DESIGN OF PREFABRICATED HOUSES

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Pares Chandra Bhattacharji

1949

This is to certify that the

thesis entitled

DESIGN OF PREFABRICATED HOUSES

presented by

Pares Chandra Bhattacharji

has been accepted towards fulfillment
of the requirements for

M.S. degree in C.E.

C L Allen
Major professor

Date 5/20/49

M-795

DESIGN OF PREFABRICATED HOUSES

By

PARES CHANDRA BHATTACHARJI

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Civil Engineering

1949

ACKNOWLEDGEMENT

The author is deeply indebted to Professor C. L. Allen and Professor C. A. Miller for their guidance and valuable advice. Appreciation is also expressed to Professor M. G. Boylan, a member of the Landscape Architecture and Urban Planning Department, for his assistance in aiding me to obtain information regarding my field.

TABLE OF CONTENTS

EVOLUTION OF PREFABRICATION AND ITS APPLICATION TO POST WAR HOUSING PROBLEMS

According to R. L. Davison, Director of Research, J. B. Pierce Foundation, "Prefabrication is the assembly, in varing degrees, of parts of subassemblies into sections to be assembled into a structure, as distinguished from the assembly of parts during erection of the building."

Mass production, industrial specialization and standardization have made possible the improvement, comforts and conveniences we are getting today. Prefabrication when applied to residential construction simply means the manufacture of parts or products in a well-integrated mechanized plant where they can be more efficiently produced than under the uncontrollable conditions existing at the building site.

The conventional method is a waste of time, labor, and material. Work generally suffers due to climatic conditions. Technicians work with utmost efficiency and safely because they have the benefit of enough light and the best mechanical facilities with required sized materials within easy reach. The raw materials are cut to the lengths required and every small part is utilized, where as in the site work system this is not at all possible. Thus, waste is also at a minimum.

One of the main obstructions in the past has been the physical problem of manufacturing a house in a factory, transporting it in sections, and erecting it on the chosen site. Now with the event of modern equipment the conventional houses in most cases are using prefabricated parts. The result may be that as time goes on it will be difficult to distinguish between a prefabricated home and one of standard construction.

This industry which promises no radical 'mechanics for living' embraces a rapidly increasing number of factories in which building walls, partitions, ceilings, floors, and roof panels can be prefabricated in completed units, shipped to the site and erected in only a few hours.

Before the war only a few concerns were regularly producing and marketing prefabricated homes. Actually war housing and war construction presented the first real opportunity to prefabricators to put their systems to a real test. After the war the Wyatt program in 1946 and the extensive demand for prefabricated units in 1947-1948, have proved "that prefabricated home industry's success or failure in the post war period will depend upon the soundness of the method of distribution it likes to follow. During the war the industry was in the research and experimental stage---with the government as its sole customer. After the war the industry will enter its distribution phase. If it chooses the right method of distribution, it will succeed---if it chooses the wrong path, it will fail. Unfortunately the industry was not old enough to have solved it before the war".

Only time will prove the rightness or the wrongness in methods of construction, distribution, and mechanizing of the established houses.

MASS PRODUCTIVE VALUE OF PREFABRICATION

According to the World Economic Conference at Geneva in May 1927,

Rationalization

Rationalization is the method of technique and of organization designed to secure the minimum waste of either effort or labor or material. It includes the scientific organization of labor, standardization of both material and of products, simplification of processes and improvements in the system of transport and marketing.

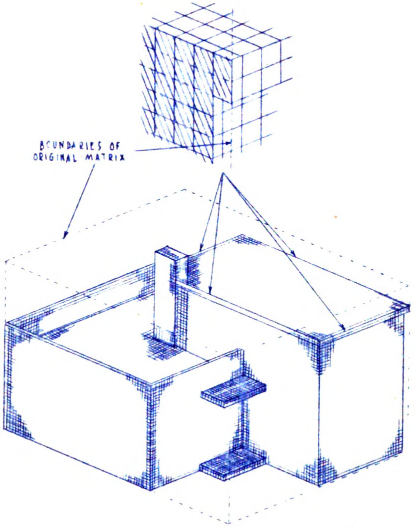
Rationalization of the housing industry must clearly begin with the rationalization of the completed house, involving first the redesign of its physical units with a view to mass production, convenient transport, and ready assembly. Its object is to provide suitable homes at reasonable cost for the entire population and at the same time to compensate all contributing producers at the existing economy.

In the rationalization of housing a complete redesign and a unified conception of structure is needed. The traditional house is a conglomeration of unrelated materials of all sorts, sizes and shapes, put together on the site to form a composite whole. Until parts are standardized, mass production cannot be possible.

The connection between standardization, mass production, between mass production and rationalization is implied by the words themselves. According to Mr. Henry Ford, "the term mass production is

Mass production

used to describe the modern method by which great quantities of a single standardized commodity are manufactured.....nor is it merely machine production.....Mass production is the focussing upon a manufacturing project of the principles of power,



THE STRUCTURAL MASS WITHIN THE METRIX

Fig. A

accuracy, economy system, continuity and speed. The interpretation of these principles, through studies of operation and machine development and their co-ordination in the conspicuous task of management, gives a normal result of a productive organization that delivers in quantities a useful commodity of standard material, workmanship and design at a minimum cost".

Full mass production of houses can be made possible by adopting two main principles. These two characteristics are uniformity of cross section at right angles to length, and repetitive features proportioned along the 'length' according to a stated gage.

Again, the parts of a house may be mass produced and mass assembled

Mass Assembled

If they are designed on a cube module; and, therefore, may be prepresented within complete structure by multiples of this cube, because one interchangeable unit of measure is found only in cubes.

The house parts standardized to meet the requirements of the mass production method must be so co-ordinated that through selection and grouping an unlimited variety of houses can be assembled. Standardization must therefore be applied to prefabricated house parts, not to the house itself.

Although wood frame construction appears to have no common unit of measure, the cross sectional dimensions that satisfy the mechanics of structure, beams strength, post strength and other requirements of different

Module
Fig. A

materials, suggest a simple relationship of a modular character. In reinforced concrete structures, standardization would be directed to the forms. To effect the highest degree of standardization such forms should be designed on the cubical modular basis. Whatever the materials or type of structure, its component parts, if standardized, must be definitely related to a base of a substantially fixed dimension in all three directions.

ECONOMICAL ASPECT OF PREFABRICATION

Less expensive

When manufactured on a large scale, it eliminates much of the middle man's profit and the waste of material and labor which are involved in the traditional construction.

Numerous tests conducted in wind tunnels, laboratories and in the field provide ample validity of this fact. New and light materials are being employed in factory built homes to give increased strength and durability.

Better construction

On the other hand machine operations are usually more precise than hand operations, and one finds an exactness in measurements and fitting in mass production homes which are absent in traditional buildings, and the result is a stronger better, and longer lasting house. Glued construction is far superior to nailing.

Better design

The engineers and architects engaged in prefabrication are always trying to draw a plan of maximum comfort, attractiveness and durability at the least possible cost. Thus, the house which is reaching the home owner is the result of research and designs far in excess of what any individual can afford in a single house.

Speed

Greater the saving in time and labor, greater the plant is well-equipped with the production equipments. The house can be constructed within a few hours on the site, which is a great handicap over the traditional orthodox system. Shopwork can be systematized and is faster than field work. Foundation work can be carried out simultaneously. There is no delay due to adverse weather conditions.

HISTORY OF PAST AND PRESENT RESEARCH AND EXPERIMENTATION ON PREFABRICATION

At the beginning of the present century many designers, like inventor Thomas A. Edison, tried to apply industrial techniques to the construction of concrete houses. Their ideas were rejected due to several practical difficulties.

During the depression of 1929 many steel fabrication companies and manufacturers of insulating board, such as American Rolling Mills, United States Steel and Republic Steel, Homosok Company, and the Celotex Corporation established a housing section to push the use of their materials. However, due to high prices and lack of mass production, they failed to create interest in the public.

Three endowed agencies which have pioneered with various types of construction, studied and tested structural materials and methods, and continually influenced the prefabrication movement are: The Pierce Foundation Housing Research Division organized in 1931, The Purdue Research Foundation Housing Project opened in 1935, and the Bemis Foundation established in 1938.

