

# Stone Veneer-Faced Precast Concrete Panels



**Sidney Freedman**

Director Architectural Precast  
Concrete Services  
Precast/Prestressed Concrete Institute  
Chicago, Illinois

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*Stone veneer-faced precast concrete panels have been used successfully to clad buildings in North America for the past 40 years. Their popularity is due to the aesthetics, strength, durability, substantial benefits and low maintenance cost of such panels. However, their successful implementation requires careful planning, proper stone selection, and skillful workmanship in producing the panels. This article provides information on stone properties, design considerations, anchorage of stone facing, panel watertightness, veneer jointing, handling, storage and shipping of panels and repair of panels, if needed. A wide variety of building applications of stone veneer-faced precast panels are given. Throughout the article, it is emphasized that for optimum results, close coordination is needed between the architect, precaster and stone supplier.*

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**N**atural stone has been used widely in building construction for centuries due to its strength, durability, aesthetic effect, general availability, and inherent low maintenance costs. In the 1960s, the practice of facing skeleton-frame structures with large prefabricated concrete components to decrease construction time and reduce costs resulted in a combination of the rich beauty of natural stone veneer and the strength, versatility, and economy of precast concrete (see Fig. 1).

Stone veneer-faced precast concrete panels offer many benefits. These include:

1. Veneer stock can be used in thinner sections because anchoring points may be placed closer together.

2. Multiplane units such as column covers, spandrels with integral soffit and sill sections, deep reveal window frames, inside and outside corners, projections and setbacks, and parapet sections are more economically assembled as veneer units on precast concrete panels (see Fig. 2). Often, it is desirable to use one of the veneer materials in a traditional manner around the lower portion of a building and extend a similar finish with veneered precast concrete panels up the exterior walls.

3. A precast concrete backup system permits faster enclosure, allowing earlier work by other trades and subsequent earlier occupancy, because each of the larger panels incorporates a number of veneer pieces. 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. In general, panels span between columns, usually spaced 20 to 30 ft (6 to 9 m) on centers, although spandrel pieces have been made as large as 6 x 43 ft and 8 x 35 ft (1.8 x 13.1 m and 2.4 x 10.7 m). Typically, a single-story panel has been 13 to 30 ft (4.0 x 9.1 m) by story height.

4. Veneered precast concrete panels can be used to span column-to-column, thereby reducing floor-edge loading and eliminating elaborate temporary scaffolding.

### GENERAL CONSIDERATIONS

The purchaser of the stone should appoint a qualified individual to be responsible for coordination. This person should oversee delivery and scheduling responsibility and should ensure acceptable color uniformity. Color control or blending of the stone veneer should take place at the stone fabricator's plant, where ranges of color and shade, finishes, and markings such as veining, seams and intrusions are viewed most easily. The amount of color control and blending to which the stone lends itself varies depending upon the type of stone used on the project. Acceptable stone color should be judged for an entire building elevation rather than as individual panels.

The responsibility for coordination should be written into the specifications so its cost can be bid. The owner, architect, and precaster should visit the stone fabricator's plant to view the stone veneer and establish criteria and methods for color range blending on the project. With proper coordination and advance planning, fabrication and shipments of the stone veneer to the precaster will proceed smoothly. If communication is lacking, major problems in scheduling and delivery may occur.



Fig. 1. The Georgia Center, Atlanta, Georgia, a 29-story building, was completed in 1964 and has 27 in. (690 mm) deep single window box units, each with 16 pieces of 1 in. (25 mm) marble veneer. Architects: Bodin and Lamberson; and Eggers and Higgins.

All testing to determine the physical properties of the stone veneer with the same thickness and finish as will be used on the structure should be conducted by the owner prior to the award of the precast concrete contract. This

will reduce the need for potentially costly repairs or replacement should deficiencies in the stone veneer be found after the start of fabrication.

Because of the need for close coordination between the precast manufac-

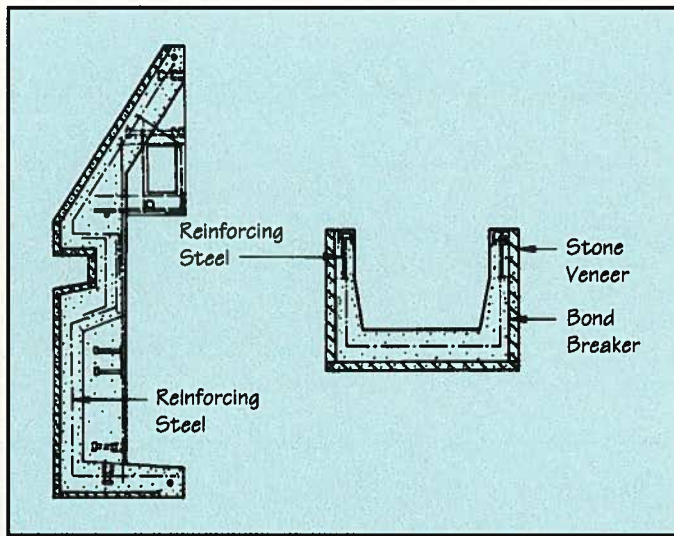


Fig. 2.  
Typical spandrel  
and column cover  
panels.

turer and stone veneer supplier, shop drawing preparation and submissions may vary from procedures established for non-veneered precast panels. Checking and approval of these details and shop drawings will be simplified and expedited if they can be combined and/or submitted simultaneously. Separate subcontracts and advance awards often occur in projects with stone-veneered panels. While these procedures may affect normal submission routines, it is not intended that responsibilities for accuracy be transferred, or reassigned. The precaster is responsible for precast concrete details and dimensions, while the stone-veneer fabricator is responsible for stone details, dimensions, and drilling of anchor holes.

The production of stone veneer panels requires adequate lead-time in order to avoid construction delays. Therefore, it is important that approvals for shop drawings be obtained expeditiously. Furthermore, it is recommended that the designer allow the submission of shop drawings in predetermined stages so production can begin as soon as possible and ensure there is a steady and timely flow of approved information to allow uninterrupted fabrication.

The precast concrete producer provides the stone quantity and sequence requirements to meet the erection sequences, which are determined by mutual agreement. For reasons of production efficiency, some concrete panels may be produced out of sequence relative to erection sequence.

The precaster and stone fabricator should coordinate packaging requirements to minimize handling and breakage. Extra stone (approximately 2 to 5 percent) should be supplied to the precaster to allow immediate replacement of damaged stone pieces, particularly if the stone is not supplied from a domestic source. The extra stone should be the largest sized pieces to be used on the project. Deliveries should be scheduled to correspond as closely as possible to actual fabrication schedules.

Samples and mock-up units are particularly important for evaluating stone finishes and acceptable color variations. Fig. 3 shows a mock-up

used to select colors of stone, windows, and caulk as well as judging overall building appearance. Mock-ups should be built to test wall, window and joint performance under the most severe wind and rain conditions. Acceptance criteria for the stone as well as the anchorage should be established in the project specifications.

## STONE PROPERTIES

Stone is a product of geologic evolution and, therefore, does not demonstrate the consistent behavior that may apply to manufactured building materials, such as concrete. The strength of natural stone depends on several factors: the size, rift and cleavage of crystals, the degree of cohesion, the interlocking geometry of crystals, the nature of natural cementing materials present and the type of crystal. The stone's properties will vary with the locality from which it is quarried. Therefore, it is important that current testing is performed on stone quarried for a specific project.

Sedimentary and metamorphic rocks, such as limestone and marble, will exhibit different strengths when measured parallel and perpendicular to their original bedding planes (anisotropic). Igneous rocks, such as granite, may or may not exhibit relatively uniform strength characteristics on the various planes (isotropic). In ad-

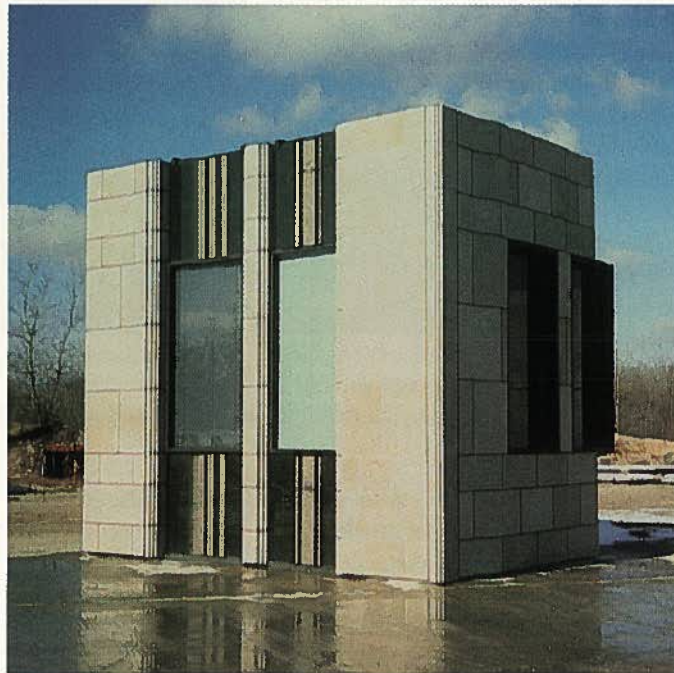


Fig. 3.  
Mock-up of  
Cityfront Center –  
NBC Building,  
Chicago, used to  
select colors of  
stone, windows  
and caulk as  
well as to judge  
overall building  
appearance.  
Architect:  
Skidmore, Owings  
& Merrill,  
Chicago, Illinois.

dition, the surface finish, freezing and thawing, and large temperature fluctuations may affect the strength and in turn influence the anchorage system.

To the degree possible, information on the durability of the specified stone should be obtained through current testing in conjunction with observations of existing installations of that particular stone. This information should include such factors as tendency to warp, reaction to weathering forces, resistance to chemical pollutants, resistance to chemical reaction from adjacent materials, and reduction in strength from the effects of weathering or wetting and drying.

Prior to awarding the precast concrete contract, tests should be performed to determine the physical properties of the stone being considered. The testing should be done on stone with the same finish and thickness to be used on the structure. Flexural tests (ASTM C880)<sup>1</sup> should be used to evaluate the physical properties and obtain the required design values. Absorption testing (ASTM C97)<sup>2</sup> may help evaluate freeze-thaw durability. These properties, along with the properties of the anchor system, should be used to ensure adequate strength of the panel to resist loads during handling, transportation, erection and in-service conditions.

The process used to obtain a thermal or flame finish on granite veneers reduces the effective thickness by about 1/8 in. (3 mm) and the physical strength to a measurable degree.<sup>3</sup> Bushhammered and other similar surface finishes also reduce the effective thickness. For 1 1/4 in. (3 cm) thick veneers, a reduction in thickness of 1/8 in. (3 mm) reduces the theoretical bending strength by about 20 percent and increases the elastic deflection under wind loads by about 37 percent.

Laboratory tests on 1 1/4 in. (3 cm) thick specimens of unaged thermally finished granite revealed that the effects of the thermal finish reduced the bending strength of the specimens by as much as 25 to 30 percent.<sup>4</sup> The loss of strength depends mainly on the physical properties of the stone forming minerals, on the coherence of the crystalline structure of the stone, and on the presence of micro and macro

Table 1. Permeability of commercial building stones,<sup>7</sup> cu in./sq ft/hr for 1/2 in. thickness.

Stone type	Water pressure, psi		
	1.2	50	100
Granite	0.06-0.08	0.11	0.28
Limestone	0.36-2.24	4.2-44.8	0.9-109
Marble	0.06-0.35	1.3-16.8	0.9-28.0
Sandstone	4.2-174.0	51.2	221
Slate	0.006-0.008	0.08-0.11	0.11

Note: 1 cu in./sq ft/hr/1/2 in. = 16.39 m<sup>3</sup>/hr/13 mm; 1 psi = 0.006895 MPa; 1 in. = 25.4 mm.

fractures in the stone.

Thermal or flame finishing of granite surfaces causes microfracturing, particularly of quartz and feldspars. These microcracks permit absorption of water to a depth of about 1/4 in. (6 mm) in the distressed surface region of the stone which can result in degradation by cyclic freezing and a further reduction in bending strength.

Weathering affects different stones in different ways. It can cause both a chemical decomposition and physical disintegration in some stones. The thinner the stone is sliced, the more susceptible it may be to weathering. Most natural stones lose strength as a result of aging [thermal cycling, e.g., heating to 170°F (77°C) and cooling to -10°F (-23°C), and wet/dry cycling].<sup>5</sup> The modulus of rupture of building stone can also be affected by freezing and thawing of the stone.

Flexural tests (ASTM C880) should be conducted on the selected stone, at the thickness and surface finish to be used, in both the new condition and the condition after 100 cycles of laboratory accelerated aging (weathering) tests to determine the reduction in strength, if any. Suggested weathering test procedures include (1) cycling between 170°F and -10°F (77°C and -23°C), while the face of the stone is submerged in a 4 pH sulfurous acid solution that simulates chemical weathering.<sup>6</sup> For warm climates, the test procedure can be modified to cycle between 41°F and 170°F (5°C and 77°C). Also, in areas where the pH of rainfall is above 6, the acid solution can be eliminated.

Absorption testing (ASTM C97), as mentioned, helps evaluate freeze-thaw durability of the stone.

Stones which have a satisfactory performance record in thicknesses, sizes and climates similar to those envisioned for a project may at the option of the designer be exempted from the above testing requirements.

For most types of stone, temperature induced movements are theoretically reversible. However, certain stones, particularly marble, when subjected to a large number of thermal cycles, develop an irreversible expansion in the material amounting to as much as 20 percent of the total original thermal expansion. This residual growth is caused by breaking of crystal bonds.<sup>7,8,9</sup> Such growth, if not considered in the stone size, may result in curling or bowing of thin marble. For relatively thick marble veneers, the expansion effects are restrained or accommodated by the unaffected portion of the veneer. Tests should be performed to establish the minimum thickness required to obtain satisfactory serviceability. Stone can be exposed to differential accelerated heating and cooling cycles and measured for deformation (bowing/hysteresis).

Volume changes due to moisture changes should be considered in design, especially for joint size. Moisture permeability of stone veneers is generally not a problem (see Table 1).<sup>7</sup> However, as stone veneers become thinner, water may penetrate in greater amounts and at faster rates than normally expected, and damp appearing

areas of moisture on the exterior surface of thin stone veneers will frequently occur. These damp areas result when the rate of evaporation of water from the stone surface is slower than the rate at which the water moves to the surface.

