

Precast Concrete Wall Panels: Historical Review

By T. W. Hunt

■IT IS A COMMON MISTAKE to think of precast concrete panels as a recent development; say, of the past ten years. Actually, limited use of panels started prior to 1912 when units were cast at the job site and tilted into place. Similar methods were used for several housing developments and buildings of various occupancies built between 1912 and 1940. Growth in the use and variety of panels has been so spectacular in recent years, that it has overshadowed much of the earlier work.

EARLY EXPOSED AGGREGATE WORK

We are inclined to think that the various methods of producing decorative surfaces on concrete panels are recent developments. In many cases this is true, but some are merely refinements of methods that have been known for many years. For example, an article in the April 3, 1909 issue of *Engineering Record* describes in considerable detail methods of exposing surface aggregate in concrete to produce a decorative finish. Three different patents were granted previous to 1918 covering methods of achieving exposed aggregate surfaces.

An example of exposed aggregate concrete produced prior to 1920 is in Meridian Hill Park in Washington, D. C. (Fig. 1). This work was directed by John J. Earley. The close-up photograph, taken in 1961, reveals how well the surface appears after more than 40 years of exposure to the elements. By 1925, the Parthenon in Centennial Park, Nashville, Tenn., was completed with the exterior surfaces of exposed aggregate (Fig. 2). In 1932, Earley and his associates started work on panels and other precast units for one of the finest exposed aggregate



Fig. 1—Meridian Hill Park, Washington, D. C.

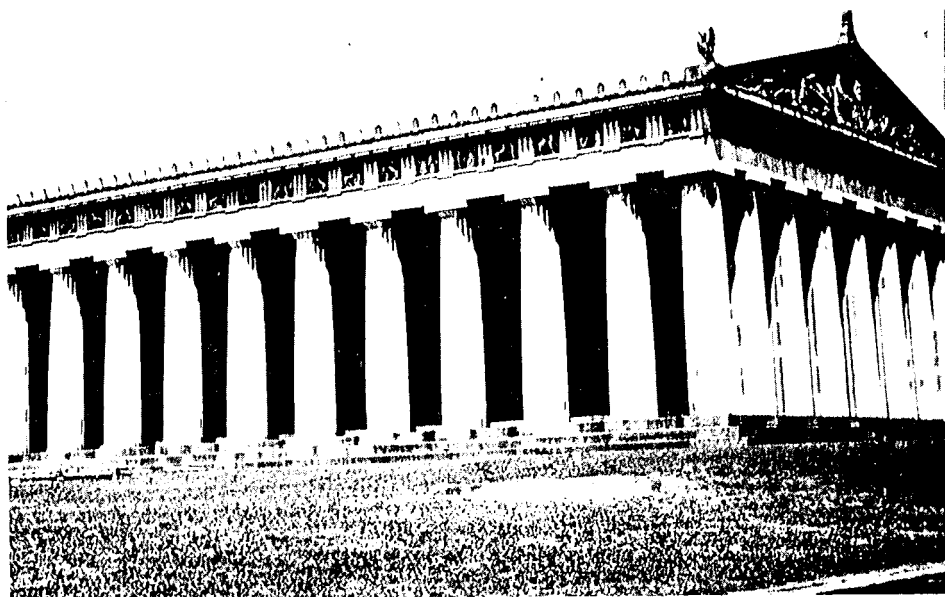


Fig. 2—Parthenon, Nashville, Tenn.

ACI member **T. W. Hunt**, decorative concrete specialist, Portland Cement Association, Chicago, is a member of ACI Committee 533, Precast Panels. A graduate of Missouri School of Mines, Rolla, he spent 20 years prior to joining the PCA staff with the Corps of Engineers.

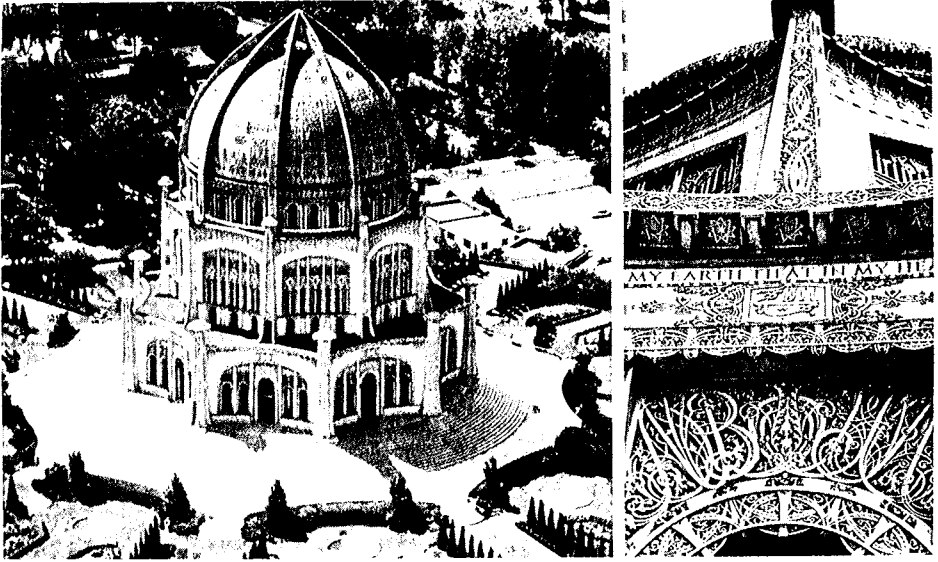


Fig. 3—Baha'i Temple, Wilmette, Ill.

structures of all time—the Baha'i Temple, Wilmette, Ill. (Fig. 3). Because of shortage of building funds the exterior was not completed until early 1943. This building is an example of decorative concrete work which is still unsurpassed in detail and workmanship.

POST WORLD WAR II DEVELOPMENT

During the ten years following the end of World War II there was a steadily expanding use of precast panels, although this growth was not startling. Since 1955, however, there has been a tremendous increase in the use of precast concrete panels of all types, and a concurrent growth in the development of new textures and patterns. Reasons for this expanding usage include improved methods of production, better handling and erecting equipment, and development of new techniques and materials. Probably the greatest factor, however, has been the realization by architects that precast panels provide a pleasing variety of surface textures and patterns and exterior designs that generally cannot be accomplished as economically in other materials.

CHANGE IN PANEL SHAPE

For many years the typical panel was rectangular in shape, with a flat surface. Usually it was of only one color, such as white aggregate in a white cement matrix. Such panels still fill a large share of the requirements but the relative ease with which an almost unlimited range of shapes, designs, colors, and textures can be produced has stimulated the imagination of engineers and architects. Some idea of the variety of shapes that have been produced may be gained from a look at several new structures.



Fig. 4—Pan Am Building, New York, N. Y.

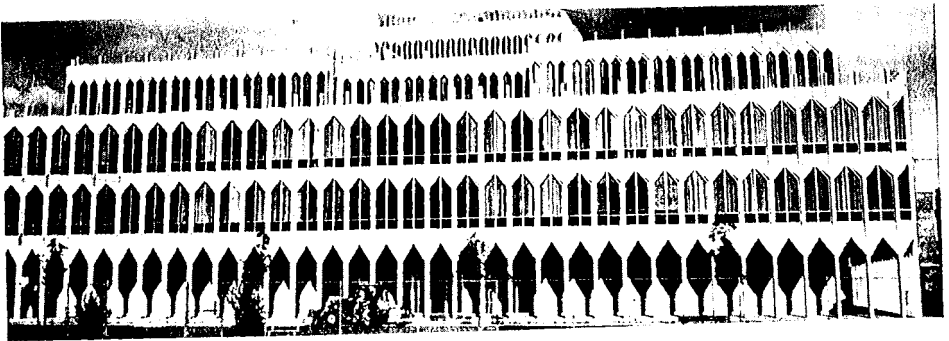


Fig. 5—Education Building, Wayne State University, Detroit, Mich.

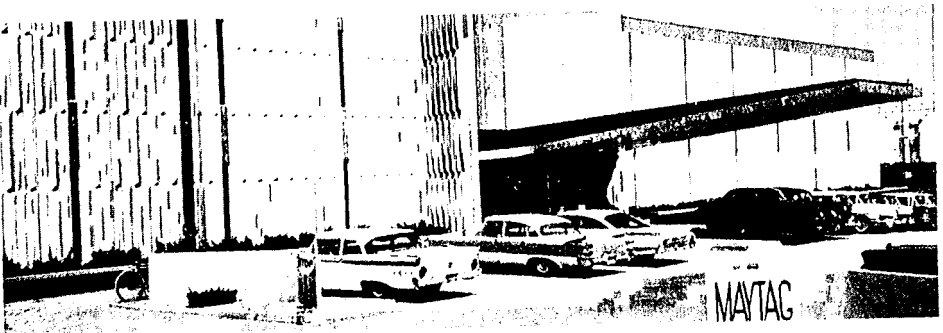


Fig. 6—Maytag Company Office, Newton, Iowa

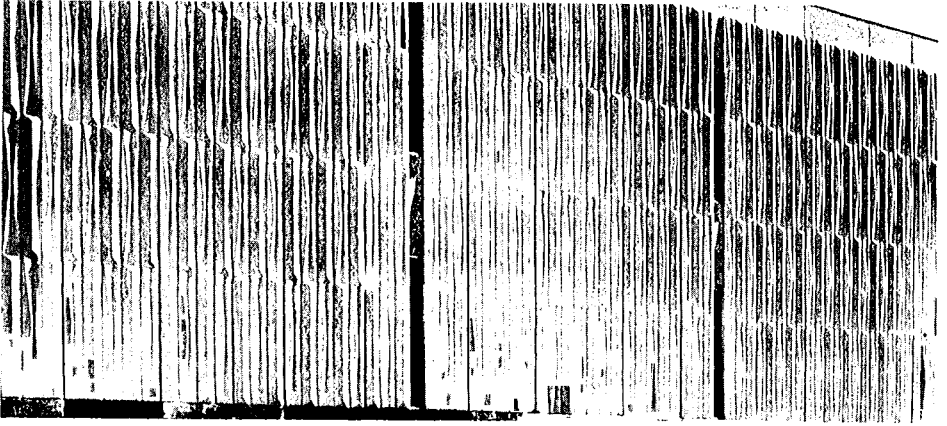


Fig. 7—Maytag Company Office, Newton, Iowa

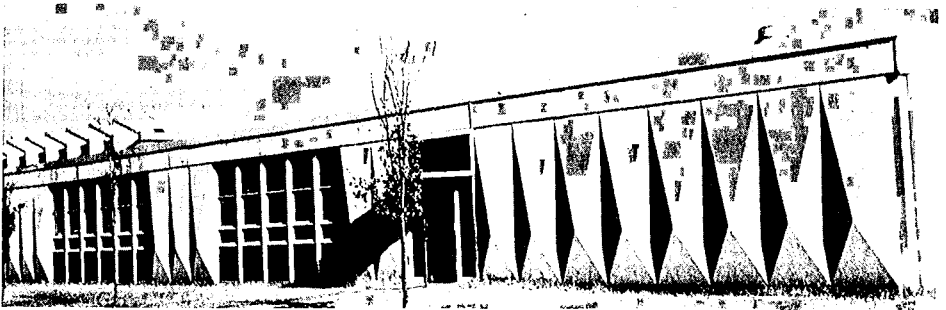


Fig. 8—Garinger High School, Charlotte, N. C.