The John B. Pierce Foundation, Housing Research Division, Raritan, New Jersey is a non-profit institution which over a long period of years has developed an unusual system of prefabrication. Standardized mass produced parts are designed for various house plans. Framework joists may be either wood or steel. Wall panels are erected horizontally in three tiers; the bottom supports the floor load; the top supports the roof; the middle encloses spaces between windows and is non-structural. Exterior panels are shop fabricated box girder units, glued, nailed and insulated faces on both sides with 3/8" plywood, framed with wood and formed and fabricated-spot-welded sheet steel. Door and window units are completely prefabricated. Heating, plumbing and wiring engineered and other parts of the design are assembled on the job.

The Housing Research Project of Purdue University first offered five houses of different materials such as wood, steel and reinforced concrete for the commercial market. The houses were studied both from the viewpoint of the values of the different types of structure involved and of the cost factor. Special studies were made on low-cost housing.

Before the prefabrication movement had taken its true shape, Bemis Industry, Inc.* maintained its laboratory and experimented with different types of construction using various materials for wall surfacing and for structure. They also did research in the use of special composition like gypsum blocks, precast gypsum slabs for walls as well as with composition board and steel panels for houses. A few models also appeared on the commercial market. Bemis industry first tried to develop modular system to simplify field construction through the use of standard members.

The war emergency gave prefabrication its first real test in the field. The prefabrication movement is being provided with a vast reservoir of actual experience which it lacked in the prewar period. Now it has

*Mr. Albert Farwell Bemis was the President of Bemis Industry and after his death a Foundation was established in Massachusetts Institute of Technology, Cambridge, Massachusetts to carry out his research program. This Foundation has collected many valuable materials and research data from a survey of about 100 companies and intends to publish it for general information.

developed to a point where they can no longer be ignored and where they are bound to influence every aspect of the post-war building picture.

The Farm Security Administration, the Tennessee Valley Authority and the Public Building Administration all gave prefabrication the chance for which it long had been waiting.

The Forest Service, U. S. Department of Agriculture in collaboration with the technical staff of the Housing and Home Finance Agency tried to assemble most of the essential scientific information on this subject for all those interested in planning or constructing wood prefabricated houses.

Farm Security Administration accepted many prefabricated systems for its rural communities and acted as field laboratory of prefabricated housing.

Tennessee Valley Authority first started their project in a conventional way but later on adopted the design of factory-fabricated houses of truckable sections.

EFFECT OF FUNCTIONALIST MOVEMENT ON THE PREFABRICATION INDUSTRY: IDEAS OF SHAPE ENGINEERING

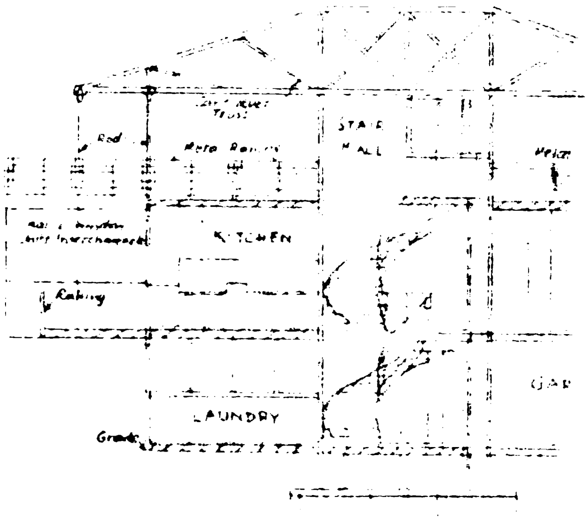
With new scientific inventions the old designing and constructional idea no longer fits with the present day needs. Only better production technique with a completely new outlook can face this problem. The functionalist movement of 1925 and the spirit of modern architecture represents an attempt, but in most cases they failed to channalize their Utopian ideas into reality.

Buckminister Fuller has designed his famous "Mast House" in 1927. According to Mr. Fuller's statement, 'The Dymaxion House is still as it has been for years---a theory only. Despite pragmatic criticism it has conscienticusly been kept so. While theoretical, it is immediately improbable by every scientific advance. It might even be more broadly stated that the Dymaxion House has been merely an attitude. An attitude of willingness to think truthfully. .....Dymaxion House may be conceived of as progressive composites of the best means of living as determined by universal survey'.

Dymaxion I
Fig. A

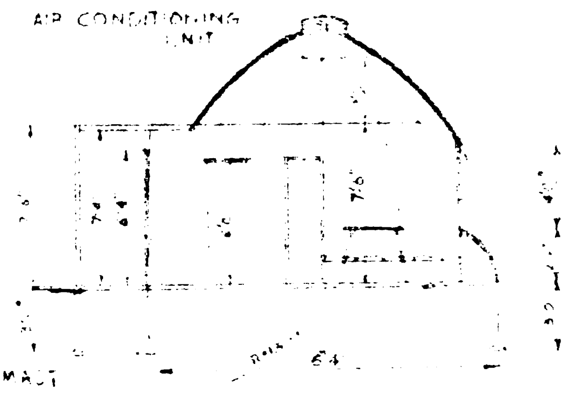
The house has five rooms and weighs 6000 lbs. with all accessories. In this house the top deck was utilized as a recreational area and covered with a pneumatic floor system to neutralize any sagging effect. The structure was tied back to the ground with further guy ropes. The walls of the house were to be double plated of casin with a vacuum between. A central lighting system was designed to diffuse light to all parts of the house by means of prisms, mirrors and lenses.

Mr. Fuller's second Dymaxion structure is based on the monocoque principle. In this case special attention was paid for betterment of living



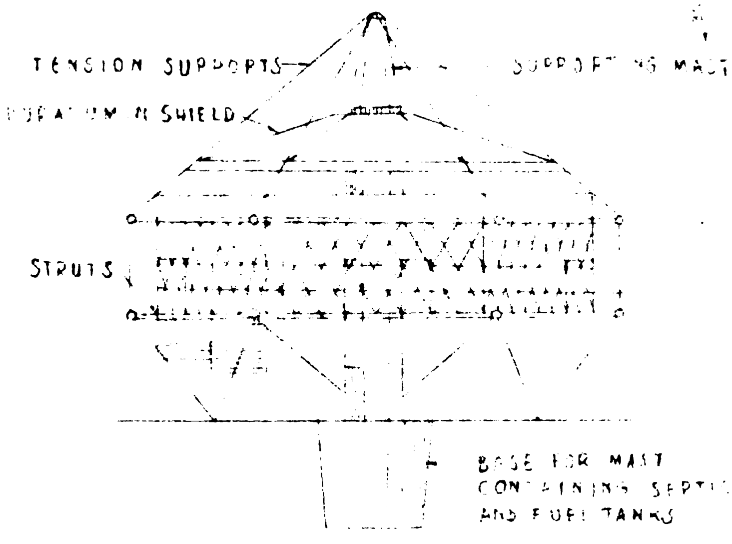
SECTIONAL VIEW OF ARCHITECT RICHARD J. NEUTRA'S DIATALUM DWELLING

Fig. B



SECTIONAL VIEW OF MARTIN WAGNER'S IRON IGLOO HOUSES

Fig. C



DYMAXION HOUSE of R. BUCKMINISTER FULLER

Fig. A

conditions and to utilize unused spaces for placing bathrooms and other service units. The main idea in this 'Mast House' is to incorporate all utility services into a compact form. Dymaxion should be regarded not merely as a house but as an expression of an entirely different philosophy of living.

Dymaxion II

Mr. Neutra has long been concerned with the possibilities of prefabrication. The Diatalum Dwelling is but one example of his effort in this field. The possibility of using prefabricated blocks based on diatomaceous earth appears to have been suggested by Neutra as early as 1923. The basically interesting thing is that this house is the suspension principle using a central mast from which walls are suspended in tension. Provision was also kept for adding successive units if expansion of the house is required. Masts or posts, made of a pair of channels, are welded into prefabricated hollow footing blocks of precast vibrated concrete each half weighing about 3/4 of a ton. Floor joists in this case, shown to be prefabricated of a pair of angles and a web plate, are framed to the masts to support the inner edges of the prefabricated diatom floor slabs. The diatalum panels are made of infusorial earth chemically compounded and hardened under steam pressure. They are light and said to be adequately strong.

