



Standard Guide for Selection, Design, and Installation of Dimension Stone Attachment Systems¹

This standard is issued under the fixed designation C1242; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Natural building stone is chosen as a building's cladding for its beauty which endures with minimal maintenance. Stone is durable when used properly. Exercising good judgment when selecting the particular stone, determining the quarrying and fabrication techniques, designing the method of attachment, and installing all components correctly maximizes these benefits. A properly executed stone cladding is designed and installed within the capabilities and limitations of the stone and support system to resist all forces that work on them.

This guide presents design principles that require consideration when designing anchorages and evaluating exterior stone to be compatible with its proposed use. It is an overview of current techniques and a review of minimum requirements for sound stone engineering and construction. The guide does not list all possible methods of attachment nor does it provide a step-by-step procedure for stone anchor engineering. Knowledge gained from new engineering designs, testing of applications, and the investigation of existing problems are continually reviewed to update this guide. Comment from users is encouraged.

Good judgment by architects, engineers, and contractors when specifying, designing, engineering, and constructing stone and other work that interfaces stone is necessary to use this guide. Users of this guide should combine known performance characteristics of the stone, the building's structural behavior, and knowledge of materials and construction methods with proven engineering practice.

1. Scope

1.1 This guide covers the categories of anchors and anchoring systems and discusses the design principles to be considered in selecting anchors or systems that will resist gravity loads and applied loads.

1.2 This guide sets forth basic requirements for the design of stone anchorage and provides a practical checklist of those design considerations.

1.3 This guide pertains to:

1.3.1 The anchoring of stone panels directly to the building structure for support,

1.3.2 The anchoring of stone panels to subframes or to curtainwall components after these support systems are attached to the building structure,

1.3.3 The anchoring of stone panels to subframes or to curtainwall components with stone cladding preassembled before these support systems are attached to the building structure, and

1.3.4 The supervision and inspection of fabrication and installation of the above.

1.4 Observe all applicable regulations, specific recommendations of the manufacturers, and standards governing interfacing work.

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical

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conversions to SI units that are provided for information only and are not considered standard.

1.6 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. (See Tables 1 and 2.)

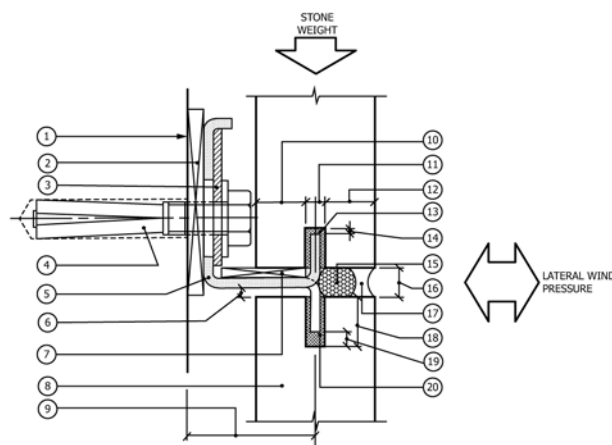
2. Referenced Documents

2.1 ASTM Standards:²

- C97 Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone
- C99 Test Method for Modulus of Rupture of Dimension Stone

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- C119 Terminology Relating to Dimension Stone
- C170 Test Method for Compressive Strength of Dimension Stone
- C406 Specification for Roofing Slate
- C482 Test Method for Bond Strength of Ceramic Tile to Portland Cement Paste
- C503 Specification for Marble Dimension Stone
- C509 Specification for Elastomeric Cellular Preformed Gasket and Sealing Material
- C568 Specification for Limestone Dimension Stone
- C615 Specification for Granite Dimension Stone
- C616 Specification for Quartz-Based Dimension Stone
- C629 Specification for Slate Dimension Stone
- C864 Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers
- C880 Test Method for Flexural Strength of Dimension Stone
- C920 Specification for Elastomeric Joint Sealants
- C1115 Specification for Dense Elastomeric Silicone Rubber Gaskets and Accessories
- C1193 Guide for Use of Joint Sealants



ANCHOR IN HORIZONTAL JOINT CAN SUPPORT GRAVITY AND LATERAL LOADS (FIGURE AS SECTION VIEW)
ANCHOR IN VERTICAL JOINT CAN SUPPORT ONLY LATERAL LOADS (FIGURE AS PLAN VIEW)

- 1 SUPPORT ANCHORAGE ON COMPATIBLE, STABLE BACKUP.
- 2 PLACE PLASTIC OR METAL ADJUSTMENT BEARING SHIM SLIGHTLY LARGER THAN ANCHOR'S FASTENED FACE. REQUIRED TO SEPARATE DISSIMILAR MATERIALS AND ADJUST TO FRAMING. MINIMIZE THICKNESS TO MINIMIZE BENDING ON FASTENER (PART 4).
- 3 PREVENT SLIP OF THE CONNECTION AFTER VERTICAL ADJUSTMENT WITH DIAGONALLY SLOTTED WASHER PLATE. WELD WASHER WITH WELD, OR SERRATED ANCHOR AND WASHER. DO NOT RELY ON FRICTION.
- 4 ATTACH ANCHOR WITH FASTENER TO BACKUP.
- 5 KERF ANCHOR. (BRAKE-FORMED SPLIT-EAR SHAPE SHOWN) OR EXTRUDED SHAPE THAT FITS INTO SAWN KERF. AVOID MISALIGNMENT AND RESULTING PRYING ON KERF FROM INACCURATE FABRICATION OR INSTALLATION. SHOULD NOT BE CONTINUOUS ACROSS PANEL JOINTS. CAPACITY OF CONNECTION IS NOT DIRECTLY PROPORTIONAL TO ANCHOR LENGTH.
- 6 MAINTAIN CLEARANCE TO AVOID CONTACT AND WEIGHT TRANSFER (UNLESS DESIGNED TO STACK). ALLOW FOR MOVEMENT, CREEP, EXPANSION, AND FABRICATION AND INSTALLATION TOLERANCES.
- 7 PLACE PLASTIC OR STIFF RUBBER BEARING SHIM FOR LEVELING, SEPARATION, AND TO PREVENT BEARING OF STONE KERF FIN ON ANCHOR RADIUS. ADJUST ANCHOR VERTICALLY WITH PART 3. NOT SHIMS.
- 8 DIMENSION STONE CLADDING FACE PANEL.
- 9 MINIMIZE DISTANCE TO MINIMIZE ECCENTRIC WEIGHT ON ANCHOR - REDUCES FASTENER (PART 4) PULLOUT AND SUPPORT ANCHOR (PART 5) DISPLACEMENT.
- 10 VERIFY INTERIOR KERF FIN. STONE HERE RESISTS NEGATIVE (OUTWARD OR SUCTION) PRESSURE. MAINTAIN SUFFICIENT WIDTH FROM MINIMUM PANEL THICKNESS.
- 11 LOCATE CONTINUOUS OR INTERMITTENT SAWCUT KERF IN CENTER THIRD OF THICKNESS. CONTROL WIDTH TO ALLOW TOLERANCE WITH KERF ANCHOR. MINIMIZE WIDTH TO MAXIMIZE EDGE DISTANCES (PARTS 10 AND 12).
- 12 VERIFY EXTERIOR KERF FIN. (3/8 IN. (10 mm) MINIMUM) STONE HERE RESISTS POSITIVE (INWARD) PRESSURE. KEEP THIS DIMENSION CONSTANT TO KEEP STONE FACES ALIGNED.
- 13 FILL KERF IN BOTTOM EDGE OF STONE ONLY AT ANCHORS WITH SEALANT TO SET POSITION AND TO CUSHION BEARING.
- 14 MAINTAIN CLEARANCE TO AVOID POINT LOADING AT TOP AND BOTTOM. DIMENSION TO EQUAL OR EXCEED PART 6. DO NOT ALLOW FLOOR-TO-FLOOR MOVEMENTS TO OCCUR IN THE KERF.
- 15 PLACE BACKER ROD OR FOAM TAPE AT PROPER DEPTH TO PREVENT THREE-SIDED SEALANT BOND.
- 16 SIZE JOINTS TO ALLOW FOR HARDWARE, TOLERANCES, CLEARANCES, APPROPRIATE MOVEMENT, AND JOINT FILLER CAPABILITY. ISOLATE DYNAMIC BUILDING MOVEMENTS FROM THIS TYPE OF ANCHOR.
- 17 FILL JOINTS BETWEEN PANELS WITH COMPRESSIBLE GASKET OR SEALANT WITH PROPER PROFILE AND COMPATIBILITY.
- 18 MINIMIZE KERF DEPTH TO MINIMIZE PRYING AND MAXIMIZE CAPACITY. MAINTAIN 3/8 IN. (10 mm) MINIMUM OR TESTED MINIMUM ENGAGEMENT.
- 19 MAINTAIN CLEARANCE TO AVOID POINT LOADING AT KERF IN TOP OF STONE. DIMENSION TO EQUAL OR EXCEED PART 6. DO NOT ALLOW DYNAMIC DISPLACEMENTS TO OCCUR IN THE KERF.
- 20 FILL KERF IN TOP EDGE OF STONE CONTINUOUSLY WITH SEALANT TO TOP OF KERF TO PREVENT MOISTURE ACCUMULATION, SET POSITION, AND CUSHION BEARING OF ANCHOR ON SIDES OF KERF.

