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Standard Guide for Design, Selection, and Installation of Stone Anchors and Anchoring Systems[1]

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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 the standard. The SI units given in parentheses are for information only.

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:*

C 97 Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone[2]

C 99 Test Method for Modulus of Rupture of Dimension Stone[2]

C 119 Terminology Relating to Dimension Stone[2]

[1] This guide is under the jurisdiction of ASTM Committee C18 on Dimension Stone and is the direct responsibility of Subcommittee C18.06 on Anchorage Components and Systems.

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[2] *Annual Book of ASTM Standards*, Vol 04.07.

TABLE 1 Dimension Stone Test Methods

Stone Type	ASTM Specification
Calcite[A]	C 503
Dolomite[A]	C 503
Granite	C 615
Limestone[B]	C 568
Marble (exterior)[B]	C 503
Quartz-Based[B]	C 616
Quartzite[A]	C 616
Quartzitic Sandstone[A]	C 616
Sandstone[A]	C 616
Serpentine[A]	C 503
Slate (roof)	C 406
Slate (walls)	C 629
Travertine[A]	C 503

[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	C 97
combined shear with tensile unit strength from bending	C 99
ultimate crushing unit strength	C 170
primary tensile unit strength from bending	C 880
capacity and deflections of panels assembled with their anchors onto their supporting backup structure	C 1201
individual anchor stength	C 1354
accelerated production of service life	E 632

C 170 Test Method for Compressive Strength of Dimension Stone[2]
C 406 Specification for Roofing Slate[2]
C 503 Specification for Marble Dimension Stone (Exterior)[2]
C 615 Specification for Granite Dimension Stone[2]
C 616 Specification for Quartz-Based Dimension Stone[2]
C 629 Specification for Slate Dimension Stone[2]
C 880 Test Method for Flexural Strength of Dimensional Stone[2]
C 1201 Test Method for Structural Performance of Exterior Dimension Stone Cladding Systems by Uniform Static Air Pressure Difference[2]
C 1354 Test Method for Strength of Individual Stone Anchorages in Dimension Stone[2]
E 632 Practice for Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials[3]

3. Terminology

3.1 *General Definitions*—For definitions of terms used in this guide, refer to Terminology C 119.

3.2 Specific definitions used in the design process are listed in 8.4.

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, 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 Provisions of dimension stone handbooks, manuals, and specifications should be reviewed for compatibility with the principles outlined in this guide.

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.

5. Installation Standards

5.1 *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:

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

5.1.2 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.

5.1.3 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.

5.1.4 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.

5.2 *Tolerances*—Installation tolerances and requirements,

[3] *Annual Book of ASTM Standards*, Vol

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:

5.2.1 Variation from plumb of wall surfaces, arises, external corners, joints, and other conspicuous lines should not exceed ¼ in. (6.4 mm) in any story or in 20 ft (6.1 m) maximum.

5.2.2 Variation in level from grades shown for horizontal joints and other conspicuous lines should not exceed ¼ in. in 20 ft (6.4 mm in 6.1 m) maximum, nor ¾ in. in 40 ft (19.1 mm in 12.2 m) or more.

5.2.3 Variation in linear building lines from positions shown on drawings and related portion of wall facing should not exceed ½ in. (12.7 mm) in any bay or 20 ft (6.1 m) maximum, nor ¾ in. in 40 ft (19.1 mm in 12.2 m) or more.

5.2.4 Variation in the face plane of adjacent pieces (lippage) should not exceed one fourth of the width of the joint between the pieces.

5.3 *Consultants*—Some conditions require professional expertise to determine proper fabrication, installation, engineering, and testing of stone construction.

5.3.1 Particular conditions where special expertise is suggested to achieve a reliable installation: In some instances the services of a professional stone cladding designer may be required.

5.3.1.1 In those instances where complex connections or extraordinary loading conditions or materials and methods of unknown or questionable performance records are likely to be considered or specified, a stone design specialist may be needed.