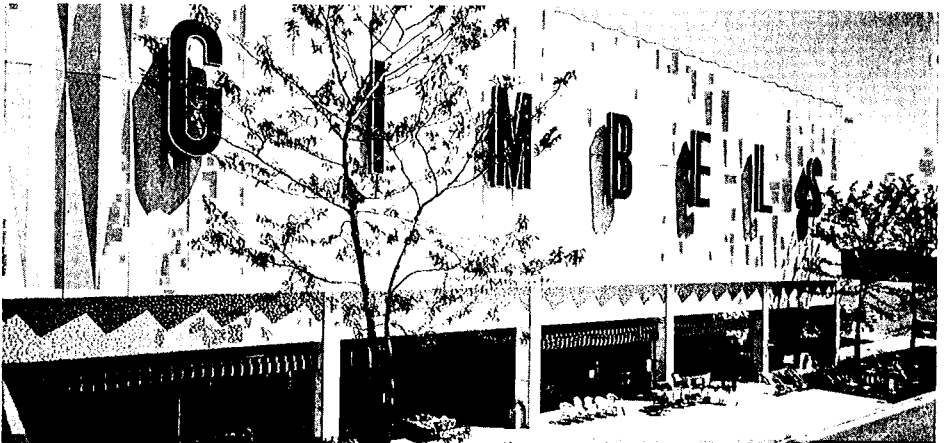


Fig. 9—Gimbels Store, Wauwatosa, Wis.



Fig. 10—Wachovia Bank & Trust Company,
Charlotte, N. C.

We have interesting panels on the exterior of the largest commercial office building, the Pan Am Building, located over Grand Central Station in New York (Fig. 4); the Education Building at Wayne State University in Detroit (Fig. 5); a new office building for the Maytag Company in Newton, Iowa (Fig. 6-7); a classroom building, part of a new high school complex (Fig. 8); a large department store near Milwaukee (Fig. 9); and a bank and office building in Charlotte, N. C. (Fig. 10).

GROWING USE OF COLOR

The increased use of color, both in the cement matrix and in exposed aggregate, has made it possible to produce patterns or designs in panel surfaces that add to their attractiveness. A few of the effects possible through combinations of two or more colors may be seen in the panels over the auditorium entrance at the Oak Park High School, Laurel, Miss. (Fig. 11); similar but larger panels enclose the Wieboldt Department Store in a Chicago shopping center (Fig. 12).

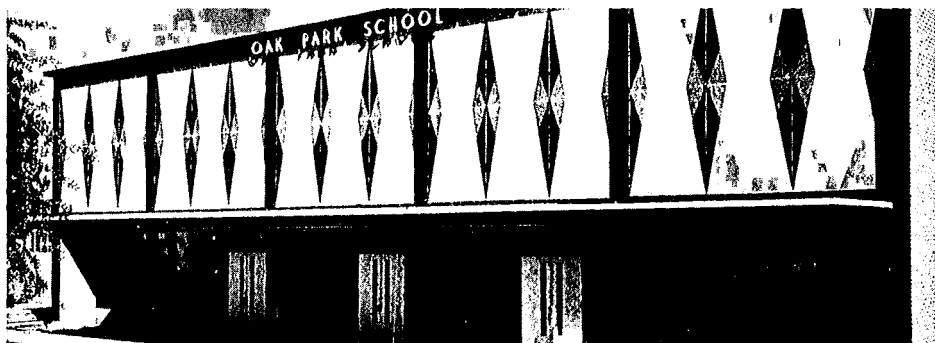


Fig. 11—Oak Park High School, Laurel, Miss.

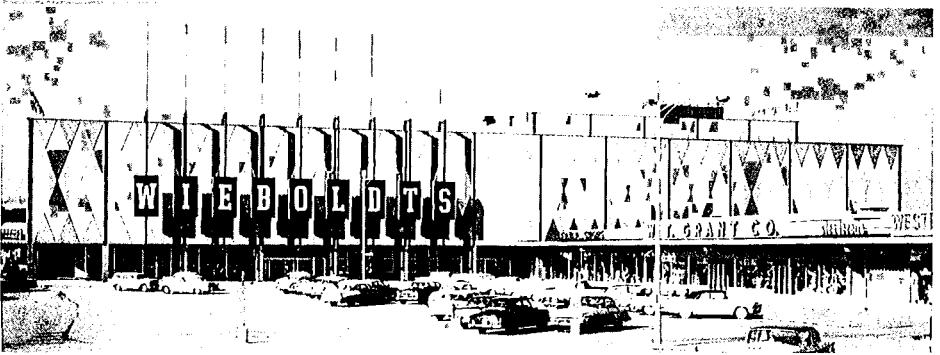


Fig. 12—Wieboldt's Department Store, Chicago, Ill.



Fig. 13—Fremont Hotel, Las Vegas, Nev.

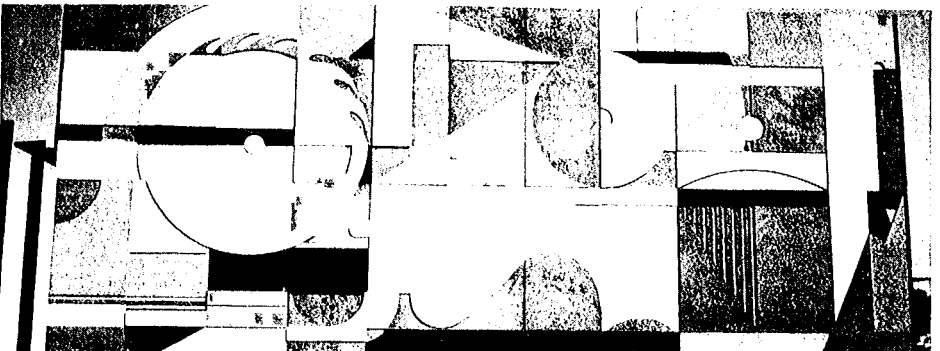


Fig. 14—Yates American Company, South Beloit, Ill.

It may be interesting to note that while these panels are rectangular in shape, by proper placement of the colored facing mixes it has been possible to create a harlequin diamond pattern. On the Wieboldt store there are nine panels to each bay, three wide by three high, with each panel being slightly under 8 x 14 ft. The L-shaped panels on the Fremont Hotel, Las Vegas, were designed to be distinctive even when surrounded by a jungle of signs and neon lights (Fig. 13).

A mural was made of 22 rectangular panels, each 6 x 14-1/2 ft., with a variety of colors being used to create an abstract representation of the products manufactured in a northern Illinois plant (Fig. 14). The designer deliberately developed a pattern that could be seen at a distance as the structure is set back from an Interstate highway with potential viewers traveling 70 mph.

DUAL PURPOSE PANELS

Another innovation has been the design of precast units to serve as both window frames and the exterior facade. When erected the units make up the entire wall surface, with no further additions. The precast exposed aggregate window frames that form the exterior of the new Bankers Trust Building (Fig. 15) on Park Avenue in New York are of white quartz aggregate in a white cement matrix with the glass being installed after the precast units had been



Fig. 15—Bankers Trust Company,
New York, N. Y.

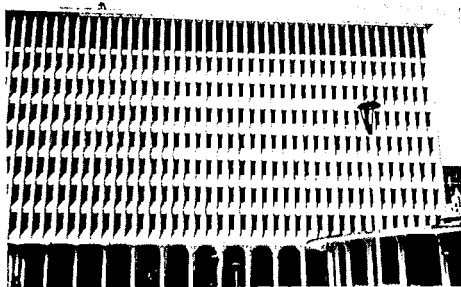


Fig. 16—City Hall, Phoenix, Ariz.

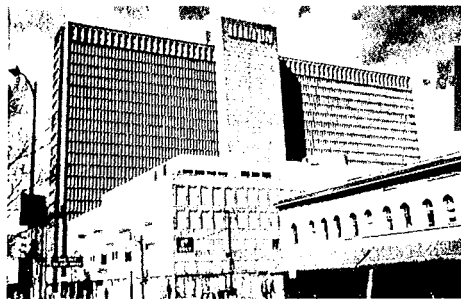


Fig. 17—Hilton Hotel, Denver, Colo.

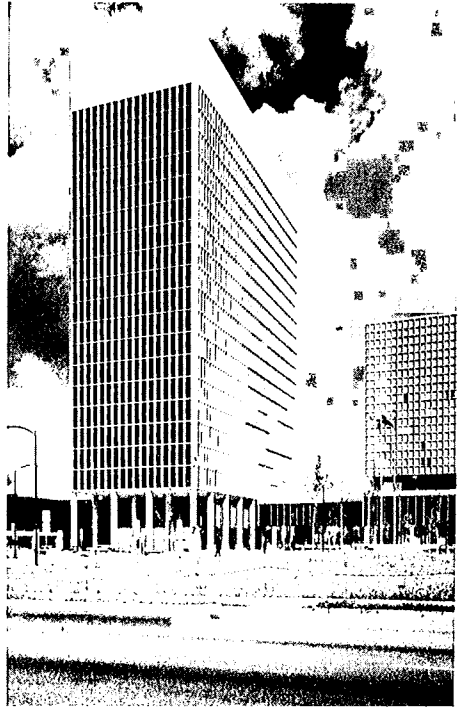


Fig. 18—500 Jefferson Building, Houston, Tex.

erected. Deeply recessed windows were provided in the frames that make up the exterior of the new Phoenix City Hall (Fig. 16), and the units on the Hilton Hotel in Denver (Fig. 17). Each unit on the hotel contains two windows. The 500 Jefferson Building (Fig. 18), erected in Houston during 1963, added a new fabrication technique to precast window unit production. The glass was installed at the precasting plant, eliminating glazing operations on this tall building. A secondary benefit of this method was that the precast units were handled a little more carefully with the glass in place.

STRUCTURAL PANELS AND UNITS

To date, practically all panels have been curtain wall units supported by the building frame. An occasional structure, however, has incorporated units that are both ornamental and structural. In some cases this has been done through the addition of an exposed aggregate surface to structural units, such as prestressed double-T members (Fig. 19). The John Hancock Insurance Building in Kansas City has a precast exterior frame of cross-shaped units with exposed aggregate surfaces on all sides (Fig. 20). This was accomplished by using white cement and white quartz aggregate in the mix and later exposing the aggregate by acid etching.