Diatalum Dwelling
Fig. B

According to Mr. Neutra, "The current study although intended to demonstrate in breadth and depth the problematics of such post war planning, concerns itself largely with one of the new elemental materials, its development, combination and application to housing.

".....Diatomaceous earth and its derivative products may fill a chapter in the book of substances, and that of human shelter as well.

".....Microscopically small infusorial sea shells piled up into big layers geologically ages ago, diatom earth is easily mined by an industry which is ready for all-round structural and house fabrication of the first magnitude. The material is combined with a few others, cement, wood fibre, plastics from agricultural waste products and aluminum; all available on the Pacific slope, as well as in many other states....."

Mr. G. F. Keck's "House of Tomorrow", shown at the Chicago Century of

House of Tomorrow

Progress, is also based on the mast principle. Radical beams extending out from the central steel mast were used for holding floors and walls. The ground floor was designed for hanger, utility rooms and garage.

Martin Wagner, city architect of Berlin, has designed a special type

Igloo House
Fig. C

of half-egg shaped earthquake, shockproof structure for solving housing construction problems in Turkey. It gives the idea of construction of light as well as strong structures by distributing stress throughout its surface.

The Forest Product Laboratory did considerable research on the use of plywood in an aircraft design and soon recognised the advantages of the

Stressed Skin
Structure

plywood box unit, assembled with glue to conform to the "stressed covering" principle, as a structural unit for prefabricated houses. The surfaces reflect a large portion of the radient heat that strikes them, and when used in conjunction with small air spaces are efficient insulators. Most of our modern timber construction follows this principle.

Mr. Gropims is one of the best known German architects. According to him: "The dwelling house should no longer look like a fort or a monument.

Its walls should be of light construction and many windowed, and it should aim at 'a beautiful life at home at the least possible cost of space, material and building expense'".

Therefore, the beauty of a modern house consists of opened walls, light structure expressive of buoyancy, clearly defined simple forms, harmonized proportions of all building parts, complete satisfaction of every material and psychic requirement.

On a previously laid concrete foundation was erected a steel frame employing channels for sills and girts, I-beams for floor framing and Z-bars for studding. In his house the curtain walls were built of 3" pressed cork sheets covered with asbestos board and floors of wood planks. The possibility of prefabrication of tall dwellings is one of the important items of Gropins' theory.

Skyscraper

At this period many other architects were thinking about changing the shape of the structure and Corwin Wilson was one of them. He tried to make trailers as permanent living quarters. The tensile strength of plywood was utilised for this egg-shaped structure. His experimental model was actually constructed in the year 1937.

There are other houses like igloos, houses like trailers, houses made of corrugated steel, bubble houses of cement blown into the surface of inflated ballons, egg-shaped, round, hexagonal, octagonal houses; but none of them solved even the major part of the problem of prefabrication. This is because the demand for such a type of housing was uncertain. The cost was not low or attractive enough to the prospective home owner to invest in a new type of structure.

DESIGNING FACTORS AND TECHNIQUE OF SITE WORK

Responsibility of the Designer

The main reason why the prefabrication system failed was because the pattern of prefabrication was lacking in one or more departments. Some concerns stressed factory fabrication with little thought to design or erection; others put the importance on new materials with little stress on factory fabrication. The person who can coordinate all these steps might be termed as a real prefabrication designer. It requires a flexible mind because he will act as an amalgam of technician, architect, artist and organizer. He must keep a thorough knowledge of materials---their qualities, characteristics, structural strength and limitation; of factory fabrication---mill procedure and organization; of site fabrication; of field erection---organization of crews and procedure of construction; of cost, transportation and architectural design.

Selection of Building Materials

Since the ideal material, unvarying homogeneous substance requiring no tolerance for expansion and contraction is not available, the problem of dimensional variation must be met. In the design and assembly of actual parts made of existing materials, compromises must be made. Except for this expansion and contraction, and its tendency to warp and twist, wood is an ideal building material. Its strength and resisting qualities can be increased by certain chemical treatment. The development of improved glues, synthetic resins, has resulted in new plywoods that are said to have enduring structural strength and lasting moisture resistance. One of the most important improvements is the plywood panel, impregnated and bonded with phenol formaldehyde resin, which is much stronger than ordinary wood. Plywood resists change of dimension and warping to a great extent, and is manufactured with a minimum waste of materials and is relatively inexpensive. Wood pulp, long used for paper, is now made into rigid board for inside use.

Due to heavy war drains on lumber and an increasing scarcity of growing timber are two important reasons for which substitutes have been developed. Houses of various materials such as of steel, aluminum, and plastics are not coming into use. There are many little known but plentiful minerals suitable for use in building materials, particularly in lightweight concrete blocks and in wall boards. They are already capturing the timber field. There are also new resins and glues by which former unusable organic matters are combined into building panels of great strength and durability.

The lightweight metal has several advantages and that is why aluminum promises to be one of the principal building materials of the future. At present two types of aluminum houses are in use. One is the so-called Butler-built of traditional design and the other is the Fuller house which is circular in shape. Another advantage of new materials is that they are

Light metals

in 'on-the-job' construction. The main reason is that the metals usually require machine-tools for cutting and shaping, and panels of wood or wood substitutes, bonded by a resin, require pressure to perfect good union.

Magnesium alloyed with aluminum is much lighter than aluminum and is rapidly coming into use in the construction of buildings. Titanium is another light metal and is the ninth most plentiful chemical element in the world. This metal is exceeded only by iron, aluminum and magnesium in metals suitable for engineering usage. Its oxide is one of the principal pigments used in white paints. The other plentiful lightweight aggregate materials suitable in construction that are now available in this country include haydite*, foamed slag, cinders, pumice, diatomite, perlite and vermiculite. Vermiculite gives a concrete weighing only from one-eighth to one-third the blocks or panel of equal size made with sand or gravel.

Other notable advances in masonry products are air-entrained concrete, new glass bricks, gypsum slabs for floors, synthetic stones and aerated ceramics. Gypsum and mixtures of asbestos and cement formed into rigid boards are increasingly used. It is relatively cheap and comparatively free from dimensional variation.

Lightweight aggregate

The recent introduction of air conditioning into houses has directed attention to insulation for different purposes, that of preventing condensation; and the most suitable form of insulation consists of bright metal surfaces such as aluminum foil.

---

*Haydite is made from the great variety of clays and shale. Foamed slags are made by treating hot molten blast-furnace slags with water. Pumice is a siliceous mineral of volcanic origin. Diatomite is composed of deposits of siliceous shells of microscopic aquatic plants called diatoms. Perlite is a natural volcanic glass. Vermiculite is a mineral that expands up to 30 times its original volume by a simple heat treatment.

APPLICATION OF ENGINEERING PRINCIPLE IN CONSTRUCTION

The application of engineering principles to the design of houses presents a complete and logical method for determining allowable loads for walls, floors and roofs. It also makes it practicable to develop house constructions that have sufficient strength yet require the least amount of material and labor. The Bureau of Engineers followed the procedure of applying loads to specimens which accurately reproduced the most important parts of a house. For each part the prescribed methods of loading in the laboratory stimulated the actual loads under working conditions. It is possible by this method of testing to determine the structural properties of a new construction without waiting for a performance test over a period of years.

Floors are subjected to transverse, concentrated and impact loads. Transverse loads may result from the weight of furniture and persons; concentrated loads occur under the furniture; and impact loads are caused by objects falling on the floor. For roofs some tests were performed by taking into consideration the action of wind, snow and weight of workmen and tools.

The wall specimens were also tested for resistance to compressive, transverse, concentrated, impact and racking loads simulating the loads to which walls of a house are subjected. In actual service, compressive loads on a wall are produced by the weight of the roof, second floor and second story walls, if any, by furniture, occupants, and by snow and wind loads on the roof. Transverse loads on a wall are produced by the wind; concentrated and impact loads by furniture or accidental contact with heavy objects; and racking loads by the action of the wind on the adjoining walls. For nonload bearing partitions, impact loads may be applied accidentally by furniture or by a person falling against the partition, and concentrated loads by furniture or by a ladder or other object leaning against the partition.

The deflection and set under each incurment of load should be measured, because the suitability of a construction depends not only on its resistance to deformation when loads are applied but also on its ability to return to its original sise and shape when loads are removed.

