

Clay Product-Faced Precast Concrete Panels



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This paper presents the design and construction considerations for designers and plant personnel necessary for using brick, ceramic tile and architectural terra cotta faced precast concrete panels. The topics covered are clay product properties and selection, design considerations, production and construction aspects, cleaning of panels and handling, storing and shipping of the panels. Also covered are the applications of thin brick, ceramic tile and full brick to precast concrete panels after the panels are cast. It is emphasized that teamwork is an essential ingredient in the successful execution of a project.

Clay product-faced precast concrete is being used increasingly today to beautify the exterior of buildings. It allows the architect the flexibility to combine the pleasing visual appearance of traditional clay products with the strength, versatility and economy of precast concrete. In specifying these products, however, it is critical for the designers to know the advantages and limitations of using clay product-faced precast concrete. Among the types of products that can be bonded directly to precast concrete are brick, ceramic tile and architectural terra cotta. These clay product facings may cover the entire exposed panel surface or only part of the concrete face, serving as an accent band.

The use of clay product-faced precast concrete panels began in the early to middle 1960s. Examples of two early projects which are in excellent condition today are shown in Figs. 1a and 1b.

The combination of precast concrete and clay products has several advantages over site laid-up masonry. First, it eliminates the need for costly on-site scaffolding, as well as the time delay necessary for performing the masonry work. In addition, panels can be produced during foundation work or superstructure construction and can be erected quickly when they are delivered, eliminating the need for panel storage at the site. Plant production provides for year-round work under controlled temperature conditions, negating any on-site delays due to inclement weather. It also allows the structure to be winterized in advance, with floor topping and finishing trades continuing without any weather delays.

Precasting allows a high level of dimensional precision and quality control. Concrete mixes and mortar batching, together with curing conditions, can be tightly controlled while site-laid masonry will have highly variable curing and mortar quality. Clay product faced precast concrete reduces efflorescence because precasting techniques do not require the use of chloride accelerators in the mortar, and better curing is obtained through plant production.

In addition, the freedom of aesthetic expression available through precasting techniques could not economically be accommodated with site laid-up masonry. Precasting techniques allow for complex and intricate detailing, such as

arches, radius panels, soldier or running bond, or any imaginable pattern, to be incorporated into the finished panel. This approach ensures that high priced and time consuming building skills are transferred from the critical path of site activities to the plant, keeping alive the great range of visual diversity of design possibilities that otherwise might be stifled by economic constraints.

Architectural precast concrete claddings offer the designer a palette of styles – allowing the designer's imagination to soar through the range of possibilities from reproduction of styles of the past to the creation of patterns for buildings of the future.

Panel configuration may cover a multitude of shapes and sizes: flat panel sections through C-shaped spandrels, soffits, arches and U-shaped column covers (see Figs. 2a and 2b). A repetitive use of any particular shape also serves to lower costs appreciably. Returns on spandrels or column covers may be produced by the sequential (two-stage) casting method or as a single cast depending on the height of the return. Panels may serve only as cladding or may be load-bearing, supporting floor and roof loads.

GENERAL CONSIDERATIONS

Structural design, fabrication, handling and erection considerations for clay product faced precast concrete units are

similar to those for other precast concrete wall panels, except that special consideration must be given to the clay product material and its bond to the concrete. The physical properties of the clay products must be compared with the properties of the concrete backup. These properties include the coefficient of thermal expansion, modulus of elasticity and volume change due to moisture.

For design purposes, clay product-faced precast panels may be designed as concrete members which neglect the

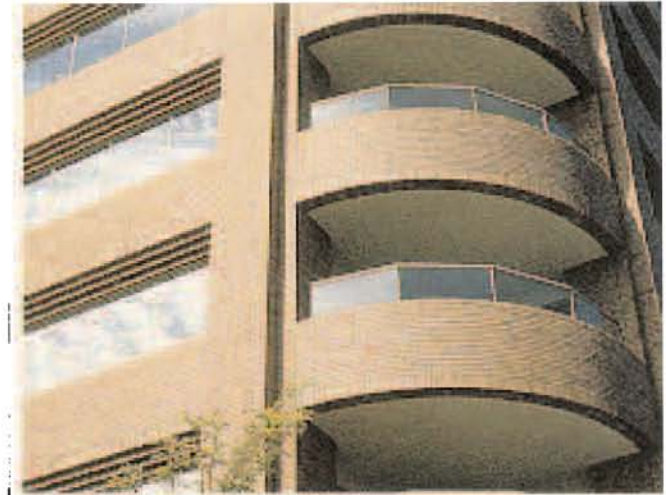


Fig. 1a. The Centennial Library, Edmonton, Alberta, Canada, was completed in 1967. Architect: Rensaa-Minsos & Associates, Edmonton, Alberta, Canada.

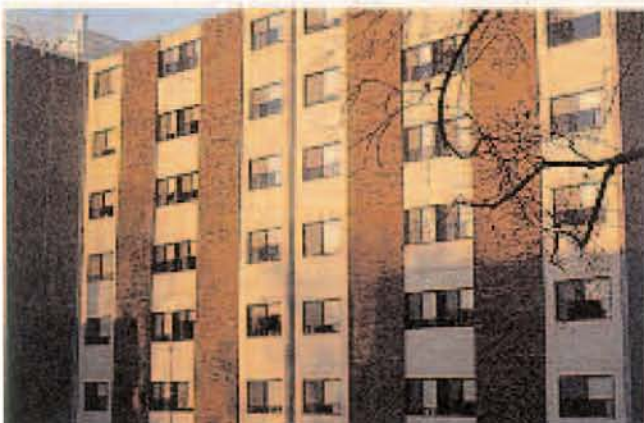
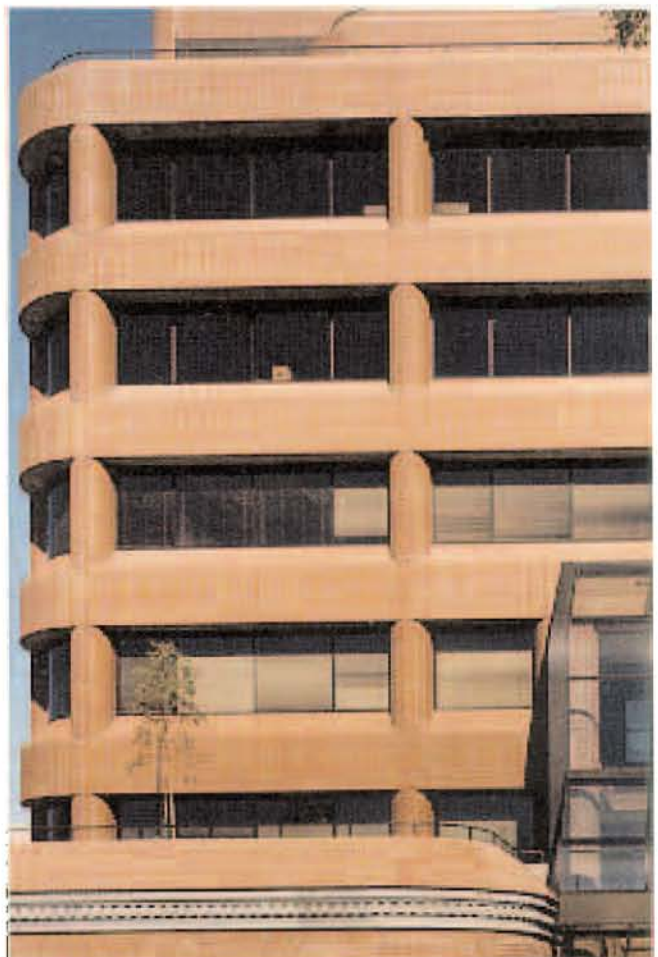


Fig. 1b. Capital Plaza, an apartment building in Concord, New Hampshire, was completed in 1972. Architect: ICO Systems, Inc., Boston, Massachusetts.



Figs. 2a and 2b. C-shaped spandrels, U-shaped column covers and curved-on-plan spandrels with brick.



