THE FEASIBILITY OF USING PAPERBOARD AS A BASIC MATERIAL FOR HOUSING SHELTERS

A Thesis

By

ROSCOE PAUL THORPE

96 P

AF 33 608 1120

Submitted to the Graduate College of the
Texas A&M University in
partial fulfillment of the requirements for the degree of

MASTER OF ARCHITECTURE

May, 1965

Major Subject: Architecture

THE FEASIBILITY OF USING PAPERBOARD AS A BASIC MATERIAL FOR HOUSING SHELTERS

A Thesis

By

ROSCOE PAUL THORPE

Approved as to style and content by:

(Chairman of Committee)

(Head of Department)

Willard Strode
(Member)

F A Hirsch
(Member)

May, 1965

TABLE OF CONTENTS

ACKNOWLEDGMENT

The writer wishes to express his appreciation to a number of people for their advice, assistance, and confidence during the development of this thesis.

The United States Air Force, most notably Major General James B. Knapp and Colonel Gerrit D. Fremouw, should be thanked for making this graduate study possible and for continued encouragement.

The writer is indebted to Professor Edward J. Romieniec, Chairman of the School of Architecture, Professors Theo R. Holleman and Willard Strode for their confidence and encouragement. Associate Professor James Marsh III is due much thanks for his direct efforts as a partner in this study and for his continued advise and counsel.

Special credit is given to the Weyerhauser Company, International Paper Company, Container Corporation of America, and Jones Blair Paint Company for their aid and assistance in making this research work possible.

Finally, thanks are due to the writer's family; daughters Pamela and Deborah, who were considerate during the hours of work; to my wife Jean, for her patience, encouragement, hard work, and love during this endeavor.

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

In our rapidly changing world, under the impact of advances in science and industry, established methods have to be continuously reviewed and re-evaluated. This is especially true with regard to the technology of buildings and structures. Most research and advancement in building has been directed toward quality and permanency. If a building could be designed and constructed so that it would last for forty years, this was considered desirable. If the building life span was of shorter length, the building was considered to have a stigma of inferiority.

With our present day technology it is not too difficult to construct buildings that will last for comparable long periods, but this may very well be longer than their usefulness. There are many examples of buildings standing empty because they have become economically or socially undesirable. Perhaps we should take another look at structural durability as one of the major factors in evaluating a building. It is the conviction of the author that light weight, non-permanent, very low cost structures can also be of great usefulness in the world today.

It has become increasingly evident that a definite need exists for very low cost structures. The basic building elements can be accomplished by industrial procedures. Structures of this type need to be designed and of course, must fit specific requirements. Changes and improvements will also be necessary to meet the needs and wants of the people in particular situations.

The purpose of this thesis is to explore one building material--namely paperboard, and to design and construct elements of buildings using this material. These elements will be related to existing, present day requirements.

Thesis Objectives

The objectives of this thesis were divided into three major parts. The first objective was to explore and to show a need for very light weight, non-permanent, easily transportable, low cost structures. This phase of the research involved contact with government and civilian agencies in order to gather together and evaluate requirements for structures of this kind. It was determined that a vital need presently exists for this type of structure in many areas. Three of the major requirements are discussed in detail in Chapter II. They are as follows: (1) Housing Shelters for Underdeveloped Countries (2) Military and Civil Defense Requirements (3) Low Income Housing in the United States.

The second objective involved a broad consideration of the materials and of the elements of structure. One of the most challenging problems facing architects today is the ability to appropriately use building materials and to utilize the advanced construction methods available as a result of this industrial era. The advances in techniques and new materials have not simplified, but rather have complicated the architect's primary mission. An architect is first concerned with design. This is his job, but he must also show equal concern with the way in which the design is translated in terms of structure and materials. The architect must be able to integrate the basic architectural idea with new structural methods and with available materials that are produced by science and industry. The movement toward use of new materials and systems has been very slow and has not been fully exploited by the architectural profession or by builders.

The third objective of this study was to show by actual construction of prototype structures the potential advantages of paperboard material. Three structures were built in an attempt to emphasize different aspects of the nature of the paper material and its combination with other materials. It is hoped that these small structures will show some of the possibilities of design and construction with this particular material, and that this study will create new interest in construction with paperboard and related light weight building materials.

Approach and Research Procedures

Corrugated paperboard has been used for years in the manufacture of containers and packaging elements with little attention given to its potential as a structural material; however, with the availability of new glues, coatings, and impregnations, corrugated paperboard and other paper products are being used to a greater extent in the construction industry. For instance paper products are commonly being used for carton forms for slabs, column forms, and honeycomb cores for doors and wall panels.

In order to learn what had been done structurally with this material, a number of companies in the corrugated board industry and various research institutions were contacted regarding their uses of corrugated board. From the answers to many letters and a number of conferences with these people, it was determined that comparatively very little had been done. In the fall of 1963 the Research and Graduate Program of the School of Architecture at Texas A&M University started an investigation to determine the structural possibilities of paperboard materials.

Analysis of early research data gave sufficient encouragement to construct and field test several small roof elements. These research elements proved very valuable in evaluating glues, tapes, fastenings, and coatings. A number of these roof elements are presently being tested under normal weather conditions.

When this research was first started it was evident that very light weight structures were in demand, but the exact areas where the demand existed were not known. A number of possibilities were explored and it was later determined that in at least three separate areas this construction technique was timely. In fact, it was learned that an urgent requirement presently exists for structures similar to the type investigated. This information gave new meaning to the research project. It was learned that many thousands of dollars had been committed very recently by the federal government for investigation of similar light weight materials and construction techniques.

CHAPTER II

THE NEED FOR VERY LOW COST STRUCTURES

Before discussing the detailed necessities for low cost, non-permanent, industrialized structures, it should be recognized that this is not necessarily a new problem nor are the basic materials new. Instead, an attempt was made to develop a new structural application of available materials and to apply it to existing building requirements.

Housing Shelters for Underdeveloped Countries

In every area of the world where the population has been increasing there is an urgent requirement for very low cost housing. Traditional building techniques and housing policies are wholly inadequate to meet this ever-increasing demand for better housing. If the problem is acute in areas where building materials do exist and some sort of local building industry has already been established, it is even worse in areas where there are no satisfactory building materials readily at hand or where no local building industry has yet come into being.

Housing requirement for population increases. Man and society are presently faced with the great problem that the world population, which now numbers about three billion people, is growing very rapidly and in the year 2000 it will probably number more than five billion people. Man and society are also challenged by the disturbing fact that only one quarter of the world population is adequately fed and properly housed. The minority, therefore, finds itself facing an overwhelming force of poverty and unrest. These problems, in many expert's opinions, are not solvable.

It is not a simple matter to convince the 700 million people who live in relative comfort that they will have to sacrifice some of what they have to make the world habitable for all. These people must be persuaded not to concentrate solely on achieving greater prosperity for themselves, but they must be made to realize the poor of the world are ever more clearly exhibiting a strong desire for an existence worthy of mankind, and are beginning to see that misery need not necessarily be their lives.[25]

In order to understand the seriousness and the magnitude of this problem as it relates to world housing, a brief summary of the population status and prediction will be presented. More than two billion of the world's three billion people live in Africa, Asia, and Latin America. Asia alone holds 57 percent of the earth's total population, Africa and Latin America, another 15 percent. The estimated average annual rate of increase in population is over 2 percent in these areas. Latin America, with a growth rate of 2.5 percent, is the world's fastest growing major region. These rates compare with a world average of 1.8 percent and a rate of only 0.8

percent for Europe. Asia accounts for 60 percent of the world's annual population increase which is about 54 million. These and other facts are given in Table I.

Migration to the cities. The rapid growth of world population is even more dangerous because the greatest increases are occurring in the urban areas. This migration from the countryside to the city must be also considered in any study of housing. The urban populations of Africa, Asia, and Latin America are growing at rates that are almost twice as high as the overall population growth rates. The estimated rate of growth for urban Latin America is 4.2 percent per year. Urban Africa and urban Asia each has an annual rate of 4 percent. (European urban growth is at the rate of 1.6 percent a year.) These staggering high growth rates mean the addition of an increasingly larger number of people to the already overpacked, underhoused city populations.

Table II shows that in 1960 an estimated 275 million Africans, Asians, and Latin Americans were living in cities of over 100,000 people. (This figure is over 50 percent higher than the entire 1960 U.S. population of about 180 million.) By 1975 the number will more than double. Further, the proportion of the populations living in urban areas of 100,000 and over will be twice as high for Africa, almost twice as high for Asia, and about three-fifths as high for Latin America in 1975.[25]

Source: United Nations, Demographic Yearbook, New York, 1962

Region	Total population	Average annual rate of increase, 1950-60	Years to double population
	Millions	Percent	Number
World	3,115	1.8	39
Africa	267	2.0	35
Asia	1,747	1.9	36
Northern America	206	1.8	39
Latin America	216	2.5	28
Europe	433	.8	87
Oceania	17	2.4	29
U.S.S.R.	221	1.7	40

TABLE I

World and Continental Population -- Mid-1962 Estimates

The figures in Table II explain why so much attention is directed to the urban housing situation and especially to the shantytowns near the large urban centers. There is no doubt that problems are evident in the rural areas, but the urgent problem is in and near the great centers of population. A selected number of examples are described below:

Bombay. The population of Bombay grew by almost 70 percent during 1950-60. About one-half of the population lives in substandard housing and a large number live on footpaths. Bombay's slums contain over half a million persons living in 9,000 dilapidated units. Another million live in 200,000 single-room tenements scattered over the city. In some cases 7 to 10 persons, consisting of two or three families, share one room.

Calcutta. With a population of nearly 6 million, Calcutta is one of the largest cities in the world. Between 1950 and 1960 Calcutta's population increased by 2.3 million.

About one-fourth of the total population lives on one-eighth of the city's land which constitutes the Calcutta slums. Nearly two-thirds of these slum families have no water supply and are without proper lighting or ventilation. In some cases, as many as 45 persons share one latrine.

Hong Kong. A population of 2.9 million, increasing at a rate of 4.1 percent a year, gives the island a density of over 7,000 persons

Source: Urban Land Institute, World Urbanization Bulletin 43, April 1962

	Population in places 100,000 and over (millions)	As percent of total population	Population in places 1,000,000 and over (millions)	As percent of total population
Year 1960:				
Africa	20	8	6	2
Asia	204	12	102	6
Latin America	51	25	25	12
Year 1975:				
Africa	48	16	12	4
Asia	486	22	221	10
Latin America	118	39	61	20

TABLE II

Estimated and Projected Urban Population, by Size Groups, for Africa, Asia, and Latin America, 1960 and 1975 per square mile. In 1957 a survey of regular housing showed that 79 percent of the households shared common facilities. About 40 percent were living in "cubicles, bedspaces, cocklofts, and on verandas." Only 7.5 percent had a living room not used for sleeping.

The new resettlement blocks provide low-rent accommodation averaging 24 square feet per person.

Rio de Janeiro. By 1960 Rio's population had added nearly 1 million people to the 1950 total of 3 million. In 1950 Rio's slums, known as "favelas", contained about 14.3 percent of the population. A 1948 survey showed that two-thirds of the "houses" were worth less than $108. Three-fourths had no toilets and about 90 percent had no piped water.

Mexico City. The population of the federal district surrounding Mexico City grew by 160 percent between 1940 and 1950. The city proper grew by 53 percent during the same period.

A citywide housing survey in 1952 showed that 34 percent of the population lived in "turgurios" - one-room apartments opening on a courtyard or passageway. Another 11 percent were living in rented "jacales" - shacks made from scrap materials. The jacales had about 34 persons per toilet but most of the toilets were out of order, and the jacale dwellers used the waste land around their shacks.[25]

Table III shows the overall housing needs of the critical areas of the world.

Economic, social, and political. The United Nations, the Agency for International Development, and the other assistance organizations are faced with the immediate problem of helping millions of people to obtain even the barest kind of shelter. Besides lacking suitable building materials and an effective industrial organization for the production of dwellings, every underdeveloped country has a housing problem that is further complicated by the fact that the people who are to obtain such basic shelters do not constitute a housing market. In most cases they have no money to pay for any kind of house or shelter. Their housing, therefore, has to be provided almost completely by their governments at the lowest possible unit cost so that the available funds can be stretched to satisfy as many people as possible. One promising solution to this emergency problem has been the establishment of government-aided self-help housing improvement projects.

