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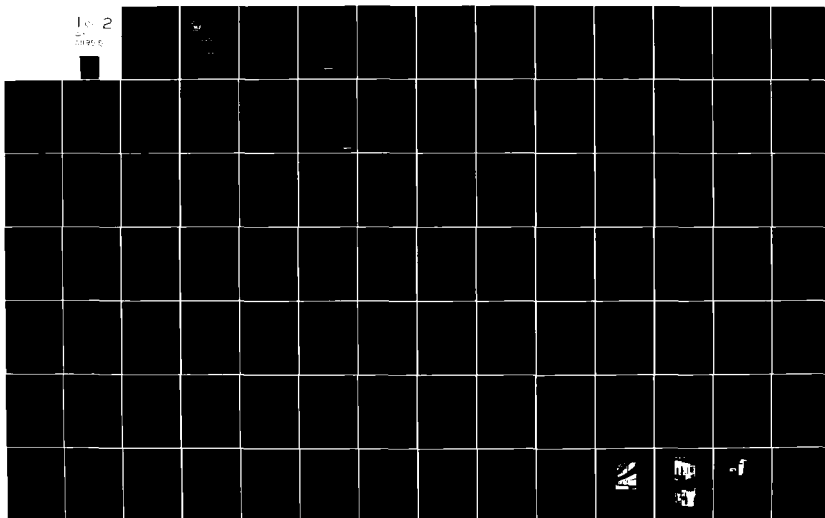
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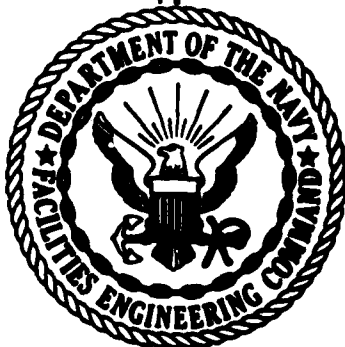
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DM-11.1	2. GOVT ACCESSION NO. A119515	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) NAVFAC Design Manual DM-11.1 Tropical Engineering		5. TYPE OF REPORT & PERIOD COVERED Design Criteria Final
		6. PERFORMING ORG. REPORT NUMBER DM-11.1
7. AUTHOR(s) Naval Facilities Engineering Command 200 Stovall Street Alexandria, VA 22332 (Code 0432)		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Facilities Engineering Command 200 Stovall Street Alexandria, VA 22332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Engineering and Design
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command (Code:0432) 200 Stovall Street Alexandria, VA 22332		12. REPORT DATE March 1980
		13. NUMBER OF PAGES 118
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Unclassified/Unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Unclassified/Unlimited		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Aggressive tropical elements; building systems requirements; concrete; doors and windows; finishes; masonry; metals; precast and prestressed concrete; thermal and moisture protection; typhoon resistant design; wood and plastics.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Guidance and policy are presented for the design, construction, and maintenance of shore facilities in the tropics utilizing qualified materials, applications, and methods to overcome the aggressive solar radiation, high humidity, salt spray, mildew, and termites. The design and materials include concrete, masonry, wood and wood products, steel and other metals, paints and protective coatings, windows, doors, roofing, ceilings, and mechanical and electrical items.		

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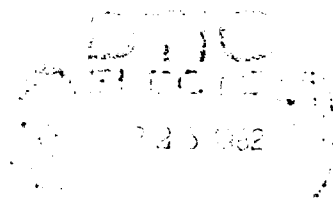
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TROPICAL ENGINEERING

DESIGN MANUAL - 11.1

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FOREWORD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command, other Government agencies, and the private sector. This manual uses, to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM headquarters (Code 04).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM Headquarters (Code 04). As the design manuals are revised, they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.



D. G. ISELIN
Rear Admiral, CEC, U.S. Navy
Commander
Naval Facilities Engineering Command

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CHAPTER 1. GENERAL INFORMATION

Section 1. INTRODUCTION

1. **SCOPE AND CRITERIA.** This manual on tropical engineering is intended for use as a guide by designers and engineers who are responsible for the preparation of plans and specifications for the construction of shore facilities in the tropics. This manual complements the requirements of the NAVFAC and DOD manuals and instructions to upgrade the quality of design and construction and, thereby, extend the economic life of shore facilities in an aggressive tropical environment. The effect of typhoons on design is also discussed.

2. **NAVFACINST 11012.98A.** The contents of this Instruction of 12 January 1967 and all subsequent changes have been incorporated into this manual.

3. **TROPICAL REGION.** The tropical region covers a broad belt of the earth's surface area, and within this area, climatic and physiological conditions vary greatly from one location to another. Also, the chemical and corrosive elements in the atmosphere in any given tropical location may vary greatly from one day to the next. Whether it be physiological or meteorological, the manual attempts to direct attention on the destructive elements found in most tropical environments and to apply the most effective solutions known and available to date to combat these elements through effective design, construction, and maintenance. The designer is reminded that "normal" construction and maintenance problems encountered in the temperate and other zones are not covered here but should be fully considered in the design.

4. **AGGRESSIVE ELEMENTS.** The primary destructive elements in the environment, which may be combined in various degrees, though they may not be all present in some areas are:

a. **Solar Radiation.** The sun, with its intense ultraviolet to infrared radiation range and the resultant ambient temperatures ranging between 60 and 100 degrees F throughout the year, is one of the most destructive natural elements. No building material is immune from its destructive rays except when properly shielded from its direct spectrum. Therefore, protecting building components from the sun's rays is one solution to the problem.

b. **Humidity.** Relative humidity within the 70% and 100% range with a yearly average between 80 and 85% attacks building materials in various ways. On wood it creates an optimum condition for dry-rot action when the moisture content is above fiber saturation. On ferrous metal, at or near dew point, moisture condensation provides the optimum condition for oxidation. The permeability and affinity for moisture of concrete, concrete products, stucco, wood, and other exterior type building materials, combined with the sun's rays, stimulate expansion and contraction which degenerate the adhesion of paint to create blisters and cracks. On gypsum, insulation, particle boards, hardboard, and other similar materials, moisture destroys their structural and functional qualities.

c. Precipitation. Precipitation over 70 inches per year affects paint, substrates, and other protective coating by providing the moisture directly on the surface.

d. Sea Spray. Sea spray in the atmosphere is carried to and deposited on building surfaces. Sea spray consists of minute salt water droplets formed by wave action and transported inland by the wind. The deposited soluble salt crystals retain a high affinity for moisture. This condition creates a residual droplet reservoir of an ionized solution on the surface of the building material. This solution is as destructive as the marine environment of the ocean. The most economically effective metallic material to resist this type of corrosive environment is stainless steel. It is for this type of environment that stainless steel is specified. Although aluminum alloys have resisted corrosion due to sea spray, certain atmospheric compositions (not fully researched) have caused breakdown of this resistance and aluminum alloy performance has not been consistent. Where moving parts are involved, aluminum alloys have been found to fail, with rare exceptions to the contrary.

e. Mildew (Fungus). Paint coatings exposed to warm, humid, and damp rooms may be attacked by mildew which thrive on the coatings. Mildew will grow on shaded exterior as well as interior surfaces of buildings, become unsightly, and eventually accelerate degradation of the coating system and substrate. Mildew primarily attacks painted surfaces. However, under ideal conditions of moisture and temperature, it also thrives on other building material surfaces.

f. Termites. Although effective toxicants have been developed to stop the destructive potential of the termite, the complete extermination of this pest does not appear to be in sight. Adequate design, proper construction, and well planned maintenance programs are the best defense against termite infestation. Termites can and do penetrate the exterior treated surfaces of wood. Therefore, treatment is not a permanent solution to the termite problem.

5. DESIGN APPLICATION. The degree of prevalence of these destructive elements varies throughout the tropics. In certain tropical areas, some of these elements are not present and for this reason the guidance provided in this manual does not intend blanket design application but rather design as applicable. The presence of destructive environmental elements should be ascertained from site investigation, previous experiences, records, and knowledgeable local personnel. Although the data developed for this manual are based on experience and studies throughout the Pacific Ocean area, most of the data are applicable to other tropical areas.

6. NAVFAC "TS" SERIES GUIDE SPECIFICATIONS. This manual does not provide for all the building systems, phases, components, trades, and materials that may be utilized in the design and construction of shore facilities in the tropics. Therefore, the utilization of NAVFAC Guide Specifications as applicable is required. Materials and designs discussed in this manual are the exceptions for tropical application.

7. DESIGN MANUALS (DM) AND DOD 4270.1-M CONSTRUCTION CRITERIA MANUAL. The basic design criteria for minimum requirements for structural integrity, safety, health, operation, and function provided in other NAVFAC and DOD Design Manuals and Instructions including related P-Publications govern with exceptions noted in this manual. This manual complements the requirements of the other NAVFAC and DOD manuals and Instructions for the design of structures in an aggressive tropical environment.

8. SAFETY AND HEALTH STANDARDS. The Occupational Safety and Health Act of 1970 became a law on December 29, 1970. It is emphasized that some items discussed in this manual such as toxicants, asbestos products, coal tar pitch, zinc-chromate and other chemicals contained in paint and other construction products have been labelled by the Occupational Safety and Health Act (OSHA) to be hazardous to health. OSHA has placed a complete ban on the use of some construction products and placed limited and controlled use of some other products. The use of such controlled products when specified in this manual shall require compliance with all regulations including the Environmental Protection Agency (EPA) regulations and the Clean Air Act.

Research is continuously being conducted by OSHA to ensure a safe and healthful environment for all concerned. Therefore, some of the items presently considered to be acceptable and others considered to be acceptable under controlled conditions may be reversed in the future. Accordingly, the latest OSHA Standards, Volumes I, II, III, and IV, shall be consulted before selection of material discussed in this manual is made, thus ensuring that facilities are designed in compliance with the Occupational Safety and Health Act, Public Law 91-596.

CHAPTER 2. SITE WORK

Section 1. EARTHWORK

1. SCOPE AND GENERAL INFORMATION. This section covers materials for embankment (fill), backfill, subbase, and base course. Top soils are not covered.

2. MATERIALS. Various types of cohesive and noncohesive soils may be encountered in the design and construction of shore facilities throughout the tropics. Coral is one of the most common materials available in the Pacific Ocean area for construction, and some understanding of its characteristics and composition is necessary for its proper application.

a. Coral. Coral is of marine origin and is geologically classified as an organic sedimentary rock. It is light in color and ranges from unconsolidated deposits of beach sand to dense deposits of consolidated limestone. The dominant material found in coralline limestone is calcite. Typical coral consists of 95 to 99 percent calcium carbonate. Coral is formed by minute marine organisms, coral polyps, and nullipore algae. Coral polyps and algae produce calcareous secretions. These secretions form skeletal remains that become limestone by gradual calcification and recrystallization. Coral growth is normally limited to water temperatures between 64 and 94 degrees F, depths less than 180 ft., and in clean circulating seawater.

(1) Types of Coral Deposits. There are four principal types of coral aggregate deposits. Ranging from the seaward edge of the reef inland to the higher elevations, these types are identified as: (1) reef coral; (2) beach coral (which primarily is coralline sand); (3) bank-run coral (sometimes referred to as run-of-the-pit or pit-run coral); and (4) quarry coral, sometimes referred to as pit-quarry coral. Cascajo and lagoon coral are not considered as principal types. Descriptions of all types are found in the Glossary of U. S. Naval Civil Engineering Laboratory Technical Report 7R-68 of 13 April 1960 and are quoted in the Department of the Army Construction Engineering Research Laboratory Technical Report M-88 of June 1974 as follows:

"The following terms denote the vernacular associated with the multitude of forms in which coral occurs: brain, mushroom, disc, leaf, finger, staghorn, and ledge. In the Pacific Ocean area, the following names and descriptions are commonly used to identify the various types of coral available.

"Limestone: A sedimentary deposit the origin of which is classified petrologically as organic residue; the deposition may be biochemical or biomechanical. Though consisting predominantly of calcium carbonate, these deposits normally contain some magnesium carbonate.

"Coralline Limestone: A biochemical limestone consisting of coral fragments and other calcareous organic detritus all intermixed and consolidated with heterogeneous calcareous sand and marine sediment. The calcium carbonate originally is crystallized in the form of the mineral aragonite which, being unstable, is altered into the more stable mineral calcite. Corals (polyps), calcareous algae, foraminifera,

shellfish (mollusca), and miscellaneous aquatic crustaceans are the principal organisms involved in the formation of this material. The porosity of coralline limestone varies with the geological derivation and is related to volume contraction associated with calcite in solution during production of magnesium carbonate in the presence of sea water.

"Reef Coral: A compact composite of coralline limestone, cellular coral, and vesicular coral rock, found in the form of existent barrier or fringing reefs; staghorn coral may be found interspersed or intergrown therewith. Though lithologically a massive material, reef coral normally is more porous than quarry coral. Particle shape of crushed reef coral varies; generally it is all angular, occasionally the coarse fractions may be predominantly finger, and occasionally the majority of fine fractions may be subround. The surface texture usually is moderately rough but sometimes may be nearly smooth. The typical color is white or nearly white, whereas coral beach sand (which usually originates from the reef) tends toward buff or tan color.

"Ledge Coral: Ledge coral (sometimes known as coral beach rock) is found at locations where natural conditions have caused calcium carbonate deposition in the form of slabs which cover the ocean bottom along the shoreline. Calcite in solution assists in filling the interstices of the rock, the initial porosity of which results from loose intergrowth of shell-bearing marine organisms.

"Lagoon Coral: Similar to reef coral except that cemented fragments normally are absent. It is usually found in lagoon bottoms mixed with coral sand (and sometimes intermixed with clays) and occasionally mixed with sands of volcanic origin. Hydraulic dredging tends to pulverize the softer coral particles which, together with any clays present, are discarded while in solution; the remaining coralline materials are pumped to shore as the principal product of the dredging operation. Lagoon coral so dredged is a fairly graded mixture of particles ranging from cobble size to fine sand size, but it is definitely an inferior coral aggregate although not as unsatisfactory as cascajo.

"Cascajo: This Spanish term peculiar to Guam where the material is most abundant, signifies gravelly coral and refers to lagoon sediment and to talus and detritus of eroded coral reefs elevated previously as the result of seismic disturbances. The petrographical structure of cascajo does not justify economy in concrete construction because the material exhibits large amounts of soft calcareous particles, ranging from silt to small cobbles, and possesses no appreciable resistance to abrasion. It is notorious for imparting poor durability characteristics to concrete.

"Coral Beach Sand: Disintegrated reef coral and fragments of marine shells. Color usually is buff; particle shape is predominantly subangular; and surface texture is nearly smooth in most cases. Coral beach sands consist of varying proportions of coralline limestone,

cellular coral, and vesicular coral rock, in addition to the calcareous marine-shell fragments interspersed therewith.

"Bank-run Coral: Loose deposits of coral conglomerate cemented with calcium carbonate, normally composed of cellular coral, compact coral rock, and a conglomeration of partly rounded coralline limestone grains. The coarse portions may be somewhat friable; the fine portions occasionally may show evidence of silt, which is easily removed by washing. Particle shape is predominantly subangular; surface texture varies from rough to moderately rough, dependent respectively upon whether coarse or fine fractions are under consideration; and the range in color is restricted to white or nearly so. The amount of fines frequently is excessive; finger coral often is interspersed in quantities that may range from minor to major proportions.

"Quarry Coral: Reef material geologically older than that in existent barrier or fringing reefs and found in the form of ancient reefs elevated above sea level. The composition is finely crystalline limestone containing fossilized coral, or stated otherwise, coralline limestone. Crushed particles usually range from angular to subangular in shape, color normally is nearly white, and predominant surface texture is either rough or moderately rough. Crusher-run sand manufactured from quarry coral usually is deficient in the PLUS No. 50 MINUS No. 30 sizes.

"Finger Coral: A remnant of staghorn or similar branching coral. These fragmentary pieces, the shape of which resembles a human finger, are relatively fragile, lightweight, and highly porous.

"Rock Flour: MINUS No. 200 material created by attrition and breakage of coral aggregate particles incident to mechanical movement during processing, stockpiling, removal from storage, and batching at the mixer.

"'Dead Coral' and 'Live Coral': It is undesirable to use the terms 'dead' and 'live' when referring to coral aggregates. 'Dead coral' is a deceptive term that too often has been used to describe coralline material that has been dried under the sun for a long time. The term 'live coral' likewise has been fallaciously used to describe coralline material removed from the sea so recently that it was yet saturated with seawater (not to be confused with 'live' in the sense that the organisms still were alive). The term 'live coral' or 'living coral' should be used only in reference to the skeleton of the live polyps or algae; such live coral never is used directly as concrete aggregate in view of the excessive organic content present. Use the term 'fresh coral' for the saturated type recently excavated from the reef under water. Use the term 'dried coral' when referring to coralline material that is in the relatively dry state (bank-run and quarry corals)."

3. SOIL TESTS. Standards for materials and testing shown in NAVFAC TS-02200 specifications are applicable for tropical construction, except for items covered hereinafter.

4. **EMBANKMENT AND BACKFILL MATERIAL.** Coral is an ideal material for embankment and backfill use. The fine material requires relatively little compacting effort to obtain desired compaction with minimal compaction equipment. Moisture content is not a critical factor in the compaction process. Normally, coral has very low amounts of plastic material. However, project specifications should include controls on plasticity as follows:

a. Liquid Limit. Liquid limit not to exceed 35.

b. Plasticity Index. Plasticity index not greater than 8.

5. **CONFINED BACKFILL.** Coral sand (noncohesive material) is an ideal backfill material if used in confined areas. It should not be used if it cannot be confined.

6. **GRANULAR FILL (SELECT FILL).** Requirements stated in TS-02200 are applicable with the inclusion of coral having a specific gravity of 2.30 or greater as an acceptable material.

7. **BASE COURSE.** Except for its low abrasion quality and low density, well-graded crusher-run coral provides acceptable base and subbase course material. For base course under flexible pavement, the requirements of TS-02686 or TS-02696 are applicable except that the following gradation is recommended:

Mechanical Analysis:

U.S. Standard Sieve Size	Percent Passing (by wt.)
2"	100
1-1/2"	90-100
3/4"	50-80
No. 4	30-60
No. 40	15-30
No. 200	5-13

Base course for rigid pavement, the requirements of TS-02685 are applicable.

Section 2. SOIL TREATMENT

1. **SCOPE.** This section covers the treatment of soil against termite infestation in areas where structures and buildings are proposed for construction.

a. Termites. The presence of termites in the tropics and their potential for destroying wood and wood products is a continual problem that requires collective preventive measures. Treatment of wood is covered in Chapter 6, Section 1, "Carpentry," of this manual.

2. **TERMITE CLASSIFICATION.** There are 56 species of termites known to exist in the U.S. and its possessions. These may be classified into two general types, the dry wood termite and the subterranean termite. Subterranean termites are the most destructive; therefore, treatment of the soil is required.

3. **TOXICANT AND TREATMENT.** Soil treatment is considered a temporary measure since its residual effectiveness is about 5 years, though longer periods can be expected depending on the environment and soil condition. The use and application of toxicants in soil treatment are covered in NAVFAC TS-02250. The approved toxicants are poisonous to humans and animals and their use is strictly controlled by the Environmental Protection Agency (EPA). Since these toxicants are under continual research and study as to their effect on the ecology, additional limitations (such as complete or limited ban on their use) may be imposed in the future and thus conformance with the latest regulations shall be verified through the EFD entomologist. Soil treatment shall not be specified where source of domestic ground water may be contaminated by such treatment.

4. **APPLICATION REQUIREMENT.** Soil treatment shall be included in construction of all buildings wherein wood is a component or where wood products may be stored. This requirement is provided to ensure some degree of protection to contents in the buildings. Guidance on material and application rates is covered in NAVFAC TS-02250.

Section 3. TIMBER PILES AND TIMBER SYSTEMS

1. **SCOPE AND GENERAL INFORMATION.** This section covers the selection of materials and preservative treatment for timber piles, timber for waterfront application, and timber for general construction. The effectiveness of wood preservative and method of application of timber piles varies considerably from one geographical area to another. Although coal tar creosote treatment usually gives long life (20 and more years) to piles in temperate waters, even the best creosote treatments are often not very effective in tropical and subtropical marine environment, with some piles failing in less than 10 years. Timber piles and timber system are not recommended for use in the tropic except as recommended herein. The varying rate of marine pile deterioration at one location compared to that at another location has been traced in part to the varied species of marine borers present, some of which are only mildly affected by creosote. Naval Civil Engineering Laboratory (CEL) has recommended dual treatment of piles by utilizing the synergistic quality of two toxicants to combat the varied species of marine borers in any given location.

2. **CRITERIA FOR USE OF TIMBER PILES.** Due to the present limited data available on the effectiveness of treatment against marine borers, the use of timber piles in waterfront structures should be restricted to fender systems, dolphins, and other structures where the replacement of the piling system can be made without costly demolition or repair work to the structure of which the timber piles are a part of the structural support system. Recommended pile system for other type structures is discussed in the Precast Prestressed Concrete section of this manual. Timber piles shall not be used on land.

3. MATERIALS.

a. Marine Piles. Materials as provided in NAVFAC TS-02310 are applicable for use in tropical environment. The treatment, handling, and driving of piles in accordance with NAVFAC TS-02310 are applicable except as noted herein.

b. Treatment. All piles shall be given dual treatment conforming to American Wood Preservative Bureau (AWPB) MP-1, except that the waterborne toxicant shall be ammoniacal copper arsenite (ACA).

c. Waterfront Timber. Timber for waterfront should be either Douglas fir or southern pine.

