ABSTRACT

"PREFABRICATED BRICK MASONRY PANELS-
DESIGN, MANUFACTURE AND APPLICATIONS"

BY S. M. PASHA

Prefabrication of brick masonry panels is the latest development in the economical and effective use of brick masonry for walls and floors. Only since 1950's efforts have been made to know more about the structural behavior and physical properties of brick masonry, its component materials, to mechanize and industrialize building construction by employing various prefabricated elements and improving conventional construction procedure.

This major technical report is based on a survey of literature on different systems, of prefabrication of masonry panels, which have evolved industrial production. It further covers the general design, architectural aspects, properties of masonry, its component materials, areas of application and recommended specifications for prefabricated brick masonry panels including costs. Illustrative diagrams and figures have been included where ever possible.

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1. PREFABRICATED BRICK MASONRY PANELS

1.1 Need For Prefabrication of Masonry Panels

Most countries are facing an acute shortage of housing after World War II. Housing is not only one of the basic needs of man but also a symbol of his social culture and economic status. Construction industry is thus one of the oldest and important industries, but it has lagged behind the other manufacturing industries in employing industrialization.

Since 1950's, increasing efforts have made in industrially developed countries to mechanize and industrialize building construction by employing various prefabricated elements and systems and by improving conventional construction procedure. Brick masonry panels are one of the many prefabricated elements used primarily for housing.

The factors which influenced the introduction of prefabricated brick masonry panels are :-

a) Shortage of skilled labour.

b) To minimize the use of on-site labour.

c) No job down-time because of weather.

d) Brick masonry built under controlled conditions.

e) Fast construction methods.

f) Savings in materials and cost of construction in comparison with conventional methods.

g). Universal availability and economy of brick as compared to concrete and other materials.

1.2 History And Development

Prefabricated brick masonry panels were first used in France, Switzerland and Denmark during 1950s. There were adopted in North America in early to mid '60s. At present more than thirty countries are manufacturing prefabricated brick masonry panels. (Ref: 3)

The research carried out in these countries on brick and brick masonry regarding structural and physical properties has led to accurate design of brick masonry using rational engineering criteria which has made prefabrication feasible.

The early methods of panelization were attempted to mechanize the brick laying process to produce standard panels using semiskilled labour. Later on the tendency was to retain skilled labour using conventional masonry practices and devicing various means to increase productivity of labour, while is some systems the emphasis has been to fully mechanize the whole system of production.

Several methods of prefabrication were introduced. These methods of prefabrication have to pass through a three-stage evolutionary process. In the first stage prefabrication usually costs more than the conventional method of construction. Nevertheless prefabrication is considered necessary and desirable to supplement the traditional methods to achieve a certain scale of production and the level of technology which can reduce the total cost of construction. During this first peroid, government and other organizations may intervene to assure continuity of demand and to support programs of research and production, by loans, interest and capital subsidies and special forms of contracts. (Ref: 9)

In the second stage many systems which are non-competitive and unacceptable are weeded out. The successful systems are consolidated and given further support.

In the third (final) stage concentrated efforts are made to apply scientific methods to design, production, distribution, erection and standardization of prefabricated panels.

Some of the systems of prefabrication which evolved successfully through the above mentioned stages and are popular at present, will be discussed in the next chapter.

Other factors such as research with new and improved brick units and mortars have aided the rapid progress in prefabrication of brick masonry panels. These will be discussed in chapter 5.

A wide range of different types and systems of these panels indicate various methods of construction often dependent on conditions of climate in different countries.

1.3 Types of Prefabrication

There are many types of prefabrication which can loosely be categorized in two basic approaches.

a) Component Approach

b) Model Approach

1.3.1 Component Approach The objective of Component Approach is to achieve construction of buildings of almost unlimited variety by using a limited number of mass-produced masonry panels. This approach is also called "Open System", andis common almost universally.

It offers flexibility in production, in type and size of plant, the selection of panel size, design, use and architecture. The extent of mechanization can be varied to suite local conditions.

The connections of panels present difficult technical problems, since the structure is as strong as the joints. The success of Component Approach also depends upon the standard modularization of the component panels. (Ref: 9)

1.3.2 Model Approach or Modular Approach which is also called "Closed System" in prefabrication of brick masonry panels is refered to prefabrication of panels to suit a particular type or types of houses to be constructed. The inflexibility of use of panels, in this system, is a disadvantage. Also the soci[illegible] political and economical conditions should be such that a highly repetitive product is acceptable to the society. (Ref: 9)

Prefabrication systems can also be divided into two categories depending upon the method of prefabrication. These are (a) Hand Laid System and (b) Mechanized System. Both the systems are discussed in detail in the next chapter. (Ref: 3)

1.4 Costs

With the present data available it is difficult to reach any definite judgement on the comparative total cost of prefabrication and conventional methods. Some systems are claimed to have lower costs like "TECAB System" which is said to cost 75% of the cost of traditionally built brick or tile insulated walls.

In Eastern European Countries much efforts and resources have been deployed in building up large panels while less emphasis has been placed on conventional methods and as such the results of these countries show economic advantage for large prefabricated panels. While in other countries efforts have been made to modernize and rationalize the conventional construction which resulted in sufficient improvement in productivity in terms of man-hours. This makes the comparasion between prefabrication and conventional methods difficult.

The total labour cost may be low with prefabrication but it may be off-set by additional cost of materials and transportation. Additional material may be required for extra strength to limit the stresses due to handling and transportation.

Since the relative cost of finishes and services like plumbing and insulation is small in developing countries, prefabrication may compare favourably there than in developed countries.

Prefabrication technology is still evolving. Improved design procedures and use of high strength light weight masonry units may reduce the cost of materials and transportation, which will favour prefabrication. Development of pre-stressed panels may further reduce the cost and virtually panels of any size may be produced.

Continuous large scale production is essential to limit unit prefabrication cost to a level competitive with conventional methods. Some authorities concluded that it is economical to use factory made load bearing masonry panels only if at least 1000 dwelling units are erected (1 unit = 25 M^3); for 250 to 1000 units, precasting at site is economical; and for less than 250 units, prefabrication is not recommended.

Modified and high-bond mortars and costly. Their use calls for joint thickness to be as small as possible to save mortar. This in turn requires small tolerance in the dimensions of masonry units. Production of masonry units with small dimensional tolerance is costly which increase the total cost of prefabrication of masonry panels.

Tables 1.1, 1.2 and 1.3 give the comparison of ranges of combined costs of superstructure, cost of transportation and man-hours for different countries in terms of local currency. The tables present a rough idea of the relative costs, but do not reflect the saving in time using prefabrication in comparison with conventional methods. (Ref: 9)

1.5 Extent of Prefabrication

The extent of prefabrication in an individual plant depends upon the local demand. As already explained previously, it is economical to use factory made load bearing masonry panels only if at least 1000 dwelling units are erected; for 250 or more units precasting at site is economical; for less than 250 units prefabrication is not recommended. Prefabrication in factory will further depend upon the cost of transportation involved for different sites.

Mass production of panels when the demand exists, is always economical. Transportation to sites normally within 100 miles radius is economical. Delivery involving transportation more than 100 miles is generally not feasible.

Acceptance of lack of individuality of prefabricated brick masonry panels, by consumer, generally depends on his level of affluence. Where average annual per capita income is low, say $2000 or less, people are willing to accept standardized accomodation than where the average income is high, say $15000 per year. Further more, the "Component Approach" is generally better suited to consumer's need for diversification than the "Model Approach".

Extent of prefabrication, in Macro Economic Terms of a country, will depend on many factors and not on merely the relative cost of prefabrication as compared with conventional methods. Dwellings present between 30% to 50% of the construction output in industrialized countries. For developing countries this percentage is low, as major expenditure is diverted on other development works. Industrialized methods of prefabrication involve higher capital investment and lower utilization of unskilled labour. There is shortage of capital but surplus of unskilled labour in developing countries. Developing countries thus face a dilemma regarding the efficiency, speed and productivity of prefabrication and social aspects of providing jobs to unskilled and unemployed labourers. Inspite of this dilemma prefabrication may be favoured for the following reasons:

(a) Prefabrication provides rapid increase in building output as compared to labour intensive methods. In long-term it will accelerate economy and provide wider and more permanent job possibilities.

(b) The non-wage costs of labour such as on-site accomodation for workers and large number of supervisory staff may swing the balance towards prefabrication.

(c) Cost of increased time by conventional methods may be crucial in some cases, especially in urban areas. This factor also favours prefabrication which requires lesser time for erection on site.

In determination of extent of prefabrication in a given area other factors such as transportation system, the role of government and other micro economical production problems should be given due consideration. (Ref: 9)

1.6 Equipment for Prefabrication

The equipment used for production of brick masonry panels varies widely. It ranges from simple hand tools to highly sophisticated automated machinery.

The hand-laying methods employs the conventional masons tools and it may further employ corner poles, jigs, templates for special shapes, lifting and handling devices, adjustable scaffolding etc. Adjustable scaffolding generally increases mason's productivity, thereby reducing fabrication costs.

To protect the panel face from contamination by the grout, pressure at the contact surface of brick face and form is created by either an inflated form face or by - applying load to brick. This procedure may be used both in hand laying method and mechanized method.

In mechanized method the handling of materials may be automated. Automated unit placing machinery may be employed for placing the masonry units with proper joint width. Pressurized grouting systems are also in use in casting method or prefabrication. (Ref: 11-2)

1.7 Advantages of Prefabrication

There are several advantages of prefabrication of brick masonry panels over the conventional methods. Some of them are described hereinafter.

(i) Elimination of Scaffolding. The need of scaffolding at site is eliminated, if prefabricated panels are used. The savings could be significant especially in higher storeys.

(ii) More Space At Site : If an off-site plant is used, the work area and storage area at site is minimum. The available space can be utilized for other purposes. It will result in relatively "clean" site. If proper scheduling of delivery is maintained, the panels can be erected as they are received, thereby eliminating storage of panels.

(iii) Complex Shapes Complex shapes can be made easily without the need of expensive false work and shoring required for on site masonry. Complex shapes with returns, projections, soffits, curves etc. can be made by adjusting jigs and forms. Repetitive use of these shapes can lower the cost considerably.

(iv) Year-round work. The factory set up allows for year round work in all weather conditions. The use of prefabrication may eliminate the need for winterizing the surface.

(v) Quality Control. More quality control can be exercised in prefabrication because of the factory set up.

Mortar batching system and grouting can be controlled effectively. Effect of harsh weather will be minimum.

(vi) Saving in construction time. Saving in construction time at site is an important feature of prefabrication, especially in case of highrise buildings. This gives as early occupancy to the owner and saves over-head charges, interim financing and allows the owner to have rental income production start sooner, in case of a commercial building. (Ref: 3 & Ref: 11-i)

1.8 Disadvantages of Prefabrication

Prefebrication has some inherent disadvantages, which are briefly described as follows:

(i) Limitation of use. The use of prefabricated brick masonry panels, like other panels, is limited with certain types of construction and cannot be employed universally as in case of on-site brick masonry.

(ii) Limitation of size of panels. The size of brick masonry panels is limited primarily by transportation and erection limitations. Architectural plan layout may in some cases preclude the use of prefabricated brick masonry panels.

(iii) Limitation of Materials. Use of masonry panels is also limited by its basic materials, brick and mortar, to withstand loadings as they occur in structure.

(iv) Absence of size adjustment. On site masonry allows to fit the other elements of structure, through variation in joint thicknesses. This is not possible in case of prefabricated panel. The use of prefabricated panels requires other crafts or trades to construct to accuracy beyond the standard construction practices of those trades.

(v) Costs. As already indicated earlier there is, in some cases, no indication that use of prefabricated brick masonry is economical than on site masonry considering costs per square foot basis. In some cases this cost may be higher than conventional methods. (Ref: 3and Ref:11-2)

1.9 State of Art

The use of prefabricated brick masonry panels in construction is increasing. These panels with a variety of bonding pattern, colour and texture have aesthetically pleasing effect. The panels have been built utilizing the methods described in this report. Figures 1.1 to 1.5 show some of the projects utilizing these panel as non-load bearing wall. However prefabricated brick masonry panels have also been used as load bearing walls, especially in low-rise buildings and dwellings.

Fig.1.1 is, "Penn Square Apartments", Denver, Colorado. This project used over 1100, 4-in. thick prefabricated pierced balcony railings. The exterior curtain walls of structure were conventionally laid.

Fig.1.2 is "Townsend Towers", Syracuse, New York. This 21-storey building used 4-in. thick standard modular unit curtain wall panels.

Fig.1.3 is "Sheraton Inn", Youngstown, Ohio. The steel frame is covered by 4-in thick, 24,000 square feet of prefabricated brick masonry panels.

Fig.1.4 is "Denver Brick & Pipe Co. Plant", Denver, Colorado. The unusual shape of the panels can be noticed.

Fig.1.5 is "Philadelphia National Bank" Philadelphia. Approximately 1100 C-shaped panels, 4-in. thick were used for column and spandrel covers for the structure.

It must be remembered that every proposed building may not be suitable for utilization of prefabricated brick masonry panels. To determine the feasibility & adoptability of a project for prefabricated brick masonry panels, following points should be investigated:

(i) Suitability of building layout for panels

(ii) Suitability of prefabrication at site or off-site considering the size of site and its location.

(iii) Schedule or complition of construction and weather conditions.

(iv) Validity of structural design if prefabricated panels are used.

(v) Possibility of reasonable quality control over other trades in case panels are used.

(vi) Economic feasibility of use of prefabricated panels based on the fore-going five factors.

Prefabrication of brick masonry is new but rapidly developing field and future innovations and research could appreciably affect its values as a design solution. (Ref:11-i)

TABLE 1.1

RANGES OF COMBINED COSTS OF SUPERSTRUCTURE PER m^2 OF GROSS FLOOR AREA

Country	Netherlands	Sweden	United Kingdom	Finland	Yugoslavia	Italy	USSR	Czechoslovakia
National Currency	Guilder	Krona	Shilling	Thousand Markka	Dinar	Lira	Rouble	Koruna
A. Traditional masonry	63	156/186	214	13.1/14.7	13 032/16 755	10699	39.0/42.2	449/540
B. Masonry block	74/79	153/154	--	--	18 128	--	40.0/44.0	--
C. In situ poured concrete	72/85	162/169	186	11.6/15.2	--	--	--	--
D. Large factory-made panels	78/106	172/195	--	--	17 148/18 875	--	39.7/43.9	291/467

TABLE 1.2

COST OF TRANSPORT OF PRECAST ELEMENTS

(In Korunas)

Transportation	Completely assembled (G 57)			Bricks and cement (T 02 B)		
	Distance in km					
	30	40	50	30	40	50
1. Materials to the site	944	944	944	2,556	2,556	2,556
2. Precast elements to the site	2,360	2,950	3,540	1,276	1,540	1,848
3. Materials used in precast elements	1,681	1,681	1.681	711	711	711
TOTAL (1 + 2 + 3)	4,985	5,575	6,165	4,543	4,807	5,115
Precentages of total cost of 1 flat*)	8.66	9.66	10.66	8.04	8.46	8.95

*) Total costs of 1 flat, 1963 averages: G57-Kcs 57,647; T 02 B-Kcs 64,289.

TABLE 1.3

MAN-HOURS PER m^2 OF GROSS FLOOR AREA FOR SUPERSTRUCTURE ONLY

Country	Nether-lands	Sweden	United Kingdom	Finland	Yugo-slavia	Italy	USSR	Czecho-slovakia	Poland
A. Traditional masonry	5.3	4.7/5.0	9.3	6.8/9.8	15/16	7.0	6.1/9.0	6.0/9.6	4.3/8.9
B. Masonry blocks	5.0	--	--	--	13/15	--	4.1/5.1	--	2.2/4.0
C. In situ poured Concrete	4.5/6.8	4.6/5.0	7.2	7.2/8.6	--	--	--	--	--
D. Large factory-made Panels	5.9/7.9	2.0/4.6	--	--	3.4/17.5	--	3.3/4.4	1.3/4.5	--

FIG. 1.1

"Penn Square Apartments", Denver, Colorado.

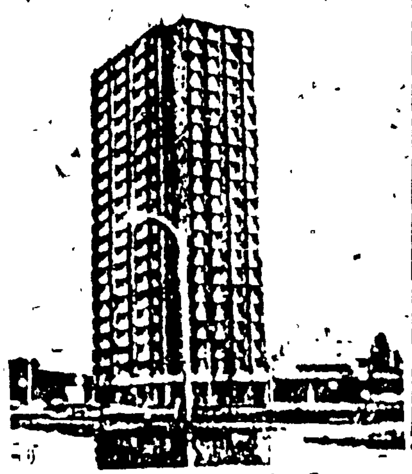


FIG. 1.2

"Towsend Tower" N.Y.

FIG. 1.3

"Sheraton Inn", Youngstown, Ohio.

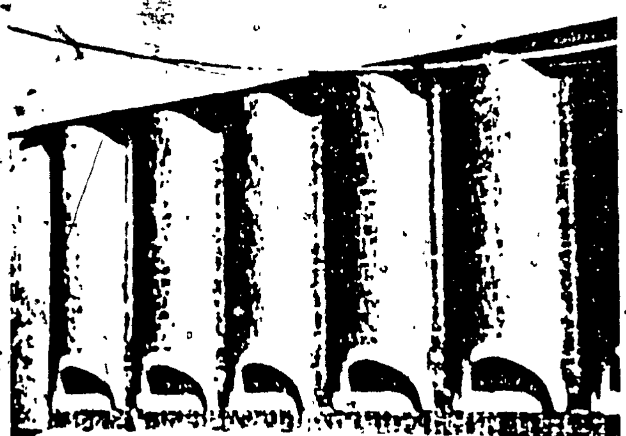


FIG 1.4

"Denver Brick And Pipe Company Plant", Denver, Colorado.

FIG. 1.5

"Philadelphia National Bank", Philadelphia.

2. SYSTEMS OF PREFABRICATION OF BRICK PANELS

2.1 Introduction (Ref:1,2,3 & 4)

There are many systems of prefabrication of masonry panels made out of solid or perforated clay units. The clay units are joined together by cement-sand mortar with or without lime content or cement grout. The clay unit can also be joined by epoxy resin or similar adhesive. The panels may be unreinforced, reinforced or prestressed.

The systems of prefabrication can broadly be categorized into two basic methods:

A. Hand-laid System

B. Mechanized System

Hand-laid system of prefabrication is usually employed at the site of work. This involves bricklaying using the coventional techniques to form panels which when set, can be transported to the site. This method is slow and thus involves higher cost persquare foot of panel. The progress is dependent on the availability of bricklayers. However this method does not require a large initial capital outlay for tools and machinery and gives flexibility of design and size of panels. The labour force can be easily varied according to requirement thereby reducing the overhead charges.

Mechanized system employs either horizontal or vertical method of prefabrication. It is fast, requires lesser skilled and unskilled labour. It is economical if sufficiently large number of panels of same size and design are produced. It has a limitation on size and design of panels and requires large initial investment in plant, equipment and machinery.

There are a number of mechanized systems of pre-fabrication which have developed beyond the experimental stage and have found practical applications in construction industry while other systems are still in experimental stage. Some of the systems which have evolved sufficiently are listed below and will be discussed briefly. (Ref: 1,2,3, 16 and 29)

1. The B.M.B. System. (Holland)
2. The Costamagna System. (France)
3. The Fiorio System. (France)
4. The Montage-Tegl System. (Denmark)
5. The Kornerup System. (Denmark)
6. The Teglment System. (Denmark)
7. The Tecab System. (Sweden)
8. The Montagebau System. (Germany)
9. The Preton System. (Switzerland)
10. The C.M. Masonry Process. (U.S.A.)

2.2 Hand-laid System

Hand-laid System of prefabrication is employed all over the world because of its simplicity and low initial cost and because it can be employed both at site of work as well as in the factory. It is particularly preferred in developing countries where labour is cheap and industrialization is rather expensive.

2.2.1 Flat Panels for Walls

Flat panels, to be used for wall are rectangular, usually of size 8'x 4' and are un-reinforced. Bricks are laid, in 1:4 cement: sand mortar to make one panel, on flat ground, previously prepared and sprinkled with sand. Two steel hooks embeded up to minimum four courses are provided for lifting. The panels are water cured for at least three days to attain sufficient strength before transporting to place of work. The walls are 4½" (half brick) or 9" thick. Hallow clay blocks can be used to reduce the weight of the panel or to give special look to the wall face.

An improvement to the above method is the use of horizontal casting on a tilting table as provided by "Canadian Structural Clay Association". The panel thus can be rolled off in vertical position while the mortar is still fresh and has not reached its initial set. This method increases the rate of production and ease in work of the bricklayer, thereby increasing his efficiency. A still higher rate of production can be achieved if loading of the tilting table is mechanised. This consists of a moving table supporting the panel forms in which the bricks are laid.

The panels can be reinforced with steel bars, if the panel is thin i.e. it is slender, or to increase its load carrying capacity and resistance against deformations, creep and shrinkage, or if wind load is to be resisted.

The size of the panel can be varied easily with the present apparatus to achieve a maximum size of 10'x5'. The joints are grouted with mortar and pointed. But joint between two panels at site is usually adequate.

Figure 2.1 shows setting station and Casting table. Figure 2.2 shows casting table load with 7 panel forms. Figure 2.3 shows pouring grout on full table ready to be vibrated. Figure 2.4 is the view of grid stripping device and curing rack. Figure 2.5 shows typical 8' x 4' modular panel, 4" thick and 3/8" strip joint. Figure 2.6 shows typical vertical joints for 4" & 6" thick panels. Figures 2.7 to 2.10 show erection of panel at site.

2.2.2 Flat Panels For Roof

The technique for making roof panels is the same as for wall panels. In this case, the brick blocks made of three bricks placed on edge and with 1:4 cement:sand mortar are placed in rows leaving a gap of 2" in between the blocks. Steel reinforcement is placed in these gaps and gaps are filled with concrete 1:2:4 cement: sand: broken stone aggregate. The panels are cured for 7 days and then transported to the site. Ceramic hollow blocks can be used in place of bricks to reduce the dead load of the panel. The reinforcement projects out of the panel end in form of hooks to overlap with those from the adjacent panel to achieve continuity over supports if desired. Otherwise the projecting bars from adjacemt panels can be welded to achieve continuity.

The panels are placed side by side to cover the space and butting joints are filled with cement-sand mortar. Concrete topping of 1" to 1½" thick with nominal reinforcement is provided for flooring which gives a monolithic and stiff slab and makes it waterproof. This roof is also termed as reinforced brick slab. The thickness of such a slab is 3", 4½", & 6" excluding the topping. A typical detail of R.B. slab is shown in Figure 2.11 (Ref: 29)

Use of prefabricated panels as R.B. slab is economical, quicker and excludes the use of shuttering. It can be used in all weathers. It keeps the site cleaner.

2.2.3 <u>Curved Panels For Roofs (And Boundary Wall)</u>

The use of curved panels for roofs is a modification of jack-arch construction. The conventional method of construction of Jack Arch Roofing was economical and durable but consumed too much of time and labour. The increase in cost of labour made Jack Arch Roofing almost obsolete. The concept of prefabrication has made it again economical. The two prefabricated components utilized in construction are

Jack Arch Panels made of brick and pre-cast I-beams.

The method of construction is that 20 bricks are laid flat on humped ground in 1:4 cement: sand mortar to make one panel of size 120 x 50 x 7.5 cms. No reinforcement is used. The height of curvature may vary from 5 cm: to 10 cm: A height of 5 cm (about 2") is preferable to give a flat look.

The roof or floor is constructed by putting these prefabricated panels on prefabricated I-beams and filling the haunches with concrete to make the floor monolithic and flat. Figures 2.12, 2.13, 2.14 show the construction procedure. (Ref:4)

The thickness of prefabricated panel can be increased so that it can withstand horizontal wind loads, when used for compound walls as shown in Figure 2.15 such panels are more stiff as compared to flat panels of the same thickness or in other words thickness of curved panels can be reduced to get the same stiffness and strength as that of a flat panel. This saves material and rapid construction saves time, labour and overheads thereby making the use of prefabricated panels more economical.

2.3 The B.M.B. System.

2.3.1 Introduction.

This prefabrication system has been developed for unit-housing construction initially in Holland and has been adopted in many other European countries. The external load-bearing cavity walls of the house consist of two wythes; the internal one is made of concrete where as the external one is a brick panel. The largest units are (10'-6") x (4'-8½") i.e. 14 brick length and 23 courses height, which is normally half the storey height. Each panel is made up of 322 bricks. A typical cross section of the wall is shown in Figure 2.16. Figure 2.17 shows the layout of the plant.

The plant has a capacity of producing prefabricated brick panel units sufficient for 1,000 houses per year and requires a crew of 20 men. The initial cost of plant is $300,000 which is about one fourth of the cost of the whole plant, which in addition to brick panels, produces other prefabricated elements for houses. Each house consumes 34 square meters (365 Square feet) of brick panels representing about 2,500 bricks. It takes 5.2 man-hours to complete one panel in the factory or 9½ square feet of panel per man-hour. It takes 7.2 minutes for each crane, crane driver and three semi-skilled labourers to install one panel.

Since the panels are half-storey high, no temporary wind-bracing is necessary. It also provides greater architectural flexibility regarding window disposition. No special trucks are needed for transportation of these panels. All these factors favour marketing of B.M.B. System.

2.3.2. Method of Production

Bricks are placed by hand in the grid spaces on the moving cars, which then pass under spray nozzels to wet the bricks thorougly. At the next station, 1:3 cement: sand mortar of low consistancy is released evenly and in a measured quantity, over the bricks to grout the joints. Special wall ties are placed in position before the car is vibrated, for fully grouting the joint, for about one minute. The next operation is laying steel sheet at a height of 2½" (size of cavity) from brick face, placing reinforcement and pouring concrete to make the inner wythe of the wall. The cars are then moved to steam-curing chamber at a temperature of 100 °F. & 100% relative humidity for a period of 24 hours. The cars are then moved to panel removal section where the panels are removed from the cars. The steel sheet is removed. Unfilled joints are repaired. Panels are washed and brushed to clean mortar staining and are then lifted and taken to storage. Each panel is marked with a code number for identification before taking to storage. The empty cars are washed, cleaned and repaired if necessary and then recycled for the next panels.

Panels of size smaller than the standard one, can be made by blanking off parts of the bench car by wooden or sheet steel forms. The mortar joints of the panels are semi-recessed and are not as good as the carefully tooled joints of high quality brick work. The joint between panels made in-place is about 2½ times wider than the ordinary brick course joints. This discrepancy in joints has not yet been overcome. (Ref: 1,2, and 3)

2.4 The Costamagna System

2.4.1 Introduction

Costamagna System of prefabrication of brick panels for walls and floors has been developed in France in mid-50's. It has an advantage that the plant can be installed permanently at one place or it can be installed temporarily at one site and then moved easily to the next site or stored. A typical layout of the plant is shown in Figures 2.18 and 2.19. The capital cost of the plant is comparatively low which is another advantage. An on-site plant capable of producing elements for 3 houses per day would cost about $60,000 where as a permanent facility for production of elements for 5 apartments of 1,000 square feet of floor area per day would cost $600,000.

It takes one man-hour to complete one square meter of interior or exterior load bearing wall panels or floor panels. In case of partition panels, which are non-load bearing and are made by battery-casting method, the productivity is much higher and is approximately 52 square feet per man-hour which is quite remarkable. This output involves prefabrication of 400 larger panels or 535 smaller panels per 8-hour shift. The consumption of tiles per shift is 2,800 for larger panels, 16" thick or 3750 tiles for smaller panels, 12" thick. An overall average output for all types of panels is 25 to 28 square feet per man-hour.

Three types of panels are manufactured in the plant:

(a) Load bearing exterior and interior panels.

(b) Non-load bearing partition panels.

(c) Finidal floor sections.

2.4.2. Load-bearing Exterior And Interior Wall Panels.

These panels are generally of the size of complete room wall and finished on both sides. Face exposed to weather may have a finish of mosaic tile, glass or terracota where as the interior face may have plaster finish.

The method of prefabrication is simple. The facade material which may be ceramic wall tiles, glass or mosaic etc, is laid face down on a smooth slab and in the steel frames. A thin layer of cement grout is spread over the facade material followed by 1" concrete layer. Tiles are placed in wet concrete and the gaps are filled with concrete with aggregate size 3/8". The panel may be vibrated if filling concrete is rather stiff.

For Exterior Panels a second layer of tiles is laid centrally with concrete ribs and joints filled with concrete as for first layer. Staggering the tiles in the two layers provides additional insulation and structural strength. The top surface which will eventually be the interior surface is then finished with Gypsum plaster.

Interior load bearing walls are made the same way. In this case instead of facade material, gypsum plaster is provided.

No reinforcing steel is used in the panels except for lifting hooks etc. Figure 2.20 shows the wall sections.

2.4.3 Non-Load Bearing Partition Panels.

These panels are usually of one storey height i.e. approximately 8 feet. Width is 12" or 16". Thickness is $2\frac{3}{4}$". The panels are plastered on both faces and fit together in tongue and groove fashion. The vertical joints are filled later-on at site. The panels are light in weight, the larger or the two weighing about 120 pounds. They may be installed vertically or horizontally as shown in Figure 2.21.

The method of prefabrication is again a simple one. Clay tiles are placed on conveyor and moved to a bench where they are joined end to end with fibrous plaster of Paris and are slid into storage conveyor. It takes about 15 minutes for plaster of Paris to set. After that the beams of tiles are placed in a multiple-casting magazine car with plastic spacers placed in between. The car carrying 10 such beams is then taken to plaster grouting station where liquid plaster floods the battery. Surplus plaster is scraped off from the top. Then it is moved forward from where the panels are lifted, 10 to 15 minutes after the application of plaster and are stored.

2.4.4 Finidal Floor Sections

These floor sections are usually of room size. The assembly consists of prefabricated components and on site, casting of concrete. It consists of a thin concrete slab pre-stressed centrally and covered with clay tiles to form ribs to be filled with concrete at site. The prestressed slab is $1\frac{7}{8}$ inches thick where as on-site concrete ribs are $1\frac{1}{2}$" to 2" deep. Figure 2-22 shows a view of "Finidal Floor Slab." (Ref: 1, 2, and 3);

2.5 The Fiorio System.

2.5.1 Introduction.

The Fiorio System, developed in France, produces all types of elements for housing like load bearing or non-load bearing walls, floor sections, balconies, stairs, landings, frontals, gable ends etc. Precision and slenderness of elements is the speciality of Fiorio System. Flexibility of the system favours to provide considerable variety of exterior and interior architectural design. The element can be economically transported to a site at a maximum distance of 100 miles from the plant. Layout of the plant is shown in Figure 2.23 and two views of the same are shown in Figure 2.24.

Capital cost of the plant is $65,000 and it has a capacity of producing elements for [illegible] apartments of approximately 1,000 square feet floor area, per day. An average output is 9 square feet of wall and floor panels per man-hour.