Such emergency projects, although they are necessary and desirable, have shed some confusion in the minds of many people and governments as to the true nature of the housing problem. Too often a housing project is undertaken because of political expediency or for humanitarian reasons, and its potential as a capital-producing resource is overlooked. This, no country with a shortage of capital

Source: United Nations, World Housing Conditions and Requirements, July 1962

(In millions of dwelling units)

	1960	1975
Due to population increase:		
Africa	0.84	1.50
Asia	5.30	9.40
Latin America	1.10	1.70
To eliminate the deficit or shortage in 30 years:		
Africa	.73	.73
Asia	4.80	4.80
Latin America	.60	.60
To replace the stock:		
Africa	1.03	1.03
Asia	7.10	7.10
Latin America	.90	.90
Total new housing needed:		
Africa	2.60	3.26
Asia	17.20	21.30
Latin America	2.60	3.20
Total	22.40	27.76

TABLE III

Estimated Annual Housing Needs in Africa, Asia, and Latin America, 1960 and 1975 or credit, (as is the case in the underdeveloped countries) can afford to do. In other words, the shortage of housing should not be thought of as a national liability; but, on the contrary, as an opportunity to develop a new asset for the national economy.[23]

It appears then that a possible solution to this critical housing problem might be a combination of the latest technology to produce building components in industrial factories, and self-help by the people themselves to assemble the unit on the site. If this is true, then there must first be an introduction and development of new production techniques. An up-to-date building industry and an up-to-date housing market, in the true industrial sense, will have to be created in each country if up-to-date dwellings are to be turned out in sufficient quantities to meet the ever-increasing demand. This approach will probably result in the creation of entirely new forms of housing, quite unlike the traditional forms.

There is a danger in setting the development sights too low. Too often the available resources of a country are evaluated on the basis of their immediate applicability, without thought to the greater benefit that could be obtained through a long-range program of integrated national development. Too often a lower-standard imitation of what has already been established in a more advanced country is accepted as the immediate housing goal. The fallacy of this approach is that it tends to perpetuate a position of relative underdevelopment; it does not stimulate new development of a truly dynamic sort.[23]

A more promising approach is to try to resolve the problem of national development in each country through continuous evaluation and re-evaluation of all the resources, both human and physical, which may become available to that country, externally as well as internally.[25]

A great amount of study and research has already been done to try and find a material and a method that would satisfy the requirement of prefabrication and be adaptable to assembly by unskilled people. Many materials including adobe, plywood, plastics, and metals have been investigated. In the last two years the United States government has sponsored a detailed study regarding the use of foam plastics. The use of foam plastics may be valid where a chemical industry is available, but if the chemicals are not readily available, the potential housing units might not be available for many years in the future.

Paper and corrugated board materials are products of industries presently existing in many areas. The raw materials are also close at hand in most parts of the world. The next chapter of this report will deal with the details of producing elements of housing from basic paperboard materials.

<u>Self-help program</u>. The idea of aided self-help for housing

is brought up at this point because of the requirement to keep the cost of a housing unit as low as possible. As pointed out previously, the housing market we are speaking of consists of families with extremely low incomes. In many cases these people are familiar with self-help because they built the shacks they are presently living in; they built them of muds, crates, straw, cardboard, and rusty sheet metal. In most cases these shacks were built on somebody elses land, without utilities and without any pattern of planning. An organized program developed through careful study could possibly provide planning, land, utilities, and components of buildings. This kind of an effort might yield a great many housing units and accommodate a large portion of the total requirement. The Economic Commission for Latin America has indicated that 2,625,625 dwelling units will be required annually by 1975.[25] The most that can be hoped for is to create some semblance of order in the chaos of the existing shantytowns.

The idea of self-help in combination with aid from government or private industry is not new. Modern self-help housing can be found in at least 64 countries around the world including such unsuspected places as France, Sweden, and Indianapolis, Indiana. These programs vary from maximum contribution, when the families provide all the labor that is necessary to build the houses, often some raw materials, as well as some money; to minimum contribution, when only supporting labor or material is added to that of a contractor's work. Traditional self-help is, of course, maximum contribution.

Results vary considerably under both types, and for every successful project, a comparable failure can probably be found. This is true for a multitude of reasons, and only recently have surveys in Asia and Africa begun the task of analyzing these projects objectively. The successes in Puerto Rico, Senegal, and probably Taiwan and Indiana, to name a few, are outstanding in their low cost, high building standards, and community spirit.[25]

Military and Civil Defense Requirements

Military requirements for shelter units. The policy of the United States in recent years has been to increase responsibility of the military forces in all areas of the world. Many of these operations have been developed to provide a fast reaction to any emergency any place in the world. These forces are sometimes large components of men and equipment or maybe only a small group sent to accomplish a special mission. Many times these short emergencies turn into extended stays. In all cases there is a major problem of housing men and equipment on a temporary basis.

A recent article in the Military Engineer, by an officer in charge of the Strike Command, indicated the importance of thinking in terms of light weight structures. "The planning officer must be completely familiar with all equipment and personnel requirements of the operational area. The limitation on available airlift deny the engineer planner the luxury of included safety factors of men, materials, and equipment. He must think in terms of the mobility of every item required, including shelters for personnel and equipment".[26]

The United States Air Force Director of Civil Engineering has recently organized a top-level emergency organization known as the Base Engineer Emergency Force.[31] This is a reposture of the Civil Engineering Force and has been set up to respond to emergencies related to the Air Force, any place in the world, whether they result from acts of aggression or from natural disasters. The new force reflects the complexity of todays sophisticated transport systems. It is designed to be a complete self-supporting unit, which will include power supply, water purification, housing shelters, and all requirements needed to complete the job. The entire unit is organized to be moved in presently available aircraft.

The United States Air Force has expressed interest in the light weight, packaged, paperboard shelter unit developed under this research project. A more complete description of this shelter unit follows later in this report.

Housing relief for disaster victims. Since 1951 the Housing and Home Finance Administration has had under its jurisdiction at least 1000 units of temporary housing of a mobile or portable character. These units, authorized by the Defense Housing and Community Facilities Act of 1951, have been the subject of a great deal of discussion over the years. The physical characteristics of the units have changed, but for the most part they have been conventional trailer houses. The hearings before the United States Senate, Sub-Committee on Housing, in February, 1956, reveals some of the great difficulty encountered when conventional temporary housing or trailer houses are used as disaster housing. The original cost, cost of storage, and deterioration are major factors, but transportation to the site of the disaster presents the greatest problem. Senator Bush's statement, before the Sub-Committee on Housing, makes the situation quite clear:

> We were up in the Naugatuck Valley yesterday, Mr. Commissioner, and in the town of Naugatuck there was a block of I would say 30 or 40 temporary houses that were put there, but they were just put in there recently. They were occupied early this year, in January. That was 5 months after the first flood, or 3 months after the second flood hit that area. The result is there were only about four houses of that block which were occupied in the little town of Naugatuck.
>
> I found that similar experiences were had over at Putnam and Winston, Conn., where belatedly these houses were moved in. I asked the mayor there why there was so little use that had been made of these and he said because they came too late. Adjustments had been made in one way or another by that time, and families had moved in with other

> families, or with relatives, or made some other disposition. The result was that these little places were mostly unoccupied. There was only about ten percent occupancy, I would say.
>
> The suggestion that Commissioner Slusser makes about mobile housing I think is the answer to that. When you need emergency housing after a disaster, you need it right away and not a month later, after you have had a chance to adjust. I think we should revise this bill so as to make it mobile housing.[20]

It would appear that a packaged, air transportable housing unit similar to the one proposed by this research might have great possibilities in a situation brought about by a disaster to the homes of people. The corrugated paperboard shelter unit would be low-cost, packaged, easy to store, transportable, and simple to assemble.

Low Income Housing in the United States

There is not much doubt that the housing situations for all groups in the United States has improved over the last decade, but the goal of the Housing Act of 1949 which states "a decent home and a suitable living environment for every American family....." has certainly not been met. We have many thousands of families living in urban slums and in shacks on the fringe areas of our cities and towns. The major reason these people lack adequate housing is that they are poor.

A great deal of help has recently come from the federal government to ease this critical problem, but most of the assistance has been directed to the poor in the central areas of the cities. There is not presently a workable program to assist the very poor families who live in run-down shacks in the suburbs of our cities and towns. In many cases, especially in the South, these people are members of minority groups. It follows that any large-scale improvement in their housing conditions involves either a rise in the level of income of the minority groups or more subsidized housing.

Thus, the poor housing of minority groups is part of the total fabric of economic and social disadvantage. An increase in income involves such significant and extensive changes as greater equality in educational opportunities, greater equality in occupational opportunities, greater equality in remuneration for work; in short, nothing less than the extensive revolution would likely produce equality for the minority groups in all spheres.

Greater subsidy for cheap minority housing, in one form or another, is perhaps a more reasonable immediate prospect. Thus, one specific change that would benefit minority groups would be measures to make mortgages on cheaper houses more attractive to lenders.[9]

The public housing programs have been successful in certain respects, but for the most part they have been too few and too expensive.[2] What seems to be required is a minimum housing unit priced low enough to be available for the many thousands of families in critical need. New materials and construction techniques may be the answer. The light weight, low cost corrugated paperboard structures of this research project could very well contribute to a program of this type.

The solution of this fringe area housing problem represents a real challenge to citizens of every community. Private enterprise has a great responsibility; the local and federal government must certainly be concerned. A possible approach might be a low cost manufactured component house, subsidized by the government. This unit might be furnished under a special program and erected for the most part by the owner occupant. This self-help idea would be similar to that proposed early in this report.

CHAPTER III

AN APPROACH TO STRUCTURE

The use of paperboard as a basic structural material is apparently a relatively new development. A se [illegible] ilable literature revealed very little of value in published [illegible] it quickly became apparent that the only way to obtain any worthwhile information would be to design, construct, and test elements of structures. The research was planned to create interest in the structural possibilities of this material.

The project objective was not to design a house, or a building, which would encompass the various mechanical and related services, but instead to investigate paper materials for their potential application to housing structures. Thus, the shelter aspect of a dwelling unit was abstracted, and the end product for investigation became the basic elements of a structural system. All advantages of the material were kept in mind throughout the research. The advantageous weight-strength ratio, ease of fabrication at low investment, and transportability were major factors considered. Some of these characteristics were explored in more detail than others.

Materials and Properties

From the old-fashioned fluting iron and the meshing of two gear-like rolls grew an industry that has played an important role in mass production, mass merchandising, transportation, and sales. Imagine a supermarket operating without the corrugated package in this day and age. A sheet of fluted paper used in hatbands and for carpet backing was the first step, the second was the addition of a flat sheet of paper to the flutes which developed into flexible, protective packaging for lamp chimneys, bottles, and other fragile glass items. This was called single-faced corrugated. By the addition of another facing, a box blank became a possibility. This then became known as double-faced corrugated board. Today many types and sizes including triple layered board are available. The numerous types of the facing materials are manufactured for varied uses. The core of the board may also change in type of flute, thickness, and treatment of material.

The paperboard industry has developed rapidly since 1894 and is now a highly mechanized system capable of producing 600 lineal feet of corrugated board per minute by one machine. Roll stands have been mechanized; corrugated rolls are chrome-plated; drying capacity has been added; adhesive applicators have been refined; the paperboard is pre-conditioned with steam jets and heated on rolls before the actual corrugating operation starts. Multiple head slitters and scorers have been developed to cut sheets to proper widths and put the long scores into the box blanks. Duplex cutters are used so that two different lengths of box blanks can be cut accurately.[34]

Production engineers questioned have stated that the production of housing components as suggested by this research would not be far different than some of the operations presently being accomplished in existing corrugated container plants. With very little additional machinery a corrugated container factory could be readied to manufacture paper wall or roof panels for housing units.

There are presently some paper companies engaged in the production of products used in the building industry. Most notable are the production of insulation and hard board. A few companies are making a variety of paper forms for concrete work. A great deal of research has been done with sandwich wall panels using corrugated or honey-combed paper as a core material. These sandwich units have been almost entirely a combination of paper, and wood or metal. This material will be discussed in greater detail in the next chapter.

Moisture treatment and waterproofing of the corrugated paper are very important considerations of this research. Only a few of the treatments were investigated. Tests indicate that a resin treatment of about 15 percent by weight provides additional strength under wet conditions and makes the paper resistant to attack by decay fungi. At this resin content, cores made from this paper retained 60 percent of their dry compressive strength, when soaked in water, and 90 percent as much tensile strength as that of dry untreated paper.[18] It has been found that silicate clay mixtures also improve the moisture resistance of the paper. Waterproofing the exterior surface of the paperboard can be accomplished by a number of methods, the choice depending on the use. The application of paraffin, lacquer, wax emulsions, and asphalt are all possibilities. Synthetic rubber systems of neoprene and hypalon appear to offer great possibilities. The hypalon system, with glass fiber reinforcing, was used on one of the structures built under this research project. Details of this waterproofing system will be outlined under the description of the project.

Adhesives and tapes are other materials important to structural work with paperboard. In the early years of the corrugated paper industry, starch paste was used as a bonding material between the core and the facings. Later, sodium silicate was used almost entirely because of the speed of drying. Most recently starch adhesives, with modifications, have again become the most used. Water resistant adhesives have been developed which use starch as a base material and additive resins such as urea formaldehyde. Polyvinyl alcohol is also being used as an additive for starch glues. The paperboard researcher has plenty of freedom when it comes to making a choice as to the type of tape to be used. Some of the types available are: (1) Plain 40 lb. kraft paper tape (2) Plain 60 lb. kraft paper tape (3) Clay filled cloth tape (4) Paper backed cloth tape (5) Plastic tapes. Of the tapes investigated under this research project, the plastic tape known as "Tedlar" proved most useful. This tape is expensive, but has many advantages; it is tough, smooth, chalk-resistant, and easy to clean. Application of this tape as a continuous hinge in a fold-up paper structure has been tested successfully.