FIG. 1 Kerf Anchor

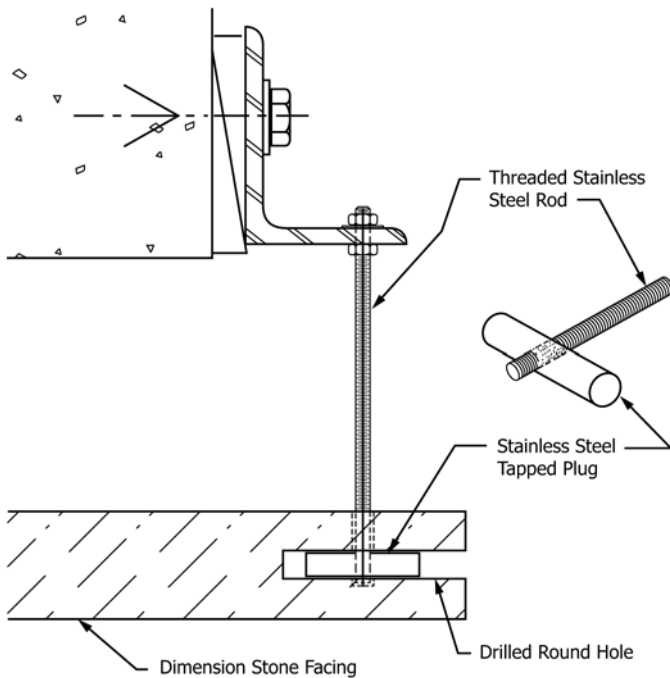


FIG. 2 Rod and Plug Anchor

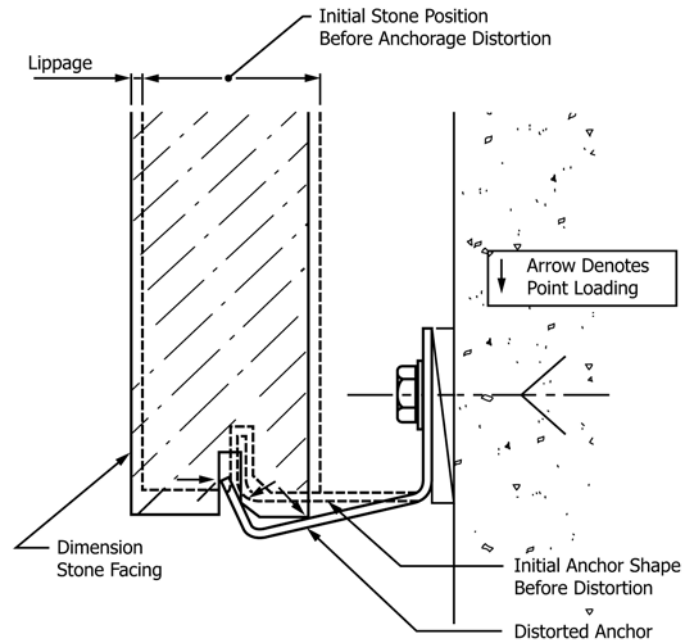


FIG. 4 Point Loading Prevention

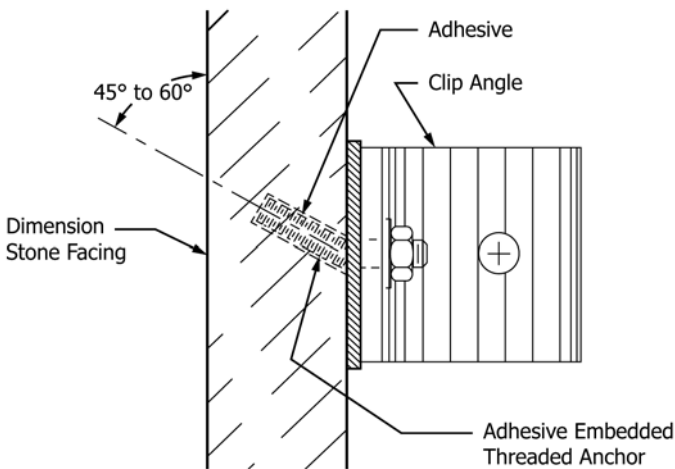


FIG. 3 Adhesive Embedded Threaded Anchor

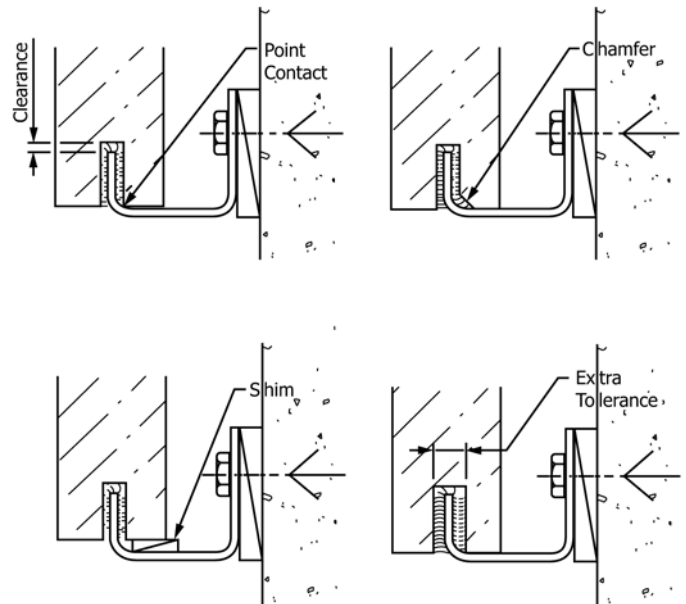


FIG. 4 Point Loading Prevention (continued)

C1201 Test Method for Structural Performance of Exterior Dimension Stone Cladding Systems by Uniform Static Air Pressure Difference

C1354/C1354M Test Method for Strength of Individual Stone Anchorages in Dimension Stone

C1472 Guide for Calculating Movement and Other Effects When Establishing Sealant Joint Width

C1496 Guide for Assessment and Maintenance of Exterior Dimension Stone Masonry Walls and Facades

C1526 Specification for Serpentine Dimension Stone

C1527 Specification for Travertine Dimension Stone

E632 Practice for Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials

3. Terminology

3.1 *General Definitions*—For definitions of terms used in this guide, refer to Terminology C119.

3.2 Specific definitions used in the design process are listed in 7.4.

4. Significance and Use

4.1 This guide is intended to be used by architects, engineers, and contractors who either design or install exterior stone cladding for architectural structures.

4.2 This guide is an industry standard for engineering design considerations, documentation, material considerations,

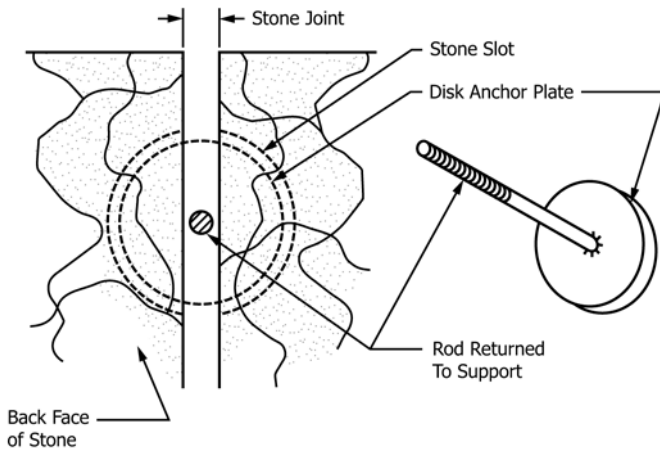


FIG. 5 Disc Anchor

TABLE 1 Dimension Stone Specifications

Stone Type	ASTM Specification
Calcite ^A	C503
Dolomite ^A	C503
Granite	C615
Limestone ^B	C568
Marble (exterior) ^B	C503
Quartz-Based ^B	C616
Quartzite ^A	C616
Quartzitic Sandstone ^A	C616
Sandstone ^A	C616
Serpentine ^A	C503
Serpentine	C1526
Slate (roof)	C406
Slate (walls)	C629
Travertine ^A	C1527

^A This stone type is a subclassification.

^B This stone type has subclassifications or grades.

TABLE 2 Dimension Stone Test Methods

Measures	ASTM Test Method
liquid porosity and relative density	C97
combined shear with tensile unit strength from bending	C99
ultimate crushing unit strength	C170
primary tensile unit strength from bending	C880
capacity and deflections of panels assembled with their anchors onto their supporting backup structure	C1201
individual anchor strength	C1354/C1354M
accelerated production of service life	E632

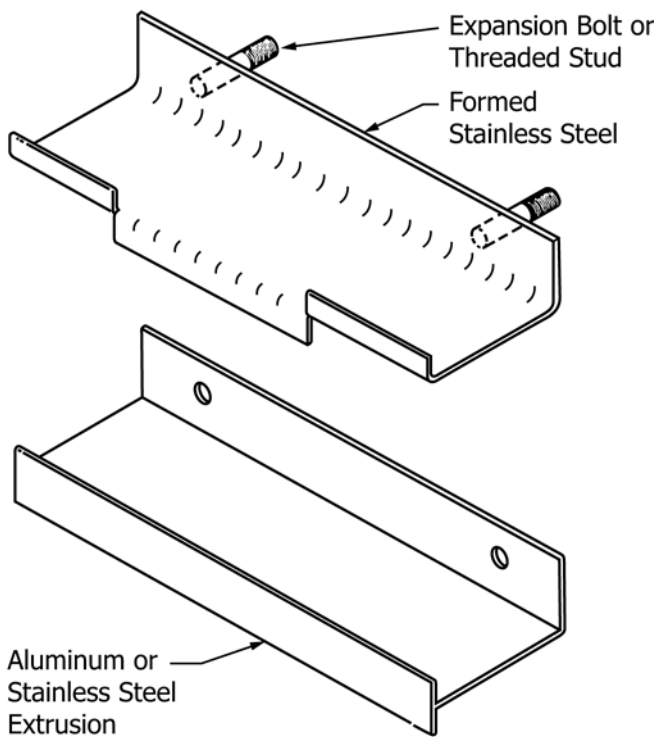


FIG. 6 Combined Anchor

anchor type applications, and installation workmanship to assist designers and installers to achieve a proper and durable stone cladding.

4.3 Stone and its support systems are part of a building's skin and shall be compatible with the behavior and performance of other interfacing systems, such as the curtainwall and superstructure frame.

4.3.1 Every stone work application shall comply with applicable building codes.

4.3.2 It is not the intent of this Guide to supersede published recommendations for specific stone types. Provisions of other dimension stone industry publications should be reviewed and considered in addition to this Guide's recommendations. All industry information should be considered with respect to project specifications and requirements. If provisions of such

publications differ from those in this Guide, it is acceptable practice to follow the publication's provisions if recommended by the stone specialist defined in 4.4 for the specific conditions of the individual project.

4.3.3 Because stone properties vary, the range and variability of pertinent properties of the stone proposed for use should be determined by testing and statistical methods that are evaluated using sound engineering principles. Use recent test data where applicable. Always reference proven performance of relevant existing structures.

4.3.4 Changes in properties over time shall be considered.

4.3.5 Overall behaviors of all building systems and components including the stone shall be interactively compatible.

4.4 *Stone Specialist*—Some conditions require professional expertise to select and plan a proper anchoring system, establish appropriate testing requirements, interpret tests, design and engineer the anchoring system, or monitor its fabrication and installation. A specialist is a person that complements the capabilities of the project team by contributing specific expert experience with the use, selection, design, and installation of dimension stone.

4.4.1 Particular conditions where special expertise is suggested to achieve a reliable installation:

4.4.1.1 Where complex connections or anchoring methods of unknown or questionable performance records are likely to be considered or specified;

4.4.1.2 Where the performance record of the specified systems and materials is not known or questionable;

4.4.1.3 When multiple cladding materials occur on the same facade;

4.4.1.4 If the supporting structure or backup is more flexible than L/600 in any direction;

4.4.1.5 If extreme loading could be caused by seismic, hurricane, tornado, or installation and handling methods;

4.4.1.6 When special building code requirements prevail.

4.4.1.7 If provisions of stone industry publications or project specifications differ from this guide.

5. Selection Considerations

5.1 Review the following factors before selecting a stone material, an anchoring system and subframe system from those options being considered:

5.1.1 Have the stone materials under consideration performed well on existing buildings in similar exposures?

5.1.2 Have the different anchoring and subframe systems under consideration performed well on existing buildings in similar exposures?

5.1.3 How is the performance of the anchor and its engagement into the stone affected by installation and handling procedures?

5.1.4 How are the performance and appearance of the subframe, the anchor's connection to the subframe, and the subframe's connections to the building structure affected by differential movements?

5.1.5 Do the physical characteristics of the stone measured by standard tests show the material has structural limitations? Which physical properties are important to the application, and which test methods measure those properties and their variability? Refer to [Table 2](#) for standard test methods and properties they measure.

5.1.6 Do the physical characteristics of the stone not measured by standard tests suggest the material may have long-term durability concerns? Other properties, including (but not limited to) resistance to chemical attack, weather-related strength reduction, and dimensional changes, might be evaluated by special laboratory tests designed to obtain data under simulated conditions.

5.1.7 Does the project location or shape develop exceptional design wind, or seismic loads, or does the stone material require higher safety factors than other stones not anticipated by statutory codes?

5.1.8 Do the anchor and subframe system accommodate building dimensional changes caused by wind and seismic sway, thermal and elastic deformation, creep and shrinkage, and their combined effects?

5.1.9 Will contiguous facade elements such as windows, other claddings, window supports, or window-washing and wall maintenance provisions influence the stone cladding, its anchoring or subframe system?

5.1.10 Do the anchor or subframe systems penetrate waterproofing, facilitate internal moisture collection, or penetrate wall insulation and cavity ventilation?

5.1.11 Do the materials used resist corrosion, galvanic and chemical reactions?

5.2 The following general rules are helpful in the design of anchors and connections:

5.2.1 The simplest connections are usually the best.

5.2.2 Make connections with the fewest components.

5.2.3 Use the fewest possible anchor connection types in any particular project.

5.2.4 Provide for adjustability in connections to accommodate tolerances in materials and construction.

5.2.5 Distribute the weight of stone or panel systems on no more than two points of connection where possible.

5.2.6 Make anchor connection locations accessible to the craftsman.

5.2.7 Design connection components and stone sinkages to avoid entrapping moisture.

5.2.8 At friction connections with slotted holes parallel to the direction of load, specify proper bolts, washers, slot size, and bolt installation procedure.

5.3 *Safety Factors*—In order to design an anchoring system, the variabilities of the materials being considered should be known and compensated. This is accomplished through the use of an appropriate safety factor to be applied to the stone, the anchorage, and the backup structure.

5.3.1 [Table 3](#) shows generally accepted Safety Factors for stone cladding by stone type. These factors are recognized by industry specialists and publications and are based upon past successful practice. These factors are based on a maximum coefficient of variation of 20 % when project samples are tested in accordance with Test Methods [C99](#) or [C880](#) for sedimentary stones in thicknesses of 2 in. (50 mm) or greater. Safety factors could be changed when conditions listed under [5.3.2](#) or [5.3.3](#) exist in the project.

5.3.2 *Exemplar Availability*: A safety factor could be modified if the long-term performance of the stone material, anchor and backup system cannot be verified by well-performing exemplars. Consult a stone specialist as defined in [4.4](#) for the appropriate change in safety factor.

5.3.3 *Structural Variables*: A safety factor could be modified if specific conditions exist on the project different from those upon which [Table 3](#) values are based. Consult a stone specialist as defined in [4.4](#) for the appropriate change in safety factor. Some specific conditions are:

5.3.3.1 Critical material strength tests show increased variability;

5.3.3.2 Life expectancy of project exceeds forty years;

5.3.3.3 Stone material loses significant strength over time;

5.3.3.4 When designing stone at anchors;

5.3.3.5 Anchor capacity tests show increased variability;

5.3.3.6 Anchors will not be inspected in final position on building;

5.3.3.7 Anchors require varied installation techniques or varied positions;

TABLE 3 Generally Accepted Safety Factors for Stone Cladding by Stone Type

Stone Type	Specification	Safety Factor
granite	C615	3
limestone	C568	6
group A marble	C503	5
travertine	C1527	8
sandstone	C616	6
slate	C629	5

5.3.3.8 Panel is used in higher-risk position such as a soffit, overhang, liner block, assembled on backup before being erected or other similar position.