Clay products are used in the prefabrication of elements to provide structural strength both in tension and compression and also as a filler material for elements like non-load bearing panels. Wall panels are finished on both faces. Service ducts for conduites and pipes etc. are provided while the elements are cast which is another added advantage. Size of panels vary but generally it is full size of wall or floor.

Wall panels are joined together with cement grout like the floor panels. Light deformed-bar reinforcement is provided in these joints thus producing a frame work of concrete as the building progresses. This gives strong monolithic and water tight structure.

2.5.2 Method of Manufacture.

Gypsum plaster is poured to the smooth floor within the forms and levelled. Clay tiles are pressed into wet plaster to form open spaces which are then filled with concrete. A coat of the desired finish is applied. The tiles have flanges which when butting together form the spaces for concrete filling. Service ducts and lifting hooks are provided before pouring concrete. The panels are kept over night before removal from forms. Curing can be accelarated by electric resistance heating of the forms. No reinforcement is used in panels except in exceptional cases. Physical characteristics of structural tiles and the bond between tiles and concrete gives the structural strength to the panel. Figure 2.25 and 2.26 show a typical joint detail. Figure 2.27 is a view of erection process of wall. It is interesting to note that wall elements have 65% voids. (Ref:1,2,and 3)

2.6 The Montage-Tegl System.

2.6.1 Introduction.

Montage-Tegl System of prefabrication has evolved in Denmark since 1963. The panels are load-bearing, insulated, cavity-wall type. The exterior wythe is made up of claybrick and the interior one of lightly reinforced concrete. The cavity between the two wythes is filled with fibre glass insulation and both the wythes are held together by a special galvanized steel or stainless steel zigzag ladder reinforcement. The panel detail is shown in Figures 2.28, 2.29. 2.30. Steel rods are provided for lifting and connections.

The panels could be half storey height or as high as 30 feet. Normally these are of storey height. The width may be between one brick length to 6 feet. Panel thickness is $7\frac{3}{4}$" (19 cms). The panels have an ultimate compressive load carrying capacity of 100 tons per linear yard. The thermal conductivity of panel, U value, is 0.09. Mortar joints are of flush type and are usually not parallel because of non-uniformity of brick dimensions, faulty brick setting, and some movement of bricks during casting and as such the joints are not pleasing to the eye.

The cost of prototype plant is $280,000 which is about one third higher than the normal cost of this type of plant. A typical layout plan of the plant is shown in Figure 2.31. The output of the factory is 2,100 square feet of panels per shift of 8 hours. This involves placing of about 10,000 bricks and 26 cubic yards of concrete. The output per man-hour is 44 square feet of panels. The installed cost of panels is 75% of similar wall constructed by conventional methods.

2.6.2 Method of Production

A thin layer of sawdust is sprinkled on the deck of the bench-car and bricks are laid facing down according to the required bond and size of the panel. Car is then moved to grouting station. Concrete mortar of ratio 1:3 is poured over the bricks to fill the joints in between the bricks. Lifting bolts and ladder type reinforcing are place in wet mortar and the panel is then covered with fiber glass insulation batts. The car is then moved to the next station where concrete is poured directly on the insulation to form the inner wythe of the panel. Electrical fittings and conduits are placed in position before pouring concrete.

The car is then taken to curing chamber where the panels are cured at a temperature of 140°F & 100% relative humidity for 4 hours. The panels are then removed. The car is cleaned, washed and is sent for the next cycle.

At the site the panels are jointed together by cement mortar. The vertical joints at the corners are not pleasing to eye and need improvement. Figure 2.32 shows one of such corner joints. Because of low value of thermal conductivity the panels are suitable for use in cold climate.
(Ref: 1,2 and 3)

2.7 The Kornerup System.

2.7.1 Introduction.

This system of prefabrication was developed in Denmark. This is perhaps the easiest and most economical system. It does not require any special machinery or big cash outlay and can be set up right at site of construction work.

The panels are of cavity-wall type with returned ends. The panels are of storey height, about 5 feet wide and 10 inches thisk. Figure 2.33 shows a typical panel under construction. These are produced by skilled masons using conventional tools and standard mortar mixes. The internal face of panels is plastered where as the external one may be plastered or bricks may show. The panels are used in conjugation with storey-heigh window and door composite assembalies.

2.7.2 Method of Production.

The plant or rather the frame is shown in Figure 2.34. It consists of four vertical 2" x 2" x ¼" angle iron guide frames. The panels are built within the frames. A similar frame is used for lifting the panels for transportation or storage. This frame provides rapid construction and handling.

The bricks are laid on a concrete sill of smooths surface and within the frame. The frame gives stability to the panel which when set can be removed and stored.

Bricklaying rate per man-day in the factory is 1500 bricks. Six bricks are used per square foot of wall. The production rate per man-hour is approximately 16 square feet. The system offers complete flexibility for pattern of bond, brick shape, texture and size of the panel. (Ref: 1,2 and 3).

2.8 The Teglment System.

2.8.1 Introduction.

This system of prefabrication was introduced in Denmark and is yet in the final stages of development. The panel consists of facing brick and expanded clay light-weight aggregate concrete. A typical cross-section of the panel is shown is Figure 2.35. The panels are of storey height i.e. 8½ feet and 4 feet wide. The panels have grooves at top and ends to facilitate jointing at site. A continuous concrete beam can run in the top groove thus ensuring higher strength, water tightening and a monolithic structure. The vertical joints between the panels are again very effective and ensure strength and water tightening.

The panel backing consists of 6½ inches thick concrete with 3/8" size coarse aggregate of expanded clay and the interior surface 3/4" thick fine-aggregate higher density concrete. The interior surface is ready for decorating. Concrete backing provides good thermal insulation and is capable of taking a load of 35 kilograms per square centimeter i.e. 450 lbs per square inch which is equivalent to 19 tons per running foot of panel. Other materials can be fastened to panels by nailing.

Flexibility of panel size and bond pattern, is also a feature.

A typical layout of plant is shown in Figure 2.36. An estimated initial cost of plant is $15,000. The designed capacity of such a plant is 30 square metres (320 square feet) per 8-hour day. If the plant is fully automated the productivity can go upto 640 square feet per day, representing 16 square feet of panels per man-hour.

2.8.2. Method of Production

Wetted bricks are set face down between the angle iron and rubber guide strips according to the required bond pattern. The bricks are end spaced by short wooden blocks. 1:3 cement: sand mortar is spread and brushed into the joints, tooled against rubber and wooden spacers. This fills the joints ½ inch measured from top of rubber spacers. 1:5 cement: sand mortar is spread over the bricks to stand up to ¼" depth over back of bricks.

The car is taken to concreting section, where a measured quantity of non-slump, no-fines light weight aggregate concrete is poured and spread to a depth of 7 inches. Lifting bolts are placed in position. Second layer 1½" thick of non slump but fine aggregate, light weight concrete is laid over the first one. The concrete is vibrated and pressed to its final level at the vibrating station to give finished surface. It is then steam cured for at least six hours in the curing chamber. At the next station the panels are removed and taken to storage. No washing or repair of panels is necessary. The cars are sent for the next cycle. Figure 2.37 shows detail of bench car deck. Figure 2.38 shows a typical industrial application of Teglment panels at site. (R1,2 and 3)

2.9 The TECAB System.

2.9.1 Introduction.

This system of prefabrication has been developed in Sweden in 1963. It is capable of producing exterior wall panels of sandwich-insulated type, interior partition walls and chimney units. In case of exterior wall panels the exterior wythe consists of bricks which may be arranged in any pattern and the interior wythe consists of tiles with inner face finished, usually with plaster. The two wythes are connected with each other by special ladder-type wall ties of galvanized or stainless steel. The cavity between the two wythes is completely filled with fibre glass insulation as shown in Figure 2.39. The normal size of a panel is 5 feet wide by 8½ feet high.

Partition wall panels are made from structural clay tiles, cement and plaster. These are lightly reinforced and are load-bearing. These panels are jointed at site by cement grout.

Production flow diagram for this system is almost similar to the B.M.B. or Montage-Tegl Systems. Capital cost of the factory is about $550,000. Its designed capacity of production of wall panels is one million square feet of exterior wall panels per year with addition facilities for production of thin partition panels and chimney units. An average output per man-hour is 25 square feet of exterior wall panels.

Estimated cost for installed panels is 75% of the cost of traditionally built brick and tile insulated walls. This system is predominant in using high volumes of structural ceramic products in prefebrication of wall panels.

2.9.2 Method of Manufacture

Wetted bricks are laid face down in the box the surface of which is previously sprayed with a solution of concrete retarder. 1:3 cement: sand mortar is poured over the bricks to fill the gaps and to a level of 1/4 inches above the bricks. The ladder type wall ties are placed in position. Fibre glass insulation is laid, over which clay tiles are placed matching spacing of wall ties. Lifting hooks are placed in position. Cement-sand grout is poured over the tiles to fill the joints and cover the back of the tiles. If a plaster finish is desired, it is applied when cement has hardened.

After the cement grout has matured sufficiently, the panels are removed from the steel box. The mortar joints are still soft from the effect of the retarder and are brushed to match raked joints on the exterior face of the panel. The panels are sent for storage. Window and door frames may be installed during prefabrication.

The tiles used for interior wythe are made of clay-saw dust. It is therefore porous, light, thermal resistant and with cement it is strong enough to take compressive loads.

At site the panels are butt-jointed together with a special glue used for the interior whythe where as cement grout is used for the face joints between bricks at the exterior wythe.

Load bearing partition panels are made from tiles in a similar way with concete grout and light reinforcement. (Ref: 1,2 and 3)

2.10 The Montagebau System.

2.10.1 Introduction.

This is a German System of prefabrication of masonry panels for walls and floors. Exterior wall panels are generally of storey height ($8\frac{1}{2}$ feet) and upto room width (maximum 14 feet) and 12 inches thick. Panels for factory walls are 7 feet wide and sometimes two storeys height. Panels consist of brick facade with structural back-up of hollow tiles. No steel reinforcement is needed except for lifting bolts and joint stirrups. Window and door frames may be installed during fabrication. The interior surface may be finished with plaster while casting. Facing bricks may have any bond or pattern. Figure 2.40 shows the wall panel and structural tiles.

Interior wall panels whether load bearing or non-load bearing, consist of single wythe of brick or structural tiles. These panels may be reinforced depending upon their height and distance between lateral supports.

Floor panels are normally of room size, subject to the capacity of the crane and are semi finished elements made up from concrete and structural tiles like the wall panels plus steel reinforcement. After installation at the site panels are covered with $1\frac{1}{2}$ to 2 inches of concrete to form monolithic and strong structure. Ducts are provided while casting.

Since solid bricks are used, the panels are heavy.

Heavy weight is encouraged perhaps as a means of circumventing quality control variations. Flexibility of system to produce any type of panel is the main feature of this system.

No data on productivity is available. The layout of plant is also not available. It is believed that this system compares competitively with conventional methods.

2.10.2 Method of Prefabrication

A grid made from 7/16 inches square rubber is fixed on a smooth platform and within the steel frame for the panel. Bricks are laid face down in the individual spaces of the grid and grouted with 1:3 cement: sand mortar filling the spaces in between the bricks and covering the bricks to one inch depth. Structural tiles are placed in this wet grout. Concrete is poured over the tiles to fill the gaps and cover the tiles to a depth of one inch over the tiles. Lifing bolts are placed before pouring concrete. The surface is plastered, if desired, after the concrete is hardened sufficiently.

Partition wall panels are cast the same way. In case of floor slabs, these are also cast the same way except that steel reinforcement is placed in the gaps in between the tiles before pouring concrete.

After sufficient curing the panels are removed and sent for storage. At site the wall panels are connected by cement grout; in case of floor panels concrete is used. (Ref: 1,2 and 3)

2.11 The Preton System.

2.11.1 Introduction.

This system of prefabrication of wall panels has been developed in Switzerland in 1960. The system is simple regarding design and manufacture and flexable regarding size of panels and virtually allows any size of panel. Generally no reinforcement is needed except joint stirrups and lifting bolts. These bolts extend to the bottom of the panel.

Special bricks of size 12" x 6" x 6" are used. These bricks have a central hole of size $2\frac{1}{4}$" x $1\frac{3}{4}$" and end groves $1\frac{1}{8}$" x $1\frac{3}{4}$" i.e. of half of the size of central core. When bricks are put together in running bond, vertical openings are formed at 6" centres in the wall. In these holes lifting rods or reinforcement can be provided. The holes are grouted, later on, with cement grout. Certain preton panels can be made out of face bricks but generally the said special bricks are used. See figures 2.41 and 2.42.

Door and window frames can be provided during prefabrication of panels. The panels have mortar in the bed joints only. The ends of the bricks are butting closely together. 1:3 cement sand mortar is used throughout. Organic plasticizing material may be added to the mix for better workability.

Construction details are shown in figures 2.43 and 2.44. These can be used for dwellings from one and two storey houses to high rise apartment blocks up to about 10 storeys.

The equipment used for prefabrication is simple one as shown in Figure 2.45. A factory of 5,000 square feet of floor area and equiped with sufficient apparatus to produce 150 to 200 apartment units per year would cost $35,000. (Each apartment having floor area of 850 to 1,000 square feet) The productivity rate is 19 to 25 square feet of panels per man-hour which can be increased depending upon materials-handling facilities.

2.11.2 Method of Manufacture

Size of panel is set on "A" frame by placing wooden separators. A course of dry bricks is laid between the uprights and against the smooth surface of asbestos-board panel of "A" frame. The bottom sides of bricks for the next course is dipped in cement grout before placing. Sufficient quantity of mortar sticks to the bottom of bricks due to high absorption. The process is repeated until the panel is completed. Half length bricks are sawn in seprate operation for the start of finishing course. See Figure 2.46, 2.47.

Since the bricks are levelled for each course and are laid against smooth face, the panel is true in size. Lifting bolts are provided at third points in the holes. These holes are then grouted with cement mortar. The panel can be provided with horizontal reinforcement during casting or vertical reinforcement placed in the holes, if needed. Joints are not tooled. Face brick panels are made the same way but with more care to give an attractive face to the wall and the joints are tooled or raked.

2.12 The C.M. Masonry Process.

2.12.1 Introduction.

The C.M. Masonry process was developed in U.S.A. (Texas) in 1963-64. The panels can be cast in any size upto 8 feet height and 12 feet length. The panels are solid, single wythe and of thickness 2 or 4 inches. 2 inches thick panels are non-load bearing. Joints are concave type. Horizontal and vertical reinforcement using #3 size deformed bars is provided which gives extra strength. Vertical bars extend out of the panels and thus no lifting hooks are needed and the panel can be welded to steel frames or jointed to concrete members as shown in figure 2.48.

Panels may have smooth ends for butt jointing or "saw-tooth" ends that may mesh together and grouted, alternately the "saw-tooth" ends when butt together, form a vertical row of openings in which single bricks can be inserted and grouted to complete the joint.

The cost of supplying, transporting and installation at site is $0.85 per square foot of 4-inches thick panel, good on one face. The cost of the plant and its productivity is not known. Productivity per man hour is 12 square feet. Figure 2.49 shows the apparatus used for casting the panels.

It takes about two hours to produce a panel 12'x8' size. It is interesting to note that same time is required to produce a smaller panel of size 9'x8'. Window and door frames can be fitted while casting the panel or "saw-tooth" edges can be provided but it will reduce the output. Different sections of the panels are shown in Figure 2.50

2.12.2 Method of Production

The two parts of the machine are spaced about 6 feet apart. The cantilever pins attached to a frame are moved forward. 2"x 3/16" flat steel shelves are placed on the pins. Bricks are then placed on the shelves in the desired bond predetermined by positioning the pins. Gaps between bricks allow for vertical reinforcement at required spacing. The two parts of the machine are moved forward such that the bricks are held now by the compression of the rubber-faced forms. Steel shelves are removed and pins withdrawn. Horizontal and vertical reinforcing bars are placed at required intercvals.

A pneumatic gasket or "Garter" is applied to the bottom and both vertical ends of the panel. Then grout of creamy consistency is poured from the top to fill all the voids. This grout consists of 2 parts high early strength cement, 1 part lime, 1 part gypsum and 9 parts screened sharp sand, by volume. The sponge rubber squeezed in slightly between bricks gives concave joints.

The panel is held for one hour and then the "Garter" is removed and jack raised to support the panel from bottom. The panel is held laterally from top. The forms are moved outwards. The panel is then lifted from bottom on textile slings and taken to storage. After 24 hours the mortar develops sufficient strength so that the panel can now be lifted from vertical rods extending out from the panel.

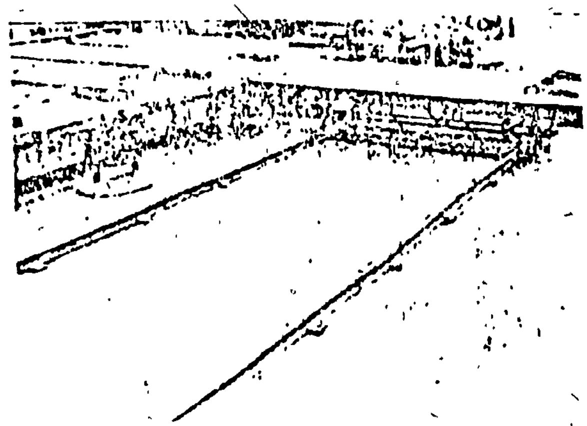


FIGURE 2.1

Setting Station and Casting Table

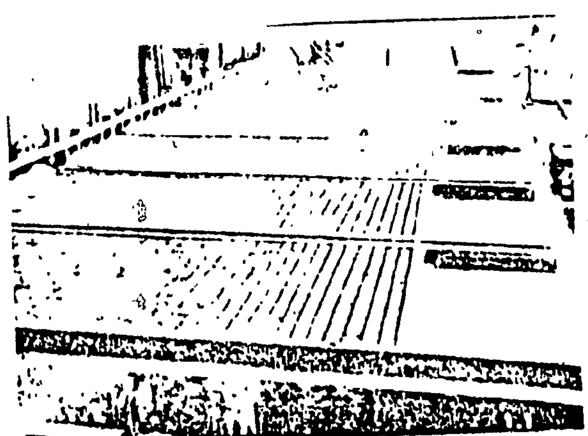


FIGURE 2.2

Casting Table Loaded With 7 Panel Forms

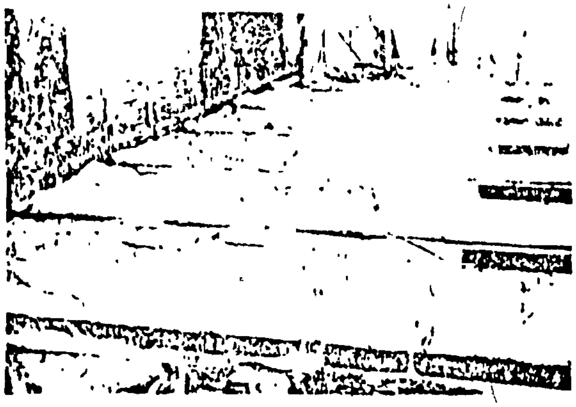


FIGURE 2.3

Pouring Grout on Full Table Ready to be Vibrated

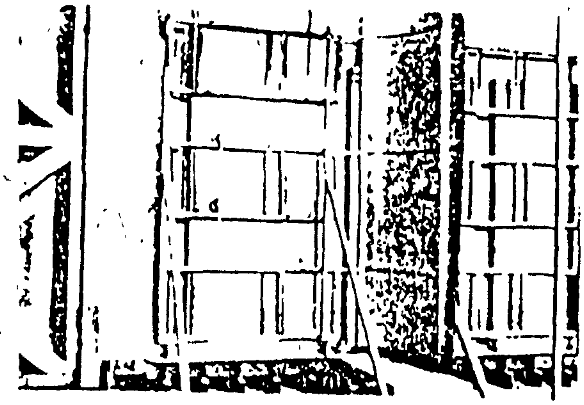


FIGURE 2.4

View of Grid Stripping Device and Curing Rack

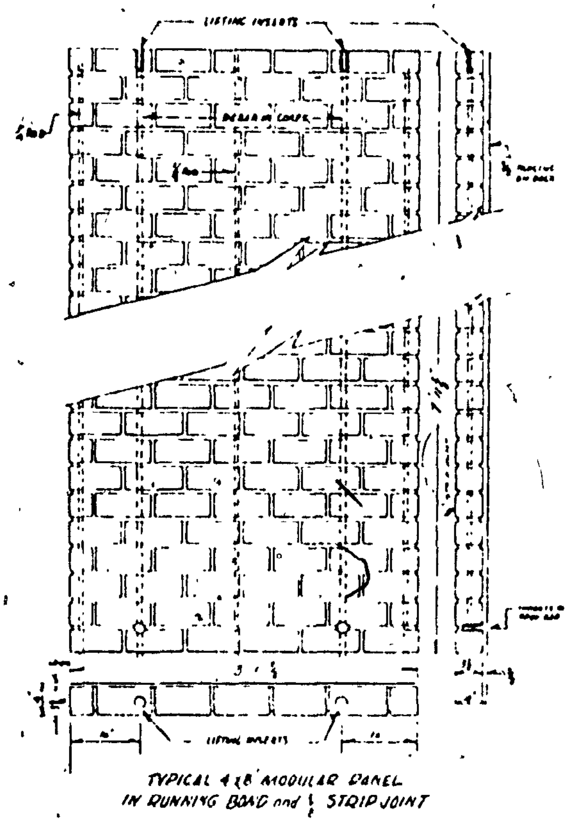


FIGURE 2.5

Typical 4' x 8' modular Panel, 3/8" Strip Joint

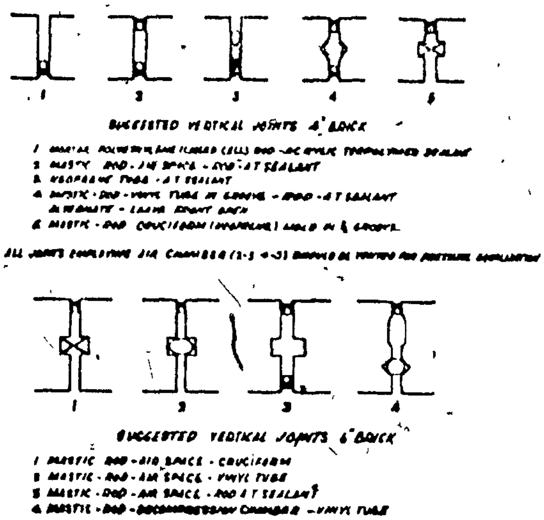


FIGURE 2.6

Typical Vertical Joints for
4" and 6" Brick Panels

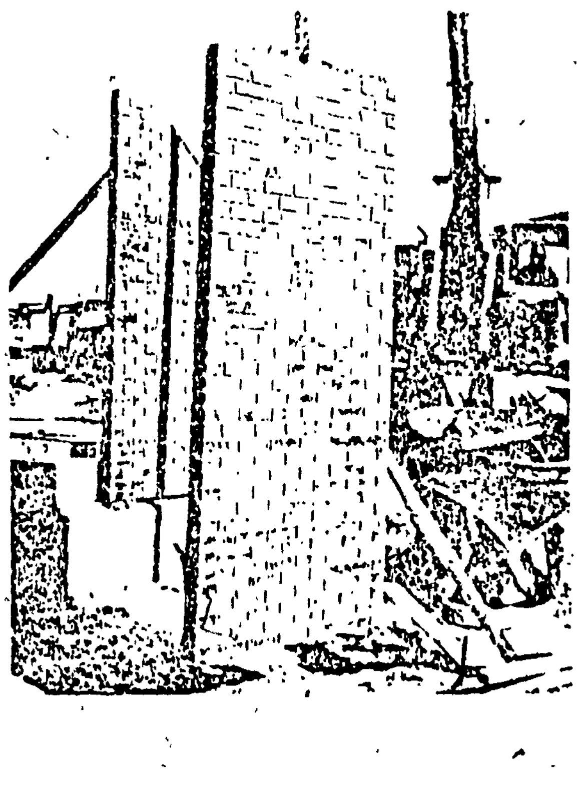


FIGURE 2.7

Erection of Brick Panel
at Site

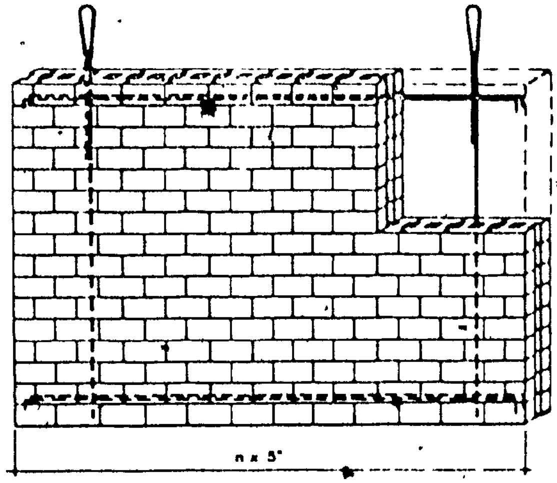


FIGURE 2.8
Reinforced Preton Panel

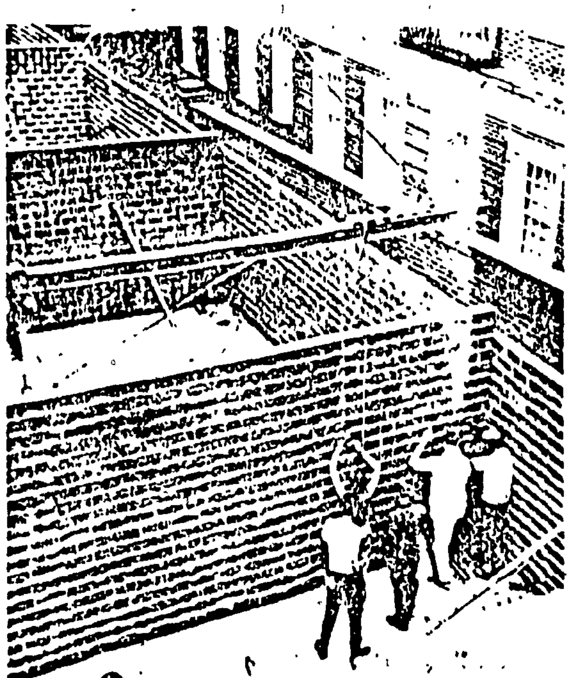


FIGURE 2.9
The Placement of the Preton Partition Panel

Fig: 2.10

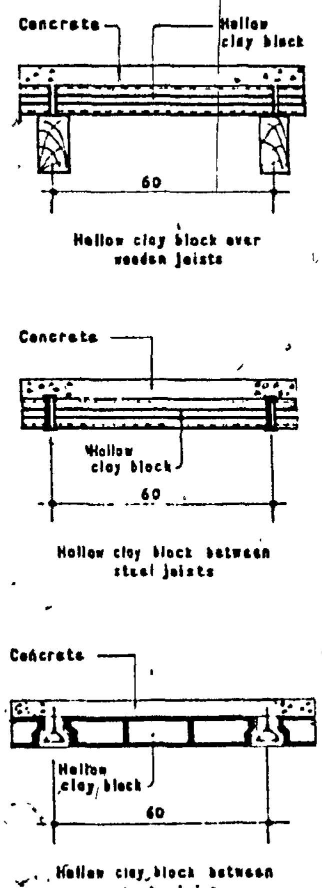


Fig:2.11
Conventional use of hollow clay blocks in floors and roofs

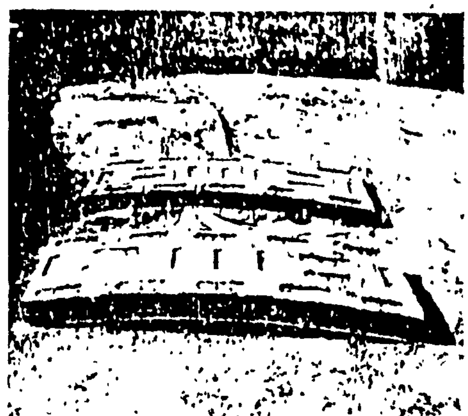


Fig: 2.12

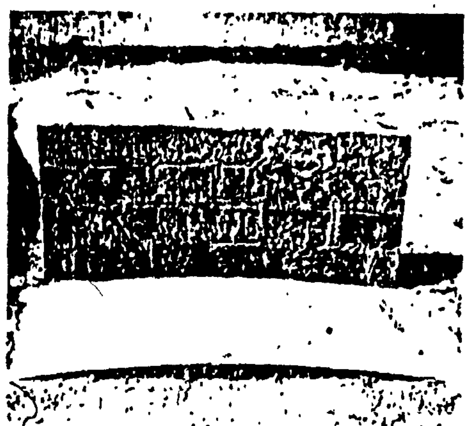


Fig: 2.13

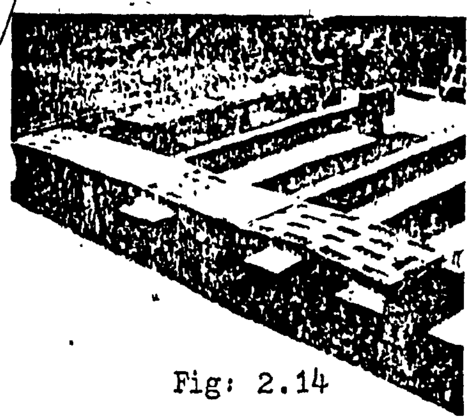


Fig: 2.14

Fig. 2.12 'Precasting of 'Jack-arch Panel'

Fig. 2.13 'Jack-arch Panel' before fitting.

Fig. 2.14 'Jack-arch Panel' placed on partially precast [illegible] and [illegible] cement concrete [illegible].