## STONE SIZES

Stone veneers used for precast facing are usually thinner than those used for conventionally set stone with the maximum size generally determined by the stone strength. Table 2 summarizes typical dimensions. Veneers thinner than those listed can result in anchors being reflected on the exposed surface, excessive breakage or permeability problems.

The length and width of veneer materials should be sized to a tolerance of +0, -1/8 in. (+0, -3 mm) since a plus tolerance can present problems on precast concrete panels. This tolerance becomes important when trying to line up the false joints on one panel with those on the panel above or below, particularly when there are a large number of pieces of stone on each panel. Tolerance allowance for out-of-square is ±1/16 in. (±1.6 mm) difference in length of the two diagonal measurements.

Flatness tolerances for finished surfaces depend on the type of stone and finish. For example, the granite industry's flatness tolerances vary from 1/16 in. (1.6 mm) for a polished surface to 3/16 in. (4.8 mm) for flame (thermal) finish when measured with a 4 ft (1.2 m) straightedge.<sup>10</sup> Tolerances should be clearly specified in the contract documents.

Thickness variations are less important, since concrete will provide a uniform back face except at corner butt joints. In such cases, the finished edges should be within ±1/16 in. (±1.6 mm) of the specified thickness. However, large thickness variations may lead to the stone being encased with concrete and thus restrict the relative movement of the materials. The aesthetic problems that occur with tolerances concern the variation from a flat surface on an exposed face and stone pieces being out-of-square.

## DESIGN CONSIDERATIONS

Structural design, fabrication, handling and erection considerations for veneered precast concrete units are similar to those for other precast concrete wall panels, except that special consideration must be given to the veneer material and its attachment to the concrete (see Appendix for typical production practices). The physical properties of the stone facing material must be compared with the properties of the concrete backup.

These properties include:

1. Tensile (axial and flexural), compressive and shear strength
2. Modulus of elasticity (axial tension, flexure, and axial compression)
3. Coefficient of thermal expansion
4. Volume change

Because of the differences in material properties between natural stone and concrete, veneered panels are more susceptible to bowing than homogeneous concrete units; also, the flat surfaces of cut stone reveal bowing more prominently than homogeneous concrete panels. However, pre-

casters have developed design and production procedures to minimize bowing. The following paragraphs explain how this may be accomplished.

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

1. Temperature differential (exterior to interior)
2. Coefficients of thermal expansion of materials
3. Ratio of cross-sectional areas of the materials and their moduli of elasticity (axial tension, flexure, and axial compression)
4. Amount, location and type of reinforcement in concrete panel
5. Use of prestressing
6. Type and location of connections to structure
7. Rigidity of connection between stone veneer and concrete backup (too rigid may cause problems)
8. Shrinkage of the concrete

Panel design must also 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 the exterior surfaces may be exposed to a large daily or seasonal range. The temperature differential is tempered by "thermal lag" due to the mass of the veneer and the concrete.

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's 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 a 4 in. (100 mm) thickness can be used where the panel is small or where it has adequate rigidity obtained through panel shape or thickness of natural stone. If the panel's thickness is sufficient, usually 6 in. (150 mm) or

Table 2. Dimensional parameters of various stone materials.

Stone type	Minimum recommended thickness in. (cm)	Length range ft (m)	Width range ft (m)	Maximum area sq ft (m <sup>2</sup> )
Marble	1.25 (3)	3-5 (0.9-1.5)	2-5 (0.6-1.5)	20 (1.9)
Travertine*	1.25 (3)	2-5 (0.6-1.5)	1-4 (0.3-1.2)	16 (1.5)
Granite	1.25 (3)	3-7 (0.9-2.1)	1-5 (0.3-1.5)	30 (2.8)
Limestone	1.75 (4.5) <sup>†</sup>	4-5 (1.2-1.5)	2-4 (0.6-1.2)	15 (1.4)

\*Surface voids filled front and back.

<sup>†</sup>Indiana Limestone Institute recommends 2 in. (5 cm).

more, two layers of reinforcement should be used, as this helps to reduce bowing caused by differential shrinkage or temperature changes. Volume changes due to moisture changes in most stones are relatively small and are usually not a critical item in design, except that bowing of the stone can occur.

Reinforcement of the precast concrete backup should follow recommendations for precast concrete wall panels relative to design, cover and placement.<sup>11</sup> Cover depth of uncoated reinforcement must be a minimum of 1½ in. (28 mm) to the back of the veneered surface. Galvanized or epoxy-coated reinforcement is recommended at cover depths of ¾ in. (19 mm).

Prestressing of panels has been effective in controlling bowing of long, flat, relatively thin panels.<sup>12</sup> Such panels are generally more susceptible to bowing. As with any multi-layer panel, trial runs may be necessary to verify analysis as to the best prestressing strand location in order to avoid an increase in bowing.

Unrestrained bowing of a panel induces no stresses. If the bowing is restrained 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. Midpoint tie back connections can help minimize convex bowing.

After initial set, concrete begins to shrink as it loses excess water to the surrounding environment. The stone veneer, especially with an impermeable bondbreaker, limits drying on the veneered side of the backup concrete. The resulting differential shrinkage of the concrete and stone veneer can cause outward bowing in a simple span panel. While homogeneous concrete panels usually bow in response to thermal gradients through the panel thickness, stone veneered concrete may also bow when the temperature is uniform through the panel thickness. This bowing is caused by differences in the coefficients of expansion of the stone and concrete.

Limestone has an average coeffi-

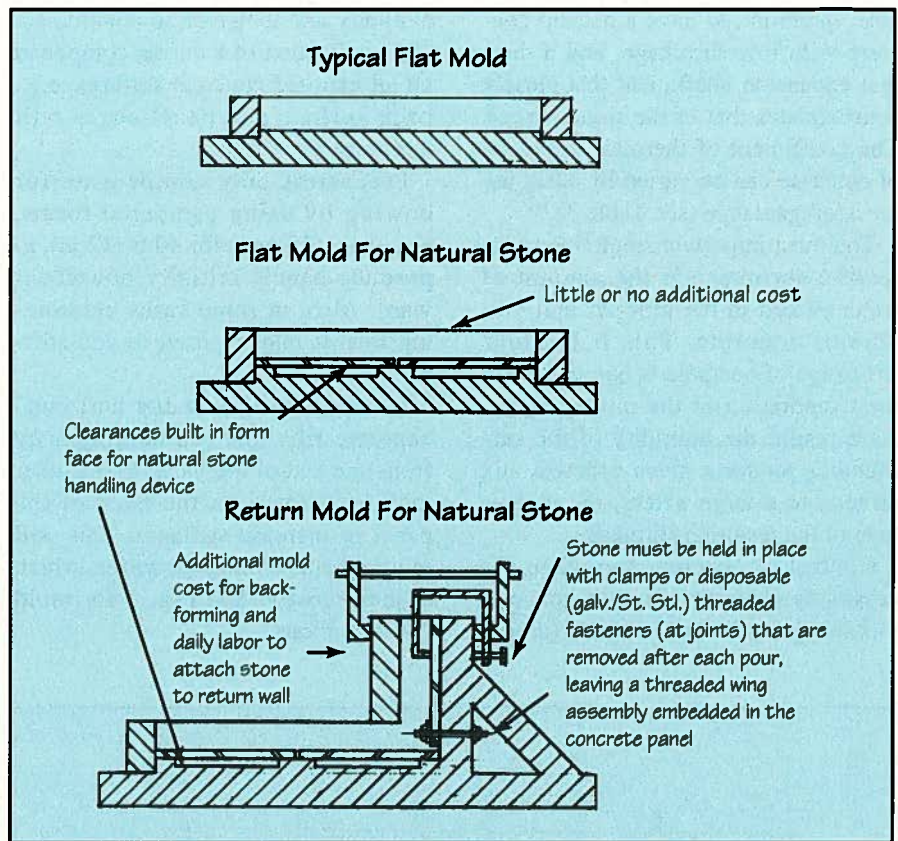


Fig. 4. Mold types showing degree of complexity.

cient of expansion of  $2.8 \times 10^{-6}$  in./in./°F ( $5.0 \times 10^{-6}$  mm/mm/°C), while granite has  $4.5 \times 10^{-6}$  ( $8.1 \times 10^{-6}$ ) and marble  $7.3 \times 10^{-6}$  ( $13.1 \times 10^{-6}$ ). Coefficients of  $6 \times 10^{-6}$  in./in./°F ( $10.8 \times 10^{-6}$  mm/mm/°C) for normal weight and  $5 \times 10^{-6}$  ( $9.0 \times 10^{-6}$ ) for sand-

lightweight concrete are frequently used.

As individual stone pieces become larger or thinner, the coefficient of expansion differentials become more important because the stone has less rigidity to resist bowing. It is desir-

Table 3. Coefficients of linear thermal expansion of aggregate and concrete.<sup>11</sup>

Type of rock (aggregate)	Average coefficient of thermal expansion $\times 10^{-6}$ in./in./°F	
	Aggregate	Concrete *
Quartzite, cherts	6.1-7.0	6.6-7.1
Sandstones	5.6-6.7	5.6-6.5
Quartz sands and gravels	5.5-7.1	6.0-8.7
Granites and gneisses	3.2-5.3	3.8-5.3
Syenites,		
Diorites, andesite	3.0-4.5	4.4-5.3
Gabbros, diabase, basalt		
Limestones	2.0-3.6	3.4-5.1
Marbles	2.2-3.9	2.3
Dolomites	3.9-5.5	----
Expanded shale,		
Clay and slate	----	3.6-4.3
Expanded slag	----	3.9-6.2
Blast-furnace slag	----	5.1-5.9

\*Coefficients for concretes made with aggregates from different sources vary from these values, especially those for gravels, granites, and limestones. Fine aggregates generally are the same material as coarse aggregates.

able, therefore, to have a backup concrete with low shrinkage, and a thermal expansion coefficient that closely approximates that of the stone veneer. The coefficient of thermal expansion of concrete can be varied by changing the aggregate type (see Table 3).<sup>11</sup>

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.

Control of concrete shrinkage necessitates close attention to concrete mix design, and curing regime (proper

humidity and temperature conditions). The application of a curing compound on all exposed concrete surfaces, e.g., back surface and panel edges will minimize shrinkage.

Precasters may compensate for bowing by using cambered forms, e.g., 1 in. (25 mm) for 40 ft (12 m), to produce 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. See Fig. 4 for mold considerations.

## ANCHORAGE OF STONE FACING

The responsibility for determining the type of anchorage between the stone and concrete backup varies on different projects. The stone fabricator or precaster appear to have the dominant responsibility for conducting the anchor tests. The architect or engineer of record will occasionally determine the type of anchorage. However, it is preferable for the architect to determine anchor spacing so that consistent information can be supplied to all bidders (refer to ASTM C1242).<sup>13</sup>

Contract documents should define clearly who drills the anchor holes in the stone; type, number and location of anchors; and who supplies the anchors. In most cases, the stone fabricator drills the anchor holes in the stone according to architectural specifications and drawings using a diamond-core bit with a non-percussive tool.

It is recommended that the precast manufacturer detail all precast units to the point where the fabricator of the veneer is able to incorporate details, sizes and anchor holes for the individual stone pieces.

It is also recommended that there be no bonding between the stone veneer and concrete backup in order to minimize bowing, cracking, or staining of the veneer. Even with concrete shrinkage kept to the lowest possible level, there may still be some interaction with the facing material either through bond or mechanical anchors of the stone veneer. This interaction is minimized by the use of a bondbreaker between the facing material and the concrete. Connections of natural stone to the concrete should be made with flexible mechanical anchors which can accommodate some relative in-plane movement.

Two methods may be used to prevent bond between the veneer and concrete to allow for independent movement:

1. A 6 to 10 mil. polyethylene sheet.
2. A closed cell  $\frac{1}{8}$  to  $\frac{1}{4}$  in. (3 to 6 mm) polyethylene foam pad. Using a compressible foam pad bondbreaker is preferred because it allows for movement of stones with uneven surfaces, either on individual pieces or between

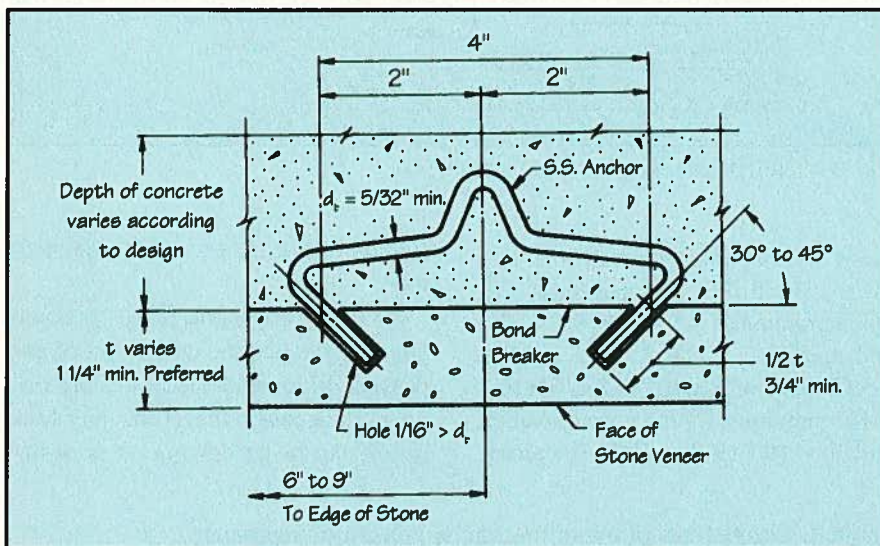


Fig. 5. Typical anchor for marble veneer.