6. Anchor Types

6.1 The following descriptions apply to components potentially common to all anchor types:

6.1.1 Connect all anchors to a stable backup. A stable backup provides sufficient strength and stiffness to resist forces, rotations and displacements induced by the anchor as it transfers reactions from the stone panel to the backup to sustain the structural integrity of the stone cladding. Strength and stiffness must also be sufficient to prevent stress concentrations that could compromise capacity, so the stone cladding system can perform as engineered.

6.1.2 Place structural shims between the anchor and backup to accommodate variances in position between the finished stone panel's position and actual location of the backup. Shims must possess permanent structural properties sufficient to transfer forces while resisting rotations and displacements between the anchor and backup that could compromise the anchor or fastener capacity, or its intended position. Insulation, waterproofing, compressible or elastomeric layers not possessing sufficient structural properties should not be used as shims, and should not be sandwiched between anchors and backup at bearing surfaces. Unintended slip at adjustment slot, whether in the vertical, horizontal, or diagonal direction, should be prevented by use of a weld washer, interlocking serrated faces, or other mechanical means.

6.1.3 Where required to adjust the stone panel's height during setting, place structural shims between the stone and

anchor to accommodate variances in position between the finished stone panel's position and actual location of the anchor. Shims must possess permanent structural properties sufficient to transfer forces while allowing rotations and slight displacements between the anchor and stone panel that, if restricted, could induce prying and compromise the anchor or stone's capacity where it is engaged by the anchor.

6.2 Precast Anchors (see Fig. 7):

6.2.1 Smooth dowels, wire hairpins (preformed wire spring-type anchors), threaded rods or bolts are used as anchors to attach stone cladding to precast concrete panels. Adhesives compatible with the stone may be used in conjunction with such anchors. However, relying solely on adhesives to support stone is not recommended.

6.2.1.1 The number of dowels is determined by analysis and testing.

6.2.1.2 The dowels anchor the cladding to the concrete backup. The angle of the dowel to the stone is usually 45°, angled into the precast, with the patterns opposing each other within the same stone. The holes for the dowels should be jig-drilled with diamond core bits. (See Fig. 7.)

6.2.1.3 The dowel embedment in to the stone should be a minimum of two-thirds of the thickness of the stone. The bottom of the dowel hole should not be closer than 3/8 in. (9.5 mm) to the face of the stone. The embedded section of the dowel into the precast concrete backup should not be less than 2 1/2 in. (64 mm).

6.2.1.4 All dowels should be within the limits of the concrete reinforcing cage when viewed in elevation.

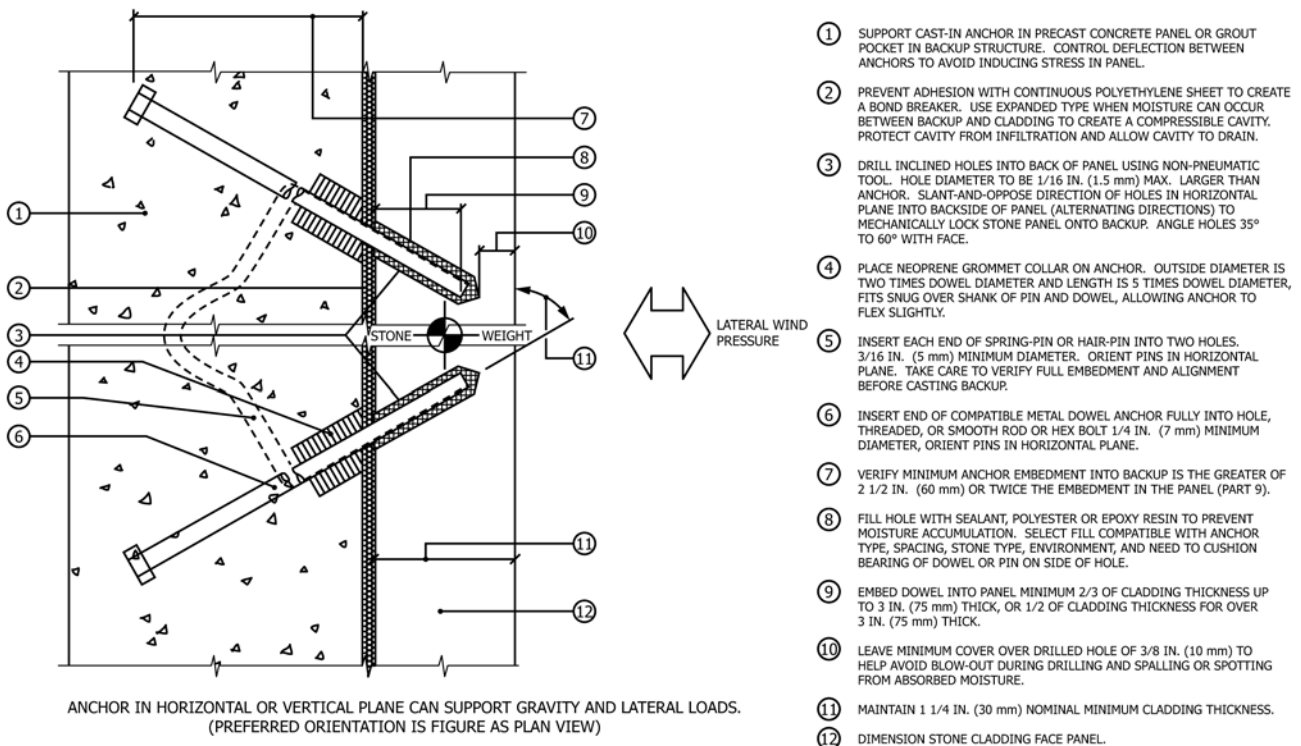


FIG. 7 Cast-In Anchors

6.2.1.5 The recommended minimum diameter of dowels is $\frac{3}{16}$ in. (4.8 mm).

6.2.2 Number of anchors should be a minimum of two per individual panel and should follow the general rules of 5.2. Use Test Method C1354/C1354M anchor testing or panel bending analysis to determine number of anchors required.

6.2.2.1 The anchor embedment into the back of the stone is usually $\frac{3}{4}$ in. (19.1 mm) deep. Two opposing holes are drilled into the back of the stone at an angle of 45° to the plane of the back. These holes are either angled toward or away from each other, depending upon the configuration of the hairpin anchor. The straight legs of the anchor are inserted into the holes, the shape of the anchor acting to keep the legs engaged. The recommended minimum distance between the bottom of the anchor hole and the finished face of the stone is $\frac{3}{8}$ in. (9.5 mm). (See Fig. 7.)

6.2.3 The precast panel must be stiffer than the stone panel so that it will deform less than the stone panel under the same load conditions.

6.2.3.1 No strength value is assigned or considered between the cladding stone and the concrete backup. A bond breaker should be provided between the stone cladding and the precast backup.

6.2.4 Anchors should angle into the back of the stone between 45 and 30° , without pointing downward when the panel is in its final installed position. Separate anchors in the same panel should point in opposite directions to lock cladding onto precast. Orient anchors perpendicular to gravity load whenever possible. Particular care should be taken when anchoring soffit stones to ensure that all anchors are splayed and effectively resist vertical and lateral loads.

6.3 Dowel Anchor (refer to Fig. 8):

6.3.1 Engage panel edge with a fixed or loose metal dowel. Avoid dowel misalignment in hole and resulting prying on stone panel that could result from dowel misalignment.

6.3.2 Transfer lateral and gravity loads from dowel to backup with metal anchor shown as a brake-formed support

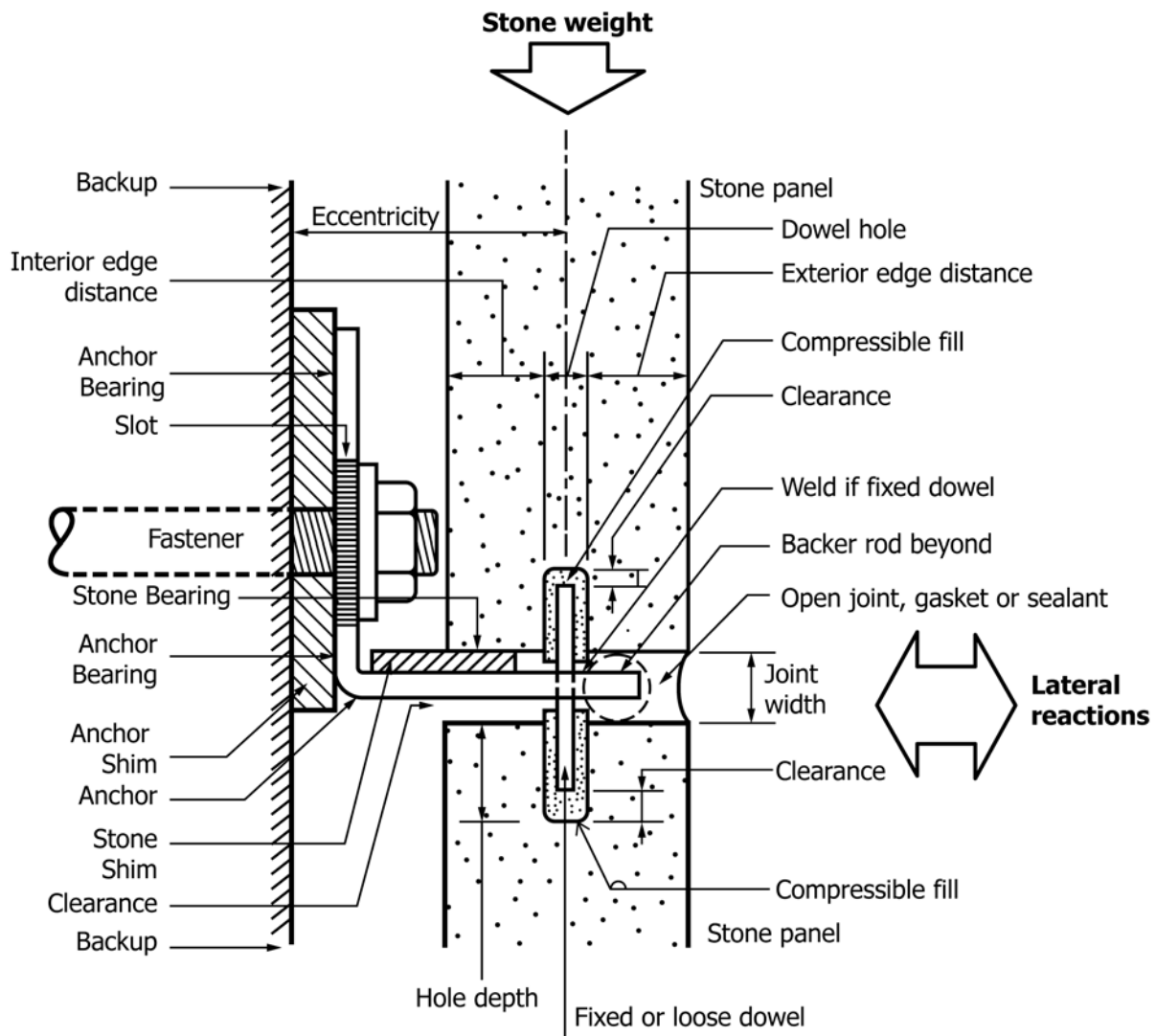


FIG. 8 Dowel Anchor (brake-formed version)

angle. Angle can also be a rolled or extruded shape. Prevent unintended slip at slot according to 6.1.2.

6.3.3 Place structural shim to transfer weight of stone to anchor and adjust its height to prevent bearing of stone on dowel end or weld.

6.3.4 Provide clearance between top-of-stone and bottom-of-anchor to avoid contact and weight transfer unless cladding system is designed to stack. Clearance must allow for differential movement including thermal volume change, creep, seismic and lateral drift fabrication and installation tolerances.

6.3.5 Minimize hole depth to improve anchor capacity. Dimension to equal or exceed 6.3.4. Do not allow floor-to-floor building movements to be accommodated as movement within the holes. Provide $\frac{3}{8}$ in. (10 mm) engagement or minimum depth as tested by Test Method C1354/C1354M. Greater engagement does not necessarily increase anchor capacity, and increased engagement could reduce capacity.