5.3.1.2 Whether such special design skill is required will depend on one or more of the following: knowledge of the performance record of the specified systems and materials; complexity of the cladding system; complexity of anchors and connections; unusual or extreme loading condition; unusual frame or structural system planned for the project; and building code requirements or orders of authorities having jurisdiction.

5.3.1.3 Multiple cladding materials on same facade.

5.3.1.4 Supporting structure is more flexible than L/600 in any direction.

5.3.1.5 Extreme loadings caused by seismic, hurricane, tornado, or installation and handling methods.

5.3.1.6 Special building code requirements prevail.

5.4 *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.

6. Materials of Construction

6.1 *Metals*:

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

6.1.1.1 Metal in contact with stone should be 300 series stainless steel, Types 302 and 304 being the most commonly used. Other metals may be used if properly protected against moisture and galvanic action. Copper and stainless steel wire are used for wire ties.

6.1.1.2 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.

6.2 *Joint Sealants*:

6.2.1 Sealants used in contact with stone can be of the type recommended for the application by the manufacturer, but proper consideration should be given to their ability to satisfy the required properties of tear and peel strength, elasticity, compressibility, durometer, resistance to soiling and fading, and compatibility with any other sealant with which it may come in contact.

6.2.1.1 The manufacturer's recommendation should be followed in respect to temperature range of application, the condition of the substrate and the necessity for a primer.

6.2.1.2 Some sealants may bleed into stone; proper testing is recommended.

6.3 *Mortar Materials*:

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

6.3.2 Non-shrink grout should not be used.

6.4 *Gasket Materials*:

6.4.1 Gasket material selection should be made to satisfy the movement and tolerance requirements. Gaskets are available in a variety of sections: tubular, lobed, and cellular being the most common. Some gasket materials may bleed into some stones and cause staining. The recommendation of the manufacturer should be followed. Testing may be prudent where information from the manufacturer is not sufficient assurance that bleeding will not occur.

6.4.1.1 Extruded gaskets are usually neoprene or vinyl.

6.4.1.2 Cellular gaskets are usually foamed butyl, polyethylene, or polyurethane.

7. Design Considerations

7.1 Before selecting an anchor system and a support system, certain factors shall be established:

7.1.1 The performance of the stone material under consideration on existing buildings in similar exposures.

7.1.2 The performance of the anchorage and support system under consideration on existing buildings in similar exposures.

7.1.3 The behavior of the anchorage. Anchor and stone together as an assembly are called an anchorage.

7.1.4 The behavior of the facade system. An anchorage with cladding upon a support system is called a facade system.

7.1.5 The physical characteristics of the stone.

7.1.5.1 Some of the material's properties and inconsistencies can be determined by Test Methods C 97, C 99, C 170, and C 880.

7.1.5.2 Other properties, including (but not limited to) bowing tendency, resistance to chemical attack, and weather-related strength reduction and dimensional changes, may be determined by tests designed to obtain such data. For instance, Test Method C 880 may be modified to produce data revealing the effect of a desired finish. Specific tests may also be designed to obtain the effect of weathering on the selected stone. Committee C-18 is in the process of developing test procedures to evaluate these properties.

7.1.6 Establish design loads and safety factors.

7.1.7 Establish wind and seismic loads.

7.1.8 Anticipate building dimensional changes.

7.1.8.1 Consider wind-load sway, thermally induced change, elastic deformation, and seismic movement; creep and shrinkage should also be considered.

7.1.9 Determine all likely combinations of building and cladding movements.

7.1.10 Accommodate contiguous substructures and components such as window supports, window washing tracks, and backup wall insulation.

7.1.11 Design moisture control through joint design, sealant choice, and internal moisture collection and ventilation systems.

7.1.12 Evaluate potential corrosion due to galvanic and chemical reactions.

7.1.13 The following general rules are helpful in the design of anchors and connections.

7.1.13.1 The simplest connections are usually the best.

7.1.13.2 Make connections with the fewest components.

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

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

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

7.1.13.6 Make anchor connection locations accessible to the craftsman.

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

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

7.2 *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. Appendix X1 discusses in detail the subject of stone safety factors.