Each specimen should be tested in accordance with B.M.S 2 of the National Bureau of Standards. This latter test will also give the requirements for the specimen and describes the presentation of the results of the tests, particularly the load-deformation graphs.

This approach has opened the way for designers to introduce unconventional materials and unusual methods for fabrication through laboratory tests to determine whether the construction possesses adequate strength.

BUILDING CODE AND SPECIFICATIONS

The United States Department of Commerce has recorded a voluntary standard of minimum requirements for one-story and two-story prefabricated homes. It includes specifications for light and ventilation, space excess, structural requirements for various parts, thermal insulation and condensation control; and requirements for heating, plumbing, and electric wiring.

<u>General Requirements</u>

1. Each room shall be provided with natural light and ventilation by means of glazed openings. Ratios between the areas of openings for light and ventilation shall not be less than shown in the table below.

Type of Room or Space	Glass Area	Openable Area
Living room, dining room, bedroom, laundry, utility room	1/10	1/20
Kitchen	1/8	1/16
Bathroom and water-closet compartment	1/10	1/20
Spaces between ceiling and roof		1/300
Basement	1/50	1/50

2. Every dwelling unit shall contain at least one bedroom, one bathroom, one living room, and facilities for cooking in separate rooms.

3. Minimum height for each story shall be: basement - 7 ft., main story - 7 ft. 6 in., second story - 7 ft. 6 in.

4. Each habitable room shall have access to each other without passing through a bedroom or bath.

5. Manufacturing tolerance shall be such as will assure assembly and erection in accordance without creating unanticipated stresses.

6. All sections, panels, materials and equipment shall be protected against damage at all times prior to the completion of the dwelling.

7. Erection shall be in accordance with the manufacturer's drawings and instructions.

8. Before a proposal can be supported for an experimental building license, it must show a degree of technical efficiency and must conform with recommended standards for structural stability, thermal insulation, fire-resistance, resistance to moisture penetration and vermin infection, and must have a party wall that will prevent the propagation of sound.

Strength Requirements

1. Foundation shall conform to the requirements of B.M.S. 107. Foundation walls must be large enough to spread the weight over the supporting subsoil and deep enough to extend below the frost line. Basement walls should be waterproofed and drainage tile laid around the basement footing in order to prevent the accumulation of soil water along the wall surface.

2. Strength of each element joints shall be determined either by structural analysis or by comparison with certified test data for generally similar elements.

3. The builder should guarantee that the structure is heavy enough to sustain a load of 40 lbs. per sq. ft. on the first floor, 30 lbs. on the second floor and 20 lbs. on pitched roofs. Where annual snowfall exceeds 60 inches, the roof shall be heavy enough to support 30 lbs. per sq. ft.

Tests shall be made in accordance with the procedures of:

(a) The National Bureau of Standards, Washington, D. C.

(b) The Forest Products Laboratory, Madison, Wisconsin.

(c) The American Society for Testing Materials, Pennsylvania.

SPECIFICATIONS FOR FLOORS, WALLS AND ROOF LOADING

Nature of Loading	Floors	Walls	Roofs
A. Uniformly distributed load 1. Live load	1. 20 lb. per sq. ft. for attics 2. 30 lb. per sq. ft. upper story 3. 40 lb. per sq. ft. main story	Load obtained by multiplying wind* vel.-press. (at 30' high above ground) by .9 or 1.1 for main or upper wall(story).	For 40° slope or less 20 lb per sq. ft. of horizontal For greater than 40°slope: 12 lb per sq. ft. of normal to new surface projection
2. Permitted deflection	1/360 of C.S. for plastered surface	Same as floor	Same as floor
B. Concentrated Load 1. Design load (acting at weakest point of panel on an area having 1" dia.)	1. 150lb. for floored attics 2. 250lb. for other cases	50# acting transversely	200# acting vertically
2. Permitted deflection	1/270 of the C.S.**	1/360 of C.S. for interior surface 1/240 of C.S. for exterior surface	1/180 of C.S.
C. Impact Load (By drop of a 10" dia. 60# sand bag) 1. Designed load under 2' drop " 4' " " 6' "	1. .... 2. Rejection if any damage 3. Rejection if any failure	1. Rejection if any damage 2. Rejection if any failure 3.	Same as walls
D. Compressive & Tensile Load 1. Design load (wind, snow & dead load)		Resulting force applied on a line 1/3 of wall thickness from inside face.	
2. Allowance		Rejection if any damage	
E. Racking Load 1. Design load		Assume equal distribution of racking load throughout the total length of all positions between door, and window opening.	
2. Permitted Displacement		1/8 inch (for 8'x8' panel)	

* Snow and wind loads must fulfill the requirement given in B.M.S. 107   ** C.S. = Clear Span.

4. Where the house is built without a basement, air vents should be installed in the foundation walls to prevent dead air pockets beneath the frame construction.

5. Where plywood is employed as the exterior surface material and is exposed to the weather, it should be bonded with waterproof, resinous glue and should meet the requirements of commercial standards C.S. 45-40 of the National Bureau of Standards.

Other Requirements

Chimneys: All chimneys and flues shall have masonry foundations and shall extend at least 2 ft. above flat roofs and one foot above the highest ridge of a pitch roof. Fire clay flue linnings shall be built into all chimneys, the walls of which should be less than 8 inches thick.

Insulation and condensation control: In order to have effective insulation the ceilings and floors of a house, as well as its exterior walls, must be fully insulated and windows and doors must be weather stripped. Homes with very large window areas shall be supplied with double pone windows having an insulation air space between the two glass surfaces.

Means shall be provided to minimize condensation on concealed or exposed surfaces of the dwelling and within spaces and materials thereof.

Electrical wiring: Both the materials and the workmanship employed in wiring a house should comply with the National Electrical Code. Several municipalities have passed ordinances requiring observance of this code, and fire insurance companies may refuse to insure premises which are not properly wired.

Plumbing: Materials and installation should be in compliance with the "Plumbing Manual" (B.M.S. 66) issued by the National Bureau of Standards.

Prefabrication Practice

There are five methods of construction which are the following:

Precut or ready cut method: The materials are cut to proper sizes, shapes and numbered in the factory. Local workmen assemble them according to the plan; and utility lines are installed in the course of erection exactly as in traditionally built houses.

Panel method: This method saves only a little more time at the site than the former one. Building materials are assembled into large walls, floors, ceiling and roof sections for quickening the process of erection. It is still necessary to apply some other finish to the interior and on the exterior portions of the building. Modular panels are designed to offer various types of houses simply by changing the arrangement of panels.

Sectional method: Instead of sending prefabricated parts in this case each section would contain one complete portion of the building: floors, walls, ceiling and roof with the plumbing and lighting equipment, bath and kitchen fixtures, heating facilities, windows, doors, even the clothes hooks in the closets and the towel racks in the bathroom installed at the factory.

Complete assembly method: This type is seldom used due to the difficulty of transporting a complete house from the factory to the site.

Cast Concrete method: This is quite a new method and may be divided into two catagories. The first is the precasting of the lightweight concrete into large floors, walls, ceiling and roof panels which are then carried to the site and erected into place by a movable crane. For heavy construction elaborate moulds are transported to the site and into these quick drying concrete is poured so as to form a complete house in one operation.

PREFABRICATION IN TIMBER

I. Selection of Wood for House Parts

For exposed exterior wall panels plywood made of phenol-resin glues of equal water resistance and durability are generally used. But the panels which are not under direct exposure are made generally with moisture resistant glues such as soybean or casein. Moisture resistant plywood of wall board grade is suitable for painted interior wall panels. However, in kitchens, bathrooms, or in places of unfavorable humidity, resin glued plywood is recommended.

Though exterior-type plywoods are more durable than the moisture resistant type, the latter can be used safely even in a dry climate if the moisture condition is favorable, i.e., no leaking through the roofs.

Floor panels should be selected from the denser hardwoods..

It is impossible to select an 'ideal' wood for a specific job. The wood which has high bending strength is sometimes found weak in stiffness. For specific reasons we have to make some compromise and adjustments---a wood that has low decay resistance can be treated with preservatives to fit it for the job and so on.

II. Design Principle

Prefabrication with stressed plywood panels occupies an important position in all wood construction, and all modern timber houses are designed on this principle.