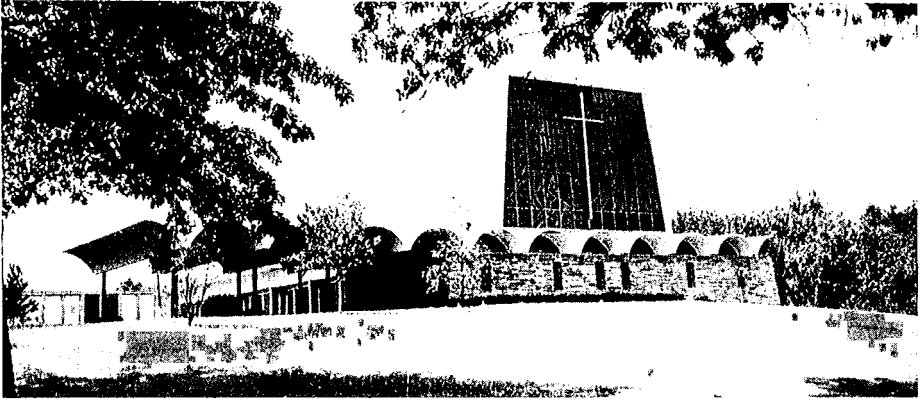


Fig. 19—Kenwood Baptist Church, Kenwood, Ohio

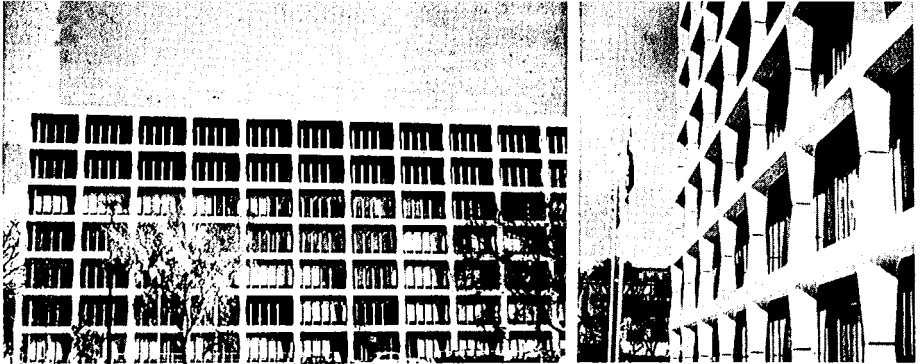


Fig. 20—John Hancock Life Insurance Co. Bldg., Kansas City, Mo.

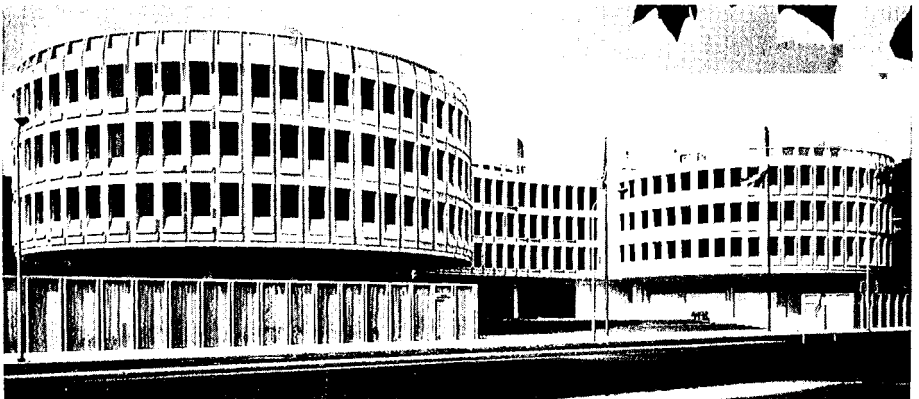


Fig. 21—Police Administration Building, Philadelphia, Pa.



SHOCKED CONCRETE PROCESS

Several years ago, a new casting method was introduced to the panel industry in the United States under the name of "Schokbeton"—shocked concrete. The machinery used in this method was developed in Holland, and a number of franchised plants have since been established in this country. The process is mainly a means of consolidating a no-slump concrete mixture by raising and dropping the form about 1/4 in. some 250 times per minute. This contrasts with conventional methods of consolidation by means of high fre-

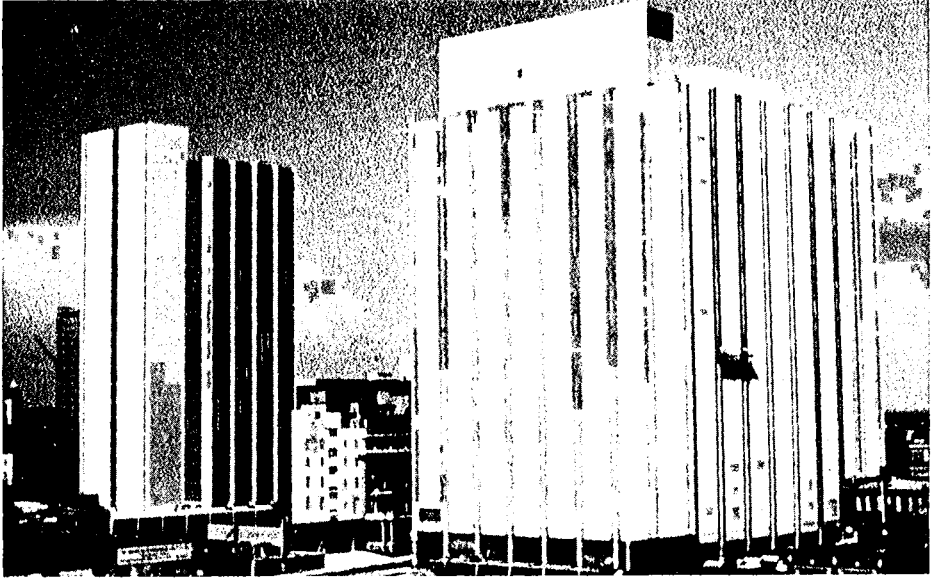


Fig. 22—Merchandise Mart, Atlanta, Ga.



Fig. 23—Library-Auditorium, Miami Beach, Fla.

quency and low amplitude vibration. Although the production of large precast panels by this method is relatively new, small concrete units have been produced in the past on so-called "drop tables" which followed the same technique without the refinement of modern machinery. The units for the new Police Administration Building (Fig. 21) in Philadelphia were manufactured from shocked concrete. These 5 x 25-ft panels not only have a fine appearance but are load-bearing structural panels that support the third and fourth floors and the roof load.



Fig. 24—Federal Science Building, Seattle, Wash.

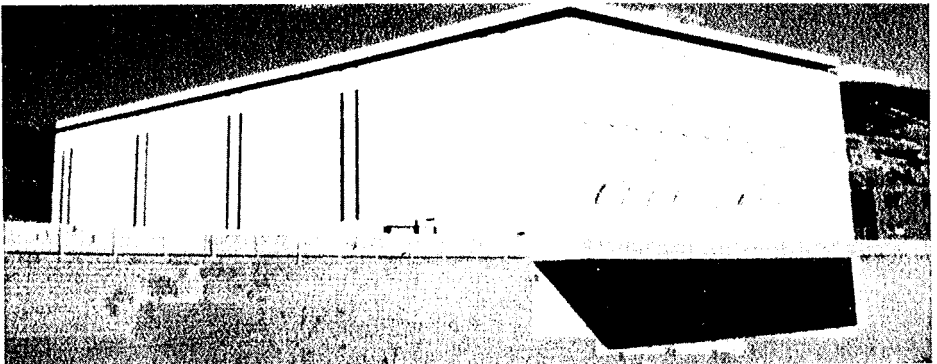


Fig. 25—University Stake House, Salt Lake City, Utah

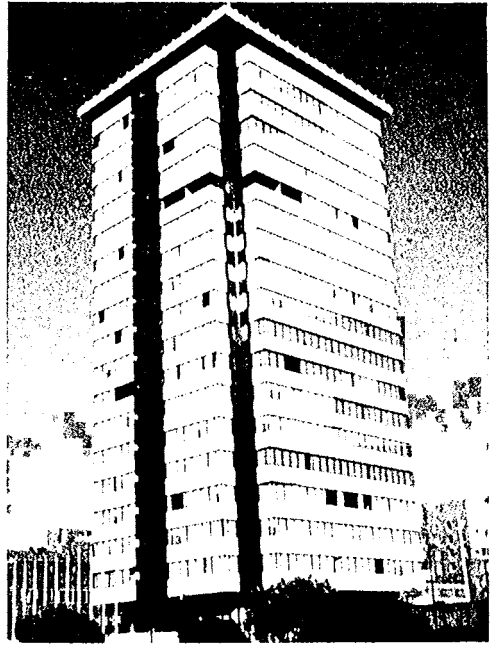


Fig. 26—International Building, San Francisco, Calif.

MISCELLANEOUS PANEL TYPES

Sandwich panels have been used to some extent for many years. As we learn more about them, it seems likely that their usage will become more widespread. About 2000 sandwich units were used to inclose Atlanta's Merchandise Mart (Fig. 22).

Details and patterns may be sculptured in sand and later translated into precast panel surfaces to produce designs such as those seen on a portion of the Miami Beach Library (Fig. 23).

Although prestressing is not new to the field of precast decorative panels, it has been used rather infrequently in the past. It seems most likely that a greater use of prestressing of panels will occur in the future. Longer units may be cast and handled when prestressed. An example is the Federal Science Building at the Century 21 Exhibit in Seattle where wall panels 55 ft long were used (Fig. 24).

SUMMARY

The great variety of textures, patterns, sizes and shapes that have been used on buildings from small one or two story structures (Fig. 25) to large multi-story commercial office buildings (Fig. 26) may be considered just a beginning. There appears to be no limit to the variations that can be developed in this expanding and challenging field.

Precast Concrete Panels: Materials and Tests

By J. A. Hanson and D. P. Jenny

■ **PRECAST CONCRETE WALL PANELS** have been largely responsible for the accelerated use and evaluation of concrete as an esthetic, architectural material. Since these panels combine the many desirable and time-proven properties of concrete with emphasized beauty and function, it is imperative that the best materials and techniques available be used to achieve the desired effects. The added cost and care required for high quality will not materially affect the competitive advantage of concrete wall panels with respect to other materials and methods. On the other hand, the superior performance of quality panels will lead to increased demand by architects and owners.

The members of ACI Committee 533, Precast Wall Panels, have considered such a philosophy to be an implied but important adjunct to their assigned mission of development of recommendations for the design, manufacture, and erection of precast concrete wall panels. In order to accomplish this mission, the committee was divided into six subcommittees with varying areas of interest. Duplication of the material considered in these subcommittees cannot be completely eliminated. Indeed, it would be most difficult to clearly separate the work of the subcommittee on materials and that of the subcommittee on tests. Consequently, this paper is a combination of the deliberations of these two subcommittees. Most of the discussion has been concentrated in the area of materials for concrete wall panels because the subcommittee on tests has published a progress report.*

*This report is reprinted in the appendix to this volume.