(1) Treatment. Timber for above tide zone use may be pressure treated (ACA) or dual treatment as noted above. Timber for tide zone and below use shall be dual treatment. (See Carpentry section of this manual for treatment.)

d. General Construction Timber. Timber for general construction should be Douglas fir or southern pine. Where "Buy American" is waived, Philippine Apitong may be specified.¹

(1) Treatment: All timber for general construction shall be pressure treated with ACA.

e. Inspection. Where large quantity of preservative treated piles, poles, and timber will be procured under the provisions of American Wood Preservers Bureau (AWPB) or Federal Specification TT-W-512, Government or an independent inspection, at the plant of the treatment, shall be included to ensure compliance.

Section 4. CHAIN-LINK FENCE

1. SCOPE AND GENERAL INFORMATION. Generally, the requirement for chain-link fence covers 2 types of conditions:

a. Security Barrier. As a physical security barrier to protect government property against unauthorized access; and

¹The "Buy American Act" requires that contracts for construction use only domestic construction materials subject to the following exceptions: (a) "The Buy American Act" is applicable only in the United States, which means the 50 states, District of Columbia, Puerto Rico, and possessions. (It does not include leased bases, occupied Japanese islands, or Trust territories.) (b) Unreasonable costs or impracticability. (c) Certain Panamanian materials. If it appears foreign materials may be involved in construction contracts being performed in the United States, Defense Acquisition Regulation DAR 18-505 must be consulted.

b. Safety Barrier. As a safety barrier to protect personnel from physical dangers.

2. **CRITERIA AND GUIDANCE**. The guidance provided by NAVFAC TS-02711 is applicable for construction in the tropics except as noted hereinafter.

a. Aluminum Fence. Since aluminum fabric can be easily sheared, its use as a physical security barrier or fence is not recommended. However, its use as a security barrier should be discussed with the naval activity concerned since there are various degrees of security requirements and aluminum fence may meet its minimum security requirements.

3. MATERIAL CRITERIA FOR CHAIN-LINK FENCE.

a. Security Barrier. Where security requirement mandates the use of chain-link fence, materials for such a fence system shall be vinyl-coated fabric conforming to Type V Federal Specification RR-F-191. Vinyl shall be thermally extruded over zinc-coated steel wire. Vinyl bonded to prime wire by thermal fusion is not recommended for tropical environment. Thermal fusion vinyl is thinner than thermal extruded vinyl and the thermal fusion vinyl fabric is not galvanized while extruded vinyl fabric is galvanized before vinyl extrusion is applied. Alternative system shall be hot-dip galvanized with a coating system of primer and finish coats as specified in the Paints and Protective Coatings section of this manual, should fund limitation preclude vinyl-coated fence.

b. Personnel Safety Barrier. Where a chain-link fence is required as a safety barrier, the composition may be Type V vinyl-coated wire fabric, funds permitting, or Type IV aluminum alloy fence. If cost is the criterion, hot-dip galvanized steel with a coating system of primer and finish coats as specified herein.

c. Fence Accessories. All accessories shall be of the same material system as the fabric and coating. Vinyl coating shall be extruded vinyl. Where aluminum is selected, all accessories, including bars, bolts, fasteners, gates, posts, and rails shall be anodized aluminum. Where galvanized steel is selected, all accessories, including bars, bolts, fasteners, gates, posts, and rails shall be galvanized steel. Where vinyl-coated fabric is selected, accessories shall be vinyl-coated, or either galvanized steel or anodized aluminum, but not both.

d. Concrete. Criteria for concrete is covered in NAVFAC TS-03300. Aluminum posts may be encased in concrete provided a protective coating (2 coats bitumen) is provided over the encased portion of the aluminum.

4. CRITERIA FOR DESIGN AND INSTALLATION.

a. Fence Posts. Post size and post spacing are covered in NAVFAC Definitive Drawing 947284. For aluminum, manufacturer's standards shall be used as a guide. In typhoon areas, wind loads shall be considered in the design of the post. Wind load shall be calculated as wind acting on a solid wall. Rigid diagonal bracing perpendicular to the plane of the fence at every second or third post as applicable on the inside (to prevent easy access) should be provided. Bracing should be designed for tension and compression.

5. MAINTENANCE. Even with the best material available and with installation under ideal conditions by competent craftsmen, the fence will require systematic preventive maintenance inspection to intercept premature deterioration of defective or damaged materials undetected during construction.

CHAPTER 3. CONCRETE

Section 1. CAST-IN-PLACE CONCRETE

1. SCOPE AND GENERAL INFORMATION. This section is a treatise on concrete that is cast-in-place to form part of the designed structure. Precast and prestressed concrete are dealt with in Chapter 3, Section 2, in this manual. Concrete is an ideal construction material for permanent type structures in the tropics, but, like most construction materials, it has advantages and disadvantages. High quality aggregates are necessary for producing good quality concrete. On many of the tropical Pacific Islands, high quality aggregates are scarce and consequently coral aggregates are used exclusively with some exceptions. There is no restriction on the use of concrete for building components in tropical areas if such component designs are generally accepted elsewhere in the United States. However, there is a limitation regarding fabrication of such components because corrosive elements are present in the aggregate and mixing water and because the hardened concrete is subjected to various deteriorative influences. From the viewpoint of strength and resistance to weathering, coral aggregate and mixing water containing chlorides can provide acceptable concrete. The area of concern, and a continuous challenge, is the corrosion of embedded reinforcing steel and the subsequent cracking and spalling of the concrete cover over the steel. The porosity of the coral concrete aggravates this situation. The extent of this corrosion problem varies within any given structure. Corrosion can occur in protected as well as unprotected areas. Reinforced coral concrete may fail within the first year. Conversely, failure may occur 18 years after construction, as happened to a long section of an eyebrow on a barracks building at Midway Island; the eyebrow sheared off at the face of the wall when the negative reinforcing steel corroded through completely. Research studies on coral aggregate concrete indicate that good quality concrete incorporating select coral aggregate is producible if a well-designed and closely monitored quality control program is mandatory as discussed below.

2. GENERAL DISCUSSION AND CONCLUSIONS.

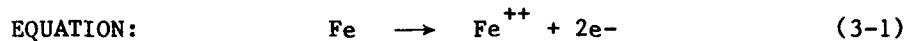
a. "Historically, corrosion of reinforcing steel leading to deterioration of concrete has been a serious problem in many areas of the Pacific where coral aggregates have been used. Many of the problems have been associated with dredged coral, either poorly washed or not washed at all, use of brackish water in concrete and little or no quality assurance or control on production of concrete.

b. "Concrete produced within the last few years using crushed coral excavated from quarries above sea level and washed with potable water (the current standard on Guam) has significantly reduced corrosion problems for normally reinforced concrete. However, as concrete coverage over normal reinforcing steel has usually been several inches thick, there was still concern that prestressed concrete with less cover might be more susceptible to steel corrosion and concrete deterioration.

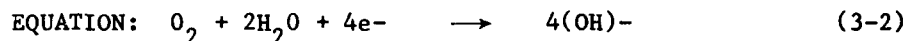
c. "The high concrete strength levels used in prestressed concrete construction, with the associated high density and relative impermeability, plus

the in-plant quality control provided by prestressing contractors, appear to have combined to significantly reduce the use of construction materials and practices that are conducive to development of corrosion."¹

3. CORROSION MECHANISMS AND INFLUENCING PARAMETERS. The corrosion of steel embedded in concrete is a major deficiency of coral concrete. Steel corrosion in a concrete environment, regardless of type of aggregate, is an electro-chemical and oxidation-reduction reaction. The oxidation or anodic half of the reaction is:



and the reduction or cathodic reaction is:



The oxidation-reduction reactions must be balanced if corrosion is to progress. Thus, the rate of oxygen transport or diffusion through the free water within the concrete to the ferrous metal surface can control the reaction rate.

a. Alkalinity. Alkalinity of the free water (electrolyte) in concrete is also important. The pH of free water in a concrete environment is normally 12.8. At this value of pH, steel is normally passive and corrosion is inhibited, but if a minor amount of chloride ions is present in the electrolyte, the passivity of the steel is destroyed and corrosion can occur. Sodium chloride (NaCl) concentrations as low as 0.2 percent significantly affect the passivation. At concentrations exceeding 0.5 percent NaCl, passivation is almost impossible to achieve.

b. Chloride and Oxygen. Studies indicate that two conditions must exist before steel will corrode in concrete: (1) sufficient chloride ions present in the electrolyte to depassivate the steel, and (2) an adequate rate of oxygen transport in the electrolyte through the concrete to the ferrous metal surface. When such conditions exist, as is often the case in many existent coral concrete structures, corrosion of reinforcement and subsequent concrete spalling can occur.

c. Mixing Water and Corrosion Inhibitors. New construction techniques to inhibit corrosion can be specified. Salt concentration in the concrete should be held to a minimum. Accordingly, neither brackish water nor seawater should be used as mix water, and no salt-contaminated aggregate should be used. The amount of concrete cover over reinforcing steel should be increased in areas of exposure. The use of low-permeability coral concrete

¹Study of Prestressed Concrete Reinforcements in Coral Aggregate Concrete, H-LA Job No. 3703003.07, Department of the Navy, Pacific Division, Naval Facilities Engineering Command.

devoid of NaCl is beneficial in retarding the rate of oxygen and chloride ion transport to the ferrous metal surface. In a few instances, cathodic protection has been used to protect reinforcing steel, but cathodic protection has been found uneconomical. Sodium nitrate inhibitors have also been used, but, to be effective, they must be added in excessive amounts. According to recent studies,* hot-dipped galvanized coatings on reinforcing steel followed by dipping in chromate solution will inhibit corrosion. The results of initial laboratory tests also reveal that epoxy coatings on reinforcing steel may provide adequate long-term corrosion protection. Field evaluation of epoxy coatings are currently being initiated by various state highway departments.²

d. Steel Coatings. After corrosion of steel reinforcement begins in an existing structure, there is no satisfactory technique to stop further corrosion. Many concrete surface coatings have been tested, but most are ineffective in preventing moisture migration in the concrete throughout a reasonable length of time. Some of the more common coatings that have been used are coal tars, cut-back asphalts, and asphalt emulsions. Properly formulated epoxy resin coatings are superior in preventing moisture migration.

4. MATERIALS.

a. General Information. Since most coral aggregates available for use in concrete are not of the highest quality, and since variation in quality of coral aggregates from approved sources can be expected, quality control in the production of concrete is very critical. Although it is not too difficult to produce concrete having compressive strengths up to 6,000 psi at 28 days, the corresponding high cement content can create problems. The tropical environment presents additional problems and their resolutions are described below.

b. Water. Water used in concrete shall be potable. Neither brackish water nor seawater should be used either in mixing or curing concrete except in nonreinforced concrete. Salt crystals have a very high affinity for moisture. A small amount of residual salt crystals on a seemingly dry concrete surface results in a damp surface, especially in a highly humid environment. Such damp surfaces can create painting problems, mold problems (mildew), and accelerate corrosion of steel embedded in concrete.

c. Cement. Either type I or type II portland cement should be specified for use in tropical environment. The type specified shall conform to the requirements stated in ASTM Standard C150. Either type II or type V may be specified for use in concrete structures continuously exposed to seawater.

d. Aggregates. Where ordinary aggregates (for example, river gravel) are not available locally, coral aggregates that generally meet the requirements of ASTM Standard Specification C33 have been proven acceptable. The specific gravity of the coralline material should not be less than 2.40.

*Technical Note TN-1447, CEL, USN CBC Port Hueneme, July 1976

²Gene Dallaire, "Designing Bridge Decks That Won't Deteriorate," Civil Engineering, Vol. 43, No. 8 (ASCE, August 1973), pp 43-48.

Coral aggregates with higher specific gravity should be specified wherever available.

(1) Fine Aggregate: Fine aggregate may be natural beach sand, manufactured sand, or a combination of beach and manufactured sand. Sand should be devoid of NaCl to the maximum extent possible. Sand dredged from the ocean or lagoon should be washed with fresh water to remove as much salt as possible.

(2) Coarse Aggregate. Generally, the density determines the quality of coral aggregate. Although a minimum specific gravity of 2.40 is recommended, aggregate with higher density should be specified if locally available. In addition to affecting concrete strength, the density of aggregate affects cement and water content, workability, and porosity of the concrete, all of which indirectly influence steel corrosion. Gradations provided in ASTM Standard Specification C33 as applicable should be used.

(a) In the Marianas, coarse aggregate for coral concrete should be manufactured from coralline limestone obtained from approved sources. Coarse aggregate shall meet the requirements of ASTM Standard Specification C33, except that abrasion loss shall not exceed 40%. Coarse aggregate, nominal size 1-1/2 inches to No. 4, should be in two separate sizes: No. 4 to 3/4 inch and 3/4 inch to 1-1/2 inches. For nominal size, 1 inch to No. 4 should be in two separate sizes: No. 4 to 1/2 inch and 1/2 inch to 1 inch. Coral aggregate should be washed with fresh water after crushing to ensure that the cement paste bonds properly with the aggregate particles. The processed aggregate should be stockpiled at minimal height to reduce segregation.

e. Additives and Admixtures.

(1) Air entrainment. Air-entraining agent (AEA) is used to improve workability of concrete, improves weathering under freezing and thawing and alternate wetting and drying, minimizes length changes, reduces bleeding, and minimizes the porosity of the concrete. Depending on the amount of entrainment (between 3 and 7%), the strength of the concrete is decreased by about 10 percent.

(2) The use of air-entrainment agent is recommended under the following controlled conditions:

(a) AEA shall comply with ASTM C260.

(b) AEA shall contain no chloride; see paragraph 4.3 in ASTM C260.

(c) Air content shall be within 3.5 and 6.0 percent by volume.

(d) Air-entrainment agent shall be compatible with other admixtures when specified.

(e) Quality control shall be included in the specifications.

(3) Retardant. The use of retardant and water-reducing admixtures in coral concrete is recommended. The admixtures shall conform to the requirements of ASTM C494, either Types A and B or Type D.

f. Embedded Ferrous Item. Except for reinforcing steel, all embedded steel, including steel pipes and conduits shall be galvanized. (See Electrical section for other electrical items and coating as required.) Wire mesh shall be galvanized. Ferrous items that are not galvanized shall be either stainless steel or plated with corrosion resistant metal. Where aesthetics is not a major requirement, the surface mounting of pipes and conduits should be permitted.

g. Reinforcing Steel. Reinforcing steel shall be galvanized for all waterfront type construction (marine environment).

(1) Galvanizing: Where galvanizing is specified, it shall be hot-dipped galvanized conforming to ASTM A123. The galvanizing may be before or after fabrication. If "before fabrication" is selected by the Contractor, all exposed steel (cut ends and damaged galvanizing) and all bent areas of the fabricated steel shall be immediately coated after fabrication with paint conforming to TT-P-641, Type II, 2 coat application. Inorganic zinc coating as recommended by the manufacturer may be used as an option. Only mild steel reinforcing bars should be galvanized. Galvanizing tends to weaken high strength steel.

(2) Accessory Items: All chairs and supports for securing reinforcing steel located within 1-1/2 inches of an exposed concrete surface shall be of nonmetallic plastic base material. Chairs and supports in concealed areas may be plastic or galvanized steel. Tie wires may be nongalvanized. Galvanized reinforcing steel shall be tied together with galvanized steel wire.

h. Curing Material. Acceptable curing materials are covered in NAVFAC Specification TS-03300. Timely application is a critical factor in the quality control of concrete. Neither seawater nor brackish water shall be used for curing reinforced concrete. If the concrete contains no embedded ferrous metal, such curing is permissible but the hardened concrete may always present problems of dampness.

5. GALVANIC CELL ACTION. When freshly mixed concrete is placed in contact with galvanized and ungalvanized steel which are tied together, the galvanic action of dissimilar metals begins. These metals in the presence of an electrolyte (portland cement paste) create an electro-chemical cell, as represented in Figure 1.

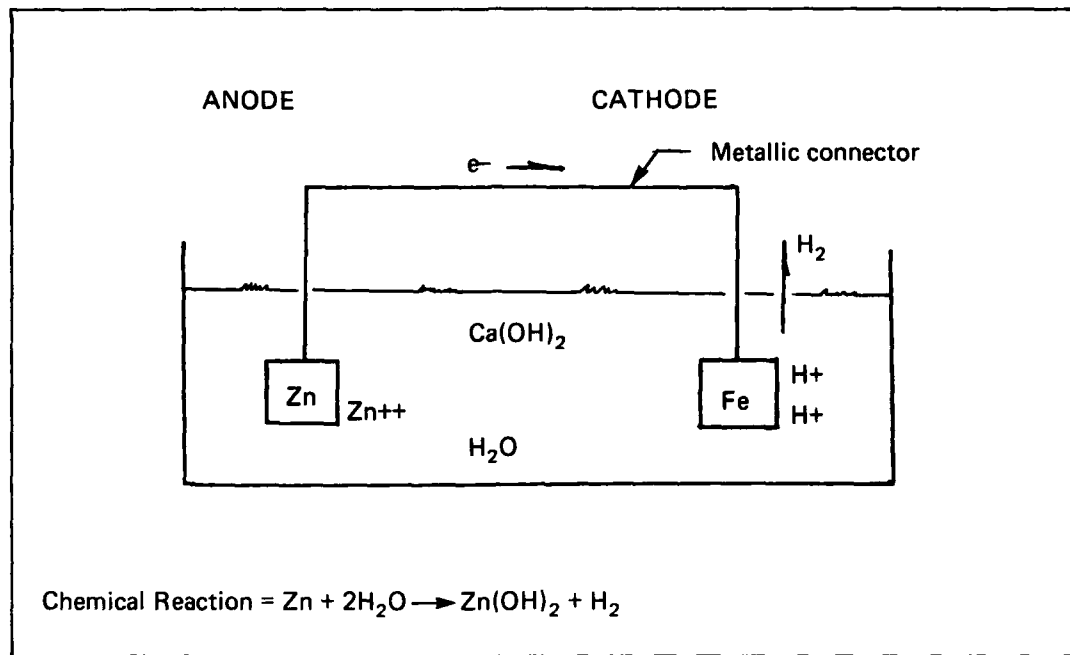


Figure 1. Electro-Chemical Reaction

This galvanic action, present in hardened and fully cured concrete, does not necessarily pose a problem because very low electron currents are present. In fact, zinc is beneficial in providing cathodic protection to the steel as explained above. However, a severe problem exists when the concrete is fresh. Until the paste sets, very large electron currents flow from the zinc anode to the iron cathode, where hydrogen ions acquire electrons and form hydrogen atoms. The hydrogen atoms combine to form molecules of hydrogen gas (H₂), which is liberated along the surface of the black steel cathode. The generation of this gas causes an expansive pressure on the concrete encasing the reinforcing bars and creates a gas-filled void along the entire surface area of the cathodic steel bars. Therefore, after the cement paste has set, a continuous disrupted region exists at the concrete-steel interface. Liberation of hydrogen depends not only on the purity of the zinc coating, but also on the composition of the cement.

a. There are three very important deleterious results:

- (1) Poor bond of concrete to reinforcing steel.
- (2) Hydrogen embrittlement of the steel.
- (3) High corrosion probability from the continuous void along the bars.

(a) Item one. The poor bond strength would affect the overall structural performance of the concrete.

(b) Item two. When high tensile steel is charged with atomic hydrogen (hydrogen ion in contact with steel) under the condition of cathodic charging, the steel is susceptible to hydrogen embrittlement. This condition could lead to brittle failure of the steel.

(c) Item three. The continuous voids along the bars will invite accelerated corrosion. Normally, in the extremely corrosive marine environment, it is likely that accelerated corrosion is the most critical result of the galvanic action.

6. DISSIMILAR METALS. Where galvanized metal is considered, to preclude the galvanic action of dissimilar metals, one of three alternative steps should be taken:

a. Eliminate the condition of dissimilar metals by providing either all-galvanized or all-nongalvanized ferrous items or ensure that all galvanized steel and galvanized conduits are separated from all bare steel before placing of concrete.

b. Coat reinforcing steel with either zinc paint or epoxy resin, but this alternative is not recommended except for miscellaneous ferrous items.

c. The use of a soluble chemical additive, such as sodium chromate (Na_2CO_4), potassium (K_2CrO_4) or chromium trioxide (CrO_3), in the mixing water in an amount such that the equivalent concentration of chromate exceeds 70 ppm when expressed as CrO_3 . This minimum concentration is necessary. The specified minimum time should be sufficient to obtain uniformity throughout each batch, and should be determined for the mix and the mixer to be used.

7. CONCRETE COVER. Where coral aggregate is permitted or specified, the following minimum concrete cover over reinforcing steel shall be provided:

- | | |
|--|--|
| (a) Concrete in contact with the ground | 3" |
| (b) Concrete exposed to the weather | 3" |
| (c) Interior beams and columns | 2" |
| (d) Interior walls and slabs | 1-1/2" |
| (e) Slabs on grade (wire fabric) | 1/2 thickness of slab but not less than 2" |
| (f) Concrete, waterfront (10 ft. below and 10 ft. above mean low tide) | 3" |

8. FINISHING AND CURING. Acceptable finishing and curing methods for various concrete items are covered in NAVFAC Specification TS-03300. Limitations

on certain curing materials, where subsequent covering or painting of concrete surface is specified, shall be included in project specifications. Sea or brackish water shall not be used for curing.

9. AESTHETICS AND CONCRETE SURFACE.

a. Concrete Surface Treatment and Textures. There are many varied ways to achieve aesthetic concrete finish other than painting. Some of the most common methods are:

- (1) Acid-etching
- (2) Blasting with abrasive, sand or water
- (3) Preformed texture (Cast-in-place)
- (4) Precast texture (Precast panels)
- (5) Tooled texture
- (6) Colors in concrete
 - (a) Colored aggregates
 - (b) Colored matrix (Pigment)
 - (c) Combination of aggregate and matrix

It should be noted that painting of concrete surface is not the only means of obtaining aesthetic concrete finish. Painted surfaces are very susceptible to mildew growth as hereinbefore stated, and unpainted concrete and CMU surfaces have been found to be less susceptible to mildew growth. Therefore, the application of surface texture other than painting, as noted above, should be seriously considered.

