies but rather to a multiplicity of small colonies in a single structure.

K. minor. This is the common dry-wood termite of Western North America. It is destructive of structures primarily in California, Arizona, and Northern New Mexico. Within parts of its range it can be highly destructive.

K. snyderi. This is the most wide-spread and destructive of dry-wood termites in North America. It is found from South Texas through the Gulf States up through coastal South Carolina. In small, isolated foci where introduced, it can be quite destructive .

K. approximatus. This is the only dark-colored eastern species. In coastal areas it has been found from Louisiana as far north as Virginia.

K. hubbard. This is the "Southern dry-wood termite." Where it is found, it is highly destructive; but its normal range is limited to the Colorado River Valley in S.E. California, most of Arizona, and part of Mexico.

K. majoriae. This is the Hawaiian dry-wood termite. In some areas of Hawaii, it is extremely destructive of structural wood and of forest products in storage.

Family: Rhinotermitidae. These are the true subterranean termites. Typically, they nest in the soil and feed on the wood which is often above the soil. However, some of these readily establish "sub-nests" (parts of the main colony) above ground, and some establish original new-colony nests in damp wood above ground such as in moisture-trappings joints in waterfront structures. The sub-nests of some are often called carton nests and have lignin as an important constituent.

Genus: *Heterotermes* (*Leucotermes*). These are tropical subterranean termites of considerable economic importance wherever found. Various species are native to various tropical areas.

H. aureus is a semi-tropical species extending into the warm-temperate area of southeastern California and parts of Arizona. It can be highly destructive.

Genus: *Reticulitermes*. Within the United States and its territories, the members of this genus cause greater financial losses than do all other termites. Typically, these are all true subterranean termites nesting in the ground and extending their destructive activities upward into man-made structures. However, where there is water-trapping construction, leaking plumbing or other moisture above ground these termites can establish colonies without the usual ground contact.

R. hesperus. This is a very destructive species wherever found. It is native to the Far West, including much of California, Oregon, Washington and Northwestern Nevada.

R. tibialis. This species does less total damage than does *R. hesperus*, but in any single structure the damage may be as great. It is found in the non-coastal West, the Midwest, and the Southwest.

R. flavipes. The fact that this is the most destructive single termite species in North America is due in part to its considerable range. It is found throughout the Midwest and the East. Two other species share the Southeast with it, but they are not found in the Northeast or the Midwest.

R. virginicus. Within its range in the Southeast, this termite is widely distributed and is at least as destructive of property as is *R. flavipes*. These two species are much alike in appearance and in actions. They respond to the same controls, so species identification is not normally required.

R. hageni. This termite shares the range of *R. virginicus*; but in most of the range it is less often responsible for damage to man-made structures.

Genus: *Coptotermes*. These are large subterranean termites found throughout the tropics, and in some areas they extend into subtropical and temperate zones. As with the *Reticulitermes*, the *Coptotermes* can establish colonies above the ground or otherwise be separated from it. Vigorous colonies have been found in ships and in floating dry docks where sources of available moisture existed.

C. niger and *C. crassus* are species common to Central America and northern South America. *C. niger* is also found on some Caribbean islands.

C. formosanus. This is an extremely destructive termite wherever found. It was introduced into the Hawaiian Islands many years ago and is now firmly established there. It has also become established in the New Orleans area. Its natural range of climate in the orient indicates that this species could easily become established along the entire West and Gulf Coasts of the United States and part of the East Coast. Individual members of a colony are larger than our native species, and developed colonies have a great many more individuals than do our native species. Compared to the shelter tubes normally built by *Reticulitermes*, *Coptotermes* tubes are like super highways compared to back-country dirt roads. They are wide, and often quite long. They are tough, and they tend to be water-repellent. Soldiers are quick to attack any intruder, and their bites can easily cut deeply into the softer areas of skin on a human hand.