A quick appraisal of precast concrete wall panels discloses this general listing of materials involved in their manufacture:

1. Concrete—and all its ingredients.
2. Reinforcement, inserts, and miscellaneous metal.
3. Insulating materials.
4. Forming materials.

To this might be added the additional categories involved in installation:

5. Jointing materials.
6. Protective coatings.

This report will deal principally with concrete since the second and third items involve panel design, the fourth is tied to fabrication and its many techniques, and the remaining two items concern erection and installation, all subjects of other subcommittee reports. However, comments will be offered on all material groupings.

CONCRETE

Cement

For precast concrete panels, a white or gray portland cement meeting the requirements of Types I, IA, III, or IIIA as specified in ASTM C150, ASTM C175, or Federation Specification SS-C-192 should be used. Other cement types are not considered necessary in precast work.

Cement of the same type and brand and from the same mill should be used for the panels on a given project to minimize color variations. Some precasters prefer to obtain a single, one-time shipment for a given project. However, these precautions alone will not automatically assure color uniformity because variables in panel manufacture may also have marked effects.

Samples provided to architects should be keyed or coded to the type, brand, and source of cement used, as well as to the facing aggregates and other materials.

Aggregate

Although much of the recent development in precast concrete panels has been in the decorative exposed aggregate curtain walls, there is still a place for the unfaced panels, either plain, patterned, or textured. The concrete used in these and in the back-up concrete for the faced panels, should, of course, be uniform, high-quality, controlled concrete in order to obtain desirable properties and performance in the panels.

ACI member, **J. A. Hanson**, manager, Products and Applications Section, Portland Cement Association Research and Development Laboratories, Skokie, Ill., is chairman of ACI Committee 213, Lightweight Aggregates and Lightweight Aggregate Concrete, and a member of 533, Precast Panels, and 435, Deflection of Concrete Building Structures.

ACI member **Daniel P. Jenny**, chief engineer, Expanded Shale, Clay and Slate Institute, Washington, D. C., is a member of four ACI Committees: 213, Lightweight Aggregates and Lightweight Aggregate Concrete; 408, Bond Stress; 531, Concrete Masonry Structures; and 533, Precast Panels.

For this type of concrete, normal weight aggregates conforming to ASTM C33 and lightweight structural aggregates meeting the requirements of ASTM C330 should be used. Maximum aggregate size is rarely greater than 3/4 in., sometimes being 1/2 in. or smaller for thin panels. This top size is an important factor in proportioning concrete. For example, optimum air contents* for both normal weight and lightweight concrete should be in accordance with Table 1.

In addition, percentage of fine aggregate to total aggregate increases as the top size of aggregate decreases.

TABLE 1—OPTIMUM AIR CONTENT

3/4 in. maximum size aggregate	6 ± 1-1/2 percent air
1/2 in. maximum size aggregate	7 ± 1-1/2 percent air
3/8 in. maximum size aggregate	8 ± 1-1/2 percent air
1/4 in. maximum size aggregate	9 ± 1-1/2 percent air

Back up concrete

This classification of concrete is also meant to include the concrete in unfaced panels.

Compressive strength is not necessarily the primary concrete property sought in panel work. Durability, impermeability, and appearance are generally more important. However, to assure these desirable properties, compressive strengths of 4000 psi or greater are recommended. High strengths are particularly important for back-up concrete since it should have aggregate to cement proportions similar to that of the high strength, exposed aggregate facing concrete, to minimize effects of differential properties. It also has significance for concrete panels that are textured by bush-hammering or sand blasting. On these the broken or open surface may lead to excessive absorption and increased permeability if low strength concrete were permitted.

As a guide for initial trial mixes to obtain concretes which will meet the above requirements, Table 2 presents suggested cement contents, aggregate percentages and water-cement ratios.

Strength tests

Standard 6 x 12-in. test cylinders for compressive strength tests should be taken whenever practicable. If low slump or zero-slump concrete is used in making the panels, internal or external vibration on the test cylinders is recommended in accordance with ASTM C31 and C192.

For a number of reasons, it may be more advantageous or desirable to perform compressive tests on cubes that are either cast or sawn. Committee 533 recommends a standard 4-in. cube with a correction factor of 0.8.

$$f'_c \text{ CUBE} \times 0.80 = f'_c \text{ CYLINDER}$$

Both values should be reported. A 4-in. cube accommodates a maximum aggregate size of 1-1/2 in. without excessive test deviations.

In addition to strength tests for compliance with specifications, it is recom-

*These air contents do not apply to the special facing mixes.

mended that producers institute day-to-day tests and maintain continuous records for quality control and demonstration purposes.

Facing aggregates

By far the most exciting development in precast concrete panels involves the myriad combinations of special aggregates exposed in the panel face for their color and texture. Such aggregates include selected gravels, limestone, quartz, marble, granite, glass, and ceramics. The precaster should be certain that all aggregates come from the same source and are of the same quality and color as the approved sample.

Because of the relatively higher cost of these aggregates, they are most generally mixed in a facing concrete which is backed up with concrete using regular aggregates. The facing layer need only be thick enough to prevent the back-up concrete from showing. Usually gap gradation is desirable to emphasize a certain size and lead to more uniformity of coverage with this particle size. Maximum size may vary from 5-in. cobbles to No. 4 sand, but the usual range is from 1-1/4 to 3/8 in. Materials, colors, gradations, size, and reveal are the variables that permit extreme freedom of architectural expression; hence, the only limits should be those of judgment based on experience or trial.

At no time should soft, nondurable aggregates be permitted for exposed aggregate work. Certain limestones and marbles may fall in this category, therefore proven performance records should accompany all facing aggregates.

Generally, panel precasters use facing aggregates that have previous service records and hence alkali reactivity is rarely, if ever, encountered. Tests for the potential alkali reactivity should be made on any new combination of aggregate and cement. This is best done by expansion measurements on mortar bars prepared and tested in accordance with ASTM C227. The coarse aggregate is

TABLE 2—GUIDE FOR INITIAL TRIAL MIXES

Compressive strength, psi	Maximum size aggregate, in.	Lightweight concrete*		Normal weight concrete*		
		Cement content, 94-lb bags per cu yd	Fine aggregate, percent of total vol.	Cement content, 94-lb bags per cu yd	Fine aggregate, percent of total vol.	Maximum water-cement ratio
4000	1/4	7.25	100	6.5	100	6.5 U.S. gal. per 94-lb bag (0.576 by weight)
	3/8	7.00	60-70	6.1	42-50	
	1/2	6.75	55-65	5.8	39-47	
	3/4	6.50	50-60	5.5	36-44	
5000	1/4	8.25	100	8.00	100	5.5 U.S. gal. per 94-lb bag (0.488 by weight)
	3/8	8.00	60-70	7.75	36-44	
	1/2	7.75	55-65	7.50	34-42	
	3/4	7.50	45-60	7.25	32-40	

*The slump of lightweight concrete in this guide is 1 to 3 in.—approximately 2 in. less than the slump of normal weight concrete at equal workability. If panel complexity should require slumps greater than 3 in., cement contents should be correspondingly increased to maintain strength.

crushed, sieved, and recombined for making the mortar. The limits of expansion should not exceed that given in ASTM C33. If the limits are exceeded it is recommended that a low alkali cement (a maximum of 0.6 percent expressed as Na_2O equivalent) be used with that aggregate or that a different aggregate be selected.

Glass aggregate is used for bright colors. This material should be specifically formulated so that it is nonreactive with portland cement.

Once in a while, coarse facing aggregates may contain particles with an iron content that results in unsightly stains. Such material would undoubtedly meet the staining requirements for ordinary plastic concrete, thus other tests or methods must be devised to eliminate this occasional trouble. Selectivity on the part of the precaster and his experience with materials and sources is currently the only assurance against iron stains from aggregate.

Facing concrete

Panels are almost always cast in a horizontal position to permit a number of different techniques to be used to gain satisfactory exposed aggregate finishes. In one method, aggregate may be spread or placed on the forms and covered or coated with a sand-cement grout using either white or gray portland cement or a pigmented matrix. In another, special aggregates may be applied to top surfaces of horizontally-cast panels. Generally, a thin layer of facing concrete containing the special surface aggregates is placed in the forms initially and then backed with regular concrete. Sometimes the facing mix is placed on the top surface and additional aggregate worked in if necessary.

Usually facing mixes with a high aggregate concentration and gap gradation are rather harsh and are mixed to a slump of 4 to 6 in. to achieve workability. By using a dry back-up mix, excess water can be drawn from the facing concrete, thus improving its quality. A measure of this improved strength may be obtained by fabricating 4 x 4 x 8-in. prisms, consisting of 4 in. of facing mix and 4 in. of back-up concrete, cast in a manner similar to the panels. After sawing the prism in half, each concrete may be tested on the resulting 4-in. cubes.

In other techniques, high cement content, low slump, and heavy vibration are combined to give facing mix strengths of 9000 to 10,000 psi and even more. When testing mixes of this type for compressive strength, special high strength capping materials should be used or the bearing surfaces should be lapped to a plane surface.

Minimum strength of facing mixes should be 5000 psi. Furthermore, cement content of facing mixes should not be less than 6 bags per cu yd, or the equivalent in cementitious materials, to assure maximum density and minimum permeability.

In all facing concrete, air entrainment is recommended. However, because of the characteristics of these mixes, a specified percentage of air often is not practical. Instead, use of air-entraining cements or air-entraining agents in amounts equal to "normal" dosage is recommended. Normal dosage results in 19 ± 3 percent in a 1:4 standard sand mortar tested in accordance with ASTM C185.

Durability tests

Because of the orientation of precast wall panels in structures and because of the high strength, low permeability characteristics of the exposed concrete, the coincidence of high degrees of saturation with severe freezing is almost non-existent. Thus excellent durability can be expected and performance and tests bear this out. Hence, it is recommended that specifications do not require freeze-thaw durability tests but do include, at all times, air-entrainment requirements.

There are certain exceptions to this general statement, such as panels located at sidewalk level, where durability tests may be considered necessary. In these instances, the reasonably realistic testing cycle of freezing and thawing in air with water flushing of the surface just prior to each freezing cycle is recommended.

Absorption tests

Tests have never adequately shown that absorption test limits on concrete are a measure of durability. Furthermore, the vertical orientation and the concrete quality are factors that make it difficult for a panel in service to reach the actual absorption condition as obtained in an absorption test. Thus, an absorption test is not recommended as a control for durability.

Absorption tests, such as ASTM C97, might be adopted by a precaster to serve as a relative measure of the ability of different concretes to resist dirt adherence and of possible staining from aggregates, fading of colors, or other factors leading to nonuniform appearance or unsightliness. At best, any absorption test is only an indicator.

Admixtures

Generally, only air-entraining admixtures conforming to ASTM C260 are used in precast panel work. Accelerating admixtures may be used for rapid strength gain. However, the general practice is not to use an accelerator but to use a Type III cement plus a curing method that leads to high early strengths needed for early form removal. Water reducing admixtures may provide benefits by reducing the amount of water for workability and by minimizing detrimental bleeding of excess water. These may find a place particularly in the harsh facing mixes with their necessarily poor aggregate gradation. Care should be exercised that the particular formulation of the water reducing admixture is not combined with retarding characteristics, or if so, that this fact be known and the retarding effects be evaluated.