The introduction of wood as a panel joining or edge material is a requirement in many designs with paperboard. The wood used can be any species available, although a wood such as cedar or redwood seems to be most advantageous. It is very possible that the wood members could be replaced by a solid paper section if production facilities for the paper were available. In certain applications, it may also be advantageous to use light weight wood members as stiffners for wall and roof panels.

Design and Construction Methods

Engineering design procedure with corrugated board is similar to that with other structural materials. Standard engineering principles and formulas apply, after working stresses have been selected. Because this is a built-up material, certain weak points are inherent. Some of these areas of weakness have been discovered through the construction and testing of simple elements of the buildings.

From a standpoint of structural and performance requirements of corrugated paperboard, at least five criteria must be considered. These are strength, stiffness resistance to surface indentation, insulation, and durability in the sense of long-term service. These five characteristics were given particular attention in this research. Other features are also important, such as acoustical properties, surface appearance, ease of maintenance, and resistance to decay, termites, and fire.

Extensive tests of paper honeycomb panels at the United States Forest Products Laboratory, and the results of the investigations of this research, show that it is possible to design light weight sandwich panels with paper honeycomb cores that generously exceed the usual criteria of strength and stiffness for roofs, walls, and floors. Table IV shows the properties of several types of core materials used for wall panels. Table V gives some indication of the stiffness and the strength of typical wall panels tested at the Forest Products Laboratory. Resistance to surface indentation is readily obtained or controlled by the characteristics and properties of the facings.[18] In the case of paper being used as a facing material, the toughness can be improved with application of glass fibers embedded in the surface coats of the waterproofing material.

Acceptable insulation is inherent in the type of core used in the

Source: United States Forest Products Laboratory, Madison, Wisconsin

Designation of core	Type of core	Weight of assembled core	Compressive strength	Shear strength
		P. cu. ft.	P. s. i.	P. s. i.
A	Paper, corrugated	1.64	30	28
B	Paper, corrugated	2.58	63	74
C	Paper, honeycomb	1.76	95	97
D	Paper, honeycomb	3.96	360	306

Core A: Corrugated paper with flutes perpendicular to the facings, 30 lb. paper (ream weight of 30 pounds--24 by 36 inches--500 sheets), 5% resin treatment.

Core B: Same as Core A, but using 50 lb. paper, and 15% resin treatment.

Core C: Expanded honeycomb paper, 60 lb. paper, and 20% resin treatment.

Core D: Expanded honeycomb paper, 125 lb. paper, and 35% resin treatment.

TABLE IV

Properties of Several Types of Honeycomb Cores

Source: United States Forest Products Laboratory, Madison, Wisconsin

Paper Core type	Facing type	Adhesive type	Stiffness Deflection inches	Stiffness Deflection span ratio	Strength
Corrugated paper	1/4" Hard board	Phenol-resorcinol	.214	1/450	315 psf
Corrugated paper	1/8" Plywood	" "	.141	1/680	325 "
Exp. honeycomb	1/4" part. board	" "	.320	1/300	121 "
Exp. honeycomb	1/4" Plywood	" "	.125	1/770	251 "
Exp. honeycomb	1/10" Paperboard	" "	.306	1/315	118 "

Notes: Test panels were 3" thick--Test spans were 90" long.

Tabulated values show the equivalent uniform loads at failure, which exceeded by many times the design load of 20 pounds per square foot. Tests were made by supporting the panel on rollers near the ends and slowly applying the load at the quarter points. The results of the tests shown in the table are before exposure to the weather. Very little change in stiffness and strength was noted after exposure to the weather for periods from one to five years.

TABLE V

Bending Tests of Sandwich Wall Panels

panels. The overall "U" value of a sandwich panel $2\frac{1}{2}$ inches thick is equivalent to a conventional wood framed wall with $\frac{1}{2}$ inch blanket insulation. If it is desired to improve the "U" value of roof or wall panels, this can be done by increasing the thickness or by reducing the size of the individual cells.

Durability over a long period of time should be considered, but is not of utmost importance considering the proposed limited use of the shelter units. Plywood sandwich panels produced at the Forest Products Laboratory have been in place in one experimental housing unit for 15 years. Paper faced panels have been in use for about five years. These panel elements have been under severe moisture conditions for this period and have not deteriorated. Improvements both in adhesives and assembly techniques should extend the durability of panels even more.

The element of quality control in the construction process is of great importance. Good bonding of the facing to the core is necessary to produce a structurally sound sandwich panel. Some of the elements constructed under this research have not been entirely successful because of this factor. The construction of a sound unit should not be difficult in the factory if careful assembly and quality control methods are followed.

Feasible Structural Elements

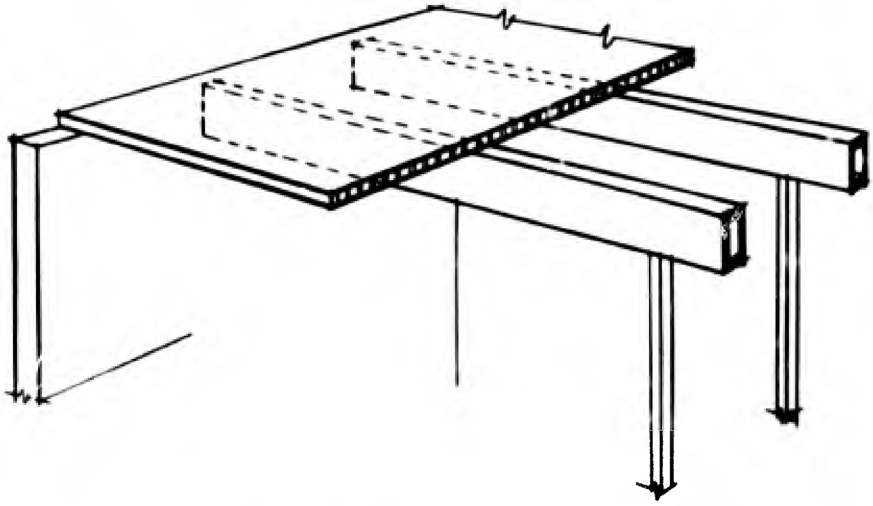
This section of the report contains descriptions and sketches showing some of the structural elements that could be advantageously constructed using paperboard as a major material. Some of these units were successfully constructed.

Beams and frames. (Figure 1) Box beams or frames are structural members with high strength-to-weight ratio that could be developed to span distances up to 50 feet. They consist of two or more vertical corrugated board webs laminated to lumber flanges. Vertical spacers would have to be installed at regular intervals along the beams length to distribute the loads and to prevent buckling. The corrugated webs should be securely glued to the flange members. The investigations in our research laboratory indicated that corrugated paperboard is not especially suitable to these members because the bending stresses are relatively high.

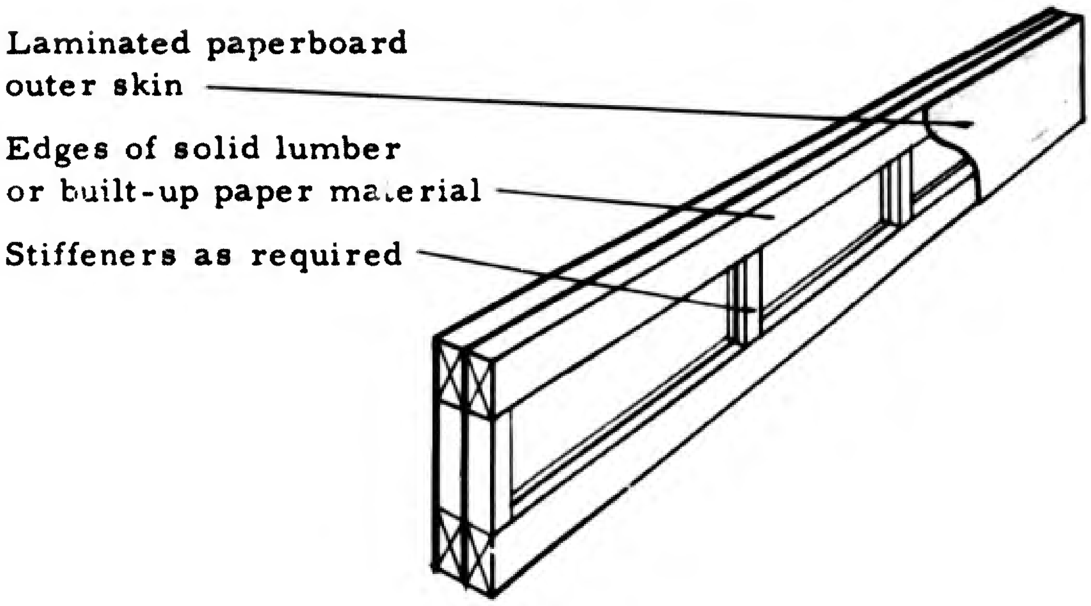
Roof and wall panels. (Figure 2) A great amount of research has been done by the Forest Products Laboratory concerning the construction and performance of sandwich panels using corrugated board or honeycomb paper as a core material. Facing materials tested were plywood, metal, cement asbestos, and paper. Thickness of these panels was from one to three inches and sizes, generally, about three feet by eight feet. The following statement from the Forest Products Laboratory report sums up the potential of these

FIGURE I

Box Beams of Paperboard



Beam System



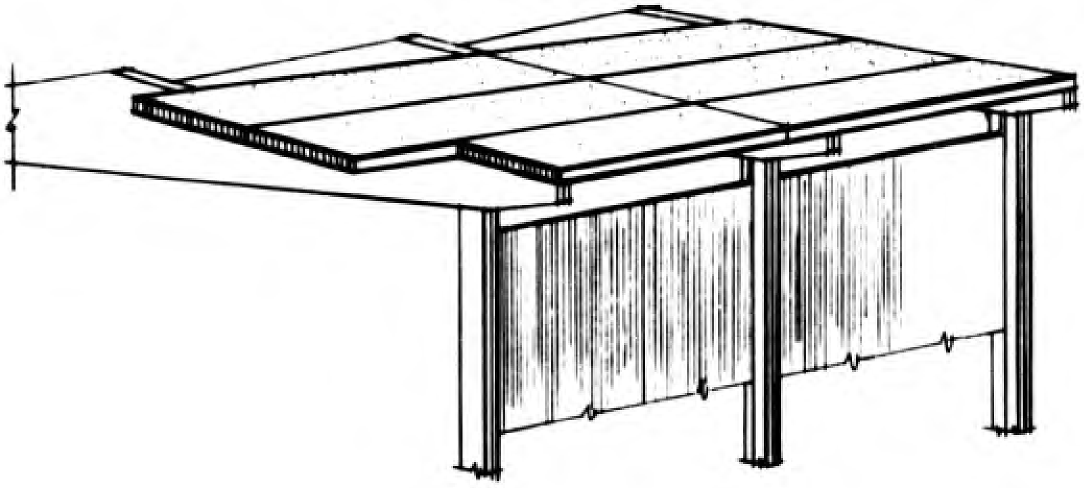
Typical Beam

FIGURE 2

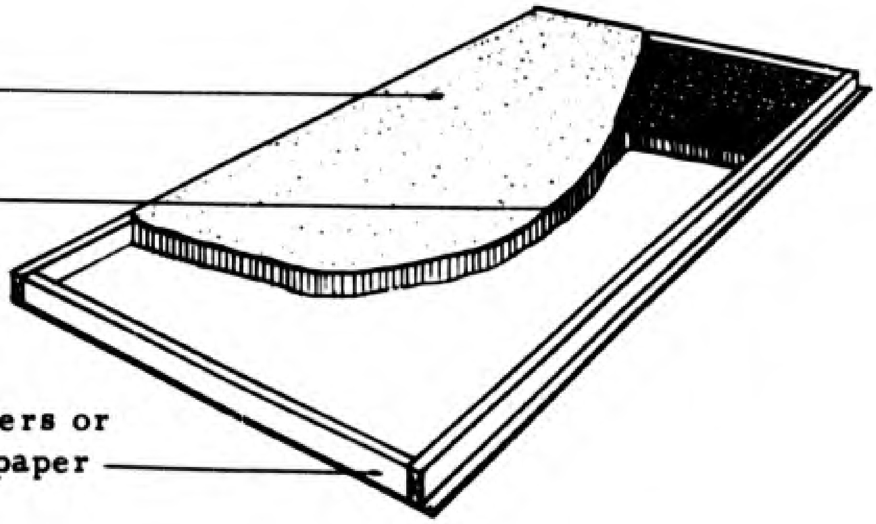
Sandwich Panels

for

Wall, Roofs and Floors



Panel System



Typical Panel

panels. "Bonding of paper honeycomb and corrugated cores between thin and strong facing sheets results in sandwich panels that are becoming increasingly important for structural applications. The panels are strong, stiff, light, and economical of raw materials. They can be made by processes that lend themselves to mass production from materials that are produced in large volume."[18]