Section 2. PRECAST AND PRESTRESSED CONCRETE

1. SCOPE. This section covers precast and prestressed concrete in general, including non-stressed decorative panels and precast manholes and covers. Prestressed concrete includes pre-tensioned and post-tensioned structural members. This section also includes the connection design and field fabrication of precast member joints.

a. Prestressed Concrete Member. The use of prestressed concrete for structural members in tropical environment is highly recommended though its potential has not been fully utilized. Its quality as a construction material (when properly designed into the structure) is considered outstanding provided that quality control is maintained.

b. Problem Areas of Precast and Prestressed Concrete. There are two major problem areas in the use of precast concrete products in certain type components used in certain type locations, namely:

(1) Corrosion of steel if coral aggregate is used.

(2) Water infiltration through construction joints of precast members.

c. Design And Construction. Design and construction criteria recommended herein can minimize these problems.

2. **MATERIALS.** All materials required for precast and prestressed concrete are described in Chapter 3, Section 1, Cast-In-Place Concrete, of this manual with exceptions for items covered herein.

a. Cement. The type of cement specified shall be based on use of the concrete members and other economic factors as applicable. Accelerative admixture shall not be used.

b. Reinforcing Steel. Reinforcing steel, including tie wires, in precast concrete panels shall be galvanized. All steel accessories shall be galvanized or stainless steel.

c. Admixture. Admixtures conforming to ASTM Standard Specification C494, Type A and B or type D and ASTM C260 may be permitted. The use of admixture should be permitted to provide the most workable concrete possible within the strength limitation specified.

d. Prestressed Cable. Prestressing cables may be galvanized. Note that hot-dip galvanizing may weaken the cable due to the annealing action. The galvanizing company shall be required to certify strength requirements.

e. Epoxy Resin. Epoxy resin grout conforming to MMM-G-650 should be specified for filler of recessed metallic items. Epoxy resin binder conforming to MMM-B-350 should be used for bonding new concrete to precast concrete members.

3. **CRITERIA FOR DESIGN.** The design of precast and prestressed concrete items is covered in the American Concrete Institute ACI Standard 318. In the design of precast and prestressed concrete items, the design of the member connections, including the proper forming and construction, should be fully detailed and delineated to ensure maximum performance. Connections and joints for curtain wall panels shall be designed to ensure watertightness.

a. Metal Connectors. Welded or bolted metal connectors shall not be used where exposed to the weather, unless such components are of stainless steel. Where connectors are recessed to allow a minimum 2-1/2" cover over the metal, the connection is considered as not being exposed to the weather. Epoxy resin filler for filler cover is recommended.

b. Concrete Strength. For prestressed concrete, the use of 5000 psi minimum compression strength concrete is recommended. For precast concrete items, the use of 4000 psi minimum compressive strength concrete is recommended for reinforced type items and 3000 psi minimum compressive strength concrete for nonreinforced items. Epoxy grout shall be specified for patching and sealing all joints.

c. Protective Concrete Cover. Concrete cover over reinforcing steel in Prestressed and Precast concrete members should be as follows:

<u>Item</u>	<u>Prestressed</u>	<u>Precast</u>
(a) Concrete in contact with ground	3"	3"
(b) Concrete exposed to the weather	2"	3"
(c) Interior beams and columns	1-1/2"	2"
(d) Interior walls and slabs	1-1/2"	2"

CHAPTER 4. MASONRY

Section 1. REINFORCED CONCRETE MASONRY

1. **SCOPE AND GENERAL INFORMATION.** This section pertains to concrete masonry units (CMU), both solid and hollow, used in general construction. Clay bricks are not included since their use cannot be economically justified for general construction in the tropics.

a. **Concrete Masonry Unit Application.** Concrete masonry units are acceptable for general construction in the tropical environment. The major drawback in their use for exterior wall construction is their porosity. The wind-driven rain in the tropics readily infiltrates the units and creates moisture problems if appropriate action to prevent water infiltration of the masonry units is not taken. The use of masonry construction should be extensively applied in tropical construction with quality controls and limitations provided herein.

b. **Infiltration.** Although some success has been achieved in stopping water infiltration through masonry units, it has been on a short-term basis and periodic surface treatment is necessary to ensure continued protection. Surface treatment is described in Chapter 9, Section 2, "Paints and Protective Coatings."

c. **Steel Corrosion.** Steel corrosion in concrete masonry construction is not as critical as in reinforced concrete. Why this is so has not been fully researched, but it can be logically concluded from past and present construction methods that three factors contribute to this favorable result:

(1) Water used in mortar is potable.

(2) Aggregate used in mortar mixture is either weathered beach sand or other types of sand that contains little or no chlorides (NaCl).

(3) Except for deformed reinforcing bars in masonry walls, generally, all embedded steel items are galvanized, and all deformed reinforcing bars are deeply embedded in either mortar or grout. Therefore, materials for mortar and embedded items should be closely monitored to ensure quality construction.

2. MATERIALS:

a. **Water.** Water used in the production of the concrete masonry unit shall be potable, and water used for the mixing of the mortar and grout for masonry construction shall be potable. Brackish water or seawater shall not be used in any connection with masonry construction.

b. **Cement.** Type I or Type II portland cement may be specified for the manufacture of the masonry units and for the mortar and grout.

c. Aggregates. When conventional aggregates are not available locally, coral aggregate that generally meets the requirements of ASTM C33 has been proven acceptable. The specific gravity of the coralline material should not be less than 2.40. Fine aggregate may be natural beach sand, manufactured sand, or a combination of beach and manufactured sand. Sand should be devoid of NaCl to the maximum extent possible. Washing with fresh water should be specified if necessary.

d. Concrete Masonry Units. Hollow load-bearing and solid loadbearing CMU's shall conform, respectively, to ASTM Standard Specifications C90 and C145.

e. Embedded Steel and Fasteners. All embedded ferrous metals, except deformed vertical reinforcing and bond-beam bars, shall be galvanized. Hot-dip galvanizing shall conform to ASTM Standard Specification A123 and shall be followed by dipping in a chromate bath (see Paragraph 3.c in Section 1, "Cast-in-Place Concrete," of this manual). Note that the chromate bath treatment is not required if the deformed bars (not galvanized) are not tied to or directly connected, in any way, to galvanized steel items. This requirement also applies to all embedded ferrous pipes and conduits which shall be covered with a bituminous protective coating before embedment in concrete. Aluminum items shall not be embedded in masonry construction.

3. DESIGN.

a. Type of Masonry Units. The weight of masonry units in general construction in a tropical environment is not of concern. However, porosity is one of the masonry problems, and design and production of masonry units should be directed towards reducing porosity, absorption, and shrinkage. Proper vibration and autoclave curing provide for better quality units. Admixtures to densify units should be considered. Masonry units shall be the load-bearing type. Except as noted above, masonry unit requirements are covered in NAVFAC TS-04230, which should be used as a guide for preparation of project specifications.

b. Mortar and Grout. Requirements for mortar and grout are covered in NAVFAC TS-04230. In addition, chloride concentration in the mortar mix should be specified to minimize corrosion of embedded steel items.

(1) All joints exposed to the weather shall be tooled to ensure maximum compaction and density of the joint mortar. Struck joints shall not be specified except for interior surfaces of walls or where water infiltration will create no problems.

c. Weep Holes. All exterior hollow block masonry-constructed walls shall incorporate weep holes to drain each CMU cell of infiltrated water and condensed moisture to the outside. Weep holes shall be provided over bond beams and other solid precast members.

(1) Specification should indicate how to prevent inadvertent sealing of such weep holes with mortar droppings during the construction of the wall. Field tests to ensure compliance should be included in the specifications.

d. Reinforcing Bars and Galvanized Items. Specifications shall include the installation of reinforcing steel (if not galvanized) separated from all galvanized items including conduits to preclude the galvanic cell action when concrete is placed.

CHAPTER 5. METALS

Section 1. STRUCTURAL STEEL

1. SCOPE AND GENERAL INFORMATION. Discussion under this section covers the use of structural steel in the construction of towers, buildings, supports, frames, and structures.

a. Structural Steel Performance. The use of structural steel in a tropical environment has been fairly successful when properly designed, erected, protected, and maintained. However, structural steel is one of the many construction components that requires a systematic maintenance program to provide economical service life.

b. Design Criteria. The key to an acceptable steel structure is a design such that the steel components can be properly and adequately maintained. An example of poor design is where structural joints are accessible to moisture, but inadequately accessible for proper inspection and maintenance. If the design of the steel structure precludes adequate maintenance accessibility, the design should also preclude moisture accessibility to such members and joints. Design should provide for adequate shedding of rainwater and should never permit its entrapment.

c. Coating System. Structural steel without some type of coating system or protective device is subjected to accelerated corrosion in a tropical environment. Coating systems of varying quality are necessary and the quality of the coating is dependent on location, degree of exposure or protection from the weather, and type of construction. See section on "Paints and Protective Coatings."

2. MATERIALS.

a. Interior Application. Generally, for interior and well protected shelters or structures, the standard ASTM A36 structural steel as covered by TS-05120 with a minimum coating system of a primer and one coat finish is recommended. The coating system should be upgraded as the corrosiveness of the environment increases. All structural steel should be factory primed before shipment.

b. Exterior Application. Structural steel exposed to the weather, though treated with a coating system, should be avoided if possible. High-strength low-alloy steel may be used if structural and economic requirements justify its use. In a tropical environment, with its seawater mist, a coating system for protection against the weather and corrosive elements is required. Generally, ASTM A36 structural steel with proper coating system is recommended. Where funds permit, galvanizing should be considered under the coating system in those structures where exposure to severe corrosion is anticipated. If not galvanized, steel shall have two coats of shop primer with two finish coats. Surface preparation should include sandblasting or mechanical brushing to near white steel.

3. FABRICATION AND CONSTRUCTION.

a. Interior. Where structural components are adequately protected from the weather, connectors may be bolts, rivets, welds, or combinations thereof. After erection, all damaged shop prime and/or finish coats shall be touched up with the same type primer or finish and given one or two finish coats as necessary. Surface preparation shall include sandblasting.

b. Exterior. Where structural components are exposed to the weather, welded connections are recommended. If either bolted or riveted connections are required for either economic or structural reasons, such connections should be kept to the minimum. In any event, the proper coating system shall be specified.

(1) Connections. Connections shall be designed to preclude pockets or recesses that can trap dust, debris, moisture, or any combination thereof. All welds shall be continuous and completely seal off all contact surfaces of the structural members.

(2) Welds. Welded joints shall be peened and power-brushed to remove all trace of weld flux (slag).

Section 2. MISCELLANEOUS METALS

1. SCOPE AND GENERAL INFORMATION. Discussion under this section covers all types of metal products and items not covered specifically in other sections. It is also intended to augment other sections where similar base metal products and items are discussed.

a. Miscellaneous Metal Items. Primarily, miscellaneous metals include anchor bolts, nuts, nails, bolts, screws, straps, connectors, fasteners, and other items used to either secure one or more structural components together or attach one construction item to another. The connections that these miscellaneous metal items create are more susceptible to corrosion than their component parts. This is true whether the connection contains dissimilar metals or not. Therefore, such hardware and the connections created are the most corrosive items on any project, when exposed to the aggressive elements. Their importance as part of the structure depend on their location and function.

(1) Where the miscellaneous metal includes handrails, protective guards, wire screens, metal trims, and other related items where aesthetics is a required feature and where the item is exposed to the elements, the selection of material becomes the architect's responsibility. Nevertheless, the material selection should follow the guidance provided herein.

b. Miscellaneous Item Quality. Items and products discussed hereinafter span a very wide range in performance and quality. The selection of items should be based on the required quality that would adequately meet the intended function of the project, and the least lifecycle cost of the item and within the available funds. Where possible, the better quality material shall be specified.

2. MATERIALS.

a. Galvanized Miscellaneous Items. The items shall be galvanized where the use of ferrous type anchor bolts, nuts, screws, nails, straps, connectors, fasteners, washers, and various types of expansion shields and anchors is permitted. This requirement shall be considered as a minimum requirement for corrosion protection, with 316 stainless steel at the other end of the performance quality spectrum.

b. Nonferrous Miscellaneous Items. Where screws, bolts, nuts, etc., are exposed to the weather, stainless steel, brass, bronze, copper, aluminum, or other corrosion-resistant metals may be specified. In addition, the electrolytic action of dissimilar metal should be considered in the selection of such metallic items, particularly where concrete is a component and where aesthetics is involved. Ferrous metal should not be used as finishing strips or components if at all possible, even if protective coating is to be provided.

c. Aluminum Items. All aluminum items, including items for interior use, shall be anodized. Anodizing shall conform to ASTM Standard Specification B580, Type B. Aluminum is recommended for metallic finish items.

(1) Where aluminum base material or equipment is secured to other types of structural material, the fastening bolts and screws shall be stainless steel for exterior application and may be either galvanized steel or stainless steel for interior application (except on inside of windows and doors where they shall be of stainless steel). Aluminum should not be used as bearing surface of moving parts or where movement is anticipated.

(2) Where aluminum alloy is specified for windows, doors, and frames, Type 6063-T5 is recommended. For structural members, Types 6061-T6 and 6063-T6 are recommended. For screws and bolts, Type 6063-T6 or 6061-T6 is recommended. Aluminum nails should be Aluminum Alloy 6061 or 5056, Federal Specification FF-N-105, Type II, Style 20. Aluminum Alloy 2024-T4 should not be used in tropical climates.

3. FABRICATION AND INSTALLATION.

a. Corrosive Environment. In a corrosive environment, even with the proper selection of materials, the careless installation procedures of components can completely negate the quality of the designed project.

(1) Dissimilar Metals. Galvanic corrosion, where dissimilar metals are encountered, creates major problem areas when not properly protected. Where dissimilar metals are specified, protective coating (insulation) between the items shall be provided. On aluminum and steel, zinc chromate, conforming to TT-P-645, is an ideal coating. Coal tar enamel is applicable for copper alloys. Proper preparation as specified in NAVFAC TS-09910 should be followed. Coatings shall be a minimum of primer and two coats.

b. Aluminum and Concrete. Aluminum placed against concrete surface including CMU construction shall be protected with roofing felt. The contact surface of the aluminum shall be coated with primer and two coats of bitumen. Synthetic or rubber-base sealants, Specification TT-S-230 or TT-S-00227,

may be used as protective barriers in addition to the coating where applicable.

c. Protective Coatings. Bituminous paint of the cut-back type conforming to either MIL-C-450 or TT-C-494 may be used as a protector in concealed areas. Where appearance is a factor, methacrylate type lacquers conforming to MIL-L-19537 may be used. A minimum of a primer and two competitive coats for bituminous paint or lacquers should be specified.

4. INFORMATION ON ALUMINUM PRODUCTS. The following background is provided on aluminum alloys for information and guidance in its selection and use in construction.

a. Aluminum. Pure aluminum is not a stable metal.

b. Aluminum Oxide. Aluminum oxide is a very stable material. This coating, oxidized on the surface of the aluminum alloy through the oxidation of the aluminum base metal, provides the protective film. When this coating is applied in the shop, by means of an accelerated electrolytic process, the process is described as "anodizing."

c. Aluminum Products. Aluminum is available in plates, sheets, foils, extrusions (various forms), and coatings. Foils are less than 0.006 inches thick, sheets are .006 through .249 inches thick, and thicknesses greater than .249 inches constitute rolled plates. Anodized mill-finish aluminum sheet can be obtained plain or in a variety of embossed patterns. Embossed sheet has been found useful in minimizing oil-canning and handling marks. Decorative and protective finishes can also be applied to aluminum sheet. Painted sheet is available in a wide range of colors. This precoated, baked enameled sheet can be cut, pierced, drilled, and formed without the finish separating from the base metal. Even if the enamel film should be broken or the metal exposed at a cut edge or drilled hole, there is no danger of the film, either flaking or staining, since there is no rust-like corrosion. Where prepainted aluminum is marred by metalwork tools in the field, the scratches can be touched up with matching enamel. Maintenance of painted aluminum is less critical than maintenance of other painted metal. The paint serves mainly as a decorative function, since aluminum is itself corrosion-resistant. Anodizing is one of the most important protective finishes for all types of aluminum. However, since the surface film may be crazed by forming and cannot be touched up, as a painted surface can, its use is normally limited to preformed shapes that may be anodized subsequent to forming. The anodized coating is much more resistant to corrosion and abrasion than is the thinner natural film. Ordinarily, anodized aluminum will be used with a clear anodized finish, but it can be impregnated with a colorant that produces a highly weather-resistant gold. Other colors suitable for exterior use, including various shades of grey, bronze, and amber can be achieved by integral color anodizing of certain aluminum alloys or by electrolytic deposition of inorganic colorants. Anodic colors achieved with organic dyes are not suitable for exterior use.

d. Aluminum Extrusions. Aluminum extrusions are available in practically any shape. They are produced by slowly forcing cast cylindrical billets while heated to a plastic condition at 600 to 800 degrees F. The billet diameters range from 4 to 16 inches. Pressures up to 5,500 tons are required

to force the hot metal through steel dies into lengths up to 80 feet. Since extrusion dies are relatively inexpensive, it generally pays to design special extruded sections to meet specific requirements rather than to use less efficient standard sections.

e. Chemical Reaction of Aluminum. Ordinarily, the chemical reaction of aluminum will produce aluminum oxide. However, under certain environmental conditions, other types of reaction producing sulfates and sulfides may precede the oxidation reaction and create an unstable condition which results in corrosion. This reaction can take place when the anodizing is crazed. Therefore, anodized aluminum is not recommended as bearing surfaces of moving parts or where there is any movement at the contact points. This is very critical where the components are exposed to the weather. This corrosive condition can be created when anodized aluminum is cut, drilled, or bent at the jobsite, and also when the bearing surface of attaching screws, nails, and bolts craze and damage the anodizing. Therefore, where aluminum is specified for exterior use in a tropical environment, anodizing should be specified for after fabrication and the use of stainless steel washers for field installation be specified wherever possible.

f. Anodizing. Because it is difficult to detect damaged anodizing or holidays (rare) on aluminum surfaces, the application of a coating system (paint) should be considered for corrosive environment. This double protection provides longer service life. Where a coating system is either required or desirable, factory-applied baked-on enamel is recommended because better quality control is maintained in the factory than in the field. Fieldcoating systems for aluminum are covered in Table 16, NAVFAC MO-110, (TT-P-645 primer and finish coats). Anodizing should be 0.7 mil minimum for exterior and interior installation.

g. Sheet Metal. Where aluminum alloy sheet metal is required, Type 3003-H14 is recommended.

CHAPTER 6. WOOD AND PLASTICS

Section 1. CARPENTRY

1. **SCOPE AND GENERAL INFORMATION.** Discussion under this section covers lumber, plywood, asbestos-cement board, hardboard, rough hardware, gypsum board, particle board, preservative treatment, and construction and fabrication methods in both finish and rough carpentry work. Plastic and plastic laminates are not covered in this manual. Use of timber is not covered in this section.

a. Limitations on Wood and Wood Products. In the tropics, lumber and wood products have a wide range of functions if selected and installed properly. In Guam and some of the other Pacific islands, the use of wood for structural members has been limited because of typhoons. Also of primary concern in the use of wood is the maintenance problem caused by termites. Designs using wood require provisions for easy access to wooden members for preventive maintenance inspection without which costly maintenance of facilities can be expected. Fungus dry rot is another serious problem that challenges the designer in the tropically humid environment.

b. Fire Protection Requirements. The use of lumber and wood products for both rough framing and finishing is also limited by fire protection requirements of the facility under design. Accordingly, fire protection engineer should be consulted before decisions are made regarding the use of wood material. In many instances, the use of wood treated with a fire retarding chemical may adequately meet the fire protection requirement. See DOD 4270.1-M or DM-8 for fire protection requirements.

2. **FIRE RETARDANT TREATMENT.** It should be noted that fire retardant chemicals are highly soluble in water. Wood treated with such chemicals must accordingly be protected from the weather and used only in interior areas and in other areas well protected from the weather.

3. MATERIALS.

a. Lumber. Species and grades of lumber specified as applicable for the intended use identified in NAVFAC TS-06100 and TS-06200 are satisfactory for tropical environment. If foreign procurement is permitted, Philippine Apitong, Tanguile, and Luan may be specified. A very critical requirement, however, is the moisture content of the lumber. The moisture content of the lumber to be set in place shall be less than 19 percent for rough lumber and 15 percent for finishing lumber. Also, all lumber (finish, trims, and rough lumber) and plywood shall be pressure treated.

b. Preservative Treatment. In the area of wood preservatives, the accepted use of existing toxicants is being continuously researched by OSHA. Therefore, designers are advised to refer to the latest OSHA 1910.100 for any changes in the presently accepted use of toxicants recommended in this manual. It is recommended that all wood treatment conform to the requirements of the American Wood Preservers Bureau Standard AWPB LP-2 and that one of the following preservatives be specified:

- (1) Ammoniacal Copper Arsenite
- (2) Chromated Copper Arsenate, Types A, B, or C, or
- (3) Fluor-Chrome-Arsenate-Phenol (Above ground use only)
- (4) Other preservatives should not be used because of certain disadvantages which may not be desirable in the end product, except for special uses covered in another section of this manual. Before specifying use of any toxicant for wood treatment, refer to latest OSHA 1910.100 for authorized toxicant and use.
- (5) Oilborne preservatives such as Creosote, Pentachlorophenol, Naphthenate, Copper-8-Quinolinolate, and waterborne preservatives such as Acid Copper Chromate and Chromated Zinc Chloride are not recommended because of cost, availability, corrosiveness, or other disadvantageous characteristics of the toxicant. The following excerpt, taken from Osmose Wood Preserving Co. of America Inc., Wood Preservation Course Manual, is provided for information on toxicant characteristics.