Fig. 3. Brick patterns must be continuous through adjacent panels.

structural action of the face veneer. The thickness of the panel is reduced by the thickness of the veneer, and design assumptions exclude consideration of differential shrinkage or differential thermal expansion. However, if the panel is to be prestressed, the effect of composite behavior and the resulting prestress eccentricity should be considered in design.

Reinforcement of the precast concrete backup should follow recommendations for precast concrete wall panels relative to design, cover and placement. Cover depth of uncoated reinforcement must be a minimum of $1\frac{1}{2}$ in. (28 mm) to the back of the clay product. Galvanized or epoxy-coated reinforcement is recommended at cover depths of $\frac{1}{2}$ in. (19 mm). Joint depth and weather exposure affect the cover requirements.

The overall size and weight of the panels are generally limited to what can be conveniently and economically handled by available transportation and erection equipment. Generally, panels span between columns, usually spaced 20 to 30 ft (6 to 9 m) on centers, although spandrel panels have been as large as 8 x 60 ft (2.4 x 18.3 m).

The standard nominal heights and lengths of the panels should 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 $\frac{1}{8}$ in. (13 mm). For economical production, the precast concrete plant should be able to use uniform, even coursing without cutting any units vertically or horizontally except as necessary for running bond patterns.

The appearance of clay product-faced precast concrete panels is principally achieved by the selected clay product, with type, size and texture contributing to overall color. Also, the clarity with which the clay product units are featured will depend upon the profile of the joint between units. This requires a choice between recessed, flush or concave-tooled joints. Most brick-faced panels have recessed joints. Because of forming requirements, it is preferable that joints between clay products be not less than $\frac{1}{8}$ in. (10 mm). A $\frac{1}{4}$ in. (6 mm) joint may be used satisfactorily when the joint faces are smooth and well defined, as in a wall of flush-pointed, smooth-faced clay products such as tile.

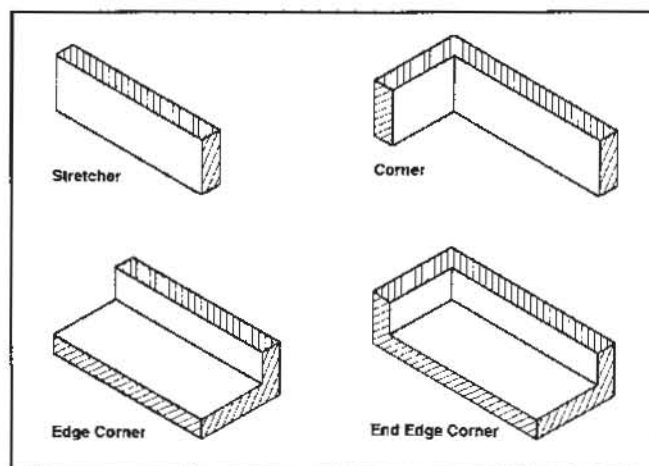


Fig. 4. Thin brick units.

The joints between panels are usually butt joints. A quirk miter joint, with the thin brick thickness being the quirk dimension, may be used if the joint sealant covers the brick/concrete interface. This precaution is necessary to prevent moisture penetration into the interface and possible brick separation under freeze-thaw conditions. The final element in the appearance of the panel is the grout, mortar or concrete used in the joints.

Both stack and running bond patterns have been widely used in precast concrete panels. With running bond, it is essential that courses start and finish with half or full bricks to avoid cutting and to match adjacent spandrels or column covers (see Fig. 3). Attempts to make the finished exterior look like running bond brick have not always been successful where the pattern is carried unbroken from panel to panel to form large walls. Where the perimeter of the panels is recognized and a narrow strip of exposed concrete is left at the ends, the running bond pattern becomes successful within individual panels from a design viewpoint (see Fig. 9). The vertical alignment of joints, especially with stack bond, requires close tolerances or cutting of brick to the same length.

Moisture can move into or across a wall assembly by vapor diffusion and air movement. If the exterior surface of a wall is partially sealed by glazed clay products, then, depending on the location of the dew point within the wall assembly, moisture may collect behind the partially sealed surface. If the moisture freezes, it will expand and may spall the exterior surface. Therefore, vapor retarders should be applied on or near the warm side of the assembly; this side should have a resistance to permeability at least five times greater than the cold side.¹

CLAY PRODUCT PROPERTIES

Physical properties of clay products vary depending on the source of clay, method of forming and extent of firing. Table 1 shows the range of physical properties of clay products. Since clay products are subject to local variation, the designer should seek physical property values from

suppliers that are being considered.

As the temperature or length of burning period is increased, clays burn to darker colors, and compressive strength and modulus of elasticity are increased. In general, the modulus of elasticity of brick increases with compressive strength to a compressive value of approximately 5000 psi (34 MPa); after that, there is little change. The thermal expansion of individual clay units is greater than the thermal expansion of clay product-faced precast concrete panels due to mortar joints.

CLAY PRODUCT SELECTION

Clay product manufacturers or distributors should be consulted early in the design stage to determine available colors, textures, shapes, sizes and size deviations, as well as manufacturing capability for special shapes, sizes and tolerances. Usually the precast concrete producer buys the clay products, but the general contractor or owner may also purchase the units and provide them to the precaster.

In addition to standard facing brick shapes and sizes (conforming to ASTM C216, Type FBX),¹ thin brick veneer units $\frac{3}{8}$ to $\frac{1}{2}$ in. (10 to 19 mm) thick are available in various sizes, colors and textures. Thin brick units 1 in. (25 mm) thick with smooth backside surfaces may also be available. The thin brick units should conform to ASTM C1088, Type TBX.² Stretcher, corner or three-sided corner units are typically available in a variety of color ranges (see Fig. 4). The face sizes are normally the same as conventional brick and therefore, when in place, give the appearance of a conventional brick masonry wall.

The most common brick face size is the standard modular, with nominal dimensions of 2 in. x 8 in. (68 x 200 mm). The actual face dimensions vary slightly among manufacturers, but they are typically $\frac{1}{8}$ to $\frac{1}{4}$ in. (10 to 13 mm) less than the nominal dimensions. The economy or jumbo size is 50 percent longer and higher, but this difference goes virtually unnoticed since the aspect ratio (length to height) is the same for both the standard and the economy modular units. The economy modular face size, 4 x 12 in. (100 x 300 mm), is popular for use in large buildings because productivity is increased, and the unit's size decreases the number of visible mortar joints, thus giving large walls a more pleasing appearance by reducing the visual scale of the wall. Other sizes, such as Norwegian, 3 in. (75 mm), non modular and oversize, may be available. Table 2 contains face sizes of several modular brick units; however, thin brick may not be available in each size.

Some bricks are too dimensionally inaccurate for precast concrete panel applications. They conform to an ASTM specification suitable for site laid-up applications, but they are not manufactured accurately enough to permit their use in a preformed grid that is used to position bricks for a pre-

Table 1. Range of physical properties of clay products.

Type of unit	Compressive strength (psi)	Modulus of elasticity (psi)	Tensile strength (psi)	Coefficient of thermal expansion (in./in. °F)
Brick	3,000 to 15,000	1.4 – 5.0 x 10 ⁶ (3.2 average)		4 x 10 ⁻⁶
Ceramic tile				
Quarry	10,000 to 30,000	7 x 10 ⁶	Approximately 0.1 compressive strength	2.2 – 4.1 x 10 ⁻⁶
Glazed wall tile	8,000 to 22,000	1.4 – 5.0 x 10 ⁶		4.0 – 4.7 x 10 ⁻⁶
Terra cotta	8,000 to 11,000	2.8 – 6.1 x 10 ⁶		4 x 10 ⁻⁶

Note: 1 psi = 0.006895 MPa.

cast concrete panel. Tolerances in an individual brick of $\pm \frac{1}{8}$ in. (± 2.38 mm) or more cause problems for the precast concrete producer. Brick may be available from some suppliers to the close tolerances [$\pm \frac{1}{16}$ in. (1.59 mm)] necessary for precasting. Close tolerances also can be obtained by saw cutting each brick, but this would substantially increase costs.