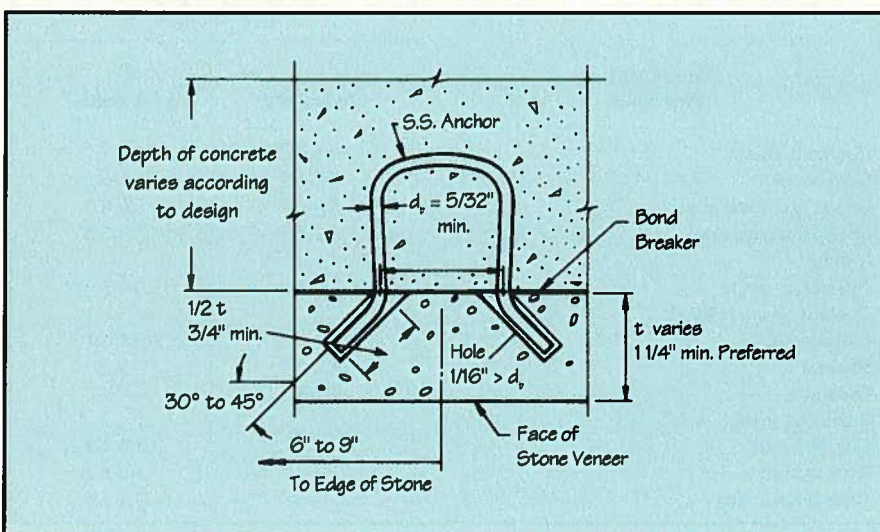


Fig. 6. Typical anchor for granite veneer.

stone pieces on a panel.

Preformed anchors, usually  $\frac{1}{8}$  to  $\frac{5}{8}$  in. (3 to 16 mm) in diameter, fabricated from Type 304 stainless steel, are supplied by the stone fabricator or, in some cases, by the precaster depending on the contract document requirements. The number and location of anchors should be determined by a minimum of five shear and tension tests conducted on a single anchor embedded in a stone/precast concrete test sample using ASTM E488<sup>14</sup> or ASTM C1354<sup>15</sup> and the anticipated applied loads, both normal and transverse to the panel. Care should be taken in grasping the anchor to assure direct tension.<sup>16,17</sup> Anchor size and spacing in veneers of questionable strengths or with natural planes of weakness may require special analysis.

Four anchors usually are used per stone piece with a minimum of two recommended. The number of anchors has varied from 1 per  $1\frac{1}{2}$  sq ft (1 per  $0.1\text{ m}^2$ ) of stone to 1 per 6 sq ft (1 per  $0.6\text{ m}^2$ ) with 1 per 2 to 3 sq ft (1 per  $0.2$  to  $0.3\text{ m}^2$ ) being the most common.<sup>12</sup> Anchors should be 6 to 9 in. (152 to 229 mm) from an edge with not more than 24 to 30 in. (610 to 760 mm) between anchors depending on the local building code. The shear capacity of the spring slip (hairpin) anchors perpendicular to the anchor legs is greater than when they are parallel (see Table 4) and capacity depends on the strength of the stone.

A typical marble veneer anchor detail with a toe-in spring clip (hairpin) anchor is shown in Fig. 5, while a typical granite veneer anchor detail is shown in Fig. 6. The toe-out anchor in granite may have as much as 50 percent more tensile capacity than a toe-in anchor depending on the stone strength. The stone anchorages on most precast panels are conservatively designed with significant redundancy and excess capacity.

The depth of anchor holes should be approximately one-half the thickness of the veneer [minimum depth of  $\frac{3}{4}$  in. (19 mm)]. Minimum concrete cover over the drilled hole should be  $\frac{3}{8}$  in. (9.5 mm) to avoid spalling during drilling and spotting from absorbed moisture. The holes should be drilled at an angle of 30 to 45 deg. to

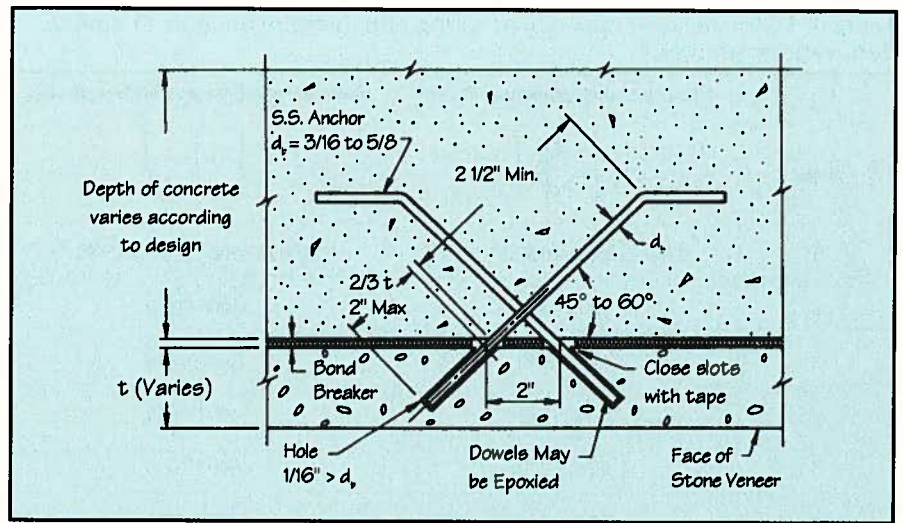


Fig. 7. Typical cross anchor dowels for stone veneer.

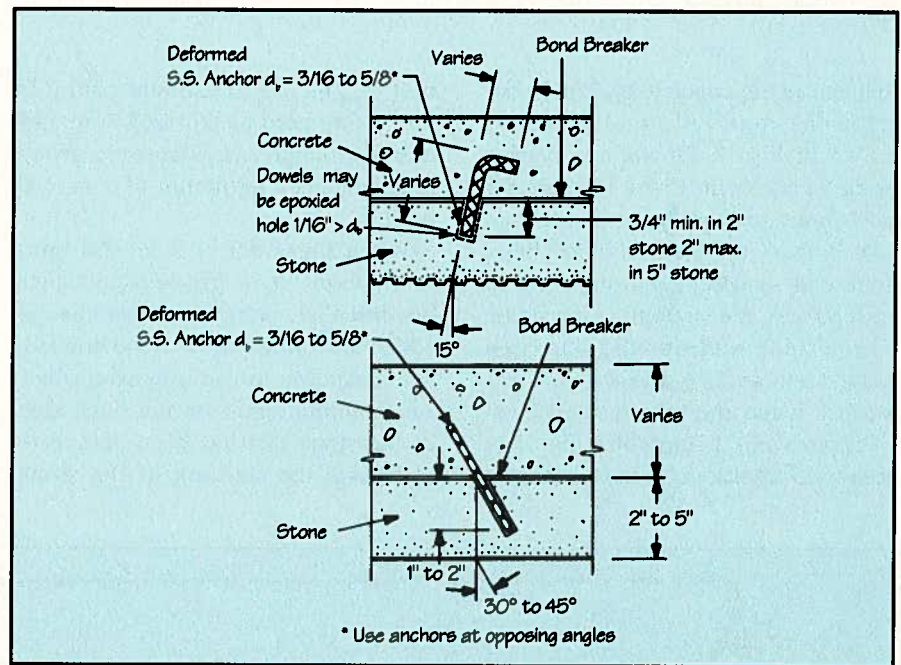


Fig. 8. Typical anchors for limestone veneer.

the plane of the stone. Holes, approximately 50 percent oversize, have been used to allow for differential movement between the stone and the concrete. However, holes  $\frac{1}{16}$  in. (2 mm) larger than the anchor are common, as excessive looseness reduces holding power. Anchor holes should be within  $\pm\frac{3}{16}$  in. (5 mm) of the specified hole spacing, particularly for the spring clip anchors.

Stainless steel dowels, smooth or threaded, may be installed to a depth of two thirds of the stone thickness, with a maximum depth of 2 in. (50 mm) at 45 to 60-deg. angles to the plane of the stone. The minimum em-

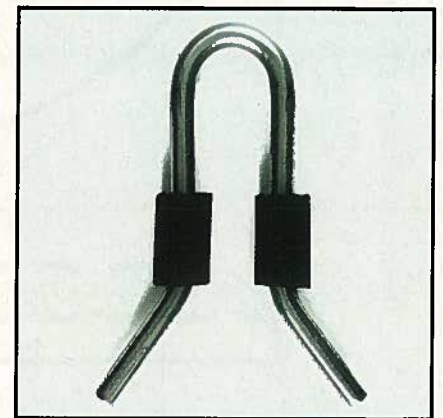




Fig. 9. Example of a compressible sleeve used to reduce stone anchor rigidity when the anchors are epoxied in the stone.



Table 4. Ultimate shear capacity of spring clip (hairpin) anchors in granite from various sources.\*

Stone	Shear parallel to anchor, lb (kg)	Shear perpendicular to anchor, lb (kg)
		
1	2400 to 2650 (1090 to 1200)	3200 to 3500 (1450 to 1590)
2	1800 (815)	2500 (1135)
3	1500 (680)	1500 (680)
4	2500 (1135)	3400 (1540)
5	2800 (1270)	4000 (1815)
6	3400 (1540)	4200 (1905)
7	1000 (455)	1660 (725)

\*Need to apply safety factor.

bedment in the concrete backup to develop the required bond length is shown in Fig. 7. Dowel size varies from  $\frac{3}{16}$  to  $\frac{5}{8}$  in. (5 to 16 mm) for most stones, except that it varies from  $\frac{1}{4}$  to  $\frac{5}{8}$  in. (6 to 16 mm) for soft limestone and sandstone and depends on the thickness and strength of the stone.

Limestone traditionally has been bonded and anchored to the concrete because it has the lowest coefficient of expansion. Limestone also has been used traditionally in thicknesses

of 3 to 5 in. (75 to 125 mm), but it is now being used as thin as  $1\frac{3}{4}$  in. (44 mm), although one limestone group recommends a minimum of 2 in. (50 mm).<sup>18</sup>

When limestone is 2 in. (50 mm) or thinner, it is prudent to use a bondbreaker, along with mechanical anchors. If limestone is to be bonded, it is desirable to use a moisture barrier/bonding agent on the back side of the stone that has been proven to eliminate the staining of the stone

veneer from the alkali salts in the concrete.

Moisture barrier/bonding agent materials include portland cement containing less than 0.03 percent water soluble alkalis; waterproof cementitious stone backing; non-staining asphaltic or bituminous dampproofing; or an epoxy bonding agent that cures in the presence of moisture. Dowels and spring clip anchors can be used to anchor limestone. Typical dowel details for limestone veneers are shown in Figs. 7 and 8. The dowels in Fig. 8 should be inserted at opposing angles to secure stone facing to backup concrete.

Some flexibility should be introduced with all anchors by minimizing the anchor's diameter to allow for the inevitable relative movements that occur with temperature variations and concrete shrinkage. Unaccommodated relative movements can result in excessive stresses and eventual failure at an anchor location. Depending on the size of the project, consideration may be given to accelerated cyclic temperature tests on the stone-concrete assembly to determine the effect of strength loss on the shear and tensile strengths of the anchors.

Some designers use two-part polyester or epoxy to fill the anchor

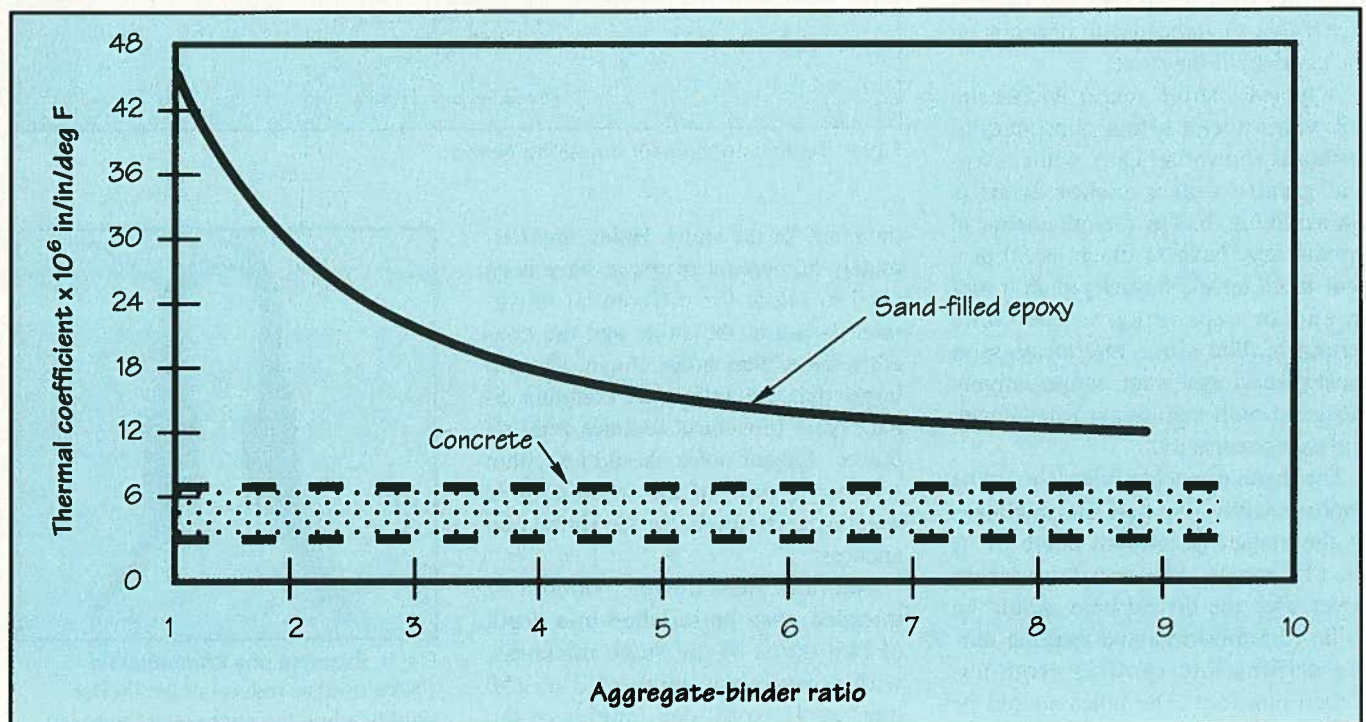


Fig. 10. Effect of changes in the sand aggregate binder ratio on the thermal coefficient of an epoxy.

holes in order to eliminate intrusion of water into the holes and to prevent the possible dark, damp appearance of moisture on the exposed stone surface. The polyester or epoxy increases the shear capacity and rigidity of the anchors. This rigidity may be partially

overcome by using 1/2 in. (13 mm) long compressible (60 durometer) rubber or elastomeric grommets or sleeves on the anchor at the back surface of the stone, as shown in Fig. 9.