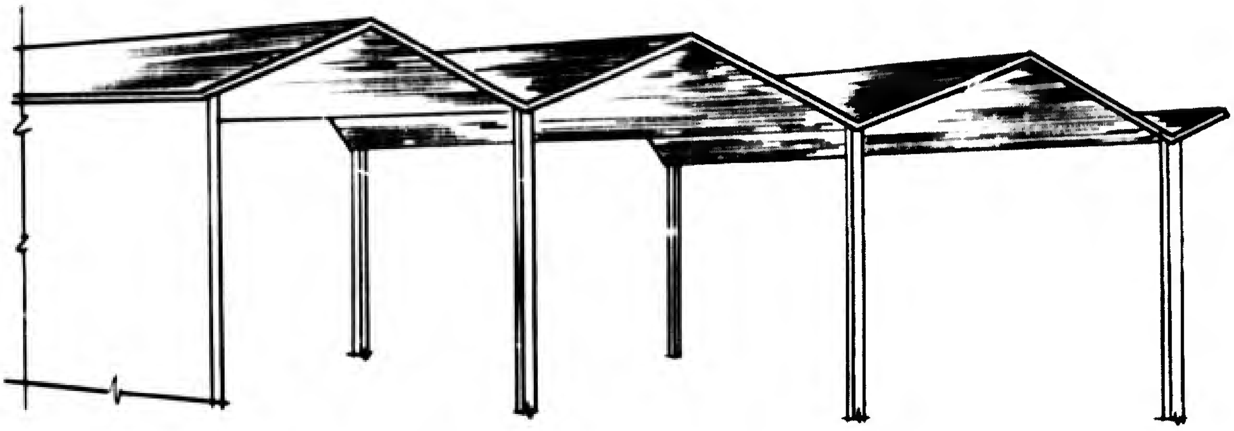
Folded plate roof panels. (Figure 3) These basic units are very similar to the sandwich panels described in the previous paragraph. A stressed skin panel could also be used which would depend on a frame with stiffners and a paper facing skin. In this roof system two plates actually lean against one another at the ridges and when properly anchored at the valleys, support great loads while spanning long distances. A system of joining the panels has been tested. There are many possible variations within the framework of the folded plate. The most important factor is the nature of the folds. The relationship between their height and pitch and span determines the rigidity and strength of the structure. This combination of roof panels affords an excellent opportunity to design a structure that can be folded and packaged for air shipment.

Curved panels. (Figure 4) Curved panels or segmental shells are actually sections of a cylinder. When placed side by side to form a roof their action is very similar to the folded plate. The curved panels could be constructed with lumber stiffners and a

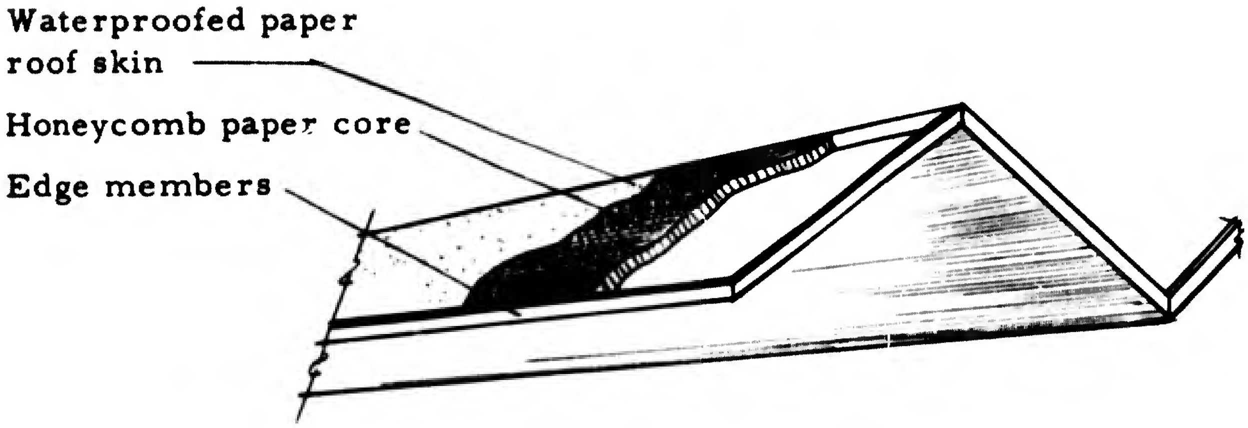
FIGURE 3

Folded Plate Roof

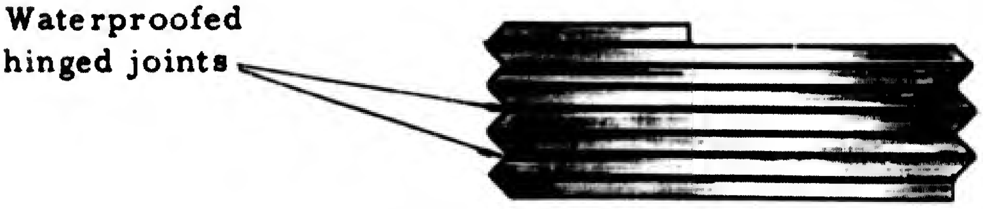
Using Paperboard



Roof System



Typical Panel

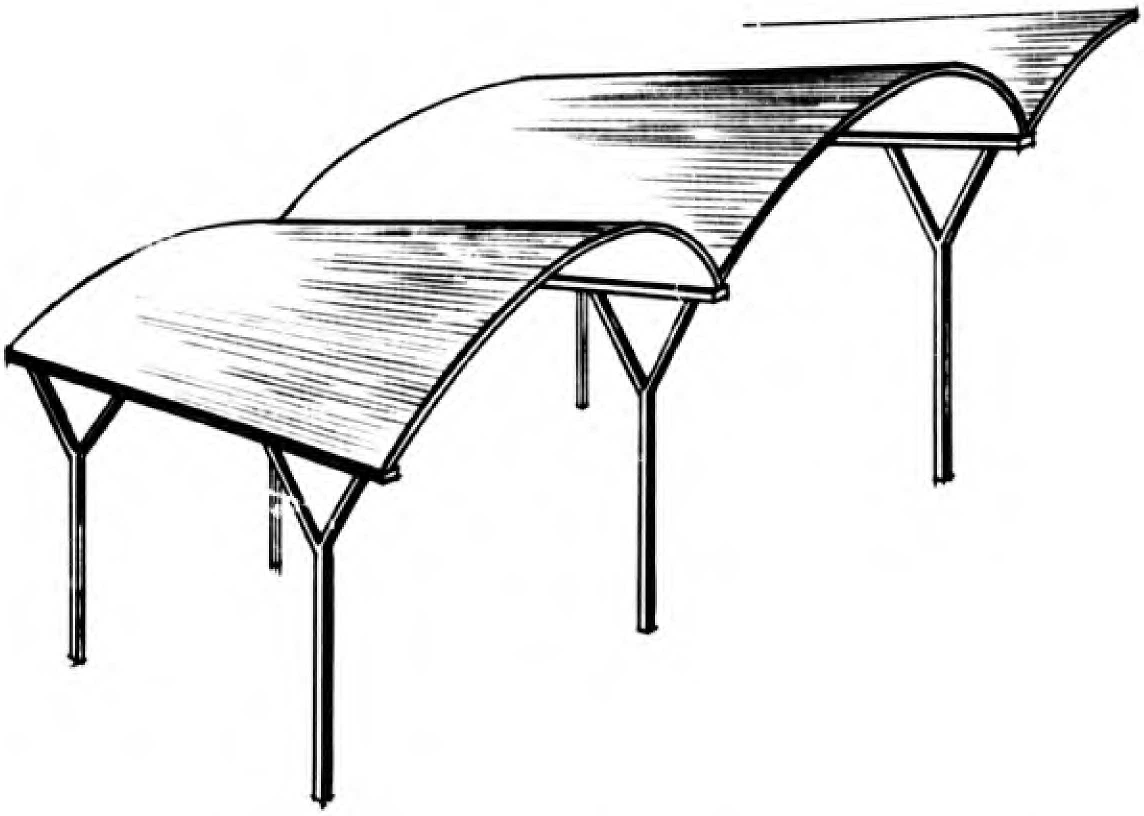


Stacked Panels

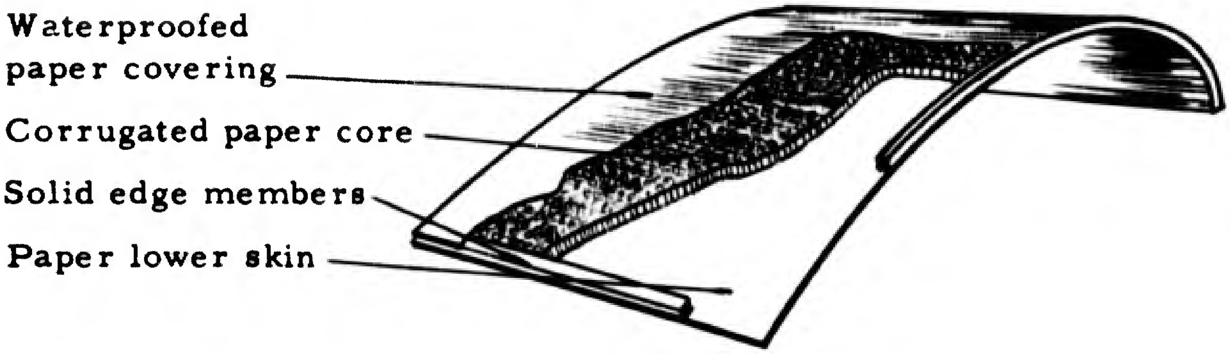
FIGURE 4

Barrel Vault Roof

Using Paperboard



Roof System



Typical Barrel Vault

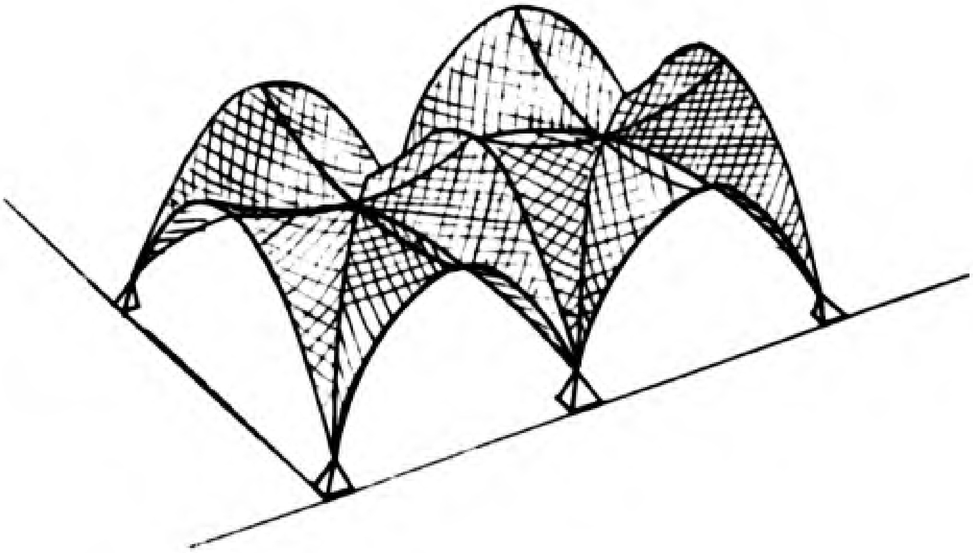
corrugated paper skin, or of an expanded paper continuous core previously described. The form of this roof is not difficult to construct; the cross section of most shells are simple arcs of circles. Such forms are geometrically simple, easy to build, and mathematically tractable.

Double curved shells. (Figure 5) The hyperbolic paraboloid is probably the best known double curved shell. It is an expressive shape, mathematically analyzable, and easy to build. The low stresses in this shell form are of great advantage if constructed of corrugated paperboard. Direct tensile and compression forces are all that occur in the skin material and these are generally very low. The geometry of the hyperbolic paraboloid is a family of identical parabolas, inverted and suspended between two other parabolas that arch upward. The resulting surface is saddle-shaped. The saddle is curved in two mutually opposed directions.[15] The combinations of hyperbolic paraboloids or sections of hyperbolic paraboloids joined together to make a larger roof are unlimited.