Whole bricks are generally not used in precasting because of the difficulty in adequately grouting the thin joints and the resultant necessity to use mechanical anchors. Extruded cut brick may have kerf lines connecting the extruded holes; the purpose of these lines is to enable the opposing brick faces to be split apart by simply tapping the end of the brick with a mason's hammer. Both sides of the brick may then be used as facing veneer. Special bricks with a sloping face are used at soldier courses or at the junction with a sloping face. The side cuts on these units are made with a masonry saw and the brick is tapped on its end to remove the waste section.

Preferably, thin brick should be a minimum of $\frac{3}{4}$ in. (19 mm) thick [many precasters have used $\frac{1}{2}$ in. (13 mm) thick brick] to ensure proper location and secure fit in the template during casting operations, and to minimize the misalignment or tilting of individual units. In site laid-up masonry, most bricks are tilted a little in one direction or an-

Table 2. Nominal modular face sizes of brick.

Unit designation	Face dimensions		Number of courses in 16 in.
	Height (in.)	Length (in.)	
Standard	2 $\frac{1}{4}$	8	6
Engineer	3 $\frac{1}{4}$	8	5
Economy 8 or jumbo closure	4	8	4
Norman	2 $\frac{1}{4}$	12	6
Norwegian	3 $\frac{1}{4}$	12	5
Economy 12 or jumbo utility	4	12	4
Triple	5 $\frac{1}{4}$	12	3

Note: 1 in. = 25.4 mm



Fig. 5a. The patterned facade on the San Francisco Museum of Modern Art has 1 in. (25 mm) thick brick on 9 in. (225 mm) thick precast concrete panels. Most panels measure 10 x 28½ ft (3 x 8.7 m) and contain 1500 to 2300 bricks per panel. Project Architect: Mario Botta, Lugano, Switzerland. Architect of Record: Hellmuth, Obata and Kassabaum, San Francisco, California.



Fig 5b. Closeup view of patterned facade.



Fig. 6. Brick-clad precast concrete panels were used to speed up the construction time required for the 10-story office building at 745 Atlantic Avenue, Boston, Massachusetts. Corbeled brick, concrete sills and lintels, and recessed windows with arches continue the architectural vocabulary of the surrounding older buildings. Architect: The Stubbins Associates, Inc., Cambridge, Massachusetts.

other so it is not quite as noticeable, particularly with bricks having surface imperfections (rough finish). On smooth or glazed face brick, imperfections become more noticeable.

Figs. 5, 6 and 7 illustrate applications of various types of brick-faced precast concrete panels.

Glazed and unglazed ceramic tile units should conform to American National Standards Institute (ANSI) A137.1,⁴ which includes American Society for Testing and Materials (ASTM) test procedures and provides a standardized system to describe the commonly available sizes and shapes, the physical properties, the basis for acceptance and methods of testing. Ceramic tiles are typically ⅜ to ½ in. (10 to 13 mm) thick, with a 1½ percent tolerance on the length and width measurements. When several sizes or sources of tile are used to produce a pattern on a panel, the tiles must be manufactured on a modular sizing system in order to have grout joints of the same width.

Glazed units may craze from freeze-thaw cycles, or the bond of the glaze may fail on exposure. The body of a tile (not the glazed coating) must have a water absorption of less than 3 percent (measured using ASTM C373)¹ to be suitable for exterior applications. However, low water absorption alone is not sufficient to ensure proper selection of exterior ceramic tiles. As a result, when ceramic tile is required for exterior use, the manufacturer of the clay product should be consulted for frost-resistant materials for exterior exposure. Glazes are covered by ASTM C126¹ and tested in accordance with ASTM C673.² Also, because glazed units have very low permeance to water vapor, it is recommended that a vapor barrier be installed on the warm side of walls.²

Figs. 8 and 9 show the use of various size tiles. See Fig. 15 for the application of 2 in. (50 mm) square tiles.

No ASTM standards exist for terra cotta, but units should



Fig. 7a. The Palace of Auburn Hills, Auburn Hills, Michigan, is clad with 9 in. (225 mm) thick curved precast concrete panels cast with a contrasting basketweave pattern of 8 in. (200 mm) square, 2 in. (50 mm) thick brick units and a rectilinear grid of blue-green glazed brick. Architect: Rossetti Associates, Detroit, Michigan.



Fig. 7b. Each panel is 20 ft (6 m) wide by 10 ft (3 m) high with a false joint in the middle. The intersection of the grids is accentuated by a cluster of glazed tile units. The panel edges are exposed concrete and deeply chamfered to provide shadow lines.

meet the minimum requirements published by the Architectural Terra Cotta Institute.⁸ Architectural terra cotta is a custom made product and, within limitations, is produced in sizes for specific jobs. Two thicknesses and sizes of units are usually manufactured: 1½ in. (31 mm) thick units, including dovetails spaced 5 in. (125 mm) on centers, size may be 20 x 30 in. (500 x 750 mm); 2¼ in. (56 mm) thick units including dovetails spaced 7 in. (175 mm) on centers, size may be 32 x 48 in. (800 x 1200 mm). Other sizes used are 4 or 6 ft x 2 ft (1200 or 1800 mm x 600 mm). Tolerances on length and width are a maximum of ± ⅛ in. (± 1.59 mm), with a warpage tolerance on the exposed face (variation from a plane surface) of not more than 0.005 in. per in. of length.

The use of terra cotta-faced precast concrete panels for restoration and new construction are illustrated in Figs. 10 and 11.

Variations in brick or tile color will occur. The clay product supplier must preblend any color variations and provide units which fall within the color range selected by the architect. Clay products also suffer from various surface defects, as do most materials used for architectural facings. Defects such as chips, spalls, face score lines and cracks are common with brick, and the defective units should be culled from the bulk of acceptable units by the clay product supplier or precaster according to the architect's requirements and applicable ASTM specifications.

DESIGN CONSIDERATIONS

The clay product surfaces are important in order to bond to the backup concrete. Textures that offer a good bonding surface include a:

- Scored finish, in which the surface is grooved as it comes from the die
- Combed finish, in which the surface is altered by parallel scratches



Fig. 8. The ability of architectural precast concrete to create the new and restore the old is demonstrated by the new 22-story San Francisco Federal Savings and Loan Building and (the barely visible) old six-story adjacent building (see Fig. 10). The 22-story tower has three different surface finishes: (1) lightly sandblasted white concrete, (2) 6 in. (150 mm) square glazed white ceramic tiles and some additional 10 in. (250 mm) square accenting blue tiles, and (3) a combination of the first two. Architect: Skidmore, Owings and Merrill, San Francisco, California.



Figs. 9a and 9b. Spandrels and wall panels on Sylvan Corporate Center, Englewood Cliffs, New Jersey, have integrally cast 8 in. (200 mm) square brick-colored tiles with pigmented mortar. A beige band of concrete surrounds the tile field. Architect: Herbert Beckhard Frank Richlan & Associates, New York, New York.

- Roughened finish, which is produced by wire cutting or wire brushing to remove the smooth surface or die skin from the extrusion process

It is preferable that the backside of clay product units have a keyback or dovetail configuration in order to develop an adequate bond to concrete. Grooved or ribbed back units



Fig. 10. Built in 1906, the six-story 88 Kearney St. is considered one of San Francisco's architectural landmarks. For that reason, it was decided that the building's terra cotta facade would be preserved on an otherwise all-new structure of slightly taller height. The terra cotta was taken off the building, piece by piece, and the pieces were identified for subsequent reassembly on new precast concrete panels. Architect: Skidmore, Owings and Merrill, San Francisco, California.