Differential thermal expansion of the stone and unfilled epoxy may cause

cracking of the stone veneer. Epoxies yield under stress, and, if properly formulated, they will accommodate relatively large dimensional changes resulting from thermal effects. It is necessary to closely match the coefficients of expansion of the stone and

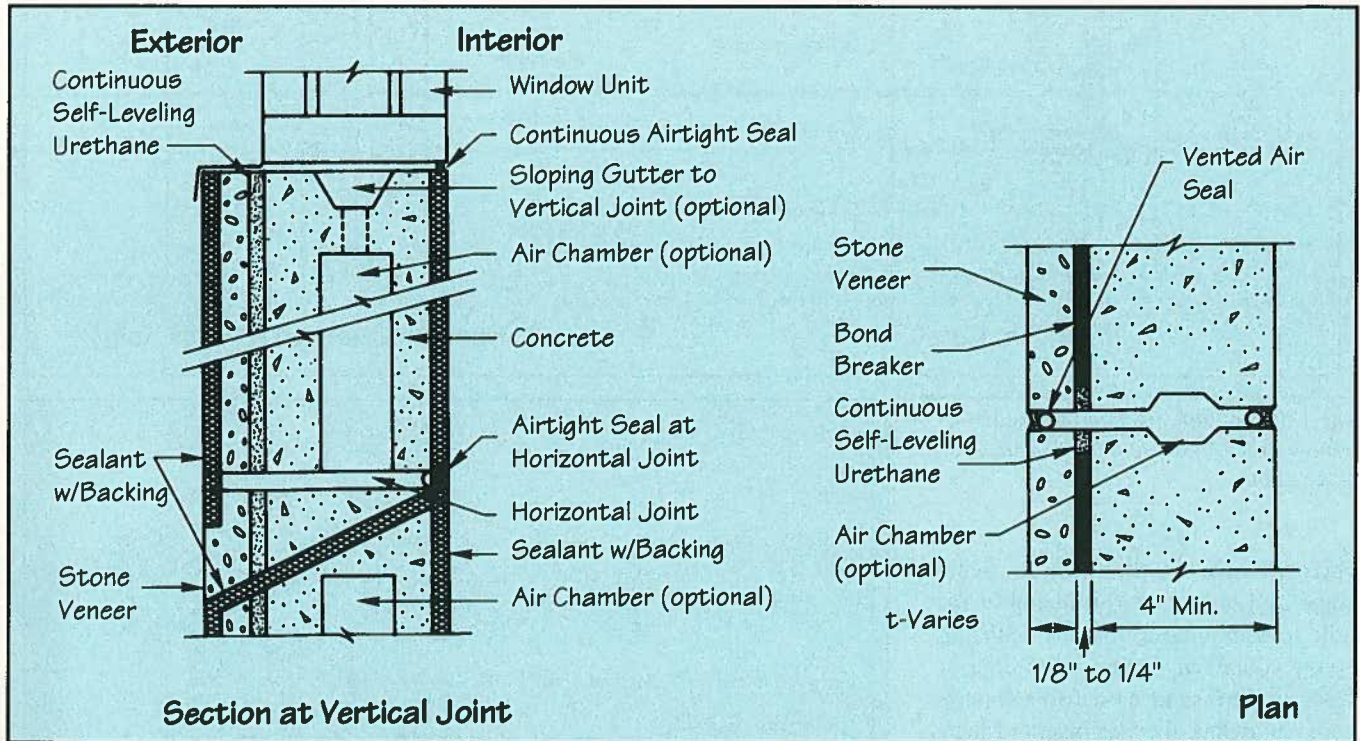


Fig. 11. Stone veneer precast concrete panel with modified joint.

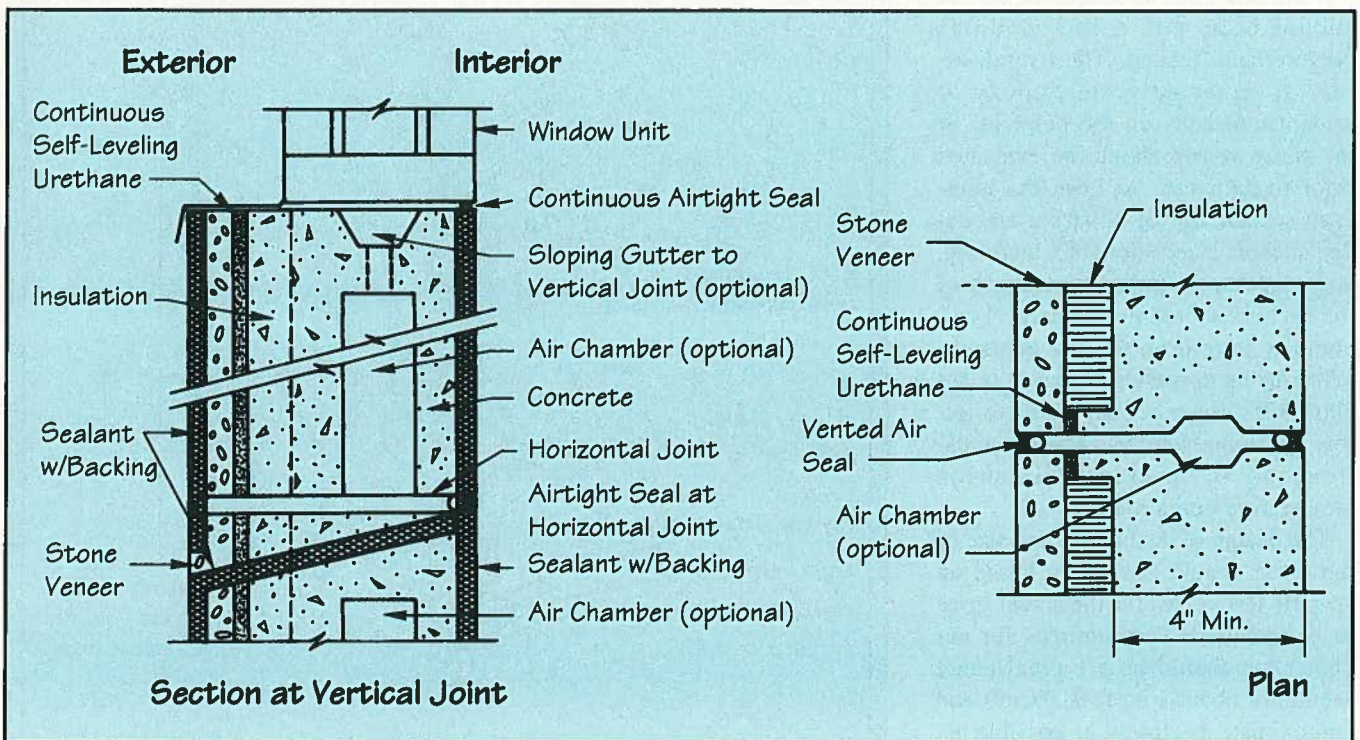


Fig. 12. Insulated sandwich-veneer precast concrete panel with modified joint.

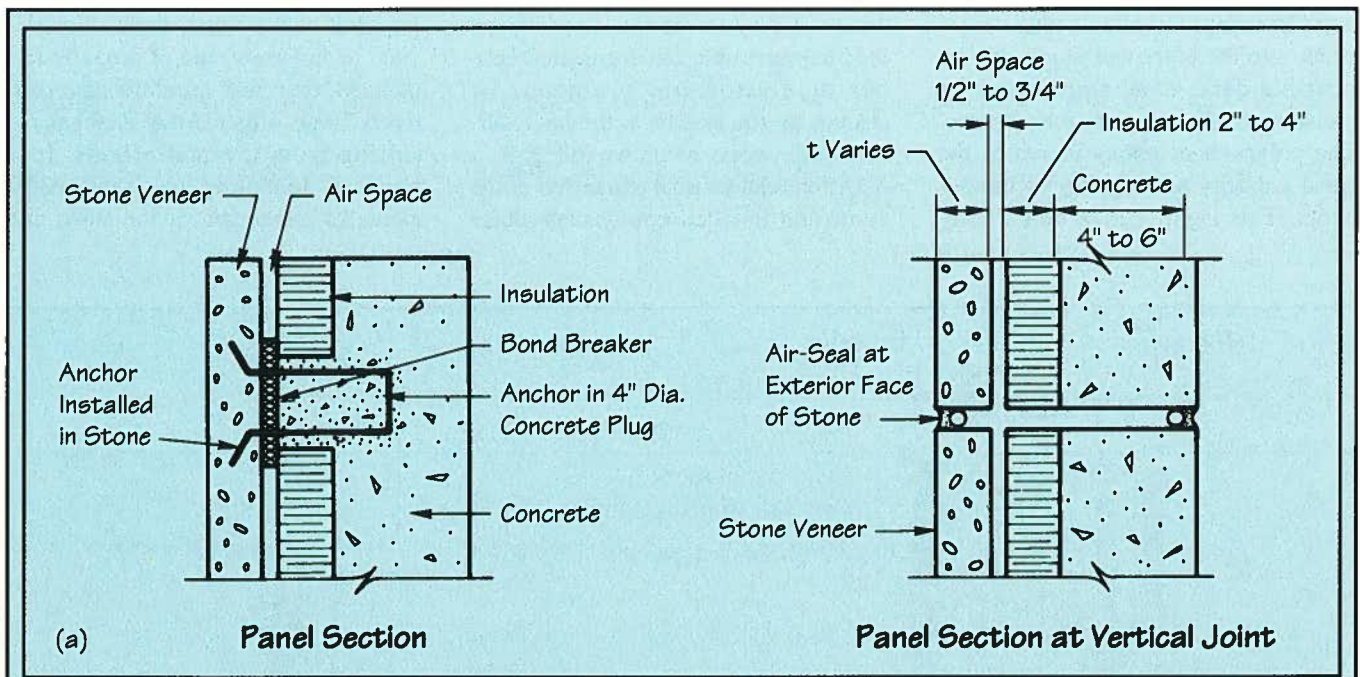
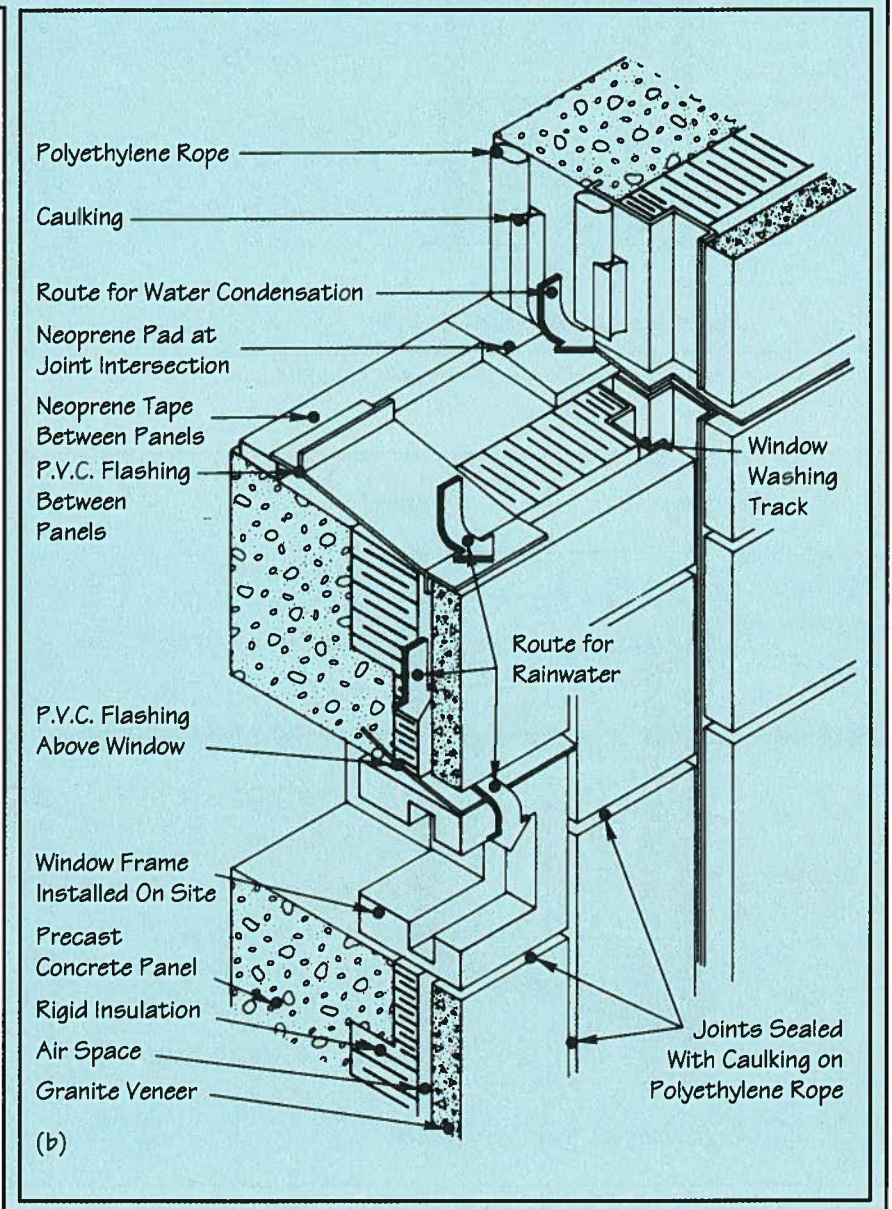


Fig. 13(a) and (b). Insulated sandwich-veneer precast concrete panel with two-stage joint.

epoxy. However, this may be overcome by keeping the oversizing of the hole to a minimum, thereby reducing epoxy volume and using stone flour or fines or fine sand as a filler for the epoxy to reduce the coefficient of thermal expansion of the epoxy and the shrinkage (see Fig. 10).<sup>19</sup>

It may be more desirable to fill the anchor hole with a low modulus polyurethane sealant. The overall effect of either polyester, epoxy or sealant materials on the behavior of the entire veneer should be evaluated prior to their use. At best, the long-term service life of adhesive-embedded anchors is questionable; therefore, any increase in pull-out strength of the anchors should not be used in calculating long-term anchor capacity. When using polyester or epoxy in anchor holes, the precaster needs to follow the manufacturer's recommendations as to mixing and curing temperature limitations.