6.3.6 Provide interior edge distance, the thickness of stone from hole to back-face-of-stone to resist negative, or outward pressure. Maintain distance even when stone panel is at minimum overall thickness. Also provide sufficient exterior edge distance, the thickness of stone from hole to front-face-of-stone to resist positive or inward pressure. Keeping this dimension constant could align the panels' finished faces during setting.

6.3.7 Bore hole for dowel with non-percussive means. Locate dowel hole in center third of panel thickness. Minimize diameter to maximize anchor capacity and proportion interior

and exterior edge distances to forces being resisted. Size hole diameter for minimum clearance around loose dowel. Fill holes with compressible and non-absorbing material such as low-modulus sealant or closed-cell sponge to prevent moisture accumulation. The fill also cushions bearing of dowel on sides of hole to minimize point bearing and stress concentrations. Wax or wrap tape on dowel, or bed a sleeve for the dowel to allow sliding where adhesion is not desired, and only small slip is needed.

6.3.8 If the anchor is designed to support stone on only one side of the anchor, weld dowel to anchor to prevent rotation.

6.3.9 Size joint to allow for anchor, tolerances, clearances, designed movement, and capability of the joint filler. Do not accommodate movement occurring in joints in the backup with this type of anchor. Unless stone cladding system is intentionally designed with open joints, fill joints between panels with compressible gasket or sealant with proper profile and compatibility. Place bond breaker at anchor and place backer rod between anchors to prevent three-sided sealant bond that could cause premature sealant failure.

6.4 Wire Ties (see Fig. 9):

6.4.1 Wire ties used on vertical panels are intended to resist only lateral loads. Weight of vertical panels should be supported by bearing on a ledge, corbel, slot, shelf, or liner separate from the ties.

6.4.2 Wire ties with portland-cement based mortar spots can be used to attach stone cladding to cast-in-place concrete or

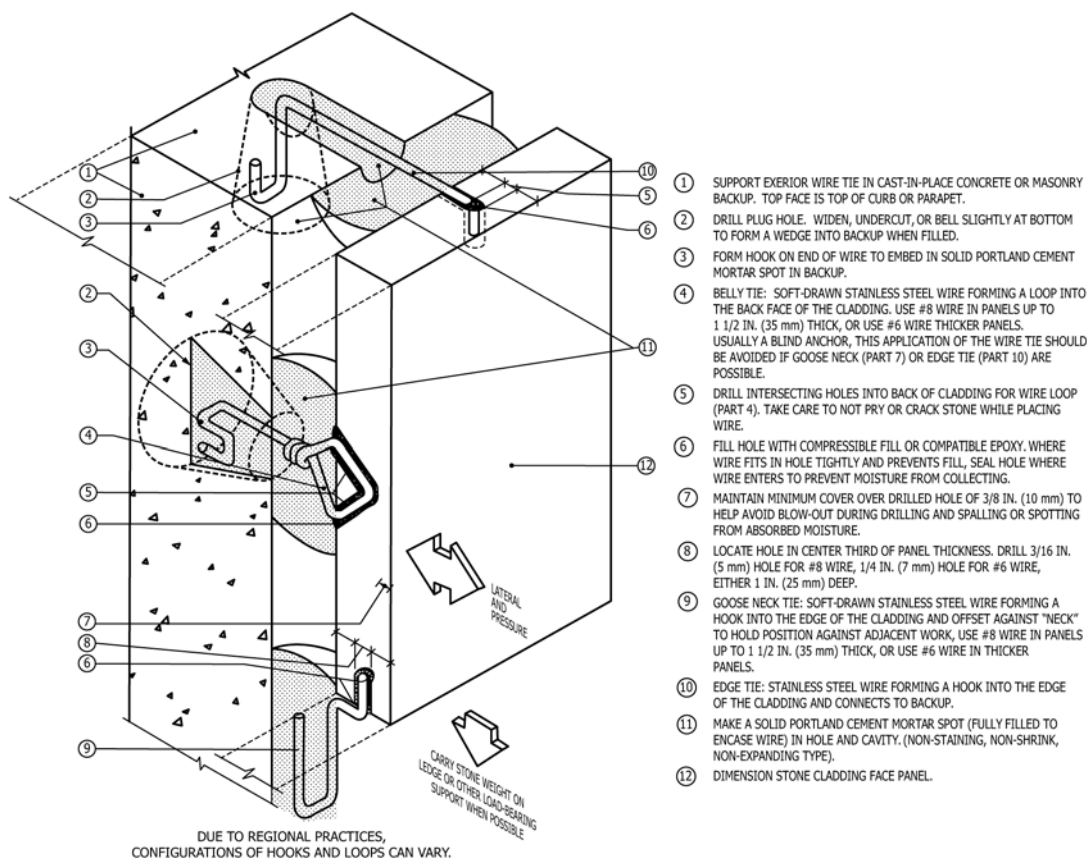


FIG. 9 Wire Ties

masonry backup on exteriors. Wire ties with gypsum or molding plaster spots can be used to attach interior stone panels to backup.

6.4.3 Some stones are stained by mortar or plaster spots. Verify compatibility of spot, tie and stone materials before installing to avoid staining. Also verify that wire ties can be used in the intended application.

6.4.4 Wire ties can hook into the edge of a panel or wrap through intersecting holes drilled into the side, or back of the stone, or both. Looping wire ties through intersecting holes in the back of the stone allows anchors to remain hidden. Wire ties should hook into or mechanically fasten into the backup to act as a tensile tie to the stone. The spot needs to be tight between the backup and the stone to provide for compression transfer. Fill anchor holes with portland-cement based mortar or epoxy. Plaster may be used on interior applications to hold wire firmly in stone. Set stone and clamp in place until spots cure.

6.4.5 Number of wires should be minimum of two and a maximum of four per individual panel and should follow the general rules of 5.2. If Test Method C1354/C1354M anchor testing or panel bending showed more than four anchors were required, then the backup must be made stiffer than the stone panel.

6.4.6 Drill holes following guidelines of 6.2.4. Tie embedment into stone, depth of holes and edge distances should follow the guidelines of 6.2.2.1.

6.4.7 Minimum recommended wire diameter is 0.148 in. (4 mm) for exterior, 0.0808 in. (2 mm) for interior.

6.5 *Face Anchors*—Face anchors are basically through-bolted fasteners. Their main use currently is corrective in nature, as a reinforcement for stone experiencing anchor failure, although it has some potential as a decorative feature. In this use, a decorative plate or washer is exposed at the exterior face of the stone with a bolt either passing through this washer or welded to it. A backup plate or washer should also be used at the back of stone to transfer lateral loads to the through-bolt. The bolt is then passed through the backup wall and secured with a nut at the opposite face of the wall. The load is adequately distributed by a plate or the bolt is anchored into the backup structure.

6.6 *Blind Anchors*—Blind anchors are those not available for visual examination during and after anchorage installation and should not be used unless no other options exist.

6.7 *Liners*—Liners are pieces of stone or metal attached to the back of the stone. Their function is to transfer loads from the stone to an anchor. Connections between the liners and stone are through a mechanical connection. An adhesive bond is used only to facilitate attachment of the liner to the stone. The mechanical connection should consist of two or more stainless steel fasteners per liner, set at a 30 or 45° angle both upward and downward from the back of the liner into the stone. The fasteners are installed after the liner adhesive has set. Liners can have a reglet cut into them to form a kerf to receive an anchor or can be square cut. Liners should be shop-installed by experience shop mechanics, preferably with controlled inspection. The fasteners should be pre-cut to calculated

lengths, such that when fully inserted in the designed holes, their ends are visible at the face of the liner. This will provide the installer an opportunity to verify that the fasteners are in place and fully inserted. (See Fig. 10a-c.)

6.8 Code requirements must be considered as minimums and not as viable substitutes for a completely engineered stone cladding system.

6.9 *Adhered Stone System Without Mechanical Anchors:*

6.9.1 Stone cladding secured by full adhesion without mechanical engagement of an anchor is an adhered system. Adhesion might be provided by polymer or cementitious compounds including but not limited to epoxy (polyester resins not permitted), structural sealant, portland cement mortar or modified portland cement mortars, and stone adhered to a structural backing in a manufacturing process. Use only adhesive compounds that are compatible with both the stone material and the substrate, and do not exhibit long-term creep. Do not use adhesive compounds that create staining or other long-term weathering defects. Adhered systems should conform to provisions 6.9.2 – 6.9.11.

6.9.2 Limit use of adhered stone systems to a height of 30 ft (10 m) above grade. Inspect the cladding hands-on approximately one year after installation, then at least once every four years to verify system is performing adequately in its application.

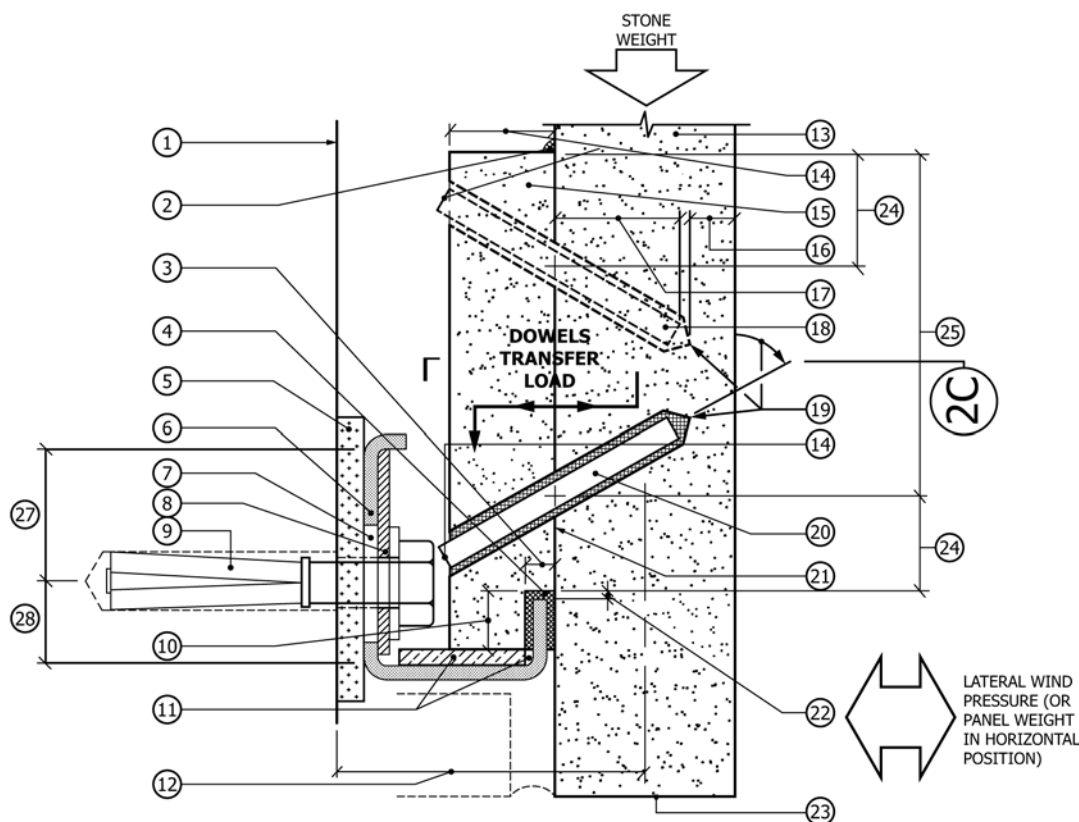
6.9.3 Only allow use of adhered stone systems on vertical planes or those that tilt backward where the cladding faces skyward. Do not use adhered stone systems overhead or on planes that tilt forward where cladding faces downward, or when bottom edge occurs directly over an opening more than 5 ft (1.5 m) above grade without supplemental mechanical anchors. Keep adhered systems a minimum 6 in. (150 mm) above grade. Do not allow the stone or setting bed's top edge, or the bonding plane, to be exposed to precipitation.

6.9.4 Total weight of stone cladding system, consisting of stone panels, joint filler, setting bed and all other lath or waterproofing adhered to the backup substrate shall not exceed 25 lb/ft² (120 kg/m²). Limit maximum stone weight to 15 lb/ft² (70 kg/m²).

6.9.5 Maximum panel size should not exceed 3 ft² (0.25 m²) and maximum height or width should not exceed 2 ft (600 mm), except for stone adhered to a structural backing in a manufacturing process. Maximum panel size can be increased to 5 ft² (0.42 m²) and maximum height or width can be increased to 3 ft (0.9 m) if the supporting substrate meets 6.9.8 stiffness criteria horizontally and vertically, and 6.9.9 adhesion parameters are visually verified for every panel during installation.