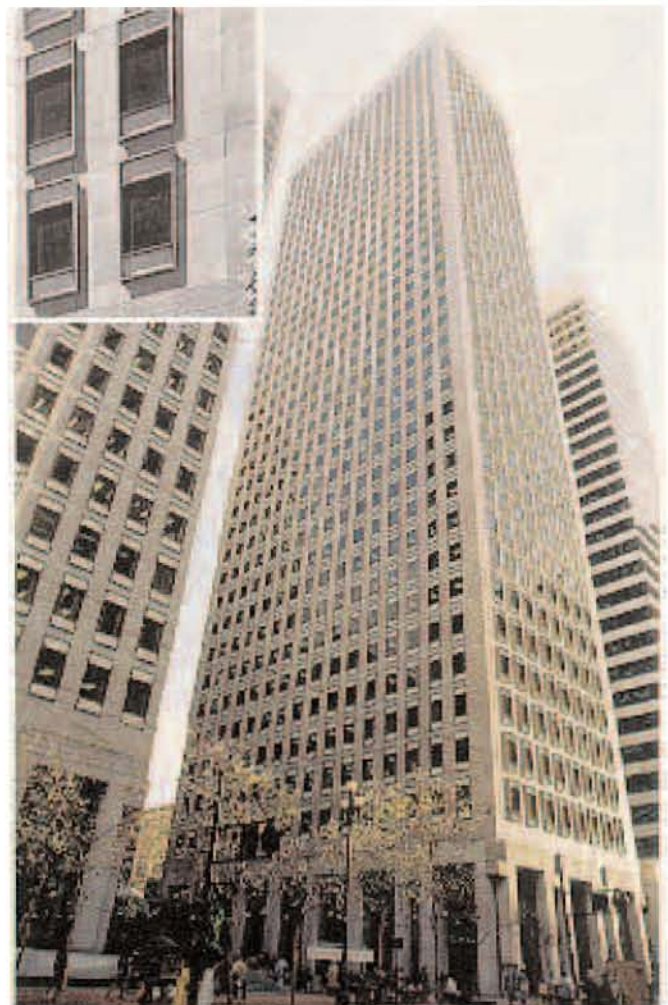


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Fig. 11. This 42-story office building, 575 Market Street, San Francisco, California has 9 ft (2.7 m) wide by 13 ft (4 m) high L-shaped terra cotta-faced precast concrete panels. Seven equal 1½ in. (44 mm) thick terra cotta pieces were placed in a structural lightweight concrete backup in the 7½ in. (190 mm) thick story high panels. Architect: Hertzka & Knowles, San Francisco, California.

also will provide an adequate bond. When thin clay products are used to face precast concrete panels, metal ties are not required to attach them to the concrete since adequate bond is achieved.

Latex additives in the concrete or latex bonding materials provide high bond and high strength, but have limitations. They are water sensitive, losing as much as 50 percent of their strength when wet (although they regain that strength when they become dry). The lowered strength of the concrete is usually sufficient to sustain low shear stress such as the dead weight of the clay product. However, when differential movements occur, additional stresses are produced which can cause bond problems.

In general, clay products that are cast integrally with the concrete have bond strengths exceeding that obtained when laying units in the conventional manner in the field (clay product to mortar). In either case, it is necessary to be careful to not entrap air or excess water-caused voids. These voids could reduce the area of contact between the units and the concrete and thus reduce bond.

The bond between the facing and the concrete depends on the absorption of the clay product and the water-cement ratio of the concrete. Low absorption will result in a poor bond, as will high absorption caused by the rapid loss of the mixing water, which prevents proper hydration of the cement and the development of good bond strength. Bricks with a water absorption of 6 to 9 percent obtained by 5 hour boiling provide good bonding potential.

Bricks with an initial rate of absorption (suction) of less than 30 g per 30 sq in. per min. (30 g per 194 cm² per min.), when tested in accordance with ASTM C67,³ are not required to be wetted. However, brick with high suction or with an initial rate of absorption in excess of 30 g per 30 sq in. per min. (30 g per 194 cm² per min.) should be wetted prior to placement of the concrete. This will reduce the amount of mix water absorbed and thereby improve bond. Unglazed quarry tile and frost-resistant glazed wall tiles, generally, are not required to be wetted. Terra cotta units should be soaked in water for at least one hour prior to placement to reduce suction. They should be damp at the time of concrete placement.

Because of the differences in material properties between the facing and concrete, clay product-faced concrete panels are more susceptible to bowing than homogeneous concrete units. However, panel manufacturers have developed design and production procedures to minimize bowing.

The likelihood that a panel will bow depends on the design of the panel and its relative stiffness or ability to resist deflection as a plate member. Critical panel lengths for bowing depend on temperature and moisture gradients, panel thickness and concrete modulus of elasticity. Panels that are relatively thin in cross section as compared to their overall plan dimensions are more likely to bow as a result of design, manufacturing and environmental conditions. Minimum thickness of backup concrete of flat panels to control bowing is usually 5 to 6 in. (125 to 150 mm), but 4 in. (100 mm) can be used where the panel is small or where it has adequate rigidity obtained through panel shape or clay product thickness.

Unrestrained bowing of a panel induces no stresses. If the bowing is restrained, by a midpoint tie back connection or by end connections that resist rotation, significant stresses may develop over time. If excessive bowing is taken out after the panel has been erected, then cracking of the panel may occur. The force necessary to straighten a bowed panel, and the resulting stresses, can be determined easily.

Panel design also must take into consideration the conditions that panels will encounter when in their final location in the structure and subjected to the wide range of seasonal and daily temperatures. In general, interior surfaces of panels are subjected to a very small temperature range while exterior surfaces may be exposed to a large daily or seasonal range.

The precaster and designer should consider the following factors in design and production in order to minimize or eliminate panel bowing:

1. The temperature differential (exterior to interior)
2. Coefficients of expansion of the materials
3. Ratio of cross-sectional areas of the materials and their moduli of elasticity
4. Amount, location and type of reinforcement in the concrete panel
5. Use of prestressing
6. Type and location of connections to the structure
7. Shrinkage of the concrete and expansion of the facing

Concrete shrinkage produces panel shortening which is resisted by the reinforcing steel, inducing compressive stresses in the steel and tensile stresses in the concrete. The magnitude of the shrinkage curvature (bowing) depends on the amount of nonsymmetry of reinforcement and on the relative areas of concrete and steel in the panel — as well as the physical properties of the bricks — as they relate to the concrete backup. Eccentric reinforcement near the clay product face increases bowing as drying proceeds. The greater the steel percentage, the higher the bowing tendency. If the panel's thickness is sufficient, usually 6 in. (150 mm) or more, two layers of reinforcement should be used, with the greater steel percentage near the drying face (the surface without clay product on it).

Prestressing of panels has been used on several projects and has been effective in controlling bowing of long, flat, relatively thin panels. Such panels are generally more susceptible to bowing. As with any multi-layer panel, prototypes may be necessary to verify analysis as to the best prestressing strand location to avoid an increase in bowing. Prism tests should be conducted on the proposed clay product to establish the modulus of elasticity. The precaster can then design the prestressed cross section for a transformed cross section based upon the ratio of the established moduli. This usually results in the prestressing strand being moved laterally off center to compensate for the transformed section. Prestressed panels which are 8 in. (200 mm) thick have been produced up to 60 ft (18.3 m) in length, with a maximum sweep (bowing) of ½ in. (13 mm). It is recommended that, in non-prestressed concrete panels, a control joint be introduced through the clay product face thickness when the panel length exceeds 25 ft (7.6 m).

Panel producers may compensate for bowing by using cambered forms, e.g., 1 in. (25 mm) for 40 ft (12 m), to pro-

duce panels initially bowed inward. Also, in some cases, reinforcing trusses may be used to add stiffness. In others, vertical and/or horizontal concrete ribs that run continuously from one end of the panel to the other may be formed on the back of the panel to increase stiffness. This will require backforming, however, which is more costly.

After initial set, concrete begins to shrink as it loses excess water to the surrounding environment. When the clay products are bonded, the shrinkage of the concrete is restrained by the facing as well as the reinforcing steel. This results in compressive stresses in the facing and tensile stresses in the concrete at the interface. The deformation resulting from these stresses may cause an outward bowing of the clay product surface.