"Wood preservatives fall into two general classes: (1) oilborne preservatives, and (2) waterborne preservatives.

"OILBORNE PRESERVATIVES

"I. Creosote - This is a word that is often used erroneously as synonymous to the entire subject of wood preservation, when in actuality, it is defined generically as certain distillates of tars. Creosote is black to very dark brown in color and is distilled from a variety of different tars. Its most common uses are marine piling, poles, and cross-ties.

"A. Coal Tar Creosote - A distillate of coal tar produced entirely by high temperature carbonization of bituminous coal. It is heavier than water and has a continuous boiling range of at least 125 degrees C.

1. Advantages

- a. Highly toxic to all wood destroying organisms
- b. Relatively insoluble in water
- c. Readily available and low in cost
- d. Penetration easily determined by discoloration of wood

2. Disadvantages

- a. Freshly creosoted lumber is a fire hazard - Can be ignited easily so care and precaution should be taken to prevent fires.
- b. Odor is unpleasant and vapors are harmful to plants.
- c. It is toxic and highly irritating to human skin and eyes, as well as to animals.
- d. Creosoted lumber cannot be painted satisfactorily.
- e. Coal Tar Creosote is essentially a by-product containing well over 100 different chemical compounds. Individual components may be removed from the creosote to meet the

market demands; thus, character of the coal tar creosotes available to the industry vary considerably.

- f. Creosote cannot be applied to wood at moderate temperatures. Heat must be applied before it can be removed from containers or penetration into the wood can be obtained.

"B. Liquid Creosote, Anthracene Oil, or Carbolineums - These are distillates of coal tar and have higher specific gravities and a higher boiling range than ordinary coal tar creosote. The chemical compounds that crystallize at ordinary temperatures are removed to leave a completely liquid oil with a reduction in evaporation when heated. These creosote oils are used primarily in open tanks for dipping, brush on, or spray treatments.

"C. Water-Gas-Tar Creosote - This creosote is a distillate of water-gas-tar with petroleum oil. The composition will vary with the character of the petroleum used. This type of creosote differs from coal tar creosote in that there are practically no tar acids or tar bases. Like coal tar creosote, the toxicity varies with the proportion of distillate obtained below 275 degrees C. Water-gas-tar creosote is generally less toxic than coal tar creosote.

"D. Wood-Tar Creosote - It is made by distilling the wood tar that results as a by-product in the destructive distillation of hardwoods or softwoods. As with the other types of creosote, any refinement of the oil will affect the quality of the creosote. This type of creosote is seldom used because it is not available in large enough quantities. Hardwood tar creosote is highly acidic and will corrode iron and steel.

"E. Creosote-Coal-Tar Solutions - This is a mixture of up to 50% coal tar with coal tar creosote and is done primarily to reduce costs. This type of preservative decreases the tendency of the treated wood to check, but is more apt to cause more 'bleeding'.

"F. Creosote-Petroleum Solutions - The primary purpose of adding petroleum to creosote is to reduce the cost of the preservative. The surfaces of the treated wood are more oily and thus checking is reduced. The toxicity is greatly reduced and there is a greater tendency to 'bleed.' Penetration with this preservative is more difficult.

"II. Pentachlorophenol - This preservative is a single organic crystalline compound soluble in oil. The term is generally applied to its solutions in petroleum oil. It can be dissolved in light and heavy oils, but in any case, it is usually used in a 5% solution by weight. Depending upon the end use of the wood treated by this preservative, the type of oil solvent is most important. The heavier the oil, the more problems will occur with such things as paintability, cleanliness and color. Depending on the nature of the oil solvent, pentachlorophenol solutions range from dark brown to nearly colorless. This preservative finds its best use for poles,

crossarms and fence posts; and when light solvents are used for dip treating of millwork.

A. Advantages

1. Highly toxic to decay and insects
2. High resistance to leaching under excessive moisture conditions
3. Good penetration qualities
4. Usually results in a cleaner, easier to handle, treated wood product than does creosote.
5. With very light oil solvents, penta solutions lend themselves well to blending with water repellents and dip treating of millwork.

B. Disadvantages

1. Pentachlorophenol is highly toxic and irritating to humans and animals (skin and eyes).
2. The treated wood is highly toxic to plants and flowers. (Fumes as well as direct contact.)
3. Penta crystals will sublime or turn to a gas upon warming. They also have a tendency to migrate in the wood towards the surface and 'bloom' or crystallize on the surface, causing a residue on surface of the treated wood.
4. It is necessary to wait a period of time before painting over penta treated wood to allow for the oil solvent to evaporate. The heavier the oil, the longer wait becomes. Some oils are so heavy, it is never practical to paint over them.
5. Penta treated wood has a long-lasting residual odor.
6. Not satisfactory for protection against marine borers.
7. Cannot be used to preserve fabrics and rope.

"III. Naphthenate Solutions - There are two naphthenates commonly used as wood preservatives: (1) Copper Naphthenate and (2) Zinc Naphthenate. This group of preservatives are single metal-organic noncrystalline compounds soluble in oil. They are not readily available for application in a pressure plant, but are available in most areas for brush, spray, or dip application. To be fully effective, most specifications call for oil solutions with at least a 2% metallic (Copper or Zinc) content.

A. Advantages

1. Not toxic to plants and flowers.
2. Can be used to treat rope and fabrics.
3. Copper Naphthenate lends itself well to applications in boats to prevent dry-rot.

B. Disadvantages

1. Copper Naphthenate, while being a very good preservative, is bright green in color and is difficult to cover with paint. The green color bleeds through the paint.
2. Zinc Naphthenate is easy to cover with paint, but it is not nearly as effective a wood preservative as is the Copper Naphthenate. In order to get paintability, toxicity must be sacrificed.
3. Has a strong, persistent, objectionable odor.
4. Its cost is usually higher than that of pentachlorophenol formulations.
5. It is rarely, if ever, used by pressure treating plants.

"IV. Copper-8-Quinolinolate (Solubilized) Osmose K-8 - This is an odorless non-crystalline, oilborne preservative which provides excellent decay resistance to wood. It is normally formulated in conjunction with water repellents to provide dimensional stability. It is neither a primary skin nor nasal irritant, and is not a sensitizer. It is an easy-to-handle liquid completely soluble in aliphatic petroleum oils (such as mineral spirits). This preservative finds its most common use in the treatment of wood which may come into intimate contact with foodstuffs, such as the flooring in refrigerated vehicles, meat lockers, and food crates.

A. Advantages

1. The only preservative permitted by the U.S. Pure Food & Drug Administration in the preservative treatment of wood in intimate contact with food.
2. Not toxic to humans or animals.
3. Is compatible with pigment systems.
4. Is paintable.
5. Can be used to preserve textiles, plastics, and paper.

B. Disadvantages

1. Not recommended for in-ground use.
2. It is not readily available for pressure plant application in most areas.

"WATERBORNE PRESERVATIVES

"This group of preservatives is used principally in the treatment of wood for building construction where the treated wood must be clean to handle, odorless, and paintable. To be effective, waterborne preservatives must be applied by pressure methods. Some of these preservatives have been developed to the extent that they can be used in ground contact or in other wet installations without losing their wood preserving characteristics.

After treatment, since water is added to the wood, it must be redried to the moisture content required for the intended use.

"Pressure treatment with waterborne preservatives should be in accordance with the American Wood Preservers Association (AWPA) Standards. Included in these specifications and standards are the following waterborne preservatives:

"I. Acid Copper Chromate - (Celcure)

Composition:	Copper, as CuO	31.8%
	Hexavalent chromium, as CrO ₃	68.2%

ADVANTAGES

1. Toxic to decay and insects
2. Paintable, clean, odorless

DISADVANTAGES

1. Corrosive to metal
2. Air dry or kiln dry necessary before use
3. Not readily available in most areas
4. High cost
5. Not recommended for ground contact

"II. Ammoniacal Copper Arsenite - (Chemonite)

Composition:	Copper, as CuO	49.8%
	Arsenic, as As ₂ O ₅	50.2%

ADVANTAGES

1. Toxic to decay and insects
2. Paintable, clean, and odorless
3. Very resistant to leaching
4. Will not bleed through concrete, plaster, or paint
5. Recommended for ground contact use

DISADVANTAGES

1. Air dry or kiln dry necessary before use
2. Not readily available in most areas
3. High cost

"III. Chromated Copper Arsenate

A. Type I or Type A - (Greensalts or Erdalith)

Composition:	Hexavalent chromium, as CrO ₃	65.5%
	Copper, as CuO	18.1%
	Arsenic, as As ₂ O ₅	16.4%

B. Type II or Type B - (Osmose K-33 or Boliden K-33)

Composition:	Hexavalent chromium, as CrO ₃	35.3%
	Copper, as CuO	19.6%
	Arsenic, as As ₂ O ₅	45.1%

C. Type III or Type C - (Wolman CCA)

Composition: Hexavalent chromium, as CrO ₃	47.5%
Copper, as CuO	18.5%
Arsenic, as As ₂ O ₅	34.0%

ADVANTAGES

1. Recommended for in-ground use.
2. Toxic to decay and insects.
3. Paintable, clean and odorless.
4. Permanent resistance to leaching.
5. Readily available.
6. Will not bleed through concrete, plaster or paint.
7. Good resistance to electrical conductivity.
8. Can be used in water.

DISADVANTAGES

1. Air dry or kiln dry desirable before use.

"IV. Chromated Zinc Chloride

Composition: Hexavalent chromium, as CrO ₃	20%
Zinc, as ZnO	80%

ADVANTAGES

1. Reasonably toxic to decay and insects.
2. Paintable, clean, odorless.
3. Good fire retardancy at high retentions.

DISADVANTAGES

1. Corrosive to metal fastenings.
2. High electrical conductivity.
3. Poor leaching resistance.
4. Kiln dry or air dry desirable before use.
5. Not recommended for ground contact.

"V. Fluor-Chrome-Arsenate-Phenol (Wolman Salts & Osmosalts)

Composition: Fluoride, as F	22%
Hexavalent chromium, as CrO ₃	37%
Arsenic, as As ₂ O ₅	25%
Dinitrophenol	16%

ADVANTAGES

1. Toxic to decay and insects
2. Paintable, clean, odorless
3. Somewhat fire retardant
4. Readily available
5. Noncorrosive to metals

DISADVANTAGES

1. Subject to leaching in-ground contact.
2. Kiln dry or air dry desirable before use.
3. Not recommended for ground."

c. Hardboard. Hardboard should not be used in tropical environment construction because it is very susceptible to moisture damage. Tempered hardboard may be used in interior and weather protected areas and not exposed to the sun and rain. Hardboard is susceptible to deterioration in humid and damp tropical climate. Tempered hardboard performs adequately inside buildings.

d. Gypsum Board. Gypsum wallboard is an economical wall finishing material if properly designed and installed. It is also an ideal material to provide adequate fire-rated protection for interior areas. Nevertheless, gypsum board is susceptible to damage in barracks and other personnel type facilities. Also, in a tropical environment, deterioration through absorption of moisture and termite attack may be a problem. Although 1/2-inch thick board may be used in some areas, minimum thickness of 5/8-inch is recommended.

(1) Requirements. The quality, grade, and use of gypsum wallboard are adequately covered in NAVFAC Specification TS-09250. However, where the building is designed for air conditioning, the interior side of exterior walls (when specified to be dry wall finish) shall be constructed with Type III, Form c-Foil back moisture resistant core gypsum wallboard, SS-L-30D. (See air conditioning section of this manual.)

e. Particle Board. Particle board has an affinity for moisture and moisture deterioration. Particle board, in tropical environment construction, shall not be used for cabinet doors and drawers. If particle board is specified for premolded counter tops, such tops shall be factory or shop fabricated and completely sealed, painted, and finished before shipment to the site to minimize moisture absorption at the site.

f. Rough Hardware. All nails, bolts, nuts, sheetmetal connectors, and screws shall be hot-dip galvanized as minimal protection against corrosion. Where metallic items are exposed to the weather, either stainless steel or copper alloy base item as applicable should be considered to upgrade the quality and reduce life-cycle cost.

g. Asbestos Cement Board. Asbestos-cement board is an acceptable construction material if provided within the confine of good construction practice normally applied in the Continental United States (CONUS). It is considered a functional fire protection material and can be applied on interior and exterior surfaces within aesthetic requirements. It must be properly handled during installation to avoid dust. Wet sawing is recommended. Because asbestos is a health hazard material, its application and use is covered by the Environmental Protection Agency (EPA) Emission Standard for Asbestos, CRF 40, Chapter 1, part 61, and OSHA 1910.1001.

4. USE AND APPLICATION.

a. Lumber and Wood Products. The use and application, including workmanship, covered in NAVFAC TS-06100 and TS-06200 apply to construction in the tropics.

(1) Because dry rot and termite damages are prevalent in a tropical environment, additional emphasis on the following items shall be included in the specifications:

(a) Test to ensure the maximum moisture content of delivered material.

(b) Proper storage and protection from the wet and humid weather.

(c) Treatment of raw wood surfaces exposed (cut, sawed, drilled, or otherwise modified) with two brush coats of the preservative used in the original treatment before assembling.

(d) For all wood placed against either masonry or concrete, the contact surface of the wood shall be coated with two coats bituminous material and separated from the concrete with roofing felt. Felt is provided to protect the coating.

(e) Wood nailers embedded in concrete shall be coated with two bituminous coats and secured to the concrete with adequate anchors.

CHAPTER 7. THERMAL AND MOISTURE PROTECTION

Section 1. ROOFING AND ROOF INSULATION

1. SCOPE AND GENERAL INFORMATION. Discussion under this section covers various types of available roofing systems and their performance in a tropical environment. The systems also include insulation when considered as part of the roofing system.

2. ROOFING SYSTEMS. The following types of roofing systems are discussed for information:

- a. Built-up Bituminous Roofing (BUR)
- b. Roll Mineral-Surfaced Asphalt Roofing
- c. Elastomeric Roofing (Sheet and Fluid)
- d. Sheet Metal Roofing
- e. Thick Butt Mineral-Surfaced Asphalt Shingle Roofing
- f. Split Shake Shingle Roofing
- g. Clay Tile Roofing
- h. Cement Asbestos Roofing

With some exceptions, these roofing systems have their applicable use in the tropics. Certain roofing systems are not recommended where typhoons are prevalent.

3. GENERAL REQUIREMENTS. Generally, the selection of a roofing system includes the roof insulation. Some roof problems experienced in the past have been traced to the incompatibility of the roofing system and the roof insulation or to the improper design of the deck to receive the roofing system. The roofing system and its substrate must be functionally compatible.

4. MATERIALS.

a. Built-up Roofing. NAVFAC Type Specification TS-07510 provides acceptable guidance for built-up roofing systems for tropical environment application, except as hereinafter noted. The built-up roofing systems described in TS-07510 are considered and proven to give the longest service life of any roofing systems known to this date for use on concrete, wood, and prepared steel decks. This slope of 1/2:12 minimum is required to provide adequate drainage within stable condition of the roofing system. Flatter slopes are susceptible to accelerated deterioration in some tropical locations. The aggregate surfacing system is not recommended for application in typhoon areas because the loose aggregate can be windblown as missiles and damage surrounding properties. For such typhoon areas, applying a modified

double surfacing treatment (as outlined in TS-07510) followed by removal of the loose aggregate after the second application should be specified.

(1) Built-up roofs with smooth surfacing of aluminum pigment or other type coating should be considered for slopes steeper than 3:12 and for roofs on structures located on airfields where aggregate surfacing, if used, may possibly be sucked into the jet engines of aircrafts. However, smooth surfacing will require periodic recoating at approximately 3- to 5-year intervals. Before selecting a roofing system, site investigation of existing roof problems should be conducted to determine the best roof system for the area.

(2) Coal tar pitch for a built-up roofing system is not readily available in the Pacific Ocean area and requires special order if specified. This system is applicable to roof slopes less than 1:12. However, because of possible accelerated damage due to accumulation of debris and the added initial cost, other design approaches for roofing should be considered. In this regard, the maintenance activity may be consulted. Emphasis should be on a systematic preventive maintenance program, with inspection as a primary function.

(3) Insulation for Built-up Roofing. Where operational requirements place the project under the energy conservation policies of the Department of Defense, the use of insulation may be included as part of the roofing system. Under this requirement, the selected insulation shall be compatible with the roof deck and the roofing system for maximum serviceable life of the composite roofing system. Some of the available and acceptable insulations for built-up roofing systems in a tropical environment are provided in TS-07241. Guidance on fire requirements and application is also provided. It should be emphasized that moisture is a major problem in a tropical environment; therefore, design and application should ensure an adequate vapor barrier and venting system.

b. Roll Mineral-Surfaced Asphalt Roofing. The quality of a roll mineral-surfaced asphalt roofing system depends on the number of underlaying sheets and the weight of the mineral cap sheet. For typhoon areas, 3-ply underlayer and 90-pound mineral cap sheet may be considered. The recommended slope is 1:12 minimum.

(1) Insulation for this roofing system, if required, is the same as for the built-up roofing system.

c. Elastomeric Roofing System. Elastomeric is the name given to polymer materials in a wide range of chemical compositions. An elastomeric is an elastomer substance that can be stretched at room temperature to at least twice its original length and return to its original length in a short time after release of the stretching force. A polymer is a substance consisting of molecules characterized by the repartition of one or more types of chemical compounds. There are copolymers, dipolymers, tri or terpolymers, quadripolymers, high polymers, etc. Natural rubber is a polymer of isoprene.

(1) An elastomeric roofing system comes in two distinct forms: liquid elastomeric which is applied as a seamless coating by brush, roller, or spray (normally over a spray-on urethane foam insulation or concrete substrate) and

sheet elastomeric laid from rolled sheets overlapped and glued in-place over various type substrates.

(2) Types of Elastomeric Roofing. Many types of elastomer coatings have been on the market in the past few years; however, the following generic polymer materials are presently manufactured and commercially available for roofing:

Liquid Applied

- | | |
|------------------------------|---------------------------------|
| (a) Chlorosulfonated | (e) Silicone |
| Polyethelene (Hypalon*) | (f) Acrylic |
| (b) Butyl | (g) Neoprene |
| (c) Polyvinyl Chloride (PVC) | (h) Rubberized Asphalt |
| (d) Urethane | (i) Urethane (bitumen modified) |

Sheet Applied

- | | |
|------------------------------|------------------------------|
| (a) Chlorosulfonated | (c) Neoprene |
| Polyethylene (Hypalon*) | (d) Polyvinyl Chloride (PVC) |
| (b) Ethylene Propylene Diene | (e) Butyl |
| Terpolymer (EPDM) | |

(3) Selection of Elastomeric Roofing. The success or failure of the selected system depends, in part, on the complete understanding of the materials (coating or sheet, and the substrate), and their physical action with or against each other. Also, the environment and physical slope of the substrate affect the performance of the system. The use of elastomeric roofing systems in the tropics has been very limited. Both liquid coating and rolled sheet applications have been tried. Observations of limited application of elastomeric roofing system indicate that the sheet application over rigid board insulation performs satisfactorily under typhoon conditions. Conclusive performance studies on liquid or sheet applied elastomeric systems in the tropics are not presently available for evaluation and their use is not recommended at this time. Should elastomeric system be contemplated, it is recommended that NAVFAC Code 0461 be consulted for guidance.

d. Sheet Metal Roofing System. The sheet metal roofing system as used herein applies to all types of galvanized sheet metal roofing, including aluminum sheet roofing, coated and uncoated, and without insulation. Although there are insulation systems available for installing with the sheet metal roofing, such insulated roofing systems are not covered in this section. In the tropics, it is assumed that this type of roof system (without insulation) is utilized in warehouses, hangars, garages and prefabricated structures where thermal insulation is not required. Also, insulated sandwiched panels are not covered in this manual; their use is not recommended if they are fabricated from steel.

*Hypalon is a copyrighted name of a polymeric material (chlorosulfonated polyethylene polymer) produced by the E. I. du Pont de Nemours & Co., Inc. and manufactured by various companies for use as roofing material.

(1) Galvanized Steel Roofing. Galvanized steel roofing systems of 24 gauge minimum have been found to perform satisfactorily in the tropics when covered with a protective coating system. Coating systems are covered in Chapter 9, Section 2, "Painting and Protective Coating," in this manual. Coating systems of manufacturers' standard quality finish product, baked enamel, or other factory applied coatings are recommended. It should be stressed that a properly applied coating system is a must in the tropics. This includes underside for protection against corrosion due to condensation.

(a) Slope and Weatherstripping. Galvanized steel roofing systems are susceptible to windblown rain leakage through joints and connection points if not properly installed. Roof slope shall not be less than 3:12; all lap joints shall be caulked with an approved type sealant; ridge and other connections shall be provided with premolded weather strips to seal off any possible entry of windblown rain. Nails, screws, bolts, or other securing devices shall be provided with neoprene or other approved type washers and weatherstripping. The heads of nails, screws, and bolts shall be large enough to preclude shearing of the metal sheets from their anchors.

(b) Typhoon Zone. Where the sheet metal roofing system is to be installed in a typhoon zone, design and installation must meet the structural requirement against typhoon winds.

(2) Aluminum Roofing. Aluminum sheet metal roofing systems, 18 gauge minimum (0.040 inch), anodized (0.7 mil) have proven to be satisfactory in a tropical environment when designed and installed properly. Screws and bolts used to secure aluminum sheeting to steel members shall be stainless steel. Nails and screws used to secure aluminum sheet onto wood members may be aluminum. Both metal securing member and the aluminum sheets shall be coated at the contact or bearing points to preclude dissimilar metal corrosion. (See Chapter 5, Section 2, "Miscellaneous Metals," in this manual for background on aluminum.)

e. Asphalt Shingle (Mineral Surfaced) Roofing. Asphalt shingles have been used primarily in family housing type construction where wood has been the primary construction material. Asphalt shingles should not be used in typhoon areas. Where conditions justify its use, guidance provided in TS-07310 is applicable in the tropics. The use of asphalt shingle roofing system has been very limited due to design limitations, and its use in the tropics has been limited by:

(1) Slope requirement of 4:12 minimum.