FIGURE 5

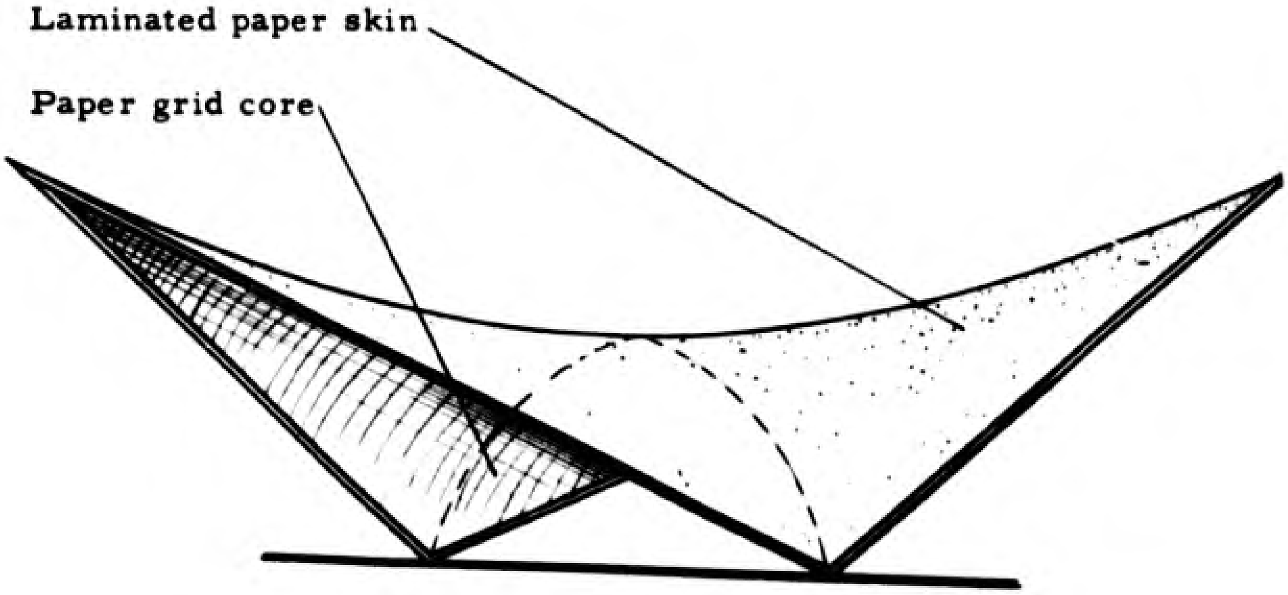
Shell Roofs

Using Paperboard



Hyperbolic Paraboloid

Roof System



Hyperbolic Paraboloid

CHAPTER IV

CONSTRUCTION OF PROTOTYPE STRUCTURES

The construction of elements of structures from commercially available corrugated or honeycomb paperboard is not presented as a new concept of building shapes or building design. Instead it is the logical application of available materials to known structural problems.

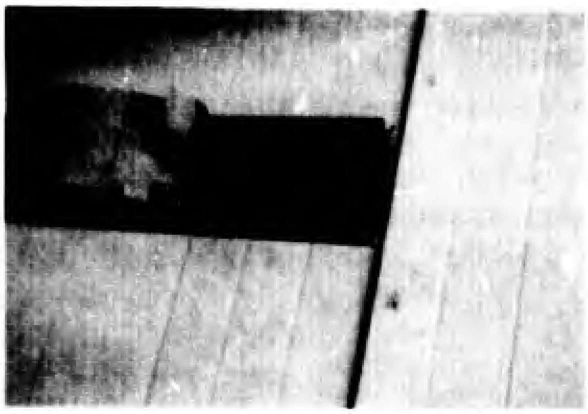
As a beginning point in the series of experiments, a number of beams were constructed of corrugated board using various kinds of cores. These beams were tested and the result showed that a paper honeycomb grid greatly increased the strength of the beams. A number of rigid frames were constructed and tested using vertical spacers at regular intervals, or a honeycomb core throughout. After careful consideration of the strength-to-weight ratio, it was again concluded that the honeycomb core contributed significantly, and would be used on a larger structure. Figure 6 shows building methods and elements of structures constructed under the initial phase of this research.

Hyperbolic Paraboloid

A hyperbolic paraboloid prototype was constructed in order to learn more about construction procedures and the structural characteristics of the corrugated paper material. The shape factor of

FIGURE 6

Basic Design Elements of Paperboard Construction



Corrugated Grid

Expanded Honeycomb Grid

Testing Paperboard Beam

Failure of Paperboard Frame

this double curved surface was believed to be outstanding for construction with this light weight material.

The curve of the surface of the hyperbolic paraboloid shell is a convex parabola when viewed parallel to one axis drawn through opposite corners, and a concave parabola when viewed from an axis 90 degrees to the first. Curves formed by the intersection of the surface of the shell with a horizontal plane are hyperbolic. The horizontal projection of such a shell may be square or diamond in shape, with the four sides of equal length. When a roof structure consists of a number of hyperbolic paraboloids, the horizontal projection of an individual shell may be rectangular in shape with adjacent sides of unequal length. In elevation, the opposite corners are raised an equal distance above the other two.[15]

Forces. The most important forces in a true hyperbolic paraboloid shell are the reactions (vertical and horizontal), the compressive force in the perimeter members, the shear force at the junction of the sheathing, and the forces in the sheathing. These forces are determined by statics. Once the forces have been determined, the member sizes and connections are designed by standard engineering procedures.[1] The method of analysis can also be applied to a series of hyperbolic paraboloids. A complete structural analysis was not attempted for this prototype structure.

Construction procedure. The shape and size of the shell constructed was based on the availability of material and the simplicity of the basic analysis. The horizontal projection of the shell measures approximately 8'0" x 8'0" with a height of 4'0". The low point of the saddle is at the mid-point, 2'0" in height.

The structure of the edge member is a 2" x 2" douglas fir element with an edging piece of 1" x 2" redwood, applied after the waterproof membrane was in place. These edging members were mitered and glued at the corners.

A honeycomb type core was constructed of strips of standard corrugated board cut $1\frac{1}{2}$" wide. The grid size of the honeycomb was set at 3" x 3". After a number of experiments, the core was laid out on a curve set by the shortest and the longest members. After the core was assembled, it was hung in the frame made by the edge members and easily developed the double curve required. The individual members of the grid are actually straight line generators. This fact makes hyperbolic paraboloids one of the most important shell shapes. (Figure 7)

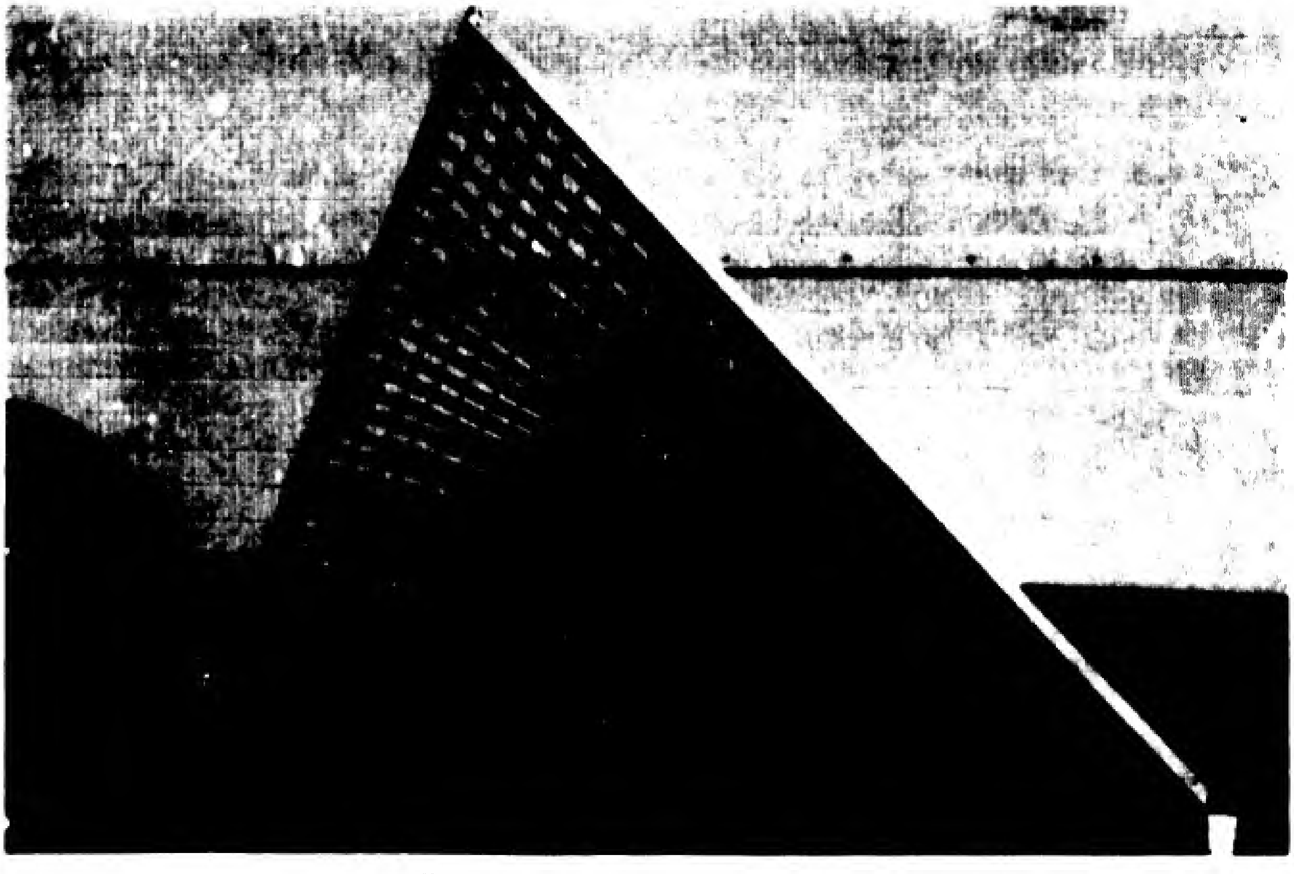
Each diaphragm (top and bottom) consists of two layers of corrugated board glued to the paper core material. The standard corrugated board sheathing was cut in narrow strips (2" to 4" wide) to permit easy adjustment to the double curved surface without special fitting. This strip covering can be applied in two ways:

1. One layer of strips placed parallel to the transverse axis

FIGURE 7

Construction of Hyperbolic Paraboloid Roof

Assembling the Paper Grid



The Grid Before Covering

where each piece bows to fit the curve of the convex parabola, with a second layer placed parallel to the longitudinal axis where pieces bow to fit the curve of the concave parabola.

2. One layer of strips placed parallel to two opposite sides of the structure, and a second layer placed parallel to the other two sides. In this system, each strip twists slightly. The total amount of twist from perimeter member to perimeter member depends on the slope of the edge members.

If the horizontally projected shape of the shell is square, the layers of strips are at right angles to each other for both systems of placement.

The first system of placing the corrugated paperboard strips was used for this research because the principal tension and compression forces in the skin act in a direction parallel to the corrugations, which provides the most efficient use of the paperboard.

The first layer was glued securely to the honeycomb core. Gluing and stapling the two layers of the facing together was done to prevent buckling and to impart additional stiffness to the shell by providing interaction between the layers. Where butt joints occurred, staples were used to transfer the forces across the joint.

After the strips were glued and stapled together the entire surface was covered with a layer of kraft paper, applied with glue. This layer was placed over and around the edge members, making a complete envelope.

As an experimental waterproof coating the entire surface was given two brush coats of butyl latex rubber. These coatings built-up to approximately five mils in thickness.[19] There was some difficulty in a few spots obtaining a bond to the paper surface. It was later learned this was only at the places where glue was applied and let dry on the surface. These spots were patched successfully. The final coating was made with white hypalon. This coating was brushed on and given a sand finish.