Shrinkage of concrete is influenced by a variety of factors, including: (1) water-cement ratio of the cement paste, (2) physical characteristics of the aggregate, (3) cement paste content and characteristics, (4) mix proportions, (5) age of concrete when exposed to drying or when an external load is applied, (6) size and shape of the member, (7) amount of steel reinforcement, (8) environmental exposure conditions such as relative humidity, temperature and carbon dioxide content of the air, and (9) curing conditions.

The most important single factor affecting shrinkage is the amount of water placed in the mix per unit volume of concrete. This is because shrinkage of concrete is due mainly to the evaporation of the mixing water. As a result, the humidity of the surrounding air for a given concrete mix affects, to a large extent, the magnitude of the resulting shrinkage. Values of final shrinkage are generally of the order of 0.0002 to 0.0007 in./in., depending on the factors listed earlier.

Control of concrete shrinkage necessitates close attention to the concrete mix design and curing regime (proper humidity and temperature) conditions. The application of a curing compound on all exposed concrete surfaces prior to stripping will result in nearly uniform shrinkage on the two faces of the panel and thus limit the magnitude of the moisture differential that causes bowing.

Moisture differences between the inside and outside of an enclosed building can also cause bowing; however, such a calculation is not precise and involves many variables. The clay products layer of the panel absorbs moisture from the atmosphere and periodic precipitation, while the interior layer is relatively dry, especially when the building is heated. This causes the inside layer to shrink more than the outside, causing an outward bow. This would tend to balance the theoretical inward thermal bowing in cold weather.

Temperature differentials between the inside and outside of a wall panel can cause the members to bow, too. It should be noted that, since dark surfaces absorb solar radiation, the color of the clay product can have a marked effect on the surface temperature reached. The temperature differential is tempered by "thermal lag" due to the mass of the clay product and the concrete.

It is desirable to have a backup concrete with low shrinkage and a thermal expansion coefficient that closely approximates that of the clay product facing. The coefficient of thermal expansion of concrete can be varied by changing the

aggregate type (see Table 1.3.1, Ref. 1), for example, to limestone, which has a coefficient of expansion closer to that of clay products.

When removed from the kiln after firing, clay bricks will begin to permanently increase in size as a result of absorption of atmospheric moisture. The design coefficient for moisture expansion of clay bricks as recommended by the Brick Institute of America (Ref. 6) is 0.0005 in. per in., and is specified as 0.0003 by Ref. 7; a coefficient of expansion of 0.0005 is typical for ceramic quarry tile.

The factors affecting moisture expansion are:

1. Time since manufacturing — Expansion increases linearly with the logarithm of time. It is estimated that approximately 25 percent of the total potential moisture expansion of bricks will have occurred within two weeks after the bricks have been fired. Also, approximately 60 percent of the total potential moisture expansion will occur approximately one year after the bricks have been fired.^{8,9} How much the brick will expand subsequent to placement in the panel depends upon how much expansion has already occurred and what proportion this represents of the total potential for expansion.

2. Temperature — The rate of expansion increases with increased temperature when moisture is present.

3. Humidity — The rate of expansion increases with an increase in relative humidity. Bricks exposed to a relative humidity of 70 percent have a moisture expansion two to four times as large as those exposed to a relative humidity of 50 percent over a four-month interval. The 70 percent relative humidity bricks also exhibit almost all of their expansion within the first 12 months of exposure, while the 50 percent relative humidity bricks generally exhibit a gradual continuous moisture expansion over a much longer period of time.

In addition to continuous permanent growth due to moisture absorption, seasonal reversible expansion and contraction of clay bricks will occur with changes in the ambient air temperature. When directly exposed to solar radiation, it is not uncommon for the exterior surface of a panel to reach temperatures of 150° F (65° C) with dark colored brick, 130° F (55° C) with medium colored brick, or 120° F (50° C) with light colored brick on a hot summer day with an ambient air temperature well below 100° F (38° C). Likewise, surface temperatures of as low as -30° F (-35° C) can be reached on a cold winter night.

The expansion of the clay products can be absorbed by four simultaneously occurring negative dimensional changes of the clay product and mortar (grout) or concrete:

1. Drying shrinkage of the mortar or concrete
2. Elastic deformation of the mortar or concrete under stress
3. Creep of the mortar or concrete under stress
4. Elastic deformation of the clay product under stress

In general, strains imposed slowly and evenly will not cause problems.¹⁰ Consider the first six months to a year after panel production (see Fig. 12). Tile expansion is small and the rate of strain application is slow, but mortar shrinkage is nearly complete. The mortar or concrete creeps under the load to relieve the tensile stress generated in the tile by the mortar

or concrete shrinkage since the tile are relatively rigid (elastic modulus of tile/elastic modulus of mortar or concrete). After this time period, the tile has many years to accommodate the additional moisture expansion.

Bond failures occur when strain rates exceed creep relief rates. This can occur when:

1. The total shrinkage is higher than normal because overly rich concrete or mortar was used.
2. A sudden rise in temperature or drop in humidity causes shrinkage to proceed faster than creep relieves the stresses that are generated.
3. The bond between clay product and concrete was never adequately achieved.
4. A sudden temperature drop imposes a sudden differential strain because the clay product and mortar (or concrete) have different thermal coefficients of expansion.

Creep in brick masonry primarily occurs in the mortar joints and is negligible. Ref. 7 suggests 0.7×10^{-7} in./in. per psi (1.02×10^{-5} mm/mm per MPa) of load.

The differences in creep characteristics between concrete and clay products, along with the differences in their respective moduli of elasticity, do not pose a problem to the production of small [less than 30 ft (9 m)] panels when good quality clay products are used. This observation is based on static load tests simulating differential creep.¹⁹

PRODUCTION AND CONSTRUCTION CONSIDERATIONS

Clay product-faced units have joint widths controlled by locating the units in a suitable template or grid system set out accurately on the mold face (see Fig. 13). The most popular grid system consists of either an elastomeric (or rubber) form liner or a wooden base tray with shaped wood joint sections. Liner ridges are typically shaped so that joints between units may simulate raked (recessed) or tooled joints.



Fig. 13. Thin brick being placed in elastomeric form liner.

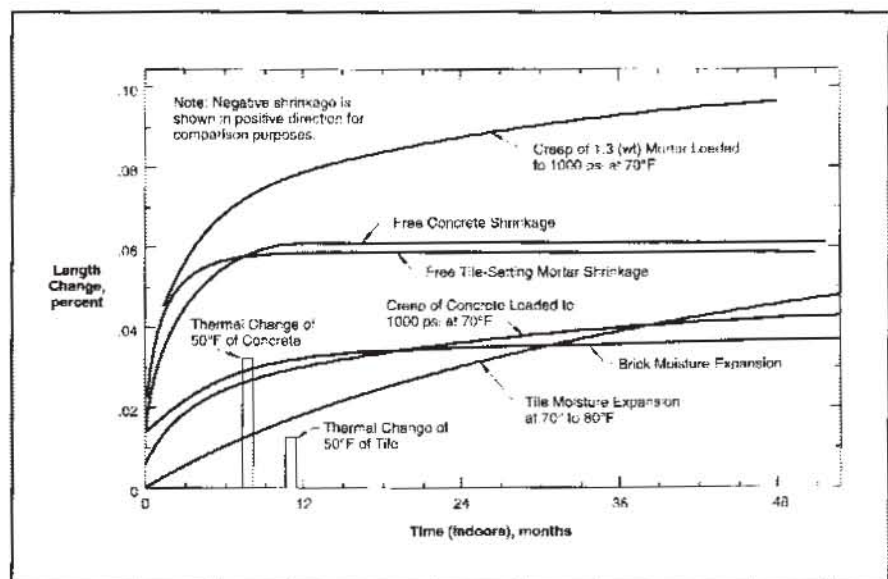


Fig. 12. Relative temperature and moisture movements of concrete, brick, tile and mortar.¹⁰

The elastomeric form liner can be produced to a tolerance of $\pm \frac{1}{4}$ in. (± 0.4 mm).