(2) Wood deck requirement.

(3) Susceptibility to damage by strong winds (not necessarily typhoon).

(4) Insulation as a component part of the roofing system not practical.

f. Shingle and Tile Roofing Systems. Split shingle, clay tile, and cement asbestos are not recommended for tropical environment for various

reasons, including susceptibility to physical damage and high initial cost in some cases.

g. Flashing and Sheet Metal. Flashing and sheet metal work are covered in Chapter 7, Section 2, in this manual. Gravel stops and similar type flashing set against concrete or masonry shall be coated to avoid aluminum contact with the concrete. In typhoon areas, aluminum thickness should be not less than 0.064-inch where exposed to the direct wind. Also, all flashings should be secured at one-half of normal or closer intervals. Galvanized steel sheet is not recommended for a tropical environment.

Section 2. FLASHING AND SHEET METAL

1. SCOPE AND GENERAL INFORMATION. Discussion under this section covers flashing, sheet metal material, and their installation. Generally, NAVFAC TS-07600, "Flashing and Sheet Metal" specification covering material and workmanship, is applicable in the tropics except as noted herein.

2. MATERIALS.

a. Flashing, Gutter, and Downspout. In an atmosphere laden with salt-spray, stainless steel for flashings, gutters, and downspouts is recommended. Where salt spray is not severe, flashings, gutters, and downspouts over wood construction may be of stainless steel, aluminum alloy (3003-H14), or copper. Where aluminum is specified, thickness should not be less than 0.032 inches. In typhoon areas, aluminum thickness should be not less than 0.064 inches where exposed to the direct wind. Aluminum may be used over concrete construction, provided that required reglets are of stainless steel or polyvinyl chloride friction type and aluminum surface in contact with concrete or masonry is coated with bituminous paint conforming to MIL-C-450. However, chromate primer and enamel shall be used where appearance is a factor. All nails, screws, bolts, and fasteners shall be stainless steel. And except where copper sheets are used, brass, bronze, or monel shall be specified as applicable. Also flashing should be secured at one-half of normal or closer intervals to ensure installation against wind factor. Galvanized steel sheet for flashing is not recommended. It should not be specified for exposed exterior sheet metal work except when fully and completely painted after fabrication and before installation for minor application. Galvanized steel sheet shall not be used for gutters and downspouts.

b. Vent Flashing. Lead sheet, stainless steel, or copper flashing is recommended for plumbing vents and other pipe penetrations through the roof. Other ferrous and galvanized flashings are not recommended.

CHAPTER 8. DOORS AND WINDOWS

Section 1. PERSONNEL DOORS

1. **SCOPE AND GENERAL INFORMATION.** Discussion under this section covers all personnel type doors, including interior and exterior wood, aluminum, and steel doors in general.

a. **General Problems.** Generally, the problem encountered in the design, fabrication, and installation of doors in tropical environment is the rapid deterioration of exterior doors and frames due to the wet, humid, and corrosive atmosphere. Therefore, the resolution of this problem is in the selection of doors that will provide the most trouble-free service at the lowest life-cycle cost. However, it should be added that the quality and serviceability of any building component in any structure are primarily the functions of the material selected and the workmanship in its installation. Regardless of the material quality, its serviceability can be nullified by poor workmanship. Workmanship is a very critical factor and more so in the fabrication and installation of exterior doors in tropical environment. Due to better quality control, factory workmanship is superior to and more consistent than field workmanship. Accordingly, template/prehung exterior doors shall be specified.

b. **Door Guide Specifications.** Aluminum, wood, fire, and hollow metal doors and frames are covered in NAVFAC TS-08120, TS-08201, TS-08310 and TS-08110. The requirements for doors provided therein are generally applicable for tropical environment except as recommended and noted herein.

2. MATERIALS.

a. **Fire Doors and Frames (Labeled Doors).** Requirements for fire doors are covered in NAVFAC TS-08310. The strict requirements for fire doors preclude changes or modifications except when approved by the fire protection engineer. However, to assure maximum protection for doors with ferrous metal components, all such metals shall be hot-dip galvanized in accordance with ASTM A385, Class B coating, Table 1. Also, fire doors and frames shall be shop-primed as specified in TS-08310 before shipment to the site. Completely factory finished doors are strongly recommended.

b. **Hollow Metal Doors and Frames.** Hollow metal doors and frames are normally specified in areas where doors are subjected to above normal physical abuse, such as kitchen doors where hand carts are used to move supplies. Because of the corrosive environment, the use of hollow metal and other ferrous metal doors is discouraged.

Where hollow metal door is normally specified, the use of solid wood core door with stainless steel protective sheet metal over both faces is recommended as an alternative. If functional requirement dictates the use of hollow metal doors, it should be limited to interior rooms and where the possibility of condensation is nil. Even under such conditions, the doors and frames shall be galvanized and factory-primed.

c. Metal-Clad Doors and Frames. Kalamein doors (metal-covered wood core) are less desirable since the sheet metal cladding is lighter and subject to faster deterioration than hollow metal doors. The only advantage of kalamein door over hollow metal door is its quietness and reduced sound transmission. Since life-cycle costs on kalamein and hollow metal doors are not available, selection between the two types should be based on the desirable features.

d. Wood Doors. All exterior doors, except for specialty doors, shall be flush solid-core wood-block Type I waterproof glue face assembly, medium density overlay (MDO) on both faces conforming to the requirements of NWMA ISI, except all woods shall be water repellent treated prior to assembly. Doors shall be designed as template hardware, prehung. All edges shall be treated again with two brush coats after fabrication and all surfaces shall be factory-sealed with spar varnish or other approved sealer before shipment.

e. Glass Doors. Where design or aesthetics of monumental or other such type structure demands solid glass or frame glass doors, the doors and frames shall be stainless steel, except where the exterior doors are in a well protected area in which case aluminum (anodized after fabrication) may be considered.

f. Interior Doors. Interior door requirements should be the same as exterior doors, except template hardware or prefitting is not required. However, treatment and sealing after fitting shall be specified.

3. USE AND APPLICATION OF DOOR ACCESSORIES.

a. Weatherproofing. Doors and frames shall be designed against rain infiltration in typhoon zones using weather stripping, interlocking thresholds, and other weather sealing devices.

b. Door Louvers. Louvered doors on exterior entrances are very susceptible to weather deterioration and shall therefore be avoided. Other means to provide the venting function should be considered. If door louvers are unavoidable, they shall be either anodized aluminum (3003 or 6063) or stainless steel with stainless steel fasteners. Wood louvers are not recommended. The treatment of exposed wood shall apply.

c. Hardware Installation. In preparing specifications for doors and hardware, the two sections shall be closely coordinated. Prehung or prefitted template hardware doors should be utilized for exterior doors to take advantage of the better quality control available at the factory.

4. DOOR FINISH (PAINT).

a. Exterior and Interior. The finishing of all doors and frames is covered in the painting section. Factory finishing of exterior doors is strongly recommended.

5. MAINTENANCE. The systematic refinishing or retouching or both of doors in a preventive maintenance program is a must in tropical environment.

Crazed or damaged finish of wood or metal doors will expose the doors to rapid deterioration and costly replacement unless corrected promptly and properly.

Section 2. WINDOWS

1. SCOPE AND GENERAL INFORMATION. Discussion under this section covers windows in general, including fixed windows and windows made from various types of materials.

a. Background, Window Report. The following is a summary of observations and conclusions based on an investigation conducted by the District Public Works Office, Fourteenth Naval District, Pearl Harbor, Hawaii in March 1960, and titled "Report on Windows, U. S. Naval Support Activity, Kwajalein, Marshall Islands." The report covers the performance of various type windows in highly corrosive tropical environment and determines which types are the most practical as to function and maintenance. The investigation covered some 300 buildings utilizing many variations of five general types of windows. These are:

Wood awning with friction type brass hardware

Sliding plate glass and/or wood sash sliding on wood tracks

Pivoted, aluminum

Projected, aluminum

Aluminum Jalousies, with wood and glass blades and with gear operators

It was concluded that:

(1) There is no known window that is completely compatible with the highly corrosive atmosphere (coral dust and salt spray) on Kwajalein. Almost any type of window exclusive of ferrous metals will give satisfactory performance if properly maintained. Some windows, however, may require weekly maintenance while others require maintenance at 3-month intervals. Every piece of moving equipment requires cleaning, greasing, and operation at frequent intervals if prolonged service is desired.

(2) Metallic materials, except ferrous metals, may be used on Kwajalein with fair results except for moving parts. Observations noted are:

(a) Wood of common types such as Douglas fir and Ponderosa pine holds up extremely well when adequately protected with paint. This protection must be re-applied as needed to prevent dry-rotting, swelling, and warping. Varnishes and lacquers soon disintegrate in the corrosive atmosphere thereby leaving the exposed wood to dry-rot. Open-grained woods such as oak, Philippine mahogany, etc., should not be used due to water penetration and dry-rot. Pressure treating will greatly increase useful life of wood.

(b) Aluminum 0.0008-inch anodized coating on 6063-T5 type aluminum provides adequate material protection for sash and frames. However, where aluminum rubs against aluminum, such as hinges, riveted joints, etc., wear from abrasion or "freezing" from encrustation of salt and coral dust soon occurs. The anodized coating has stood up well for as many as 8 years on 6063-T5 type aluminum on Kwajalein. This time of exposure is considered as an adequate test and encourages further use for sash and frames only. Anodized aluminum, in general, requires less maintenance than does wood since painting is not required. There is no known aluminum awning type window manufactured that provides a simple friction type hardware such as is made of bronze for wood sash. In many instances, aluminum hardware was frozen beyond repair after only 6 months' exposure and some individual lever arms showed complete oxidation.

(c) Brass when used for hardware holds up extremely well. All parts must be of the same material, however, and not coated with other metals. Hardware must be cleaned and greased at time of installation and further cleaned, greased, and operated at frequent intervals.

(3) The above-listed windows have all been tested not only under the severe exposure but also under lack of maintenance and lack of care in operation. Therefore, it would be logical to conclude that the best window for Kwajalein would be that window which has stood up best under these conditions with improvements on those features which have given trouble in the past.

(4) The awning type window is most satisfactory at Kwajalein because it permits a maximum protection from driving rain. Single unit operator, vice gang operator, is best for two reasons: (a) It permits the most simple arrangement from the standpoint of maintenance and operation and (b) it permits a maximum of flexibility in setting degree of openings. For example, during a rain, the sash under the eaves (sheltered) can be left open more than can the lower sash which is exposed to the windblown rain.

(5) Brass operators and fittings are in excellent condition. They are strong enough to withstand the rough handling and after 8 years of severe exposure, with little maintenance, many have been restored to satisfactory operation by cleaning and greasing.

(6) Wood sash is the most satisfactory for several reasons: (a) it is compatible for use with the brass hardware, (b) it is the most economical to install and maintain (repaint every two years along with the rest of the building, and (c) broken sash can be easily replaced.

2. DESIGN CRITERIA.

a. Selection of Window Type. The selection of window design should be based on the following criteria:

- (1) Type and function of building
- (2) Wind condition, prevalent wind velocities, sheltered area or in direct wind path
- (3) Whether building is air conditioned or not

(4) Preference of the activity based on past experience

b. Recommended Window Types. There is a limited number of window types that are considered to provide acceptable service in tropical environment. The following functional window types are recommended:

(1) Awning type with fixed or vertically moving pivots

(2) Projected type with fixed or vertically moving pivots

(3) Jalousie (case vice strip). Jalousie type windows are not recommended for air conditioned areas due to their high infiltration factor. Jalousie windows are not recommended for typhoon zone areas, except where some degree of air and water infiltration are operationally acceptable.

3. MATERIALS.

a. Wood Window and Frame. Wood awning and projected types are recommended when specified as follows, in addition to standard requirements. Wood shall be Douglas fir or Ponderosa pine; clear, vertical grain without sapwood and pressure treated with Ammoniacal Copper Arsenite (ACA) in conformance with the American Wood Preservers Association (AWPA) Standards. All hardware (metal parts) shall be stainless steel, bronze, or brass.

(1) Fabrication of Windows. Except for glazing, window shall be factory fabricated complete, including jamb, sill, head, all hardware, and finish. Window shall include weather stripping and be weathertight.

(2) Installation. Where window frame comes in contact with concrete (including masonry), the contact surfaces of the frame and concrete shall be given two bituminous coats before installation. All trims shall be treated wood and primed completely before installation. For painting, see Chapter 9, Section 2, "Paints and Protective Coatings," in this manual. All metallic parts shall be lubricated with a thin film of heavy lubricating oil or grease after installation.

b. Aluminum Window and Frame. Aluminum, as a window material, is recommended when specified as follows. Standard requirements also apply:

(1) Aluminum shall be 6063-T5 or 3003 alloy, welded or fuse welded frame, and sashes with a minimum anodized coating of 0.7 mil after fabrication .

(2) Bearing surfaces such as bushings, sleeves, and pivots on operating parts shall be stainless steel, nylon, or other approved material.

(3) Gear or roto type operators shall not be used except where base material is stainless steel and packed and sealed in grease box.

(4) Weather stripping shall be either neoprene or other approved material.

(5) All surfaces of aluminum installed in contact with concrete including masonry shall be covered with either two coats of bituminous

material; alternatively, with either one coat of chromate primer and one finish coat of TT-E-489 enamel or one coat ASTM D-41 primer and one coat aluminum paint.

(6) All bearing surfaces shall be cleaned and lubricated after installation.

(7) Jalousies shall be stainless steel throughout. Aluminum is not recommended for jalousies, except when moving parts and bearing surfaces are as specified herein.

c. Stainless Steel Window and Frame. Stainless steel is recommended as a first line material for window construction. All hardware shall be stainless steel. All bearing points of moving parts shall be lubricated.

d. Air and Water Infiltration. All specifications for window quality shall include standards that will assure against water damage to fixtures and equipment. See ASTM E283 and E331.

e. Screens. Fiber glass screen, although susceptible to physical damage and burning, is considered the most ideal. Where screen is subject to continued physical abuse, such as on mess hall screen doors, stainless steel screen is recommended.

(1) Family Housing. Where screen doors are specified, it is difficult to determine whether replacement will be due to corrosion or physical damage. It is a toss-up between fiber glass and aluminum alloy screens.

(2) Copper and Copper Alloys. Copper, commercial bronze, bronze carbon steel (galvanized and painted), and monel shall not be specified for use in tropical environment due to corrosion and difficulty in cleaning.

(3) Fabrication. Care must be exercised to avoid dissimilar metals among the frame, connectors, spline, and screen fabric for window. Also, the design of sash shall prevent entrapment and accumulation of debris in the spline channel. Otherwise, conditions created by entrapped debris and moisture might generate galvanic cell action.

Section 3. FINISH HARDWARE

1. SCOPE AND GENERAL INFORMATION. Discussion under this section covers builders' hardware materials for doors, cabinets, closets, counters, toilet and bathroom accessories, and miscellaneous work benches except window hardware. This section shall be coordinated with Chapter 8, Section 1, "Doors," in this manual.

a. Corrosion. Hardware corrosion and subsequent malfunction is a major maintenance problem faced in tropical environment construction. Where air conditioning is included in the building, corrosion of interior finish hardware is reduced, but where natural ventilation of building is utilized, corrosion is still a problem to be resolved.

b. Dew Point Moisture. The condensation of moisture on building surfaces due to high humidity is lightly touched in various sections of this manual and discussed in Chapter 10, Section 2, "Air-Conditioning," of this manual in more detail. The reader should be familiar with the condition and its effect on metallic items.

c. Hardware Selection. Except for the requirements noted herein, selection as to function, quality, and finish shall follow the guidance provided in TS-08710.

d. Template Hardware. All exterior doors shall be provided with template hardware. See section on "Personnel Doors" for rationale.

e. Typhoon Areas. In typhoon zones, locksets should include dead bolts, and hinges should be provided with larger screws or bolts as applicable to resist typhoon force. The use of additional hinges should also be considered to resist the typhoon wind forces. Standard lockset and 1-1/2 pairs hinges with standard screws have been found to be inadequate.

2. MATERIALS.

a. Locksets. Selection of locksets for military construction shall conform to FF-H-106/GEN and ANSI A156.2, except as herein modified.

(1) Exterior Locksets. In a salt spray environment, all exterior locksets shall be stainless steel, including bolts, front, strike, escutcheons, knobs, and all interior working parts. The cylinder of the lock shall be stainless steel. All screws, bolts, and nuts shall be stainless steel.

(2) Interior Lock and Latch Sets. All interior lock and latch sets shall be either bronze or stainless steel, including bolts, fronts, strike, escutcheons, knobs, and all interior working parts.

b. Hinges. Although hinges are not by themselves a major maintenance problem, they add to, at a lesser degree, the overall corrosion problem of builders' hardware. The corrosion problem is more aesthetic rather than functional, although frozen hinges due to corrosion can be expected. Selection shall conform to NAVFAC TS-08710 and ANSI A156.1, except as herein modified.

(1) Exterior Door Hinges. All hinges on exterior doors, whether exposed on the interior or exterior side of the door, shall be stainless steel with stainless steel screws, bolts, and pins.

(2) Interior Door Hinges. All hinges on interior doors shall be either bronze or stainless steel, finish as applicable for the project. Screws, pins, and bolts shall be bronze or stainless steel. Nylon or teflon bearings may be provided.

(3) Hinge Metal. Except for stainless steel, ferrous metal shall not be used as base metal for hinges. Functional features such as tip design, type bearing, loose or fast pin, etc., shall be as required.

(4) Dissimilar Metals. Where aluminum doors or jambs or both are involved, the problem of dissimilar metals shall be considered and covered in the specification.

c. Door Closers. There are 3 general types of door closers: (1) surface, (2) concealed, and (3) jamb spring hinge. All three types operate generally on the same principle. All are spring-powered and control is governed by a piston forcing a fluid through a controlling orifice. The primary requirement of door closer is to provide long and reliable service with minimum inconvenience. Aesthetic is secondary except as noted in TS-08710.

(1) Selection Of Door Closer. Closer selection shall conform to TS-08710 and identification shall conform to ANSI A156.4, except as herein modified.

(2) Exterior Door Closer. All closers for exterior doors whether they are inside or outside mount, shall be of stainless steel with the exception noted hereinafter. If possible, all closers on exterior doors shall be inside bracket or door mount as applicable. Exterior mount shall be avoided wherever possible. The use of nonferrous metal closers such as aluminum and bronze, is permissible where door utilization is minimal and mounting on the inside of exterior doors.

(3) Interior Door Closers. All interior door closer material shall be optional, limited to nonferrous metals. Ferrous metal, except stainless steel, should not be specified.

d. Panic Hardware. The requirements covered under locksets are applicable for panic hardware.

e. Miscellaneous Hardware. Generally, all miscellaneous hardware for exterior doors shall be stainless steel except where aluminum doors and frames are permitted. Aluminum threshold may be provided with the standard precautions for installation of aluminum items.

(1) Bathroom and Toilet Finish Hardware. Bathroom and toilet finish hardware shall be bronze or stainless steel. Ferrous metal items should not be specified. Finish shall be as applicable for the project.

(2) Cabinet Hardware. Cabinet hardware shall be brass, bronze, chrome plated if required or stainless steel. Ferrous metal items should not be specified. Finish shall be as applicable for the project.

f. Aluminum Base Metal. See Paragraph 4 of Section 2, "Miscellaneous Metal," of this manual for background information.

3. INSTALLATION AND WORKMANSHIP. Generally, installation and workmanship on builders' hardware are covered in NAVFAC TS-08710. The following additional guideline is provided relative to the installation of builders' hardware items:

a. Copper Alloy. Copper alloy screws or bolts shall not be used to secure or connect aluminum items, even if the copper alloy item is plated. Stainless steel or aluminum screws should be specified.

b. Stainless Steel. Stainless steel screws and bolts should be used on items exposed to the weather.

c. Aluminum. Where aluminum threshold is secured to concrete floor, the contact surfaces of the threshold and concrete shall be brushed with two coats each of bituminous enamel coating.

d. Galvanized Items. The use of galvanized bolts and screws exposed to the weather is discouraged. Copper alloy screws and bolts shall not be used to secure or connect galvanized items, nor shall galvanized screws and bolts be used to secure or connect copper alloy items.

CHAPTER 9. FINISHES

Section 1. ACOUSTICAL TREATMENT

1. **SCOPE AND GENERAL INFORMATION.** Discussion under this section covers the design and installation of acoustical tile and board ceilings and walls, including the ceiling suspension system and wall furring as applicable.

a. **Humidity and Condensation.** In the tropics, the primary cause of impairment of acoustical treatment is the high humidity. All metallic items are very susceptible to "sweating" under high humid condition. The slightest difference in the temperature of the metal (lower temperature) and the surrounding air (at or near dew point) will condense moisture on the metal. Even exposed nail heads have been found with condensate under these conditions. On ferrous metal, the subsequent rust stain creates a maintenance problem. More on dew point and condensation is discussed in Chapter 10, Section 2 of this manual. Therefore, it is imperative that continual awareness of this problem be maintained during the design stage and that the use of ferrous metal be prudently limited.

2. **RELATED DESIGN.** The effect of a typhoon on acoustical treatment is not a problem except where the acoustical treatment is a drop ceiling with the attic space vented to the outside in which case differential pressure could create uplifting of the tiles. The use of storm shutters to seal off attic vents before a typhoon condition develops, the design and location of attic vents, and water damage caused by the entrance of windblown rain through exterior vents are described in the "Typhoon-Resistant Design" section of this manual. Also, see Chapter 10, Section 2, Paragraph r of this manual for air conditioning requirement of ceiling space.