Class: Insecta (continued)

Order: Hymenoptera. The name of this order of insects means "membrane-winged". These are the bees, the wasps, and the ants. Not all individuals have wings. In the family Mutilidae (velvet ants), only males have wings. In the family Formicidae (true ants), only the reproductives, both male and female, have wings, and both workers and soldiers are wingless. All members of this order undergo complete metamorphosis. From the egg hatches a larva which, after a period of growth, changes into a pupa. After a period of development, the pupa becomes an adult. Depending on various factors, the adult will be a male or female reproductive or a soldier or a worker. Some hymenoptera have no soldiers, and some have neither soldiers nor workers.

Family: Xylocopidae. These are the large carpenter bees. They resemble very large bumble bees, but can quickly be differentiated from them by their wide heads. They cut nearly round holes into wood which may extend for a foot or more. These are divided into several broad chambers, each with an egg and with food for development. Two species have damaged property in the United States. There are no workers or soldiers.

Genus: *Xylocopa virginica*. This is found in the eastern United States. Individual attacks do little structural damage, but repeated, uncontrolled attacks can be serious.

X. basilianorum. This is the carpenter bee of the Southwest which has at times been quite destructive.

Family: Formicidae. This is the family of ants. There are workers and soldiers, and some species have two or more types of each of these castes. Some species have secondary as well as primary reproductives. Ants can be found in nearly all types of terrestrial ecological situations in which they can find food and shelter, and their food range is extensive. Many species are found in wood. Some live inside dead twigs of shrubs and trees. Some will nest in cracks in dead trees. Some will nest in soft, decayed wood. The true carpenter ants will cut nesting galleries in sound wood.

Genus: *Campanotus*. These are the carpenter ants. In nature, they enter a tree at a broken branch or other opening into the heartwood where they make their galleries. They do not eat the wood. They run about over the trees, looking for small insects which form much of their diets; and in this way they are beneficial to the tree while hollowing it. They will nest inside man-made structures, often in places difficult to locate. When numerous over extended periods they can cause considerable damage.

C. herculeum *ligniperdus* has two varieties in the Pacific Northwest and southeast Oregon. They typically damage trees at the groundline and will damage unprotected wood on the ground.

C. herculeum *pennsylvanicus* is the Eastern black carpenter ant. On occasions, it has caused considerable financial damage when it has worked extensively for long periods when not reported for control.

Order: Coleoptera. This is the order to which all beetles belong. Eight separate and distinct families of beetles have members that are destructive of wood in storage or in use. 45 species in 36 genera that are destructive of property are mentioned below. Metamorphosis is complete.

Family: Lyctidae. This is the family of the lyctus powder-post beetles. The adults do not directly damage wood. The females deposit eggs in the pores of open-pored woods. On hatching, the larvae bore into the wood which they turn into tightly packed powdery frass. Emergence holes are typically round, and beneath them piles of frass may develop.

Genus: *Lyctus*. There are four species destructive of property in North America.

L. parallelopipedus. This is the most destructive lyctus beetle in the eastern United States. Hardwood items in storage, including pallets, can be completely destroyed. Emerging beetles will reinfest wood in storage areas.

L. planicollis. This powder-post beetle is widely distributed and highly destructive.

L. bruneus. This species is widely distributed, but serious property damage is localized.

L. linearis. Like *L. bruneus*, this beetle is widely distributed, but serious property damage is localized.

Genus: *Minthea rugicollis*. This is an introduced species which is now established on both the East Coast and the West Coast.

Family: *Ptinidae*. These are the spider beetles. Most do not do any damage to wood in structures. Two species do damage to wood.

Genus: *Ptinus bruneus*. This spider beetle is occasionally the cause of damage to softwood boards in old buildings.

P. fur. This beetle damages plant and animal matter in storage; and it will bore into pine and oak woodwork.

Family: Buprestidae. These are called the flat-headed borers because the larvae are shaped somewhat like a horseshoe nail. They are often destructive of living trees, and most do not damage wood in storage or use, but there are exceptions to this generality.