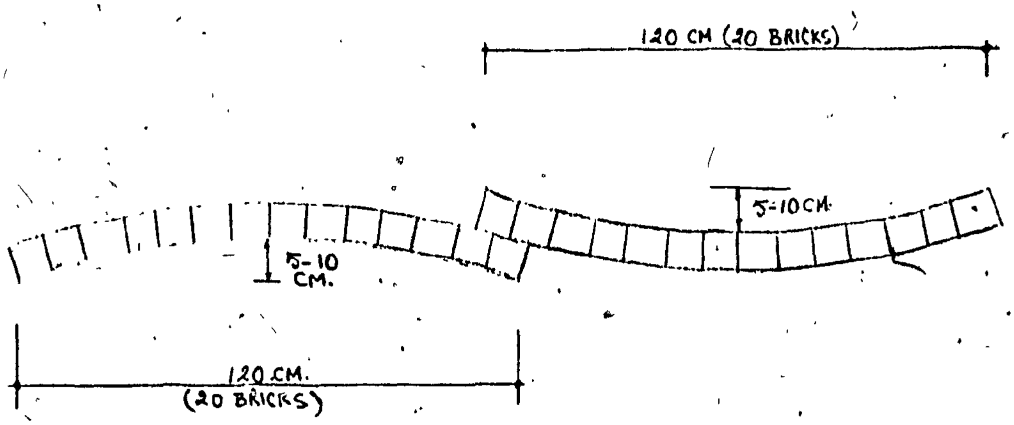


Fig: 2.15

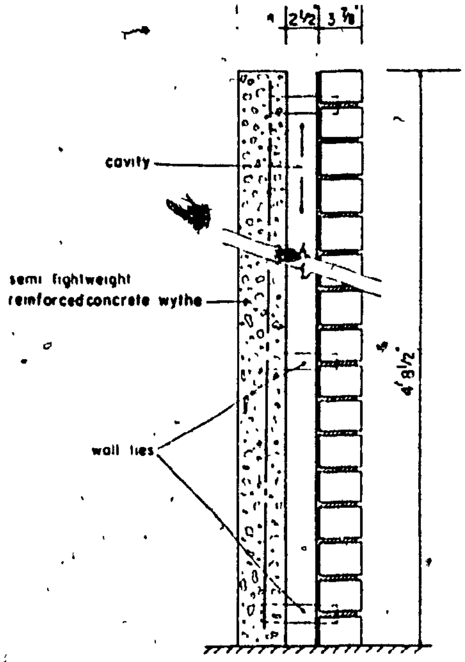


Figure 2.16
CROSS SECTION OF B.M.B PANEL

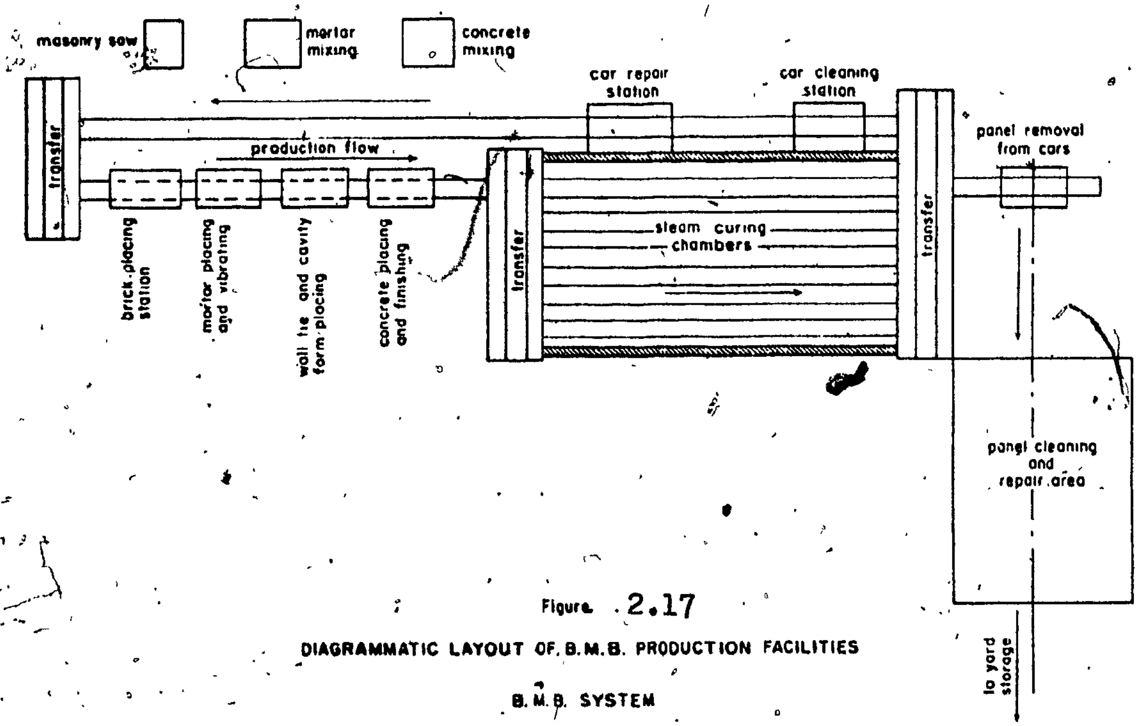


Figure 2.17
DIAGRAMMATIC LAYOUT OF B.M.B. PRODUCTION FACILITIES

B.M.B. SYSTEM

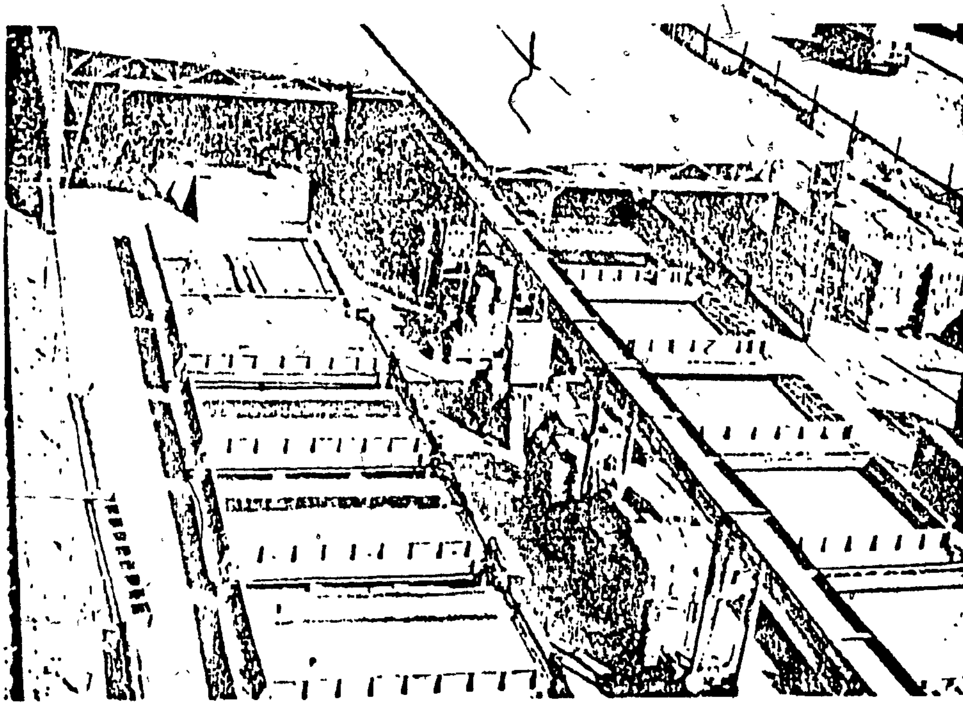


Figure 2.18

General View of an On-the-Site Factory

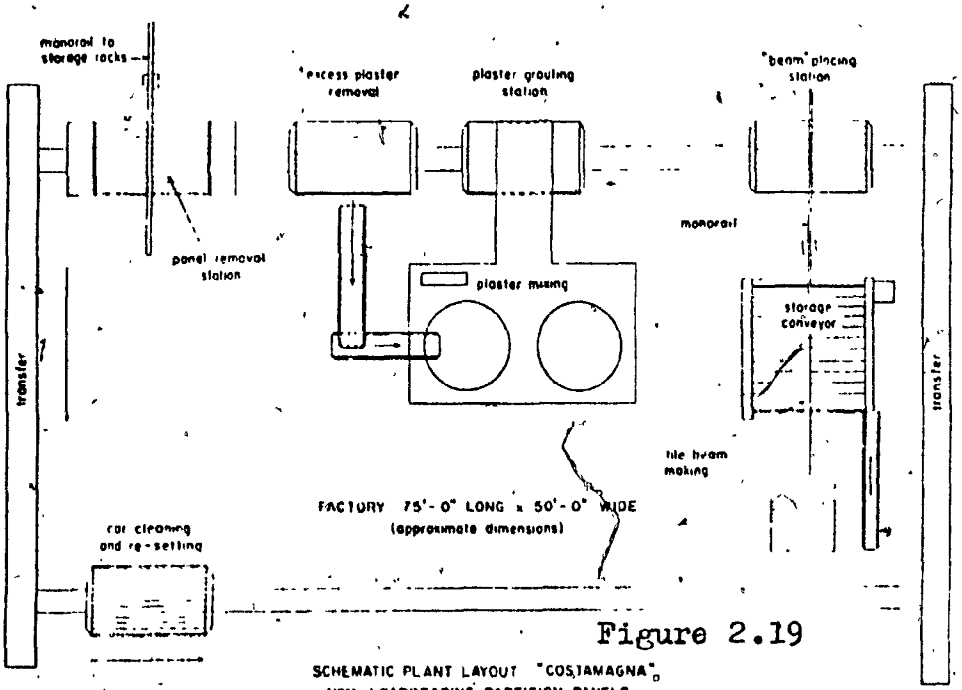


Figure 2.19

SCHEMATIC PLANT LAYOUT "COSTAMAGNA"
NON-LOADBEARING PARTITION PANELS

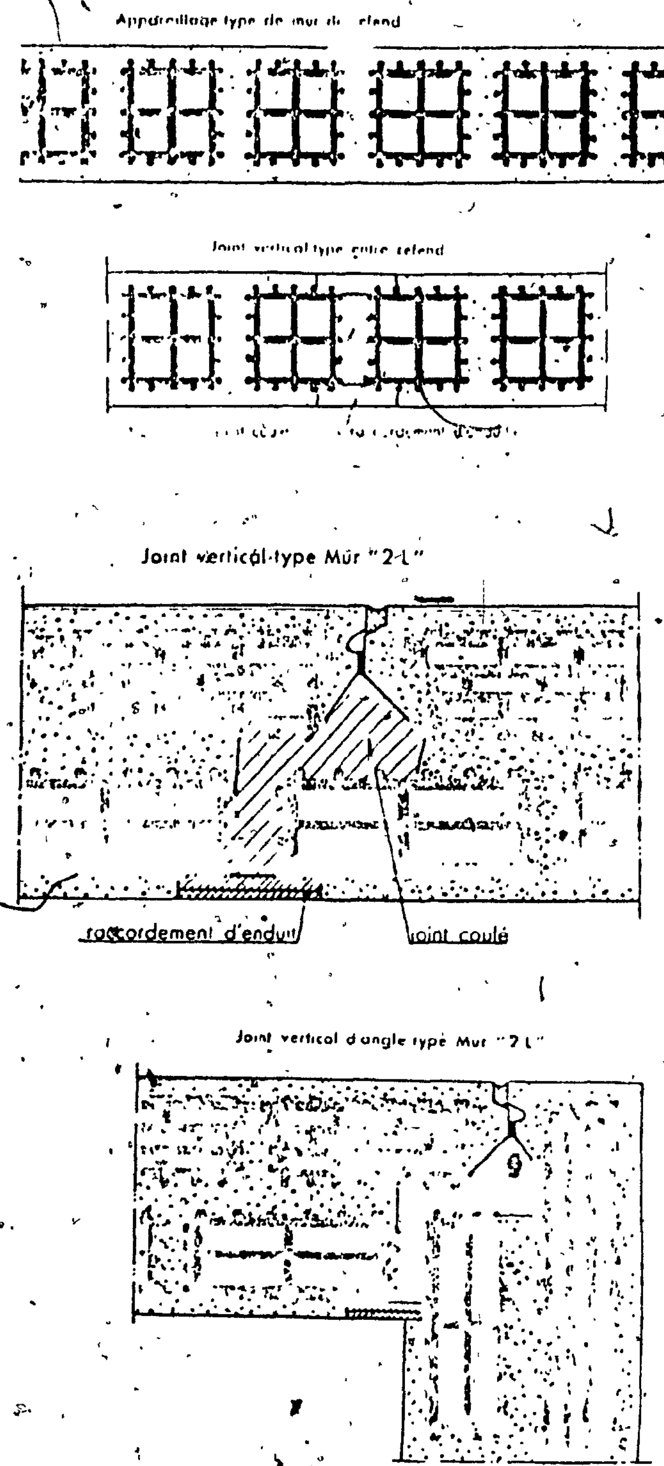


Figure 2.20

Wall-Section Details (Supplied by Veron Costamagna & Cie.)

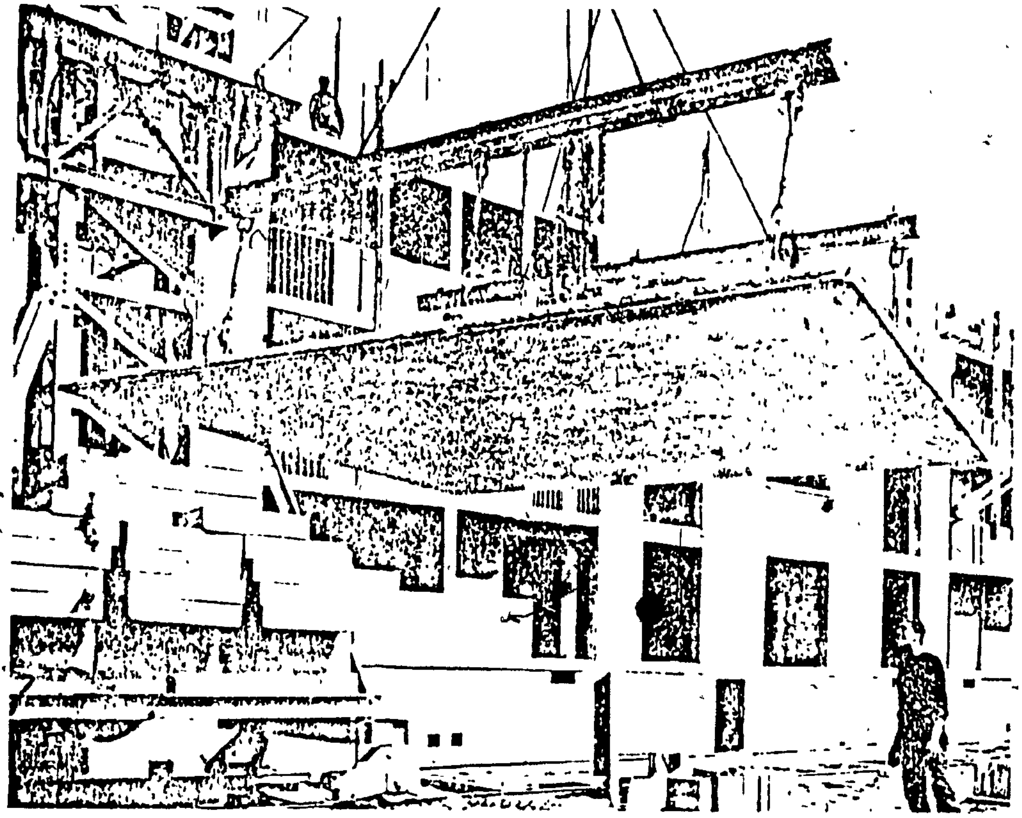


Figure 2.22

Precast "Finidal" Floor Section Being Hoisted into Position

Figure 2.21

Installation of Tile Plaster Partition Panels

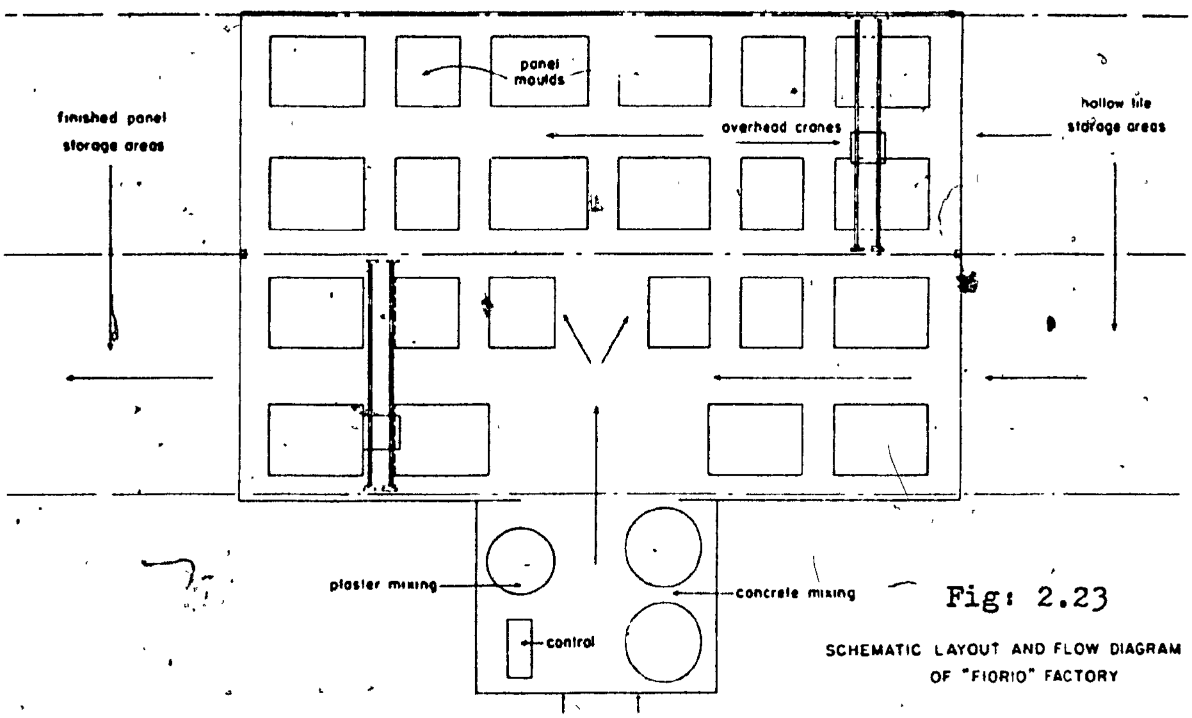


Fig: 2.23

SCHEMATIC LAYOUT AND FLOW DIAGRAM OF "FIORIO" FACTORY

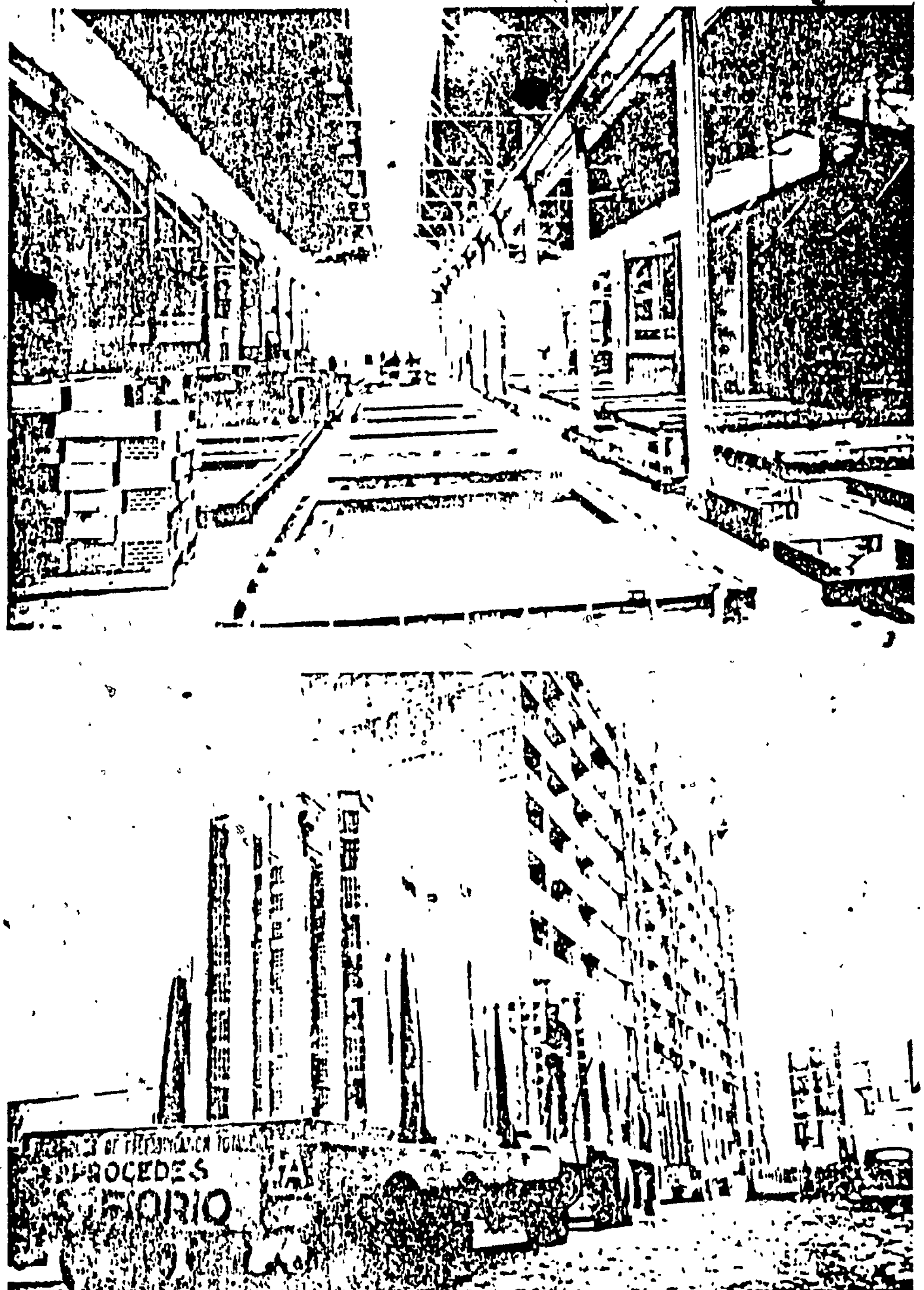


Figure 2.24

Top: Factory Floor Layout for Panel Prefabrication

Below: Panels Loaded on Trailer. Note Tile Ends Exposed.

Section of Vertical Junction of Exterior and Partition Wall Elements

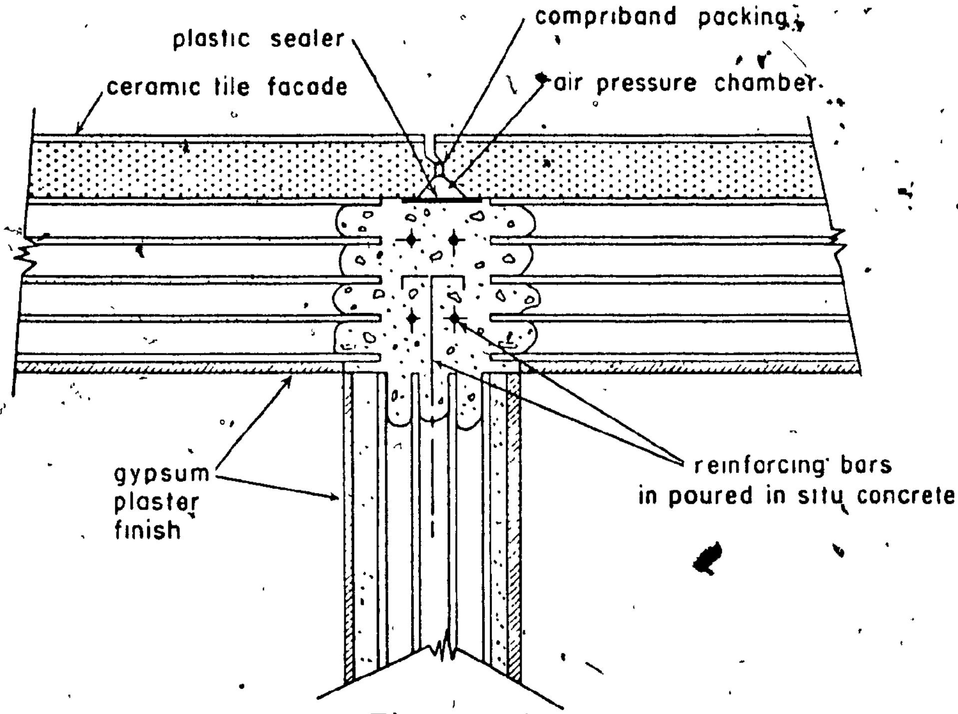


Fig: 2.25

SECTIONAL PLAN

Typical Horizontal Joints

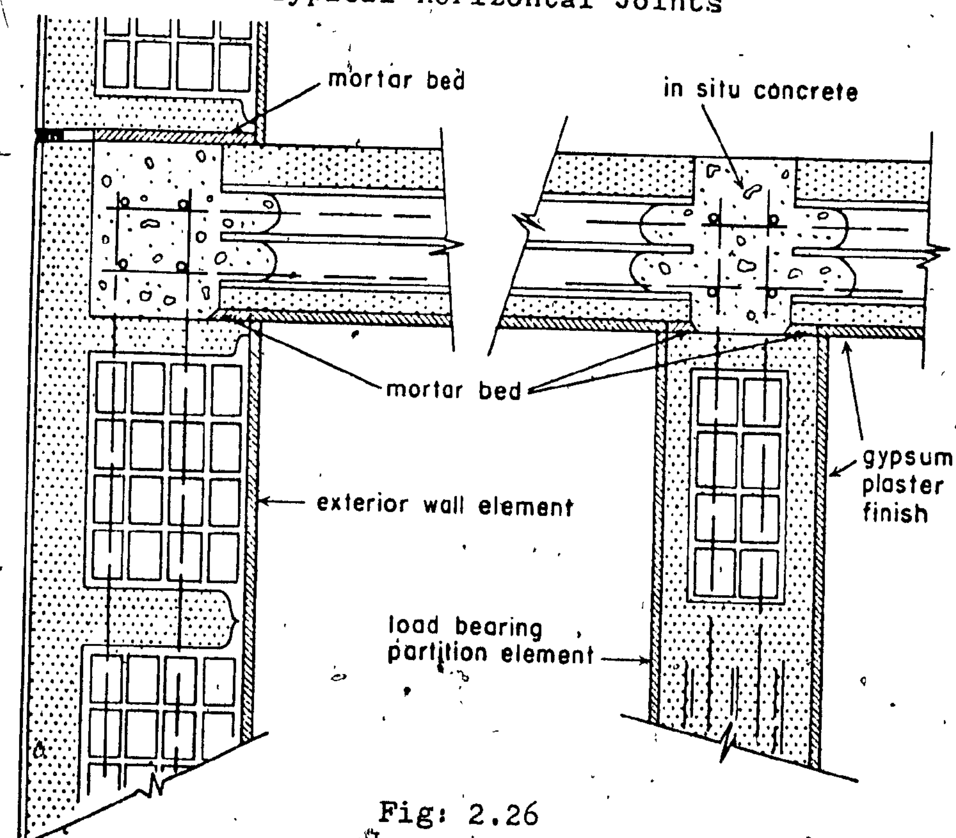


Fig: 2.26

SECTIONAL ELEVATION

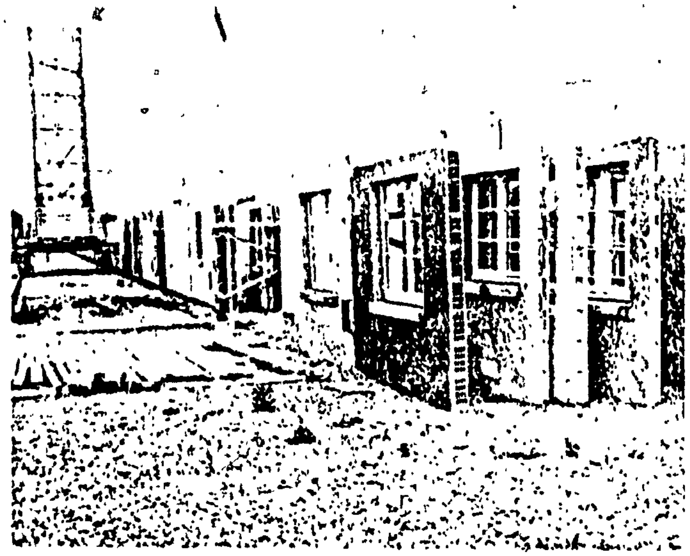


Fig: 2.27

Finished Elements in Storage

Elements are said to be only 35 per cent solid

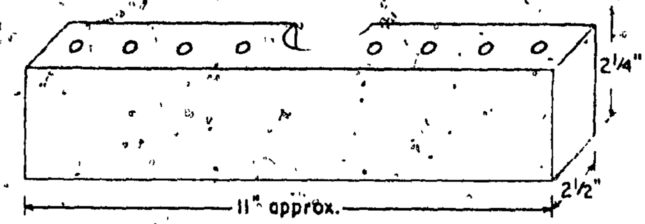


Figure 2.28
NOTE GROOVE IN BACK OF BRICK

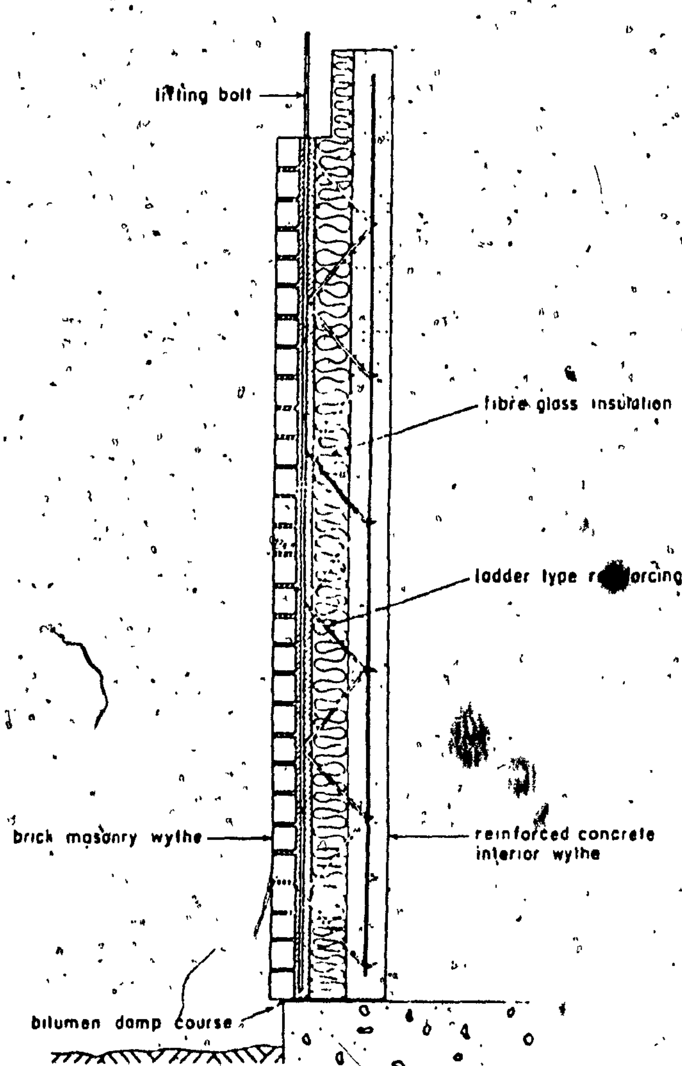


Figure 2.29
VERTICAL SECTION OF PANEL

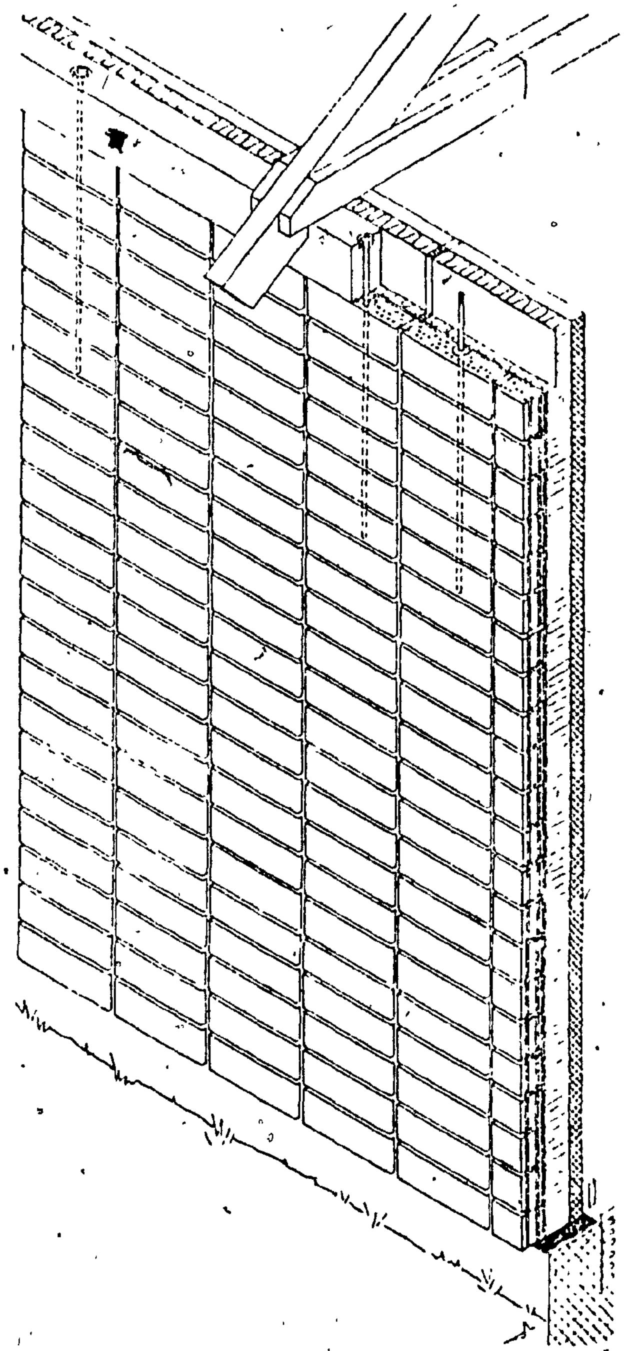


Figure 2.30

CONSTRUCTION DETAIL
Of Connection between
Panel and Rooftruss.