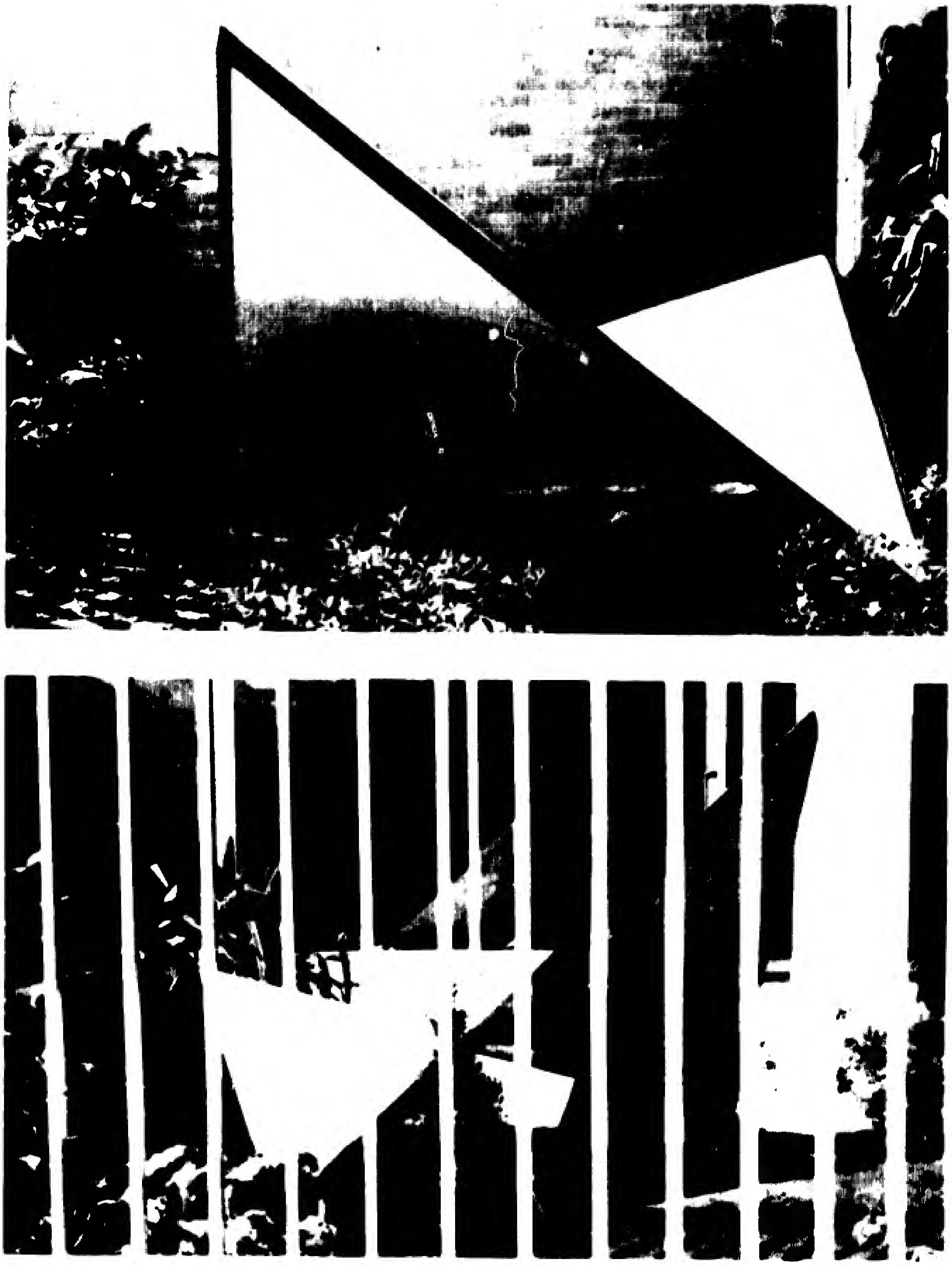
The finished prototype roof unit was set up in normal outdoor weather conditions for a period of about six months. (Figure 8) During this weather test no recognizable failures were noticed, and the unit was still capable of taking the original design roof loads. This type roof element could be joined together with other similar units to make a larger enclosure.

Barrel Roof Shells

In order to gain additional knowledge of the problems associated with the construction of corrugated paperboard structures, a three element barrel shaped roof was constructed. The broad objectives were to further develop and prove the structural effectiveness of the material and to suggest economical construction methods. The detailed objectives were as follows:

FIGURE 8

Completed Hyperbolic Paraboloid Roof



1. To develop an initial design for a series of curved shells and to verify this design by tests. These tests would prove the adequacy of the design and establish working stresses for the corrugated board.

2. To develop and apply methods of fabrication to include adhesives, stapling, cutting, and joining.

3. To test the directional tendency of the material and to note any deflections or deformation in either direction.

4. To evaluate the durability of the corrugated elements after being exposed to normal weathering for a period of time.

Design principles. To cover an area of approximately 12'0" x 16'0" with a thin light weight material such as a 1/8" thick sheet of corrugated paperboard, the material must first be laminated for thickness, and then must be used in a shape in which the stresses are manageable. It was determined a series of cylindrical shells would be constructed and tested. The cylindrical shells were selected because of the structural efficiency obtained from this shape. This type of shell structure also has manageable geometry from both a design and construction point of view. The segment of a cylinder is a typical shell form with a singly curved surface.

In spite of its form and curvature the segmental shell, which is being considered, has nothing in common with the familiar form or statical principles of the arch. It is a completely different design consideration. The action in a segmental shell can be understood by considering the fact that a sheet of paper, normally almost incapable of resisting bending, can be made stiff by being rolled up. If the paper is durable and folded at equal intervals against the curve, one gets a series of relatively strong segmental shells.[15] Under heavy loads they will spread sideways and collapse; but if they can be made to retain their curvature, their strength is many times greater than a flat sheet.

When one considers a series of these barrel shapes, the similarity to a series of "T-beams" becomes apparent. In a "T-beam" the slab spans from beam to beam; it is stressed in bending and at the same time acts as a compression area for the main beam. The slab thus serves as a double function. If the slab is now curved to a shell form the longitudinal forces replace the bending forces. The shell acts as a composite girder in the direction of the main span, very much like a "T-beam" that is free from bending.[1]

The height of the shell is decisive for load-bearing capacity, and should normally be about one-tenth of the span. If the curvature is very shallow, an edge beam will certainly be required. Most shells that have been constructed of wood or plastic have used an edge beam. The corrugated paper shells under consideration have been designed to eliminate the edge and rely only on the strength of the panels to carry the loads. The small wood strip at the intersection of the shells is used mainly as a joining member.

Design calculations were made to determine the sizes and thickness of the sections to be constructed.

To summarize, the cylindrical shell behaves much like a folded plate composed of numerous narrow strips. The loads are first transferred to the folds and are then resolved into components tangential to adjacent strips. In the longitudinal direction the strips act like beams, restrained from deforming freely because of the continuity with their neighbors. The increase in load-carrying capacity in this type of shell is due primarily to the fact that the lever arm of the resisting forces has been increased significantly. Instead of being equal merely to the depth of the slab, it now amounts to the rise in the shell. Thus by space geometry alone, it is possible to greatly increase the strength of a plate.

Construction procedure. Paper for the barrel shells was standard weight single faced material commonly used in the boxing industry. It was furnished in a width of 64 inches, the flutes were type "A", and the thickness of the sheet was one-eighth of an inch. The initial approach was to attempt a method of construction that could be used in mass production of barrel roof elements in an industrialized procedure.

A cylindrical form 16'0" long was constructed of electrical cable spools and mounted in such a way that it would rotate on a shaft. It was planned that the material would be rolled on this long cylindrical form. The butt joints between the sheets were staggered. The adhesive to bond the paper sheets was spread continuously as the corrugated paper was rolled on the drum form. The finished paper tube, to be about one and a half inches thick, was then to be cut longitudinally to make the three equal sections of the curved roof structure. Unfortunately, this scheme did not prove to be workable. The longitudinal deflection of the drum form proved most difficult. This was partially corrected, but was responsible for a small amount of creep as each sheet was rolled on the drum. After much correction, adjustment, and concern it was decided to abandon this idea and try to produce a shorter cylindrical section, which could later be joined to make a 16'0" long barrel roof section.

The short cylinder procedure was designed to produce a tube 64 inches long of corrugated paperboard; this was the width of the paper. A continuous rolling system was set up so that the material could be rolled directly from the spool to the large cylinder form. Adhesive was applied between each layer of the corrugated board. Ten layers of material were used to make a laminated wall thickness of about one and one-quarter inches. A 6 inch lap joint was devised so that the short sections could be joined together. Generally, this procedure worked satisfactorily, although it was difficult to apply enough tension to get a good bond between the sheets.

One of these short cylinders was completed and ripped longitudinally to make the three sections of the cylindrical shell.

In summary, this method of making corrugated board tubes, long and short, is very practical and could easily be applied to a machine operation. With a proper industrialized system the alignment could be perfected so that the paper would roll straight, the glue could be spread quickly and evenly to assure a good bond, and the tension between the rolls could be regulated to assure a constant contact. (Figure 9)

A construction method to produce a section of a short cylinder was worked out in order to be a assured of a bond between the sheets. The procedure required the same short cylindrical form, but only one-third of the cylindrical tube was constructed at a time. By using this method the adhesive could be evenly applied and staples could be used to aid in fastening the sheets together. A 6 inch lap type joint was provided so that the short sections of the cylindrical shells could be put together to make a 16'0" long roof unit.

One of the most difficult problems to be solved was to properly support the shells in order to develop only membrane stresses. A long barrel, supported only on the ends, and retaining its shape, carries loads by longitudinal tensile and compressive stresses and transverse shear--actually beam action. If the barrel shape is supported along the longitudinal edges, arch action takes place. It