6.9.6 Use only stone material having physical properties that are suitable for mechanically-attached systems, free of cracks, seams, and any other characteristic that could compromise the structural integrity of the panel or its adhesive attachment. Clean the back surface to be adhered of all dirt, debris, loose stone or sediment before applying adhesive.

6.9.7 Provide movement joints to relieve in-plane movement stresses and prevent development of excessive in-plane shear between the cladding and backup support. To limit cracking, unless engineering analysis proves different joint



NOTE 1—Use where edge of stone is exposed or not accessible by anchor. Anchor beneath linear can support gravity and lateral loads (figure as section view). Anchor on side or top of liner can support only lateral loads (figure as plan or inverted section view).

FIG. 10 a: Stone Liner Block with Kerf

spacing or joint width is appropriate, movement joint minimum width should be $\frac{3}{8}$ in. (10 mm). Movement joint should extend full depth through scratch coat, be sealed with backer rod and sealant or equal, and be spaced maximum 15 ft (5 m) apart.

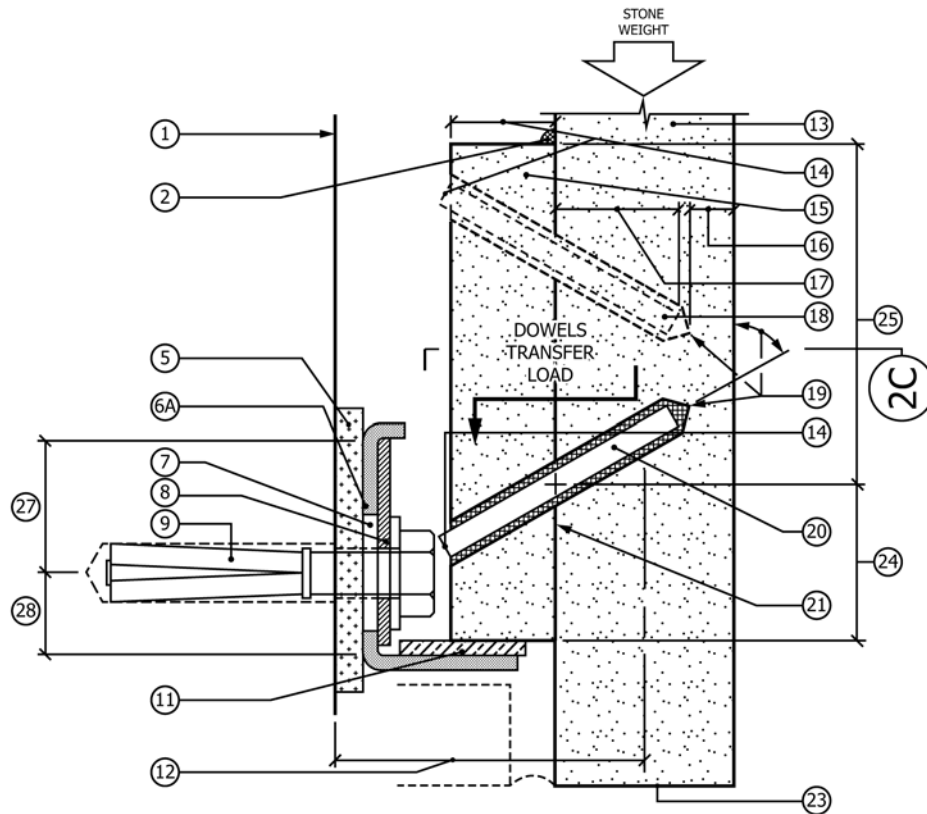
6.9.8 Most masonry standards limit deflection of supporting substrate to span/600 to 800 when laterally bracing conventional brick veneer in a cavity wall. Supporting substrate must be stiffer than the stone cladding to limit cracking caused by deflection. Deflection causes curvature that can develop excessive in-plane shear that cracks adhesive bond and tension that can crack mortar and panels. To limit cracking, limit deflection of span between supports to span/1000 or stiffer under design loads.

6.9.9 Capacity and integrity of adhered system must be tested by assuring all cladding is fully adhered. Fully adhered means a 4 in. (100 mm) wide continuous perimeter of the panel's back face is 100 % bonded, and the remaining area inside the perimeter is 95 % bonded. Where governing Building Code dictates minimum shear capacity requirements for an adhered stone attachment system, before installation begins, confirm the system's shear capacity meets governing Building Code minimum in accordance with Test Method C482. Verify panels are fully adhered by removing panels to observe coverage. Capacity should be checked after appropriate exposure to temperature and moisture effects.

6.9.10 It may be prudent to increase safety factors to greater than shown in Table 3 and indicated in 5.3.3.4 unless exemplars prove long-term good performance after inspections according to 6.9.2.

6.9.11 In service, visually inspect entire installation for distress periodically according to Guide C1496. If distress is discovered that might compromise integrity, check capacity.

6.9.12 During installation, supplement quality assurance practices stipulated by the manufacturer of the adhesive compound to verify adhesive coverage. Verify adhesive compound fully covers back of panels and face of substrate by removing and replacing a sample population of panels to observe coverage prior to initial set of adhesive. Fully covered means a 4 in. (100 mm) wide continuous perimeter of the panel's back face is 100 % covered, and the remaining area inside the perimeter is 95 % covered, with no voids greater than $1\frac{1}{2}$ in.² (1000 mm²). The sample population should begin by evaluating one random panel in the first five set, then continue with one random panel in the next ten set, then continue with one random panel in every next 25 set, each day per each crew. Finding a panel that does not satisfy coverage requires sampling to restart and repeat. Finding a second panel that does not satisfy coverage within that group requires all panels since the last conforming population to be removed and reset.



NOTE 1—Anchor is placed under liner block and can support only gravity loads (figure as section view). Provide lateral support with additional anchors.

Parts 3, 4, 10, 22, and 26 are not used on Fig. 10b.

FIG. 10 b: Stone Liner Block without Kerf (continued)

6.9.13 After installation, confirm shear bond capacity of adhered system by field testing three panels for every 5000 ft² (460 m²) of cladding. Within each panel to be tested, cut a 6 in. (150 mm) square through the stone and into the adhesive bed without cutting the structural substrate and apply load to 100 lb/in.² (690 KPa). Frequency of tests should increase for applications posing greater potential hazard to passersby if a failure occurs. Frequency of tests could decrease for applications posing no hazard to passersby if a failure occurs. Replace entire panel where testing occurred after restoring substrate and adhesive assembly.

7. Design Process

7.1 *System Parts*—There are five main interrelated parts in a stone facade system that are to be considered when designing the cladding system:

7.1.1 *Stone Panels*, cladding the facade,

7.1.2 *Joints*, between the panels,

7.1.3 *Anchor*, connecting the cladding to the supporting backup,

7.1.4 *Subframes*, connecting the anchors to the building structure where the anchor does not attach directly to the building, and

7.1.5 *Primary Building Structure*.

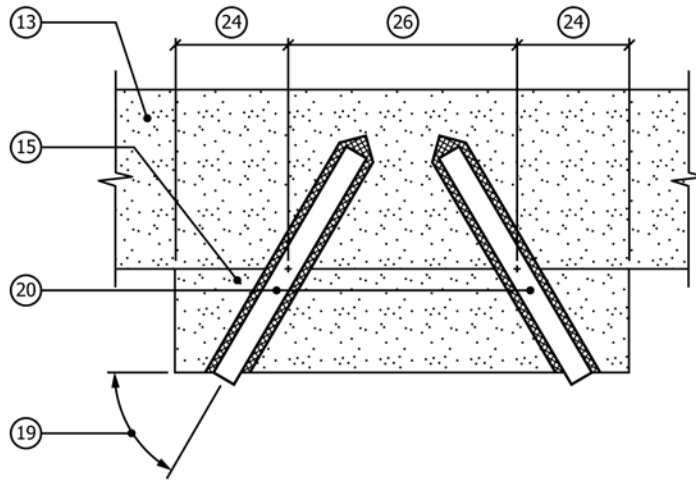
7.2 *Process Purpose*—In this section a recommended process is provided to help designers select and design anchors that provide a reliable and durable overall cladding system.

The process begins with preliminary design by evaluating exemplars, then confirms the system's fitness with engineering by structural analysis and appropriate physical tests. Engineering first evaluates individual parts of the system, then evaluates key assemblies of parts, then evaluates the fully built system.

7.3 *Process Scope*—This section outlines primary elements that should be considered in the design process. Extent of exemplar assessments, analyses and tests needed to formulate a well-performing preliminary design and establish its reliability and durability varies with the type of project, its size, location, and applicability of exemplars. Consider employing a specialist experienced with stone materials, anchors, backup and building structure to develop an assessment, analysis and testing program appropriate for the project if additional expertise is needed. All listed elements are not required for all projects. Some projects may require elements not listed.

7.3.1 Proposed cladding systems which have stone materials in thickness modules, panel sizes, anchors, and backups very similar to well-performing exemplars in the same climate may, at the architect's option, be exempted from some or all of the testing program if analysis assures the system is reliable and durable.

7.3.2 Proposed cladding systems that do not have sufficiently-old well-performing exemplars sharing similar stone materials in thickness modules, panel sizes, anchors and backups and in the same climate probably require testing and analysis during preliminary design. At the architect's option,