3. **MATERIALS.** Material requirement for acoustical treatment is covered in NAVFAC TS-09500, except as specified herein.

a. **Acoustical Tile.** Material recommended for spaces subject to high humidity, such as in bathrooms, are covered by TS-09500. This recommendation shall be applied to construction in the tropics.

b. **Suspension System.** Suspension systems as applicable are covered in TS-09500, with exceptions as herein provided.

c. **Runners.** The main runners and cross runners, including wall channels, miscellaneous moldings, and accessories, shall be aluminum alloy anodized and finished as applicable, except where fire-rated installation is a requirement. In fire-rated areas, concealed grid system with galvanized steel and factory finished with baked-enamel or gypsum board with glued on tile is recommended.

d. **Hanger Wire.** Where the hanger wires are located in attic areas vented to the outside in a salt spray environment, the wires shall be stainless steel. It should be noted that attic areas above air conditioned spaces where cold water lines or A/C ducts are located shall not be vented and shall be air conditioned to preclude condensation problems.

4. **APPLICATION AND INSTALLATION.** Dissimilar metal installation shall include standard preventive measures against electrolytic corrosion.

a. **Aluminum Material.** Ensure that all aluminum material is anodized with a minimum 0.007-inch thickness.

b. **Protective Coatings.** Where aluminum is in contact with concrete or masonry, the aluminum contact surface shall be coated with bituminous paint conforming to MIL-C-450 or chromate primer and two-coat enamel finish where appearance is a requirement.

c. **Fastenings.** All nails, screws, bolts, and fasteners shall be stainless steel or aluminum, except where galvanized steel is used (in concealed areas) galvanized screws and bolts may be used in lieu of stainless steel. Do not use aluminum for securing suspended ceiling system onto concrete or masonry walls.

d. **Wood Nailers.** Where wood furring strips are required, material and application shall conform to the carpentry section of this manual.

Section 2. PAINTS AND PROTECTIVE COATINGS

1. **SCOPE AND GENERAL INFORMATION.** This section will include information on the selection, storage, and application of paints and protective coatings for structures in tropical areas of the Naval Shore Establishment, as well as surface preparation and other pre-application requirements. Although the words "paints" and "protective coatings" are used interchangeably in this section, it should be noted that protection of expensive structures from weathering is the main purpose of their use. Appearance is an important but secondary consideration.

a. **Severity of Environment.** Because of the severity of many tropical environments (high solar radiation, high temperatures, high rainfall, and salt spray), paints will frequently not perform as well at tropical locations as at normal stateside locations. Mildew defacement and deterioration of paints may occur rapidly if preventive measures are not taken. Procurement delays, inadequate storage facilities, application equipment failures, and general remoteness from more populated locations with available technical help may add further problems to the painting program. Thus, it is extremely important that information presented in this manual and referenced reports be utilized to their maximum extent.

b. Available Assistance.

(1) **Printed Criteria.** Two basic documents for all painting programs in the Naval Shore Establishment are NAVFAC MO-110, "Paints and Protective Coatings," and NAVFAC Specification TS-09910, "Painting of Buildings (Field Paintings)." Sections of MO-110 on programmed painting, safety, painting operations, and paint materials are especially relevant.

(2) **Personal Assistance.** Quick verbal or written assistance is available from coating specialists at NAVFAC, Code 0454B, Autovon 221-0464)

or CEL, Code L52, Autovon 360-4234). They may be able to rapidly resolve apparently difficult problems by virtue of their laboratory and field experience and access to information on similar problems.

2. PROGRAMMED PAINTING. Each shore activity should have a specific maintenance painting program that includes inspection, planning, materials selection, procurement and storage, equipment requirements, recordkeeping, and a schedule for surface preparation and repainting. Once a new structure is painted, it should be placed into the activity's program of maintenance painting.

3. PAINT SELECTION. Table 1 lists many of the factors important in the selection of a paint for a particular job. Table 2 lists the types of paints commonly used on different substrates and indicates the relative durability of each. The more severe the tropical environment, the more durable the paint should be. Tables 3 and 4 list a few recommended systems for Naval activities. Their selection has been based upon a combination of properties such as resistance to sunlight, rate of cure, tolerance to dampness, ease of applications, and general performance in a tropical environment. More detailed information on these or alternate systems can be found in MO-110 or TS-09910. In Table 5, references are listed for information on special purpose coatings. The systems listed in Tables 3 and 4 and referenced in Table 5 are for new unpainted surfaces. Localized repairs to a coated surface are ordinarily best made by cleaning exposed substrate as described in Tables 3 and 4 and spot priming and topcoating with the same type of material existing on the surface. Topcoating of a weathered paint is generally done with a similar type of topcoat. In tropical areas, biocides are generally added to paints to impart resistance to mildew growth. Because the list of approved biocides is frequently revised, NAVFAC or CEL should be contacted if there is any question about the use of a particular biocide. Microorganisms may utilize the oils in oleoresinous or alkyd paints as a source of food. Dirt, pollen, or other surface contamination may also accelerate the growth of microorganisms. Softer coatings permit more rapid penetration by mildew. Thus it is desirable to obtain hard, inert paint film and keep them free of contamination. Because of the high temperatures and rainfalls in tropical areas, all coatings should be stored indoors, preferable at temperatures of 70 degrees F or less. No more paint should be procured at one time than can be used in 1 year.

a. Exterior Paint System for Masonry. In the tropics when water infiltration and mildew growth are problem areas where masonry units are used, experience has shown that the following preparation and paint system provide the best results and is recommended for application:

(1) Surface Preparation. Both chemical and mechanical means shall be specified for preparation of masonry and concrete surfaces. See paragraph 6.2 of TS-09910 for details on surface preparation.

(2) Filler. On new surface, apply TT-P-19 cement emulsion filler. On painted surface (when necessary), apply TT-F-1098. See paragraph 7.2 of TS-09910 for detailed procedure for preparation and application of filler.

(3) Finish Coat. Two coats of TT-P-19 with mildewcide is recommended.

b. Exterior Paint System for Concrete. Treatment for concrete surface shall be the same as for masonry except filler may be deleted where concrete surface is smooth and dense.

4. SURFACE PREPARATION. Chapter 4, Section 4 of MO-110 provides a good general description of various available methods of surface preparation. In tropical areas, special care must be taken to determine that wood, concrete, and masonry surfaces are dry before painting them. Latex paints may be more tolerant of damp surfaces but they are also slow drying where the humidity is high. Efflorescence (white to gray powdery products) may occur on concrete surfaces, especially on interior walls of air conditioned buildings. Where moisture migration through concrete or masonry walls from the outside to the inside presents a problem, the outside should be sealed to correct the problem. Efflorescence on walls should be treated as described in CEL Techdata Sheet 77-10 before coating. If interior concrete walls are continuously damp, cracks in roofs that allow the entrance of rainwater must be suspected. These and cracks around windows must be repaired before painting. In preparing steel surfaces for painting, use should be made of the surface preparation standards listed in "Steel Structures Painting Manual, Vol. 2, Systems and Specifications."

In topcoating weathered paints, all mildew, dirt, grease, chalk, or other contaminants that might deter good bonding must be removed along with loose paint. Dirt, mildew, and other airborne contaminants collect rapidly in protected areas such as under the overhangs of roofs. Cleaning is probably best done scrubbing with a warm solution of trisodium phosphate and then rinsing in water. About one cup of trisodium phosphate (sodium phosphate or sodium metaborate may be used where phosphates are prohibited) should be used with each gallon of warm water, and rubber gloves should be used to protect the hands from this caustic solution.

5. PAINT APPLICATION. Chapter 4, Section 6 of MO-110 provides a good general description of various methods of paint application. The actual selection of brush, roller, or spray (air or airless) may be determined in good part by the availability of equipment and the skill of the operators. Table 9 lists factors that may be important in this selection.

Table 1. Important Factors in Paint Selection

1. Nature of Substrate (wood, concrete, steel, etc.)
2. Condition of Substrate (rough, smooth, rusty, weathered, etc.)
3. Condition of any Existing Paint
4. Severity of Environment (marine, underground, chemical, etc.)
5. Equipment and Experience of Personnel in Surface and Preparation and Coating Application
6. Limitations of Time and Accessibility
7. Biological Problems (mildew, fouling, etc.)
8. Economic Considerations (life-cycle costs)

Table 2. Types of Paint Commonly Used on Different Substrate

Substrate	Paint	Comments
Interior Wood	Oil	Generally slow drying and relatively soft.
	Alkyd	May be hard or soft.
	Latex (Vinyl or Acrylic)	Can be applied over oil, alkyd, or latex primer.
Exterior Wood	Oil	Good wetting of weathered wood and paint chalk. Slow drying, soft.
	Alkyd	Good wetting, variations give variety of properties.
	Silicone Alkyd	Good wetting, good gloss.
	Latex (Vinyl or Acrylic)	Poor wetting of weathered wood and paint chalk. Easily applied.
Interior Masonry, Plaster, and Wall Board	Acrylic Latex	Easily applied, brushing is good on coarse surfaces, must remove all loose chalk.
	Vinyl Latex	Same as Acrylic Latex.
	Chlorinated Rubber	Good for water sealing.
Exterior Concrete and Masonry	Acrylic Latex	Fill coats of these materials will reduce water penetration.
	Vinyl	Good resistance to water, poor to strong solvents.
	Epoxy	Good durability and chemical resistance.
	Urethane	Good durability and chemical resistance.
Exterior Iron and Steel	Oil	For mild environments only.
	Alkyd	For mild environments only.
	Silicone Alkyd	For mild environments only, good gloss.
	Inorganic Zinc	Very abrasion-resistant, limited life in seawater without topcoat.

Table 2 (Cont'd)

Substrate	Paint	Comments
	Vinyl	Good durability, easily touched up.
	Epoxy	Good durability and chemical resistance, but chalks in sunlight.
	Urethane	Aliphatic type has good weathering over epoxy primer.

Table 3. Recommended Systems for Interior Painting

Substrate	Surface Preparation	Prime Coat(s)*	Topcoat(s)*	Comments
Wood	See TS-09910, para. 5.1	(1) TT-E-543 (alkyd)	(1 or 2) TT-E-506 (alkyd)	Gloss, white and tints
		(1 or 2) TT-E-508 (alkyd)		Semigloss, white and tints
		(1 or 2) TT-E-489 (alkyd)		Gloss, fast dry, wide range of colors
Plaster and Wallboard	See TS-09910, paras. 5.2 and 5.3	(1) TT-E-534 (alkyd) or TT-P-001984 (latex)	(1 or 2) TT-P-1511 (latex)	Gloss and semigloss, white and tints
		(1) TT-P-29 (latex)	(1 or 2) TT-P-29 (latex)	White and tints
		(1 or 2) TT-P-1511 (latex)		Gloss and semigloss, white and tints
Concrete and Masonry	See TS-00910, para. 5.2	(1) TT-P-95, Type I (chlorinated rubber)	TT-P-95, Type I (chlorinated rubber)	Water resistant, choice of gloss and colors
		(1) TT-P-29 (latex)	(1 or 2) TT-P-29 (latex)	White and tints
		(1) TT-P-95, Type I (chlorinated rubber)	TT-P-95, Type I (chlorinated rubber)	Water resistant, choice of gloss and colors
Iron and Steel	Class 3 of MO-110, para. 4.4.3.7 (Class 1 or 2 OK for touch-up or repair)	(1) TT-P-645 (alkyd)	(1 or 2) TT-E-506 (alkyd)	Gloss, white and tints
		(1 or 2) TT-E-508 (alkyd)		Semigloss, white and tints
		(1 or 2) TT-E-489 (alkyd)		Gloss, hard, fast, dry, wide range of colors

*Number of coats in parentheses.

Table 3. (Cont'd)

Substrate	Surface Preparation	Prime Coat(s)*	Topcoat(s)*	Comments
Aluminum, tin, lead, or brass	Solvent clean, see TT-C-490, (1) MIL- P-15328 (0.3 to 0.5 mils)	(1) TT-P-645 (alkyd)	See galvanized steel	Never use a red lead primer on aluminum; may not be necessary to paint these metals

*Number of coats in parentheses.

Table 4. Recommended Systems for Exterior Painting

Substrate	Surface Preparation	Prime Coat(s)*	Topcoat(s)*	Comments
Wood	See TS-09910, para. 5.1	(1) MIL-P-28582 (alkyd)	(2) MIL-P-52324 (alkyd)	White and light tints
			(2) TT-P-81 (alkyd)	Medium shades
			(2) TT-P-37 (alkyd)	Deep colors
			(2) TT-E-489 (alkyd)	Gloss, hard, fast dry, wide range of colors
			(1) TT-P-19 (acrylic latex)	White and tints, use fill coat primer on porous blocks
Concrete and Masonry	See TS-00910, para. 5.2	(1) TT-P-95, Type I (chlorinated rubber)	(1) TT-P-95, Type I (chlorinated rubber)	Good waterproofing, choice of gloss and colors. See Table 5 for swimming pools, floors, and tanks.
Iron and Steel	Class 3 of MO-110, para. 4.4.2.7 (Class 1 or 2 acceptable for touch-up repair)	(1) TT-P-86, Type II or III (alkyd); Use Type III for quicker cure; Use TT-P-645 on housing where lead is prohibited	(2) MIL-P-52324 (alkyd)	White and light tints
			(2) TT-P-81 (alkyd)	Medium shades
			(2) TT-P-37 (alkyd)	Deep colors
			(2) TT-E-489 (alkyd)	Hard, glossy, good for trim
		Other Systems		See Table 5 for specialized and more severe environments
Galvanized Steel	Solvent clean (1) MIL-P-15328 (0.3 - 0.5 mils)	(2) TT-P-641 (alkyd)	(2) Of iron and steel above	Use topcoat recommended for environment

*Number of coats in parentheses.

Table 5. Reference to Information on Special Purpose Coatings

Special Purpose	Source of Information
Steel Potable Water Tank Interiors	CEL Techdata Sheet 77-09
Steel Fuel Tank Interiors	TS-09802
Concrete Fuel Tank Interiors	TS-09801
Marine Sheet Steel Piling	TS-09805 and CEL Techdata Sheet 77-18
Water front Structures	MO-104
Fleet Moorings	MO-124
Fuel Lines Under Piers	CEL Techdata Sheet 75-26
Pavement Striping	CEL Techdata Sheet 75-33
Sign Painting	MO-110, Table 7 and Chapter 11
Swimming Pools	CEL Techdata Sheet 77-10
Floors	MO-110 Tables 17 (wood), 18 (concrete), and 19 (metal)
Heat-Resistant Coatings	MO-110, para. 10.2.2.6
Chain-link Fencing	MO-110, Table 16

Table 6. Factors Affecting Selection of Method of Paint Application

Characteristic	Brush	Roller	Spray
Speed (Rate of paint application)	Fair	Good	Excellent
Ease of Application (Lack of dependence on operator skill)	Fair	Good	Poor
Simplicity of Equipment (Ease of repair, cleanup, etc.)	Excellent	Excellent	Poor
Safety (Requirement of protective equipment)	Excellent	Excellent	Poor
Material Conservation (% of paint reaching substrate)	Excellent	Good	Poor-Good*
Portability (Handling at difficult job sites)	Excellent	Good	Poor
Versatility (Adaptability to special jobs, paints, etc.)	Good	Fair	Excellent
Initial Economics (Purchase of equipment and accessories)	Excellent	Excellent	Poor
Long Range Economics (Replacement, repair, etc.)	Fair	Fair	Excellent
Hiding Power (Ability to obscure underlying surface)	Good	Fair	Excellent
Uniformity (Ability to provide uniform surface)	Poor	Fair	Good

*Varies greatly with particular equipment and operator.

CHAPTER 10. MECHANICAL

Section 1. PLUMBING

1. **SCOPE AND GENERAL INFORMATION.** Discussion under this section covers interior and exterior piping, distribution system, plumbing fixtures, fixture fittings, sprinkler systems, compressed air systems, and other plumbing materials used in general construction work. Of all the construction trades, plumbing installation is the least affected by the destructive elements of the tropics. The major concern, other than the normal "wear and tear" and normal deterioration, is the corrosion of ferrous products used by the trade and the effect of corrosive soil on metallic items including copper alloys and galvanized steel.

a. **Criteria and Guidance.** Generally, plumbing shall conform to the guidance provided by NAVFAC TS-15401, except as herein noted. It is noted that there are many types of materials available for water and sewer piping systems, such as cast iron, steel, concrete, asbestoscement, plastic, and clay. Serviceability and economic performance vary with the material selected. The criteria used in the selection of the recommended piping system are economics (initial investment) and performance of the materials as primarily experienced on Guam.

2. MATERIALS.

a. **Underground Water Piping.** Buried piping 4 inches in diameter and larger, shall be cement-mortar lined cast-iron pipe Type III, Class 150, with complete coating of pipe and gland; bolts and nuts conforming to WW-P-421, with mechanical joint fittings conforming to ANSI A21.10 or A21.11, are recommended. Piping 3-1/2" and smaller shall be copper tubing, type K (annealed, optional), conforming to ASTM B88 with flared brass or solder-type bronze or wrought copper fittings conforming to ANSI B16.26 or B16.22. Polyvinyl chloride (PVC) pressure pipe conforming to AWWA C-900 may be used in lieu of the cast-iron pipe. Installation shall conform to manufacturer's recommendations.

b. **Protective Coating For Copper Tubing.** Where copper tubing is to be buried under a concrete slab in coral material, piping shall be provided with wash primer MIL-P-15328, primer TT-P-645, and two coats of coal tar conforming to MIL-C-18480 or wrapped with 15 lbs. asphalt felt, hot-applied.

c. **Aboveground Piping.** Water lines in buildings and structures should be brazed or solder-joint copper with brass or bronze fittings conforming to ANSI B16.18 or B16.22.

d. **Steel Pipes.** Where steel pipe is necessary for strength or other requirements, such uninsulated piping exposed to the weather should be galvanized and protected with a coating system as follows, subject to temperature limitation:

- (1) A pretreatment coat conforming to MIL-P-15328.
- (2) One coat of zinc chromate primer conforming to TT-P-645.
- (3) Two coats of enamel paint conforming to TT-P-489.

If nongalvanized black steel or wrought iron is specified, the above coating system applies except the primer shall be two coats vice one.

e. Insulation and Protective Covering. Insulation and protective covering specified in NAVFAC TS-15250 are applicable for tropical environment application, except as herein noted.

(1) Condensation. Condensation is a serious problem in a tropical environment. Mildew growth is a problem and all vapor barriers and coatings shall include mildew resistant properties.

(2) Metal Jackets. Insulated piping exposed to the weather shall be provided with aluminum or stainless steel jacketing without exception to minimize mildew and physical damage problems.

f. Plumbing Fixtures. The use of enameled steel or cast-iron fixtures is not recommended for location with salt-laden atmosphere. Vitreous china fixtures are recommended.

g. Plumbing Accessories. Avoid the use of zinc-alloy castings for handles and fitting in fixture trims and accessories. Heavily chrome-plated bronze, stainless steel, or plastics in some cases is preferred for handles, towel bars, soap dishes, towel and tissue dispensers, and shower rods.

h. Fire Sprinkler System. The guidance provided in NAVFAC TS-15514, for sprinkler system is applicable for tropical environment.

i. Interior Air Line Piping. Pipe may be seamless or welded steel, or copper. Ferrous pipes shall be factory treated and primed as specified hereinbefore. Field paint shall include touch-up of primer and a minimum of one finish coat of TT-P-489.

j. Pipe Supports. All hangers and metal pipe supports shall be galvanized, treated, and painted as specified herein for piping.

k. Escutcheon Plates and Miscellaneous Finish Items. Miscellaneous finish items shall be either noncorrosive plated metal or stainless steel. Miscellaneous rough hardware such as sleeves shall be hot-dip galvanized steel and painted after installation.

Section 2. AIR CONDITIONING

1. SCOPE AND GENERAL INFORMATION. Criteria provided in this section shall apply to air conditioning in tropical environment and augment the criteria for design of air conditioning in Chapter 5 of DM-3, Mechanical Engineering, which is also applicable to tropical engineering except as revised in this manual.

a. Background. Until recently, air conditioning systems were installed mainly in operational and technical facilities. In general, these spaces had heavy and continuous internally generated sensible heat loads such that humidity within the spaces could be reasonably controlled. Therefore, operation and maintenance problems in air conditioning was limited to normal wear and tear and the prevention of corrosion of the equipment due to the aggressive tropical environment.

b. Humidity Problems. With the increased use of air conditioning for personnel comfort, facilities such as living quarters having little internally generated sensible heat are creating humidity problems. Coupled with this situation, the buildings are often either masonry or concrete construction for resistance against the corrosive tropical environment and high typhoon winds. This type construction has high thermal storage capacity and a very stabilizing effect against space temperature changes. This permits very close control of space temperatures, but at the same time makes control of humidities very difficult. In many instances, high room humidities have resulted in dew point condensation with resulting dampness, mildew and fungus growth, odors, and accelerated corrosion and deterioration of personal effects, furniture, and painted surfaces.