The design of anchorage and size of the stone should always be based on specific test values for the actual stone to be installed. Test samples for anchor tests should be a typical panel section of about 1 sq ft (0.09 m<sup>2</sup>) and approximate as closely as possible actual panel anchoring conditions. A



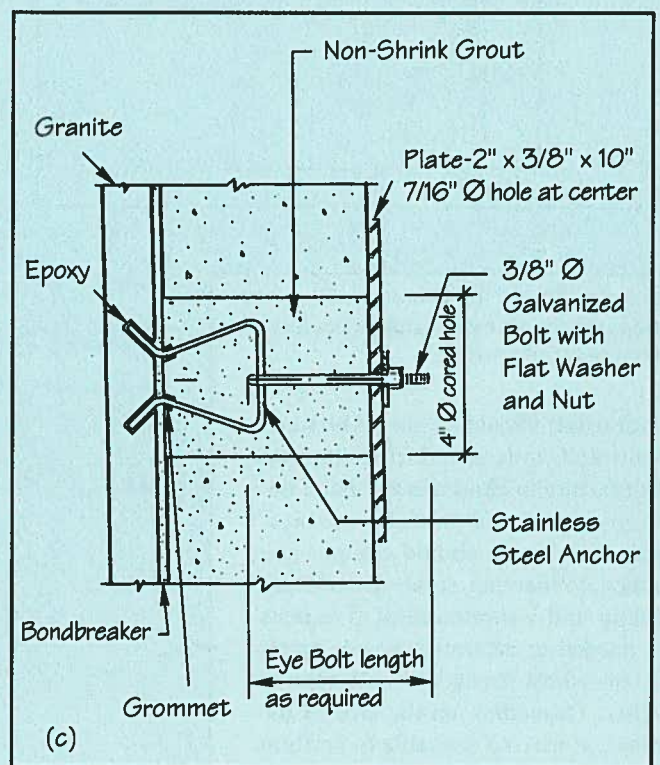
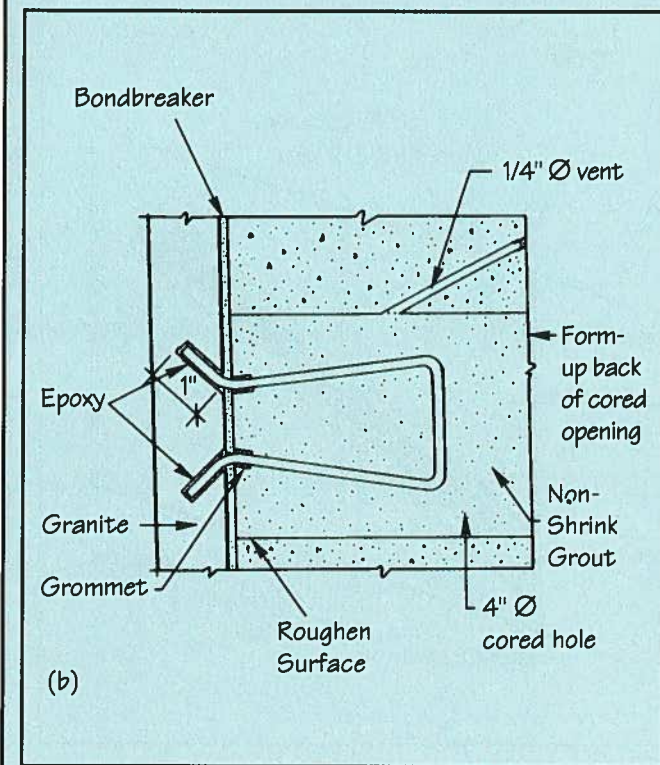
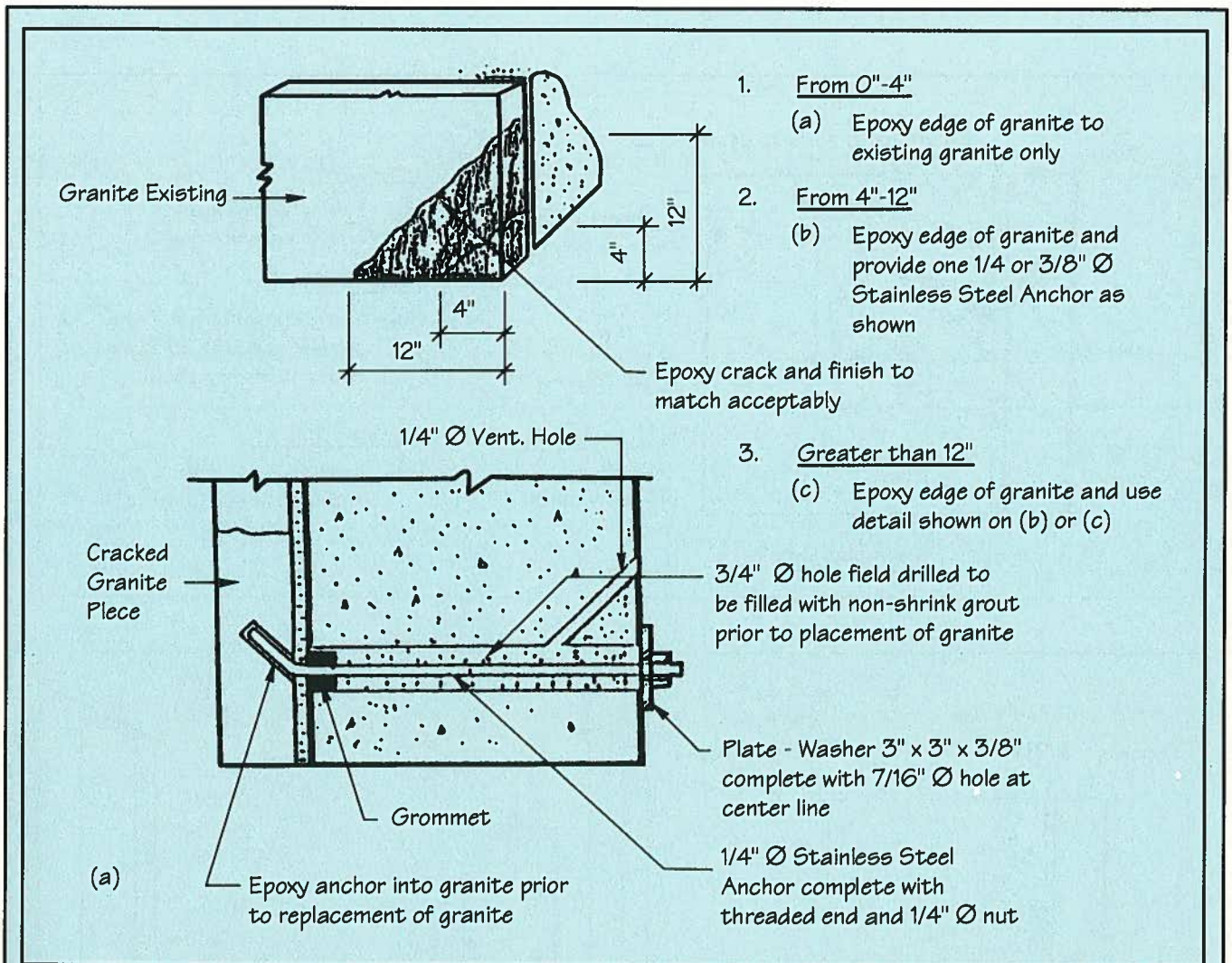
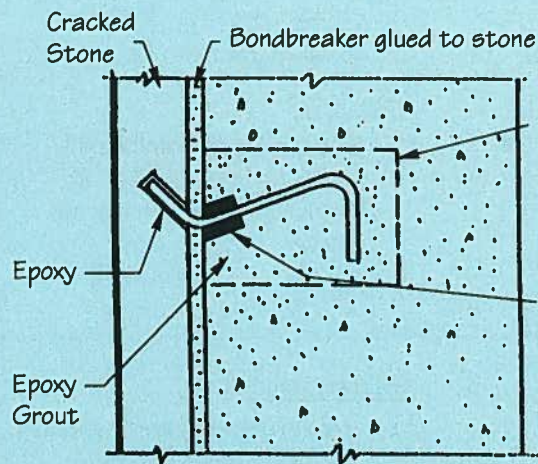


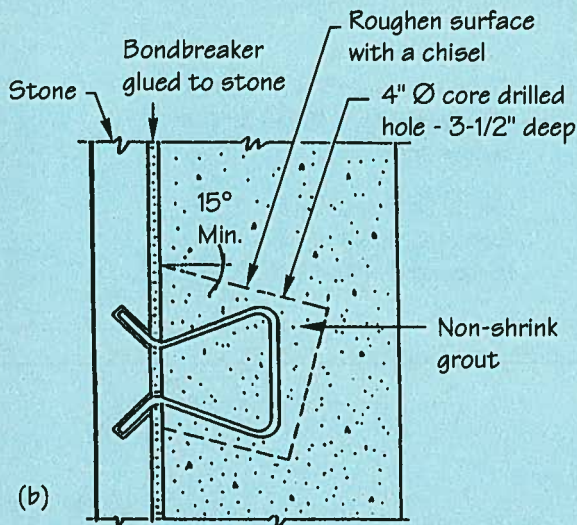
Fig. 14(a), (b) and (c). Granite slab repairs where access to back of precast concrete is possible.



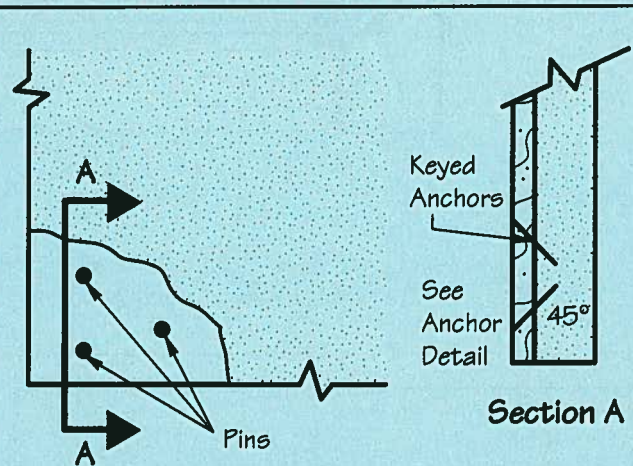
(a) Broken Granite Slab Repairs

1. From 0"-4"  
(a) Epoxy edge of granite to existing granite only
2. From 4"-12"  
(b) Epoxy edge of granite and provide one 3/16" Ø Stainless Steel Anchor as shown
3. Greater than 12"  
(c) Epoxy edge of granite and use detail shown on (b) or (c)

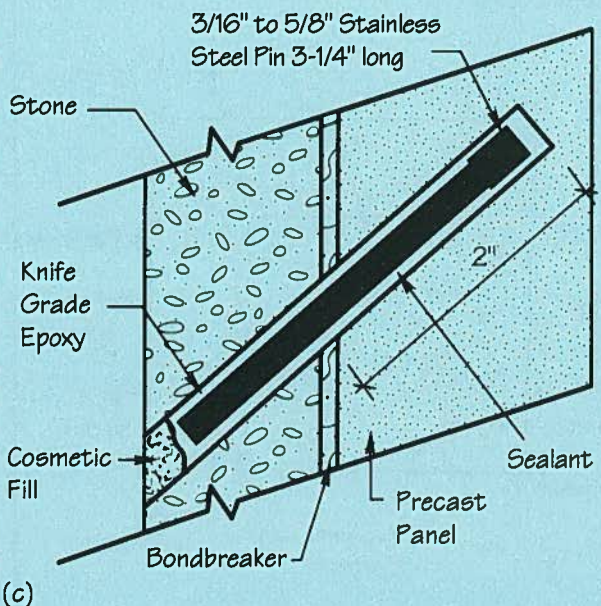
Note: Epoxy edge of stone and finish to match



(b)



Section A



(c)

Fig. 15(a), (b) and (c). Granite slab repairs where access to back of precast concrete is not possible.

bondbreaker should be placed between stone and concrete during sample manufacture to eliminate any bond between veneer and concrete surface. Each test sample should contain one anchor connecting stone to concrete backup and a minimum of five tests are needed to determine tensile (pull-out) and shear strength of each type of anchor. Depending on the size of the project, it may be desirable to perform shear and tensile tests of the anchors at intervals during the fabrication period.

The stone trade associations and the suppliers of different kinds of building stones recommend safety factors. Because of the expected variation in the physical properties of natural stone and to account for the risks of brittle failure and for possible weathering effects, recommended safety factors are greater than those used for manufactured building materials, such as steel and concrete.<sup>20</sup> The minimum recommended safety factor, based on the average of the test results, is 4 for anchorage components. If the range of test values exceeds the average by more than  $\pm 20$  percent, then the safety factor should be applied to the lower bound value (see the Appendix to ASTM C1242 for a discussion on safety factors).<sup>13</sup>

Finite element analysis may be a useful technique for evaluating stress in a veneer panel system.<sup>17,21</sup> This necessitates testing to determine the spring constant values for the panel's material components to model the assembly. Stone veneer should be tested in flexure (ASTM C1352)<sup>22</sup> and the section properties and modulus of elasticity should be determined. For some stones, the modulus of elasticity varies with stress levels. Granite rift (bedding planes), direction and grain size influence modulus of elasticity. Shear and tensile tests are required for the anchors.

The spring constant of a compressible bondbreaker should be determined. For insulation, compressive-spring and shear-spring constants should be determined if no bondbreaker is used. The 4 in. (100 mm) diameter concrete plugs encasing the anchors (see Fig. 9) when an air space is used, should be treated as a short circular beam. The circular beam and concrete backup can have their properties determined by calculation for use in modeling.

### PANEL WATERTIGHTNESS

The bondbreaker between the stone veneer and concrete backup may function as a vapor barrier on the concrete's exterior face, keeping moisture in the veneer or at the interface unless drainage provisions are provided. After some period of time, gaps also may develop between the stone

veneer and the concrete backup at the bondbreaker. These gaps could allow moisture penetration due to capillary action and gravity, particularly where the window or roof design allows water to puddle on top of the panel.

One method that has been used to solve this problem is a modified rain-screen joint (two-stage joint) as shown in Fig. 11. This approach provides an air-tight 1 in. (25 mm) wide urethane seal, bonded to the stone veneer and concrete backup, and continuous along both sides and top of the panel. Other designers have used a sealant applied to the top and side edges of the stone/concrete interface after the panels are cast. Care must be taken to ensure that the sealant used is compatible with the sealant to be applied to panel joints after erection of the panels.

The bondbreaker should not be sealed at the bottom of the panel. This ensures any moisture that somehow penetrates behind the stone veneer, can drain freely. In the case of long panels, a sloping gutter is sometimes used not only under the window but also at every horizontal joint.

Fig. 12 shows an insulated sandwich-veneer precast panel constructed using a logical extension of the modified rain-screen joint. The free movement of the stone veneer is provided by the insulation itself with anchorage of the concrete to the stone similar to Figs. 5 to 8. An air space is not provided and the bottom part of the panel is open at the insulation to drain any possible moisture.