Each panel consists of two plywood faces glued to either side of an inner structural framework to form a box girder. This helps the entire panel to act as a unit similar to a box girder, and as a result it will

HOUSE PARTS	RECOMMENDED TIMBER	QUALITIES NEEDED
Structural Members	Southern yellow pine, Douglas fir, eastern hemlock, spruce, white fir	High bending strength and stiffness
Roof Boards	Douglas fir, western larch, southern yellow pine, hemlocks, ponderosa pine, white fir, spruce	Good nail holding power high stiffness, little tendency to warp
Flooring	Hard maple, oak, beech, birch, black walnut	Living room floor: minimum warping and shrinkage, high resistance to wear. Kitchen floor: ability to withstand washing and high resistance to wear.
Sub-Floors	White fir, larch spruce Douglas fir, southern yellow pine, hemlocks, ponderosa pine	workable, good nail holding power, high in stiffness
Siding	White pines, western red cedar, red wood	No warping, workable, good painting characteristics
Shingles	Western red cedar, northern white cedar, red wood	High decay resistance, no splitting during nailing, little tendency to curl.
Sash	White pines, red wood, bald cypress	No freedom for warping, workable, good paint qualities, screw holding power.
Girders, Posts, etc.	Douglas fir, western larch, southern yellow pine	High string and good decay resistance

deflect only fractionally as much under a given load as would the framework and faces when nailed together.

Calculation of Strength and Stiffness of Panel:

If 'b' is the basic width between longitudinal members and 'h' is the thickness of the plywood cover, the strength and stiffness of the panel can be determined from the formula:

$$b = 31\,h\sqrt{\frac{h}{\text{parallel plies thickness}}} \qquad \text{for three plies}$$

and,

$$b = 36h\sqrt{\frac{h}{\text{parallel plies thickness}}} \qquad \text{for five plies or more}$$

Any clear width of covering in excess of 'b' between any two longitudinal members should be neglected. If the clear distance is greater than '2b', the panel should not be considered as having stress covering.

The stiffness can be obtained by calculating the moment of inertia of the section and from known values of modules of elasticity of the section.

Strength Variation Due to Opening on Stressed Cover Panel:

Generally the covering of a stressed cover panel is designed to carry a portion of the total load imposed on the panel, so the effect of openings cut through the stressed covers must be considered in computing the strength and stiffness of the panel. Reduction in strength or stiffness cannot be assumed from the decrease of moment of inertia because the reduction in strength is not so great as that of inertia, while stiffness at design load appears to be little affected by holes in the stressed covers. For a large size opening it should be reinforced with additional joist extending the full span length.

The exterior panels are constructed with 3/8 inch three-ply plywood on the outside and 1/4 inch three-ply plywood on the inside. The general size of the panel is 4' x 8' x 3". The frame work consists of vertical members made of 1" material 2 3/8" wide, spaced approximately 1' apart with two end headers to which plywood faces are glued. The plywood projects beyond the framework of the panel forming a continuous right angle groove.

Wall Panel Construction

The upper face of the floor panel is of 5/8" plywood of five plies and the lower faces are glued to a structural framework consisting of three nominal 2 by 6 inch members placed 2 ft. apart with end headers. All parts of the panel acts as a unit and therefore the panels can be substituted for the usual 2 by 10 inch joists spaced 16 inches apart as ordinarily used in house construction. With the exception of the kitchen and the utility room the upper 5/8" plywood is faced with birch 1/8" thick to form the wearing and finished floor surface.

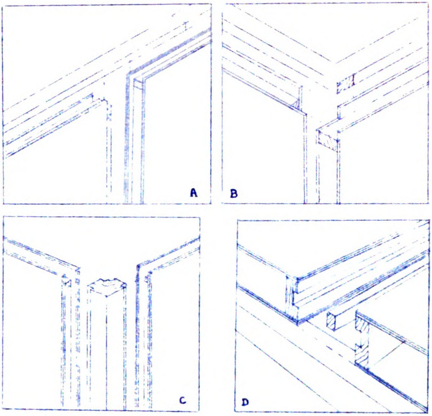
Floor panel Construction

The flat roof and the simple gable roof are the most readily prefabricated type. Stressed cover panels are particularly suitable for flat roofs because such panels are especially box beams, thus providing both coverage and strength. Since deflection under is the critical factor in employment of such a panel, stiffness is generally the most important property for which these panels are designed.

Roof Construction

Pitched roofs can be designed for complete prefabrication, usually the gable ends are prefabricated in sections for quick assembly at the site. In roof construction various types of trusses have been adopted in order to allow greater flexibility in layout of rooms.

PANEL JOINTS



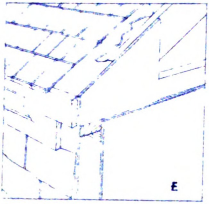
A. Joints between panels with the help of male and female studs

B. A typical corner joint with cover of one panel overlapping edge of the other

C. A corner joint with mullion

D. A spline joint

JOINTS BETWEEN ROOFS AND WALLS



E. A truss-type roof.
The upper chord is firmly held to lower chord of truss with nail-glued gusset plates and truss fastened to wall plate.

Joint Design:

The joint design is very important in prefabricated house construction because it governs to a great extent the degree to which parts are interchangeable and the ease with which the structure can be erected.

The function of these joints is to resist both lateral and lifting forces exerted by the wind and resist the outward thrust. This joint transfers loads from pitched roofs to the walls without exerting appreciable thrust upon the walls. The gusset joint between upper and lower chords is an excellent device for transfer of load stresses from the rafter to the joint.

Between Roofs and Walls
Fig. E

The Forest Products Laboratory has designed a joint for flat-roof houses employing stressed covered roof panels. The amount of thrust action on the walls from roof loads depends upon the amount of deflection produced in the panel by the loads. If panels are designed for adequate stiffness, thrust action under load should be reduced to a negligible amount.

A tongued and grooved joint is the most common form of stressed cover construction. This joint is usually nailed and the male stud is often beveled to permit easier fitting during site assembly. A mullion joint is a prototype of the former one. It serves as a spacer between panels and is usually nailed into place between edges of panel covering material. It also serves sometimes as a load bearing member. Mullion type corner joint has the advantage that it permits a flush exterior joint between panel and mullion that does not require a corner cover board. Tongue joint is adoptable for corner and partition joining. Spline joint is used to connect floor and roof panel as a load-transferring member.

Panel Joints
Fig. A-D

The joint is proportionately stiffer as its vertical dimension is increased. Sometimes it is fitted in place without glue.

In timber construction glue is the strongest bonding material. The quality of a glue joint is determined by tests under shearing loads; if shear failure occurs near the glue bonds, in such a test, the strength of the bond is considered to approach that of the wood in shear. Glue must be applied with pressure, and the maximum permissible gluing pressure is fixed by the crushing strength of the wood. Lack of adequate and well-distributed pressure is sometimes the cause of defective joints. In nail gluing size and spacing of the nail, proper driving and direction of nailing are important factors; but in pressure gluing attention should be paid to adequate distribution of pressure and maintenance of proper temperature. For hardwood joints applicable pressure varies from 150 to 200 lbs. per sq. in. A low pressure between 100 to 150 lbs. per sq. in. is desirable for softwood joints.

Glue Joints vs. Nail Joints

The gluing surfaces of framing members should be planned to a tolerance of at least 1/64" to assure smooth joining surfaces. The factors which govern allowable tolerance include: (1) the capability of machines to approach design dimensions under commercial operating conditions, (2) the property of material being worked, and (3) the extent to which design dimensions can be exceeded on the plus or minus side. Again the amount of tolerance which should be allowed depends entirely upon the nature of the house to be built and also on the physical and machining properties of the materials. Under the best machining conditions and with proper care, a tolerance up to $\pm$.0005" can be obtained.

Allowable Tolerance

To retard the transmission of water vapor into the wall or roof, moisture barriers are used. If the barrier is so located that the temperature on its warm side is above the dew-point temperature of the room, then there will be no condensation on the barrier. The materials which act as good moisture barriers are asphalt-impregnated kraft paper, duplex sheets, double faced aluminum foil mounted on paper core or insulating materials mounted on a vapor resistant paper. Some of the phenol-resin-impregnated papers are very good as moisture barriers. All the moisture barriers are generally placed within the panels and against the back of the face near the inside of the rooms.