2. DESIGN CONSIDERATIONS. The design of air conditioning systems for tropical environments has its own special considerations. One of particular importance is that air conditioning in tropical environments is operated throughout the year, mainly to provide comfort from the oppressive humidities that prevail throughout most of the year. As a result, there may be mild climatic periods and nights when the outside ambient temperatures may be about equal to or even less than the inside temperature. Often, these mild temperatures occur coincident with heavy rainfall periods of extended duration, when outside humidities become highest. Failure to recognize these conditions could lead to very unsatisfactory air conditioning system performance that in cases may be worse than having no air conditioning at all. To protect facilities against high inside humidity space conditions, the design, system selection, and installation procedures for air conditioning equipment may be taken as follows:

a. Fan Coil Unit. Room fan coil units shall not be used.

b. Air Handling System. Air conditioning shall be provided by an all air type system. The system may be a central air handling type with chilled water coils or a unitary (single or multiple) direct expansion type unit capable of controlling the dew point of the supply air for all conditions of load. Reheat, when required, shall be applied centrally using recovered heat. Heat recovery may be double bundle condensers or separate, auxiliary condensers, run-around closed loop, refrigerant hot gas, solar, etc.

c. Design Analysis. The predesign analysis shall include the use of air conditioning systems such as variable volume constant temperature, by-pass variable air volume, variable temperature constant volume and terminal air blenders. In addition to first cost and life cycle cost considerations, system selection shall be based on the capability of the air conditioning system to control the humidity in the conditioned spaces continuously under full load and part load conditions. When a computer energy analysis is utilized, it shall consider the dehumidification performance of the air conditioning

system under varying internal and external load conditions. Where it appears that the latent heat gain into the building and/or the type of air conditioning and control system might result in moisture problems, it is recommended that the energy analysis computer program be capable of taking these items into consideration.

d. Air Handling Unit. Air handling units should be the drawthrough type in order to utilize the fan energy for reheat. Coils shall have low by-pass factors.

e. Outside Air. Outside air shall be conditioned at all times through a continuously operating air conditioning system. Outside air shall be adequate in quantity to slightly pressurize the building under most conditions of wind velocity and building exhaust. The percentage of outside air over exhaust air should generally be in the range of 20 to 30 percent.

f. Dehumidification Load. In addition to calculation of the cooling load at maximum design conditions, a cooling load calculation should also be made for the low temperature, high humidity conditions to determine the greatest dehumidification load that may be encountered on cloudy, humid days.

g. Supply Air. The supply air temperature and quantity, and chilled water temperature shall be based on the sensible heat factor, coil by-pass factor, and apparatus dew point.

h. Vapor Infiltration. Latent heat gain due to water vapor flow through walls and roofs shall be included in the cooling load analysis whenever the ambient design dew point exceeds room design dew point by more than 20 degrees F.

i. Wet and Dry Bulb Temperatures. The 1 percent wet bulb temperature and 2-1/2 percent dry bulb temperature from NAVFAC P-89 shall be used in the design calculation for equipment selection.

j. Dual System. The cooling capacity of chilled water systems of 100 tons and over shall be divided between two chillers to assure reliability and constant chilled water supply without temperature fluctuations and to prevent short cycling. The combined capacity of the two chillers shall not exceed the total requirement including diversity. Selection of chiller capacity should be based on the analysis of part load operating hours for extended periods at low load conditions.

k. Packaged Unitary System. Packaged unitary units with multiple reciprocating compressors (not to exceed four) shall be used for systems between 35 tons and 100 tons. Each compressor shall have separate and independent refrigerant circuits and provide multiple steps for capacity control. For systems up to 35 tons, single compressors with a minimum of three-step capacity unloading shall be used.

l. System and Piping Arrangement. The refrigerant piping for compressor, evaporator, and condenser of direct expansion systems shall be kept to a minimum and shall be provided with necessary accessories to insure proper oil return and uniform circuit distribution at minimum coil load. Consideration shall be given to the need for unloading, split-row coils, back pressure

regulators, and hot gas by-pass. Direct expansion multi-zone systems shall not be used.

m. Cooling Tower. Cooling towers shall be selected on the basis of a 7 degree F approach temperature. Condenser water flow should be as low as possible based on life cycle costs of fan energy versus compressor energy and consistent with the chiller manufacturer's recommendation. Towers with long hours of operation should be of the draw-through type to reduce fan horse power requirements.

n. Bathrooms and Storage Areas. Private bathrooms and public toilets, closets, and storage rooms shall be air conditioned. Toilet air conditioning should be by exhausting conditioned air from adjacent air conditioned room.

o. Private Bathrooms. Private applies to residences and apartments and to private bathrooms of BEQ's and BOQ's and similar installations where the fixtures are intended for the use of a family or an individual. Bathroom exhaust shall be by individual exhaust fans controlled by light switches or timers. Back-draft dampers shall be provided to prevent air flow when fans are not running.

p. Public Toilets. Public applies to toilet rooms of schools, gymnasiums, BEQ's, BOQ's, public buildings, bars, public comfort stations, and other installations (whether pay or free) where a number of fixtures are installed so that their use is similarly unrestricted. Toilet exhaust requirements shall be 2 cfm/sq. ft. Bathrooms should be kept under negative pressure with respect to adjacent rooms.

q. Comfort Criteria. Indoor summer design conditions shall be 78 degrees F db and 50% RH for human comfort applications. For communications facilities, indoor design conditions shall be as required by electronic equipment manufacturer.

r. Attic and Enclosed spaces. Dead attic spaces, created by suspended ceilings and by cold water piping or A/C ducts passing through enclosed spaces such as these, shall not be vented outside and provisions shall be made to circulate conditioned room air through such enclosed space to preclude condensation problems.

s. Piping:

(1) The passage of cold or chilled water piping through enclosed building spaces, especially through concealed ceiling spaces, should be minimized.

(2) Insulation thicknesses as shown in NAVFAC Specification TS-15250 are selected to prevent surface condensation based on 85 degree F db and 85% RH ambient air. Consideration should be given to the need for increased thickness where higher than normal conditions are to be encountered.

(3) Insulation materials, application and installation for pipe, fittings and valves shall conform to the requirements specified in NAVFAC Specification TS-15250 for cold piping below 35 degrees F. Cellular glass

insulation only shall be used. Flexible unicellular insulation shall not be permitted.

(4) A vapor barrier shall be provided for all cold piping 60 degrees F and below. Special attention must be given to the details of construction and to the specification for the vapor barrier. This will ensure a complete moisture and vapor seal where insulation terminates against metal hangers, anchors, and other projections through insulation on cold surfaces with vapor barriers. The specifications or drawings should require that the ends of pipe insulation be sealed off with a vapor barrier coating at valves, flanges and fittings and at intervals not to exceed 15 feet on long runs of pipe. Lateral joints of pipe insulation sections shall be coated with vapor barrier coating compound to ensure vapor seal of insulation sections. Pipe insulation vapor barrier jacket shall be factory applied.

t. Roof Mounted Equipment. Roof mounted equipment shall be discouraged, especially in typhoon areas. Roof mounted equipment create roof construction and maintenance problems that cannot be justified. This recommendation does not preclude use of roof-top equipment rooms.

u. Condensation. Avoid installation arrangements that contribute to condensation problems. For instance, locating cold components over windows or outside entrances could lead to warm moist infiltrating air condensing on the overhead located cold surfaces and causing a drip condition. Locating cold equipment and cold piping in enclosed ceiling spaces where there is possible build-up of warm moist air can also create a dripping problem.

v. Building Design. Design the building to be compatible with the air conditioning system.

(1) Minimize exterior area such as semi-enclosed stairwells which permit air stagnation. See subparagraph 2 below.

(2) Air condition corridors and hallways or consider partitions between them and air conditioned spaces as exterior walls, pressurize slightly and provide adequate ventilation in such non-air conditioned areas to prevent fungus growth.

(3) Limit exterior shading devices to shading fenestration only.

(4) Exhaust conditioned air through public toilets. Locate exhaust over or close to shower areas. Do not utilize natural ventilation for toilet areas in air conditioned buildings.

(5) The building insulation shall be of sufficient thickness to maintain the exterior surface temperature above the ambient dew point temperature. However, it should be recognized that regardless of how much insulation is used, condensation will occur under certain weather conditions so that it is imperative that the architectural design of the building provide the capability to eliminate the moisture as rapidly as possible.

CHAPTER 11. ELECTRICAL

Section 1. ELECTRICAL, GENERAL

1. SCOPE AND GENERAL INFORMATION. Discussions under this section cover electrical materials and equipment used in general construction.

a. Aggressive Elements. Salt-laden air and high humidity are the primary causes of nearly all the electrical maintenance problems in a tropical environment. Termites cause some damage to cables, poles, and other wood items. In typhoon areas, infiltration of windblown rain, and blown down power poles and lines cause general damages to facilities, equipment, and structures.

b. Design Considerations. Generally, in all electrical design, construction, and installation, use "noncorrosive" electrical items as much as possible, and utilize the structures or enclosures to protect equipment against the elements. Another protective measure is the application of some type of protective treatment or coating. Also arcing of high potential lines (due to sea spray deposits) and moisture on insulation is an item of concern.

c. Aluminum. Where the use of aluminum alloy materials is permitted, such aluminum alloy items should be anodized after fabrication of the parts and before assembly of the complete item. That is, anodizing shall be performed after cutting, bending, forming, and drilling of the parts have been all completed. Aluminum alloy should not be used where movement of contact or bearing surfaces is expected. Cable trays shall be 6000 series aluminum. See Chapter 5, Section 2, "Miscellaneous Metals," in this manual for background information on aluminum alloy.

d. Dissimilar Material. Dissimilar metal construction in the presence of high humidity in tropical environment is very conducive to corrosion. Therefore, every precaution shall be taken to ensure isolation of dissimilar metals.

e. Electrical Code. Electrical installations shall conform to the National Electrical Code (NEC), except for the modifications provided herein-after.

2. MATERIALS.

a. Protection Against Humidity and Moisture. The following guidance is provided for the protection of electrical material and equipment against the high humidity and moisture in a tropical environment.

(1) Electrical Components. Switches, fuses, contacts, oil-immersed transformer windings, heater elements, distributors, and spark plugs shall not be treated with fungus-resistant coating. Other materials and components which are inherently fungus-resistant or are protected by hermetic sealing need not be treated nor coated.

(2) Circuit Elements (Low Temperature Rise). Circuit elements not covered above and which have a temperature rise of not more than 75 degrees F when operating at full load shall be coated with a fungusresistant varnish conforming to Specification MIL-V-173. The method of treatment shall be in accordance with Specification MIL-T-152. Circuit elements include, but are not limited to, solenoids, relays, terminal and junction blocks, capacitors, and control coils.

(3) Circuit Elements (High Temperature Rise). Circuit elements such as motor coils, generator and dry type transformer windings, and similar electrical components, which have a temperature rise exceeding 75 degrees F when operating at full load, shall not be coated with a fungitoxic compound. Instead, such components shall be given two coats of varnish conforming to type M, grade BB or CB, and one sealer coat conforming to type M, grade CB of Specification MIL-I-24092. The coats shall be applied by the vacuum-pressure, immersion, centrifugal, pulsating-pressure, or built-up method so as to fill all interstices in the coils and preclude the entrapment of air or moisture. The sealer coat may also be applied by brushing or spraying.

(4) Ferrous Items. Where steel is necessary as a base material, such material shall be galvanized, plated, or clad. Stainless steel shall be utilized where applicable.

b. Lighting Fixtures. All parts of fixtures should be of inherently corrosion-, moisture-, and fungus-resistant materials, such as nonferrous metal, glass, or plastic; 6000 series aluminum alloy containing not more than 0.1 of one percent copper is recommended. Parts and fastenings may be of corrosion-resistant steel type 316. Certain parts and louvers may be of plastic materials, and when removable for servicing, should have means of retention during the operation. Wiring should be type AF fixture wire. Lampholders should be of either porcelain or phenolic material, and when equipped with pigtails, the pigtails should be type AF fixture wire. Lamp bases and lamp sockets should be of the same type of material.

(1) Fluorescent Fixtures. Fluorescent fixtures should be the rapid start or slimline type; ballasts shall be Class P, nonautomatic reset.

(2) Reflectors and Diffusers. Translucent parts (glassware) of fixtures should be glass or methyl methacrylate plastic material.

(3) Vaportight Fixtures. Fixtures exposed to the weather or in protected open areas (including open-roofed areas such as porches) should be the vaportight type. Ferrous metal parts, including zinc-coated ferrous metal, should not be used in these fixtures. Fixtures for exterior security lighting should be waterproof construction.

(4) Lampholders and Miscellaneous Parts. Bakelite lampholders have proved to be unsatisfactory in service. Lampholders used should be porcelain, with asbestos insulated pigtails. Painted steel light fixtures have proved unsatisfactory in all installations. The standard factory-applied finishes are not sufficiently resistant to the corrosive atmospheric conditions. Aluminum (noncopper bearing) 6000 series alloy fixtures have proved to be satisfactory for general purpose use. Fasteners and globe-mounting

screws must be of nonferrous noncopper bearing metal, monel, or stainless steel.

c. Switches and Breakers. Wall switch and receptacle bodies should be porcelain or mineral-filled phenolic plastic. Wall switches should be single unit type; receptacles may be the duplex type. Metal parts and fastenings, including yoke mounting screws, should be nonferrous metal. Wall switches and receptacles known to the trade as the "interchangeable type" should not be used. Ferrous metal outlet boxes should be avoided. Plastic (noncombustion supporting) outlet and switch boxes should be used. This does not apply to panel boxes because of electrical code regulations. Wall switches, except for current-carrying portions, should be of nonmetallic construction. All fasteners should be of a nonferrous material. If galvanized steel conduits, outlet bodies and boxes are used and encased in concrete, a heavy coating of alkali-resistant coal tar base paint (MIL-P-15147) should be applied before installation.

(1) Circuit Breakers. Circuit breaker switches (multi-breaker type) in the past have generally proved unsatisfactory for use in the Marianas. Multi-breakers overloaded periodically over a period of several months had a tendency to weaken and no longer stayed closed at their rated amperage. Multi-breakers were also very susceptible to shorting caused by ants working inside and around contact points.

(2) Breaker Type and Material. Circuit breakers should be the solid state or magnetic type vice the bimetallic trip. Plastic materials should be the mineral-filled phenolic type.

d. Conduits and Wiring. The climatic conditions in most tropical environment areas are such that all locations should be classified as a Damp Location, as defined in the National Electrical Code. Type RH wire has proved unsuitable in all installations. RH-RW wire used on branch circuits, or other applications subject to periodic loading, deteriorates due to fungus attack where the sheath has been removed, such as the pigtailed in the outlet boxes. In feeder circuits, or circuits where there is a constant flow of current, the heat produced from the power loss appears to protect the circuit from fungus attack. Use of TW has proved satisfactory for light switching circuit applications; however, on feeder circuits THW or XHHW insulation is recommended because of the additional current carrying capacity allowed. Mineral-insulated metal sheathed cable, Type MI, may be used for service feeders and branch circuits exposed to weather or continuous moisture, for underground runs embedded in masonry or concrete, buried in fill, or where exposed to oil, gasoline, or other conditions not having a deteriorating effect on the metal sheath. The sheath of mineral-insulated metal sheathed cable exposed to destructive corrosive conditions shall be protected by materials suitable for these conditions. Where such a cable is to be buried in or under a concrete slab, or in coral material, the cable shall be provided with wash primer MIL-P-15328, primer TT-P-645, and two coats of coal tar conforming to MIL-C-18480. Type MI shall be used in refrigerated spaces and where specified by the National Electrical Code. A green TW equipment ground wire, sized per NEC 250-95, is required in all branch and feeder circuit conduits.

(1) Conduit Coatings. Plain, non-galvanized, ridge steel conduit has exhibited an extremely short service life. Steel conduit must be galvanized and be treated with a protective coating. Galvanized steel pipe wrapped with resin-impregnated glass cloth has been tested and found most satisfactory for underground work and when encased in concrete. In floor slabs, steel conduits should be encased with a minimum of 3 inches cover below so as to limit rusting due to moisture permeating up through the floor slab. Where steel conduit enters or exits concrete, or where steel conduit connects to terminating points encased in concrete, the conduit should receive for a minimum distance of six inches from the concrete, both interior and exterior, a heavy coating of an alkali-resistant coal tar base paint (MIL-P-15147).

(2) Aluminum Conduits. Aluminum alloy conduits, fittings and boxes may be used either indoors or outdoors, either exposed or concealed but not in concrete. Aluminum conduit shall not be embedded in concrete or in earth and shall not be used with either brass or bronze floor boxes.

(3) Copper Conduits. Data on copper silicon conduit is limited, but indications are that it is suitable for use in a tropical environment, except in concrete.

(4) Plastic Conduits. Plastic (PVC) schedule 40 conduits and fittings should be in accordance with Article 347 of the National Electrical Code and Federal Specification W-C-1094. In general, PVC should be used underground and where encased in concrete.

(5) Polyvinyl Chloride-Jacketed Galvanized Steel Conduits and Fittings. On piers and in other hostile environments where galvanized steel conduits are normally specified, PVC-jacketed galvanized steel conduits and fittings conforming to MIL-C-29169 shall be utilized. It may be used under piers and docks and locations exposed to weather. Korkap and Plasti-bond are some of the available product names. Other documents which form a part of the specification for the plastic coated galvanized steel rigid conduits and fittings are American National Standards Institute (ANSI) Standard C80.1, UL Standard UL-6 and Federal Specification WW-C-581.

(6) Nonmetallic Conduits. Plastic fiber, vitrified-clay, and fireclay-cement (soapstone) conduit and fittings may be used in underground ducts. Plastic conduit and fittings may be used where concealed in concrete within buildings.

(7) Security Conduits. Conduits carrying power for classified communications equipment and classified communications circuits must be installed in galvanized rigid steel conduits, with or without PVC jacket.

(8) Buried Conduits. All galvanized ferrous items encased or buried in concrete shall be coated with coal tar base coating conforming to MIL-C-18480. Aluminum shall not be buried in concrete. Conduits should be exposed or surface mounted wherever possible.

e. Exterior Power Distribution System. Guidance for the construction of both the underground and overhead distribution system is covered in NAVFAC TS-16301 and TS-16302, respectively, except as herein provided.

(1) Underground Distribution. Generally, power distribution systems should be designed for underground installation, funds permitting. If direct burial is utilized, the cables shall be protected from physical damage with route markers and plastic warning polyethylene tapes over the cables. Wood shall not be used for protective cover. Except for good engineering consideration, there is no special requirement for duct systems, except all ferrous items shall be hot-dip galvanized and coated with coal tar or paint as applicable in conformance with requirements of this manual. Direct buried cable should be cross-linked-thermosetting polyethylene or ethyl propylene insulated, tape shielded, and jacketed with PVC or neoprene. The tape shield shall be 10-mil copper half-lapped to give the cable a "rodent-resistant" rating. If voltage rating is less than 1,000 volts, the copper tape shield shall be omitted.

(2) Overhead Distribution. Damage report on 1976 Typhoon Pamela indicated that among 900 wood poles damaged and required replacement, 70% had underground termite damage in varying degrees.

(a) Poles. Wherever possible and applicable, use of prestressed concrete poles is recommended. If use of wood poles is necessary, they should be double treated with pentachlorophenol and ammoniacal copper arsenite (ACA) vice creosote to more adequately resist attack from subterranean termites. Wood poles should be limited to systems serving noncritical areas. The requirement for prestressed concrete poles is much more critical in typhoon areas than in other nontyphoon areas. Where wood poles are used, soil treatment shall be provided during backfilling. All checks and cracks in wood poles shall be protected and filled with a preservative grease of 10% pentachlorophenol.

(b) In typhoon areas, the following additional requirement to strengthen overhead electrical system is provided:

Concrete poles shall be designed against uprooting of the poles.

All wood poles shall be line-guyed and every fifth pole shall be guyed 4 ways.

(c) Pole roofs or caps should be provided for the tops of all wood poles. Prior to installation of the caps, the top of each pole should be given a 1/4-inch thick coating of a 10% pentachlorophenol grease and allowed to dry for a period of approximately 24 hours. Pole caps should be either neoprene manufactured for the purpose or sheet aluminum. The neoprene rubber should conform to ASTM D752. The cap shall have an outer coating of chlorosulfonated polyethylene rubber to resist sun and weather. The cap should be held in place using at least four aluminum nails having large heads. Aluminum caps should be made of alloy number 1100-0, mill finish, approximately 0.0085 inches thick, and 15 inches in diameter for Class 3 and larger poles, and 10 inches in diameter for Class 4 and smaller poles. The aluminum should be fitted over the top of the pole and nailed around the sides using at least six 1-inch minimum aluminum nails having large heads.

(d) Conductors. Either copper, aluminum, or copper-clad steel may be used for overhead distribution. If copper is specified, harddrawn is

preferable. The minimum wire size should be No. 6 AWG. Aluminum shall be AAC or AAAC. ACSR is expressly forbidden.

(e) Messengers and Guys. Messengers and guys should be either aluminum or copper-encased steel. The cable should be carefully installed. Abrasions and cut ends should be sealed with a solder coating.

(f) Pole Hardware. Pole line hardware and fittings should be silicon-bronze, stainless steel, copper-encased steel, or aluminum-encased steel. Dissimilar metals should not be used in direct contact or within 1/4-inch of each other.

(g) Guys. Guys for major or permanent antenna systems should be phosphor-bronze with phosphor-bronze turnbuckles or copper or aluminum-encased steel ("Copperweld" and "Alumoweld"). Hardware and fittings should be silicon-bronze, phosphor-bronze, or aluminum alloy. Anchors should be the precast concrete type, preferably with copper or aluminum-encased steel metal parts. The preformed type of guy grips or copper - or aluminum-encased steel ("Copperweld" and "Alumo-weld") are suggested as options to bolt-type clamps.

f. Transformer and Switchgear.

(1) Distribution Transformers. Generally, transformers should be padmount types and conform to the guidance provided in NAVFAC TS-16335, except as herein specified. The transformer shall be liquid-filled sealed type without the breather pipe or dry type totally enclosed self-cooled for less than 600 volt application.

(2) Switchgear. Switchgear should be totally enclosed and weather proof. All switchgear enclosures should include thermostatically controlled space heaters.