In some cases, this grid system has successfully incorporated loose rubber joint strips of Shore A-60 durometer hardness to form a "build-as-you-apply-brick" grid (see Fig. 14) or has used urethane, plaster or sand to ensure proper location and secure fit during the casting operation. Clay product units should be checked for tight fit and wedged if not tightly secured — especially on return sections — to prevent grout leakage to the exposed face of the panel.

Using a grid system, the joints are recessed, usually $\frac{1}{4}$ in. (6 mm), and are filled with either a 1:4 cement-sand mortar or the structural concrete used in the structural component of the panel. Colored joints are not necessary, although such an architectural choice can be accommodated. The aggregate in the concrete for the joints should have a maximum



Fig. 14. Saw-cut bricks placed using loose rubber strips to separate the bricks.



Figs. 15a and 15b. The Nikko Hotel, San Francisco, California uses 2 x 2 in. (50 x 50 mm) tiles, which were supplied face-mounted on 12 in. (300 mm) square paper sheets (see inset). Architect: Whisler-Patri, San Francisco, California.

size of less than the joint width. Joints narrower than $\frac{1}{8}$ in. (10 mm) may have to be filled from the front after the panel has been stripped, which adds to the cost.

Steel reinforcement is positioned in the panel, and connection hardware and handling inserts are located and secured. Then the backup concrete is placed in a normal manner. Care must be taken during concrete placing and consolidation to prevent movement of the individual facing materials, which would upset the appearance of the finished surface.

Tiles, measuring 2 x 2 in. or 4 x 2 in. (50 x 50 mm or 100 x 50 mm), may be supplied face-mounted on polyethylene or paper sheets and secured to the mold by means of double-faced tape or a special adhesive. The space between the tiles is filled with a thin grout and then the backup concrete is placed prior to initial set of the grout. Fig. 15 shows a project that uses 2 x 2 in. (50 x 50 mm) tiles which have been placed with the method described. For the best appearance, narrow tile joints should be filled from the front, particularly if cushion edged tiles are used.

After the concrete cures and the panel is removed from the mold, joints may be filled, if necessary, with pointing mortar or grout carefully formulated for color and texture. Before pointing, joints should be saturated with clean water. After the joints are properly pointed and have become thumbprint hard, they may be (1) tooled to a smooth concave surface, which offers the best durability, or (2) struck and troweled flush with the face of the clay units. Initial

grout cleanup should be done within 15 minutes of pointing to avoid hard setting of the grout on the units. Final cleanup should be completed within 60 to 90 minutes.

CLEANING

Mortar stains may be removed from brick panels by thoroughly wetting the panel and scrubbing with a stiff fiber brush and a masonry cleaning solution.⁶ A prepared cleaning compound is recommended; however, on red brick, a weak solution of muriatic acid and water (not to exceed a 10 percent muriatic acid solution) may be used. Acid should be flushed off the panel with large amounts of clean water within 5 to 10 minutes of application. Buff, gray or brown brick should be cleaned in accordance with the brick manufacturers' recommendations, using proprietary cleaners rather than acid to prevent green or yellow vanadium stains and brown manganese stains.

Following the application of the cleaning solution, the panel should be rinsed thoroughly with clean water. High pressure water cleaning techniques, with a 1000 to 2000 psi (6.9 to 13.8 MPa) washer, may also be used to remove mortar stains. Many precasters apply a water-based retarder to the face of the brick or tile prior to placement in the mold to facilitate mortar stain removal. With antique brick, the retarder may sometimes cause discoloration of the surface, and retarder paper precut to the brick dimensions is laid in the form liner face-up prior to setting the brick.

When tile or terra cotta joints are grouted after the panel is stripped, a clean, hard rubber float should be used for spreading grout and fully packing joints. Excess grout should be removed by holding the float at a 90-degree angle and moving it across the panel diagonally to the joints. To maintain a uniform grout color and texture, colored grout should be cleaned off the panels with a cheesecloth pad and/or terry cloth towel prior to grout setting.

Proper cleaning of tile surfaces eliminates the need for acid cleaning. However, should some residue be left on an unglazed tile or terra cotta surface, it can be cleaned after 10 days with a 5 percent solution of sulfamic acid for gray or white joints, and a more dilute (2 percent) solution for colored joints. Cleaning the panels too early may embed the cement paste into the pores of the clay product. The surface should be thoroughly rinsed with clean water both before



Fig. 16. Support framing is kept away from brick edges to prevent spalling.



Fig. 17. A vertical easel was an effective restraint for 65 ft (19.8 m) long prestressed concrete panels during stockpiling.

and after cleaning. Glazed tile manufacturers generally do not recommend the use of acid for cleanup purposes.¹¹

HANDLING, STORING AND SHIPPING

In all operations after removal from forms, clay product-faced precast concrete panels are handled, stored and shipped on the concrete edges of the panel or on their backs with the facing up. To avoid chipping or spalling (see Fig. 16), panels must not rest, at any time, on their faces or on any of the clay product edges or corners.

Bowing of panels in storage can be minimized by providing blocking so that the panels remain plane. Long panels stored on A-frames should be supported across their entire length. Storing panels so that flexure is resisted about the strong axis will minimize stresses and bowing. It is preferable to store panels as near vertical as possible (see Fig. 17). Where feasible, panels should be oriented in the yard so that the sun does not overheat one side (store with length oriented in north-south direction).

During shipping, panels must be placed on padded racks or other measures must be taken to prevent chipping of edges or damage to returns (see Fig. 18). Long returns at sills and soffits generally create handling problems unless proper procedures are worked out ahead of time.

Should minor damage occur to the clay product face during shipping, handling or erection, field remedial work can be accomplished easily, including replacement of individual clay products.

However, because one color will not match all of the various hues in use on any one job, it is important to determine the quantity of patching that will be permitted. Patching samples should be viewed at a distance or height consistent with actual panel locations. Also, a panel must be viewed in its entirety from a 20 ft (6.1 m) distance, not just examined for individual unit deficiencies.

APPLICATIONS OF CLAY PRODUCTS AFTER CASTING OF PANEL

Thin brick and ceramic tile as well as full brick have been laid at the precast concrete plant and at the jobsite on a panel ledge, generally created by a recess on the precast



Fig. 18. Panel edges protected to prevent chipping during shipping.

concrete panel face, or on a shelf angle. Fig. 19 shows the use of a bullnose to provide a shadow line between the field-laid brick and precast concrete.

Thin Brick and Ceramic Tile

Thin brick and ceramic tile may be applied to a recessed concrete surface that has been properly roughened by sand-blasting or bushhammering using dry-set mortar conforming

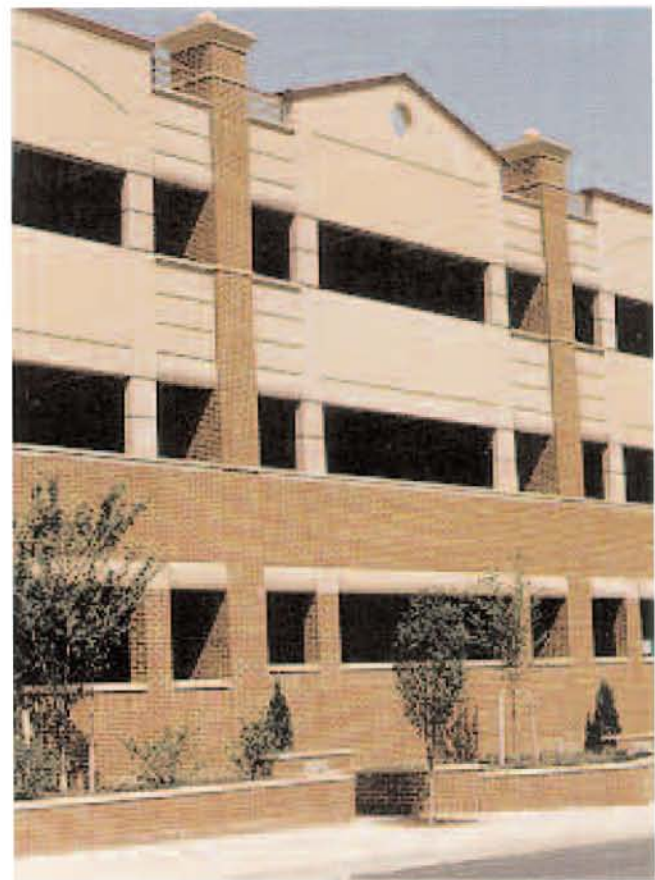


Fig. 19. Spandrels on the Poplar and Walnut Parking Garage, Reading, Pennsylvania, are designed with segmented bullnose ledges and integral copings. The ledges support field-laid brick. Architect: Synergetics Architects, Reading, Pennsylvania.

with ANSI A118.1 or latex-portland cement mortar conforming with ANSI A118.4.³ Installation specifications for both dry-set and latex-portland cement mortars are contained in ANSI A108.5.⁴ When dry-set mortar is used, the necessity of wetting either the concrete surface or clay product is eliminated. Since lattices vary considerably, each

latex manufacturer's directions must be followed explicitly, particularly in regard to curing.