Retarding admixtures generally have no place in precast concrete panel work. A retarded concrete may not permit the top surfaces of a panel to be finished off or textured rapidly enough to fit the high speed casting cycles generally found in plant production. Also, a few tests have indicated a greater tendency toward efflorescence with some retarders, especially when panels receive accelerated curing. On the other hand, retarding admixtures will increase the efficiency and uniformity of aggregate exposure when using surface retardation. Surface retardants for aggregate reveal are discussed in the section under formwork.

Pigments

To augment the architecture of concrete panels, color tints in the matrix may be obtained through the use of pigments. Pigments commonly used for this purpose are finely ground natural or synthetic mineral oxides. Synthetic oxides are perhaps more satisfactory from the standpoint of more attractive shades and greater permanence.

Iron oxides produce shades of yellow, buff, tan, brown, maroon, red, and black. Chromium oxide produces green and cobalt oxide, blue. Variable amounts of these materials, expressed as a percentage of the cement content by weight, produce various shades of these colors. Amounts in excess of 5 percent seldom accomplish further color intensity. Pigments used with white cement will produce clearer shades than with gray. It is good practice to blend the pigment with the cement in the dry state prior to mixing.

Recently, organic, phthalocyanine dyes have been used successfully in concrete to produce light to dark shades of blue and green. Their service record is, of necessity, quite short. While their initial cost is quite high, they are used in small quantities of less than 1 percent by weight of cement. As a further advantage, they can be dispersed in the mix water, thus eliminating the need for preblending.

In the use of any coloring agent it is important to have tests or performance records that reliably indicate their color stability in concrete. Furthermore, it should be realized that concrete colored by pigments, as well as with colored aggregates, may weather to some degree so that the panel's color intensity may be dulled in time.

REINFORCEMENT

The type and quality of reinforcement for concrete panels will depend on the size and function of the wall panels. Dimensions vary so widely that all sizes and kinds of reinforcement common to general concrete construction may be used. These include structural, intermediate, and high strength deformed bars, high-tensile rods and strands for prestressing purposes, and black or galvanized welded wire fabric with a wide variety of mesh spacings and wire gages. A recent development has been the production of mesh with deformed wire.

The requirements for thin wall panels are closely allied to those of "Minimum Requirements for Thin-Section Precast Concrete Construction (ACI 525-63)," which allows a minimum cover of 3/8-in. and requires the use of 2 x 2-in. mesh for elements with a section thickness of 3-in. or less. For this minimum cover, galvanized mesh is desirable; for covers of 3/4 in. or more, galvanized reinforcement is not necessary, although many precasters prefer its use.

Three-layer sandwich panel construction requires concrete ribs or metal shear ties to connect the outer structural concrete wythes. The metal ties are often fabricated of expanded metal or of various truss-type products produced commercially for masonry reinforcement or building studding. Metal shear ties should incorporate diagonal members for proper resistance to horizontal shearing deformation in sandwich panels.

INSULATING MATERIALS

The highly insulative sandwich wall panel involves a design compromise between high resistance to heat transfer, economy, and structural requirements such as strength, weight, bond, and stiffness. A wide variety of sandwich materials are available to provide the desirable thermal properties. Since conductivity, a measure of heat flow, varies with density, unit weight may be used to classify these insulating materials.

Under 15 lb per cu ft

Plastic materials—Polyurethane foam (boards or granules), polystyrene foam (boards or granules).

Glass materials—Foamed glass (boards or granules), glass fiber (batts).

Paper honey-comb—Usually filled with insulating granules or aggregate.

15 to 50 lb per cu ft

Foamed concrete—Autoclaved cellular concrete (boards), nonautoclaved cellular concrete (boards or plastic fill).

Mineral aggregate concrete—Vermiculite (boards or plastic fill), perlite (boards or plastic fill).

Some of the prefabricated concrete insulating materials may have high initial rates of absorption. In sandwich panel construction, these materials are placed in direct contact with the plastic concrete faces and over-dessication of the fresh concrete may occur to the extent that cement would not properly hydrate. These insulation materials should have a water repellant coating which does not hinder bond and which prevents accumulation of moisture thereby maintaining their high insulation value.

FORMING MATERIALS

Structural formwork

Good forms are vitally important in precast panel work and the type depends on considerations of cost, maintenance, re-use, and detail, and possibly salvage.

Concrete, wood, and steel forms are quite common. Polyester resins reinforced with glass fiber are finding more and more applications. For complicated details, molds of plaster, gelatine, or sculptured sand have been used successfully and, depending on the size of the cast, these molds are often combined or reinforced with wooden forms.

Liners

Patterns and textures, that range from muted expression to bold relief, are obtained with different types of liners.

Rubber matting is effective and the concrete faithfully reproduces the most complicated surfaces. Commercial material is generally satisfactory but it should be tried beforehand, especially if pigments are used, to determine whether staining or discoloration results. Trials will also determine the best time for stripping so that the surface remains intact and the liners can be re-used.

Wood, either as boards, plywood panels, or nailed-on inserts, works well. Liner surfaces should be sealed with shellac and then lightly coated with form oil prior to casting.



Pleasing and unusual architectural effects in concrete can be obtained by the use of forms made of plastics. The plastic sheets used for this purpose may be vacuum-formed to provide bold or muted patterns to an extent limited only by the architect's imagination. The concrete surfaces can be either glossy-smooth or textured. In either case, no parting agents and no subsequent treatment to the concrete surfaces are required. The extremely fine finish of plastic formed concrete greatly enhances the attractiveness of integral colors and, because of high reflectivity, smaller amounts of pigment are required to obtain a given color intensity. The glossy surfaced concrete, while performing in an excellent manner for indoor decoration, is not recommended for exterior exposure by reason of gradual and nonuniform disappearance of its reflectivity. For outdoor exposure it is recommended that either textured surfaces or smooth but nonglossy surfaces, achieved through early form removal, be used.

Polyethylene film laid over uniformly distributed cobblestones provides dimpled surfaces. Pieces of polystyrene foam, shaped and attached to the form, impart deeply impressed designs after removal from the concrete face.

Retarders

When exposed aggregate panels are cast face down, it is quite common to use commercially available chemical retarders on the form to achieve the required reveal of the special facing aggregates. These retarders generally consist of various hydroxylated organic compounds and may be either organic solvent or water soluble. Most suppliers provide several grades depending on the depth of reveal desired. For 3/8-in. aggregates, exposures to depths of 1/16 or 1/8 in. are practical, and for aggregates up to 3/4 in., the etch may be increased to 1/4 in. although generally it is somewhat less. Light or medium grade retarders are employed for these aggregate sizes and, in the case of flat forms, a retarder-impregnated cloth has been used quite successfully. For aggregates larger than 3/4 in., the desired reveal may be considerably greater, and a retarder in gel form is available for this purpose. Care should be taken to insure uniform application of the gel to the structural form. For the exposure of aggregates of 1/4-in. size or smaller it may be better practice to use methods other than chemical retarders.

Many factors affect the optimum time interval when the panels should be removed from the forms and the retarded paste brushed and washed away. Since the most suitable time may vary from 12 to 24 hr after casting, preliminary tests should be performed before setting up the casting cycles for a large contract.

After aggregate is properly exposed, and the panel is well cured, a mild acid wash of 5 to 10 percent muriatic acid will clean and brighten the colored aggregate. Immediately thereafter the panel should be thoroughly flushed.

JOINTING MATERIALS

Joint sealants may be classified into three general categories: (1) cement mortars, (2) mastics, primarily oleo-resinous (oil base) caulking compounds, and (3) thermosetting plastics including polysulfides and epoxy resins. Of

these, only the mastics and thermosetting plastics should be used as sealants in precast concrete panel installations. Cement mortars are not extensible and cannot accommodate the movement of the larger panels.

The oleo-resinous (oil-base) compounds vary in performance depending on brand and formulation but even the best dry out in time and must be renewed. The service life of the better materials may be in excess of 5 years with an occasional instance of satisfactory performance considerably longer.

Polysulfide sealants are usually two-part compounds, and they are more expensive than oil-base caulking materials. The higher initial cost is more than offset by lower maintenance costs and assurance of weather-tight joints. Proper formulation and proper installation of polysulfide sealants result in good adhesion, flexibility, and durability.

It is desirable to use the minimum amount of sealant required to make a satisfactory joint. Not only is it more economical, but it results in better sealant life as a relatively thin band of material is less likely to fail than a thick section of sealant. It is good practice to fill most of the joint space with some type of premolded elastic material and to use the sealant only in the exterior 1/2-in. portions of the joint. A variety of materials are available for use as joint fillers including sponge rubber; polyvinyl chloride; and foamed polyethylene, polyurethane, and polystyrene. The foamed or sponge material should be compressed to about one-half their unrestrained thickness when they are installed so that they will continue to fill the joint should contraction of the panel widen the joints. The polysulfide sealant should be installed to a depth of about one-half the width of the joint, but not exceeding 1/2 in.

Good workmanship by qualified sealant applicators is the biggest factor leading to satisfactory performance. The American Standards Association has adopted a standard specification: "Polysulfide-Base Sealing Compounds for the Building Trade," ASA A116.1-1960.

PROTECTIVE COATINGS

Protective coatings, primarily clear silicones, remain an area of controversy among panel manufacturers. Some feel their water repellant properties prevent discoloration and keep colors bright. Others, are concerned that the benefits are overrated and that possible harmful effects, such as surface spalling, may occur under certain conditions. Tests have shown that these water repellants do not improve resistance to frost action and that this property is best achieved in the concrete by means of air-entrainment. Furthermore, it is difficult to repair the face of a panel that has already received a silicone coating. However, it is generally agreed that panels coated with silicones are much easier to clean.

When coatings are used, their behavior should be based on prior experience under similar exposure conditions. Care should be exercised to apply in the proper manner and the coverages recommended by the manufacturer and also to prevent accidental application on those surfaces that will be in contact with joint sealants. It should be recognized that silicones have a limited useful life and need renewal from time to time.



Documents

Document Sharing Hub

Precast Concrete Wall Panels: Design Trends and Standards

By Victor F. Leabu

■THE EVOLUTIONARY PROCESS in the development and use of precast concrete for wall panels has been phenomenal in all phases of design, construction, and to some extent, standardization. However, a standardization of design practice or a recommended design guide has yet to be developed for this unique type of construction material.

Many unusual, unique designs and methods of construction of precast concrete wall panels have been successfully executed in the past, and are in constant development today. The structural integrity, safety, feasibility, and economy of the many types of precast wall panels developed in the past two decades have depended to a great extent on the skill and judgment of the architect and engineer, and to the success and capability of the precast concrete industry in the execution of the plans and specifications of these elements in the field. In many cases, only past experience and experimentation have been the key to the design standard used for future development of the precast wall panels.