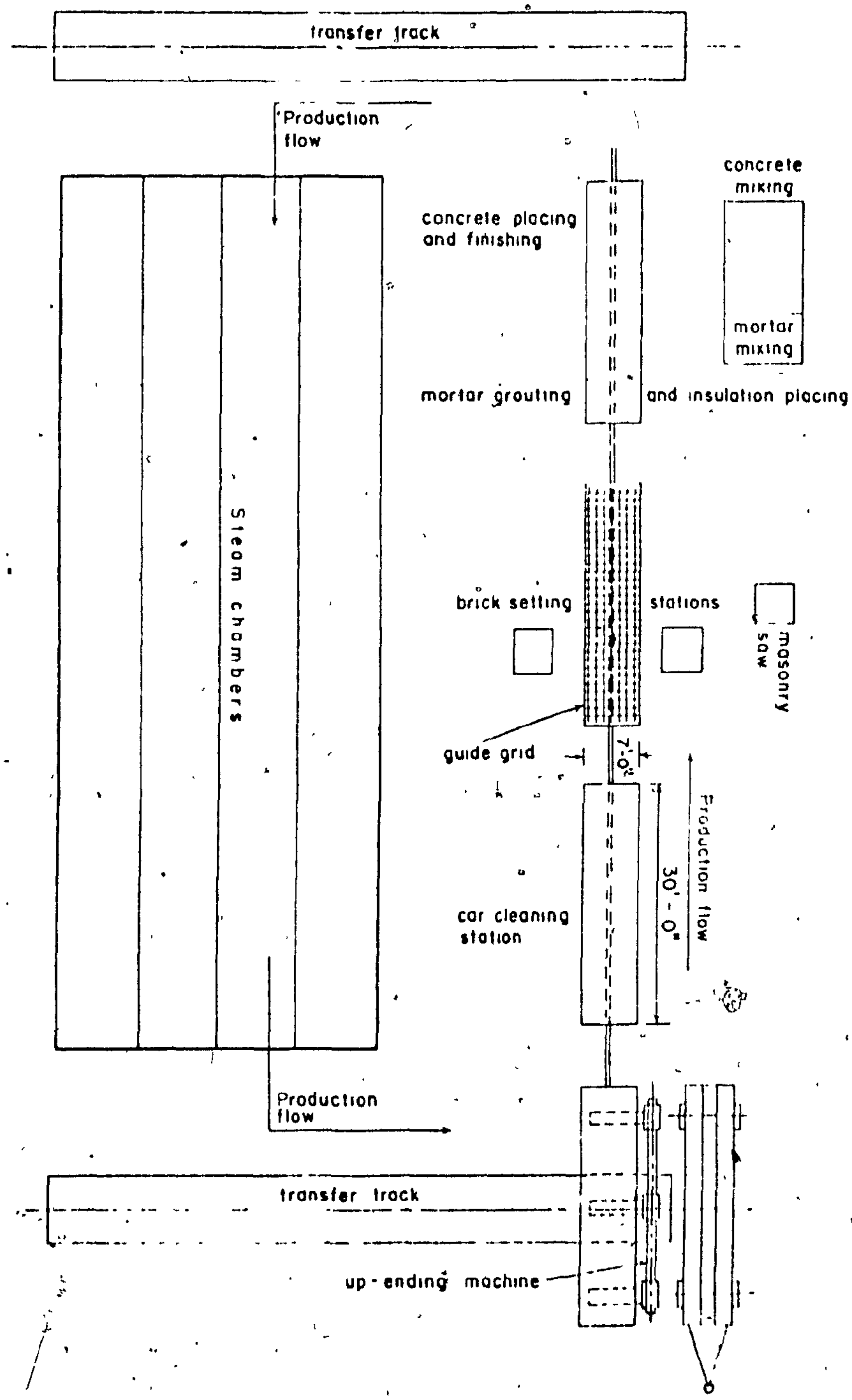
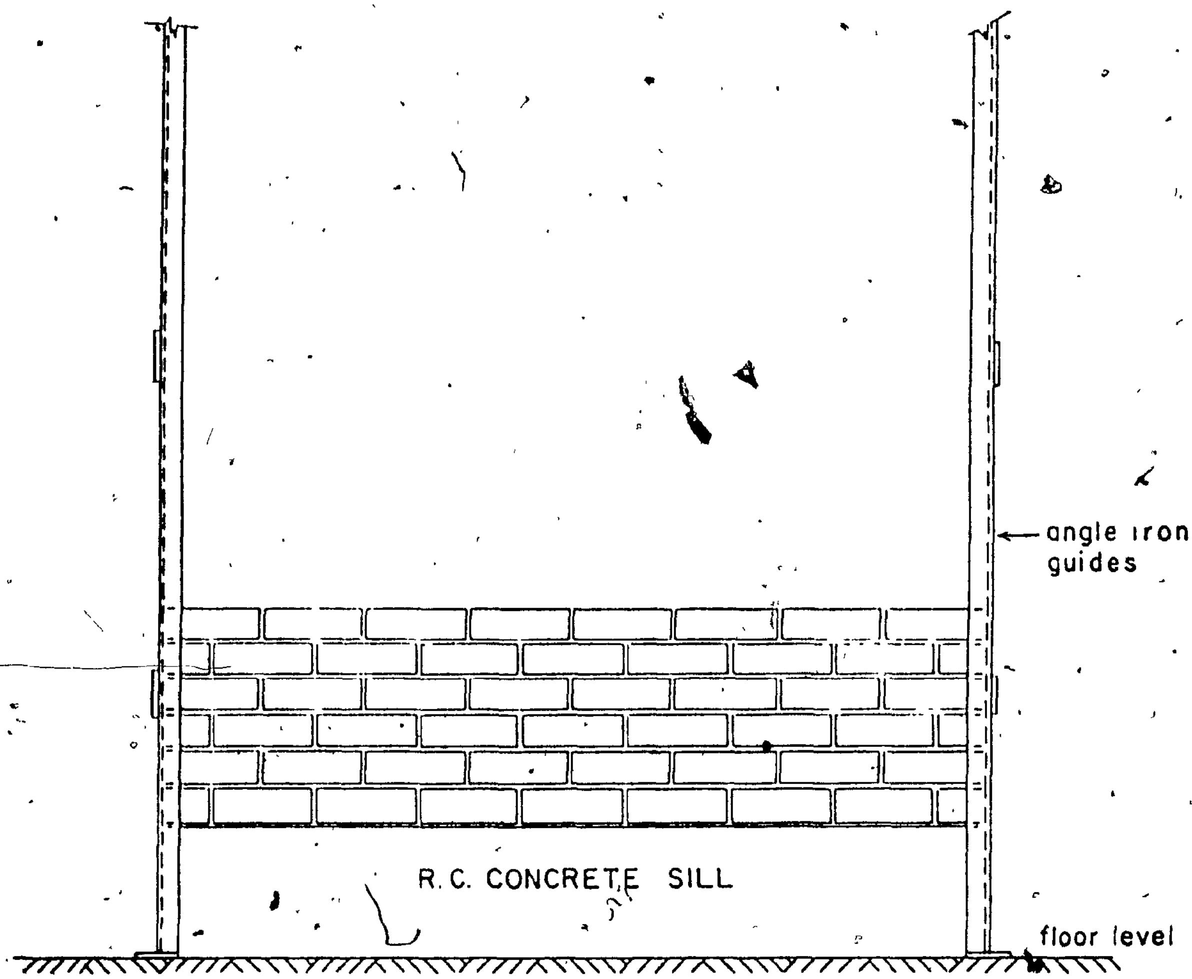


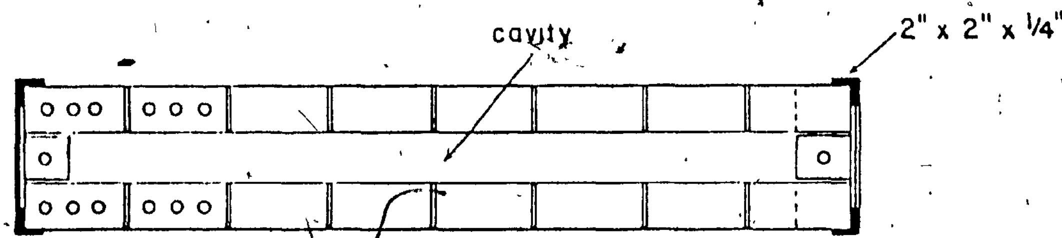
Figure 2.31

SCHEMATIC PLANT LAYOUT
MONTAGE - TEGL SYSTEM

Figure 2.32
Corner Joint Detail Before Trowelling of Mortar



ELEVATION OF KORNERUP PANEL
AND GUIDE FRAMES



PLAN

Figure 2.33

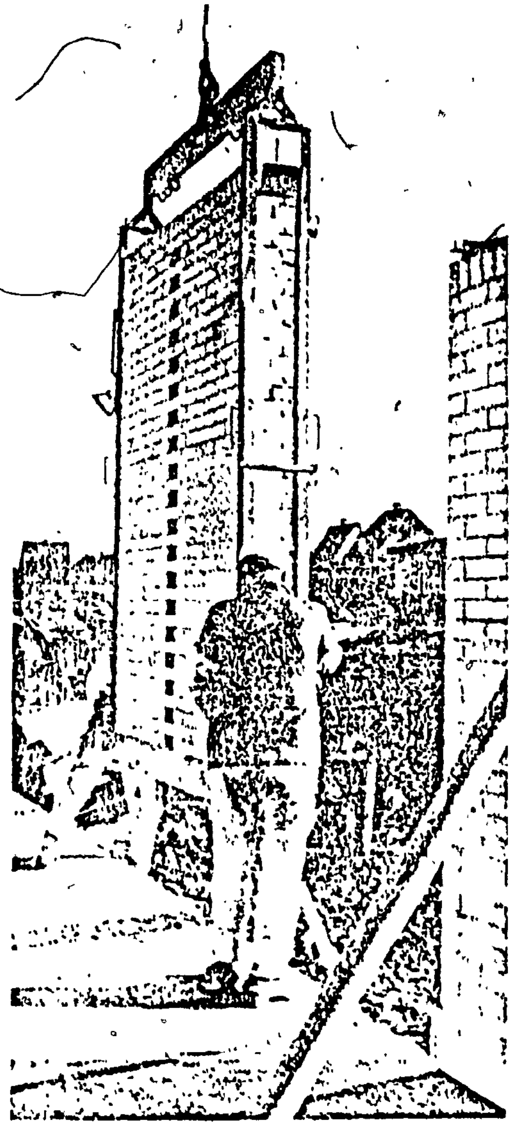


Figure 2.34

Placing a Kornerup Panel.

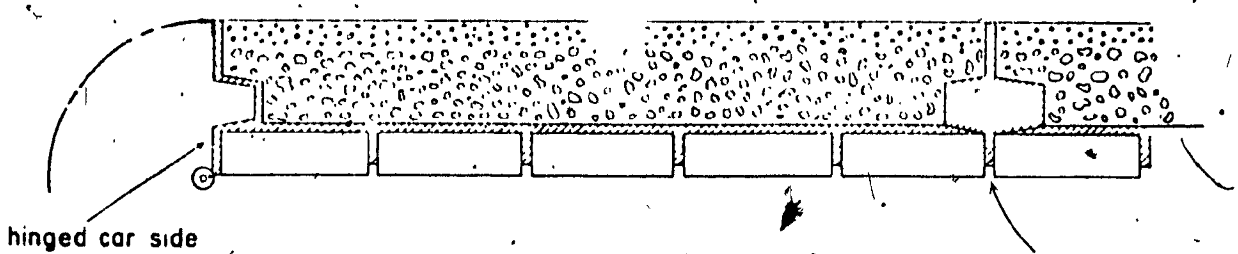


Figure 2.35

CROSS SECTION OF PANEL

TEGLMENT

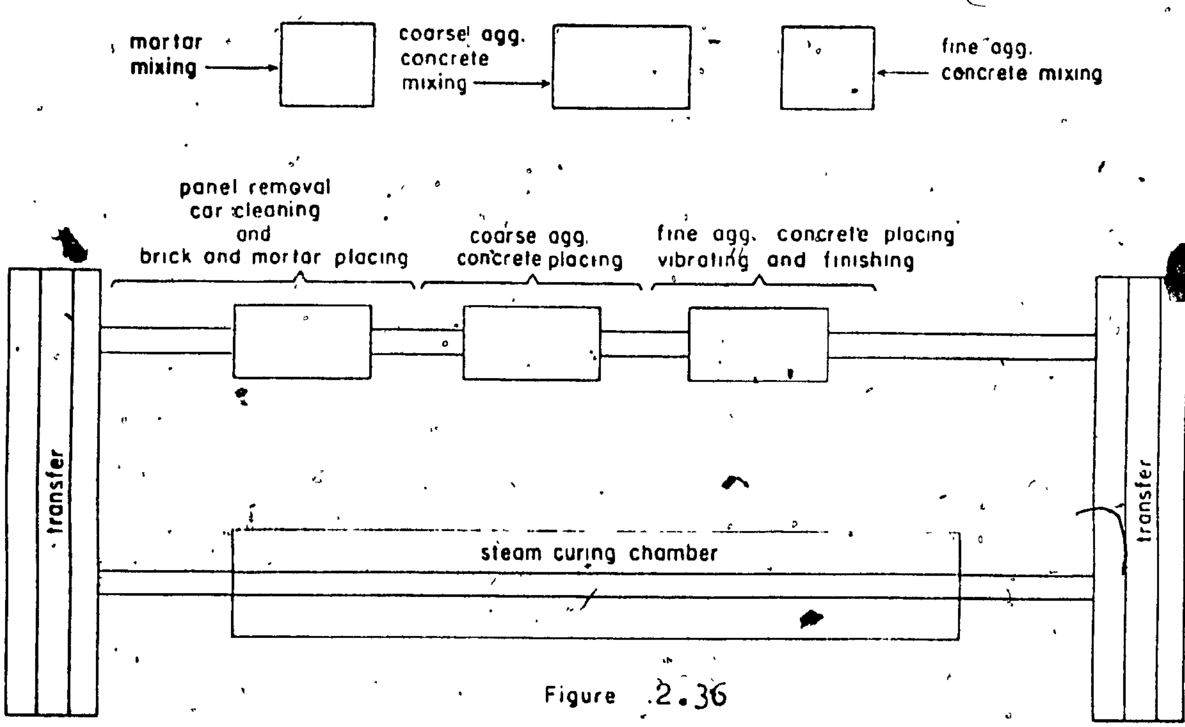


Figure 2.36

DIAGRAMMATIC PLANT LAYOUT

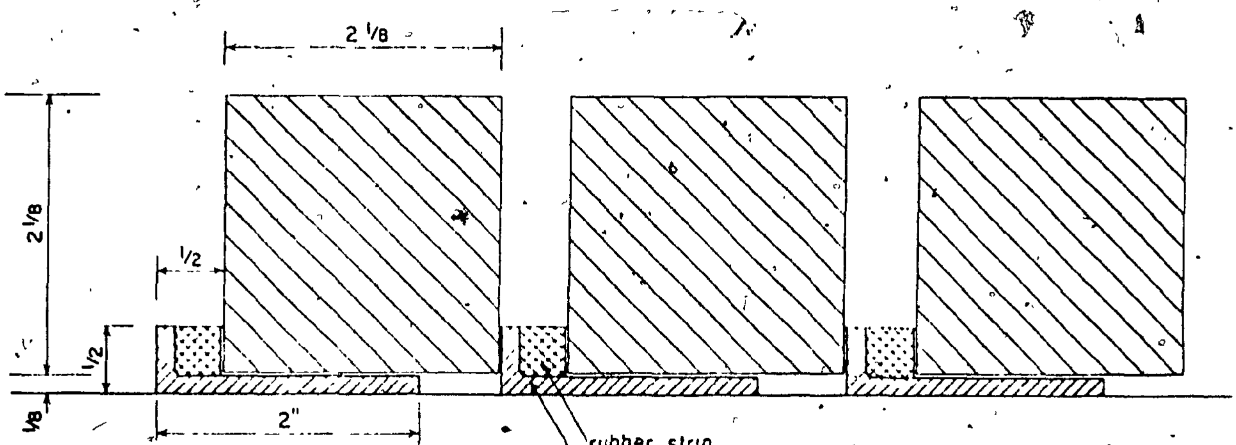


Figure. 2.37

DETAIL OF BENCH CAR DECK

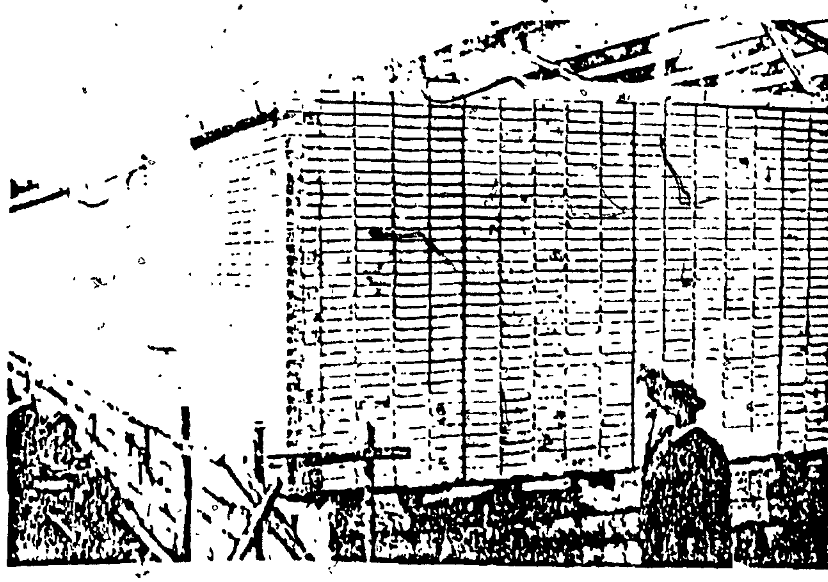


Figure 2.38

Typical Industrial Application of Teglment Panels

Figure 2.39 Panel Detail

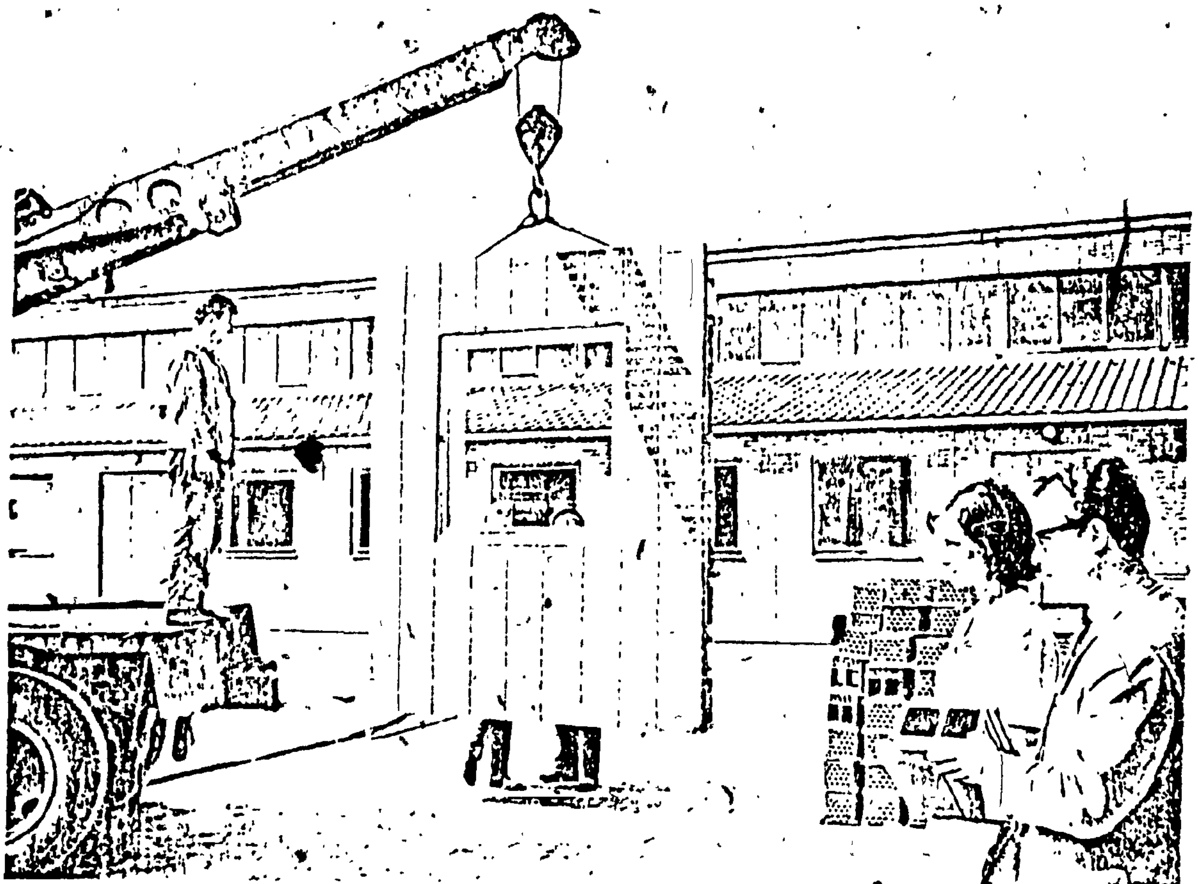


Figure 2.40

Montage Bau Panel ready for Installation.

Figure 2.41

Multi-Cored Brick.

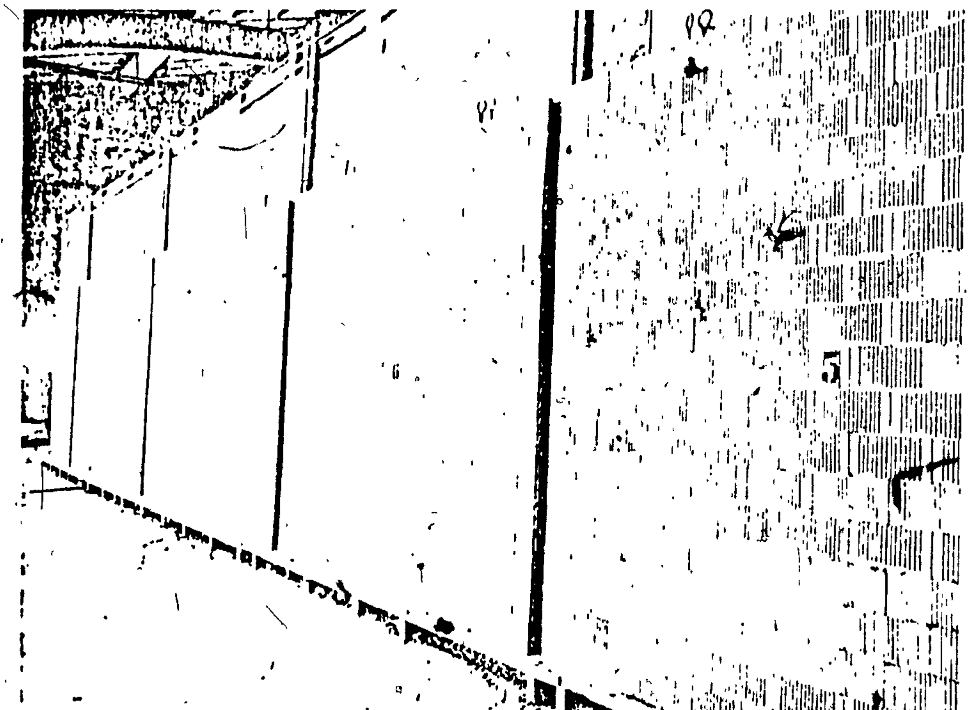


Figure 2.42

Prefabrication Factory, Preton System, Pfungen, Switzerland.

PRETON - Wall Elements

Section

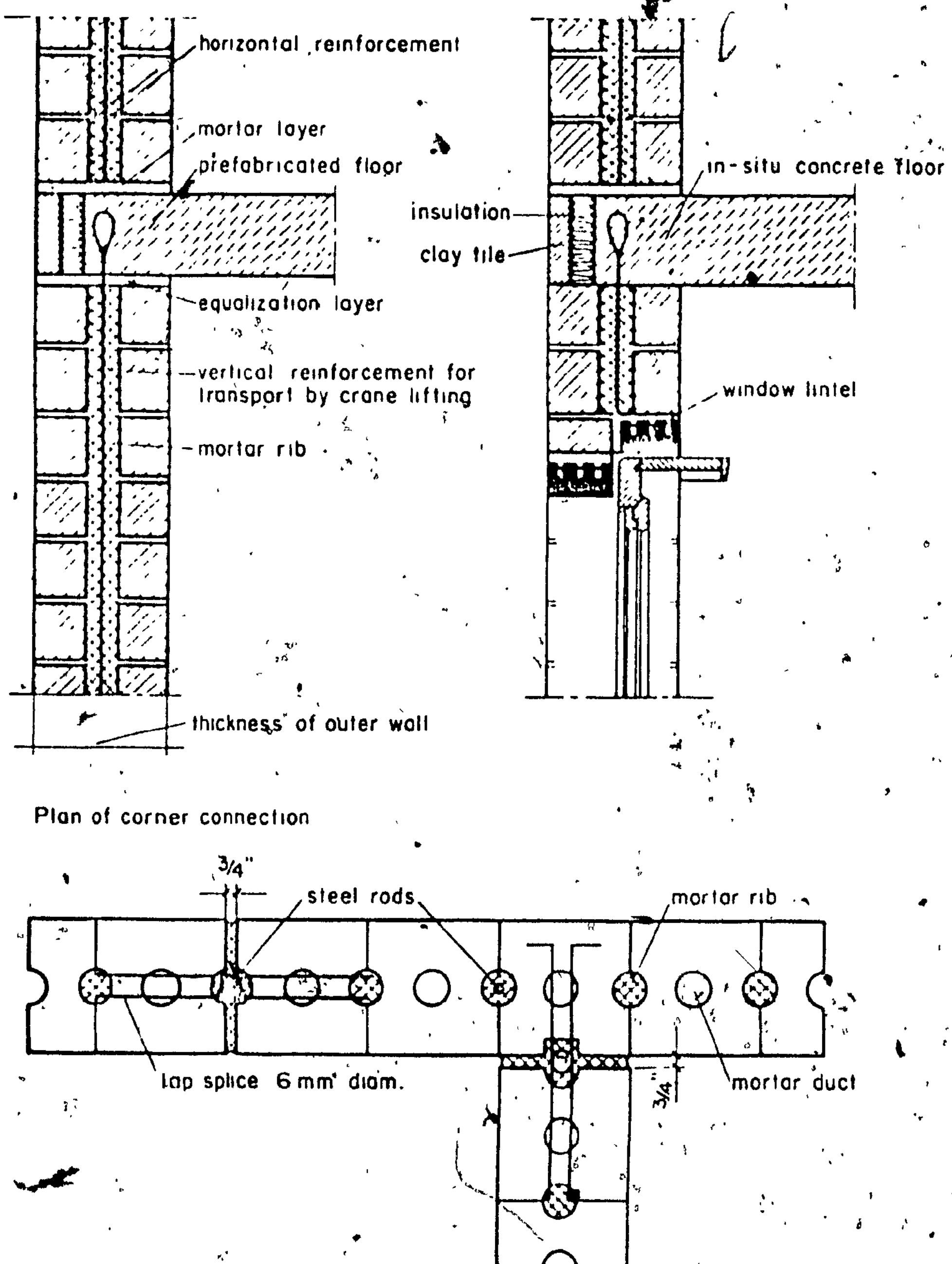


Figure 2.43

CONSTRUCTION DETAILS.

Drawing by Bureau B.B.R. Zurich.