8. Design Process

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

8.1.1 *Stone Panels*, cladding the facade,

8.1.2 *Joints*, between the panels,

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

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

8.1.5 *Primary Building Structure*.

8.2 *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.

8.3 *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.

8.3.1 Proposed cladding systems which have stone materials in thickness modules, panel sizes, anchors, and backups very similar to well-perfoming 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.

8.3.2 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, 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.

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

8.3.4 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.

8.3.5 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.

8.4 *Terminology*:

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

8.4.1.1 *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.

8.4.1.2 *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.

8.4.2 *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.

8.4.3 *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.

8.5 *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:

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

8.5.1.1 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.

8.5.1.2 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.

8.5.1.3 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.

8.5.2 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 decifer 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.

8.5.2.1 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.

8.5.2.2 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.

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

8.6 *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:

8.6.1 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:

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

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

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

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

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

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

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

8.6.2 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. See Appendix X1).

8.6.3 Test actual anchor engaged into sample of project stone using Test Method C 1354 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 8.5.2. 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:

8.6.3.1 Structural calculations cannot conclusively model anchor behavior, or

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

8.6.3.3 Anchors resist both lateral and gravity loads, or

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

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

8.6.3.6 *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 (see Appendix X1) is reached in both directions. Find fracture capacity by loading in the direction that pulls the panel off the building until failure.

8.6.4 Test full-size panel-and-anchor assembly using Test Method C 1201 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:

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

8.6.4.2 Continuous edge anchor is not effective across entire panel length per 8.6.3.4.

8.6.5 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.

8.6.6 Use Test Method C 880 or C 99 specimens fabricated from low-stressed regions of Test Methods C 1354 and C 1201 specimens and compare them to initial Test Methods C 880 or C 99 data to correlate results of the different strength test results. Consider difference, variability and behavior when finalizing anchor and system strength.

8.6.7 Test for durability when well-performing exemplars of sufficient age are not available by tailoring a project-specific procedure that follows Practice E 632. Test should evaluate all the following elements that occur in the project climate:

8.6.7.1 Freeze-thaw cycling,

8.6.7.2 Extreme temperature cycling with or without moisture,

8.6.7.3 Resistance to chemical pollutants,

8.6.7.4 Resistance to chemical reaction from adjacent building components,

8.6.7.5 Strength reduction and warping tendency when exposed to above weathering forces, or a combination thereof.

8.6.8 Use Test Method C 880 or C 99 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:

8.6.8.1 Project uses large quantities of stone, or

8.6.8.2 Stone material variability, or design, or both, suggest strength must be monitored and maintained, or

8.6.8.3 Geologic deposit, or quarry conditions, or both, may not assure material consistent with the initial tests will be provided for the entire project, or

8.6.8.4 Loads approach maximums allowed.

9. Anchor Types

9.1 *Anchor for Attaching Stone to Precast Concrete*:

9.1.1 Dowel-type cladding anchors are generally smooth or threaded 300 (usually Type 302 or 304) series stainless steel rods inserted into holes in the back of the stone cladding.

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

9.1.1.2 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. 1.)

9.1.1.3 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 $\frac{3}{8}$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 2½ in. (64 mm).

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

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

9.1.2 Spring-type anchors, often referred to as hairpin anchors, are preformed from 300 series stainless steel. The recommended minimum diameter is $\frac{5}{32}$ in. (4.0 mm). Hairpin anchors are oriented perpendicular to the load. The number of anchors is determined by analysis and testing.

9.1.2.1 The anchor embedment into the back of the stone is usually ¾ 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. 1.)

9.1.3 Precast cladding anchors, whether dowel or hairpin type, have certain shear and tensile (pull out) values for each stone variety and concrete type and strength. These values are determined from tests of the actual concrete and cladding stone being considered.

9.1.3.1 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.

9.1.4 Cladding anchors should be uniformly distributed.

9.2 *Wire Ties*—Wire ties have been used longer than any other technique in anchoring stone. They are simple and follow the general rules as stated in 7.1.9. They are used extensively in interior applications, around elevators, stairs, and lobbies and used on exteriors for low- and medium-size buildings. (See Fig. 2.)