The construction of an insulated sandwich-veneer precast panel with a  $\frac{1}{2}$  to  $\frac{3}{4}$  in. (13 to 19 mm) air space is shown in Figs. 13(a) and (b). In order to minimize bending of the stone wire anchors, the anchors are embedded in 4 in. (100 mm) diameter concrete plugs, which penetrate the insulation. The plug is separated from the back side of the stone by a small section of a corrugated plastic formliner or voided plastic eggcrate to allow air circulation, or by a polyethylene foam pad. In most cases, it has been found that since the concrete plug is separated from the stone, it does not represent a serious thermal bridge and to date, major condensation or discoloration of the exterior wall has not been reported.

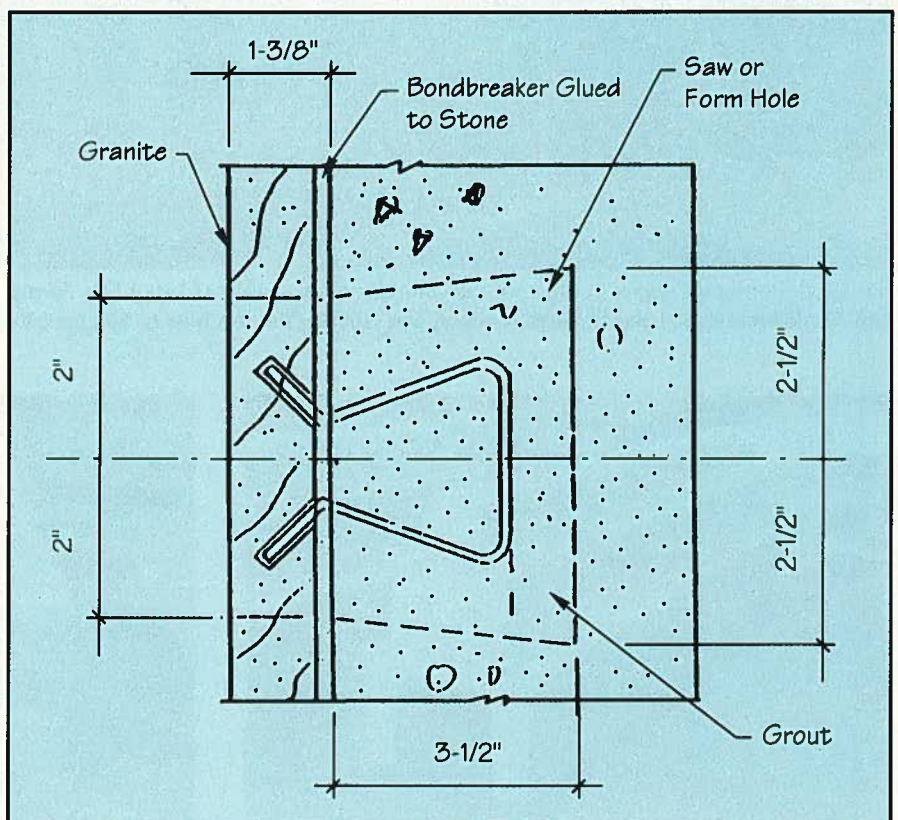


Fig. 16. Granite anchor detail for post applied granite slab (stone piece not available to be cast in precast concrete panel).

The air space, which is vented through the jointing to the outside environment, forms a pressure equalizer. Pressure equalization is achieved by leaving an open horizontal joint at the windows, which necessitates proper

flashing details, or by using shiplapped horizontal panel joints which are also left open. With pressure equalization, water should not penetrate the wall system far enough to cause any problems.

## VENEER JOINTING

In the form, the stone veneer pieces are temporarily spaced with a non-staining, compressible spacing material, such as rubber, neoprene, or soft



Fig. 17(a). Portland Oregon Temple for the Church of Jesus Christ of Latter Day Saints , Lake Oswego, Oregon. Architects: Lee, Ruff, Stark Architects, Lake Oswego, Oregon and Leland Gray Architects, Salt Lake City, Utah.



Fig. 17(b). Marble faced precast concrete fins are 3 x 6 ft (0.9 x 1.8 m) x variable length.



Fig. 17(c). Intermediate panels are 5 ft 10 in. x 1 ft 4 1/2 in. (1.8 x 0.4 m) x variable length.

plastic wedges, or a chemically neutral, resilient, non-removable gasket, such as sealant backer rod, which will not stain the veneer or adversely affect the sealant to be applied later. Shore A hardness of the gasket should be less than 20.

The gaskets should be of a size and configuration that will provide a re-

cess to receive the sealant and also prevent any of the concrete backup from entering the joints between the veneer units. Non-acidic based masking or duct tape (other types will stain stone) may also be used to keep concrete out of the stone joints so as to avoid limiting stone movement. Spacer material should be removed

after the panel has been removed from the form unless it is a resilient sealant backup.

Joints between veneer pieces on a precast element are typically a minimum of 1/4 in. (6 mm) with 3/8 in. (9.5 mm) preferred although they have been specified equal to the joint width between precast elements, usually 1/2,



Fig. 18.  
Hospital Corporation of America Data Center, Nashville, Tennessee.  
Architect: Gresham, Smith and Partners, Nashville, Tennessee.

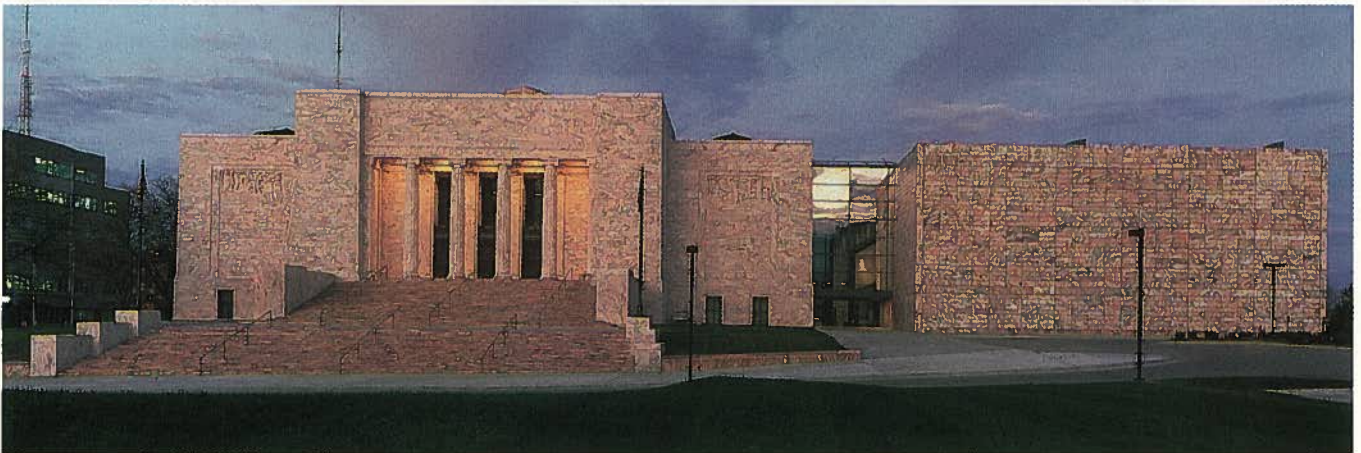


Fig. 19(a). The new wing for the Joslyn Art Museum, Omaha, Nebraska has 1 1/4 in. (3 cm) marble with 6 3/4 in. (170 mm) concrete backup. Lead Designer: Sir Norman Foster and Partners, London, United Kingdom; Architect of Record: Henningson, Durham & Richardson, Inc., Omaha, Nebraska.



Fig. 19(b). Panels ranged from 20 to 218 sq ft (1.8 to 20.3 m<sup>2</sup>).



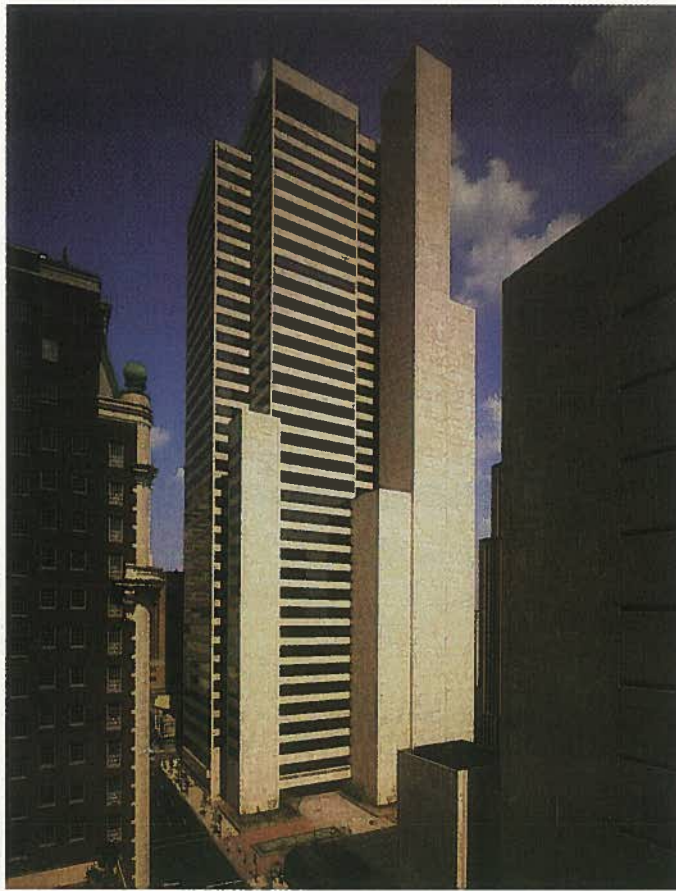


Fig. 20.  
Southwestern Bell  
Texas  
Headquarters,  
Dallas, Texas.  
Architect: JPL  
Architects.

$\frac{3}{4}$  or 1 in. (13, 19 or 25 mm), depending on the panel size. Because the actual joint width between precast panels, as erected, depends largely on the accuracy of the main supporting structure, it is not realistic to require matching joint widths between stone pieces and between panels.

Often, an invisible joint is specified, e.g., less than  $\frac{3}{16}$  in. (5 mm), especially on polished veneer. This

is simply not possible because the joint must have the width necessary to allow for movements, tolerances, and other dimensional or volumetric changes. Also, due to tolerances and natural warping, adjacent panels may not be completely flush at the joint, and shadow lines will appear. Rather than attempting to hide the joint, the joint should be emphasized by finding an aesthetically pleasing

joint pattern with a complementary joint size.

When stone veneer is used as an accent or feature strip on precast concrete panels, a  $\frac{1}{2}$  in. (13 mm) space is left between the edge of the stone and the precast concrete to allow for differential movements of the materials. This space is then caulked as if it were a conventional joint.

The sealant between stones or panels should be an elastomeric, usually urethane, polysulfide, or silicone, that will not stain the stone-veneer material. Some grades of silicone sealants are not recommended by their manufacturers for applications on stone, as they may stain light colored stones or may cause a change in surface moisture absorption characteristics that can be seen whenever the stone is wet.

In some projects, caulking between stone pieces on a panel may be installed more economically and satisfactorily at the same time as the caulking between precast elements. On other projects, consideration may be given to caulking the veneer material at the plant. Plant caulking of stone-to-stone joints is recommended in areas subject to freezing and thawing, if panels are to be left in prolonged storage during the winter.

## HANDLING, STORAGE AND SHIPPING

In all operations after removal from forms, the veneer-faced precast panels should be handled, stored and shipped



Fig. 21(a). Airline Pilots Association Headquarters, Washington, D.C. Architect: Vlastimil Koubek, Washington, D.C.



Fig. 21(b). Closeup of  $1\frac{1}{4}$  in. (3 cm) travertine clad mullions meeting spandrel at third floor.



Fig. 22.  
Roseville Telephone  
Company, Roseville,  
California. Architect:  
Williams + Paddon  
Architects &  
Planners/Inc.,  
Roseville, California.

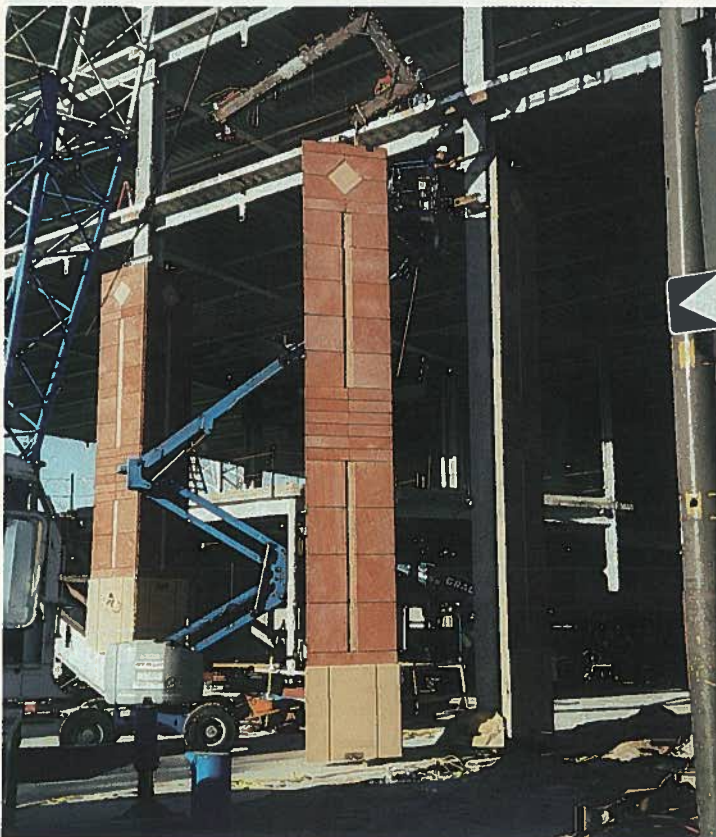


Fig. 23(a). Collier Center, Phoenix, Arizona. Architect: Opus  
Architects & Engineers, Phoenix, Arizona.



Fig. 23(b). Closeup of completed lower story panels.



Fig. 24. Sacramento Municipal Utility District Customer Service Center, Sacramento, California. Architect: Williams + Paddon Architects & Planners/Inc., Roseville, California.