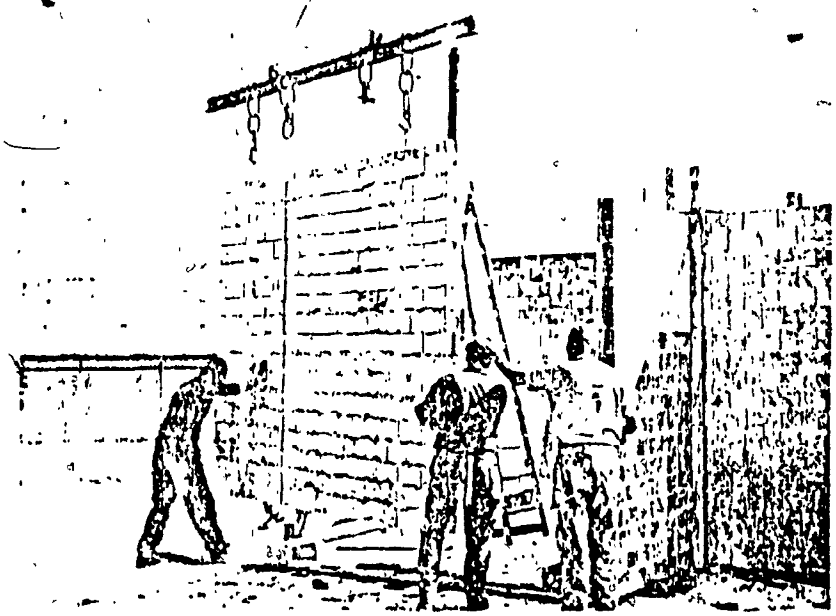


Figure 2.44
Placing a Panel on a Prepared Mortar Bed.

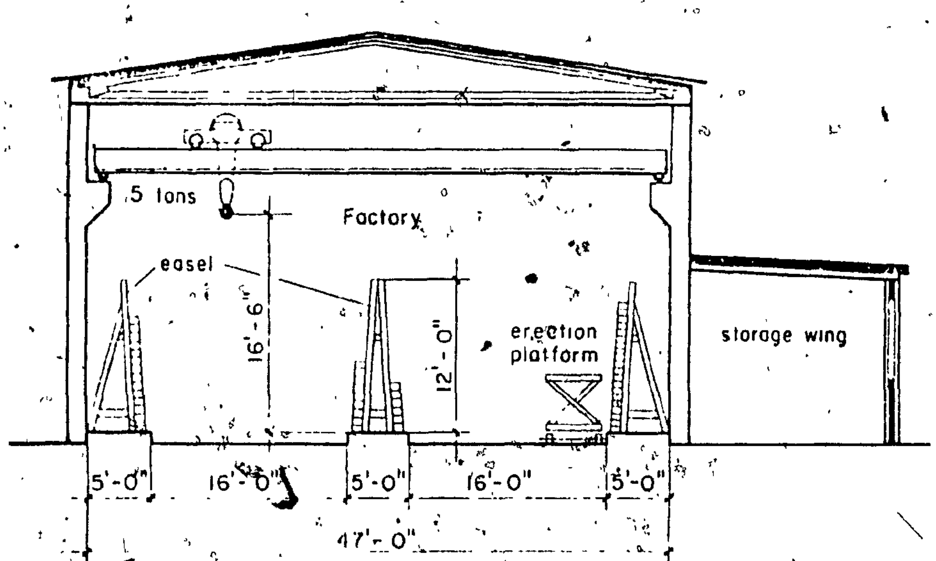


Figure 2.45
ELEVATION OF FACTORY

Drawing by Bureau B.B.R. Zurich

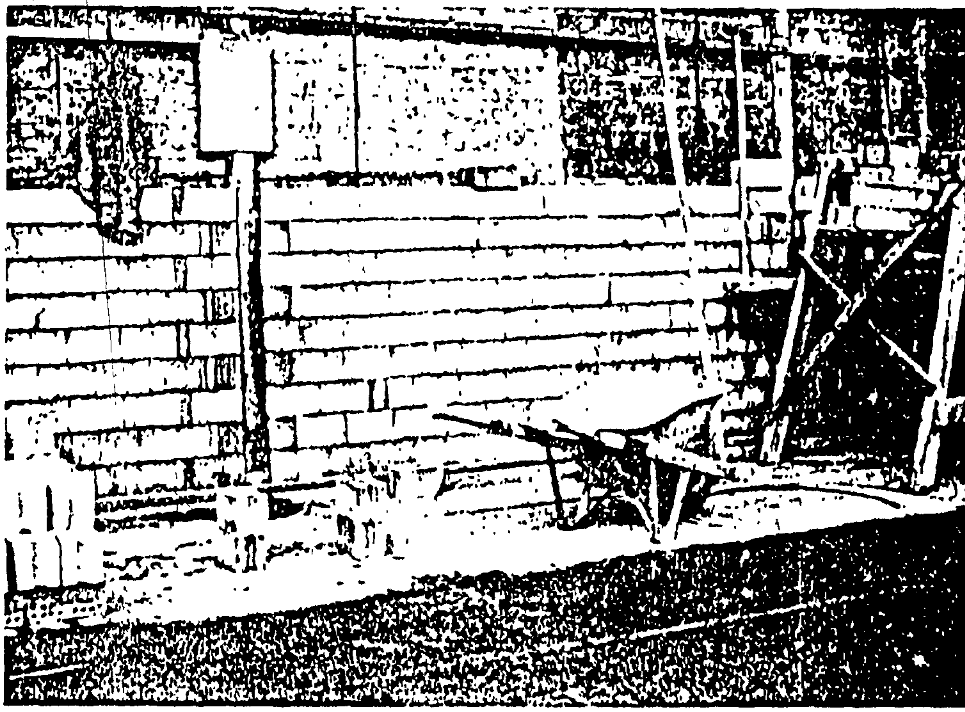


Figure 2.46
Preton Elements During Manufacture
Note Course Lines on Easel-Faces and Shop Drawing.

Figure 2.47
Elements 20 feet long x 4 feet high in Factory Wall

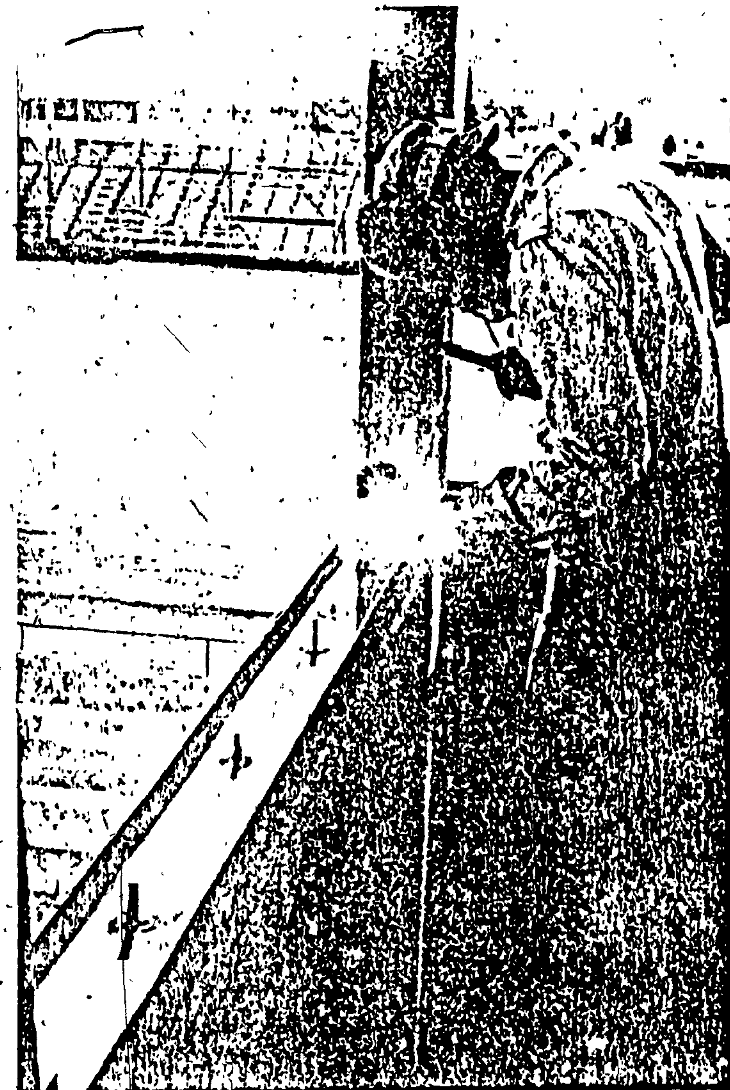


Figure .2.48

Welding a C.M. Panel to a Steel Structural Member.

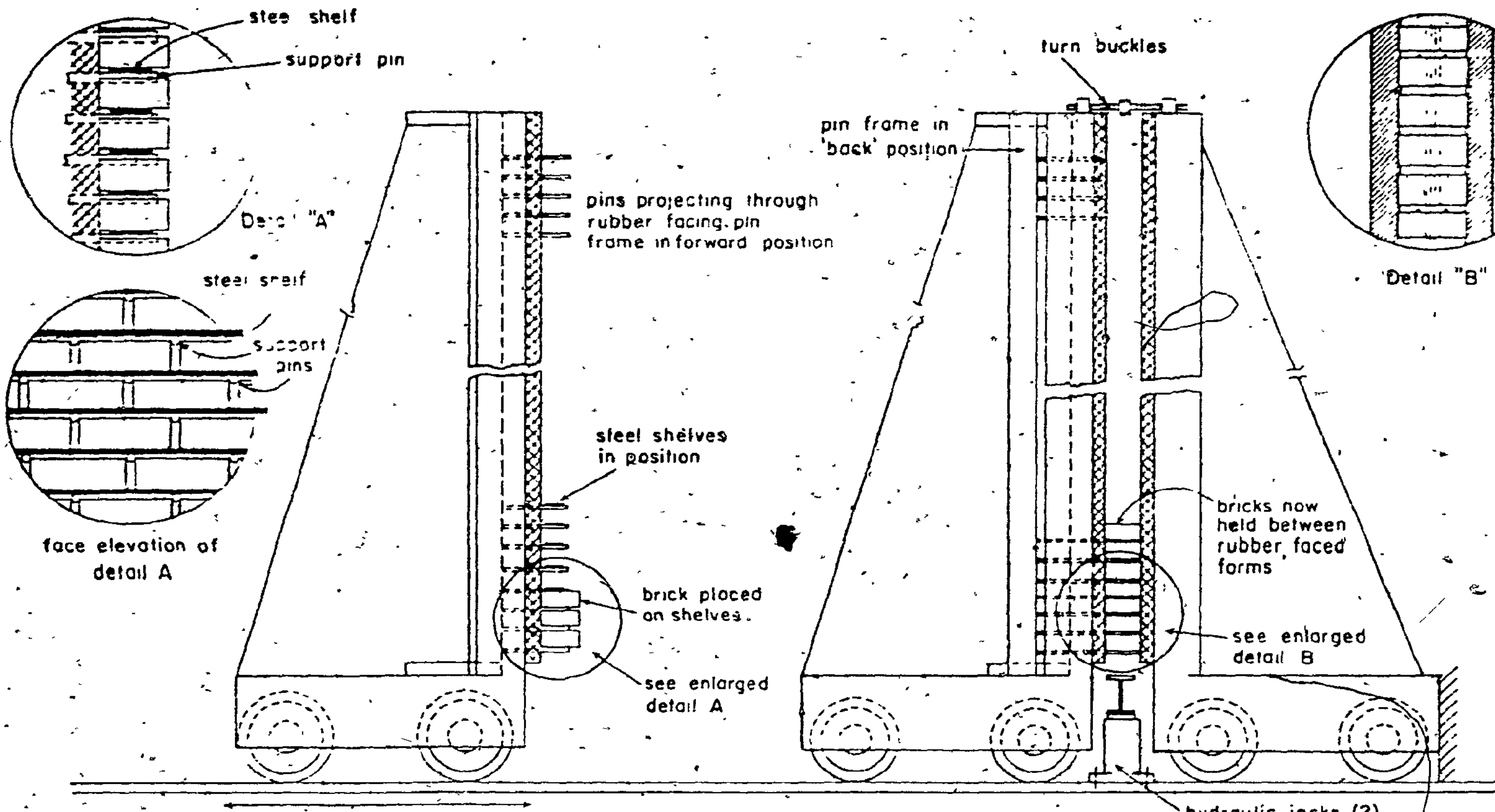
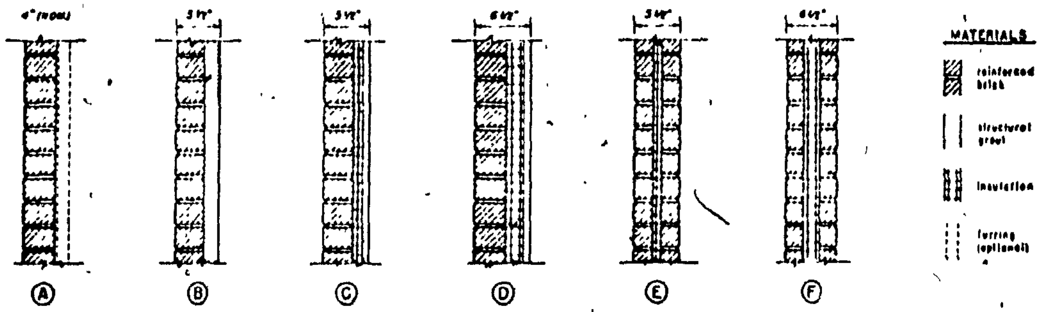


Figure 2.49

SCHEMATIC DRAWING OF GM MASONRY PROCESS BRICK PANEL MACHINE.



COMPOSITE WALL PANELS *VERTICAL SECTIONS* by CM Masonry Process Corporation

WALL PROPERTIES

WALL TYPE	APPROXIMATE WEIGHT LBS PER SQ FT	SOUND TRANSMISSION LOSS, DB	"U" VALUE BTU PER SQ FT PER °F	APPROXIMATE HEAT GAIN BTU PER SQ FT	APPROXIMATE COST PER SQ FT*
4" BRICK, ONE FACE	40	47	0.70	160	0.85
4" BRICK, TWO FACE	40	47	0.70	160	0.90
**4" BRICK, FURRING	45	50	0.40	90	1.10
**4" BRICK, FURRING, INSUL.	45	50	0.12	27	1.15
6" (BRICK, 2" GROUT)	60	52	0.60	130	1.30
6" (BRICK, 1" INSUL, 1" GROUT)	54	50	0.30	65	1.35
7" (BRICK, 2" INSUL, 1" GROUT)	56	50	0.12	26	1.45
6" (BRICK, 1" CAVITY, BRICK)	54	50	0.42	90	1.70
6" (BRICK, 1" INSUL, BRICK)	54	50	0.20	43	1.80
7" (BRICK, 2" INSUL, BRICK)	56	50	0.12	26	1.90

FRAME, WOOD SIDING	20	30	0.50	169	0.80
FRAME, INSULATED	20	30	[illegible]	37	0.85
BRICK VENEER	60	52	[illegible]	76	1.25
BRICK VENEER, INSULATED	60	[illegible]	[illegible]	2.6	1.30

* THESE ARE APPROXIMATE COSTS ASSUMING [illegible] SIMPLEST [illegible] CONSTRUCTION AND INSTALLATION. ACTUAL COSTS MAY [illegible] DING UPON SPECIFIC JOB CONDITIONS. IT IS ALSO ASSUMED THAT DELIVERY [illegible] PLANT. FURTHER DISTANCES WILL NECESSITATE ADDITIONAL TRANSPORTATION COSTS. [illegible], ADD APPROXIMATELY 50 CENTS PER SQUARE FOOT PER [illegible] FACE.

** ALL VALUES FOR [illegible] INCLUDE THE APPLICATION OF SHEETROCK AND WALL FINISH.

3. GENERAL DESIGN AND ARCHITECTURAL ASPECTS OF PREFABRICATED MASONRY PANELS

3.1 General Introduction

Brick, which is the first modular and first prefabricated unit produced by man at the dawn of our civilization, is the basic component of prefabricated masonry panels. Masonry in general has not been given due attention as has been given to other materials like steel, concrete and timber etc. as regards theory of design and construction practice. Since prefabricated masonry panels are an off shoot of masonry in general, they inhereted the same lack of knowledge. The economy and quick construction in almost all weather conditions associated with prefabrication have attracted the attention of engineers and architects to develop a radically new approach to design, to create new exciting architectural shapes and forms and to use the panels as a structural or non-structural element, based on the knowledge gained in this field through recent research work.

Apart from bricks, ceramic blocks and other clay products can be used for panels. Bricks may be solid or perforated and of any practical size. The panels may be plain, reinforced or prestressed depending upon the requirements.

Building ceramic are made out of earth that has been subjected to special heat treatment. This treatment changes the internal structure of the material at atomic scale. Some special ceramics possess great strength and rigidity. The strength can be as high as 500,000 psi. For masonry panels ordinary ceramic products made from clay are used which have crushing strength ranging from 2500 psi to 5000 psi. Some of the geometric shapes of bricks and ceramic blocks generally used for wall or roof panels are shown in Figures 3.1 to 3.5 (Ref: 7)

3.2 Prefabrication And Structural System in Building

There are two basic approaches to types of prefabrication. The component approach and the model approach Component approach means construction of a variety of buildings by using a limited number of mass-produced interchangeable components. Use of panels is concerned with this approach. The model approach is not applicable here.

There are three basic structural systems as follows:

a) Linear Structural System which is composed of specially arranged sets of linear systems in form of beams, columns, girders or arches constituting a basic 3-dimensional structure of a building. This is not applicable to use of panels.

b) Planar Structuror System is composed of specially arranged sets of planes or 2-dimensional elements in form of walls, floors, diaphragms to constitute a basic

3-dimensional structure of a building. Prefabricated panels are applicable to this system.

c) <u>Composite Structural System.</u> is a combination of linear and planer system. Here again panels can be applicable.

The masonry buildings in particular can be classified as monolithic structures, polylithic structures and hybrid structures.

<u>Monolithic Structures.</u> are constructed from masonry in such a way that this masonry is fully continuous throughout the structure.

<u>Polylithic Structures.</u> are constructed from different prefabricated masonry units. The strength and performance of such structures depends upon the efficiency of joints between two prefabricated units. The joints are usually of cement-sand grout. Presence of joints makes the structure discontinuous and as such it's behavior is different from that of a monolithic structure.

<u>Hybrid Structure.</u> consists of a linear or planer frame or a combination of both, with masonry infill panel walls connected to the basic frame. Here again application of prefabricated panels can be found.

3.3 <u>Function of prefabricated panels.</u>

Prefabricated masonry panels serve simultaneously several functions of importance as on-site brickwork namely:-

a) They can provide complete frame work consisting of walls and floors to support all loads acting on them.

(ii) Transmission Loss 45 To 49 Decibels.

(a) Single masonry wall weighing more than 36 lbs per square foot including plasters.

(b) Composite masonry as in i-c above, except gypsum lath supported on furring.

(iii) Transmission Loss 40 to 44 Decibles.

(c) Single masonry wall weighing at least 22 lbs per square foot including plasters.

3.9 Fire Rating

An important characteristic of brick masonry is its excellent fire-resistant qualities. In fact masonry fire-proofing of structural steel columns, beams and other elements is universally accepted practice. As such prefabricated brick masonry panels provide fire proofing of the building. Lining material like cement-sand mortar or gypsum plaster are also fire-proof. In case the lining is of some combustable material then according to "ASTM", if W, C and F respectively are the flame spread rating for wall, ceiling and floor linings, then

$$C + 2W + \frac{F}{2} < 75$$

8" WIDE WALL

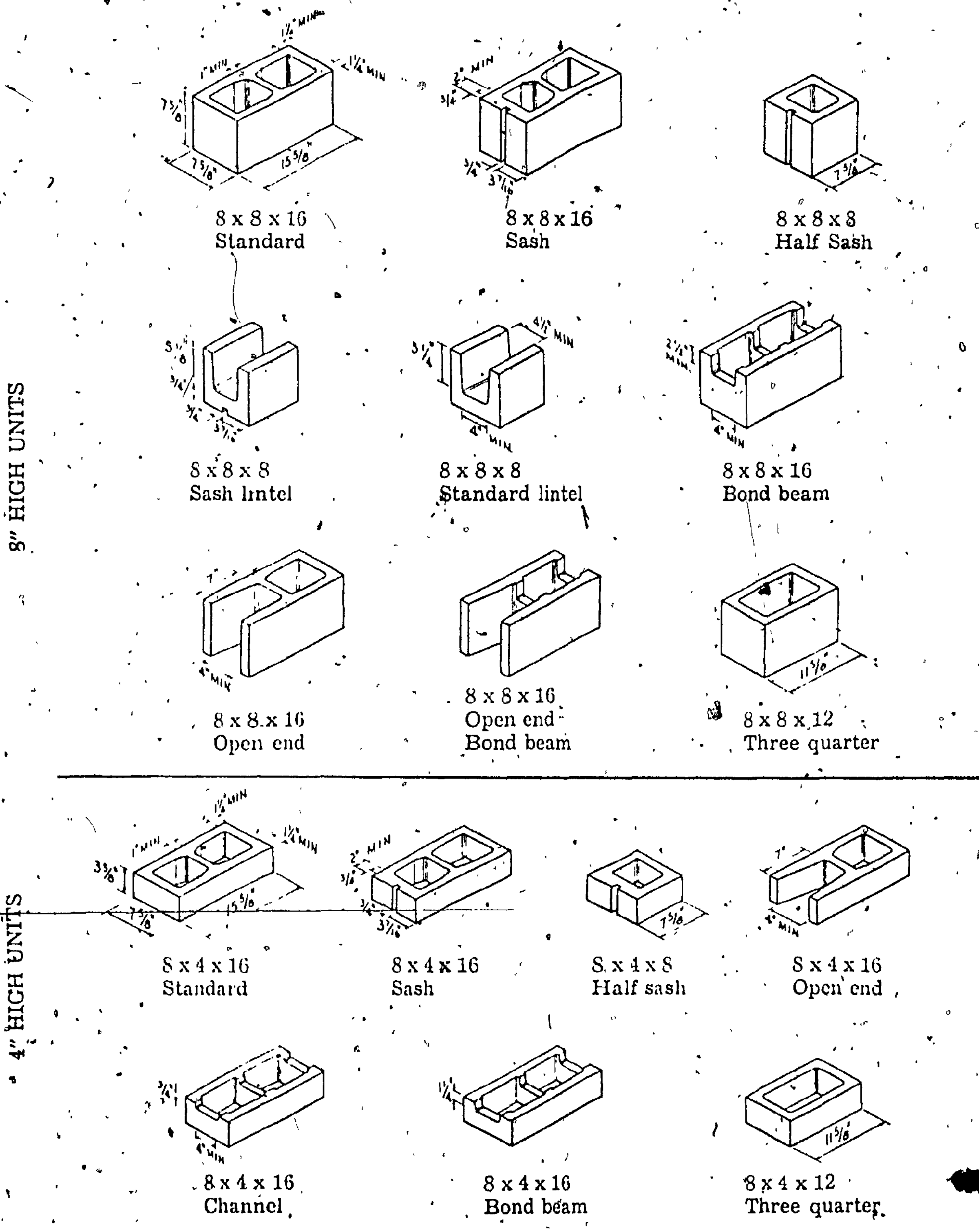


Figure: 3.1

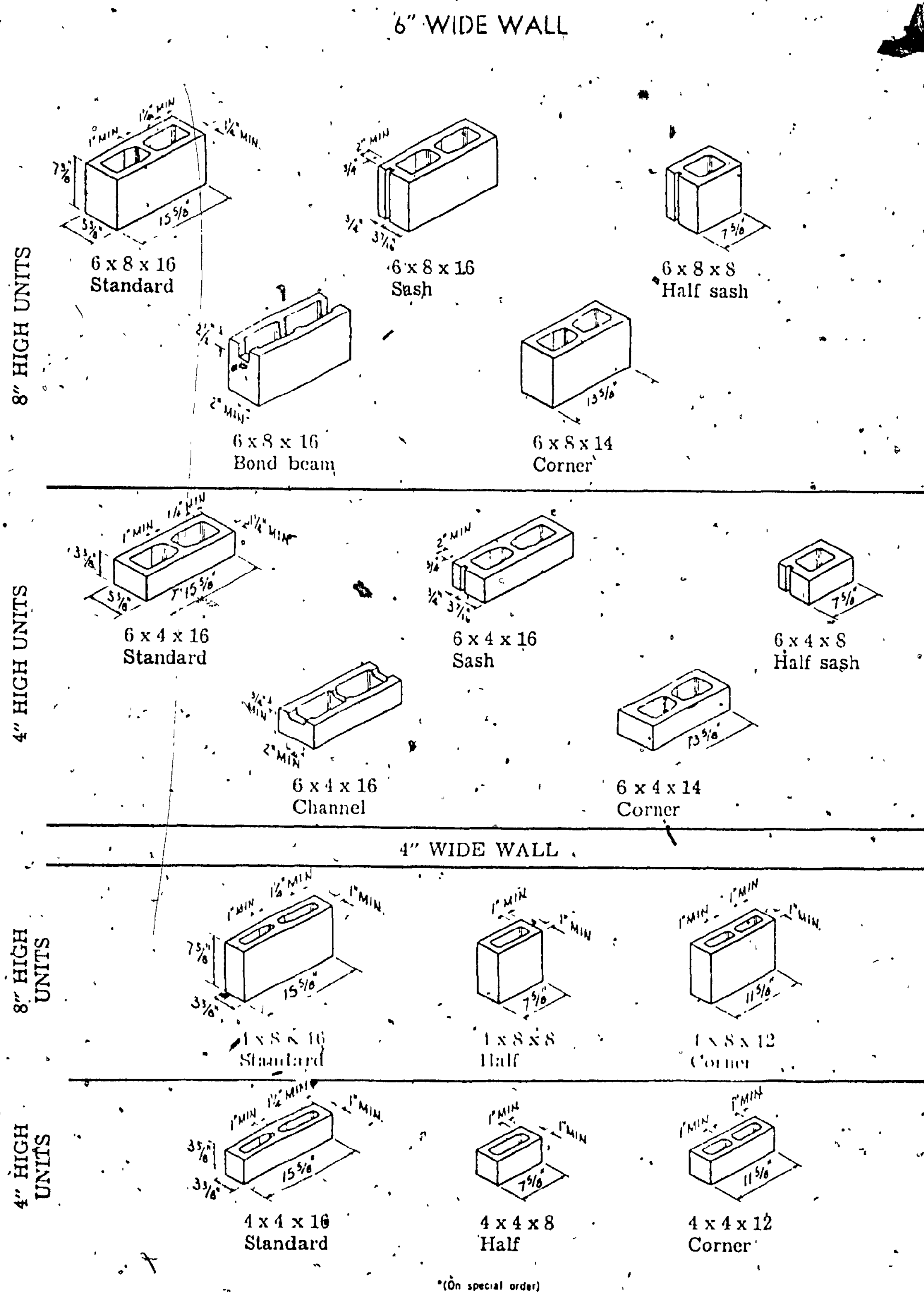

6" WIDE WALL
8" HIGH UNITS
6 x 8 x 16
Standard
6 x 8 x 16
Sash
6 x 8 x 8
*Half sash
6 x 8 x 16
Bond beam
6 x 8 x 14
Corner
4" HIGH UNITS
6 x 4 x 16
Standard
6 x 4 x 16
Sash
6 x 4 x 8
Half sash
6 x 4 x 16
Channel
6 x 4 x 14
Corner
4" WIDE WALL
8" HIGH UNITS
4 x 8 x 16
Standard
4 x 8 x 8
Half
4 x 8 x 12
Corner
4" HIGH UNITS
4 x 4 x 16
Standard
4 x 4 x 8
Half
4 x 4 x 12
Corner
*(On special order)

Figure:: 3.2

12" WIDE WALL

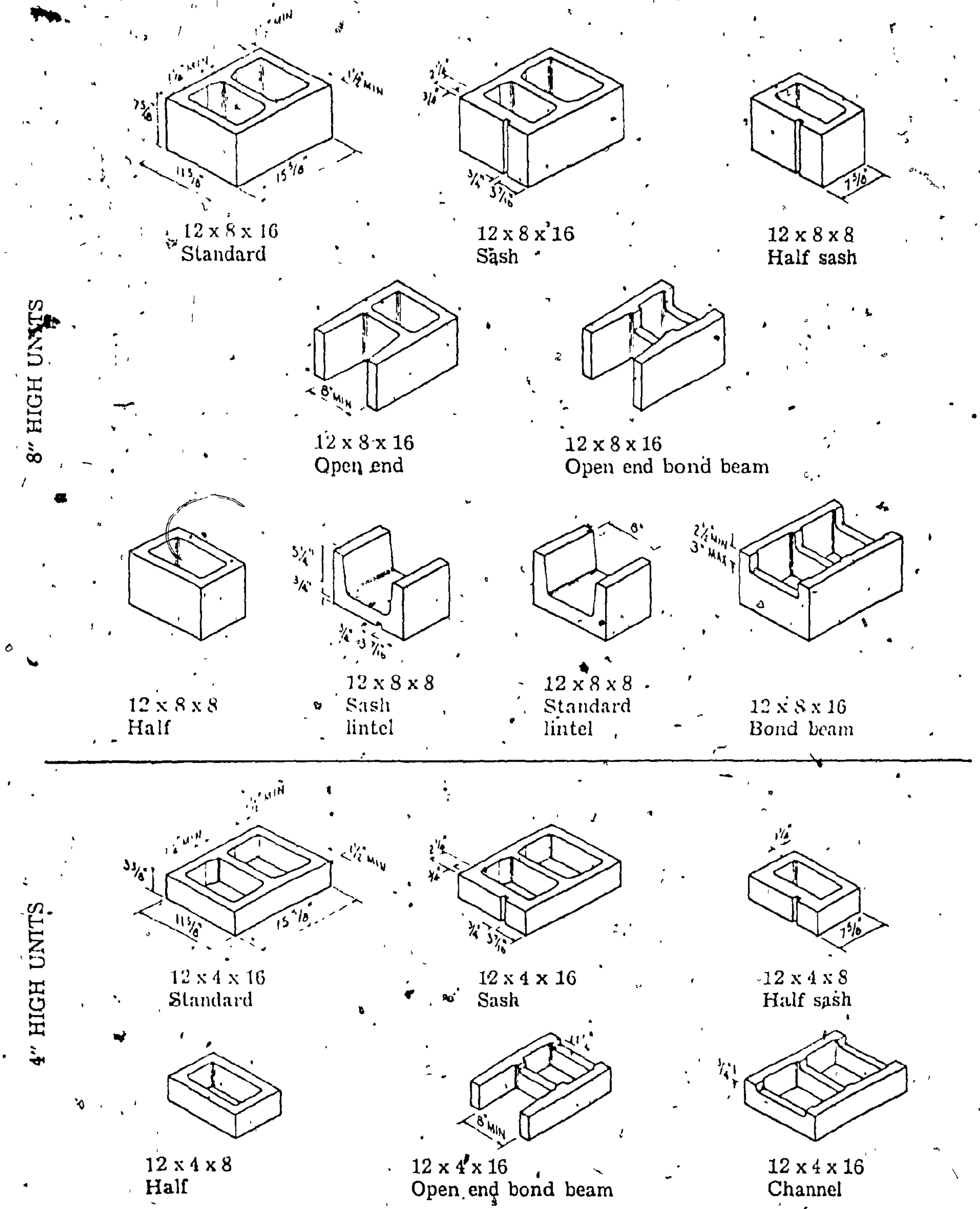
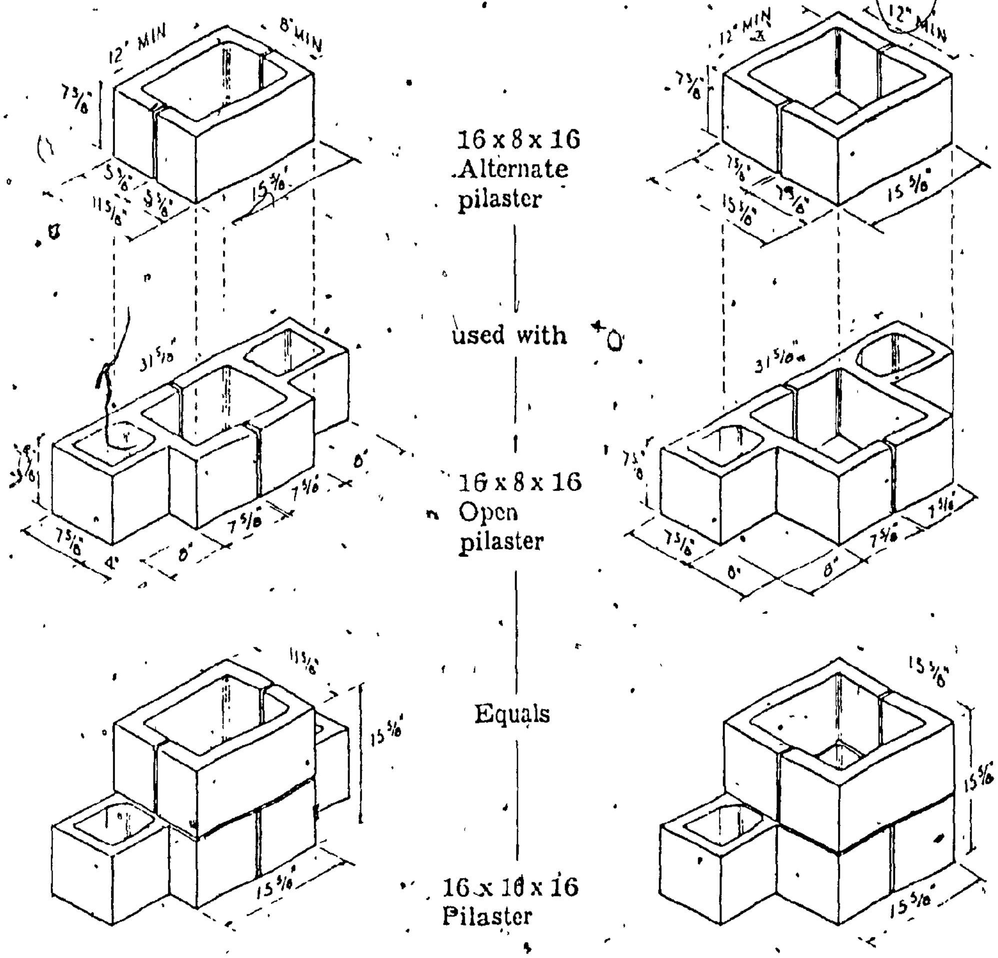