Since about 40 percent of the concrete panel drying shrinkage occurs within 30 days, it is preferable that at least one month elapse between casting and application of brick or tile to allow the shrinkage to occur.



Fig. 20a. The surface of the panel is lightly sandblasted prior to parging with a skim coat of latex-portland cement mortar.



Fig. 20d. Grout is placed into the joints using a baker's bag or large caulking gun. Excess grout is struck from the brick surface using a rubber-faced float. The float is worked at 45 degrees to the surface.



Fig. 20b. A second coat of mortar is applied to the panel surface using a notched trowel. The glazed brick is then applied to the panel surface.



Fig. 20e. As the grout begins to set, the joints are tooled.



Fig. 20c. The bricks are tapped into the mortar using a rubber mallet. Level and alignment are also checked at this point.



Fig. 20f. After the grout has cured, the panel is cleaned using stiff brushes and then rinsed with low-pressure water.



Fig. 21a. Saskatoon City Hospital walls are precast concrete sandwich panels incorporating insulation and a rain screen, with ceramic tile on the exterior. Architect: City Hospital Architects Group, Inc., Saskatoon, Saskatchewan, Canada, a Joint Venture of Folsstad & Friggstad Architects, Billington Poon Associates Ltd. and Arthur Erickson Architects.



Fig. 21b. The paper-faced 2 in. (50 mm) square tiles on a 1 ft (0.3 m) square sheet were applied in the plant using latex-portland cement mortar and easily adapted to the complex wall profiles.

The mortar is first applied to the concrete panel with the flat side of the trowel to get good mechanical bond with the precast concrete. Prior to initial set of the mortar, the notched edge of the trowel is scratched over the surface to obtain the desired thickness of the bond coat. A small quantity of mortar then is troweled onto the back of the thin brick or tile (which has a keyback or dovetail configuration) to promote good mechanical bond and full unit support.

When thin brick or tile have smooth backs, the rows of mortar formed by the trowel notches should be aligned at right angles to the mortar rows on the precast concrete.

Applying the thin brick or tile with pressure and a slight twisting or sliding motion is another way to promote good bond. Proper beat-in with a hand rubber float, wooded mallet, trowel handle or power impacting vibrator also improves bond and helps achieve level surfaces without high corners.

Units are then grouted and tooled using dry-set or latex-portland cement grouts conforming with material and installation specifications contained in ANSI A118.6 and ANSI A108.10.⁴ Joint size should be selected so as to avoid excessive cutting of the thin brick or tile, and can typically be 4 to 1/2 in. (6 to 13 mm) wide.

A step by step procedure for the application of glazed thin brick is shown in Fig. 20.

ANSI A118.1⁴ and ANSI A118.4⁴ require a minimum of 4-week shear bond strengths of dry-set mortars ranging from 250 psi (1.72 MPa) for glazed wall tile to 100 psi (0.6895 MPa) for quarry tile; with latex-portland cement mortars, the minimum 4-week shear bond strengths requirements are 300 psi (2.07 MPa) for glazed wall tile and 150 psi (1.03 MPa) for quarry tile. Laboratory tests on thin brick veneer show shear bond is in the 200 to 400 psi (1.38 to 2.75 MPa) range.¹³

Immediately after stripping a panel, joints in thin brick veneer should be filled with latex-modified portland cement grout and tooled. Leaving joints ungrouted has been done frequently to save money and achieve the popular deep raked joint look; unfortunately, ungrouted joints are susceptible to freeze-thaw damage.

Joint grouting improves the adhesion of even properly installed units. Tests have shown that grouted joints improve

the shear bond by about 10 percent when there is full contact with the bond mortar and by about 73 percent when there are voids in the bond mortar. For tensile bond, there is a 36 percent improvement in units with full bond contact and a 98 percent improvement in units with voids in the bond mortar.¹²

All excess grout material should be removed as grouting is carried out, using a damp cloth or sponge. Excessive early water application can retard the latex cure and re-emulsify the latex polymer.

Maximum variation of finished surface (local smoothness) should be 1/4 in. in 10 ft (6 mm in 3.05 m), with no more than 1/8 in. (1.59 mm) variation between adjacent clay products.

Applications of both plant and site applied tile using latex-portland cement mortar are shown in Figs. 21 and 22.



Fig. 22. The Ravenna Eckstein Community Center in Seattle, Washington uses precast concrete panels articulated with reveals and recesses varying from 3/4 to 1 1/4 in. (19 to 35 mm) to reflect the adjacent 1911 school's proportions. Ceramic tile was then selectively field-laid on the concrete to reference the school's brick and terra cotta banding and details. Architect: ARC Architects, Seattle, Washington.

Full Brick

Full brick supported on a concrete ledge or steel shelf angle requires anchors to provide lateral support. The anchors should be flexible, capable of resisting tension and compression resulting from forces perpendicular to the plane of the wall, but permitting slight vertical and horizontal movement parallel to the plane of the wall. This flexibility permits differential movements between the precast concrete and the clay product veneer without cracking or distress.

Wire anchors (ASTM A82 or B227, Grade 30HS)¹ should be at least $\frac{3}{16}$ in. (W 2.8) in diameter and hooked on one end and looped through a $\frac{1}{4}$ in. (25 mm) wide, 12-gage (2.68 mm) steel sheet bent over the wire (see Fig. 23). The steel sheet is dovetailed on the other end to fit into a minimum 22-gage (0.73 mm) dovetail slot in the concrete panel. The dovetail adjusts vertically so that the wire anchor can be placed in the bed joint of the brick.

It has been found that a 16-gage (1.52 mm) dovetail anchor slot fails at approximately the same load as a 26-gage (0.46 mm) thick slot embedded in concrete, so there is not much advantage to using heavier anchor slots to achieve increased load capacity. Instead, more anchors should be used to obtain the required load capacity.³

The minimum 3 in. (75 mm) wide wire anchors should be embedded at least $1\frac{1}{2}$ in. (38 mm) [preferably 2 in. (50 mm)] into the bed joint of the brick, with a minimum $\frac{1}{4}$ in. (16 mm) cover of mortar between the anchor and the exterior wall face. The size and spacing of anchors are based on tensile and compressive loads induced by wind suction and pressure on the walls.^{1,2,4,5}

Most designers use the simple force multiplied by the contributory area to determine anchor loads. When this technique is used, additional anchors should be provided at all openings and discontinuities, such as windows, shelf angles and con-

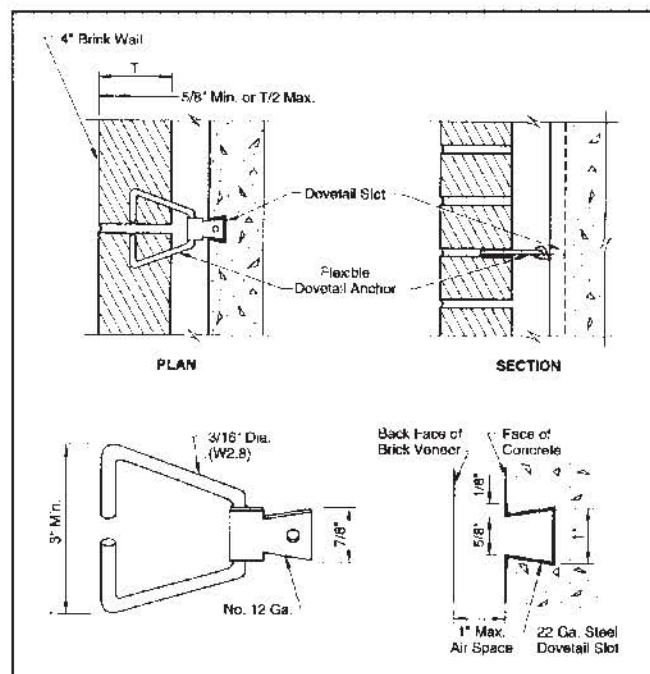


Fig. 23. Anchorage of brick to precast concrete using dovetail anchor and slot.