Figure 9

Construction of Barrel Vault Roof

Construction Progress

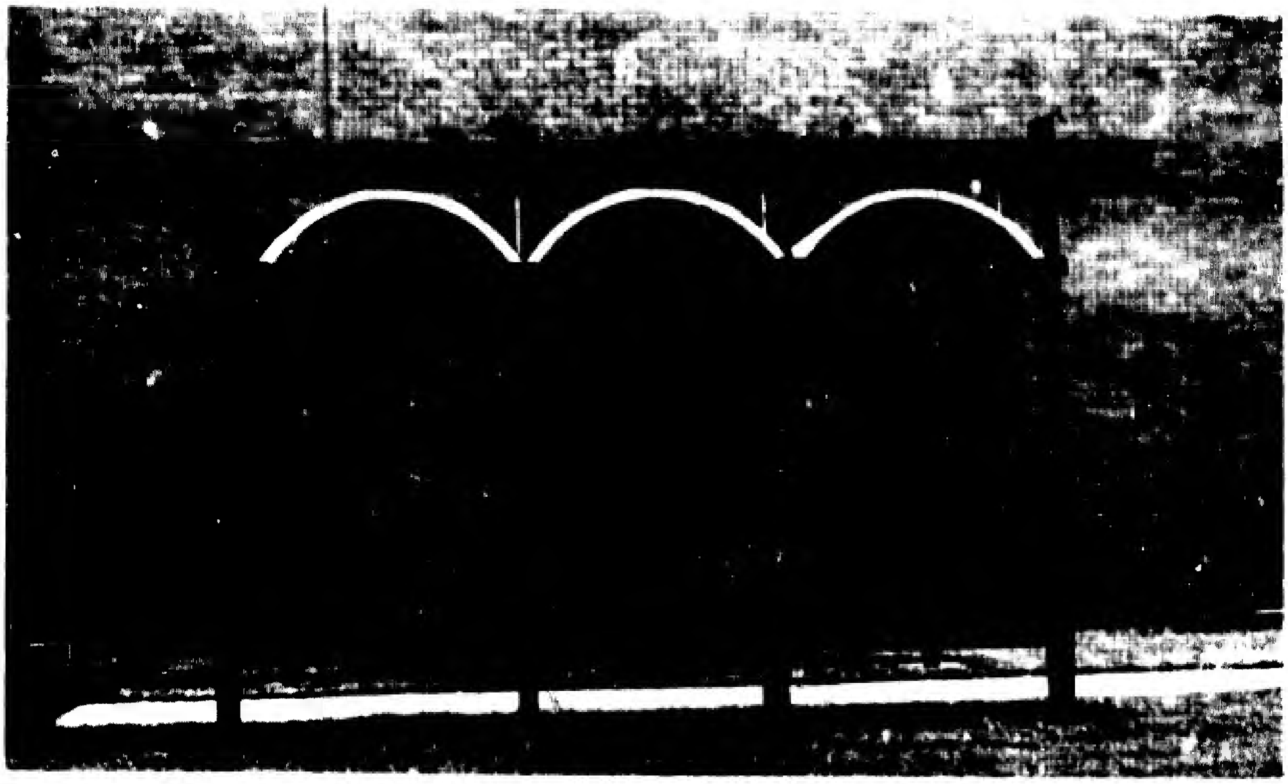
Waterproofing Assembled Units

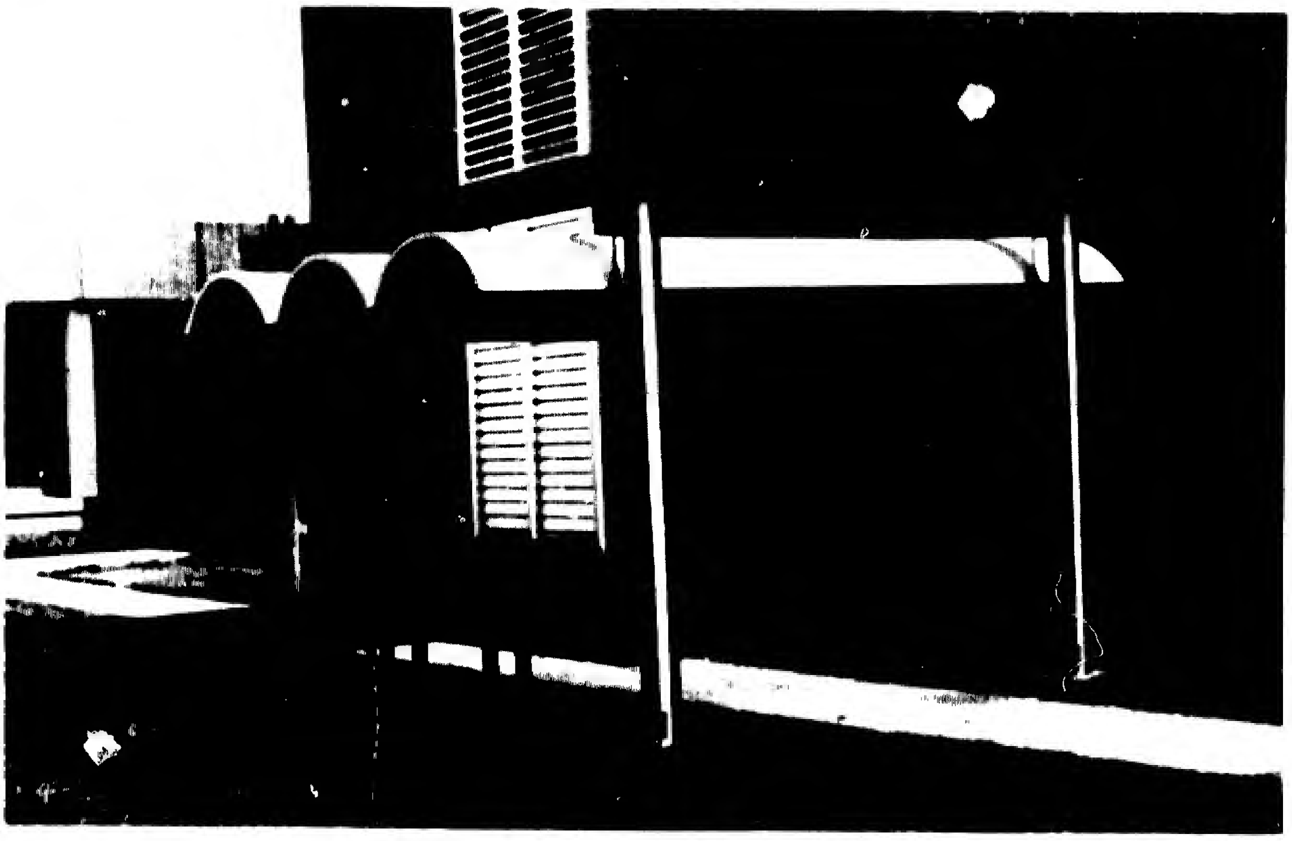
was determined the best way to avoid arch action would be to provide end stiffners of wood, and to provide a very minimum wood member as a joining element in the longitudinal direction. The longitudinal piece used was standard yellow pine 2" x 4" placed flat so that the two barrel edges could come together and be fastened to this member. Glue and nails were used at this connection. Wood stiffners, at the ends of the barrel shapes, were constructed of exterior grade plywood. By using an end member of this type the curved shape can be retained and any tie rods required can be eliminated. (Figure 10)

The roofing system used was a fluid application of neoprene and hypalon. These synthetic rubber type products were rolled on to form a multiple layered coating. The paperboard roof surface was first given a prime coat of diluted neoprene. It was then given a standard rolled coat and sprayed with a light layer of continuous strands of fiber glass. This material was used to give puncture strength to the roof covering. Each of the three rolled applications of liquid neoprene yielded a dry film thickness of about three mils. Each layer was dried before the next one was applied. The final coating was white hypalon with a dried thickness of about two mils. These four applications required about four gallons of liquid per 100 square feet and made a total membrane thickness of 10 to 15 mils. After a short drying period these layers air-cure into a homogeneous membrane that is light weight, strong, and resilient.

FIGURE 10

Completed Barrel Vault Roof





This was very likely the first time a roof coating of this type was applied to a corrugated paper deck. Generally, it proved to be a very satisfactory application.

The three barrel vaults were hung from a wood frame and weather tested for a period of about six months. With the exception of four punctures of the roofing material, during the erection procedure, the test was considered a success. No deflection or other failure was noted during the test period.

Folded Plate Structure

This prototype folded plate paperboard structure was designed and constructed to investigate methods of fabrication of a transportable packaged shelter unit. As indicated previously, the United States Air Force has expressed interest in a unit of this type.

Design consideration. The design for this prototype structure includes additional specific considerations not required previously.

This unit would, no doubt, be shipped by air, so the total size and weight were a big factor in the design. All structural elements were selected for the best weight-to-strength ratio. Items were designed to stack without wasting space in the package.

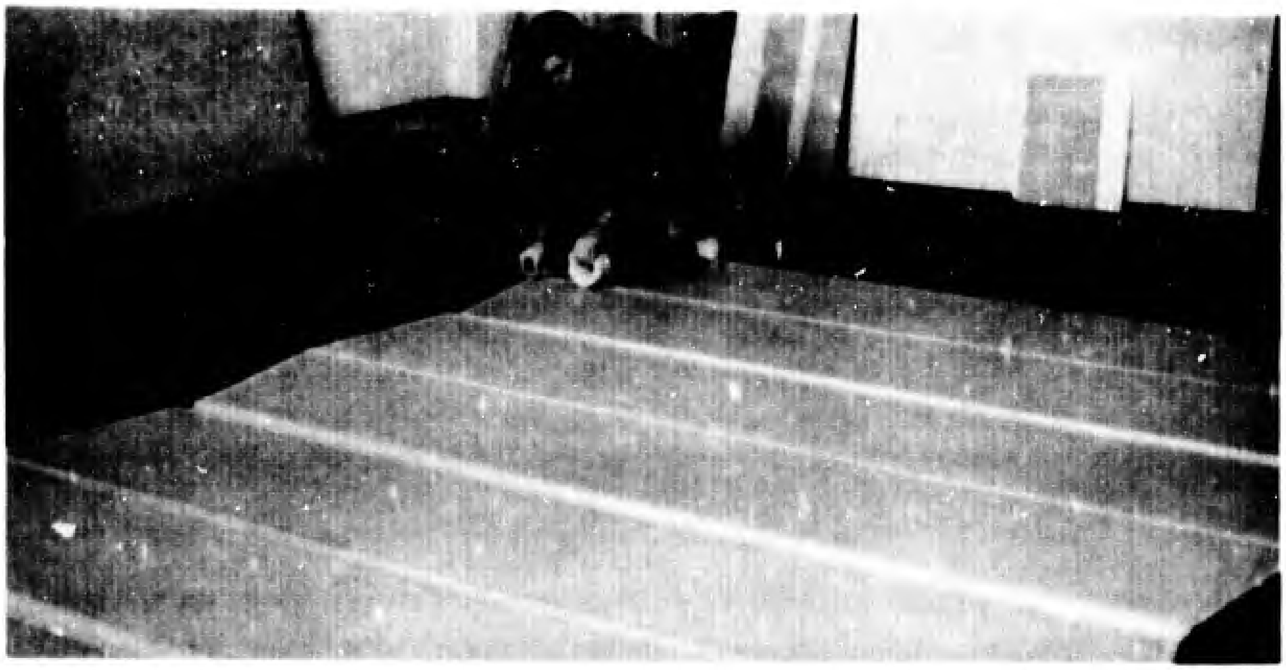
The folded plate roof system was a major consideration for this prototype structure. The zig-zag form was selected for this construction because of its strength, simplicity, and ability to be folded flat for packaging. The folds are in the direction of the span and parallel to each other. Instead of increasing the carrying capacity of the slab by introducing ribs, the slab is deformed by folding so that it achieves an increased structural height and the forces are not only sustained vertically to its axis, but also partly parallel to the neutral plane.[1] There are many complicated folding systems that have special structural advantages. Additional reasons for selecting the zig-zag folded roof system were the facts that it could be joined at the edges initially, entirely waterproofed, neatly stacked for shipment, and easily unfolded for erection at the construction site. (Figure 11)

A modular panel wall system was developed in order to be able to select the panel type to be used in any particular situation. In cold climates a solid honeycomb paper panel would be used; in hot climates a screen panel could be substituted, or if required a door could replace a panel unit. The wall system was designed for simplicity of erection and the possibility of disassembly and erection on another site. The small triangular sections above the wall plate would be screened for ventilation or covered with a plastic sheet to emit light.

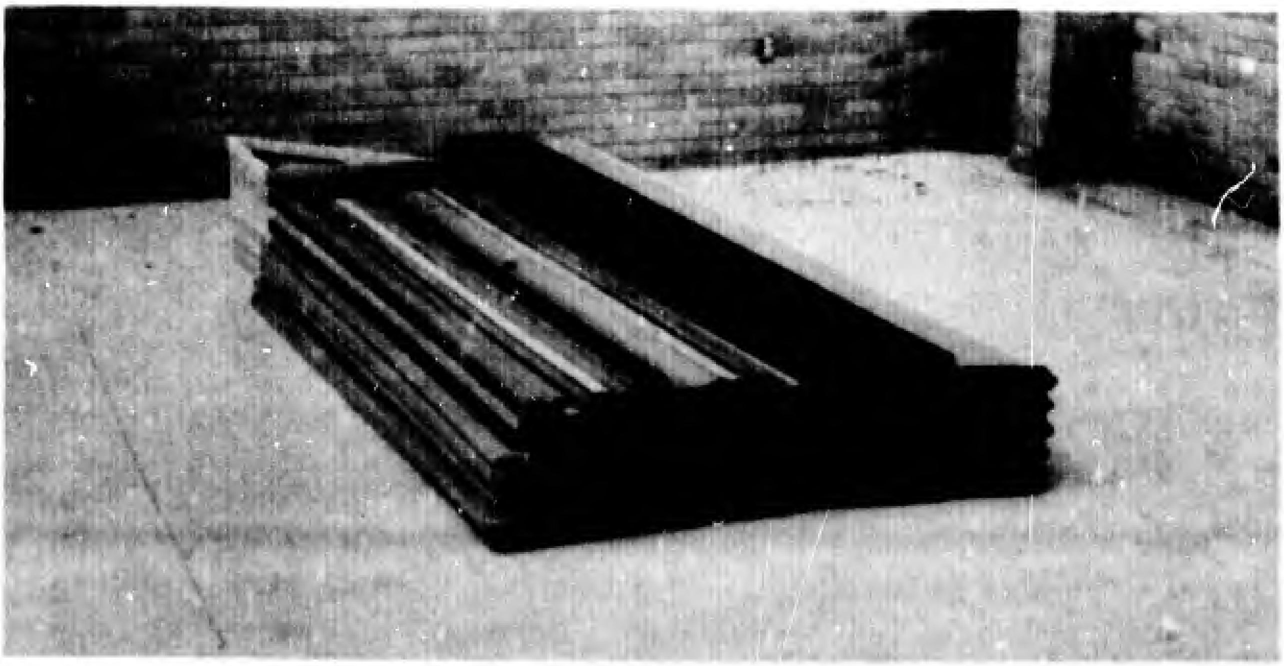
Although a floor system was not constructed as part of this project, it was a design consideration. For very simple shelters it

FIGURE 11

Construction Details - Folded Plate Roof



Folded Roof Laying Flat



Components Stacked Ready for Shipment

would seem adequate to lay a six mil plastic sheet directly on the leveled ground and place a one inch honeycomb paper rigid panel on the sheet. This panel would have to be faced on one side with a plywood or plastic skin. The section of the floor could be constructed with a lap type joint, so that a level floor could be maintained. The floor panels would be hinged in such a way that they could also be used as the shipping container for the shelter.

Construction procedure. In this prototype structure the major material used was a thin sandwich panel comprised of a paper honeycomb core with facings of heavy kraft paper. The thickness of the panels was one inch overall with a honeycomb size of one and a half inches. These panels are commercially available in sizes up to about 6' x 16'. The paper used was untreated.