Figure 3.3

PILASTERS FOR 8" WIDE WALL



12 x 8 x 16
Alternate
pilaster

used with

12 x 8 x 16
Open
pilaster

Equals

12 x 16 x 16
Pilaster

16 x 8 x 16
Alternate
pilaster

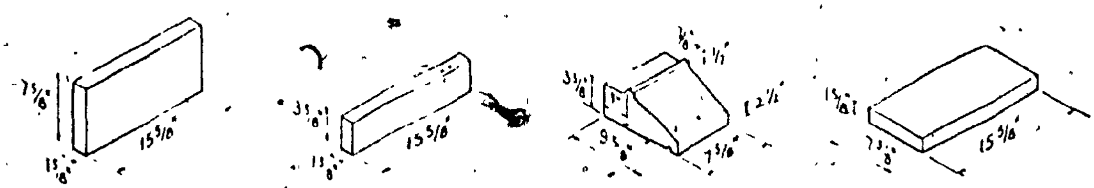
used with

16 x 8 x 16
Open
pilaster

Equals

16 x 16 x 16
Pilaster

ACCESSORY BLOCKS



2 x 8 x 16
Veneer

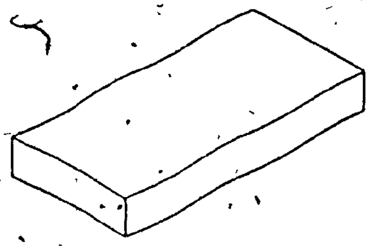
2 x 4 x 16
Veneer

10 x 4 x 8
Sill

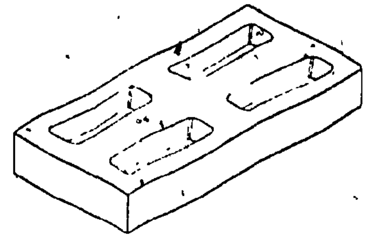
8 x 2 x 16
Cap

Figure 3.4

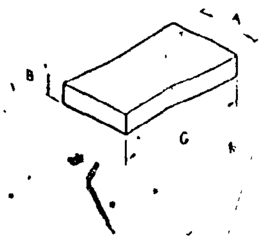
ARCHITECTURAL FEATURE UNITS



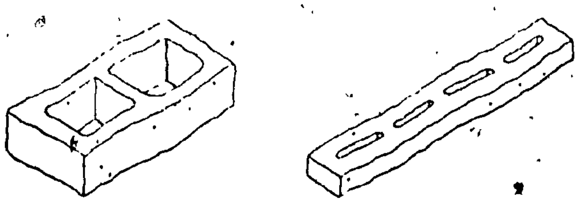
Cap or paving unit



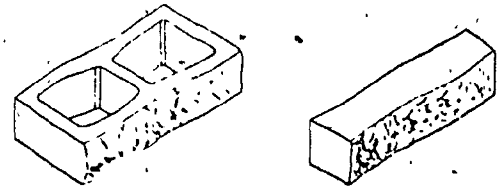
Cap or paving unit (reversed) some units are manufactured with indentations on underside which acts as a mortar key.



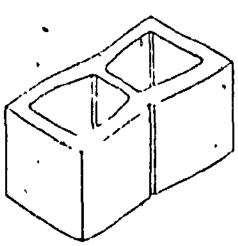
CAP OR PAVING UNIT SIZES															
MODULAR								STANDARD							
UNIT NO	A	B	C	UNIT NO	A	B	C	UNIT NO	A	B	C	UNIT NO	A	B	C
1 M	3 5/8"	2 1/4"	7 5/8"	8 M	7 5/8"	2 1/4"	15 5/8	1 S	3 3/4"	2 1/4"	8"	8 S	8"	2 1/4"	16 1/2"
2 M	3 5/8"	2 1/4"	15 5/8"	9 M	9 1/4"	2 1/4"	15 5/8"	2 S	3 3/4"	2 1/4"	16 1/2"	9 S	10"	2 1/4"	16 1/2"
3 M	5 5/8"	2 1/4"	7 5/8"	10 M	11 5/8"	2 1/4"	15 5/8"	3 S	5 7/8"	2 1/4"	8"	10 S	12[illegible]"	2 1/4"	16 1/2"
4 M	5 5/8"	2 1/4"	15 5/8"	11 M	15 5/8"	2 1/4"	15 5/8"	4 S	5 7/8"	2 1/4"	16 1/2"	11 S	3 3/4"	1 5/8"	16 1/2"
5 M	7 5/8"	2 1/4"	7 5/8"	12 M	3 5/8"	1 5/8"	15 5/8"	5 S	8"	2 1/4"	8"	12 S	6 5/8"	1 5/8"	16 1/2"
6 M	7 5/8"	2 1/4"	9 1/4"	13 M	5 5/8"	1 5/8"	15 5/8	6 S	8"	2 1/4"	10"	13 S	8"	1 5/8"	16 1/2"
7 M	7 5/8"	2 1/4"	11 5/8"	14 M	7 5/8"	1 5/8"	15 5/8"	7 S	8"	2 1/4"	12 1/4"	14 S	12 1/4"	1 5/8"	16 1/2"



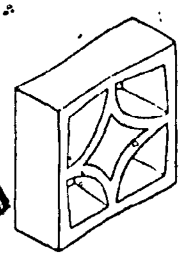
Slumped



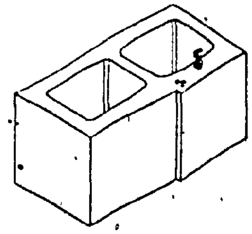
Split faced



Center scored



Screen block



Offset face

Figure 3.5

BRICK PATTERNS AND JOINERY

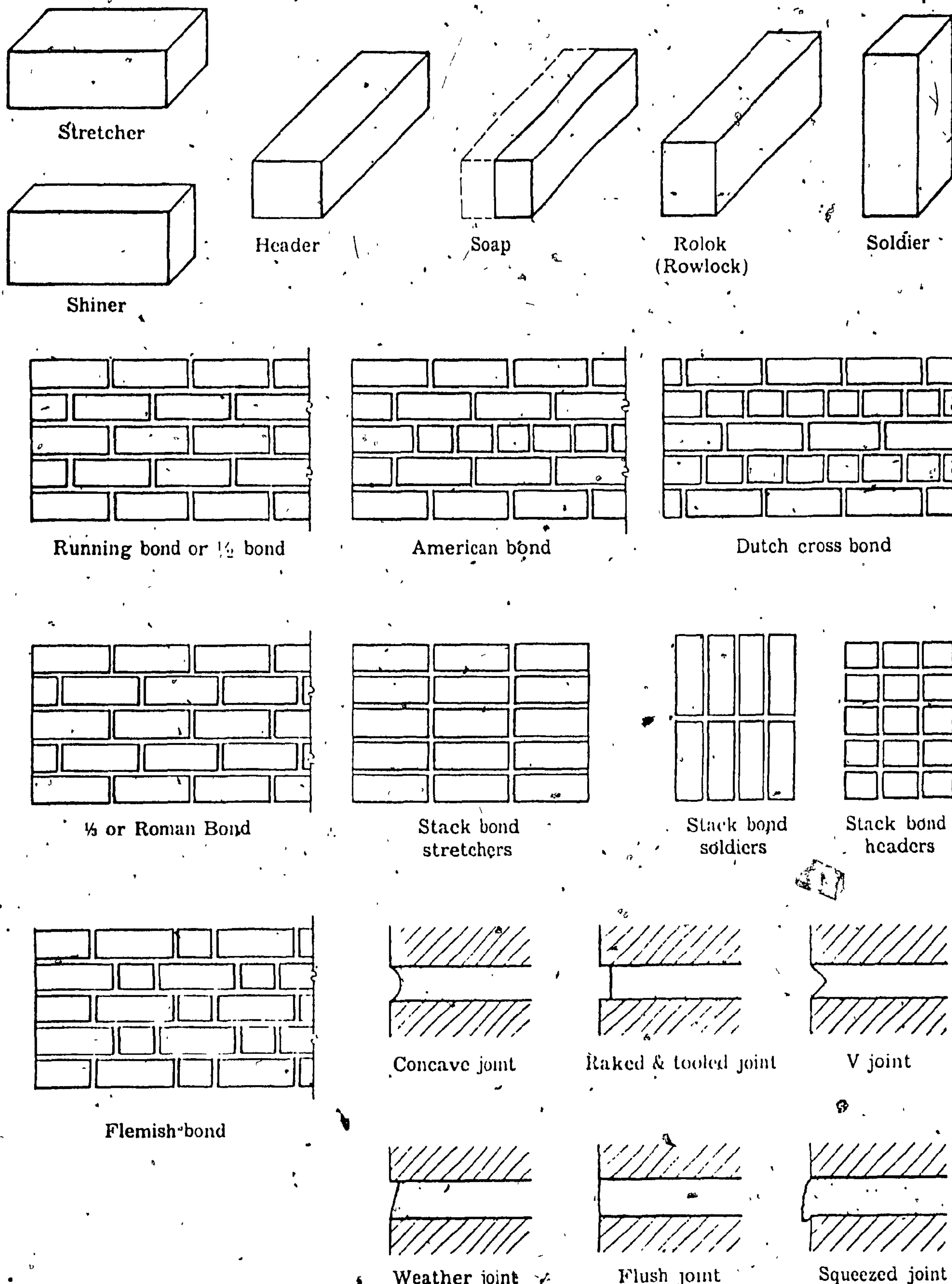
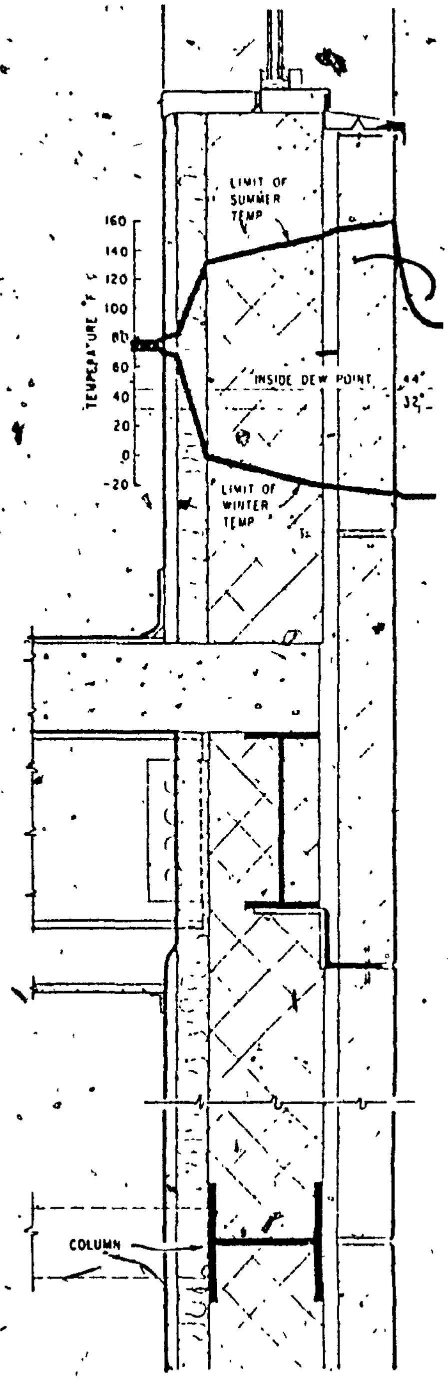


Figure 3.6

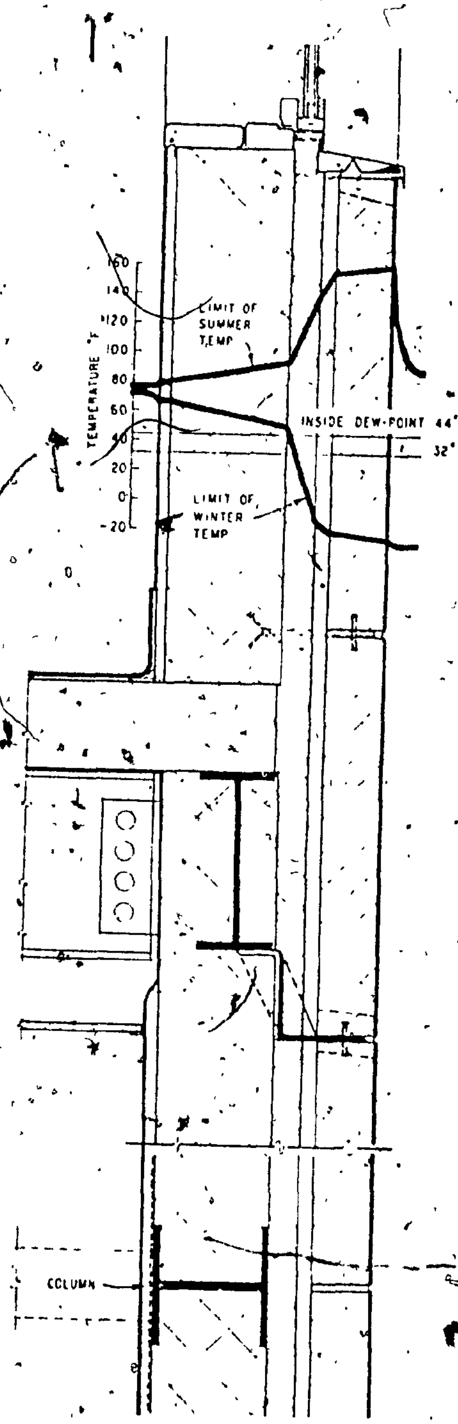


Wall No. 1

Masonry wall insulated on inside

Figure: 3.7

Figure 3.8
Masonry wall with insulation moved towards the outside



Wall No. 2

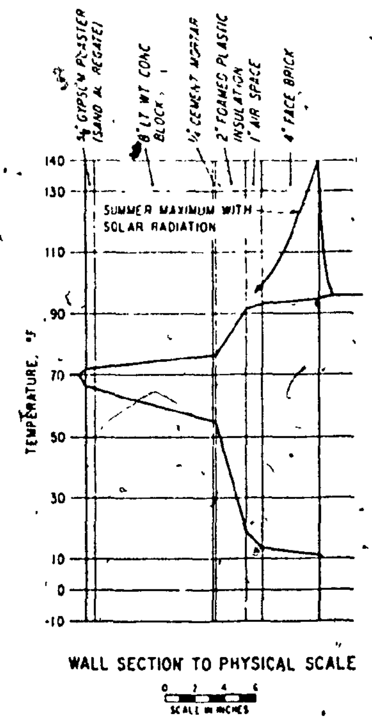


Figure 3.9

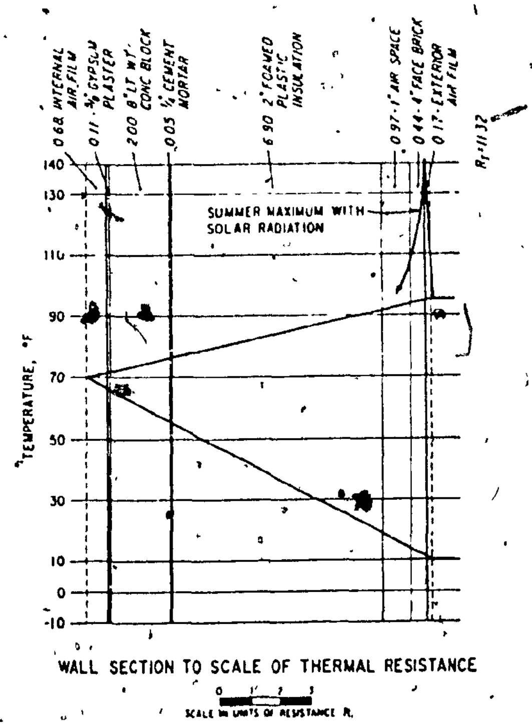


Figure 3.10

TABLE 3.1 ARITHMETIC DETERMINATION OF TEMPERATURE GRADIENT

Component	Thickness, n, in.	Conductivity, k	Conductance, C = k/n	Resistance, R = 1/C	Temperature Drop deg F	Interface Temperature, deg F
						70
Internal Air Film (still air)			1.46	0.68	4	
						66
Gypsum Plaster (sand aggregate)	¾		9.10	0.11	1	
						65
Concrete Block	8		0.50	2.00	11	
						54
Cement Mortar	¼	5.0	20.00	0.05	0	
						54
Foamed Plastic Insulation	2	0.29	0.145	6.90	36	
						18
Air Space	1		1.03	0.97	5	
						13
Face Brick	4	9.0	2.25	0.44	2	
						11
External Air Film (15 mph wind)			6.00	0.17	1	
						10
TOTAL				11.32	60	

The Overall Coefficient of Heat Transmission, U = 1/R = 1/11.32 = 0.09 Btu/sq ft/°F/hr

Table 3.1

4. AREAS OF APPLICATION OF PRE-FABRICATED MASONRY PANELS.

4.1 Introduction.

Prefabricated masonry panels find very wide application in all types of buildings and some other structures, but the maximum application is in residential and commercial buildings.

Masonry panels have found their use in construction of single or double storey dwellings, tall apartment buildings, condominium buildings, students residences in college campuses, nurses residences near hospitals, hotels, motels, hospital, office buildings, ware-houses, factory enclosures etc. Curved panels have found their way in construction of under-ground tanks. See Figures 4.1, 4.2, 4.3, 4.4, 4.5, and 2.15.

The panels can be used for compound walls and even earth retaining structures, called reinforced earth.

Application of these panels will mainly depend on the functional requirements, ease in jointing, strength of joints, transportation range and over all saving in cost and time.

4.2 Application of pre-fabricated masonry panels as Non-Structural Elements.

Prefabricated masonry panels are being used on large scale, as non-structural element in a variety of residential, commercial and industrial buildings. In case of highrise buildings or factories the frame is usually of steel or concrete. Prefabricated masonry panels are fixed in the frame to form exterior non-load bearing walls or interior partition walls. The panels can be jointed to concrete members by cement mortar or other adhesives. In case of steel frame the rods projecting out of the panel can be welded to the frame.

Although such non-load bearing panels are treated as non-structural yet their contribution to over-all strength, rigidity and stability of building is real and should be taken into account during the design of principal structural systems. If their contribution due to certain reason, is not desirable, they must be designed and jointed in such a manner that they will not be damaged or distorted by the normal movement of the principal structure. For this reason overall structural response of the building should be properly evaluated. This will avoid many un-necessary troubles with panels and partitions.

4.3 Application of Prefabricated Masonry Panels as Structural Element

Application of prefabricated brick masonry panels, as structural elements for walls and floors, is quite widespread especially in dewelling units, residential and commercial buildings of few storey height. The panels are capable of taking vertical and horizontal loads. The structure is made monolithic at joints between wall and floor panels by pouring concrete and providing necessary joint reinforcement. Wall panels may be of plain or reinforced masonry where as floor panels are always reinforced to resist flexure. Prestressing of such panels increases their capacity to take more loads. Wall panels are usually of one storey height. However these could be of half storey or two-storey height depending upon the building and construction and handling facilities. Floor panels are usually of room size. A common practice is to use "partically" prefabricated floor panels, which when in place, are covered with 1" to 2" layer of concrete to provide a monolithic floor.

Exterior wall panels may be of single wythe or two wythes. The air gap between the two wythes provides thermal and acoustical insulation and stops moisture travelling from exterior face to the interior one. The air gap may be filled with mineral wool or some other insulating material to decrease the conductivity of panel. The interior surface is usually prefinished, ready for decoration. The bricks may be solid of perforated depending upon the strength and weight requirements.

Structural requirments and design for such panels are discussed at the end of this report, but still it is not out of way to mention here that all possible loading cases and their combinations must be considered in accordance with the code for the structural design of these panels.

Prefabricated masonry panels, un-reinforced and curved, can be used for jack arch roofing or floors. The haunches are then filled with plain concrete.

4.4. Reinforced Prefabricated Masonry Panels.

Reinforced brick masonry is not a new thing. Sir Marc Isambard Brunel, invented reinforced brick masonry (R.B. Masonry) about 150 years ago. The first major use was in 1825 for "Thames Tunnels." The reinforcement was wrought iron bolts. The problem with recent R.B. masonry is of providing continuous spaces for vertical steel. Slotted bricks may be used but it will increase labour cost. The most popular method is to provide vertical steel bars in the cavity which is then filled with concrete.

It is interesting to note that when the panels is under compressive load the mortar in the horizontal joints tends to spread out like a rubber layer and thus fails under tension. It is therefore necessary to provide horizontal reinforcement in the joints at proper intervals to restrain the lateral spread of mortar joints. Thus reducing the bursting tension developed in brick panel under load or in other words the load carrying capacity of the panel is increased.

4.5 Prestressed Prefabricated Brick Masonry Panels

Prestressed prefabricated brick masonry panels find their use mostly for floor construction. Figure 4.6 shows a cross-section of a typical cored brick used in such panels. The hallow spaces reduce the dead load of the panel. For prestressed floor panels, cored bricks are designed 200 mm. high, 243 mm wide and 225 mm long. The cavity percentage being 46 to 70 per cent. The size of floor panel can be for a span of 600 cms or more. The panel thickness is equal to brick height. With large loading it is advisable to provide a thin reinforced concrete slab instead of thicker bricks in the zones of high pressure. The width of floor panels is 90,120 or 180 cms. to make them inter-changeable with the reinforced concrete panels used in practice. The prestressing steel is placed in the holes specially provided for it. Steel is anchored in concrete at both ends.

Figure 4.1 Large curved section of tank placed on a bed of Sarabond mortar

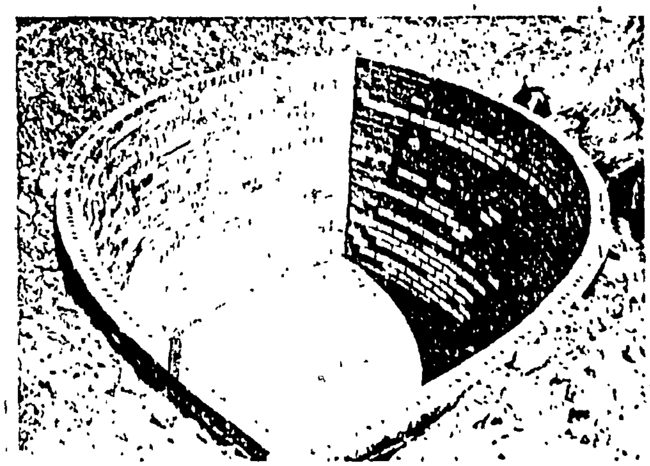


Figure 4.2 Curved design eliminates necessity for bracing the tank.

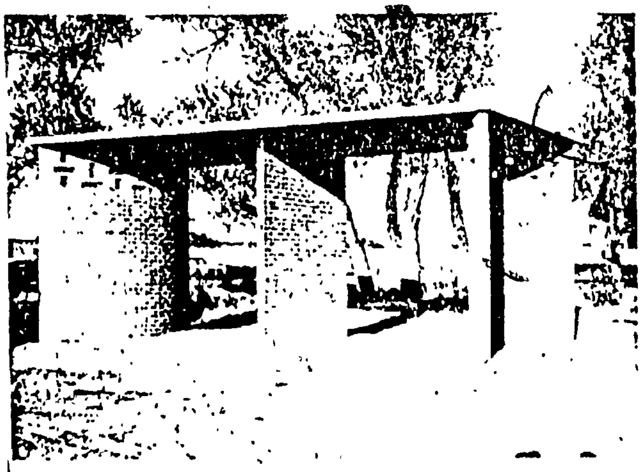


Figure 4.3. Since completion, the Fort Collins Interstate Highway Rest Area has become a showplace of the Colorado highway systems.

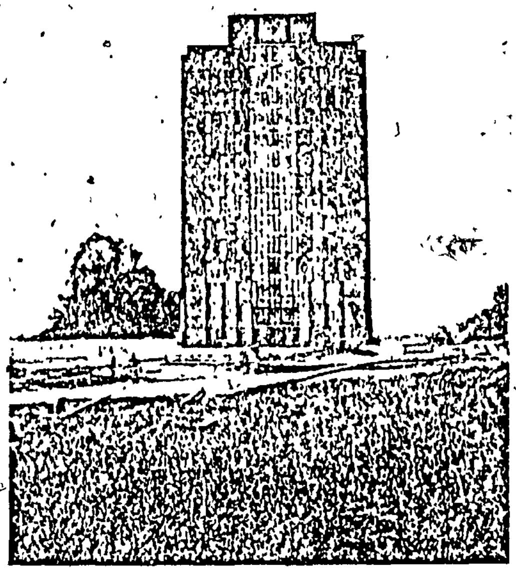


Figure 4.4

Completed Students' Residence

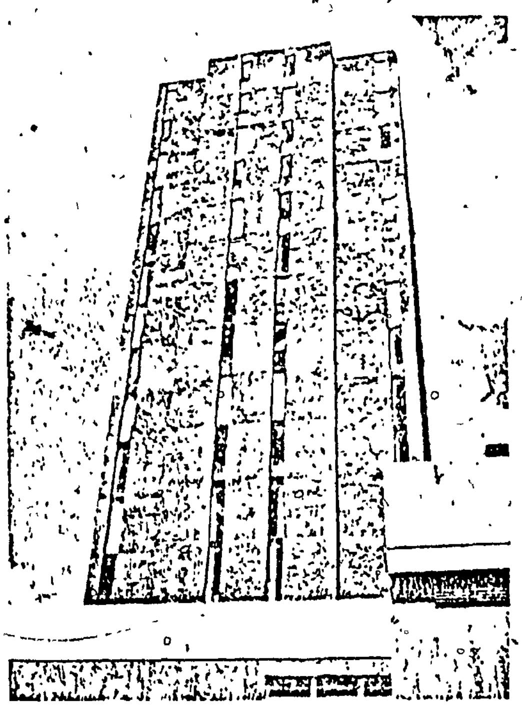
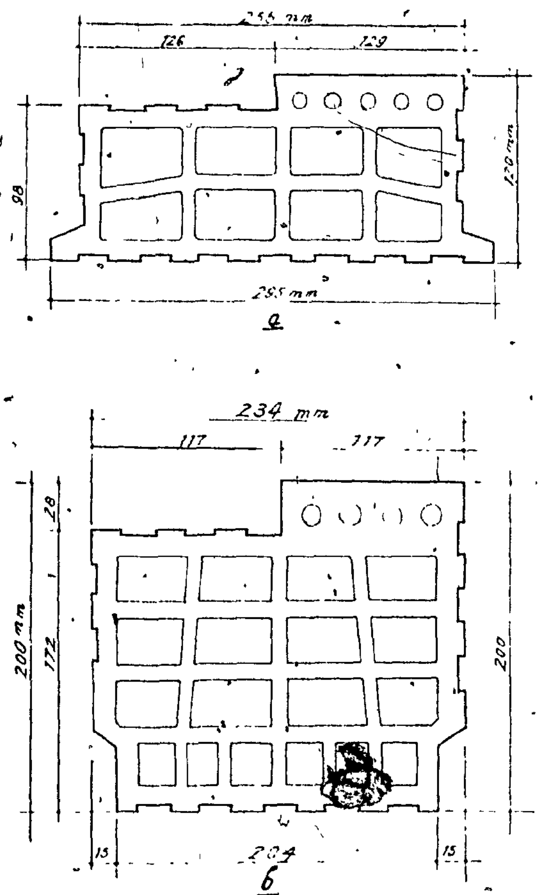
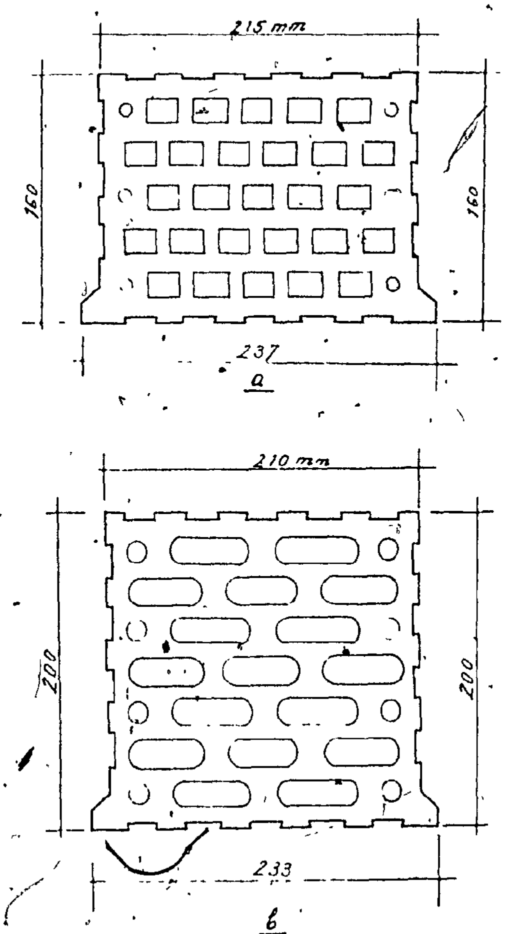


Figure 4.5

Note Mottled Appearance of Brickwork



Ceramic cored bricks for: (a) floor panels and (b) pre-stressed floor panels.