Genus: *Buprestis*. Two species in this genus will destroy wood in storage and in use.

B. aurulenta. This is the golden buprestid beetle. It is a western species which has at times been shipped east with lumber. It will attack coniferous woods in structures and completely destroy them. Very dry wood can delay full development of larvae for up to 25 years.

B. langi. This is a western buprestid beetle with habits like those of *B. aurulenta*.

Family: Oedemeridae. One of the oedemerid beetles is of very real importance to the Navy.

Genus: *Nacerda melanura*. This is the wharfborer. It is destructive of wood in many damp places such as: cellars, seashore boardwalks, utility poles in damp ground, building-support piling near water, piling for piers and wharves above the low-tide line, bulkhead timbers, and the underside of wharf decking.

Family: Curculionidae. These are weevils.

Subfamily: Cosoninae. These are broad-nosed bark weevils.

Genus: *Hexarthrum ulkei*. Sometimes called the Old Wood Weevil, it is destructive of seasoned coniferous woods in the eastern United States.

Genus: *Tomolips guercicola*. This is a softwood weevil, destructive of seasoned coniferous wood.

Genus: *Pselactus spadix*. This weevil is destructive of damp wood beneath buildings and of piling at and just above the high tide line.

Family: Bostrichidae. These are known as the large, or the false, powder-post beetles.

Genus: *Xylobiops basilaris*. This is common in the eastern and southern States. The greatest damage is done to recently cut wood; but damage is also done to hardwood species in manufactured items.

Genus: *Polycaon stouti*. This is a Western species which is shipped to the East in materials of the softer hardwoods, including veneer stock and furniture.

Genus: *Dinoderus minutus*. This is a cosmopolitan species breeding in bamboo. It is often shipped into the United States.

Genus: *Scobicia*. Two species are of importance.

S. bidentata. This is common in the midwest in newly-cut hardwood lumber. It is shipped both east and west in wooden items.

S. declivis. This is the lead-cable borer. It is common in California and Oregon. It feeds in all sorts of hardwoods, and is occasionally shipped East.

Genus: *Stephanopachys*. There are two important species in this genus.

S. rugosus. This is native to the eastern States. It destroys softwood lumber such as floor joists and flooring.

S. substriatum. This is native to the northern States, and is moved out when wood is shipped. It attacks softwood species in structural lumber and furniture.

Genus: *Rhizopertha dominica*. This is the lesser grain borer. In addition to destroying seeds, it destroys seasoned hardwoods.

Family: Anobiidae. These are the Deathwatch Beetles, or the Anobiid Powder-Post Beetles. In chewing wood, the larvae often snap the individual fibers. This creates a sound which can easily be heard in a quiet building. Hence the common name for this group.

Genus: *Hadobregmus*. These are all softwood powder-post beetles.

H. gibbicollis is considered the most destructive native powder-post beetle in the Pacific Coast States. It damages dry, undecayed wood.

H. carcinatus feeds on flooring and beams of buildings. It can cause much damage.

H. umbrosus is often found in the woodwork of furniture.

Genus: *Anobium punctatum*. This cosmopolitan species causes considerable damage in pine flooring, joists and furniture.

Genus: *Petalius bistriatum*. This is primarily found in the East where it damages pine flooring, joists, and furniture.

Genus: *Ernobius mollis*. This is a European native now well established in the United States. It attacks lumber in storage and in use. It causes serious damage to pine and spruce woodwork, especially flooring.

Genus: *Nicobium hirtum*. This is a European species found in furniture in the United States, particularly in the Southeast.

Genus: *Ptilinus ruficornis*. This is a common pest of woodwork and of stored wood products.

Genus: *Trichodesma gibbosa*. This is larger than most anobiids. It seriously damages sweetgum joists and studding in Tidewater Virginia.