(3) Protective Shelter. In the tropics, due to the salt and moisture-laden air, all ferrous items, no matter how good the quality of the finish, are highly susceptible to accelerated corrosion when exposed to the weather. This is true with some noncorrosive materials such as copper, brass, bronze, and aluminum in certain types of application. Also, damage to the protective coating on equipment can be expected during routine operational inspection and maintenance of transformer and switchgear facilities. Furthermore, typhoon damage reports indicate that these exterior type installations are very susceptible to damage by flying debris. In view of the problems noted above, and in accordance with the recommended criteria for minimizing use of ferrous items exposed to the weather, no matter what the quality of the protective coating may be, pad-mounted transformer and switchgear installations shall be protected from the weather with a structural shed-type enclosure of either concrete and/or masonry. The design of the structure shall follow the criteria provided in this manual.

g. Grounding. In coral areas, ground rods shall be installed in drilled post holes backfilled with volcanic or other similar clay material. Use of water piping system for grounding should be avoided.

CHAPTER 12. DESIGN FEATURES AND CONSTRUCTION

Section 1. BUILDING FEATURES AND APPLICATION

1. **SCOPE AND GENERAL INFORMATION.** All the various types of construction materials available in CONUS are also available for use in a tropical environment. However, the corrosive and degrading elements in the tropics limit their use to certain building components and locations. This part of the manual discusses the application of material and building features, in the design of structures so as to augment their performance, increase service life of the structure, and minimize life cycle cost.

2. STRUCTURAL DESIGN.

a. **Materials.** Reinforced concrete, concrete masonry, and structural steel are considered to be the best all-around material presently available for structural design in a tropical environment as previously noted. Their application and use are recommended as noted hereinafter.

b. **Prestressed Concrete.** Prestressed concrete is considered one of the better materials for all-around structural application in columns, beams, and structural slabs. It is also an ideal product for power poles, piles, and sheet piles. There is no limitation in its application in the tropics.

c. **Precast Concrete.** Precast concrete panels are applicable for roof decks, wall panels, and decorative panels. Precast members have also been used for curbing, prefabricated manholes, precast covers, lintels, sills, casings, and fence posts. Sound engineering practice is the only limitation in its use in the tropics.

d. **Shotcrete (Guniting).** Shotcrete has limited use in new construction and repair work. Its quality and performance as a construction material is considered better than cast-in-place concrete in certain applications and is somewhat higher in cost. However, it should be emphasized that the quality and performance of shotcrete are critically dependent on the mix design, the competence of the nozzleman, the capacity of the equipment, the structural design of the shore facility, and the conditions under which it is gunned. Because its efficacy has proved to be erratic for reasons noted above, the placement of coral concrete by means of the shotcrete method is not recommended except for repair work, protective cover, lining of reservoirs and canals, and encasement of structural steel. The high adhesion to other construction materials is one of its better qualities. If its use is intended, necessary guidance is available in ACI Publications SP-14 and SP-14A and ACI Standard 506. It is not recommended for general construction in the tropics for reasons noted above.

e. **Masonry.** Concrete masonry unit construction is widely used in the tropics and sound engineering and architectural practices are the only limitation in its use. However, as discussed in this manual, exterior surfaces of building walls must be treated to minimize water infiltration.

f. Structural Steel. Structural steel is recommended for interior use and in areas well protected from the weather. Where there is an engineering choice between concrete or structural steel in exposed applications, the order of preference is prestressed concrete, cast-in-place concrete, and structural steel. All the protective criteria that normally apply and are discussed in this manual shall be applied in tropical design. For exterior applications galvanizing with a protective coating as specified in this manual is recommended.

g. Wood. Wood (timber) is not recommended for use as structural members. The exceptions are in the construction of temporary facilities and family housing projects outside of typhoon zones. It is noted that in the Philippines, Micronesian Islands, American Samoa, and other islands with indigenous populations, the life style and architectural heritage emphasize wood construction which blends into the natural environment of the area. Where this is found to be true, structural design should follow accordingly; however, the criteria discussed in this manual (regarding lumber) should be considered in the design.

3. STRUCTURAL AND ARCHITECTURAL DESIGN FEATURES. Air conditioning of buildings in the tropics requires strict adherence to criteria to control problems due to the high humidity. Close coordination with the mechanical branch in the selection of materials and detailing of structural and architectural features to ensure compatibility and maximum effectiveness of design is required. Also certain types of construction and design features and certain types of material are complementary. Such combined application of good design and quality material provides a synergistic system for longer service life to the structure. Some of these design features are discussed below.

a. Vapor Barrier. In selecting building materials, careful consideration shall be given to vapor barriers, paints, and other finishes with respect to vapor flow through the walls and roofs to preclude moisture accumulations and condensation within the building structure, reduction of thermal performance, and increased latent heat load in the space. The vapor barrier application and location shall be based on analysis of the highest vapor pressure differential and direction of vapor flow during the various seasons of the year.

b. Penetration Details. Infiltration through the building envelope shall be minimized by carefully detailing all joints, cracks, openings, and penetrations through walls and roofs to assure proper sealing and caulking.

c. Floor Height Clearance. Floor-to-floor height determination shall be based on space requirements for the installation of ducted air conditioning systems. Presently, floor height clearance for BOQ's and BEQ's is set by NAVFAC, therefore, NAVFAC approval for deviation is required.

d. Suspended Ceiling. Suspended ceilings should not be used when avoidable. When suspended ceilings are required, exterior walls above ceilings should be sealed carefully to preclude infiltration of moist air.

e. Closets and Bathrooms. Closets and bathrooms shall be provided with louvered doors to permit equalization of vapor pressure through moisture diffusion.

f. Eaves, Eyebrows, and Canopies. One of the best protective building features is the wide eave (4 ft. minimum) to protect windows, doors, louvers, and other wall openings from the weather. It also minimizes the occupants' discomfort during rains when closing of windows is not required, and the cooling breeze flows through the building. Depending on the design and location, the effectiveness of a wide eave can greatly increase the service life of the components protected. See Figure 2. Where air conditioning is required, the overhang conserves energy by shading the walls during the hottest time of the day. The width of the overhang is a compromise among geographic location, latitude, function, and architectural aesthetics.

g. Canopy. Protection of the entrance may be provided with a canopy or extended eyebrow as shown in Figure 3.

h. Recessed Doors and Windows. Where operational or functional requirements permit the recessing of windows and doors, such features should be included in the design of the building. One example is shown in Figure 4. Combination of eyebrow and recessing may be used where conditions are severe.

i. Baffles and Screens. The design of baffle and screen walls around doors and louvered openings should be based on operational needs. See Figure 5.

j. Termite Preventive Design. The battle against termite infestations shall be in three specific areas:

(1) Treatment of the soil under and around the structure.

(2) Treatment of all wood used in the structure.

(3) Design that provides adequate accessibility for inspection and maintenance are:

(a) Termite shields consisting of corrosion-resistant sheet metal. See Figure 6.

(b) Termite curbs made of concrete to facilitate termite inspection. See Figure 7.

(c) Where concrete slab-on-grade incorporates blockouts to provide entry for piping, conduits, etc., such blockouts shall be sealed with an approved type non-shrink grout.



FIGURE 2
Protective Eave and Eyebrow Over Windows

(d) Minimize cracks in the concrete slab on grade under interior walls by means of thickened section and added reinforcing steel, similar to the thickened section under exterior walls.

(e) Limitation. The utilization of any of the above designs depends on the degree of possible termite infestation. Knowledgeable personnel in the using activities should be consulted to determine final resolution of the matter.

k. Water Infiltration Through Masonry. Where building use and economical design permit the construction of exterior walls separate from the adjacent floor slab, the upper foundation elevation for the masonry walls should be at least a minimum of 3/4-inch below the elevation of the adjacent slab. This will prevent infiltrated water in the CMU cells from flowing under the first course of blocks and thence into the interior of the building. If properly constructed, the weep holes will funnel the water to the exterior. Where the footing for the wall is an integral part of the adjacent slab, the top of the footing area should be at least a minimum of 3/4-inch below the floor elevation. When an interior masonry wall butts against an exterior



FIGURE 3
Canopy Shelter Over Entrance



FIGURE 4
Recessed Doorway

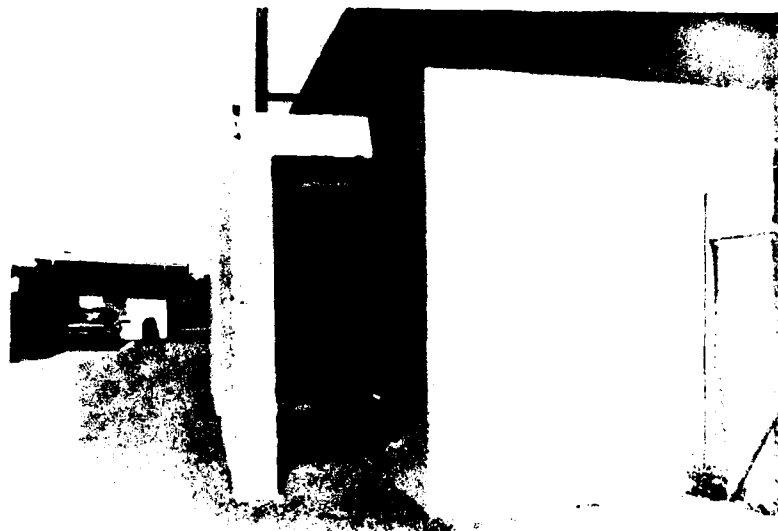


FIGURE 5
Protective Baffle

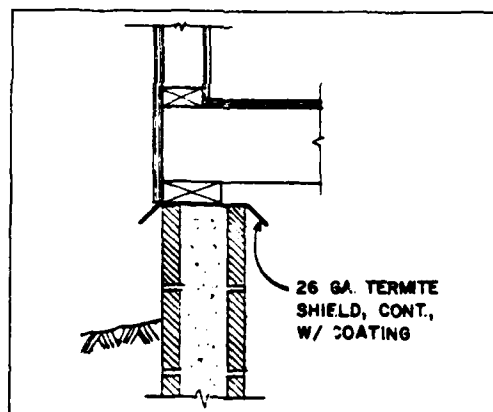


FIGURE 6
Termite Shield and Crawl Space

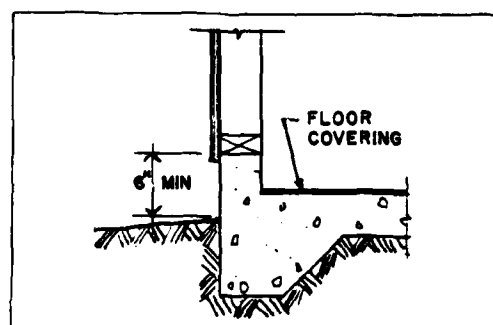


FIGURE 7
Concrete Curb

masonry wall, cutting the CMU to match horizontal joints may be avoided by lowering exterior wall CMU one-half the height of a CMU below finish floor, as shown in Figure 8.

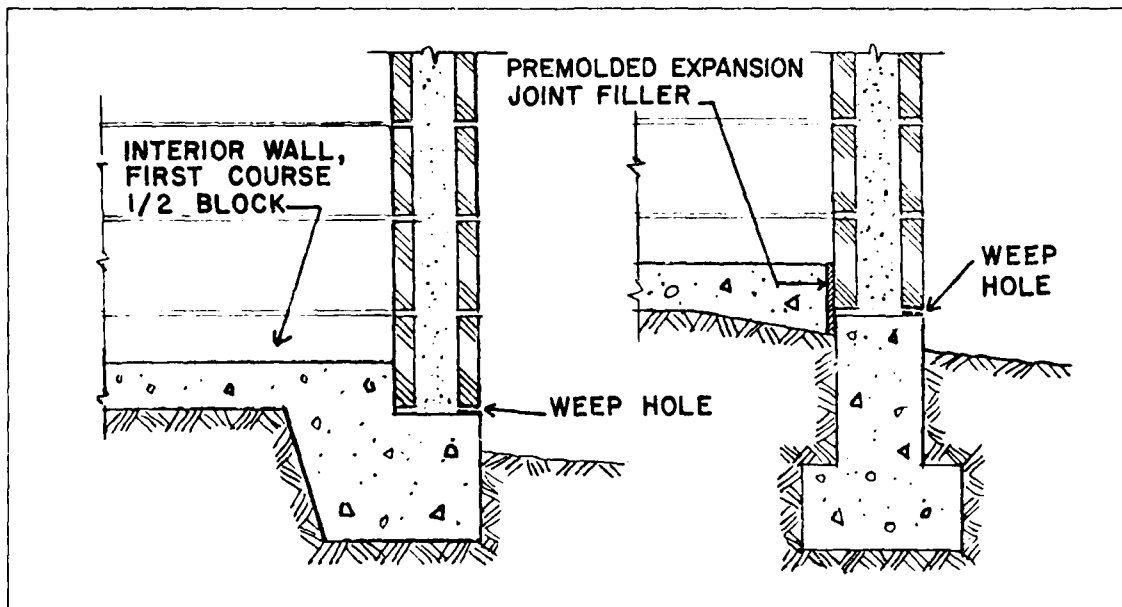


FIGURE 8
Depressed Block Wall Bases With Weep Hole

Section 2. TYPHOON-RESISTANT DESIGN

1. SCOPE AND GENERAL INFORMATION. A typhoon, for the purpose of this manual, is defined as any tropical storm with wind velocities in excess of 90 mph.* Normally, all tropical storms are accompanied by heavy rainfall which is driven horizontally by the winds. It is this winddriven rain against windows, doors, ventilators, walls, louvers, and roofs that has caused much of the costly water damage to structures and equipment. The adequacy of structural design to resist wind loads is not covered in this manual, except for secondary effects as noted hereinafter. The design factors discussed hereinafter should not be limited to typhoon zones if such factors will provide desired protection to structures in areas subjected to wind velocities less than 90 mph. In such tropical storm zones, designs and specifications shall provide for adequate protective features to minimize, and eliminate if possible, costly losses. Wind velocity data for most areas are provided in NAVFAC DM-2.

*The term "typhoon" is customarily used in the Pacific Ocean area to denote such tropical storm. In other areas, customary and equivalent terms are either "cyclone" or "hurricane."

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2. BUILDING COMPONENTS AND STRUCTURES. The building components and structures discussed in this manual regarding protection against typhoons are:

- a. Doors and windows
- b. Walls (constructed of concrete, wood, metal, or cement asbestos)
- c. Louvers and ventilators (fixed, mechanical, and gravity types)
- d. Roofing
- e. Materials (susceptible to water damage)
- f. Prestressed concrete poles
- g. Chain-link fence
- h. Structural components
- i. Protective coatings and paints
- j. Grading around buildings
- k. Utilities (Water, Sewer and Electrical)

3. CRITERIA DEVELOPMENT. "Lessons Learned from Typhoon Pamela," which is an analysis of the damage resulting from the typhoon that struck Guam on 21 May 1976, is the base from which the following design criteria was developed to minimize typhoon damages to shore facilities, and to either reduce or eliminate operational shutdown due to flooding of structures and equipment damage. In addition to the high winds, the second major cause of damage to equipment and facilities was water damage and flooding caused by the heavy rainfall accompanying the winds. Major breakdown of the utility systems (water, sewage treatment, and electric power plants) was by flooding. Therefore, the design of structures should provide adequate drainage, weather-tightness, and resistance to flooding, in addition to structural integrity.

4. DESIGN CRITERIA.

a. Area Grading. The area surrounding any building shall be designed to remove 27 inches or the maximum rainfall recorded for the area per 24 hours if available. Old buildings around new construction not designed to withstand typhoons should be upgraded or demolished.

b. Critical Water Supply, Sewage, and Electrical Systems. All critical water and sewage pumping stations should have standby power or be connected to a typhoon-proof power facility through underground service lines. This requirement should be included in the project scope. All electrical service and distribution lines to critically important facilities shall be installed underground if possible.

c. Weatherproofing. In order to assure maximum weathertightness, the design action shall consider the following:

(1) Minimize the number of exterior doors and windows and decrease, as much as possible, the size of window openings.

(2) Provide weather stripping on all exterior doors. Design doors to withstand the windload for the area as provided in DM-2 by increasing the size of hinge screws, increasing number of hinges or both, and provide auxiliary deadbolt or lockset with deadbolt.

(3) Utilize interior partitions in the structural design as shear walls to resist lateral forces as much as possible.

(4) Utilize concrete and CMU for major components. Concrete and CMU buildings, with concrete roof decks, have proven to be ideal for tropical areas which have been periodically struck by typhoons.

(5) In typhoon zones, wood construction (structural) should be limited to temporary buildings where termite infestation could weaken the structure and make it vulnerable to typhoons. Only treated lumber shall be used. Effective protection against termites and dry rot should be applied.

(6) Exterior Wall Louvers and Roof Ventilators. For design purposes, louvers, exhaust vents, and roof vents in typhoon zones shall be identified as to either of two types, based on function:

(a) Type 1 louvers that are required for possible operational use during typhoons, for example, such as in power plants, lift stations, A/C intake (medical, communication, etc.), and standby generator rooms. Type 2 louvers that may be closed or sealed during a typhoon, such as attic vents, roof vents, and certain type mechanical room vents. Type 2 vents should be operable type with effective weather-stripping which will not allow the passage of wind-driven water when louvers are in the closed position. Alternative methods for type 2 may be vertical baffles or shields constructed in front of fixed louvers to preclude entrance of horizontally-driven rain. Storm shutters, if considered, should be attached type and not removable. Type 1 vents should be designed with baffles or shields constructed in front of the fixed louvers to preclude entrance of horizontally driven rain. Baffles and shields may be constructed of either concrete or masonry. Where attic vents are required, the location should be in the soffit rather than fully exposed in the wall wherever possible to prevent entrance of windblown rain. The design of roof vents in typhoon prone areas is discouraged. Roof vents, if necessary, shall be enclosed within a protective structure or designed for sealing against typhoon winds.

(7) Sliding doors in housing units, when specified, shall be designed to withstand typhoon wind load and weathertightness shall be a prime requisite.

(8) Damages to structural steel buildings are usually limited to sheet metal roofing and siding that are blown off due to oscillation and tearing of the sheet metal at the fasteners. Design should include closer spacing of purlins and girts, and large head fasteners. Inadequate lateral

bracing may contribute to sheet metal failures. Design shall ensure adequate bracing.

(9) Steel buildings with sheet metal sidings should be designed with high concrete foundations or curbs to separate the steel from the corrosive influence of the soil.

(10) For ease of removal during a typhoon, carpet should not be glued to the deck. Water damage due to flooding can be minimized if carpets can be removed and rolled away.

(11) Built-up roofing, with double surface treatment and loose gravel swept off, should be used. (See Roofing Section.)

(12) Window shutters are recommended if they are designed to be secured in place and closed for typhoon conditions. Removable types are not recommended, except for operational facilities where special storage space for the shutters is provided. Hardware shall be stainless steel for moving parts and either anodized aluminum or exterior treated plywood panels with adequate coating system.

(13) Asbestos-cement board or shingles shall not be used for siding.

5. ELECTRICAL DISTRIBUTION SYSTEM. The design of electrical distribution systems for typhoon areas is covered in the electrical section of this manual.

6. TYPHOON DAMAGE REPORT.

a. Lesson Learned. The following excerpt from "Lessons Learned from Inspection Evaluation of Damages to Facilities Caused by Typhoon Pamela, 15 July 1976," is provided for background information on design against typhoon damage:

"The major mechanical equipment associated with the utility systems is housed in structures designed to withstand typhoon force winds. Four different ventilation methods for disposing of equipment heat are employed in these structures. The ventilation methods are:

"1. Fixed louvers on two or more sides of the buildings with no method of closure.

"2. Adjustable louvers on two or more sides of the building, providing weathertight closure.

"3. Mechanical ventilation through ducted, electrically-powered unit ventilators.

"4. Roof-mounted power exhaust fans.

"The uncontrolled entry of water into mechanical equipment space was either directly responsible for equipment becoming inoperable or contributed significantly to the time required to return the equipment to operation after shutdown for other reasons (primarily loss of electrical power). Where significant water damage occurred, the principal source of water entry was

through the ventilation system. The facilities affected, type of ventilation employed, and type of damage are as follows:

FACILITY	TYPE OF VENTILATION	DAMAGE
Piti Power Plant	Fixed louvers ventilating basement, roof-mounted exhaust fans on turbine deck	Flooding of basement
Tanguisson Power Plant	Power unit ventilators	No significant water damage. Cooling water channel silted up requiring shutdown.
Naval Station Sewage Treatment Plant	Fixed louvers in gas room and main sewage pump room	Water logged interior, miscellaneous damage.
Orote Power Plant	Closable louvers. Roll-up overhead doors.	No significant water damage. Remained in operation.
Naval Hospital Emergency Generator	Fixed louvers	Water drenched equipment unsafe to continue operation."

b. Analysis and Evaluation. A comparison of data shows that the only power plants which did not sustain significant water damage were the Orote diesel plant and the Tanguisson steam plant. Both plants were able to close off the ventilation to prevent intrusion of wind-driven rain.

c. Recommendations. All ventilation openings into mechanical equipment space should be provided with a closure system capable of preventing the intrusion of water in typhoon force winds. Such systems should be operable from within the structure so that the arrangement of open and closed vents can be changed as the direction of the wind changes with passage of the storm. This is a typical operational facility where removable shutters are acceptable, provided storage space is available.

d. Telephone System. Generally, the telephone system should follow the criteria provided for electrical system noted above.

7. WATERFRONT FACILITIES.

a. Mooring Buoys. Mooring buoys shall be designed with an anchoring system to resist typhoon wind and wave action.

8. AIR CONDITIONING SYSTEM. To minimize typhoon damage to air conditioning equipment, specifically that which supports operational facilities, the following measures shall be taken:

a. Fresh Air Intake. Fresh air intake shall be designed to prevent water infiltration through the application of operative louvers, protective screens, or other type of protective features.

b. Exterior Located Equipment. Condensers and other equipment shall be enclosed in protective concrete or masonry structure. The structure may be wall enclosure or leanto. It shall be designed to protect the equipment from damage by windblown debris.

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