Brick for: (a) inside wall panels and (b) out wall panels

Figure 4.6

5. PROPERTIES OF BRICK MASONRY AND ITS COMPONENTS.

5.1 INTRODUCTION.

The two components of prefabricated masonry panels are the clay units, bricks in this case and the jointing material, usually cement-sand mortar. The bricks and mortar when put together, to form a panel, yield an improved performance which will be discussed later.

The bricks are of smaller size as compared to the size of panel. Smaller size of brick does not improve the structural characteristics of the resulting masonry but it is adopted because of economic reasons. It is economical to produce bricks of smaller size on mass scale. It is easier and economical to joint these bricks to form a panel of any size and shape than to produce a single monolithic clay panel. However ceramic tiles or panels have been developed which may be storey-high, thus eliminating bed joints and reducing cost of labour but flexibility of size and shape is rather difficult.

The weaker part in a masonry panel is the joints. Strength of a panel will depend, ordinarily, on the strength of mortar or grout and thickness of joints. The strength of ordinary mortar can be increased by addition of certain organic compounds or the mortar can be replaced by certain adhesives like latex or epoxy resins. Such adhesives are quite expensive and the bricks to be jointed have to be of exact dimensions and true to the shape which is quite difficult to obtain. As such these adhesive have not found wide application in prefabrication of brick masonry panels.

The properties and performance of a masonry panel are controlled by those of the bricks and mortar and their interaction. The interaction between bricks and joint material leading to failure mechanisms of masonry panels will be discussed first. The properties of bricks and joint material which affect the failure mechanisms of masonry panels will be discussed later.

5.2 Failure Mechanisms of Brick Masonry Panels.

5.21. Compression.

Bricks and joint material have different characteristics of strength and deformation. The uniaxial strength of bricks is ordinarily more than the modulus of elasticity (Em) of the joint material. That means if both components could deform freely under load, the lateral strains of the joint material would by far exceed that of the brick. This is particularly true if the external load exceeds the uniaxial strength of the joint mortar. Since a sufficient bond exists at the interface of bricks and joint material, the lateral strains in both of them will be equal at the interface. As the joint material is confined by bricks in the masonry, it under goes a triaxial state of stress. Due to this state of triaxial compressive stress in the joint material, the masonry can take more compressive load exceeding the uniaxial strength of the joint material. Since the bricks are also confined, they are also under triaxial state of stress.

The masonry units under compressive load, develop tension in both the lateral directions, balancing the internal stresses in accordance with Hook's law and Poisson's ratio. The higher the ratio of joint thickness to the brick thickness, the higher will be the lateral tensile stress in the brick. The lateral tensile stresses increase with decreasing strength and modulus of elasticity and increasing Poisson's ratio of the joint material. This is a clear indication to keep the joint thickness as small as possible, within working limit and to use high strength joint material.

A masonry panel will fail under compression as soon as the strength of bricks under triaxial stress is exceeded or if the bricks are unable to confine the joint material as in the case of thin panels. The bricks are brittle, therefore, they will crack and ultimately fail in the direction of the applied external load i.e. perpendicular to the direction of the maximum lateral tensile stress. This is an indication that even if the bricks in a panel are loaded with axial compressive load, the strength of the masonry panel will depend upon the tensile strength of the bricks. In other words the strength or load carrying capacity of a panel can be determined if the tensile strength of bricks and that of the joint material are known.

The thickness of joint varies while placing the bricks in the joint material and because of the variation in dimensions of the bricks and also because of brick absorbing water from the mortar or due to poor workability of mortar. All these factors result in uneven support of brick over mortar. This gives rise to local stress concentration as well as shear and flexural stresses develop in bricks which deteriorates the case further. Due to this factor it is not possible to obtain a reliable relationship between the strength of masonry panel and that of its components; brick and mortar.

The prediction of masonry strength from known characteristics of brick and the joint material used in masonry is, therefore, not reliable. Acceptance of bricks requires experimental determination of compressive strength of a particular type of masonry panels rather than to predict it from known properties of brick and joint material. Due to these uncertainities the allowable stresses for masonry are rather low which makes the use of masonry panels as load bearing walls uneconomical. A rough indication is that for bricks in the intermediate range laid in cement-lime-sand mortar, the change in wall strength is related to the fourth root of the change in mortar strength. A change in brick strength is said to be more critical, being approximately proportional to the square root.

5.2.2. Tension.

The tensile or flexural strength of a masonry penel is determined, normally, by the tensile bond strength of the brick and the joint material at the interface which is the weakest link in the panel. The bond at the interface is low if ordinary mortars are used as joint material, which results in low tensile strength of masonry panel. Generally the tensile strength is taken zero for design purpose.

5.2.3 Shear.

The shear strength of masonry panel depends upon the bond between the brick and mortar at the interface as well as the stress acting perpendicular to the joint. "Mohr-Coulomb" theory of internal friction may be used to describe the shear strength of masonry and its failure mechanism under shear.

5.3 Cracking Of Masonry Panels Due To Physical Conditions.

Cracking of Masonry panels may occur due to physical conditions and may lead to failure. Such cracks may be due to the properties of bricks and mortar like shrinkage, expansion and creep, discussed later, or due to excessive deformation of supports, vibrations or temperature changes, which are briefly discussed here.

5.3.1 Cracks due to Excessive Deformation of Supports.

Cracks in load bearing brick masonry panels due to deformation of supports are the most frequent cause of damage of panels. There can be two cases; first, the upper floor is more deformed than the lower one; second, the lower floor is more deformed than the upper one.

In case the upper floor is more deformed, the portion of load transmitted to brick panel will depend on the rigidity of panel and the upper floor; the shrinkage and expansion of the panel; the rigidity of the panel's support i.e. the presence of a beam or another wall panel beneath.

In case the lower floor is more deformed, the cracking will depend on the size of the brick panel; position and size of openings and their location in the panel; strength of panel; fixity and interaction of panel with other elements like beams, columns and other panels.

Some of the possible crack locations are shown in Figure 5.1 The width of such cracks is fairly large, some times more than 10 mm. Transmission of load from brick panel to support occurs through an arching effect. Appearance of cracks affects the capacity of thermal insulation and weather resistance of the panel adversely. Tests have revealed that cracking occured in even very small deflections like 1/800 to 1/4000 and that panels with openings are very sensitive to deformations, resulting in cracking. It was further revealed that cracking deflection is a function of span (L) of the panel and also depends on the quality of materials of brick panel. So in place of a form limitation f/L = a constant, where "f" is the unit stress alowed in masonry, one should rather use the form f/kL in which "k" = constant function of the quality of brick masonry of the panel.

5.3.2 Cracking Due To Moisture Change in Masonry Panels.

Brick masonry in the panel under goes volume changes like shrinkage and expansion due to moisture changes. Such changes are the sum of volume changes of mortar and bricks. Bricks may absorb moisture during prefabrication of panels; during transportation and storage, through weather conditions and through moisture inside the room by diffusion or capillarity. This moisture in excess of the balance hygroscopic humidity results in shrinkage. Masonry panel, especially if thick, takes long time to dry out. If "t" is the drying time of the panel then

$$t = s \times d^2$$

where d = thickness of panel

s = coefficient depending upon the type of material and is taken as 0.28 for ordinary clay bricks.

Shrinkage through diffusion of moisture should be differenciated from other forms of shrinkage e.g.

(i) Hydraulic shrinkage at the end of binding process

(ii) Hardening shrinkage if hardening takes place through air

(iii) Cyclic shrinkage- the reversible part of hardening shrinkage

Hydration and hardening shrinkage are sort of "manufacture shrinkage". Panels which are not treated in an autoclave or delivered too soon, show a high degree of manufacture shrinkage and are likely to develop more cracks or wider cracks.

Cyclic shrinkage is due to "rewetting" of panels. cracks are mostly caused by this type of shrinkage. Value of maximum shrinkage allowed in different countries varies from 0.5 to 0.68 mm/m.

Cyclic expansion occurs in brick masonry panels due to moisture changes similar to cyclic shrinkage. The expansion rate varies from 0.1 to 0.2 mm/m. such changes when combined with temperature changes can result in cracks and may cause damage.

5.3.3 Cracking Due To Temperature Changes

Change in dimensions of the panels takes place with change in temperature. These changes are daily as well as seasonal. A large range and frequency of such changes will result in cracks. The coefficient of thermal expansion is $3.4 \times 10^{-6}/F$. In case of harsh climate it is advisable to provide temprature reinforcement in the panels exposed to weather.

If the temperature falls below the freezing point of water and the panel is not properly insulated, a freezing plane will develop in the panel. Repeated freeze-thaw cycles will damage the masonry, resulting in failure of the panel.

5.3.4. Cracking Due to Differential Deformation

In case of mixed structure like concrete and masonry cracks may develop due to differential deformation of different elements. If different quality of bricks are used in the panels, it can also result in differential deformation, leading to cracks. The same thing may happen if masonry stresses vary from one place to another.

5.4. Major Parameters Controlling The Characteristics of Masonry Panels.

In addition to strength and deformation characteristics of masonry panels some other factor may influence the behaviour of masonry and in some cases may dominate. The shape, size and weight of bricks are controlled by economic factors. The size and weight should be such as to provide ease in handling.

In some cases masonary panels may be prefered because they are highly durable, fire resistant and aesthetically attractive while in some other cases dimensional stability and resistance to cracking may be more important and still other considerations could be thermal insulation or acoustical properties. All these considerations play an important role in selecting the type of masonry unit, its material and the type of panel.

The characteristics which control strength, deformations, as well as other economic, aesthetic and physical properties of masonry panels are listed below for each component part of masonry.

(i) Masonry Units.

(a) Compressive and tensile strength under uniaxial or triaxial state of stress.

(b) Modulus of elasticity, Poisson's ratio, ductility and creep.

(c) Surface properties, particularly surface roughness.

(d) Water absorption characteristics.

(e) Freez-thaw durability and resistance to chemical attack.

(f) Volume changes due to changes in moisture content, temperature or chemical reaction.

(g) Unit weight, shape and coring or perforation.

(h) Ease of handling and size.

(i) Types of units and construction.

(ii) Joint Material.

(a) Compressive strength and behaviour under uniaxial or triaxial stress states.

(b) Modulus of elasticity Poisson's ratio, ductility and creep.

(c) Bonding characteristics.

(d) Workbility , flow and water retentivity.

(e) Volume changes, shrinkage.

(iii) Grout.

(a) Compressive strength

(b) Workbility and flow

(c) Bonding characteristic to masonry units and reinforcing bars.

(d) Water retentivity, volume changes, shrinkage.

(iv) Bulk Properties of Masonry.

(a) Masonry patterns.

(b) Surface finishes.

(c) Influence of thickness on thermal insulation and acoustical properties.

5.5 Description of materials.

5.6 Masonry Units.

Common masonry units are clay bricks usually of rectangular shape. The bricks may be solid or perforated and may have different shapes and sizes. Some of the bricks are shown in figure 3.1 to 3.6 The purpose of coring pattern may be reduction in weight, improved ease in handling, provision of spaces for reinforcing bars, improvement of thermal insulation and such other characteristics.

The bricks are made of clay, shale, fire clay or mixtures thereof by firing them at temperatures between 750 to 1300 °C (1400 to 2400 °F). They consist of sand, aluminates and various impurities. Method of manufacture has a remarkable effect on the end product.

Maximum size of a brick is restricted by weight and ease in handling and the requirement to manufacture reasonably crack-free bricks. Half size or quarter size in addition to full size bricks are also manufactured to avoid cutting of bricks during construction. Clay tiles usually have larger size as the thickness is smaller. Ceramic tiles of storey height have been manufactured to eliminate bed joints and to reduce labour cost at site.

In case of perforated bricks the cells may be parallel or perpendicular to the direction of external load. Because of continuous cavity the thermal insulation of the panel is improved. Presence of cavities also reduce the dead weight of the panel, thus resulting in saving of material.

Sand-lime building bricks consist of silicious sand and calcium hydroxide. These bricks are manufactured under pressure and hardened under high temperature in an autoclave. Their shape and size are similar to normal clay bricks.

Special ceramic hollow blocks having thin shells and webs have amazingly high crushing strength and are used for floor panels because of their lightness. Special provision of hollow spaces is made to accomodate reinforcing bars for interlocking with concrete poured at site.

Structural glazed masonry units are another example. The glazed surface provides a sanitary finish and is highly resistant to abrasions, assuring a long life free of maintenance. They are highly fire resistant, have zero flame spread and no toxic fumes. Glazed acoustical tiles absorb sound. Their aesthetic value is pleasing, many colours, textures and design are available. See Figure 5.2.

5.7 Compressive Strength of Bricks

Unless a higher compressive strength is required, it may not be more than 750 lbs./in^2. The compressive strength of brick is dependent on

i). The type of clay used.

ii) The method of manufacture and degree and duration of burning,

iii) The shape and size of unit.

iv) Porosity.

The first two factors are dedicated to a large extent to the location of factory. The third factor is almost standard and could be changed according to customers requirement. Standard English brick size is $8\frac{5}{8}$" x $4\frac{1}{8}$" ; if the depth is $2\frac{5}{8}$". Average crushing strength of a normal brick is about 3500 lbs/in^2. If the depths were increased to $2\frac{7}{8}$", the strength could fall to say 3000 lbs/in^2. On the other hand if the unit made out of the same clay, had dimensions $8\frac{5}{8}$" x 7" x $2\frac{5}{8}$" depth, the compressive strength could be in the order or 5000-6000 psi. Similarly a certain unit 8" x 4" x 3" deep, nominal size, may have a crushing strength of 10,000 lbs/in^2 where as a unit of size 12" x 4" x 3" deep and made out of the same material may crush at 8000 lbs/in^2.

It is important to note that the crushing strength is affected not only by shape and size of brick but also by the method of setting and firing in the kiln. Bowing of units may also be a factor in testing.

Crushing strength quoted by a manufacturer always refersto the strength as laid on the normal bed face.

The compressive strength of clay bricks may range from 3000 to 20,000 psi (20 to 140 MN/m^2) of gross area. The modulus of rupture varies from 10 to 30 percent of compressive strength.

Coring patterns affect the load carrying capacity of brick. Distribution and intensity of stresses in brick are influenced by the size, shape and pattern of perforations, in addition to other factors. Well rounded perforations reduce stress concentration and thus improve masonry strength.

The ratio of the compressive strength of masonry to that of brick is called the efficiency factor. This factor may be as low as 5% and rarely exceeds 60%. This is so mainly because of the comparatively lower strength of mortars. Use of high strength mortars and adhesives improves efficiency factor of masonry.

The compressive strength of sand-lime building brick may range from 1000 to 15000 psi (7 to 100 MN/m^2) of gross area of brick. The modulus of rupture is approximately 20% of comoressive strength.

Figures 5.3 and 5.4 show relation between strength of brick work and the brick units, depending upon the mortar strength.

5.8 Shrinkage and Creep

Shrinkage and expansion of bricks result from change of moisture content in the brick. Loss of moisute causes shrinkage and gain of moisture results in swelling. Moisture gain or loss depends upon the porosity and internal surface area.

Total height of joints in a wall panel is generally less than 20% of total height and as such shrinkage of masonry mainly depends upon shrinkage of bricks.

Shrinkage strain of burnt clay bricks is normally less than 2×10^{-4}. The initial swelling of bricks may not be totally recoverable through loss of moisture due to reaction of water with fired clay resulting in permanent expansion.

Creep of bricks is generally negligible. However certain bricks may have creep 1.2 to 1.8 times the elastic strain. Creep of masonry is generally due to creep of mortars.

5.9 Modulus of Elasticity and Poisson's Ratio

Modulus of elasticity of brick, "E_b", is influenced by the same factors which influence its compressive strength f_{bu}. An approximate relation between the two is

$$E_b = 300 \, f_{bu}$$

Poisson's ratio for burnt clay bricks varies from 0.2 to 0.3 and increases slightly with increasing compressive stress.

Modulus of elasticity of masonry "E_m" depends on the modulus of elasticity of the brick "E_b" and that of mortar "E_r" and can be estimated from the longitudinal strains of both components.

Table 5.1 gives the value "E_m", the modulus of elasticity of brick work for different combinations of mortars and brick strength.

5.10 Rate of Absorption

The rate of absorption is the amount of water absorbed by a dry brick in a given time period during which it is partially immersed in water. The initial rate of absorption is a function of the pore structure of brick which controls the suction.

The rate and the amount of water take-up of a brick is a meaningful property for many purposes. The durability under freeze-thaw conditions is related to the ability of brick to resist complete saturation. This can be measured in a standard way by comparing 24 hours immersion values from a cold water test with those from a 5 hours boiling test. When this ratio of cold and boiled water take-up is 0.8 or less, depending upon tensile strength, brick is thought to be capable of resisting the expansive force from the freezing of contained water..

Rate of absorption affects the workability of mortar and its bond with brick. When the absorption rate is too high, it should be reduced by immersion in a tank of water for a short period. Saturation of brick should not be allowed. No wetting of brick be allowed in frosty weather.

5.11 Joint Materials

Conventional mortars are commonly used as joint material. Addition of certain organic compound modifies such mortars, increasing their tensile strength. Certain adhesives have high strength, but are costly. The joint materials may be therefore grouped as follows,

(i) Conventional mortars.

(ii) Modified mortars.

(iii) High-bond adhesives.

5.12 Conventional mortars

5.12.1 Ingredients

Conventional mortars consist of a mixture of a cementitious material and aggregate. The aggregate invariably consists of natural sand. The gradation curves for sand are specified in ASTMC 144(8) and (9). Tables 5.2 and 5.3 give the ASTM standards for sand and cement. The cementitious material normally consists of portland cement with or without lime. Lime is added to increase the workability of mortar.

5.12.2 Properties

The desirable properties of a mortar are,

(i) Workability.

(ii) Good water retentivity

(iii) Sufficient early stiffening

(iv) Development of suitable early and final strength.

(v) Good adhesion & bond

(vi) Durability

Workability, water retentivity and bond are the properties which lime imparts, while cement and sand confer to strength and durability. Cement-lime mixes are generally superior to staight lime or cement mixes. In case of prefabricated masonry panels, addition of lime, despite of its good workability and water retentivity, is generally avoided because of its slow strength gain and low final strength which depends on the take up of carbon dioxide from the air. In addition lime mortars do not harden in a wet environment. Prefabrication of brick masonry panels require early setting mortars so that the panels can be handled while still "green" to speed up production.

5.12.3 Plasticizers

Plasticizers of the air entraining type improve frost resistance when the masonry is still "wet" and aid workability. They may result in a poor bond particularly with a high suction brick, if not correctly treated.

5.12.4 Pigments

When pigments are used they tend to adulterate the mix because of their non-cemetitious character and relatively high surface area and thus they reduce bond strength and in some cases compressive strength. Where carbon black is used as colouring pigment, quantities greater than 3 percent by weight of cement may affect these properties.

5.12.5 Chlorides.

Calcium chloride and frost inhibitors based on calcium chloride should not be used in mortars. Such additives cause diliquesence and an increased risk of corrosion to reinforcing steel bars and oter ferrous metals when present.

5.12.6 Sulphate Resistance.

When brick panels are likely to remain permanently damp and in position of extreme exposure bricks of special quality or bricks which have been shown to perform satisfactorily under such conditions should be used. As an added precaution cement having sulphate resistance should be used. When using sulphate resistant cement, which has a delayed setting time, the masonry panels when still "green" should be kept well above freezing point to allow for sufficient hardening before moving.

5.12.7 Mix ratio.

The aggregate to cementitious material ratio of the mixture is controlled between $2\frac{1}{4}$ & 3 times the sum of the individual volumes of cementitious materials.

5.12.8 Water-Retention.

Another requirement for mortar is water-retention limit. The flow after suction of mortar possessing an initial flow of 100 to 115 percent must exceed 70 percent.

5.13 Properties of Cement Mortar.

Portland cement is the major constituent of masonry cements and its proportion mainly determines the performance of mortar. Such mortars can develop considerably higher strength, the final strength depending mainly on the water-cement ratio. Because of its faster rate of hardening portland cement mortars have a limited "pot life" which is the period of time during which the mortar maintains its workability.

5.13.1 Hydration

Tricalcium silicate and tricalcium aluminate are the two chemical compounds in Portland cement that contribute to early strength development, were as addition of gypsum delays the initial setting time. Portland cement requires water to initiate and continue the hydration for setting and hardening. Availibility of water for hydration is thus of importance.

When mortar is mixed, water is added until the mortar attains the required workability. This water is readily available for hydration of cement which begins with hydration of tricalcium aluminate, while the mortar is still on the mason's board or in masonry panel. Hydration of tricalcium aluminate continues and the hydration of tricalcium silicate becomes important. Hydration continues, along with absorption of water by masonry units. This results in decreasing the amount of water available for hydration, thereby slowing the process until the hydration process is finally stopped.

5.13.2 Curing.

Sufficient curing of masonry panels is therefore necessary to prolong this hydration process. Application of water or maintenance of moist environments prolongs the hydration period and this increases the mortar strength. Curing during the early period is most effective. Application of water, on dried mortar, at a later stage will reactivate the hydration process but the finally attained strength will be lesser than that in the first case.

Laboratory tests to determine the hydration period in masonry, relying only on the water initially in the mortar and no addition or prevention of evaporation, showed that less than 3 days of hydration are available for the mortar immediately adjacent to the mortar joint surface. To increase this period of less than 3-days, in order to attain higher strength, curing is undoubtedly important.

Curing under normal temperature steadily increase the strength of mortar to its final value like in case of concrete. Curing under elevated temperature, like steam curing gives a rapid rise in the initial strength which then droops to the final value. The graphs for curing conditions vs. strength are shown in Figure 5.4

5.13.3 Workability

The workability of masonry mortar can loosely be defined as its ability to spread easily, its ability to cling to vertical surfaces and its resistance to flow during placement of a masonry unit. In other words, the workability of a mortar is recognized by its adhesion, cohesion, density, flow-ability, plasticity and viscosity. There is no one test measuring all these properties defined collectively as workability except the judgement of the mason using the mortar. In flow test, in laboratory, a truncated cone of mortar is subjected to twenty-five ½ in. drops of a standard flow table. The diameter of the distributed sample is equated to the original diameter on the conical mortar sample. Mortar mixtures and water additions guaged to this standard mortar flow are then used in evaluating relative workability and other properties.

Workability is important not as far as brick layer is concerned but it is also a key factor in the ultimate structural performance of a masonry panel. More over workability depends not only on mortar but on the brick also i.e. it depends on the water retentivity of mortar and the initial absorption rate of brick.

5.13.4 Water retentivity

Mortars that stiffen rapidly in contact with a high suction brick due to their low water retaining capacity will not give complete bond. They will tend to bridge across small surface indentations in the brick thereby reducing area of bond. Bricks with very dense and impermeable surface may not absorb enough water to remove water film between brick and mortar, ~~which leads to~~ separation of brick from actual cementitious materials. On evaporation of water the mortar hardens leaving unbonded surface areas of brick. Water retentivity is thus dependent mostly on mortar and to some extent on brick.

Water retentivity is therefore the ability of mortar to retain water in its mix when subjected to an absorptive force of brick. It is measured in laboratory as the flow of mortar, after it is subjected to a vacuum of 2 in. of mercury for one minute, in comparasion with the original flow of mortar.

With low retentivity, the mortar looses water rapidly, making placement of bricks difficult. With high retentivity, the mortar does not loose water and the brick unit "floats" on it, causing delay in construction. A proper and balanced water-retentivity of mortar is therefore necessary.

Water retentivity of mortar can be increased by addition of plasticizers like limestone, clay and lime.

5.13. 5. Plasticity

Deficiency of plasticity in mortars, like strong high-cement mortars, tends to bridge surface indentations as explained before. In that case considerable pressure must be applied when laying bricks, which may delay construction. More plastic mortar will fill such indentation easily, thereby making the brick laying process easy.

5.13.6 Compressive strength

Compressive strength of a mortar is a measure of its ability to support compressive loads and shows the degree of hydration which in turn depends on other characteristics of mortar. Compressive strength of masonry panel depends not only on the brick but also on the strength of mortar. It has experimently been shown that there is no great advantage to be gained, when using bricks with crushing strength of less than 3000 lbs/in^2, from using a mortar much stronger than 1000 lbs/in^2 or, when high strength bricks are used, a mortar stronger than 2,500 lbs/in^2. A proper balance of the strength of brick and that of mortar is therefore desirable to obtain good result within economic limitations.

It generally follows that low strength mortar be used with low-strength bricks and high strength mortar with high-strength bricks. For high strength bricks a cement-sand mortar of ratio 1:3 is sufficient to meet the requirement

Compressive strength of mortar is evaluated in laboratory by making 2 in. cubes of mortar, which when harden after curing, are put to compression till they fail.

5.13.7 Tensile Bond.

Tensile bond strength is the adhesion between the mortar and the brick at the interface and is dependent both on brick as well as mortar. Tensile bond is important not only from strength or load point of view but also with regard to stresses generated by volume changes or temperature changes.

In laboratory it can be measured by the tensile force needed to separate two bricks jointed by the given mortar.

Tensile bond strength increase with water-cement ratio, by weight, where as the compressive strength decreases as shown graphically in Figure 5.5

5.13.8 Volume Changes.

Mortar in masonry shrinks as water in its mix evaporates. Shrinkage results in volume changes leading to movement of wall panel and affects distribution of strains in masonry.

In laboratory shrinkage of mortar is determined by measuring the shrinkage of 1 x 1 x 11¼ in. prisms of mortar. The specimens are measured for length as a function of time during air storage.

5.13.9 Air content.

If air-entering agents are added to mortar, they form air bubbles which contribute to workability and cohesiveness at a reduced water content. They increase water-retentivity of mortar and the freeze-thaw durability of hardened mortar but decrease its compressive strength.

It has been estimated that 1 percent increase in air content causes about 2 percent decrease in compressive strength.

5.13.10 Water content.

Amount of water in a mortar or the water cement ratio has a great influence on the characteristics and strength properties of mortar. Water is required for hydration of cement in the mix. Higher water content increases workability, volume changes, and tensile bond strength of mortar but decreases compressive strength and durability as shown in Figure 5.5

Water should be free of organic and other impurities. In general water suitable for drinking is suitable for making mortars.

5.13.11 Flexural Stength.

Flexural strength of a masonry wall panel is a function of the tensile bond strength of mortar. It also depends on the type of masonry unit, the workmanship and the ambient conditions.

Flexural strength increases with increase of amount of cement in mortar, increase of workability and increase in curing period, especially initial curing. For design purpose flexural strength of prefabricated masonry panels is disregarded and steel reinforcement is provided where needed.

5.13.12 Modulus of Elasticity & Poisson's Ratio

The modulus of elasticity, E_r, of mortar can be related to its ultimate compressive strength f_{ru} and may be expressed as

$$E_r = 1000\ f_{ru}$$

Poisson's ratio of hydraulic and lime mortars is approximately 0.2 and increases rapidly as the uniaxial strength of the mortar is approached. At failure the value of Poisson's ratio exceeding 1.0 has been observed.

5.13.13 Creep.

Creep of masonry is generally dependent on the creep of mortar as the creep in bricks is usually neglegible. Creep of mortar depends on the age of mortar at time of loading, duration of loading, contents of mortar especially the amount of cement and the water cement ratio, thickness of joint, confinement of joint material, and curing treatment. Value of creep may be as large as 3 times the plastic strain.

5.14 Modified Mortars.

Addition of certain organic additives increases the strength of ordinary cement-sand mortars. These additives extend the conditions under which cement-sand mortar and other cement products are more useful rather than an agent which increase strength.

Increasing the strength of the mortars and the strength of the bond between mortar and brick, the structural strength of masonry can be markedly increased. The inherent high strengths of brick and other clay products can be more fully utilized in masonry panels and other structures as better mortars are developed. The strength of these mortars is such that the masonry frequently behaves as a monolithic unit.

Polymeric additives, especially synthetic latexes, have wider commercial acceptance than other types of organic additives. Their use had generally been restricted to mortars for resurfacing, patching or grouting applications except for commercial "Ployvinylidene Chloride Latex". The latex is added to ordinary cement-sand mortar and this modified mortar is used by masons with ordinary tools for construction of wall panels.

Wall panels utilizing such mortars have been tested structurally and uses based on their high strength have found a place in masonry design, especially prefabricated brick masonry panels. Such panels with liquid "sarabond" polymer adhesive and butyl rubber caulked joints have been used successfully on commercial scale for navel homes in Gulfport, Mississippi. "Sarabond" additive will be discussed here briefly.

Other requirements like workability, water retentivity etc. for these improved mortars are the same as for conventional mortars.

5.14.1 "Sarabond" Brand Mortar Additive.

Sarabond, which is a liquid polymer additive, was developed by the Dow Chemical Company about 20 years ago, for use in concrete bridge deck resurfacing and for chemical resistance. This additive was then further developed to produce a mortar. the strength of which approaches that of brick . Sarabond mortar cubes alone show a compressive strength of 8000 psi. Thus sarabond mortar permits the designer to take advantage of the inherent tensile strength of bricks, especially in the design of partition walls and masonry panels.

The bricks chosen for use with this type of mortar should have the following characteristics for maximum utilization of mortar strength.

i) The average compressive strength of brick should not be less than 6000 psi.

ii) The initial rate of absorption of brick should be less than 35g per 30 square inches of net surface area.

iii) Brick units should be extruded, side cut units.

iv) Brick should conform to requirements of ASTM C216 or C62, Grade SW.

v) No silicone treatment should be permitted on any surface of the brick to be bonded to mortar.

vi) Surfaces of bricks to be bonded to mortar should be free of loose sand or other loose coating materials.

It is interesting to note that some bricks not meeting the above requirements, when used with sarabond mortar, result in satisfactory masonry where as other bricks meeting all these requirements may not give good results. It is therefore necessary to test the compatibility of brick and mortar before using a certain type of bricks on large scale. Bricks produced at the same site may vary in properties over a period of time. Different shaped units of the same clay and manufacturing process may also perform differently.