Moisture Barrier

Flexible or blanket type of insulation is generally used for insulation of floors and walls. Fill or batt type is used where the wall space is to be filled completely with insulation. One type of reflective insulation is made by cementing aluminum foil to a strong back of paper. Then sheet steel coated with a non-corrosive material is also another variety of reflective type. In many cases cork blocks, corrugated boards, processed paper blankets, honey combed paper products are used. They also can be used in partition walls to check sound transmission.

Insulation and
Fire Resistance

Resin bonded plywood is generally used for inside walls because they offer greater resistance to fire than plywood glued with vegetable glue. To secure greater resistance a mineral wool of high density is often used as an insulating material.

The Forest Products Laboratory test data helps to determine the thermal conductivity of a given wood at known moisture content. Thermal factor effects stressed-cover panel thickness; so in stressed cover construction, the designer should first determine the size

Thermal Factor

of the framing members and wall thickness required to support all loads imposed.

Good spraying requires highly skilled workmen capable of gaging the amount of paint applied by a nice sense of timing together with knowledge of the equipment and its adjustment. Painting at the factory presents two great problems, (1) that of transporting and erecting painted units without much damage, and (2) that of providing for drying of coatings without extra floor space and delay in production. Generally a sealer and a coat of primary paint should be applied at the factory. For flat panels rotating rollers are very convenient. To apply sealers and water repellents, a dipping process is used; but it is unsuitable for top coats. The drying of paint coating can be hastened by controlling the temperature at 140 deg. F.

Painting Technique

Better Construction

Inspection of raw materials is essential for checking physical defects. During processing dimensional accuracy should be checked by standard instruments primarily to parts involving critical joints. The jig governs the dimension of the finished parts to a degree of precision depending somewhat upon its construction. True alignment of the bolt holes in the top of the jig is essential for precision assembly of framing panels. Inspection of workmanship is also necessary for controlling the quality.

Quality Control

Pneumatically operated jigs permit rapid assembly of simple panel components. Where production volume permits, jigs can be set up for mass production of parts. In large scale production handling of frameworks and panels in various stages of construction should be done by conveyor systems.

Overhead conveyor systems are suitable for painting and other finish work on panels. The continuous moving belt or chain conveyor system is very suitable for mass-scale production, but their use is limited because it requires very slow speed inside to give opportunity to the workers for applying glues, nails, insulations, etc.

Production Control

PREFABRICATION IN CONCRETE

Precast units erected as complete structures had been used at the end of the last century so the idea of precasting reinforced concrete parts is an old one---as old as reinforced concrete itself. With the development of new techniques and due to present day housing demands, this branch of reinforced concrete structure is again gaining in importance. Now a precase concrete is just as strong and durable as site cast concrete. If we consider the vast number of concrete structures that have been built in place or with structural units, we find that the percentage of failure is very small. This is because the experienced producers of precast parts have always avoided the mistakes that caused defects under actual service conditions. Precast reinforced concrete has, however, proved a great success in the Soviet Union, Great Britain, Australia and Germany. Although the production of precast units has steadily increased during recent years in the United States, its future market will be determined by its quality, design principle and efficiency of production.

Advantages of Precast Construction

1. Factories are better equipped with tools and machinery, and the permanently employed labor becomes more skilled and better organized.
2. The cost of moulding and scaffolding can be minimised by adopting standard sizes.
3. It results in higher quality concrete, less shrinkage and more accurate placing of reinforcement because technical control in the workshop is better than on the site.
4. The production of precast units in the factory is independent of climatic conditions.

5. It is easier and faster to erect and dismantle the structure.

6. Wastage is minimised and so ultimate cost is low.

Method of Design

They may be classified into three groups. The first one replaces

Subdivision of Monolithic Structure

monolithic design by prefabricated units of similar shape but in a workshop and hauled to the job. The precast parts are placed in position and joined so as to reproduce as nearly as possible the monolithic structure from which they have derived.

The second one employs standard units such as columns, beams, joists,

Special Design of Structures

slabs, etc., which are designed as self-contained units with a special view to their convenient manufacture, handling and erection and with certain resistances to specified loads.

The combination of both precast and in-site concrete is designed in such a way that the precast units make up a self-supporting skeleton. At

Combination of Prefabricated Units with Parts Cast In-site.

the same time, they also form the complete moulds for the remaining part of the structure to be cast in-site.

In the first two methods it is essential that the connection between the prefabricated units restore perfectly all the continuity qualities possessed by the monolithic structure.

Treatment of Concrete:

Selection of fine and coarse aggregate of suitable quality and thorough mixing of concrete are two important factors in making good concrete. Sufficient time for proper mixing should always be provided. In otherwords, mixers of adequate capacity must be used so workmen do not have to neglect the time element to meet production schedules. Timing devices should be installed on mixers so the operators do not have to guess. Moreover, clearing devices should be installed in mixers so each batch is completely discharged. Otherwise, lumps of concrete mixed in the early morning may be used in concrete units and structures several hours later. This retampered concrete accounts for structural defects later in service.

Grading and Mixing

When concrete of semi-dry consistencies is employed, experienced manufacturers find it expedient to dry mix the concrete; fine and coarse aggregates for at least two minutes to assure uniform dispersion of cement throughout the batch. This is very important. Then water is added and the concrete is mixed for two or three minutes. With plastic mixers an abundance of water is used to assure proper hydration of the cement and dry mixing is not so important. But concrete of plastic consistencies, too, must be thoroughly mixed for two or more minutes.

A dense high-strength concrete of low water content can also be produced by vibration. Vibration can be produced either internally or externally in the concrete by vibrators attached to the framework. However, in all cases the desirable degree of vibration must be determined by experience or tests. The advantages claimed for vibrated concrete are mainly due to the fact that much drier concretes can be used. By vibration greater density, increased strength, impermeability and durability, and better bond between concrete and steel can be obtained.

For plastic concrete pressure moluding is generally suitable. Excess water is removed by the application of high pressure amounting to one ton per sq. in. Very strong moulds are, therefore, required and consequently this method is only applied to a restricted range of products of simple form and moderate size. The advantages of pressure treatment are similar to those obtained by vibration.

For treatment of plastic concrete, the combination of vibration and pressure gives still greater compactness. This result is obtained in a shorter time than if vibration or pressure alone was used. In the combined method a low pressure is sufficient because the vibration facilities compress by rendering the particles of the mixture mobile. Similarly better and quicker results can also be obtained by the combination of heat treatment with vibration, or with pressure moulding or with both.

Importance of Curing

Proper curing of concrete with water, steam or a combination of both cannot, under any circumstances, be neglected in the production of sound, dense and high-strength concrete. No matter how much care has been exercised in the selection of aggregates, time of mining with proper amount of cement, it is of major importance to cure concrete to avoid structural and other defects and to assure a long life expectancy. Adequate curing prevents the evaporation of mixing water in concrete of semi-dry consistency which is needed to properly hydrate the cement. Proper curing also prevents the rapid evaporation of the free water in plastic concrete mixtures thus minimizing volume change, including shrinkage, cracks and other objectionable defects. Careful curing of precast concrete floor and roof gives maximum density, impermeability and strength.