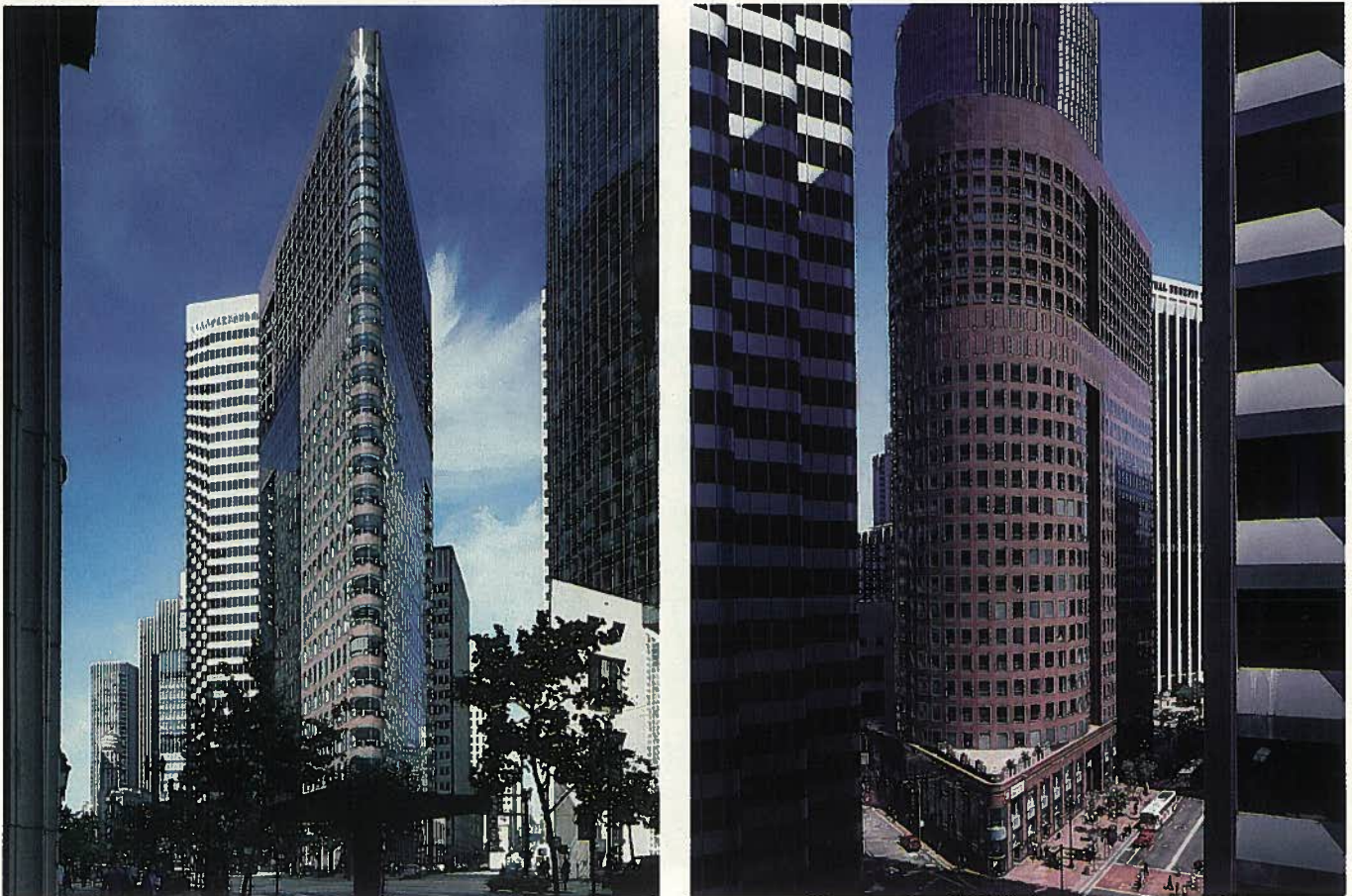


Fig. 25. 388 Market Street Building, San Francisco, California. Architect: Skidmore Owings & Merrill, San Francisco, California.

on the concrete edge of the panel or on their backs with the stone facing up. The panels should not at any time rest on the veneer face or on any of the veneer edges or corners. To minimize the effects of the sun on bowing, panels are sometimes stored on edge with the length oriented to north and south. In order to prevent staining, wood blocking should be covered with a plastic film or some other non-staining material to prevent contact with the stone veneer. Also, contact between the stone and oil and asphalt-based compounds should be avoided.

Once the panels are ready for loading, they may be cleaned (if part of the contractual obligations) with stiff fiber, or stainless steel or bronze wire brushes, a mild soap powder or detergent and clean water using high pressure, if necessary.<sup>23</sup> No acid or other strong chemicals that might damage or stain the veneer should be used. Information from stone suppliers or trade associations on methods of cleaning oil, rust and dirt stains on stones should be made available to the precaster.

During shipping, the panels may be placed on special rubber padded racks and care taken to prevent chip-

ping of edges and damage to returns. Long returns at sills and soffits generally create handling problems, unless proper procedures are worked out ahead of time.

## REPAIR

In the event minor damage occurs to the veneer stone during shipping, handling or erection, field remedial work can be performed successfully. The precaster normally does such repairs, with repair procedures developed in consultation with the stone fabricator.

Epoxy, stone dust, and a coloring agent, if necessary, are used to repair small chips or spalls. These patches can be finished to the same surface texture as the stone facing. If it is necessary to replace a stone piece, satisfactory techniques have been developed for when the back of the panel is accessible or after the panel has been erected and the back of the panel is inaccessible (see Figs. 14, 15 and 16). Note that each anchor should be oriented so that when the panel is erected on the building, the two anchor prongs will be horizontal.

## APPLICATIONS

Over the last 40 years many structures have been constructed with stone-veneer-faced precast concrete panels. Several examples are shown to illustrate the use of the various types of stone.

### Marble

The base structure of the Portland Oregon Temple for the Church of Jesus Christ of Latter Day Saints, Lake Oswego, Oregon consists of 1<sup>1</sup>/<sub>4</sub> in. (3 cm) Vermont marble facing backed with 4 in. (100 mm) of precast concrete [see Figs. 17(a), (b) and (c)]. The roof and base of the entry overhang has 1<sup>1</sup>/<sub>8</sub> to 1<sup>1</sup>/<sub>2</sub> in. (29 to 38 mm) green slate with a 4 in. (100 mm) concrete backup.

The 10 x 15 ft (3 x 4.5 m) panels on the Hospital Corporation of America's Data Center, Nashville, Tennessee have 1 in. (25 mm) thick marble veneer on a 5 in. (125 mm) precast concrete backup (see Fig. 18). The concrete has two layers of reinforcement. The project was completed on a 14-month fast track schedule.

Architectural precast panels for the new wing of the Joslyn Art Museum,

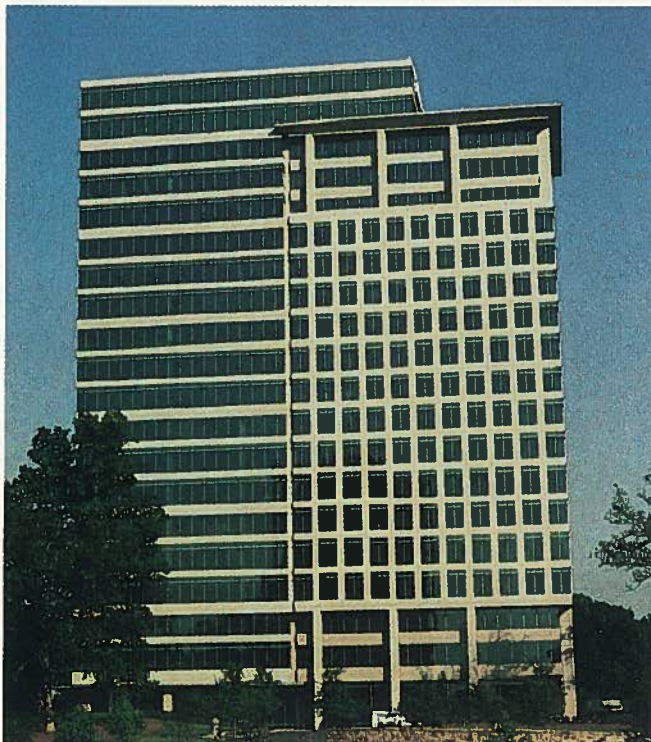


Fig. 26(a). Promenence in Buckhead office building, Atlanta, Georgia. Architect: Smallwood Reynolds Stewart Stewart & Associates, Atlanta, Georgia.

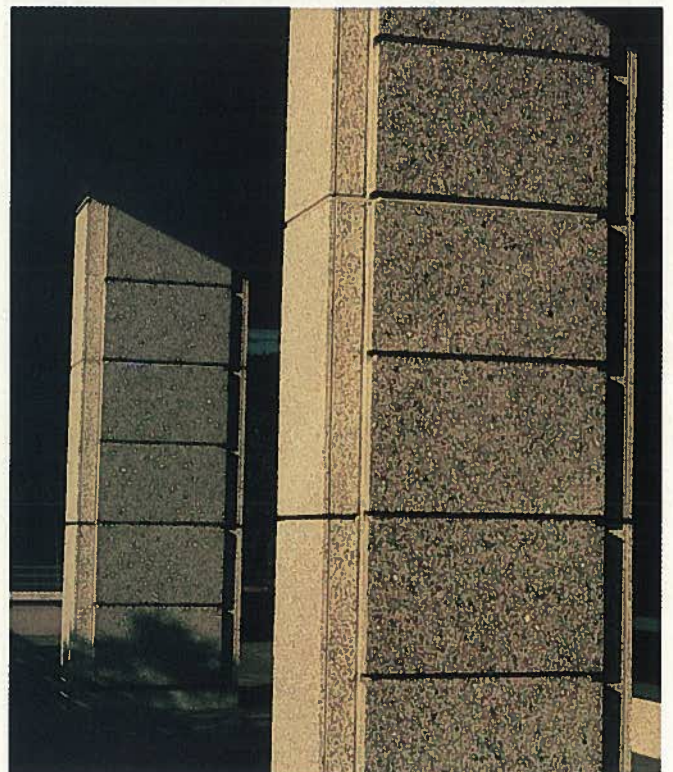


Fig. 26(b). A close-up of column with granite cast in precast concrete.

Omaha, Nebraska are clad in pink 1 $\frac{1}{4}$  in. (3 cm) Etowah Fleuri Georgia marble to match the original stone building constructed in 1931 [see Figs. 19(a) and (b)]. Labor and material costs were reduced using this system compared to traditional stone cladding systems. There were 199 panels with the heaviest piece weighing 22,100 lbs (10023 kg).

### Travertine

Over 73,000 pieces of 1 $\frac{1}{4}$  in. (3 cm) travertine were anchored to 7055 precast units to produce 600,000 sq ft (55800 m<sup>2</sup>) of cladding for the Southwestern Bell Texas Headquarters, Dallas, Texas (see Fig. 20).

The Airline Pilots Association Headquarters, Washington, D.C., has 330 precast concrete units with 1 $\frac{1}{4}$  in. (3 cm) thick travertine inset on 4 $\frac{3}{4}$  in. (121 mm) thick concrete [see Figs. 21(a) and (b)]. The precast concrete units with 4400 travertine pieces clad over 30,000 sq ft (2787 m<sup>2</sup>) and were erected in less than 6 weeks.

### Sandstone

Precast concrete panels are integrally cast with 1 $\frac{1}{4}$  to 1 $\frac{3}{4}$  in. (3 cm to 44 mm) Arizona Red Sandstone on 4 in. (100 mm) thick concrete backup for the Roseville Telephone Company in Roseville, California (see Fig. 22).

Two in. (50 mm) thick red sandstone was anchored to 4 in. (100 mm) thick precast concrete on the Collier Center, Phoenix, Arizona (see Fig. 23).

Two panel types were specified for the Sacramento Municipal Utility District's Customer Service Center, Sacramento, California (see Fig. 24). One panel was integrally cast with 1 $\frac{1}{4}$  to 1 $\frac{3}{4}$  in. (3 cm to 44 mm) thick Arizona Red sandstone facing on 4 in. (100 mm) thick concrete while the other panel was cast with a light sandblast finish. The darker sandstone panels are featured on the lower levels of the seven building complex.

### Granite

The 26-story 388 Market Street building in San Francisco, California

is clad with 1915 panels that are faced with 1 $\frac{1}{4}$  in. (3 cm) red granite cast in precast concrete [see Figs. 25(a) and (b)].

The first three floors of the Promenade in Buckhead office building in Atlanta, Georgia is clad with 1 $\frac{1}{4}$  in. (3 cm) flame finished granite on 4 $\frac{3}{4}$  in. (120 mm) precast concrete [see Fig. 26(a)]. Above the third floor, the building is clad with precast panels with a heavy sandblast finish to match the granite [see Fig. 26(b)].

The 30-story State Office Tower II in Columbus, Ohio has 1 $\frac{1}{4}$  in. (3 cm) thick granite on 5 and 7 in. (125 and 175 mm) thick precast concrete backup [see Figs. 27(a) and (b)].

### Limestone

The two 18-story towers for the GSA Federal Building in Oakland, California are clad with 1 $\frac{3}{4}$  in. (44 mm) beige and white-hued limestone supported on 2208 precast concrete panels [see Fig. 28(a)]. Precast concrete was selected as the backing because of the plastic shaping possibili-

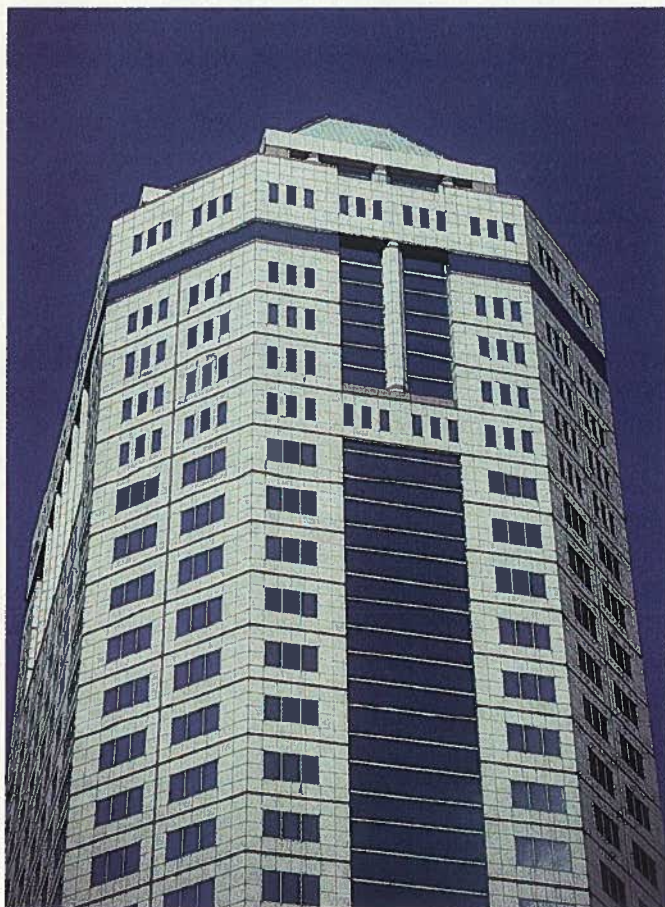


Fig. 27. State Office Tower II, Columbus, Ohio. Architect: Bohm-NBBJ, Columbus, Ohio.