Genus: *Xestobium rufovillosum* damages woodwork in cool humid parts of buildings in New England.

Genus: *Xyletinus peltatus* is widely distributed in the eastern United States. It can do great damage to cellar joists and flooring in damp buildings. It works in both hardwoods and softwoods, reducing them to powder. It is often associated with fungi in moist wood.

Family: Cerambicidae. There are three common names appropriately used for the members of this family: (1) Powder-Post Borers, because of the damage done by the larvae; (2) Roundheaded Borers, because of the shape of the larvae; and (3) Longhorned Beetles, because of the long antennae on the adults.

Genus: *Opismus quadrilineatus*. This western species, known as the Spruce Limb Borer, is destructive in seasoned softwoods.

Genus: *Hylotrupes bajulus*. The Old House Borer. This is highly destructive of the sapwood of softwood species in buildings.

Genus: *Smodicum cucujiforme*. The Flat Oak Borer. In the eastern United States it is found in dry hardwood lumber and in buildings.

Genus: *Eburia quadrigeminata*. The Ivory-Marked Beetle damages dry hardwoods.

Genus: *Callidium*. In this genus are the Black-Horned Beetles. They attack coniferous structural wood and stored lumber.

C. antennatum is the Black-Horned Pine Beetle. It is found throughout the U.S. but is most common in the South.

C. texanum is the Black-Horned Juniper Borer. It attacks a variety of coniferous woods throughout the U.S.

Genus: *Chlorophorus annularis*. This bamboo borer is widely distributed.

Genus: *Anoplodera* (*Leptura*). Various species attack hardwoods, softwoods, drywood and damp wood. Damage can be extensive in poles, posts and crossties, etc.

Genus: *Ergates spiculatus*. This is the Ponderous Pine Borer. It damages dry coniferous woods such as poles and posts.

Genus: *Neoclytus acuminatus*. This is the Red-Headed Ash Borer. It attacks unseasoned hardwoods and is often built into structures.

Genus: *Orthosoma bruneum*. This is the Brown Prionid. It attacks the heartwood of most wood species, damaging structural wood, crossties, poles and posts.

Genus: *Parandra brunnea*. This is the Pole Borer. It attacks the heartwood of most wood species if moist or on the ground.

Genus: *Stenodontes clasytonus*. This is the Hardwood Stump Borer. It attacks damp wood with ground contact. It destroys crossties.

Genus: *Tragosoma harrisi*. This beetle attacks the heartwood of most species if moist. It destroys structural wood and poles.

Appendix II

Decay Hazard Areas Around the World

DECAY HAZARD AREAS AROUND THE WORLD

Chapter 6, "Selection of Treatment for Wood Use," provides guidance on the physical and chemical protection required for a variety of structural elements exposed to differing weather conditions. In providing this guidance, it repeatedly refers to five different types of decay-hazard areas. A large-scale map of these areas will often be misleading because of significant differences in the building site's mircro-climate, so it is better to determine the actual micro-climate for each building site.

The recommendations in Chapter 6 can be used on a world-wide basis if the reader can determine the type of "Decay Hazard Zone" (degree of decay hazard) for any particular area of the world. This Appendix provides a method for making such determinations, but to do so the user must have certain specific information about the weather at the site. With this information, the reader can determine the climate type according to the basic system of C. Warren Thornthwaite, after which Appendix 6-A provides further guidance for determining the Decay Hazard Zone.

(2) C. W. Thornthwaite devised a system for classifying all possible climate provinces, an improvement on the widely used system devised earlier by W. Koppen. Although the system uses terms which may be new to many who have only limited backgrounds in climatology, his system is really quite simple and easy to use. It uses only three basic terms, one for each of three elements of the weather, to define each type of climate. These are: (1) precipitation effectiveness, (2) temperature efficiency, and (3) seasonal distribution of precipitation. With his five humidity zones, six temperature zones, and four types of seasonal distribution of precipitation effectiveness there would be 120 types of climate theoretically possible. However, of these theoretical 120 types, only 32 actually exist on earth. Of these, only 19 exist within the contiguous 48 United States; and these have been combined by Robert Z. Page into the five decay hazard zones (of Chapter 6) for which specific recommendations have been made for wood protection.