The precast concrete wall panel has evolved from the heavy piece of flat, gray concrete used to enclose the secondary type of building or warehouse structure, to the imposing elegant aggregate surface precast curtain walls of exotic shapes. This rapid development has instituted the need for some kind of standard, design, or recommended practice for continued progress in the precast wall panel field and has been the motivating force in organizing ACI Committee 533, Precast Panels.

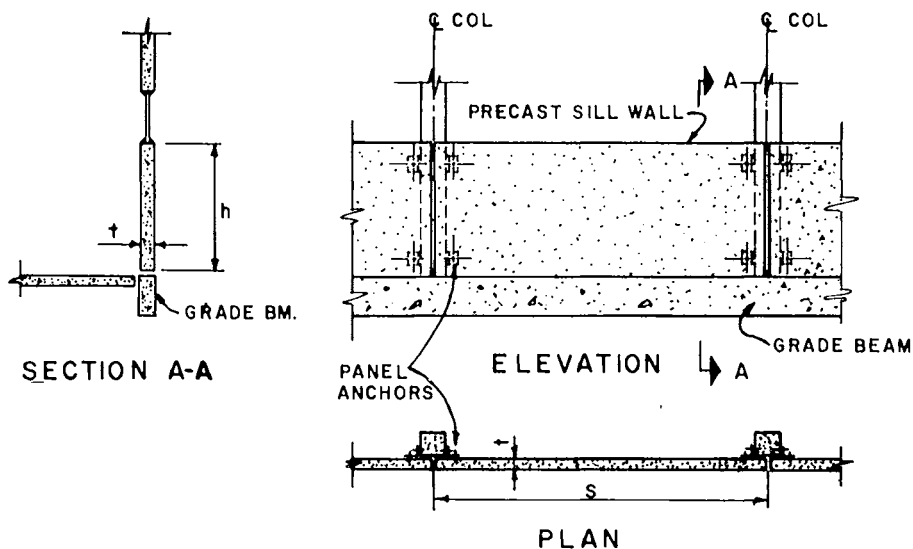


Fig. 1—Precast concrete sill wall

The first precast wall panels were 8 to 10 in. thick solid concrete averaging 8 to 10 ft wide by 20 to 30 ft long and used as sill or closure walls (Fig. 1). These panels were generally fabricated on the site and in many cases, tilted into position. This type of precast wall panel is usually designed using the provisions of the current ACI Building Code. The panel is considered as a reinforced concrete wall with the exception of being precast instead of cast-in-place. Critical design conditions during fabrication and erection are considered in the design.

Precast sandwich panel

The development of the precast sandwich panel, approximately 20 years ago, gave spectacular rise to the use of the precast wall panel. These panels, 4 to 6 in. thick, consist of an insulation core (such as foam glass, glass fiber, or expanded polystyrene or polyurethane) sandwiched between two layers of normal weight or lightweight concrete (Fig. 2 and 3). These lightweight members provided the construction industry with a precast concrete panel that could compete with the thin-metal curtain wall in weight, cost, and insulation efficiency.

As a result of this development, precast concrete panels, which were previously used as sill walls supported on grade beams and spanning between columns or isolated footings, could now be suspended between columns as

ACI member **Victor F. Leabu**, chief structural engineer, Giffels and Rossetti, Inc., Detroit, is a member of ACI Committee 533, Precast Panels, and 347, Formwork for Concrete. He is a graduate of the University of Michigan and is a registered professional engineer.

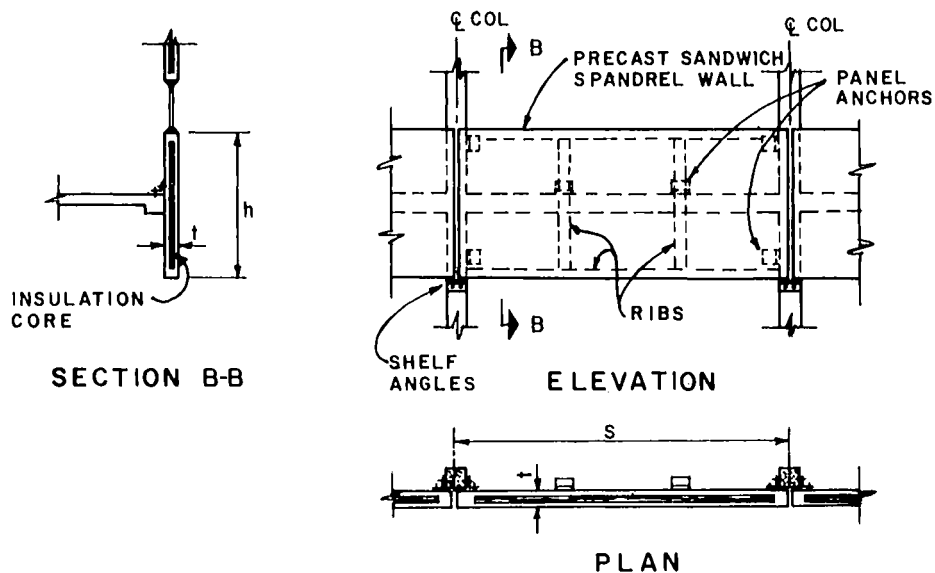


Fig. 2—Precast concrete spandrel wall

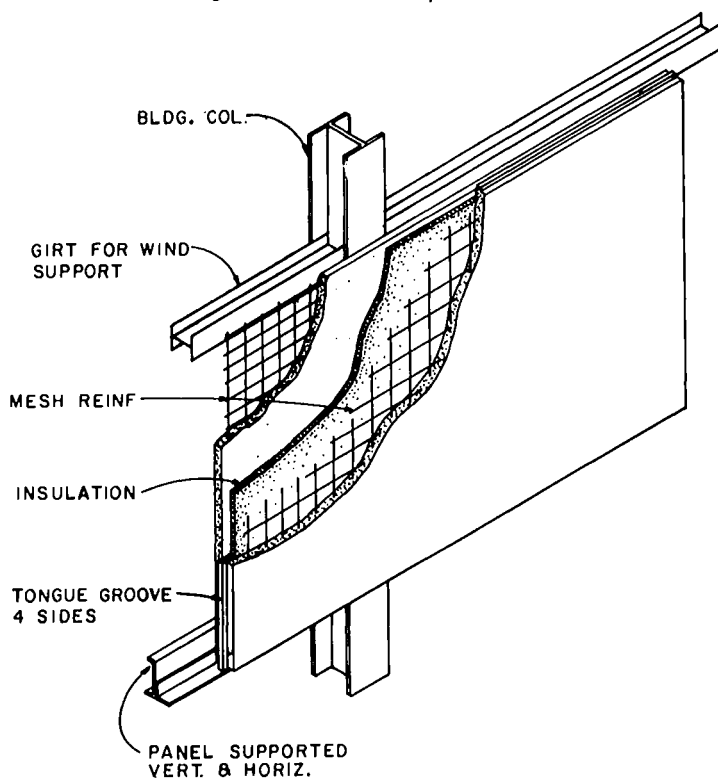


Fig. 3—Typical sandwich wall construction supported on structural frame

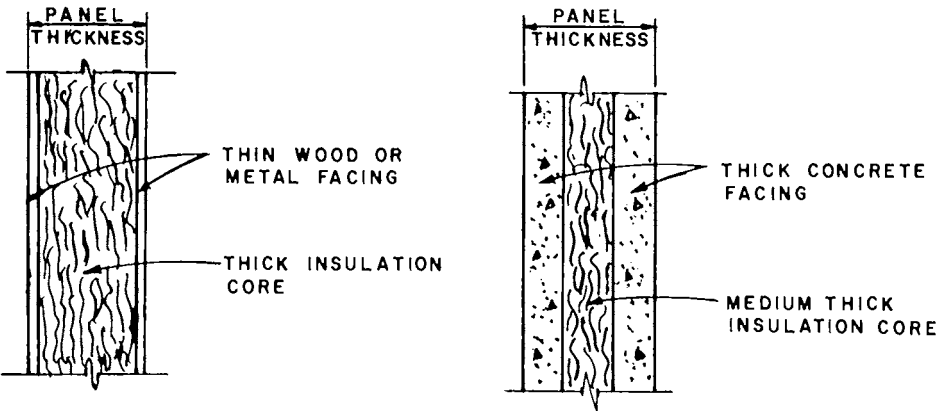


Fig. 4—(left) Wood or metal curtain spandrel panel and (right) precast concrete sandwich panel

spandrel walls or spanned vertically from floor to floor. In many cases, the insulated sandwich panel is used as a closure curtain wall, tongue and grooved on all four sides and supported vertically and horizontally by a concrete or steel structural framing system.

A satisfactory standard for the design of sandwich or insulated precast wall panels has yet to be developed. In contrast to the metal or wood sandwich panel, the precast concrete sandwich panel has a high ratio of skin area to insulation core area ranging from 1 to 3. This ratio for the metal or wood sandwich panel is usually between 0.1 to 0.5 (Fig. 4). The degree of composite action of the concrete layers and the variety of insulation cores used in this type of panel is reported elsewhere in this symposium, but the ability of the wall panel to resist bending and compressive loads may still require further investigation and research. Most wall panels of the sandwich type are being developed on the basis of past experience and engineering practice.