- ① SUPPORT ANCHORAGE ON COMPATIBLE, STABLE BACKUP.
- ② SEAL EPOXY FILLET ON TOP SIDE OF LINER WITH CAULK BEAD TO PREVENT CONDENSATION FROM ENTERING THE LAMINATION IF STONE ABSORPTION OR ENVIRONMENT RESULTS IN MOISTURE ON INSIDE OF PANEL.
- ③ SAWCUT REBATE IN EDGE OF STONE LINER BLOCK TO FORM A KERF WHEN ASSEMBLED ONTO FACE PANEL (PART 3). CLEAN EXCESS EPOXY FROM GROOVE IMMEDIATELY AFTER LAMINATION.
- ④ FILL KERF WITH COMPRESSIBLE MATERIAL TO HOLD PANEL POSITION AND CUSHION BEARING OF ANCHOR ON KERF.
- ⑤ ADJUST IN-OUT POSITION WITH PLASTIC OR METAL BEARING SHIM SLIGHTLY LARGER THAN ANCHOR'S FASTENED FACE. REQUIRED TO SEPARATE DISSIMILAR MATERIALS AND POSITION ANCHOR RELATIVE TO FRAMING. MINIMIZE THICKNESS TO MINIMIZE BENDING ON FASTENER (PART 9). THICKNESS AFFECTS FASTENER CAPACITY.
- ⑥ SUPPORT PANEL ON BACKUP (PART 1) WITH KERF ANCHOR. BRAKE-FORMED SHEET METAL, EXTRUDED, OR MODIFIED ROLLED SHAPE THAT IS NON-CORRODING AND FITS INTO SAWN KERF. AVOID MISALIGNMENT AND RESULTING PRYING ON CLADDING FROM INACCURATE FABRICATION OR INSTALLATION. SHOWN AS LATERAL PRESSURE AND WEIGHT SUPPORT.
- ⑥A SUPPORT PANEL WEIGHT ONLY ON BACKUP (PART 1) WITH SHELF ANGLE. BRAKE-FORMED SHEET METAL, EXTRUDED, OR MODIFIED ROLLED SHAPE THAT IS NON-CORRODING AND FORMS BEARING LEDGE. AVOID UNLEVELNESS AND RESULTING INSTABILITY FROM INACCURATE FABRICATION OR INSTALLATION. SHOWN AS WEIGHT SUPPORT ONLY.
- ⑦ ADJUST UP-DOWN POSITION OF ANCHOR (PART 6) RELATIVE TO BOTTOM OF LINER BLOCK (PART 15) WITH VERTICAL SLOT. ALLOWS FOR HEIGHT ADJUSTMENT AND FASTENER PLACEMENT TOLERANCES.
- ⑧ PREVENT SLIP OF THE CONNECTION AFTER VERTICAL ADJUSTMENT WITH DIAGONALLY SLOTTED WASHER PLATE, WELDED WASHER, OR SERRATED ANCHOR AND WASHER. DO NOT RELY ON FRICTION.
- ⑨ ATTACH ANCHOR TO BACKUP WITH FASTENER.
- ⑩ MINIMIZE KERF DEPTH. INCLUDING VARIANCES PER PART 22, MAINTAIN 3/8 IN. (10 mm) MINIMUM ENGAGEMENT OR TESTED MINIMUM.
- ⑪ BEAR STONE ON PLASTIC OR NON-COMPRESSIBLE RUBBER SHIM FOR LEVELING, SEPARATION, AND TO PREVENT PRYING OF STONE KERF FIN ON ANCHOR RADIUS. MAINTAIN ADEQUATE ENGAGEMENT IN KERF (PARTS 3 AND 10). ADJUST ANCHOR VERTICALLY WITH PART 7, NOT SHIMS.
- ⑫ MINIMIZE DISTANCE TO MINIMIZE ECCENTRIC WEIGHT ON ANCHORAGE, TO REDUCE FASTENER (PART 9) PULLOUT AND KERF ANCHOR (PART 6) DISPLACEMENT.
- ⑬ DIMENSION STONE CLADDING FACE PANEL.
- ⑭ ENGAGE DOWELS IN LINER FULL DEPTH (THICKNESS) OF LINER BLOCK. PRECUT DOWEL ENDS TO BE EXPOSED AS SHOWN SO ENGAGEMENT CAN BE VERIFIED.
- ⑮ STONE LINER BLOCK. SAME MATERIAL AS FACE PANEL (PART 13). ANCHOR CAPACITY VARIES NONPROPORTIONALLY WITH LENGTH OF BLOCK, THICKNESS OF BLOCK AND QUANTITY OF DOWELS ENGAGED.
- ⑯ LEAVE MINIMUM COVER OVER DRILLED HOLE OF 3/8 IN. (10 mm) TO HELP AVOID BLOW-OUT DURING DRILLING AND HELP PREVENT SPALLING OR SPOTTING FROM ABSORBED MOISTURE.
- ⑰ EMBED DOWEL INTO PANEL MINIMUM 2/3 OF CLADDING THICKNESS UP TO 3 IN. (75 mm) THICK, OR 2 IN. (50 mm) MINIMUM FOR CLADDING OVER 3 IN. THICK.
- ⑱ LOCK BLOCK WITH END CRAMPS OR SECONDARY DOWELS IN OPPOSING SLOPE TO PRIMARY DOWELS FULLY EMBEDDED IN APPROPRIATE EPOXY. PARTS TO BE NON-CORRODING METAL. REQUIRED ONLY IF PRIMARY DOWELS (PART 20) DO NOT OPPOSITELY SLANT TO, OR MECHANICALLY PREVENT BLOCK FROM DISENGAGING FROM FACE PANEL (PART 13) PER FIGURE 8C.
- ⑲ DRILL INCLINED-AND-OPPOSING DIRECTION HOLES OR TOENAIL HOLES IN HORIZONTAL PLANE THROUGH LINER (PART 15) INTO FACE PANEL (PART 13) FOR DOWELS (PARTS 18 AND 20). CLAMP DURING DRILLING AND DOWELLING.
- ⑳ TRANSFER LOAD FROM FACE PANEL (PART 13) TO LINER BLOCK (PART 15) WITH PRIMARY DOWELS FULLY EMBEDDED IN APPROPRIATE EPOXY. PARTS TO BE NON-CORRODING METAL. SLOPE IN DIRECTION OF LOAD OR TOENAIL UPWARDS AND HORIZONTALLY IN OPPOSITE ANGLES PER FIGURE 8C. DO NOT USE FASTENERS WITH EXPANDING SLEEVES IN LIEU OF DOWELS.
- ㉑ LAMINATE LINER BLOCK TO FACE STONE WITH COMPATIBLE EPOXY ADHESIVE. APPLY AFTER PROPER SURFACE PREPARATION. ALLOW TO CURE PROPERLY WITHOUT DISTURBING.
- ㉒ MAINTAIN CLEARANCE AT ROOT OF KERF TO AVOID POINT LOADING. ALLOW FOR SHIM VARIATIONS (PART 11), MOVEMENT, FABRICATION, AND INSTALLATION TOLERANCES.
- ㉓ EXPOSED BOTTOM EDGE THAT PREVENTS ANCHOR ACCESS TO EDGE.
- ㉔ KEEP DOWELS (PARTS 18 AND 20) 3/4 IN. (20 mm) MINIMUM FROM ROOT OF KERF (PER PART 10) AND EDGE OF BLOCK (PART 15).
- ㉕ HEIGHT OF BLOCK TO BE MINIMUM THREE TIMES EDGE DISTANCE (PART 24).
- ㉖ KEEP DISTANCE BETWEEN DOWELS (PARTS 18 AND 20) MINIMUM FOUR TIMES EMBEDMENT DEPTH (PART 17).
- ㉗ ESTABLISH MINIMUM ALLOWABLE BEARING HEIGHT ABOVE FASTENER (PART 9) TO CONTROL PULLOUT DUE TO LOADS PERPENDICULAR AND AWAY FROM FACE PANEL.
- ㉘ ESTABLISH MINIMUM ALLOWABLE BEARING HEIGHT BELOW FASTENER (PART 9) TO CONTROL PULLOUT DUE TO ECCENTRIC WEIGHT OF FACE PANEL(S) (PART 13).

NOTE 1—Parts 1–12, 14, 16–18, 21–23, 25, 27, and 28 are not used on Fig. 10c.

FIG. 10 c: Plan View Showing Horizontal Toenailing of Primary Dowels (continued)

systems without exemplars require an extensive testing program and analysis to attempt to predict system reliability and durability in the proposed application and its climate.

7.3.3 Projects to be built very similar to well-performing exemplars require less rigorous analysis and testing.

7.3.4 Projects to be built of less-commonly-used materials or common materials in unconventional systems lacking precedents of well-performing exemplars require more rigorous analysis and testing.

7.3.5 Assess exemplars to develop cladding system concept and complete preliminary engineering and testing before determining if the desired stone or the proposed cladding backup is appropriate. Do not choose a stone material for its appearance without verifying it is appropriate for the project climate. Also, do not choose a backup system without matching it to the project climate, stone anchor requirements and architectural arrangement of cladding.

7.4 Terminology:

7.4.1 *exemplar, adj*—a constructed example sharing some similar parts, assemblies, arrangements or exposures with the proposed system.

7.4.1.1 *well-performing, adj*—the example is serviceable its entire expected life. Serviceable stone cladding systems maintain their original integrity without more than routine upkeep. How long an example should be serviceable will vary by building type, owner, user, builder or designer, but the longer it remains serviceable, the more reliable and durable it is. A well-performing exemplar is only as reliable and durable to the extent its cladding system performs as expected over time.

7.4.1.2 *poor-performing, adj*—stone-cladding system integrity declines unexpectedly before it should. While observable deficiencies may show some parts of an example to be poor-performing, absence of seen problems without confirming performance by inspecting concealed conditions or testing does not necessarily make it a well-performing example.

7.4.2 *durable, adj*—the building system performs reliably during its entire service life and will endure environmental exposure and changes in adjacent elements without diminished serviceability. Make the design durable by assessing exemplars and including their well-performing elements while avoiding their poorly-performing elements.

7.4.3 *reliable, adj*—the building system performs while remaining in a safe state under load cases outlined by code or greater loads if required by the project. Establish reliability using an engineering evaluation that shows how well loads on cladding are carried through the panel, anchors and backup support system to the building structure.

7.5 *Preliminary Design*—Assess exemplars to extract concepts critical to developing preliminary designs with high reliability and durability. Assess both well-performing and poor-performing exemplars. The highest reliability and durability can be attained when the preliminary design includes elements of well-performing exemplars and excludes elements of poor-performing exemplars. General exemplar assessment should include the following:

7.5.1 Buildings using the same stone material being considered in the architectural concept, in an environment similar to the new project's location.

7.5.1.1 Check stone panel sizes, thickness, support points where possible. Research whether current quarry operations yield similar product and if tests of recently fabricated material are consistent with past production ten, twenty or fifty years ago. This check will help keep the architectural concept compatible with the structural properties of available stone materials and suggest the extent of new testing necessary.

7.5.1.2 Determine the realistic fabrication limitations of the stone by examining joint widths, piece sizes, piece shape, material quantity, visual range and consistency of color, veining, and markings, type of finish, cleanliness in its location of use on the building. Research by visiting the quarry, or fabricator, or both, when possible or practical whether current fabrication capabilities and currently quarried deposits represent stone material observed an exemplar.

7.5.1.3 Learn properties of currently produced stone by visiting the quarry, or fabricator, or both, when possible or practical, and by obtaining previous test reports or a written statement from the producer to compare it to stone material observed on exemplar.

7.5.2 Buildings supporting cladding with similar anchors or backup being considered for the new project, independent of stone type. Obtaining this information likely requires contacting potential anchor manufacturers and stone installers to locate exemplars and once exemplars are identified, perhaps contacting their structural engineer or architect. An experienced cladding specialist could help decipher this information without excavating the wall. Marrying the appropriate support with the desired material is as critical to attaining a durable project as choosing the appropriate stone type.

7.5.2.1 Inspect the facade surface as closely as possible for symptoms of internal distress such as staining, cracks, spalls, open joints, shifted panels. Using binoculars and hands-on where possible, check arrises, sills, copings, building corners, plane changes, and where cladding meets windows, curtainwall and roof at conditions similar to the proposed project.

7.5.2.2 Inspect the facade as closely as possible for signs of difficult fit, such as lippage, warped planes, uneven corners and tapering joints. Try to learn if building structure, backup, stone fabrication, or setting caused the problems.

7.5.3 Examine buildings that feature similar architectural elements or arrangements being considered, independent of stone, anchor, or backup type.

7.5.4 *Minimum Panel Thickness*, can vary with stone type, panel size, panel location and orientation on the building, exposure and expected service life, anchor type and arrangement, handling or shipping concerns, and architectural features like finishes and reveals. 7.5.4.1 recommends minimum nominal panel thicknesses of common stone types in typical conditions. Consider changing recommended thicknesses when conditions presented by 7.5.4.2 – 7.5.4.7 occur on the project.

7.5.4.1 *Stone Type*—Recommended minimum nominal thicknesses of exterior vertical, flat, smooth-finished panels that duplicate well-performing exemplars are: 30 mm (1 ¼ in) for granite, slate, high density limestone, group A marble and travertine; 50 mm (3 in) for coarse grained quartz-based stone and low-density limestone.

7.5.4.2 Size and Location on Building—Thicknesses shown in **7.5.4.1** could reduce if panels are smaller than approximately $\frac{3}{4}$ m² (8 ft²), or could increase if larger than 1 $\frac{1}{2}$ m² (16 ft²) or occur in high wind pressures.

7.5.4.3 Orientation and Exposure on the Building—With considerations in **7.5.4.2 – 7.5.4.7**, thickness could increase if panel experiences greater weather exposure than **7.5.4.2**'s typical panel or it is a coping, soffit, cornice, sill, overhang or liner block.

7.5.4.4 Expected Service Life: With Considerations—With considerations **7.5.4.2 – 7.5.4.7**, thickness could increase if facility is expected to remain in service longer than its exemplar.

7.5.4.5 Anchor Arrangement and How It Engages The Panel—With considerations **7.5.4.2 – 7.5.4.7**, thickness could increase if support and arrangement of anchors in combination with panel size cannot be refined to reduce stresses below allowable. Slots, notches, rebates, holes, or other hidden-face fabrications required for the anchor to engage and connect to the stone affect overall panel thickness. Comply with **5.3** principles to arrange anchors.

7.5.4.6 Handling or Shipping Concerns—With considerations **7.5.4.2 – 7.5.4.7**, thickness could increase if the fabricators specific review of project conditions or industry's published standards recommend so to address handling, shipping or other fabrication concerns.

7.5.4.7 Architectural Features—With considerations **7.5.4.2 – 7.5.4.6**, thickness could increase if exposed face finish or finishing process, reveals or false joints reduce the effective structural capacity or potential durability of the panel.

7.6 Engineering and Testing—Use conventional structural engineering analysis methods with appropriate physical testing of system samples to predict the structural capacity of the stone cladding system. The engineering and testing program should include the following:

7.6.1 Tests of samples from **Table 2** to confirm stone material properties exceed minimums required by design. Only test for properties important to how the stone will be used. New tests may be required if:

7.6.1.1 Existing data is more than two-years old, or

7.6.1.2 Existing data is not from area of quarry where project stone will be extracted, or

7.6.1.3 Project is large enough to justify project-specific tests or more specimens, or

7.6.1.4 Stone subjected to conditions different from conditions covered by existing test, or

7.6.1.5 Material properties are too variable to depend upon available data, or

7.6.1.6 Use of stone in system causes particular properties shown by structural analysis to approach maximum allowable design stresses. Test those properties;

7.6.1.7 If the desired stone has no exemplars in the project's climate.

7.6.2 Structurally analyze stone panel and compare test data to allowable design stresses (ultimate strength from tests reduced by safety factor appropriate for material and application).