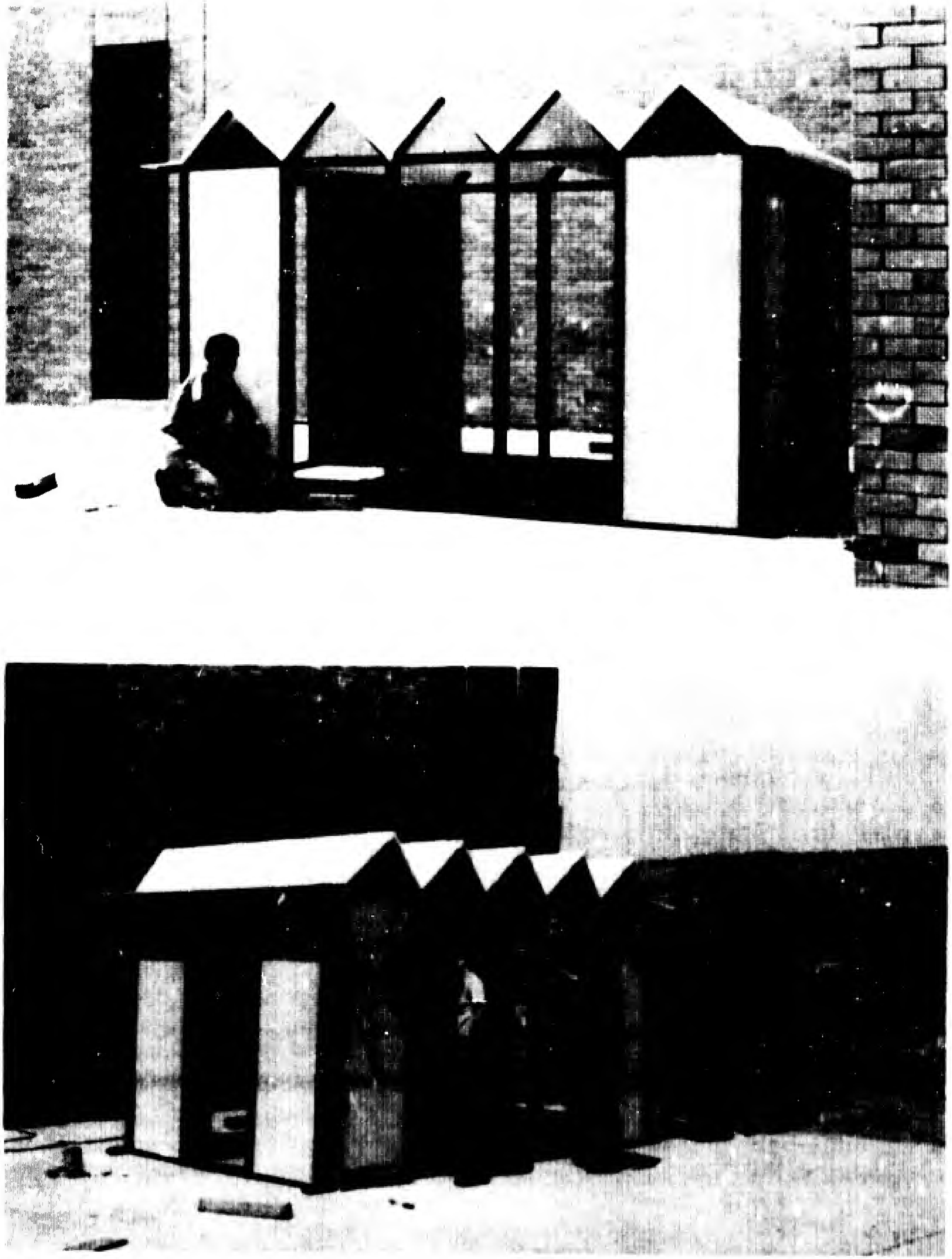
The panels for the roof were first cut to size, edges beveled, and then the entire perimeter was sealed with a kraft tape. This sealing operation was entirely a hand procedure, but if handled by a machine it could have been accomplished much simpler and better. The next operation was to form a continuous waterproof hinge to join the roof panels together. Tests were made of a plastic tape known as "Tedlar"; it was found to be very tough and to accomplish the hinging job very well. Other types of tape were used with varying success. The exact type of joint and tape to be used will depend greatly upon the possibility of disassembly and relocation of the structure. By folding back the roof panels, it is quite easy to package the roof of the structure for shipment.

The walls were designed and constructed of paper covered panels similar to the roof. A redwood modular frame was built to simplify connections and add stiffness to the wall. This light framing system also allows the flexibility of substituting a screen panel, a glass panel, or a door in place of any solid wall. The wall framing was constructed for easy assembly by unskilled workers, and also for the possibility of disassembly. Electrical wiring or piping runs could be located in the wood members by routing out a portion of the section.

Waterproofing treatments for this structure were basically the same as those used on the barrel roofed structure. In this experiment three coats of neoprene was used, along with one coat of white latex paint. The underside of the roof was finished with two coats of latex paint. Time did not permit any lengthy weather test of this structure. (Figure 12)

FIGURE 12

Completed Folded Plate Shelter Structure



CHAPTER V

CONCLUSION

Construction and use of corrugated paperboard as a major structural material is feasible with respect to shelter units for housing. The paper industry and various agencies of the government have shown a definite interest in this research, and desire to learn more about the possible structural value of this material.

There can be no doubt in the minds of responsible men that a great need exists for some type of housing assistance for the emerging nations. Next to food, shelter is man's most important consideration. A home protects him from the natural elements which are his enemy, but it also protects and shelters his inter-self. It is a place, no matter how simple, where he can retreat and gather together his abilities to face his other problems. It should be the objective of every developing country, and of those interested in these countries, to immediately create an environment that will provide better health and better living conditions for as many people as possible and thus enable them to become more productive in the development of the nation. The primary long range housing objectives in a new society should be the creation of a housing market sufficient to sustain the development of industrialized facilities capable of producing housing of an increasingly desirable type at a price that can be met by a steadily rising level of national income.[23]

The United States Defense Department has a constant requirement for light weight, transportable shelter units. This statement by an Air Force officer in charge of research buildings indicates the need: "We very definitely have a requirement for such shelters, primarily to replace tents in the Tactical Air Command package of material for air transport to forward bases. It should be light weight, prefabricated, transportable, and low cost -----. In addition, the shelters should provide insulation for use in cold and hot climates, should provide more livability than tents -------be modular and adaptable to different sizes and uses."

The housing stituation in the United States is certainly better than in most areas of the world, but much is left to be accomplished. The recent demand for equal rights puts a new emphasis on this problem. This statement by Marcus Whiffen gives some hint as to the seriousness of the situation, "Cries for freedom and human dignity are quickly followed by demands for a better life. Millions of people the world over are learning that poverty and degradation are not the foreordained or inescapable way of life. They are learning that technology can free them from misery---they know that wealth exists, unequally distributed. They cannot long be denied first-class world citizenship--a question which was once economic has now become more of moral choice."

From the evidence in the previous paragraphs it can be concluded that a definite need presently exists for low cost housing shelter units.

Many experts are of the opinion that the housing problems of the world can never be solved. Those who believe there is some hope generally agree that a new technology of building must be developed. Most housing units are still built by conventional methods, this means a single house must consist of about thirty thousand separate pieces, hand-assembled on site--with time out for bad weather. It consumes up to fifteen man-years of work from raw material to completion. A conventional wall---studs, rough boarding, and clapboard---contains the equivalent of two and a half inches of solid wood throughout, and costs about seventy-five cents a foot. And of this wood, 34 percent of the raw materials has been wasted in conversion to lumber, and another 20 percent lost on the job in odd ends and sawdust. For every wall built there is material---properly converted---to build three to ten other, better walls.[12]

There can be no doubt that this conventional method of house building cannot possibly answer the housing needs outlined earlier in this report. It would be too costly and take too much time. The solution must develop from an up-to-date building industry, in the true industrial sense. The idea of a solution---based on the use of paperboard as a major material---is certainly a possibility, but will require a lot more research. There are many disappointing reports to be studied regarding similar research projects that have not materialized. Very likely these projects were valid, but the time was wrong. Today, the time may be right. Certainly the need exists. A complete solution to satisfy the requirement is a very large and complex problem. Perhaps this research project has stimulated some thoughts toward a solution.

Although many aspects of building research with paperboard were not covered in this project, a great amount of design and construction experience was gained. The overall paper industry was researched in order to learn the basic materials available. These materials were studied regarding uniformity, strength, and durability. Much knowledge was gained about glues, tapes, and joining methods. The important problem of waterproofing was explored and samples were tested for relatively short lengths of time. This problem is a major one and will require much additional research.

For considerations where air shipment is a major factor, the weight and packaged size of a shelter unit seems reasonable. For a shelter unit of about 200 square feet, the package size would be less than four feet wide by fourteen feet long by two feet high. This would include the roof, walls, rigid floor, and fastenings required to assemble the structure. The total weight of the package would be about 300 pounds.

Within the scope of the research it was not possible to develop any meaningful costs. If these procedures are to be industrialized, the cost factors will have to be based on the manufacture of hundreds of units. Buckminster Fuller has done work with paperboard geodesic dome structures and gives some hints to what the costs may be. "Large paper manufacturing mills have the capacity to produce 3000 domes per day, each dome with a floor area of 1000 square feet. Estimates are that domes of this type would be retailed in the $500.00 price range; that is, at approximately $.50 per square foot." This cost of $.50 per square foot seems to be a very realistic figure for the total price of the finished material. If self-help is used for erection and utility work, the total cost of a finished unit could be kept very low.

In conclusion, it should be clearly pointed out that a great amount of research and hard work will need to be accomplished before a marketable shelter unit can be manufactured. Some of the problems relating to construction with paperboard have been solved; many others need additional study. It is strongly believed that paperboard material has advantageous properties and that with continual development can play an important part in the solution to the problems as outlined. If the aim to achieve a habitable world is important, then we must find the right approach; and we must continuously progress in a never-ending cycle of research and development.

BIBLIOGRAPHY

Books

1. Angerer, Fred. Surface Structures in Building. New York: Reinhold Publishing Corporation, 1961.

2. Bach, Kurt W. Slums, Projects and People. Durham, N. C.: Duke University Press, 1962.

3. Banfield, Edward C. and Morton Grodzins. Government and Housing in Metropolitan Areas. New York: McGraw-Hill Book Company, 1958.

4. Beyer, Glenn H. Housing: A Factual Analysis. New York: Social Science Research Council, 1950.

5. Cherner, Norman. Fabricating Houses from Component Parts. New York: Reinhold Publishing Corporation, 1957.

6. Colborn, Fern M. Buildings of Tomorrow. New York: Whiteside, Incorporated, 1955.

7. Darlington, Robert P. Modular Practice. New York: John Wiley and Sons, Incorporated, 1962.

8. Duncan, Beverly and Philip M. Hauser. Housing a Metropolis--Chicago. Glencoe, Illinois: The Free Press of Glencoe, Illinois, 1960.

9. Glazer, Nathan and Davis McEntire. Studies in Housing and Minority Groups. Berkeley: University of California Press, 1960.

10. Grebler, Leo. Production of New Housing. New York: Social Science Research Council, 1950.

11. Kelly, Burnham. The Prefabrication of Houses. New York: John Wiley and Sons, 1951.

12. Koch, Carl. At Home With Tomorrow. New York: Rinehart and Company, Incorporated, 1958.

13. Mark, Robert W. The Dymaxion World of Buckminster Fuller. New York: Reinhold Publishing Corporation, 1960.

14. Pickering, Ernest. Shelter for Living. New York: John Wiley and Sons, Incorporated, 1947.

15. Siegel, Curt. Structure and Form. New York: Reinhold Publishing Corporation, 1962.

16. Smith, C. W. New Frontiers for Home Builders. San Antonio, Texas: Housing Research Foundation.

17. Tiemann, H. D. Wood Technology. New York: Pitman Publishing Corporation, 1942.

Reports

18. Anderson, L. O. Performance of Sandwich Panels. Forest Products Laboratory, Madison, Wisconsin, 1959.

19. Fluid Roofing Systems of Neoprene and Hypalon. E. I. DuPont De Nernours, Wilmington, Delaware, 1963.

20. Housing Relief for Disaster Victims. Commi tee on Banking and Currency, United States Senate, Washington, D. C., 1956.

21. Measures for the Economic Development of Under-Developed Countries. United Nations, New York, May, 1951.

22. NAHB Research House. National Association of Home Builders, Washington, D. C., 1960.

23. Paraskeropoulos, Stephen C. ORA Research Project 05125. Agency for International Development, United States Department of State, July, 1962.

24. Research on Structural Systems Utilizing the Foam Plastics as a Structural Material. University of Michigan, Ann Arbor, Michigan, June, 1964.

25. Study of International Housing. Subcommittee on Housing, United States Senate, Washington, D. C., March, 1963.

Articles

26. Cameron, H. F. "Engineers in Strike Operation." Military Engineer, January, 1965, p. 22.

27. Chidester, G. H. "The Future for Pulp and Paper." Forest Products Journal, May, 1964, pp. 232-235.

28. "Future of Urban Environment." Progressive Architecture, October, 1964, pp. 164-190.

29. Hemming, Charles B. "Economics Main Concern in Gluing." Forest Products Journal, February, 1964, pp. 61-62.

30. Koch, Carl. "Building Component Design." Progressive Architecture, June, 1964, pp. 172-173.

31. Meredith, W. E. "Base Engineer Emergency Force." Air Force Civil Engineer, November, 1964, pp. 2-5.

32. Parasherapoulos, Stephen C. "Architectural Research in the Use of Foam Plastics." Cellular Plastics, January, 1965, pp. 1-11.

33. "Portable Plastic and Plywood School Units." Architectural Record, February, 1963, pp. 183-185.

34. Rennicke, Norbert G. "Corrugated Box Manufacture." Paper Trade Journal, August, 1964, pp. 32-35.

35. "Roof Shells of Lapped Plywood." Progressive Architecture, June,1963, pp. 134-135.

36. Rutcliff, Richard A. "Housing Standards and Housing Research." Land Economics, November, 1952, pp. 328-332.

37. Shiffer, E. T. "Industrialized Building Systems in Western Europe." Progressive Architecture, October, 1964, pp. 192-200.

38. "United States Progress in Preassembly." Progressive Architecture, October, 1964, pp. 201-220.