Advantages of Curing

The advantage of steam curing over water spray is the high temperature

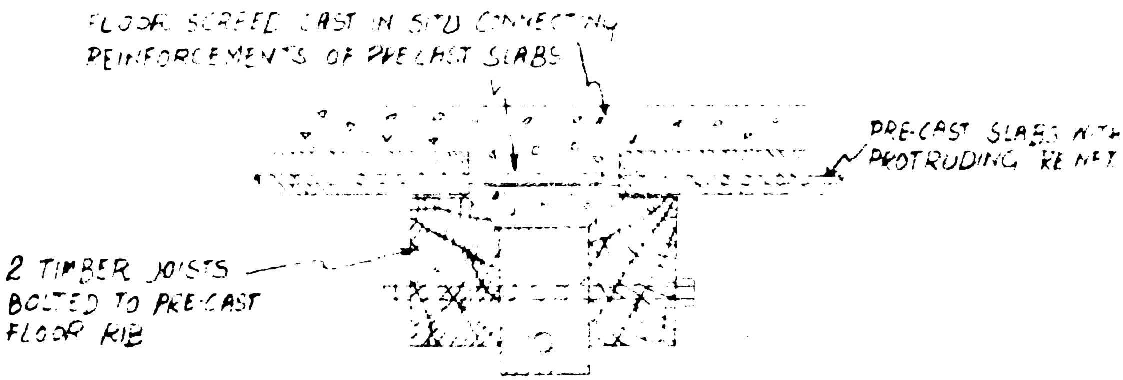
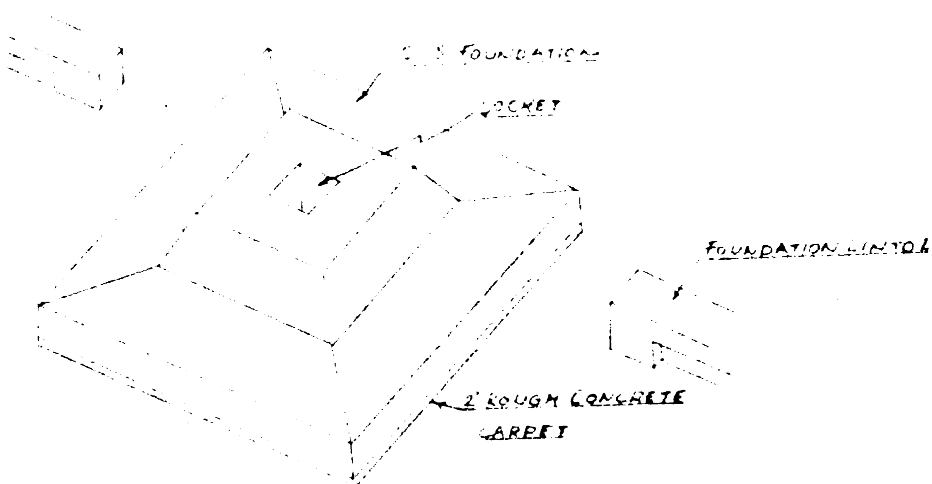


Fig. 1



SOCKET FOUNDATION

which accelerates hardening of concrete. In southern climates steam curing is not so necessary because water spray is just sufficient provided the units are kept constantly wet.

Infra-red curing is also used sometimes in the precast industry. One advantage derived from accelerated curing is earlier freeing of moulds so that in mass production, the mould can be restricted to the money expendable on the mould requirements for two to four hours instead of from twelve to twenty-four hours.

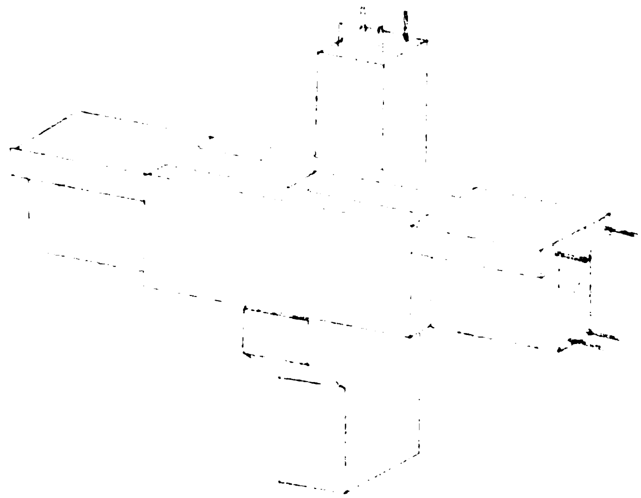
Precast concrete being factory-produced can be more easily controlled than other forms of concrete,and therefore, full advantage can be taken of improvements in strength and other qualities resulting from careful grading, batching and mixing. The controlling fact in the strength of any mixture is the ratio of water to cement, and this can be far more easily maintained under factory conditions than it can be done outside on the site. Again, the whole economics of precast concrete depends upon a proper choice of aggregates with regard to type and sise, and the suitable proportioning of these together with the cement and water in the mixture. By making the right choice and maintaining the relationship, the time of curing may be determined.

Joint Design

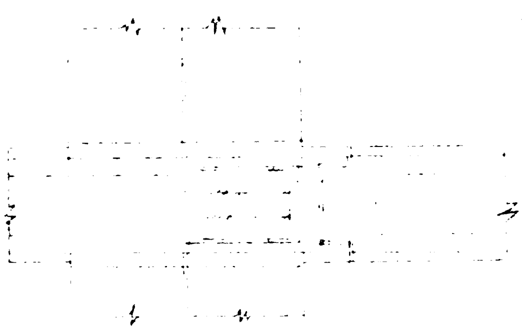
The value of joint between two precast units is measured by the degree to which the continuity qualities possessed by the corresponding monolithic structure are provided by the joint in question. Beam joints may be sub-divided into three classes---rigid metal joints, welded joints and joints by concrete case in-site.

Rigid metal joints consist of steel chanels or angles fixed to the ends

JOINT DESIGN



FULL CONCRETE SPIKE



FULL SOCKET TYPE

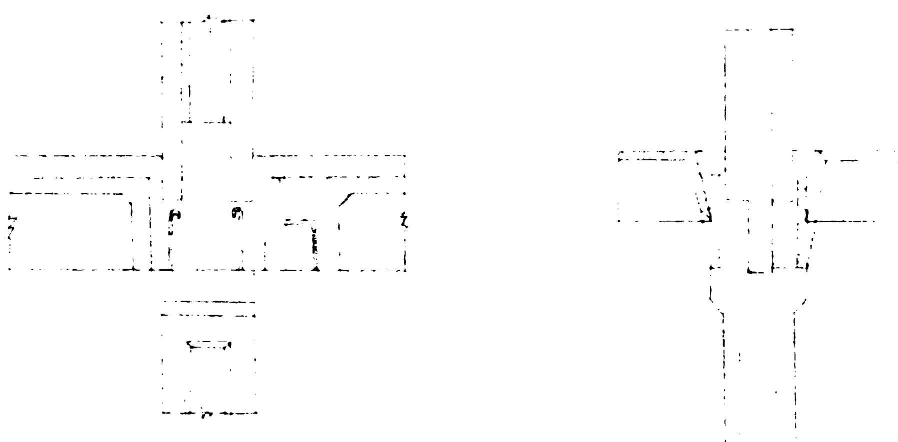


Fig. A

of a beam. During the cast of a beam the reinforcements are held at the ends by templates to ensure that they will register with the holes in the steel section. The space between the prefabricated units at the joints are filled with concrete any time after the connections have been made. Fig. 1

The welded joints connect corresponding bars which during manufacture have been left exposed. This type of joint requires only a small space between the units which is later filled in with high-grade cement mortar.

A joint by concrete cast in-site should have roughed surfaces on those parts that come in contact with the in-site concrete. There should be no reinforcement projecting beyond the over-all length of the unit. To improve the bond between concrete splices cast-in-site and precast units, a few vertical concrete nibs or bosses are sometimes cast on the ends of the prefabricated units.

Joint Between Columns: Columns need some temporary location during the time of joint construction but it is difficult sometimes to make accurate connection between columns. This is due to (1) difficulty of keeping the upper column in proper position until the poured concrete has hardened and (2) difficulty in getting full contact at the top surface of the joint. Sometimes metal joints have been used for connecting columns of large cross-sections. However, these joints are very expensive and require a large amount of steel. Another kind of connection between columns is illustrated in Fig. A. The main beam,which is in channel form, is placed with the sides of the channel on brackets forming the head of the lower column. The only reinforcement projecting into the connection is the main bars from the lower column. After the upper column has been placed, the socket is filled with concrete.

Considerations in Floors and Beams Design

For the purpose of decreasing weight a rectangular cross-section of beam may be improved by reducing the depth at the ends of the beam and by providing openings near the neutral axis at mid-span.

The tee-section is economical in resistance to bending and may be improved by varying the width of the flange reaching its maximum near mid-span, in accordance with the diagram of the bending moments. In a similar manner the web thickness may be varied in accordance with the diagram of the shear forces.

The I-section with stiffeners may be improved for the purpose of providing uniform resistance by thickening the top flange and narrowing the web towards the mid-span. The size of the bottom flange is generally defined by the amount of main steel embedded and could be decreased also towards the supports, if some of the reinforcement bars were bent upwards to assist the shear resistance of the concrete web. Prefabricated I-shaped concrete beams are sometimes used for erection of complete precast houses. Whether it is to be used as a beam or as a part of a wall, every unit has the same cross-section: 9" deep, with a web 1" thick, and flanges 6" wide.