7.6.3 Test actual anchor engaged into sample of project stone using Test Method **C1354/C1354M** or structurally analyze stone and anchor device to confirm anchor strength exceeds minimum required by design. Modify test procedure if required to match project conditions according to **7.5.2**. Isolating the anchor-to-stone condition may be necessary to verify anchor safety factors, which are higher for this part of the system than other system parts. New tests may be required if:

7.6.3.1 Structural calculations cannot conclusively model anchor behavior, or

7.6.3.2 Loads on anchor approach maximum allowed according to calculations not based upon tests, or

7.6.3.3 Anchors resist both lateral and gravity loads, or

7.6.3.4 Continuous edge anchors are less stiff than stone and thus may not provide effective support its full length, or

7.6.3.5 Anchor position in stone varies due to tolerances, or movement, or both, in facade system, or

7.6.3.6 Modifications to Standard Test Methods—Modify anchor test procedure to duplicate project conditions when:

(a) An anchor supports gravity and lateral loads. Preload anchor in test fixture with design gravity load times its factor of safety in the direction the load acts before adding lateral load;

(b) An anchor accepts differential floor-to-floor movement or bridges an expansion joint in backup. Set anchor in test fixture at extreme engaged and disengaged positions to determine condition causing minimum capacity.

(c) An anchor resists lateral loads in reversing directions. Apply loads in both directions at one times design load in that direction, repeat at two times design load, then three times, and continued until factor of safety is reached in both directions. Find fracture capacity by loading in the direction that pulls the panel off the building until failure.

7.6.4 Test full-size panel-and-anchor assembly using Test Method **C1201** to confirm system strength exceeds minimum required by design. Testing the assembled system may be necessary to verify behavior of the panel and assure parts work together properly. Also, isolating full-size panel from backup may be necessary to verify system factor of safety, which is higher for the panel-and-anchor assembly than the remaining facade system. Tests may be required if:

7.6.4.1 Panel is large and acts in two-way bending, or

7.6.4.2 Continuous edge anchor is not effective across entire panel length per **7.6.3.4**.

7.6.5 Where the backup is not the primary building structure engineered by others, structurally analyze backup to confirm movement and deflections can be accommodated where anchors engage stone. Confirm backup's connections to building can adjust to fit tolerances of structure without being altered. Detail structural design to not compromise integrity of thermal, moisture, and vapor retarder envelopes.

7.6.6 Use Test Method **C99** or **C880** specimens fabricated from low-stressed regions of Test Methods **C1354/C1354M** and **C1201** specimens and compare them to initial Test Methods **C99** or **C880** data to correlate results of the different strength test results. Consider difference, variability and behavior when finalizing anchor and system strength.

7.6.7 Test for durability when well-performing exemplars of sufficient age are not available by tailoring a project-specific procedure that follows Practice E632. Test should evaluate all the following elements that occur in the project climate:

- 7.6.7.1 Freeze-thaw cycling,
- 7.6.7.2 Extreme temperature cycling with or without moisture,
- 7.6.7.3 Resistance to chemical pollutants,
- 7.6.7.4 Resistance to chemical reaction from adjacent building components,
- 7.6.7.5 Strength reduction and warping tendency when exposed to above weathering forces, or a combination thereof.

7.6.8 Use Test Method C99 or C880 specimens fabricated from stock produced for the project at appropriate intervals to confirm stone material strength remains relatively consistent and exceeds minimum required by design for the entire project. Test these specimens immediately during production to minimize potential delivery of understrength stone to project. Conditions in which this type of production testing may be required include:

- 7.6.8.1 Project uses large quantities of stone, or
- 7.6.8.2 Stone material variability, or design, or both, suggest strength must be monitored and maintained, or
- 7.6.8.3 Geologic deposit, or quarry conditions, or both, may not assure material consistent with the initial tests will be provided for the entire project, or
- 7.6.8.4 Loads approach maximums allowed.

8. Materials of Construction

8.1 Metals:

8.1.1 Metals used for anchors or anchorage system components are selected according to their use:

8.1.1.1 Metal in contact with stone should be AISI Type 304 or 316 stainless steel, or bronze, or aluminum coated with epoxy paint or equivalent coating after fabrication. Mill finish or anodized aluminum can be used with granite. Consult metal industry references regarding specific application limitations and requirements, however, use Type 316 stainless steel when the project is exposed to chlorides, including locations exposed to deicing salt-laden road mists and locations within 5 to 10 miles of a saltwater body. Copper, brass and stainless steel wire are used for ties.

8.1.1.2 Stainless steel components less than ¼-in. (6-mm) thick should not be welded. Where welding is required in the assembly, use low-carbon versions of the alloys such as Type 304L where Type 304 is allowed and Type 316L where Type 316 is allowed.

8.1.1.3 Exterior wire ties used with cement mortar spots should be ductile stainless steel. Avoid copper and aluminum with mortar due to incompatibility. Stainless steel, copper, brass and aluminum can be used with gypsum or molding plaster for interior applications. Verify mortar or plaster will not darken or stain stone before using wire ties with spots for anchors.

8.1.1.4 Metal not in direct contact with stone exposed to weather should be stainless steel, galvanized steel, zinc-rich painted or epoxy-coated steel, or aluminum.

8.2 Sealants Used at Anchors:

8.2.1 Sealants to be used in anchor kerfs, slots or holes should be chosen for their proven durability and predicted compatibility with the stone, anchor, and any material occurring in the joint. The design authority should select a sealant that is recommended for the application by the sealant manufacturer, and has performed well under similar conditions. Consideration should be given to the sealant's ability to satisfy the required properties of resistance to staining and bleeding, surface adhesion, tear and peel strength, elasticity, compressibility, durometer hardness, and compatibility with any other building components that are likely to be in or near the anchor space.

8.2.1.1 The sealant manufacturer's recommendations for preparation of stone substrate, temperature range and conditions during application, and the necessity for a primer should be followed. The sealant manufacturer's recommendations should include tests performed with and without primer on the project's stone(s). Before beginning installation, verify performance on-site with sample applications and field tests. Repeat testing to confirm quality of installation.

8.2.1.2 Some sealants contain ingredients that may cause deleterious effects to the stone over time, such as: bleeding into stone, fluid migration, surface staining and dirt pickup. Before installation begins, the sealant manufacturer should test the proposed sealant on the project's stone in wet and dry conditions and ultraviolet exposure to verify no deleterious effects are likely to occur. Examination of exemplars may be the most reliable indicator of the potential for deleterious effects.

8.2.1.3 Sealants used at anchors should be compatible with sealants used in joints when they are in close proximity, even when they are not in contact. Techniques of applying and tooling sealant at anchors, and removing excess, frequently wipes residue onto surfaces where joint sealants may occur, or compounds involved with sealant work contaminate those surfaces. Avoid using incompatible sealants to avoid premature sealant failures or other deleterious effects.

8.3 Mortar Materials:

8.3.1 Portland cement, masonry cement, and lime used in preparing cement and lime mortar should be non-staining.

8.3.2 Non-shrink grout should not be used.

8.4 Gaskets Used at Anchors:

8.4.1 Gaskets to be used in anchor kerfs, slots or holes should be chosen for their proven durability and predicted compatibility with the stone, anchor, and any material occurring in the joint. The design authority should select a gasket that is recommended for the application by the gasket manufacturer, and has performed well under similar conditions. Consideration should be given to the gasket's ability to satisfy the required properties of resistance to staining and bleeding, tear strength, elasticity, compressibility, compression set, durometer hardness, resistance to ultraviolet, ozone and other atmospheric exposure, and compatibility with any other building components that are likely to be in or near the anchor space.

8.4.1.1 Follow the gasket manufacturer's and stone fabricator's mutually-recommended preparation of stone substrate to retain the gasket's designed position. Before beginning

installation, verify performance on-site with sample applications and field tests. Repeat testing to confirm quality of installation.

8.4.1.2 Some gaskets contain ingredients that may cause deleterious effects to the stone over time, such as: disintegrate, or penetrate into stone, also atmospheric degradation, surface staining and dirt pickup. Before installation begins, the gasket manufacturer should test the proposed gasket on the project's stone under wet and dry conditions, ozone and ultraviolet exposure, to confirm no deleterious effects are likely to occur. Examination of exemplars may be the most reliable indicator of the potential for deleterious effects.

8.4.1.3 Gaskets can be manufactured by extruding in a variety of shapes: tubular, lobed, cellular, and dual-durometer. Extruded solid or cellular foamed gaskets are usually santoprene or silicone. Neoprene, butyl, and vinyl materials should be avoided due to their poor resistance to atmospheric exposure and potential for staining. Gasket material should be selected and manufactured in accordance with Specification C509, if cellular, Specification C864, if solid, non-silicone, and Specification C1115, if silicone, to possess the properties required for proper performance in the intended application.

9. Installation Standards

9.1 *Documentation*—The basis for standard workmanship shall be established in the design documents issued to describe, regulate, or control the construction. These documents may be issued by the architect, engineer, the design-build authority, the contractor, or others authorized to impose law or code. Examples are as follows:

9.1.1 The architectural drawings and specifications identifying stone type, finish, thickness, sizes, and details and the relationship to other architectural elements and the building structure.

9.1.2 The architectural drawings and specifications identifying the scope of work and the materials required. These may: (1) define the performance criteria to be satisfied, (2) specify the standards of performance to be used in meeting those criteria, (3) provide for adequate performance guarantees for the materials and methods of construction, and (4) prescribe definitive material details and systems to satisfy project requirements. In addition, the specifications shall establish stone fabrication and installation tolerances. The tolerances recommended by stone trade associations could be used as a guide and included in the specification.

9.1.3 Project specifications shall cite the ASTM standard material specification (see 2.1) governing the stone intended for use and identify the classification or grade within that standard specification.

9.1.4 Shop drawings indicating in detail all parts of the work required, including material types, thicknesses, finishes and all other pertinent information dealing with fabrication, anchorage, and installation. The drawings shall show contiguous materials or assemblies which are provided by others in their range of positions according to their specified tolerances.

9.2 *Tolerances*—Installation tolerances and requirements, once specified, bind the installation contractor, by contract, to perform the work within those specified tolerances. The

specification requires the installation contractor to progressively examine the construction to which his work attaches or adjoins, reporting to the prime contractor any condition that may prevent performance within the standard established. Some commonly specified installation tolerances follow:

9.2.1 Variation from plumb of wall surfaces, arises, external corners, joints, and other conspicuous lines should not exceed $\frac{1}{4}$ in. (6.4 mm) in any story or in 20 ft (6.1 m) maximum.

9.2.2 Variation in level from grades shown for horizontal joints and other conspicuous lines should not exceed $\frac{1}{4}$ in. in 20 ft (6.4 mm in 6.1 m) maximum, nor $\frac{3}{4}$ in. in 40 ft (19.1 mm in 12.2 m) or more.

9.2.3 Variation in linear building lines from positions shown on drawings and related portion of wall facing should not exceed $\frac{1}{2}$ in. (12.7 mm) in any bay or 20 ft (6.1 m) maximum, nor $\frac{3}{4}$ in. in 40 ft (19.1 mm in 12.2 m) or more.

9.2.4 Variation in the face plane of adjacent pieces (lippage) should not exceed one fourth of the width of the joint between the pieces up to but not more than $\frac{1}{16}$ in. (1.5 mm) unless panel finish is not smooth or panel size exceeds 20 ft² (1.8 mm²).

9.3 *Workmanship*—Good construction requires mechanics that have previous successful experience installing similar stonework to do the new work. Less experienced personnel can only be allowed when they work in a crew continuously with the mechanic who has previous successful experience. Similar work means same type of site fabrication, anchorage, setting method, and support system as the new work.

10. Sealant Joints

10.1 Joints between stones should accommodate the following:

10.1.1 Stone dimensional tolerances,

10.1.2 Setting tolerances,

10.1.3 Dimensional changes in stone due to causes such as temperature changes, hysteresis, and moisture,

10.1.4 Building movement, such as column shortening and elongation, structural drift and twist and spandrel deflection,

10.1.5 Long-term effects caused by creep or plastic flow,

10.1.6 Anchors, and

10.1.7 Sealants and backer rod for correct sealant aspect ratio.

10.2 Horizontal joints usually accommodate more dimensional change than vertical joints.

10.3 Unrestrained movements within stone cladding normally cause no stress problems. Restraint imposed upon the movement of the cladding can result in excessive stress and eventual failure. Provision for soft, structurally open joints can prevent such failure.