Fig. 24. The low-scaled, arched facade of Oriole Park at Camden Yards presents itself in the form of elaborate cornices and rustication joints. Brick anchored to dovetail slots in the precast concrete was field-laid on concrete ledges via scaffolding following precast concrete erection. Architect: Hellmuth, Obata and Kassabaum Sports Facilities Group, Kansas City, Missouri.

crete ledges, where stresses are known to be higher. They should be spaced not more than 3 ft (0.9 m) apart around the perimeter of an opening and within 12 in. (300 mm) of the opening.

ACI 530 recommends that there be one anchor per $4\frac{1}{2}$ sq ft (0.42 m²) of wall area.⁷ The maximum spacing between anchors should not exceed 24 in. (600 mm) vertically and 36 in. (900 mm) horizontally. Anchors in alternate courses should be staggered. Applicable building codes should be consulted for additional reinforcement requirements, such as those for resistance to seismic forces acting parallel to panels and for stack bond (which is weaker than running bond).

The published tests^{8,9} on dovetail anchor slots and dovetail anchors indicate an ultimate tension range of 713 to 965 lbs (323 to 438 kg) and ultimate compression with a 1 in. (25 mm) cavity of 560 lbs (254 kg) for a 12-gage (2.68 mm) dovetail anchor in a 22-gage (0.73 mm) dovetail slot (see Fig. 23). A safety factor of 3 based on failure mode should be applied to arrive at design values.

To avoid anchor buckling, the distance between the inside brick face and the concrete panel should not be greater than 1 in. (25 mm) nor less than $\frac{1}{8}$ in. (13 mm). This space should be kept free of mortar or other rigid material to permit the differential movement between the concrete panel and brick.

Brick- and split-face block supported on concrete ledges and attached to the precast concrete panels with dovetail anchors are shown in Figs. 24 and 25.

Shelf angles may be used to support the full brick veneer at each floor, or at least every other floor, in place of a concrete ledge (see Fig. 26). The shelf should be made of structural steel conforming to ASTM A36¹ and properly sized and anchored to carry the imposed loads. Anchor bolt holes should be horizontally slotted to allow for ease of construction and horizontal movement. For shelf angles supporting unrein-

forced masonry, deflection should be limited to $1/600$ but not exceed 0.3 in. (7.5 mm). A small space should be left between the lengths of angles to allow for horizontal thermal movements.

For severe climates and exposures, consideration should be given to the use of galvanized or stainless steel shelf angles. With shelf angles, continuous flashing should be installed to cover the angle. To ensure adequate resistance to corrosion, coatings or materials should conform to ASTM A123 or ASTM A167.² The suggested minimum level of corrosion protection for coatings of anchor material^{6,11,18} is either ASTM A153, Class B-2, or ASTM A167, Type 304.²

Horizontal pressure-relieving joints should be placed immediately beneath each angle. Pressure-relieving joints may be constructed by either leaving an air space or placing a highly compressible material under the shelf angle and sealing the joint with an elastic sealant and backer rods⁴ (see Fig. 27).

Flashing in a masonry wall supported on shelf angles is important for the proper drainage of water that may penetrate the masonry.⁵ Flashing is not required if the masonry is supported on a concrete ledge that has a slope of $\frac{1}{8}$ in. in 5 in. (3 mm in 125 mm), although weep holes are necessary. Flashing materials are generally formed from sheet metals, bituminous-coated membranes, plastics, vinyl or combinations thereof, the selection being largely deter-



Fig. 25. Panels for the Oakland County Jail Addition in Pontiac, Michigan, were delivered to the site complete with slots for dovetail anchors to support split face block. Architect: NSA-HDR — A Joint Venture, Southfield, Michigan.

mined by cost and suitability. The cost of flashing materials varies widely. Only superior quality materials should be selected, however, since replacement in the event of failure would be exceedingly expensive.

Flashing may be installed in a continuous reglet or recess in the concrete. To be most effective, the flashing should ex-



Fig. 26. The column covers on the City Crescent Federal Office Building, Baltimore, Maryland, have field-laid bricks that are supported on shelf angles welded to the precast concrete. Architect: The Weihe Partnership, Washington, D.C.

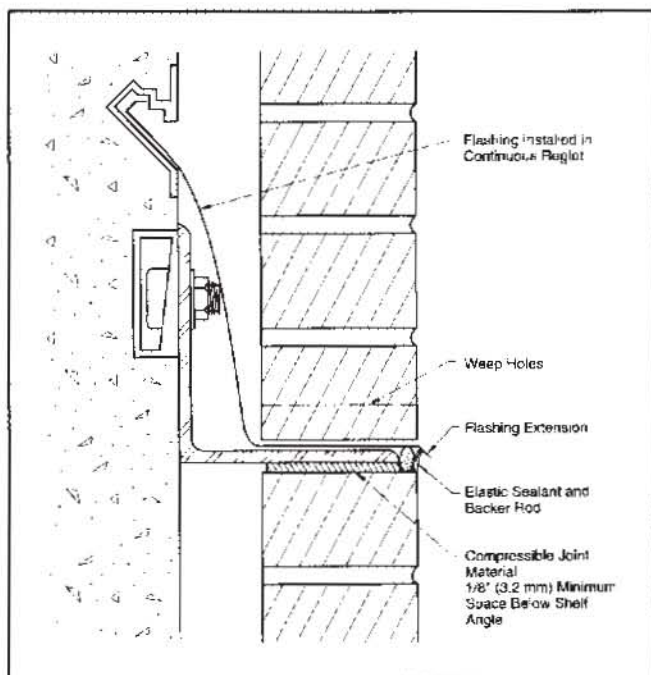


Fig. 27. Shelf angle with flashing and weep holes.

tend 1/8 in. (13 mm) beyond the wall surface and be turned down at a 45-degree angle to form a drip. Weep holes, at least 1/8 in. (6 mm) in diameter, should be provided in head joints immediately above the flashing or concrete ledge at intervals of 16 to 24 in. (400 to 600 mm) maximum to permit drainage of accumulated water.

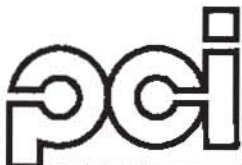
If, for aesthetic reasons, it is necessary to conceal the flashing, the number and spacing of weep holes are even more important. In these cases, the spacing should not exceed 16 in. (400 mm) on center. Concealed flashing with tooled mortar joints can retain water in the wall for long periods of time, thus concentrating the moisture at one spot.

WORK AS A TEAM

Clay product-faced precast concrete panels offer a flexible and economical way to achieve the desired appearance through prefabrication. The designer must develop a good working relationship with both the precaster and the clay product supplier so that all parties are aware of expectations and potential problems with, for example, returns, soldier courses, joints and window details. The contract documents should clearly define the scope of veneer patterns. When this occurs as it should, the result is a pleasing combination of aesthetic beauty and durability.

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