(3) Precipitation effectiveness is the ratio of precipitation divided by evaporation (P/E). The P/E ratios for each month are totalled to obtain the annual precipitation effectiveness for the location. Thornthwaite recognizes five basic humidity types derived by his method. To help the reader quickly appreciate Thornthwaite's humidity provinces, the name of each province is followed by its typical vegetation type and rainfall in inches/year: A - wet (rain forest) (128 and above); B - humid (forest) (64-127); C - subhumid (grassland) (32-65); D - semiarid (steppe) (16-31); E - arid (desert) (0-16).

(4) Temperature efficiency is the sum of the twelve monthly thermal efficiency coefficients. Thornthwaite recognizes six thermal efficiency types (°F): A^1 - Tropical, (Hot (123 and above); B^1 - Mesothermal, Temperate (64-127); C^1 - Microthermal, Cool (32-63); D^1 - Cold, Taiga (16-31); E^1 - Tundra (1-15); F^1 - Permafrost (0).

(5) Thornthwaite uses four types of seasonal distribution of precipitation effectiveness. These are: r - adequate in all seasons; s - summer deficiency of rain; w - winter deficiency of rain; d - deficient in all seasons.

(6) The following are Thornthwaite's 32 climate types:

1. AA'r
2. AB'r
3. AC'r
4. BA'r
5. BA'w
6. BB'r
7. BB'w
8. BB's
9. BC'r
10. BC's
11. CA'r
12. CA'w
13. CA'd
14. CB'r
15. CB'w
16. CB's
17. CB'd
18. CC'r
19. CC's
20. CC'd
21. DA'w
22. DA'd
23. DB'w
24. DB's
25. DB'd
26. DC'd
27. EA'd
28. EB'd
29. EC'd
30. D'
31. E'
32. F'

(7) When the climate types indicated by Thornthwaite's elements are delineated on a map, it shows Thornthwaite's climatic provinces. However, in many areas of the world, these cannot merely be used as a map of decay hazard areas. Diurnal changes in relative humidity must also be taken into account. Within limits, temperature is important in the decay of structural wood. It affects moisture movement into and out of buildings that are heated and cooled, and it sets the lower limits for fungus growth.

Rainfall, in all the ways it is measured, is also important. Continuing light rains and torential downpours have in common little more than total volumes of precipitation. Frequent or continuing, gentle moistening of structural wood can often support life-shortening decay fungi much more than can occasional heavy rains. Due to the drying time required for large structural timbers, Thornthwaite's four types of "seasonal distribution of precipitation effectiveness" only help delineate areas of differing decay hazards. A map based only on these factors will be of only very limited value in areas of within 50-to-250 miles (80-to-400 kilometers) of many coastal areas, because of their normal shifts of relative humidity (RH).

(8) The RH values used to construct the map of decay hazard areas (Fig. 6-2) in coastal zones (including the Great Lakes area) were: (1) an average noon July RH of 60% or above, (2) an average 8 p.m. July RH of 70% or above, and (3) an average 8 p.m. January RH of 70% (in the southern United States, and in other areas with relatively warm January temperatures). With these values imposed on the Thornthwaite system prior to consolidation of his climate provinces into five zones, a highly useful map can be drawn for any area.

If only a particular location is of concern, a large-area map is not needed. The following table lists the five decay hazard zones according to Robert Z. Page, and their derivation from the C. W. Thornthwaite system. The table shows the allowances for the high RH in coastal areas which can raise a Thornthwaite number from one Page zone to the next higher Page zone. Using this system, a reader can easily apply the recommendations for structural wood protection provided in Chapter 6.