In a sandwich panel, the most desirable action of the panel under load is as an integral single unit with the full thickness always effective. Composite

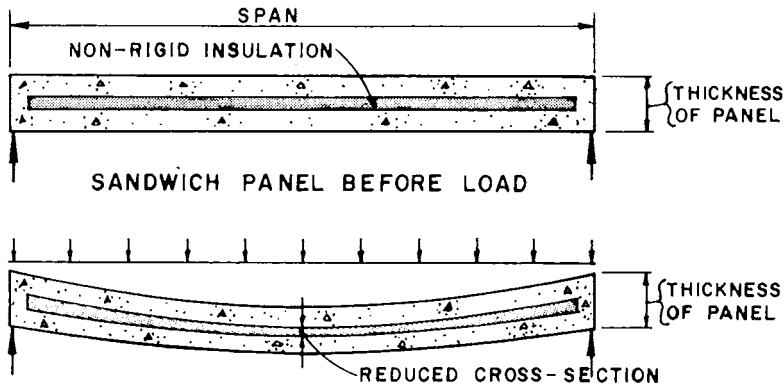


Fig. 5—Precast sandwich panel in bending

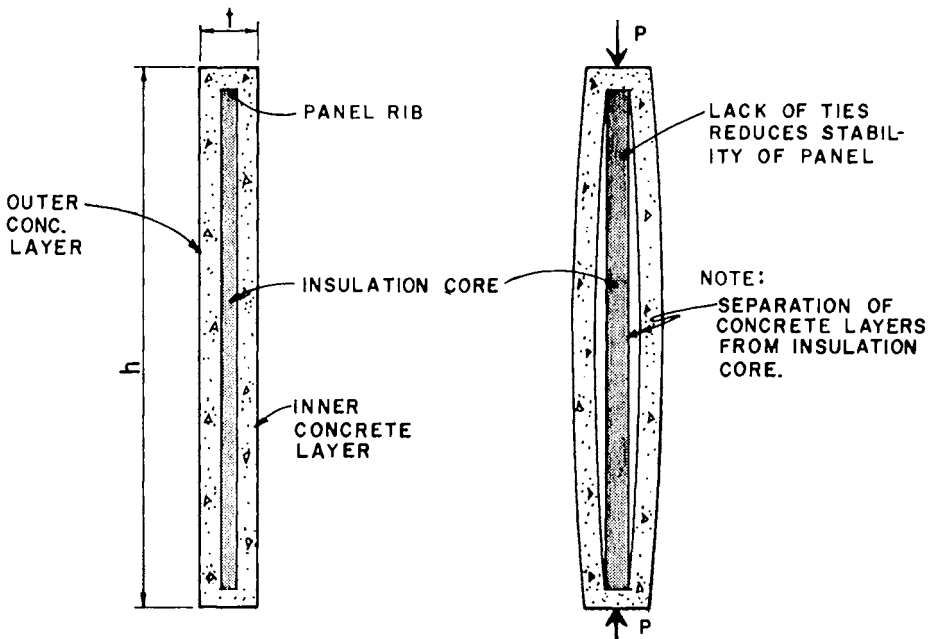


Fig. 6—Precast sandwich panel in compression

action of the sandwich panel depends to a great extent on the type of insulation core (rigid and nonrigid) used, the thickness of the concrete layers, and the use and spacing of concrete ribs and mechanical shear ties. The lack of composite stability due to insufficient ribs, mechanical shear ties between the concrete layers, and the use of nonrigid insulation core, reduces the effective cross section and the load carrying capacity of the precast wall panel in shear, bending, or compression (Fig. 5 and 6).

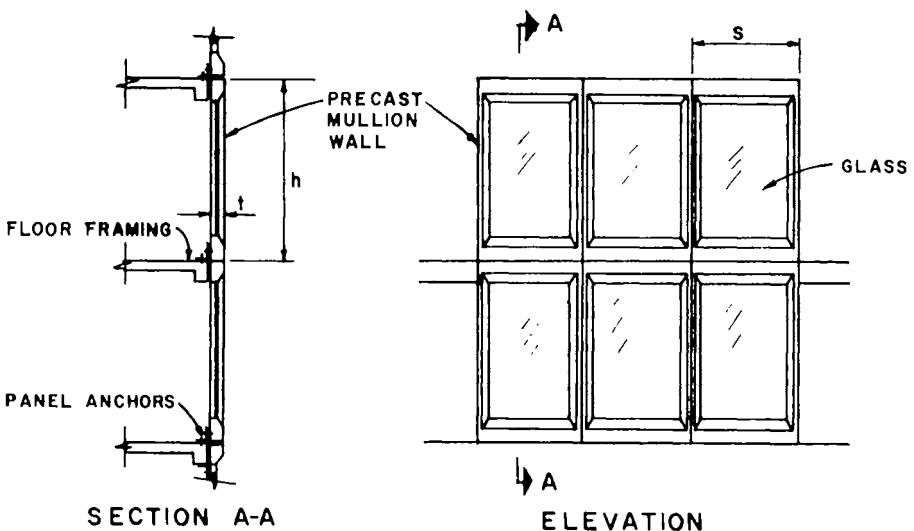


Fig. 7—Window type mullion wall panel

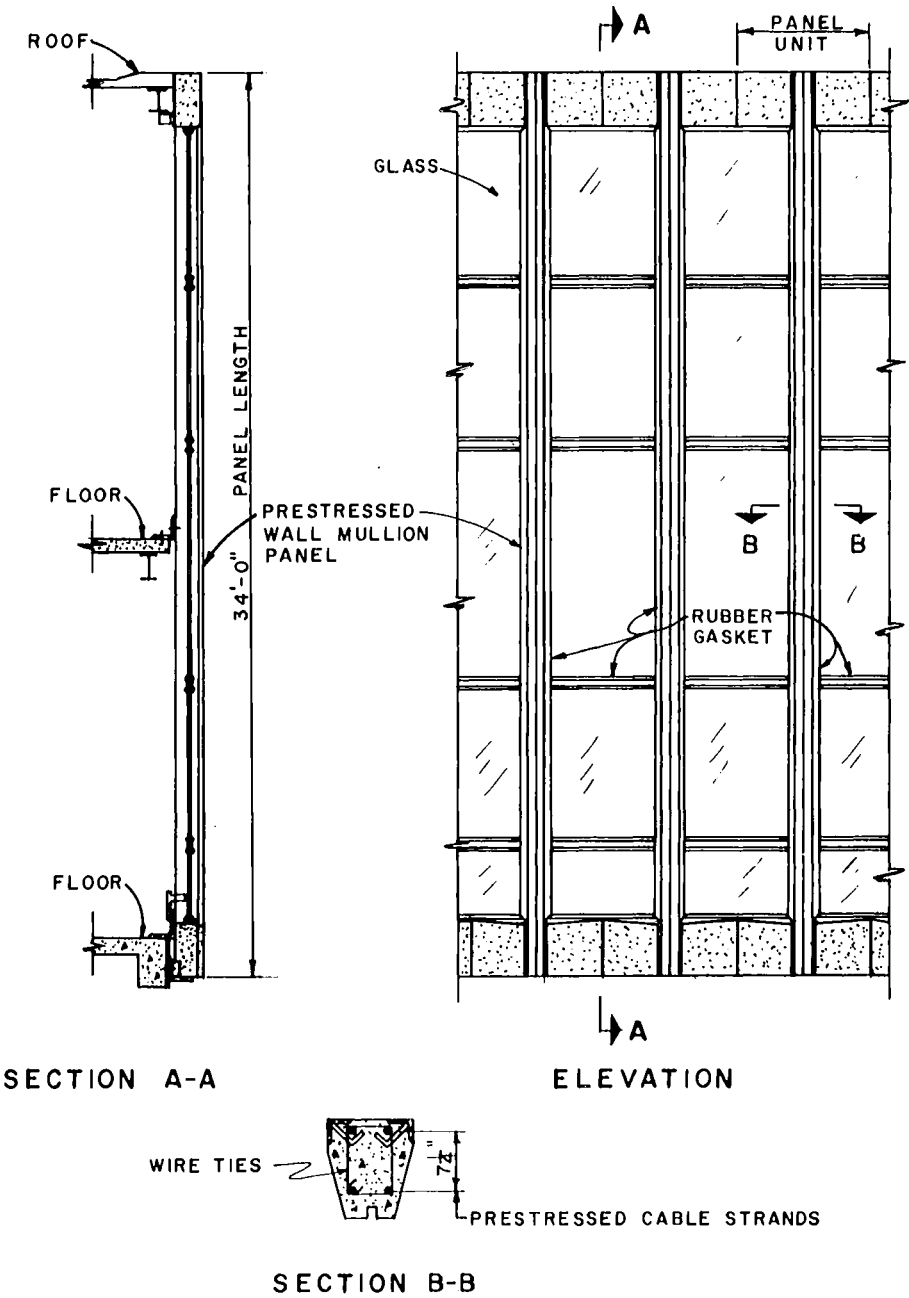


Fig. 8—Precast prestressed concrete mullion type wall

Special type panels

More recent developments of precast concrete wall panels have involved the use of a variety of surface treatments, such as exposed aggregates, mosaic, glass and marble chips, as well as textured and smooth surface finishes that are obtained by the application of industrial techniques developed in the precast industry.

A variety of shapes limited only by the imagination of the architect and designer have become popular in the field of precast wall panels in the past 6 years. The window-type mullion wall panel, with or without integral surface facing, is common in the curtain walls used on many highrise structures being built today. In many cases, this type of precast wall panel is replacing the metal curtain wall, not only on the basis of esthetics, but also on the basis of economy (Fig. 7 and 8). In many cases, the designer now has a material that can be molded in any conceivable shape made possible only in precast concrete.

Prestressed panels

Many variations of the mullion-type panel are now being used. In many cases, the precast sections have been developed on relatively thin cross sections by the use of prestressed concrete. The use of prestressing, both post-tensioning and pretensioning, has made the handling and erection of large precast units as well as thin sections possible without cracking or overstressing due to service loads (Fig. 8).

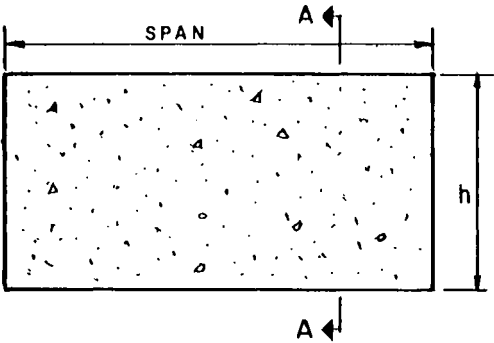
SUGGESTED PRELIMINARY DESIGN RECOMMENDATIONS FOR PRECAST WALL PANELS

To cover the many variations and unlimited types, shapes and configurations of precast wall panel units in a design standard would be impossible within the scope of this paper. Therefore, the following suggested preliminary design recommendation is intended as a guide, a general reference and as a beginning to the more important aspects of precast wall panel design. Continued effort of ACI Committee 533, Precast Panels, will no doubt, refine and further develop this recommendation for formal presentation to the Institute as a recommended practice for precast wall panels for the use of the designing engineer and the precast industry.

Scope and limitations

The following suggested minimum design recommendations for precast wall panels are preliminary in development and do not include all the design criteria and formulas required for precast panels. Materials, tests, fabrication, tolerances or erection standards are not included. These sections are in the process of development by other subcommittees of ACI Committee 533.

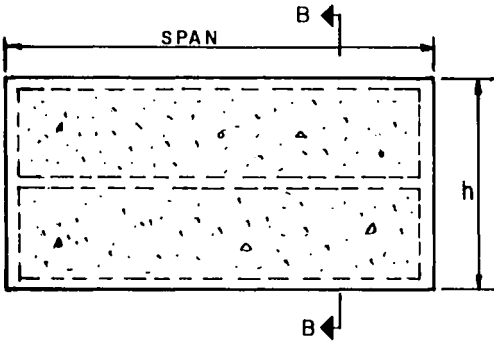
The design recommendations cover only the types of precast construction used as precast wall panels. This includes wall panels of solid, ribbed, cored or sandwich-type of construction (Fig. 9) cast from normal weight or light-



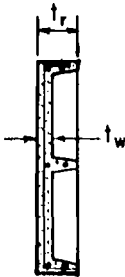
SOLID PRECAST PANEL



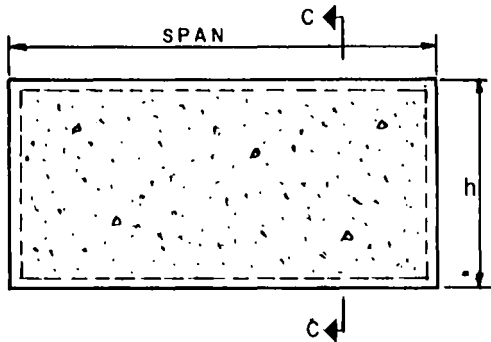
SECTION A-A



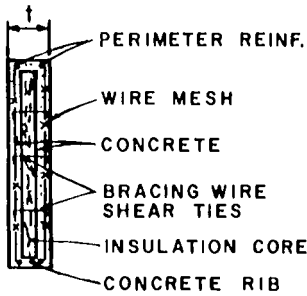
RIBBED PANEL



SECTION B-B



SANDWICH PANEL



SECTION C-C

Fig. 9—Solid, ribbed, and sandwich type precast concrete wall panels

weight concrete with or without integral surface facing. Prestressed wall panels are also included in this standard.