Because of the extensive use of sarabond in prefabricated brick masonry panels, the efficiency of connections and erection attachments is very important. Pull out, Shear and 'Torque' test are made to ensure reliability of such panels. Figure 5.6 shows a panel under Diagonal Shear Test; figure 5.7 shows a transverse wall test and figure 5.8 shows placing of a prefabricated masonry panel in position at site. The details of these tests are omitted here.

5.15 High-bond Adhesives.

High-bond adhesives are the latest development replacing the concept of conventional or modified mortars. The basic function is the same: To bind structural units together and to act as adhesive and a sealant. There are two categories of such adhesives/mortar systems.

(a) Organic Mortars that are strong in tension and compression both

(b) Fiber Reinforced Conventional mortar that is used to coat the faces of wall. No mortar is placed between the masonry units.

These adhesive are used for quick prefabrication of masonry panels at reduced cost. Such adhesives are used for concrete block masonry panels more than in brick masonry panels.

5.16 Organic Mortars

There are at least four types of organic mortars on the market.

i) Threadline, manufactured by the Dow Chemical Company and Midland and marketed through their construction division known as AMSPEC, of Columbus, Ohio.

ii) Bricon Bond, manufactured and distributed by the Bricon Corporation of Lafayette, LA.

iii) Thermoset, manufactured and marketed by Thermoset Plastic Corporation of Indianapolis, Ind.

iv) Beadline, manufactured by Albert Chemical Sales, of Hamilton, Ontario, Canada and Marketed by Whiteroc Coating, of Glenview.

All these epoxy resin type adhesives are costly and as such the joint thickness has to be very small to save material cost. This demands true size and shape of bricks which are costly to produce. These costs are the main hurdle in the wide use of these adhisives.

These thin-bed adhesives using an epoxy resin with or without latex and cement additives combined in an oil or water emulsion, are generally applied to masonry units with a caulking gun instead of a trowel. While applying these thin-bed adhesives the following points should be considered:

i) These adhesives are expensive and should be used sparingly.

ii) Application is best done by a caulking gun which puts down a 3/16 in. bead. The adhesive then spreads under the next superimposed masonry unit and permits small adjustments for tolerances.

iii) The "pot life" of the adhesive must be reasonable for both hot and cold weather.

iv) Cleaning of tools and equipment by dispersion in water must be simple and complete.

v) The setting time should be reasonable in hot and cold weathers so that placing of successive course of masonry units is not delayed.

vi) layout course, usually set in conventional mortar must be in level and straight so that the successive courses set in high strength adhesive are in good inter-face.

vii) Masonry units should be clean, and free of dust and should be dry.

viii) Dimensional tolerances of masonry units should be checked by dry lay-up of small panels on a level bed.

5.17 Fiber Reinforced Mortars.

This is a surface coat of conventional portland cement mortar reinforced by addition of glass fibers to increase its tensile strength and is applied to both exterior and interior surfaces of the masonry panel. No mortar is placed between the masonry units. This is also called surface bonding. Two types of such mortars available in market are:

i) Bloc bond, manufactured by Owens-Corning Fiberglas Corporation, of Toledo, Ohio.

ii) Sure Wall, manufactured by W.R. Bonsal Company of Lilesville, N.C.

The procedure of panel construction is simple. Masonry units are dry stacked and then plastered on both sides with surface bonding mortar. This requires lesser skill as compared to conventional way of construction of a wall panel. Dry stacking and surface bonding by a trained worker results in greater productivity per day than trowel and mortar construction.

Flexural strength of such panel is improved over that of a panel built conventionally with mortar in joints.

Partition panels made this way are less expensive than framed walls, with equal sound transmission.

Bloc Bond is a mixture of Portland Cement, hydrated lime, an agent providing water resistance and alkali-resistant glass fibers that imparts tensile strength to mortar.. The saving in construction time is up to 50% and the panel is water, fire and sound resistant.

Surewell is similar to Bloc Bond except that it has a mineral filler which makes it possible to achieve a smooth plaster finish suitable for low-income housing, commerical and industrial uses. Construction of wall panels using surewell saves construction cost by 4-5 cents per square foot of wall.

Fibre reinforced mortars have successfully been used in construction with concrete blocks. Their application to prefabricated brick masonry panels on commercial scale is still under research.

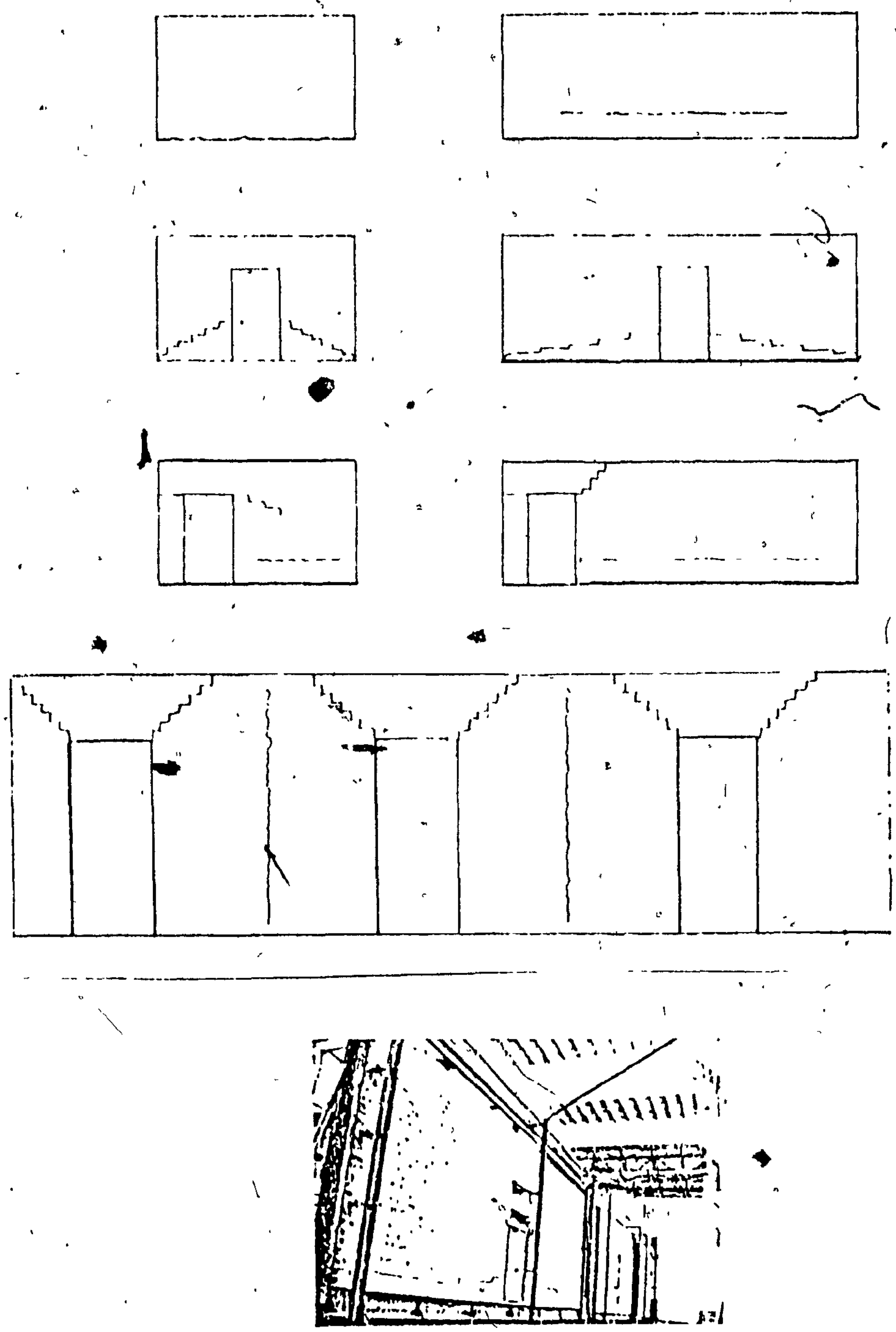
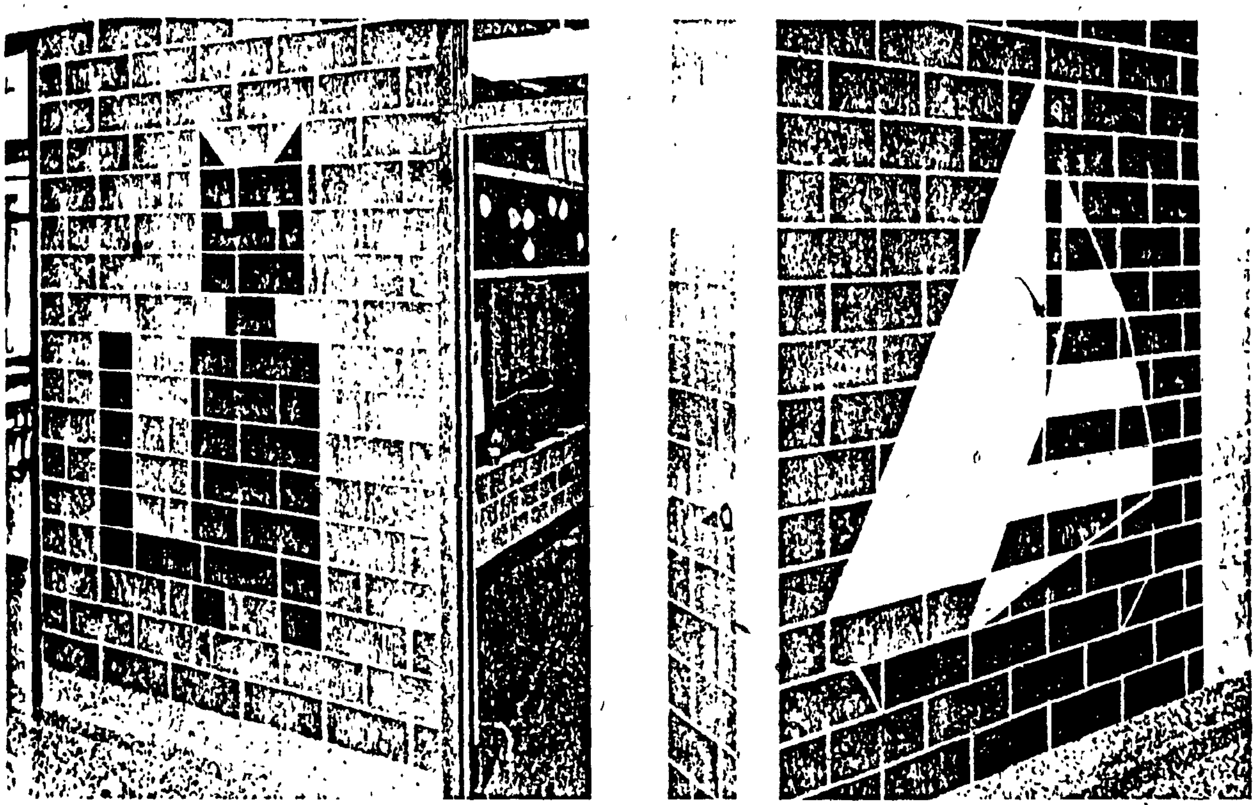


Figure 5.1

Cracks in Masonry Panels



Structural glazed tile used for wall surface designs.

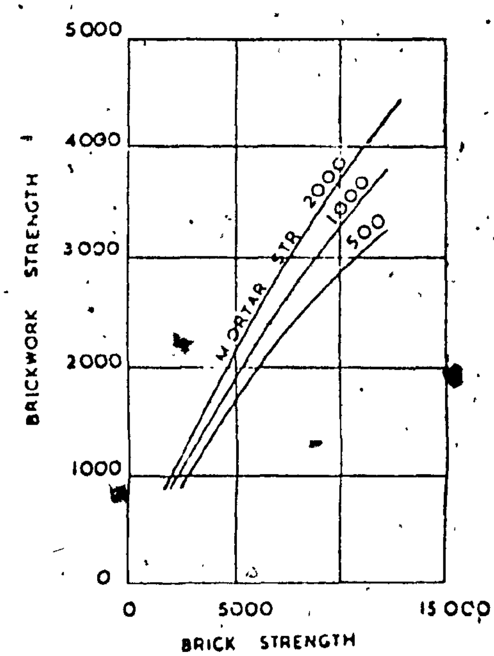
Figure 5.2

Structural Glazed Masonry Units

Crushing strength of unit lbf/in²	Mortar (proportions by volume)		
	Grade I 1 : 0,¼ : 3	Grade II 1 : ½ : 4½	Grade III 1 : 1 : 6
1,500	0.9	0.6	0.5
2,000	1.1	0.7	0.55
3,000	1.3	0.9	0.6
4,000	1.5	1.1	0.7
5,000	1.7	1.3	0.8
6,000	1.9	1.5	1.0
7,000	2.1	1.7	1.2
8,000	2.3	1.9	1.4
9,000	2.5	2.1	1.6
10,000	2.7	2.3	1.8
11,000	2.9	2.5	2.0
12,000	3.1	2.7	2.2
15,000	3.7	3.3	2.8

Young's modulus of elasticity (E values) × 10⁶ lbf/in² for brickwork. Note: linear interpolation between values is permissible

Table 5.1



Relationship (in lbf/in²) between crushing strength of brickwork and strengths of bricks and mortar (after Thomas 1953)

Figure 5.3

Materials

Natural Sand and Manufactured Sand

Grading

Item	Limit
Percent Passing Sieve	
No. 4 (4.76 min.)	100
No. 8 (2.38 mm.)	95 to 100
No. 100 (149 – μ)	25 max
No. 200 (74 – μ)	10 max
Percent Modulus	1.6 to 2.5
Water Demand, ratio by weight	0.65 max

Composition

Deleterious Substances	
Friable particles, max., % by wt.	1.0%
Lightweight particles with specific gravity of 2.0 or less, max., % by wt.	0.5%
Organic Impurities	
Color standard	
Petrographic analysis	
Cube strength, ratio of unwashed to washed sand mortars, %, min.	95%
Soundness	
Weight loss after 5 cycles, max.	
Sodium sulfate solution	10%
Magnesium sulfate solution	15%

Table 5.2

Aggregates for Masonry Mortars
ASTM Designation: C 144-66T

Physical Requirements	
Fineness, residue on a 325 sieve, max., %	15
Soundness	
Autoclave expansion, max., %	1.0
Time of Setting, Gillmore Method	
Initial Set, min. hr.	2
Final Set, min. hr.	24
Compressive Strength, 2-in. Cubes	
7 days, min., psi (kg/cm^2)	500 (35)
28 days, min., psi (kg/cm^2)	900 (63)
Air Content, min., %	12
Water Retention, flow after suction, min. % of original flow	70
Optional	
Water soluble alkali, max., %	0.03

Table 5.3

Standard Specification for Masonry Cement
ASTM Designation: C 91-66

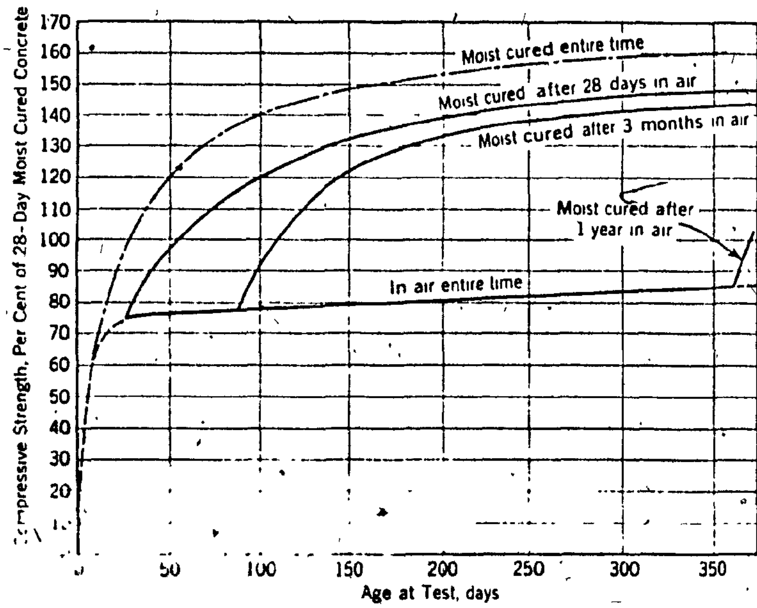


Fig. 5.4 Effect of curing conditions on strength of concrete. (From earlier edition of Ref. 3, Portland Cement Assn.)

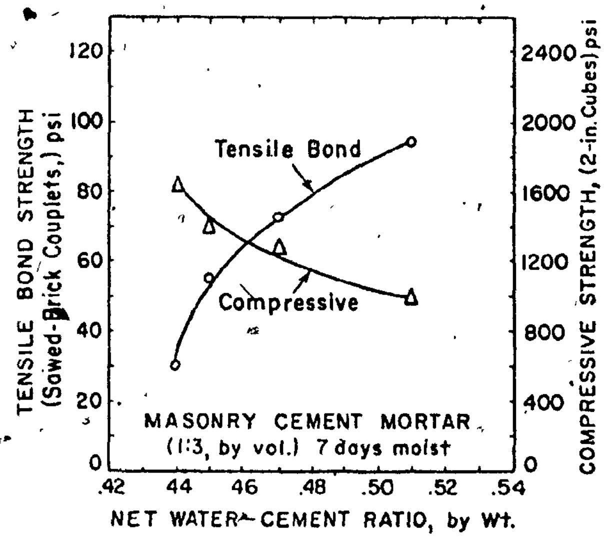


Fig: 5.5 *Effect of water-cement ratio of masonry cement mortars on tensile bond and compressive strength.*

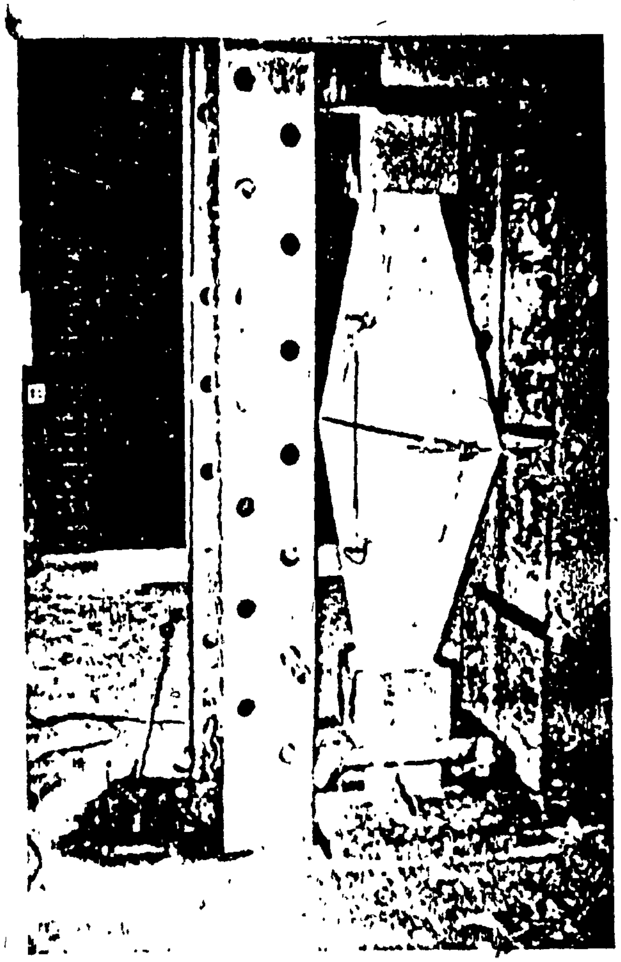


Fig: 5.6- Diagonal Shear Test

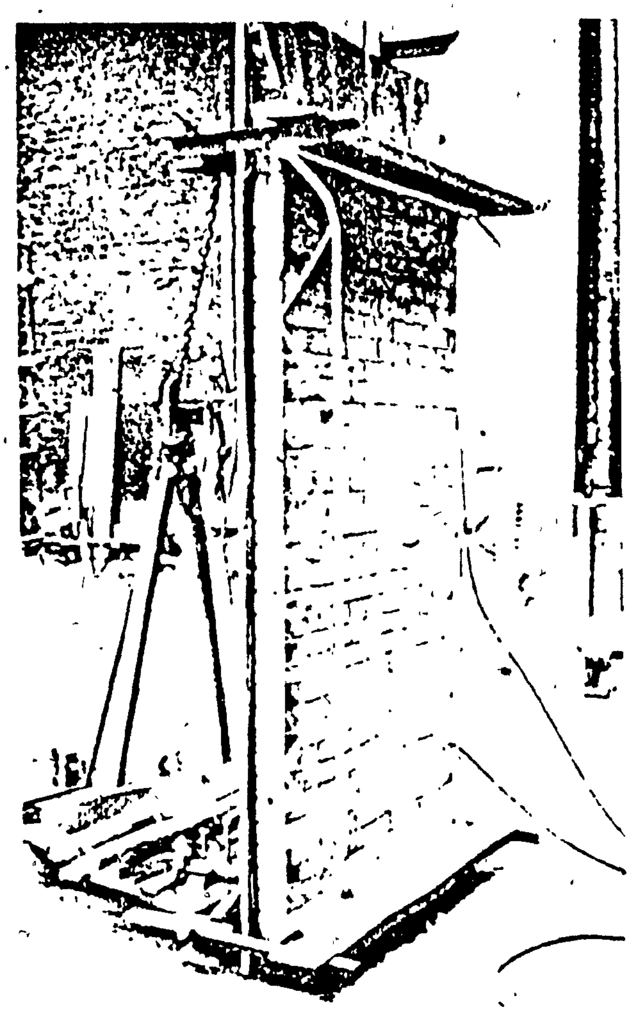


Fig: 5.7 –Transverse Wall Test

Panels in Colorado

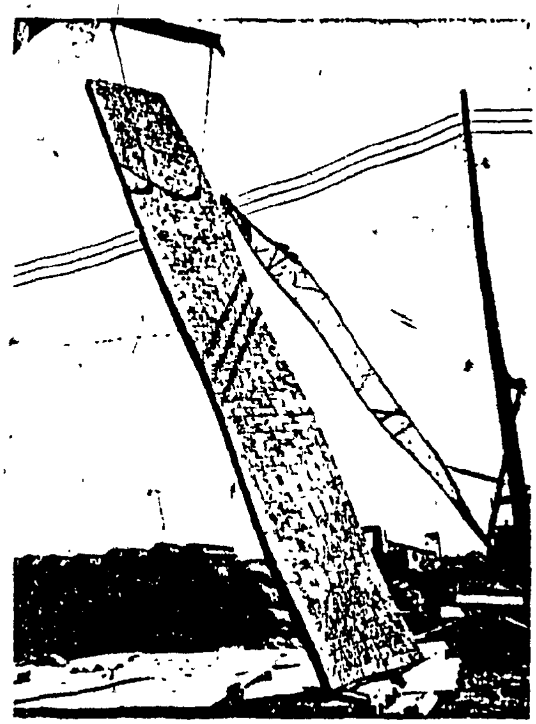


Fig: 5.8 *Experimental panel constructed for the Samsonite Corporation. The panel is 27 ft. high, 4 to 6 ft wide, and 6 inches thick.*

6. RECOMMENDED SPECIFICATION FOR PREFABRICATED BRICK MASONRY PANELS

6.1 Scope.

The specifications cover the structural design and quality control for load bearing or non-load bearing prefabricated brick masonry panels. These do not cover the method of prefabrication or field erection and jointing. The dpecifications have been taken from technical notes on brick construction, number 40A, Dec/Jan., 1974. Published by Brick Institute of America.

6.2 Materials

6.2.1 General

The type and grade of materials used shall meet the applicable standards set forth by, C.S.A. or National Building Code of Canada (NBC), together with the following additional requirements.

6.2.2 Hollow Bricks

Hollow bricks cored in excess of 25% but less than 40% of gross cross-sectional area, shall meet the requirements for appropriate grade and type in the following specifications

i) ASTM C652-standard specification for hollow brick or

ii) Canadian Standards Association (C.S.A.)

6.3 Design

6.3.1 General

The design shall consider all loading and restraint conditions, from initial fabrication to in-service conditions in the completed structure, including storage, transportation and erection.

6.3.2 Structural Design.

The structural design of prefabricated brick masonry panels utilizing solid units shall be in accordance with section 3, non-load bearing brick masonry of building code requirements for engineered brick masonry.

Structural design of reinforced, prefabricated brick masonry panels utilizing hollow blocks shall be made in accordance with National Building Code requirements for reinforced masonry.

6.3.3 Design Loads

The design loads shall be of the type and magnitude required by National Building Code of Canada. Panels and connections required to resist wind and siesmic loads shall be designed to resist the specified positive and negative wind pressures and siesmic design loads in all directions.

6.3.4 Lifting Devices

Lifting devices and their connections to the panels shall have an ultimate capacity of four times the dead weight of the appropriate portion of the panel. Inclination of the lifting forces shall be considered.

6.4 Dimensions.

6.4.1 Standard Dimensions.

The standard nominal widths and heights of the panels shall be in multiples of nominal individual masonry unit heights and lengths. The actual specified dimensions may be less than the required nominal dimensions by the thickness of one mortar joint, but not by more than ½ in.

6.4.2. Custom Dimensions.

For custom installations, all dimensions of panels shall be as shown on drawings or as specified.

6.4.3 Thickness of Panels.

The actual thickness of the panels shall be as required by the structural design and/or fire ratings for the type of construction and occupancy as required by National Building Code.

6.5. Workmanship.

6.5.1 General

For facing panels the workmanship and appearance shall be equal to or better than that of the sample submitted for approval. The method of fabrication shall be such as to prevent the misalignment or "cocking" of individual units and the joints shall be even and properly aligned with adjacent panels. If the method of fabrication results in grout or mortar staining of the face of the panel, such stains shall be removed by proper methods, before the panel is delivered to the job site, and it shall be protected from further staining during storage, shipment and erection.

6.5.2 Dimensional Tolerances

Based on actual dimensions, a prefabricated brick masonry wall panel shall not vary from the specified dimensions by more than the following:

10 ft. or under - plus or minus 1/8 in.

10 ft. to 20 ft. - plus 1/8 in. or minus 3/16 in.

20 ft. to 30 ft.- plus 1/8 in or minus 1/4 in.

For each additional 10 ft. - plus or minus 1/16 in.

The maximum permissible variation from the specified thickness of prefabricated brick masonry panels shall be not greater than minus 1/8 in. or plus 1/4 in. The panels shall have a maximum out-of-square (difference in length of the two diagonal face measurements) differential of not greater than 1/8 in. per 6 ft. or an absolute maximum of 1/4 in.

6.5.3. Warpage

The faces of the panels shall not be out of plane more than 1/8 in for each 6 ft. of either height or width.

6.5.4 Location inserts and and fittings

The location of anchors, inserts, lifting and connections devices shall not vary from conter line location shown on the plans and/or shop drawings by more than 3/8 in.

6.6 Quality Control

6.6.1 Preparation of Materials

6.6.1.1 Bricks

When required the initial rate of absorption of the brick shall be adjusted by wetting the units prior to pouring grout or spreading mortar to prevent premature stiffening of the grout or mortar due to rapid loss of mixing water to the units.

6.6.1.2 Mortar and Grout

In the interest of accuracy and control the mortar and grout shall be proportioned by weight on the basis of the unit weights of the ingredients as given in standard specifications for mortar for unit masonry, ASTM C 270, or standard specifications for mortar and grout for rainforced masonry, ASTM C 476, or standard specification for Portland cement-lime mortar for brick masonry BIA MI (technical notes 8A) or C.S.A.

If a high-bond mortar additive is used, mortar and grout shall be proportioned and mixed in accordance with the additive manufacturer's specifications.

6.6.2 Quality Control Tests

6.6.2.1 Bricks

For each 50,000 bricks of a given type used in the fabrication of panels; at least 10 shall be selected and subjected to compressive strength and absorption tests in accordance with standard methods of sampling and testing brick, ASTM C 67.

6.6.2.2. Mortar and Grout

After the formulation of mortar or grout has been established, a representative batch shall be sampled and not less then 12 standard 2 in. cube specimens moulded, following the procedures contained in the applicable sections of tentative methods of test for compressive strength of hydraulic cement mortars, ASTM C 109 or C.S.A.

Three specimens each shall be tested at 1,3,7 and 28 days and the relationship between the early age strength and the 28-day strength determined. This procedure need be repeated only when the mortar or grout formulation is changed.

There after, during regular production runs, at least one representative batch of mortar or grout shall be sampled each day and three cube specimens moulded and tested after 1,3 or 7 days as a quality control check.

6.6.2.3 Panel Assemblage.

The compressive and flexural strengths of the panels shall be checked for every 5000 sq.ft. of panel or every storey height, particularly for different combinations of brick and mortar or grout, by testing small, un-reinforced assemblages, representative of the full size panel.

The test specimens for both compressive and flexural tests shall be one brick unit in length and thickness, stack bond, and the height shall be at least 5 times its thickness (seven courses high for standard size brick) or if the height is less than as specified above, the test results for compressive prisms shall be reduced by the proper h/t (height to thickness ratio) correction as stated in building code requiredments for engineered brick masonry. If the relation between the 7-day and 28-day strengths of such small specimens has previously been established, they shall be tested after aging for 7 days. Six such specimens shall be prepared. Three shall be capped with gypsum and tested as compressive prisms in accordance with standard methods of tests for compressive strength of masonry assemblages, ASTM E 447 or C.S.A. The remaining three shall be tested as simple horizontal beams with third-point loading following the procedure outlined in standard methods of test for flexural strength of concrete, ASTM C 78.

Note: while good correlation has been established between the results of compressive prism tests of brick masonry and those of full size wall sections under a variety of loading, slenderness and bending conditions, the same situation does not exist in flexural or transverse strength tests. Therefore, the flexural tests for the purpose of checking quality control should be supplemented initially with uniform load tests of full size wall panels in accordance with standard methods of conducting strength tests of panels for building construction, ASTM E 72 in order to obtain design information.

6.7 Identification and Marking

Each individual prefabricated member shall be marked to indicate its location in the structure, it's top surface and the date of fabrication. Identification marks shall correspond to those shown on the placing plans.

6.8 Shop Drawings

Shop drawings shall include all details of reinforcement, connections, inserts, anchors, bearing seats, lifting inserts, panel dimensions, coursing and size, shape and location of openings.

6.9 Handling, Storage and Transportation

During curing, storage and transportation, the panels shall not be overstressed, warped or otherwise damaged. Panels unacceptably damaged shall be replaced. The architect or engineer, at his discretion, may allow repair and/or replacement of damaged areas of panels which have incurred minor damage during curing, storage or transportation. The damaged areas, such as minor surface or corner chippage, shall be repaired or replaced utilizing proper construction practices to the satisfaction of Architect or Engineer.

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