The capital letter "H" following a Thornthwaite climate number and its coded description shows where allowances are made for high relative humidity in coastal zones. The need for the Page change to the Thornthwaite system becomes obvious when one compares Fig. 6-2 with Thornthwaite's map which shows almost the entire southeastern U.S. as having BB'r type climate (humid, temperate, rain all seasons). It is of some interest to note that W. Koppen treats this area the same way.

While Thornthwaite is correct in his handling of this large area, and while his methods and his maps generally are improvements over the earlier work by Koppen, Thornthwaite's system can be used to indicate areas of decay hazards only with the R.H. adjustments made by Page. For example, the decay hazards for untreated wood are much the same in New Orleans, LA and Savannah, GA. These two coastal cities are in the Thornthwaite BB'r climate zone, but so also are Birmingham, AL and Columbus, GA where the decay hazard is less. What separates the coastal cities from the inland cities as regards decay hazard is the diurnal changes in R.H. The inland cities retain the BB'r rating, and are found in Page Zone II, while the coastal cities (and areas) are rated BB'rH and so are elevated to the next higher decay hazard zone, Page Zone I.

Decay Hazard Table - Basis for Constructing a Five-Zone Decay-Hazard Map According to the System of Robert Z. Page

R.Z. Page Decay Hazard Zone Number	C.W. Thornthwaite Climate Numbers and Types with the Letter "H" added for high R.H.
Zone I	(1)AA'r, (2)AB'r, (3)AC'r, (4H)BA'rH, (5H)BA'wH, (6H)BB'rH, (9H)BC'rH.
Zone II	(4)BA'r, (5)BA'w, (6)BB'r, (9)BC'r, (7H)BB'wH, (8H)BB'sH, (11H)CA'rH, (14H)CB'rH, (16H)CB'sH, (17H) CB'dH, (18H)CC'rH, (19H)CC'sH. (20H)CC'dH.
Zone III	(7)BB'w, (8)BB's, (11)CA'r, (14)CB'r, (16)CB's, (17)CB'd, (18)CC'r, (19)CC's, (20)CC'd, (15H)CB'wH, (24H)DB'sH, (25H)DB'dH, (26H)DC'dH.
Zone IV	(12)CA'w, (15)CB'w, (24)DB's, (25)DB'd, (26)DC'd, (28H)EB'dH, (29H)EC'dH, (30H)D'H.
Zone V	(28)EB'd, (29)EC'd, (30)D', (31)E'

INDEX

Reproduced by NTIS

National Technical Information Service
Springfield, VA 22161

NTIS does not permit return of items for credit or refund. A replacement will be provided if an error is made in filling your order, if the item was received in damaged condition, or if the item is defective.

This report was printed specifically for your order from nearly 3 million titles available in our collection.

For economy and efficiency, NTIS does not maintain stock of its vast collection of technical reports. Rather, most documents are printed for each order. Documents that are not in electronic format are reproduced from master archival copies and are the best possible reproductions available. If you have any questions concerning this document or any order you have placed with NTIS, please call our Customer Service Department at (703) 605-6050.

About NTIS

NTIS collects scientific, technical, engineering, and business related information — then organizes, maintains, and disseminates that information in a variety of formats — from microfiche to online services. The NTIS collection of nearly 3 million titles includes reports describing research conducted or sponsored by federal agencies and their contractors; statistical and business information; U.S. military publications; multimedia/training products; computer software and electronic databases developed by federal agencies; training tools; and technical reports prepared by research organizations worldwide. Approximately 100,000 *new* titles are added and indexed into the NTIS collection annually.

For more information about NTIS products and services, call NTIS at 1-800-553-NTIS (6847) or (703) 605-6000 and request the free *NTIS Products Catalog*, PR-827LPG, or visit the NTIS Web site **http://www.ntis.gov**.

NTIS
Your indispensable resource for government-sponsored information—U.S. and worldwide

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161   (703) 605-6000