These minimum design requirements for precast wall panels are to be used in connection with "Building Code Requirements for Reinforced Concrete (ACI 318-63)."

Applicable codes, standards, and recommendations

All references to codes, specifications, recommended practices and standards listed or appearing in the design recommendations, are applicable:

"Building Code Requirements for Reinforced Concrete (ACI 318-63)."

"Specification for the Design, Fabrication and Erection of Structural Steel for Building (AISC 1961)" and "Specification for Architecturally Exposed Structural Steel (AISC 1960)."

"Aluminum Construction Manual," Aluminum Association (1959).

"Recommended Practices for Welding Reinforcing Steel Metal Inserts and Connections in Reinforced Concrete Construction (AWS D12.1-61)."

"Manual of Standard Practice for Detailing Reinforced Concrete Structures (ACI 315-65)."

Applicable ASTM specifications covering material used in precast concrete.

"Minimum Requirements for Thin-Section Precast Concrete Construction (ACI 525-63)."

All recommended standards and practices not listed above, but included in other sections of the ACI Committee 533 report are part of this recommendation.

Design methods

The design of the precast wall panels should be made either with reference to allowable working stresses, service loads, and the accepted straight line theory of flexure (working stress design) or with reference to load factors and strengths (ultimate strength design) as given in ACI 318-63.

The control of construction should be consistent with the design method selected by the engineer and approved by the local building codes.

Design loads

The provisions for the design herein specified are based on the assumption that all precast wall panels will be designed for all the dead and live loads carried by the panels and that the live loads will be in accordance with the general requirements of applicable local building codes pertaining to this type of construction.

1. Where precast wall panels are used as load bearing walls or story columns, load reductions for multiple stories will be permitted.

2. Where wall panels are used to resist wind and/or seismic forces, these forces should be determined in accordance with recognized methods and/or by the local codes and should be combined with the effects of dead and live loads carried by the precast wall units.

3. Wall panels and connections designed to resist wind should be designed for equal positive and negative pressures and if located in seismic areas, for

earthquake forces acting in any horizontal direction including torsional forces resulting from seismic loads.

4. The effects of forces due to concrete shrinkage, temperature differential, creep, prestressing, handling and erection loads, and *eccentric* loads should be considered in the design where required and as given by ACI 318-63.

Design stresses

Notation—

- A_b = Bearing area of precast wall panel in contact with supporting frame (sq in.).
 A_c = Maximum area of supporting member that is geometrically similar to and concentric with the bearing area of the precast wall unit (sq in.).
 E_c = Modulus of elasticity of concrete as given in ACI 318-63.
 F_a = Allowable direct compressive stress (psi).
 f_a = Computed direct compressive stress (psi).
 F_b = Allowable maximum bending stress (psi) for panels loaded normal to face of panel.
 f_b = Computed bending stress (psi) for panels loaded normal to face of panel.
 F_{br} = Allowable maximum bearing stress (psi).
 F_c = Allowable compressive stress (psi) in flexure for panels used as beams and loaded in plane of panel.
 f_c = Computed compressive stress (psi) for panels used as beams and loaded in plane of panel.
 f'_c = Specified compressive strength of concrete at 28 days or at earlier age as determined by cylinder test (psi).
 h
 or = Height or distance (span) between supports (in.).
 l
 t_e = Effective thickness of precast wall (in.).

Allowable design stresses in normal weight and lightweight concrete and for reinforcing and prestressing steel should conform to the requirements of ACI 318-63.

Specific allowable design stresses pertaining to wall panels are included for reference. Panels should conform to the requirements of ACI 318-63, except as herein noted.

Precast wall panels used as bearing walls or columns loaded in plane of panel—The allowable direct compressive stress in the concrete for concentric loads, based on working stress design, should not exceed the following for normal weight concrete:

$$F_a = 0.2f'_c \left[1 - \left(\frac{h}{40 t_e} \right)^3 \right]$$

The above equation is plotted for $f'_c = 3000, 4000, \text{ and } 5000$ psi in Fig. 10. When the reinforcement in the bearing wall is designed, placed, and anchored in position as for tied columns, the allowable stresses shall be those for tied col-

umns in which the ratio of vertical reinforcement should not exceed 0.04. For concentrated loads, the length of the wall to be considered as effective for each should not exceed the center to center dimensions between loads nor should it exceed the width of the bearing plus four times the wall thickness.

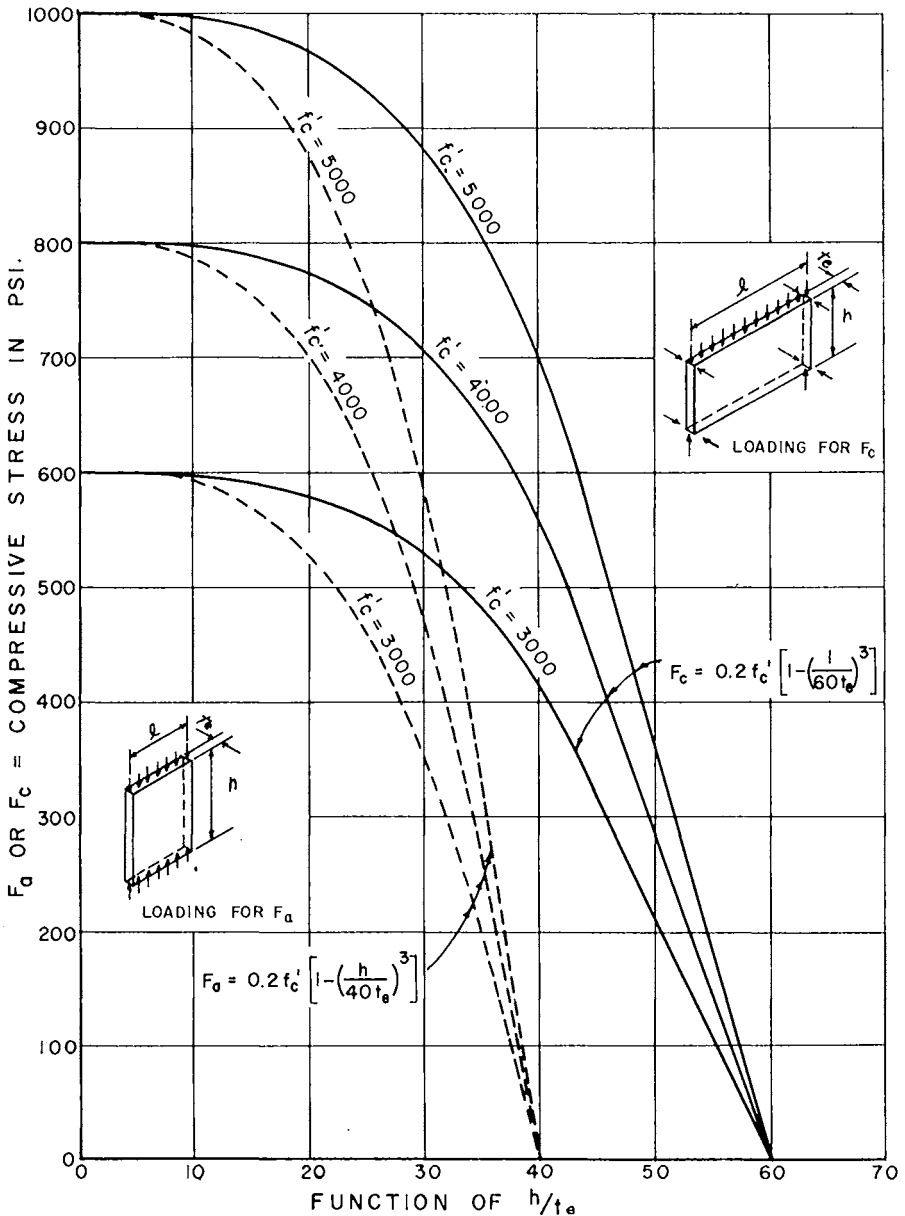


Fig. 10—Recommended allowable compressive stress for precast concrete panels based on h/t_e ratios

Precast wall panels used as beams loaded in the plane of the panel—Allowable compressive stress in concrete for precast concrete walls which span horizontally as deep beams between columns, supports or isolated footings, should not exceed the following for normal weight concrete:

$$F_c = 0.2f_c' \left[1 - \left(\frac{l}{60 t_e} \right)^3 \right]$$

Where height of panel $h \leq 8$ ft. The above equation is plotted for $f_c' = 3000, 4000$, and 5000 psi in Fig. 10.

Precast wall panels used as beams or slabs loaded normal to panel—Allowable compressive stress in concrete for precast panels which span vertically, horizontally or as a two-way slab should be as per ACI 318-63 considering the proper effective sections for the solid, ribbed, cored, or sandwich panels.

Precast wall panels controlled by compression and designed for combined compressive stresses—These panels should meet the following requirements:

1. Panels subjected to direct loads and bending about one principal axis should be so proportioned that

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1$$

2. Panels subjected to bending about two principal axes should be so proportioned that

$$\frac{f_c}{F_c} + \frac{f_b}{F_b} \leq 1$$

Maximum bearing pressures—Maximum bearing pressures under precast wall panels (i.e. on area A_b), supported on steel or concrete frame should not exceed the following:

$$F_{br} = 0.4f_c' \sqrt[3]{A_c/A_b} \leq f_c'$$

Effective section

Solid panels—

1. In solid concrete panels without a surface facing, the effective thickness of the concrete panel should be the full thickness.

2. In solid concrete panels monolithically cast with a surface facing having a compressive strength equal to or greater than the concrete back-up of the panel, the effective thickness should be equal to the panel total thickness minus the depth of the reveal of the exposed aggregate surface where the depth of reveal exceeds 3 percent of the total panel thickness.

3. In solid concrete panels that have a separate facing that is not cast monolithically with the panel, the effective structural thickness of the panel should be the total panel thickness minus the separate facing thickness.

Ribbed panels—

1. In ribbed or T-beam construction of wall panels, the flange and stem should be built monolithically for effective integral action.