10.3.1 A soft joint is one that precludes transfer of a load from an adjacent stone across a joint, provided each stone is individually anchored and, depending upon the sealant used, is usually dimensioned at two to four times the anticipated movement. For example, for an anticipated $\frac{3}{16}$ in. (4.8 mm) of movement, use a joint width of $\frac{3}{8}$ in. (9.5 mm) to $\frac{3}{4}$ in. (19.1 mm). In some designs, stones are stacked to transfer gravity loads. In the case of unengineered walls, if these stacks are applied more than 30 ft (9.14 m) above the adjacent ground

elevation, they should have horizontal supports spaced not over 12 ft (3.66 m) vertically above the 30-ft (9.14-m) height.

10.3.2 To maintain the unrestricted performance of a soft joint, the characteristics of the joint sealant should be considered.

10.3.3 Care should be exercised in the setting process to preclude the chance inclusion of hard materials in open joints. Resulting stress concentrations at restraint points can result in spalling of the stone or possible failure of the anchorage, or both.

11. Backup Structure

11.1 The backup structure is the means by which loads applied to the stone and anchors are transferred to the building's structure. This backup may be the building structure, a masonry wall, a metal strut system, or a prefabricated assembly. Whatever backup system is chosen, an understanding of the properties of that structure is prerequisite to the design of a cladding system. The design of the backup system should take into account gravity, wind, seismic, window, maintenance platform, shipping, and erection loads and the stone attachment means.

11.2 *Stone Setting on Masonry Backup:*

11.2.1 Masonry backup is appropriate (1) where the backup wall is part of the building design, such as a foundation, shear or bearing wall, (2) where a more dense masonry wall is required to reduce sound transmission, or as a protection from possible hazards, and (3) where the stone sizes or patterns are such that only a masonry wall is a practical backup wall. There are two general methods of setting stone on masonry backup: mortar set and dry set.

11.2.2 In a mortar set system, all stone joints are filled with mortar. Metal strap or rod anchors are used to attach all or portions of the stone to the backup. One end of the anchor is set into a sealant-filled hole or slot in the stone and the other is secured to the wall by suitable mechanical fasteners. The gravity load of the stone is carried by the foundation or relieving angles. A cavity is left between the back of the stone and the backup. The anchor must be capable of transferring the wind load to the backup.

11.2.3 In a dry set system, the stone is attached to the backup by anchors with a cavity between the back of the stone and the backup wall. The stone joints are filled with nonrigid materials, such as gaskets or sealants. Because a cavity exists between the back of the stone and the backup wall, the anchors should be designed to accommodate the wind loads. This system is not practical for cladding with irregularly shaped, small, or rubble stones.

11.2.3.1 The gravity load is carried by the foundation or relieving angles. When the gravity load is carried by a relieving angle, each stone is laterally restrained with either strap or dowel anchors. Strap anchors are appropriate where the stone is stacked vertically or is resting on setting shims. These anchors should be designed with sufficient flexibility to compensate for differential movement in the structure, such as that which can occur between the stone and a masonry backup wall.

11.2.3.2 There are several ways for attachment of the anchor to the backup wall. Expansion bolts may be used in 75 % solid

concrete masonry units. For hollow concrete masonry units used as backup walls, through bolts with fish plates should be used. The anchors may also be bolted to an intermediate structure, such as an angle, tube or channel which is in turn fastened to, or build into, a backup wall designed to carry such load.

11.2.3.3 Expansion bolts have limitations which should be considered in their use. Manufacturers of fasteners have conducted product testing and make test results available.

11.3 *Concrete and Masonry Backup Walls:*

11.3.1 Cast in place concrete backup walls are subject to shrinkage and expansion in the horizontal and vertical directions; the amount of dimensional change depends upon such factors as ambient temperature and humidity, mass, moisture content, reinforcement ratios, cement-to-aggregate ratios, and building height. These effects should be determined by the engineer of record. The greatest amount of dimensional change due to shrinkage usually occurs within the first eighteen months that the concrete is in place.

11.3.2 Concrete block walls are subject to shrinkage in both the horizontal and vertical directions. Reinforcement should evenly distribute the shrinkage. Dimensional changes usually occur within a month following the setting of the block.

11.3.3 Brick walls set with standard mortar are usually initially stable in dimension. However, bricks are subject to irreversible, net, long-term moisture, and freezing expansion in addition to reversible thermal expansion.

11.3.4 Terra cotta block backup walls are subject to expansion when wet and contraction when dry. It is possible for the expansion to continue through repeated wettings. If restraint to this expansion exists, the face of the wall can be deflected laterally.

11.4 *Metal Framing Systems:*

11.4.1 There are two types of frames: one composed of individual members fastened to the structure, usually referred to as struts, the other, a prefabricated assembly attached to the structure in large sections, usually referred to as trusses. Either system can be constructed of standard rolled structural sections or heavy-gage, galvanized, cold-formed sheet steel sections or aluminum sections prefabricated to suit the anchorage and building structural connections.

11.4.2 *Strut Systems:*

11.4.2.1 Struts are normally provided in floor height increments and usually not more than 15-ft (4.6-m) lengths.

11.4.2.2 The system should be designed for the maximum allowed deflection established by the engineer of record.

11.4.2.3 When struts expand vertically from floor to floor, a means should be provided for accommodating expansion and deflection in order to allow the strut to move independently of the struts placed above and below. To accomplish this, a horizontal expansion joint in the stone and backup structure is usually placed at or near the floor line.

11.4.2.4 Where the spandrel extends above and below the floor line, or from the floor line to the window head below, the required expansion joint is usually placed at, and as part of, the window head assembly.

11.4.2.5 Where spandrel and floor-to-floor strut systems interface, an expansion joint is required to accommodate differential movement.

11.4.2.6 Strut designs should consider the loads applied by contiguous window assemblies. This load data should be provided by the window fabricator and should include the amount of lateral displacement allowed in the window assembly at the head, sill, and combined assembly.

11.4.2.7 In the design of floor-to-floor struts, care should be taken to consider deflection of these struts under wind load. Lateral supports may be used above the ceiling line to shorten the unsupported height of the strut.

11.4.2.8 In the case of spandrel struts, rotation should be considered with the deflection check. It may be necessary to include a brace to either the bottom of the spandrel beam, if one exists, or to the slab behind. When a brace is applied to the floor slab, the floor structure should be checked for the effect of the applied load.

11.4.2.9 It is usually preferable to place the struts at fifth point locations behind each stone panel, though placement at other locations may be required due to the stone jointing pattern or lateral load factors. Placement of the struts at joint locations can reduce the number of struts by 50 %, but the decision to do so should take into consideration a requirement for longer and stronger shelf angles, thicker stone, or both. As with the requirement for proper structural analysis of the anchorage, a similar analysis is required for strut placement.

11.4.3 Truss Systems:

11.4.3.1 Prefabricated metal truss assemblies enable early closure of a building and offer good insulating capability. This lighter weight can be a major consideration in high-rise buildings and when seismic loading must be considered. This method of stone backup lends itself to the development of prefabricated facade configurations of almost any complexity.

11.4.3.2 The truss should be fabricated in accordance with AISC specifications and finished for corrosion prevention. The stone can be fixed to the truss at the truss fabrication shop. An alternative would be to ship the truss to another location and fix the stone to the truss there.

11.4.3.3 Trusses can be designed in floor height or structural bay width sizes, or both. In the floor height or combined configuration, the design is similar to that used for individual floor-to-floor struts except that provisions should be included for resistance to racking of the truss from transportation and installation loads and building structure movements. In the bay width design, additional complexities may be encountered due to elastic deflection in the slab edge, rotation of the supporting spandrel beam, or long-term effects such as creep in concrete structures.

11.4.3.4 Compared to the stone it supports, a metal truss is laterally more flexible under wind load. This factor should be considered when analyzing the structural behavior of the assembly under load.

11.4.3.5 Suspension of the truss from, or at, the columns should limit deflection.

11.4.3.6 Any loads from windows or other contiguous building components that might be transferred to the truss assembly should be accommodated in the design of the truss.

11.4.3.7 Truss assemblies are often designed with large areas and resultant large weights. This suggests consideration of redundant building connections to preclude catastrophic failure of the entire truss assembly in the event of a primary truss connection failure. These redundant connections can be part of the truss lateral bracing or can be separate connections.

11.4.3.8 Loading tests done on mockups are to be carried to a multiple of design load and hold time. Such test loads and hold times are to be determined by the architect or engineer of record. Each connection on the truss must perform as expected under these conditions without permanent set. Anchors should be load tested to confirm calculated performance predictions. The need for separate stone tests are discussed elsewhere in this guide.

11.5 Precast Concrete Backup:

11.5.1 Precast concrete backup systems are used to permit faster enclosure, allowing earlier work by other trades and subsequent earlier occupancy. Attachment of the system to the building can be accomplished completely off the floor and does not require elaborate temporary scaffolding.

12. Water Infiltration

12.1 Regardless of the care taken to preclude water intrusion behind stone cladding by the use of joint design or sealants, it should be accepted that leakage will occur during the lifetime of the building. A secondary defense should be established to preclude the entrapment of this water and subsequent intrusion into the interior of the building. This is best accomplished through the use of flashing and weeping.

12.1.1 Provided that fire safing does not interfere, the provision for flashing and weeping should be provided at each floor or some multiple of floors. A maximum of two floor multiples, or 25 ft (7.6 m) is suggested. Weeps at the flashing should be spaced horizontally approximately 16 to 24 in. (40.6 to 61.0 cm) apart. Often, weeps are placed at joint intersections where there will be no interference from anchors and where the weep tubes can be easily encapsulated with sealant.

12.1.2 The cavity between the back of the stone cladding and the backup structure should be vented to remove vapor through the use of vents. The size and number of the vents should be determined by the design engineer.

12.1.2.1 The weep and vent tube should have an outside dimension that can be accommodated in the joint width. Rope or felt wicks can also perform the function of the weep.

12.1.2.2 The vapor vent tubing should run vertically behind the stone to a height that will prevent wind-driven rain from intruding into the cavity. (See Fig. 11.)

12.1.3 Much of the water vapor occurring behind a stone cladding derives from the higher humidity of the building's interior. A proper vapor barrier should be provided as part of the exterior wall backup system, extending from the floor slab to the slab or structure above, and from window unit to window unit, completely isolating the exterior wall cavity from the interior.

12.1.4 Failure to provide an effective vapor barrier will allow condensate to form on the interior side of the stone, which can become entrapped in kerfs and holes, possibly leading to freeze-thaw cycling failures that can destroy the

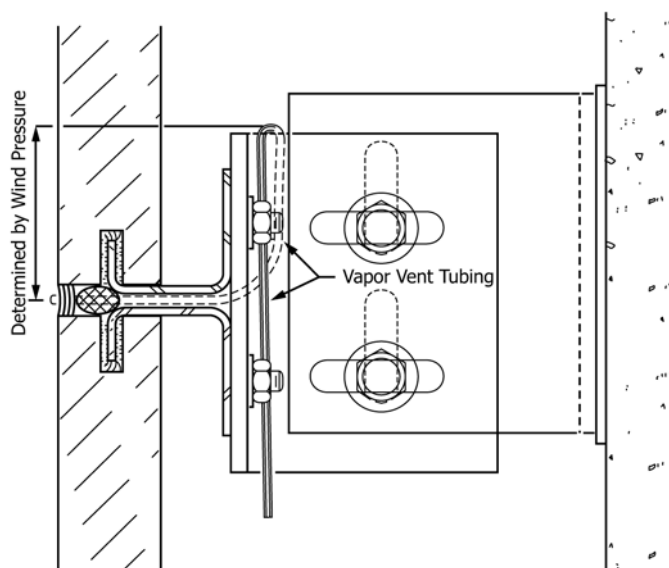


FIG. 11 Vapor Vent Tubing

integrity of the stone at the anchorage points. Further, the condensate can lead to the deterioration of sealants through sealant subsurface liquification and to the corrosion of steel.

Even if no structural failure occurs, entrapped condensate can migrate to the face of the stone and cause staining.

12.1.5 The joint sealant is the primary defense against water intrusion but cannot be relied upon to provide a waterproof barrier. The sealant should be carefully chosen and specified. Several types are available, each with its own characteristics regarding adhesion, cohesion, elongation, lifespan, modulus, and color. Oil-based and non-skinning sealants should not be used due to the probability of staining the stone or themselves becoming stained. Adhesion of properly selected and applied sealant to the stone is usually not a problem. However, adhesion to adjacent surfaces may become a problem. Certification by the sealant manufacturer of the suitability of the product for the intended application should be obtained prior to its use on the work. The recommendation of the manufacturer should be followed regarding the possible requirement for priming the surface of these materials. It is strongly recommended that a test panel be erected in the field at least one month, preferably three or more, prior to job application, as a step toward confirming performance.

13. Keywords

13.1 anchor types; backup; consultants; design considerations; design process; exemplar; joints; materials of construction; stone anchors; stone installation; stone testing; water infiltration

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