Trussed beams are applied with advantage to longer spans where a large percentage of bending resistance is taken by the structure itself.

While deciding a type for a given job, one must consider first the amount of monolithic action required in the finished floor. Then attention should be paid to decrease the weight of the unit.

All joints, beams, girders and other floor units should show some mark plainly indicating the top of the unit and the size of the main reinforcement. This mark should also indicate the length, size, type of reinforcing and the carrying capacity of the unit.

Factor of Safety in Design

The determination of factor of safety in precast construction is quite different from that of monolithic reinforced concrete structures. The allowable load on a unit is usually determined by dividing the breaking load by load factor. The American Concrete Institute recommends for the test of such an individual unit as a simple beam, that it shall sustain without complete failure a load of at least 2.25 times the design load based on allowable stresses in bending and shearing as given in its regulation. With regard to allowable deflection, the member shall be considered to have passed the test if the maximum deflection at the end of twenty-four hours does not exceed a value equivalent to the square of the span divided by 12,000 times the total thickness of the member.

Production Technique

All production plants follow more or less the same type of casting operations. For straight line production method each casting yard must have at least a few steel trucks on which the steel casting tables should run. Before casting each table is cleaned with mechanically operated steel brushes or by an air hose or liquid soap. Outside forms are then set and locked to the table. All surfaces to be exposed to the concrete are then treated with a parting agent---a mixture of liquid soap thinned with gasoline. Bucks are then bolted to the side form for windows and doors and inserts are placed for roof slab openings. Since each table is used for casting a particular type, the door and window bucks must be cleaned and placed at locations handy to the respective tables on which they are fitted. Reinforcement is then set in place and concrete is poured in the form by a mechanically operated conveyor belt which receives its load from a hopper suspended directly over the belt. The conveyor belt is rigidly framed and runs overhead on tracks. With this belt being movable and the table carrying the form running on a track at right angles to the belt, every part of the form can be brought under the hopper-gate mouth. When the form has been filled, the concrete is vibrated and the table is pulled by a small lift truck to the finishing yard. The truck has a special arm that engages the bottom angle of the table. When the table has been brought for towed finishing, the arm is dropped and the truck returns to the next vibrated table. The table passes through the curing room (for approximately four hours) to the steaming room. When panels have steamed for approximately six hours, they are moved out to a rotator located underneath the craneway. Panel sections are then rotated to a vertical position and made ready for delivery.

New Erection Technique

Recently a very important improvement has been made in the method of tilting the walls into place. With the help of new power equipment, mass production and also reduction of reinforcing steel in walls can be made possible. This idea, to use a lifting device of structural steel sections fastened to the wall, is to take the stress of erection. After the wall is tilted into position, the lifting rig is removed and is used to tilt another wall in the same way. The steel is only used to take the temperature stress. Another method suggested was that of casting the entire wall on a pallet which will take the erection stress and then tilting the panel up. This would enable the walls to be tilted up in twenty-four hours to thirty-six hours, after casting. The pallet would swing free of the wall after the wall has reached the vertical position.

The concrete floor of the building can be used for casting the walls in a horizontal position. The edge of the form can be adjusted according to the wall dimensions.

This plan offers wide architectural flexibility and lends itself to many economics and short cuts. The need for presently scarce mason labor is greatly minimized by this method and also carpenter's work is reduced to interior partitioning.

ROLE OF LIGHTWEIGHT CONCRETE IN PRECAST INDUSTRY

The most important development in concrete construction in recent years has been the production of lightweight units. Lightweight concrete is of two types, cellular and gas concrete, and those made with a lightweight aggregate. In the former one hydrogen gas bubbles are generated in a mixture containing lime or cement by the incorporation of finely divided aluminum or zinc powder. The cellular structure produced this way is retained after the cement has set and a lightweight product obtained thereby. Lightweight aggregates are either obtained from natural sources or are specially processed. The natural lightweight aggregates are nearly all volcanic in origin, pumice being the most widely used of this group. Processed aggregates include foam slag, expanded slate, etc.

Pumice stones have sp. gr. 1.12 and can be used for lightweight concrete construction having a crushing strength of 1500 p.s.i. at 28 days. The weight per cu. ft. of concrete is nearly 75 pounds. Time required for various operations concerned with the manufacture of slabs runs as follows: Pouring concrete - 12 minutes, vibrating - 7 minutes, finishing - 17 minutes, curing in steam tunnel - 6 hours, stripping from forms - 10 minutes and cleaning forms - 15 minutes.

In hot climatic regions pumice concrete was found to be very good. The material has inherent thermal insulation qualities, freedom from condensation, high degree of sound absorption, and can be made earthquake resistant and thoroughly fire proof. Beautification can also be made either interiorly or exteriorly to give each unit a 'different look'.

In wet localities, a prefabricated lightweight concrete house can be built that should prove entirely satisfactory if the roof is pitched to drain and provided the exterior concrete walls are waterproofed. Vinyl resins, pigments and solvents can be used as paints for this purpose. Three coats of paints applied in suitable colors would yield a waterproof job pleasing to the eye.

Pumice concrete and lightweight precast concrete houses presents a challenge and opportunity to both architects and engineers.

BIBLIOGRAPHY

1. Prefabricated Home Manufacturer's Institute, Washington D. C., "Modern Homes by Modern Method".

2. Graff, R. K., Matern, R. A. and William, H. L., "The Prefabricated Houses".

3. Portland Cement Association, "Tilt-Up Construction".

4. Carr, A. L., "A Practical Guide to Prefabricated Houses".

5. B.M.S.* -62 (N.B.S.*), "Structural Properties of a Precast Joist Concrete Floor Construction", sponsored by Portland Cement Association.

6. Portland Cement Association, "How to Design and Build Precast Joist Concrete Floor".

7. Billing, Kurt, "Structural Precast Reinforced Concrete".

8. B.M.S. - 26 (N.B.S.), "Structural Properties of Nelson Precast Concrete Foundation Wall Construction", sponsored by the Nelson Cement Stone Co., Inc.

9. Bruce, Alfred and Bank, Harold Sand, "A History of Prefabrication", (The John B. Pierce Foundation, Housing Research Division).

10. B.M.S.-104 (N.B.S.), "Structural Properties of Prefabricated Plywood Lightweight Construction for Walls, Partitions, Floors, and Roofs, sponsored by Douglas Fir Plywood Association.

11. Sheppard, Richard, "Prefabrication in Building".

12. B.M.S.-18 (N.B.S.), "Structural Properties of 'Prefab' Construction for Walls, Partitions and Floors", sponsored by the Harinschfeger Corporation.

13. United States Department of Commerce, "Prefabricated Homes", (Commercial Standard CS 125-47).

14. Bemis, Albert Farwell, "The Evolving House", Vol. #3.

15. B.M.S.-46 (N.B.S.), "Structural Properties of 'Scot-Bilt' Prefabricated Sheet-Steel Construction for Walls, Floors, and Roofs, sponsored by Gloves-Wernicke Co.

16. National Homes Corporation, Lafayette, Indiana, "Loading Tests of Prefabricated Wall Panel Sections".

17. B.M.S. (N.B.S.), "Methods of Determining Structural Properties of Low Cost House Construction".

18. B.M.S.-112 (N.B.S.), "Properties of Some Lightweight Aggregate Concrete With and Without Air-entraining Admixture".

19. Townes, C. A., Chief, Department of Regional Studies, T.V.A., "Design of Prefabrication: Some Personal Observation".

20. Hansen, Howard J., "Modern Timber Design".

21. McKenuee, O. W., "Prefabs on Parade".

Periodicals

1. Journal of American Concrete Institute, 1946-47.

2. Concrete, 1946-48.

3. Engineering News Records, 1947-48.

4. Civil Engineering, 1945-47.

5. Engineering, 1947-48.

6. American Builders and Building Age, 1944-46.

7. Architectural Records, 1942-47.

8. Architectural Forum, 1940-47.

9. American Lumberman and Building Products Merchandiser, 1948.

10. Science News Letters, 1947.

11. Pulp and Paper of Canada, 1947.

*B.M.S.--Building, Materials and Structures.
N.B.S.--National Bureau of Standards.