Fig. 28(a). GSA Federal Building, Oakland, California. Architect: Kaplan McLaughlin Diaz, San Francisco, California.

ties that allowed substantial in-and-out relief in the exterior plane [see Fig. 28(b)].

The 38-story NBC Tower at Cityfront Center, Chicago, Illinois is clad with some 2500 precast concrete panels, each of which has a 2 in. (50 mm) or  $2\frac{3}{4}$  (70 mm) thick limestone veneer cast integrally with 5 in. (125 mm) thick concrete backing (see Fig. 29).

The Terry Sanford Institute of Public Policy, Duke University, Durham, North Carolina had approximately 4500 pieces of custom-fabricated gray German limestone inset into a system of precast concrete panels during fabrication (see Fig. 30). Rather than simply butt against each other, the limestone inset corner pieces were cast in a dovetail pattern replicating stone masonry construction. This distinctive look was achieved by casting one leg of the corner joint and then rotating the cured piece and casting the second leg with a cold joint (sequential casting).

#### Accents or Feature Strips

There are a variety of ways that stone veneer can be used as an accent

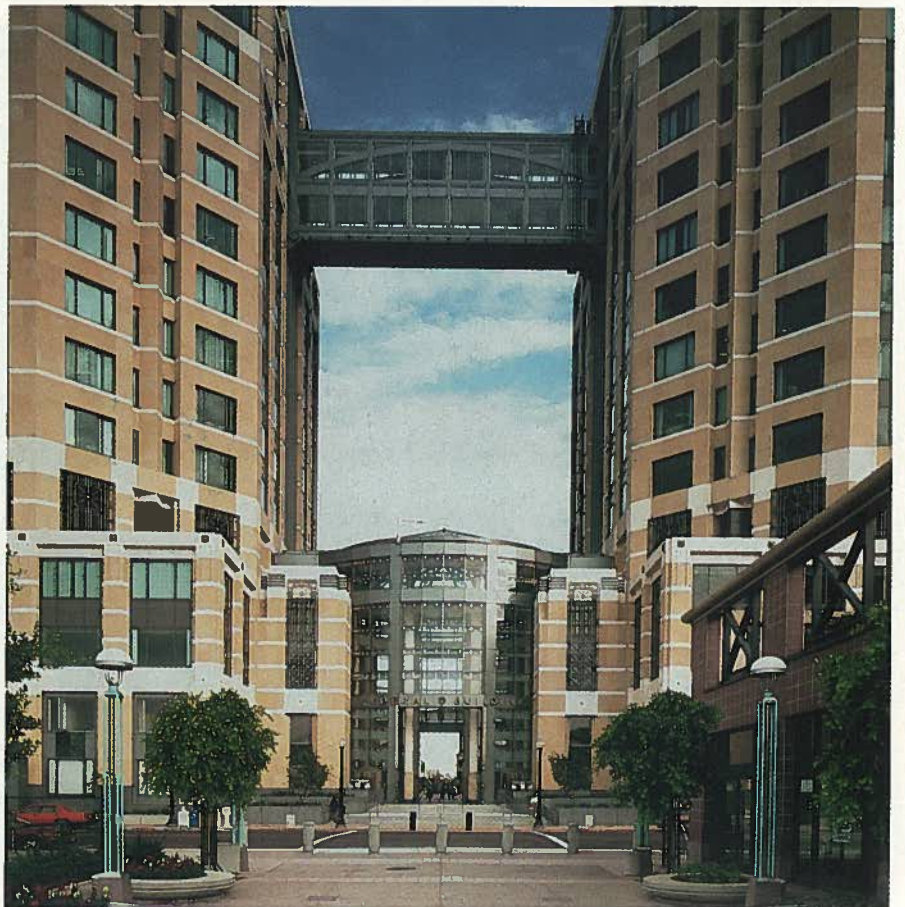


Fig. 28(b). Close-up of building showing in-and-out relief.

Fig. 29.  
NBC Tower at Cityfront Center,  
Chicago, Illinois. Architect: Skidmore,  
Owings, & Merrill, Chicago, Illinois.



Fig. 30.  
The Terry Sanford  
Institute of Public Policy,  
Duke University,  
Durham, North Carolina.  
Architect: Architectural  
Resources Cambridge  
Inc., Cambridge,  
Massachusetts.





Fig. 31(a). Munsell II office building in Alpharetta, Georgia.  
Architect: Harris-Fritz Architects, Marietta, Georgia.

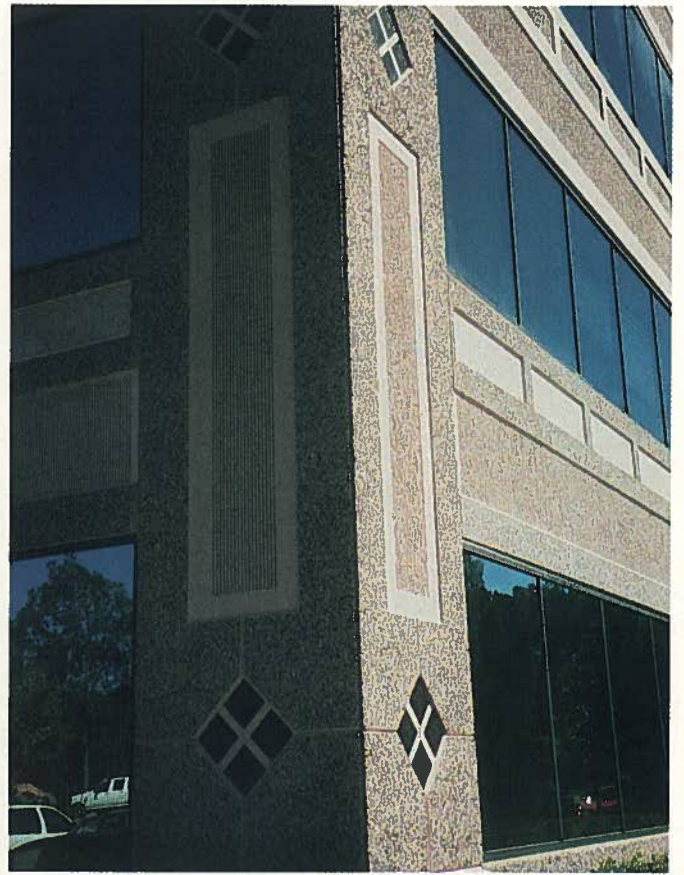


Fig. 31(b). Close-up of black granite accents.



Fig. 32.  
Mountain Fuel North  
Service Center, Salt  
Lake City, Utah.  
Architect: Richardson  
Companies, Salt Lake  
City, Utah.





Fig. 33(a). Shriners Hospital for Crippled Children, Sacramento, California. Architect: Odell Associates, Charlotte, North Carolina. Associate Architect: HDR, Omaha, Nebraska.

or feature strip on precast concrete panels. Several approaches to accent or feature strip applications are shown in the following figures:

Black granite 8 in. (200 mm) square accents were used on the Munsell II office building in Alpharetta, Georgia [see Fig. 31(a) and (b)].

Precast concrete panels with polished granite insets were installed on metal warehouse buildings and reinforced brick buildings, precast concrete energy plants and brewery buildings, and the new steel-framed office building for the Mountain Fuel North Service Center, Salt Lake City, Utah (see Fig. 32).

Architectural precast concrete panels on the Shriners Hospital for Crippled Children, Sacramento, California are 6 in. thick (150 mm) and have an integral horizontal band of 1¼ in. (3 cm) red granite attached with one anchor per 2 sq ft (0.19 m<sup>2</sup>) running the length of the building at every story [see Fig. 33(a) and (b)]. Green terra-cotta medallions project within the horizontal granite band for design emphasis.

Minnesota red granite with a thermal finish, 1 ft wide x 2 ft long x 2 in. thick (0.3 m x 0.6 m x 50 mm), was backed with 4½ in. (114 mm) of concrete and attached with three anchors per granite piece for the State Com-

Fig. 33(b). Close-up of horizontal band of polished red granite.





Fig. 34(a). State Compensation Insurance Fund Regional Headquarters, Stockton, California. Architect: Hornberger + Worstell, Inc., San Francisco, California.

pensation Insurance Fund Regional Headquarters, Stockton, California [see Fig. 34(a) and (b)].

### CONCLUDING REMARKS

Stone veneer-faced precast concrete panels have performed with generally excellent results over the past 40 years. Numerous examples of their successful use have been documented in this article. The prefabrication of the stone veneer on the precast concrete provides an economically viable solution to cladding today's structures. The objectives of both the precaster and the stone fabricator are the same, namely, to provide the owner and architect with the best possible work based on clearly written specifications.

Proper planning and qualified personnel to coordinate scheduling, delivery, and color blending of the stone must be built into the cost of the project. The contract documents should clearly define who has responsibility for determining the type, number and location of anchors; who drills the anchor holes in the stone; and who supplies the anchors. When this occurs as it should, the project proceeds smoothly.

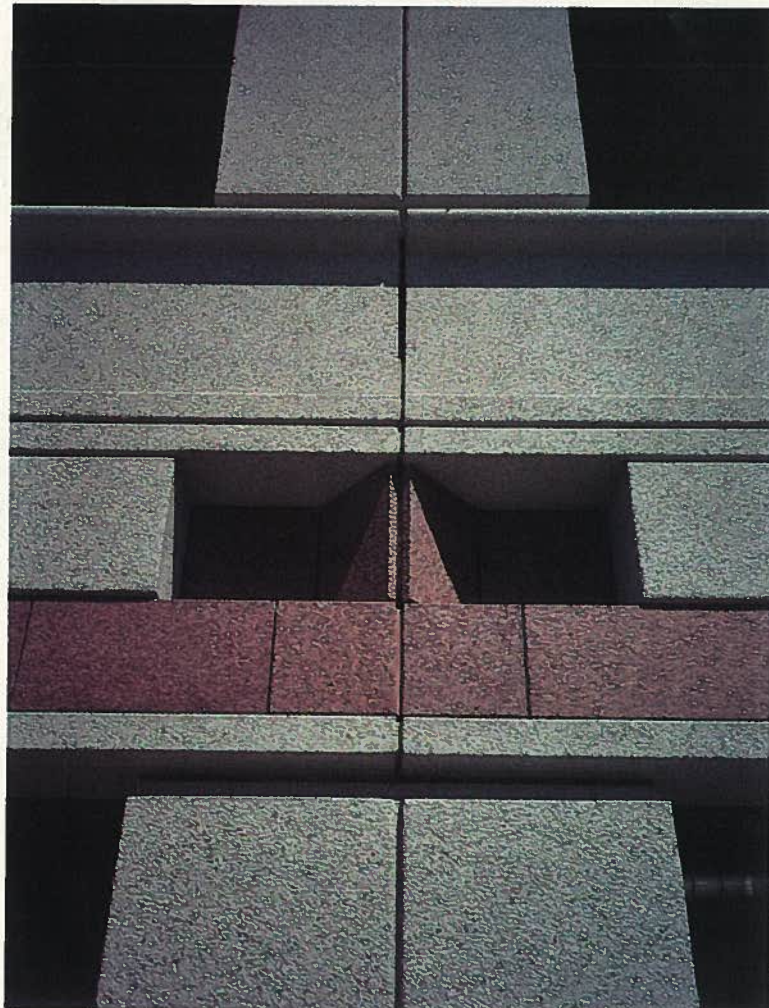


Fig. 34(b). Detail of horizontal band and inset section.

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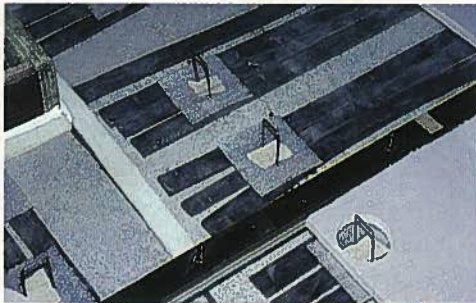
## APPENDIX

### TYPICAL PRODUCTION PRACTICES FOR STONE VENEER-FACED PRECAST CONCRETE PANELS

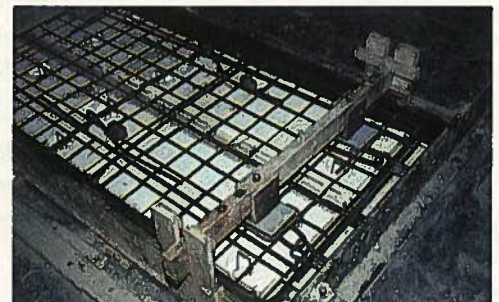
(Sequences shown are from several projects and are used to illustrate specific points.)



1. Stone is carefully placed in the form either manually or with a vacuum lifter. Since cut stones can be stained by oil and rust, the forms for the precast concrete should be lined with polyethylene sheets or other non-staining materials.
2. Compressible spacer material is placed between the stone slabs in the form.
3. Bondbreaker is placed over the back of the stone; spring clip anchors can be seen penetrating through, together with the connection hardware in place, and the prestressing strand already stressed.



4. For an insulated sandwich panel with an airspace, rubber strips are placed to create the airspace (to be removed when panel is stripped), anchors are inserted and a polyethylene foam pad bondbreaker is placed and taped.
5. Two layers of insulation are placed, and insulation joints are taped and caulking is used between insulation layers.
6. All reinforcement, prestressing strand, connection and lifting inserts, and additional attachments such as window washer inserts or tracks are assembled in the form prior to placing the concrete.



7. Backforms, if necessary, are fixed in the form and concrete is placed and vibrated.
8. Finished panel being lifted.