MARBLE INSTITUTE of America
Setting the Standards in the Natural Stone Industry

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Dimension Stone Anchorage Theory, Practice, & Components

Forward: This bulletin is intended to serve as a general guide to the practice of mechanically anchoring dimension stone. Reading this document will not make one a stone cladding engineer, in fact, it is not written with the intent of guiding engineers. It was prepared as a guide to the tradesperson, and provides general valuable insight as to how stone anchorage devices interface with the stone panels and the building structure. Common anchorage devices are discussed, as well as some guidance regarding why certain anchor device selections may be more appropriate than others in particular situations.

1.0 Stone Anchorage Theory: Webster's dictionary defines the word "anchor" as "any device that holds something else secure," and that is simply the role of the dimension stone anchor: to hold the dimension stone securely.

1.1. Newton's law states that "a body at rest tends to stay at rest, unless acted upon by an outside force." So obviously, there must be an outside force involved, or there would be no reason to anchor the stone at all. Actually, there are three primary outside forces:

1.1.1. Gravity: This is perhaps the easiest of the forces to comprehend, because anyone who has lifted a piece of stone understands that it is heavy. Gravity is always vertical in direction, and always proportional to the mass of the stone panel. Obviously, gravity is the same intensity regardless of the location of the building (assuming the building is on this planet).

1.1.2. Wind: Perhaps not as obvious as gravity, wind exerts pressures on the buildings walls, and can be both positive (the wind pushing on the wall cladding) or negative (the wind sucking on the wall cladding). Typically, negative wind loads are greater than positive wind loads on a given building, and wind loads near corners or other regions of discontinuity of the building tend to be greater. Wind loads will always be in a direction normal (perpendicular) to the face plane of the stone, and will be proportional to the area of the stone panel. In some cases, wind loads can be additive to gravity loads, for instance the wind suction acting on a soffit panel, or windloads acting on a clip design, causing it to rotate in the same manner as the gravity loads already imposed upon it. Design windloads change based on the building's location, height, shape, and neighboring influences. Windloads will be expressed as a pressure, either pounds per square foot (lbs/ft²) in U.S. customary units, or Pascal (Pa) in SI units.

1.1.3. Seismic: Seismic loads are due to accelerations of the earth during an earthquake or aftershock. Unlike windloads, seismic loads can be both perpendicular and parallel to the face plane of the stone, and will be proportional to the mass of the stone panel. In general engineering practice, as mandated by code, seismic and wind loads need not be considered cumulatively, as the probability of the building experiencing simultaneous maximum occurrences is negligible. Seismic loading is regionally specific, as the probability of an earthquake, as well as the maximum possible intensity of an earthquake vary based on the building's location. For forces occurring perpendicular to the face of the stone in thin stone clad-

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ding applications, windloads will generally be greater than seismic loads and will usually govern most aspects of the design.

1.2. Load Paths: It has been said that structural engineering can be thought of as a two part process. Part one is to identify and quantify the loads, while part two is to create a path to carry those loads back to the earth. In section 1.1 we've identified the primary loads, and the next task is to create the load path that will carry these loads back to the ground. That load path starts with the stone panel, which will transfer the loads to the stone anchors. The anchors then transfer the loads to the building frame, which transfer the loads to the building's foundation and footings, which ultimately transfer the loads back to the earth. If the preceding reminds you of someone singing "the leg bone's connected to the hip bone…", you may be more intuitive than you think. The human body's musculoskeletal system works similarly. If you pick up a heavy object with your hand, that load is transferred from your hand, to your wrist, to your arm, shoulder, torso, hips, legs, ankles, feet, and ultimately carried back to the earth. And if that object happens to be an umbrella on a windy day, a significant portion of that load is lateral windload.

1.2.1. The Stone Panel as a Beam: The first part of this load path is the stone panel. (See Figure 1) Sophisticated computer programs exist to accomplish finite element analysis of the stone panel and allow engineers to identify omni-directional stresses within the stone panel when subjected to loads. While these programs are useful and necessary to analyze non-rectilinear panels, or panels with asymmetrical anchorage configurations, in most cases the stresses within the stone panel can be calculated with more conventional methods. We can think of the stone panel being a simple beam, one which receives a uniform load along its span, and carries those loads back to the anchor points, which more often than not, occur at the stone panel's perimeter. Resisting this load results in a flexural stress within the stone panel, and the design engineer must ascertain that this flexural stress does not exceed the allowable flexural stress (allowable stress would be the stone's flexural strength divided by the appropriate factor of safety). The flexural stress experienced by the stone involves three basic considerations: load, span, and depth (thickness). Obviously, the greater the load, the greater the stress experienced within the stone panel. The span, or the distance between the anchor points greatly affects the stress within the panel. Increasing the span not only increases the bending stresses within the stone beam, but also increases the area, which increases the total load, therefore it has a "squared" relationship – all other things being equal, doubling the span will quadruple the stress. The last factor is the depth of the beam, or in this case, thickness of the stone slab. This also has a "squared" relationship to stress, so that doubling the thickness will reduce the stress by a factor of four.

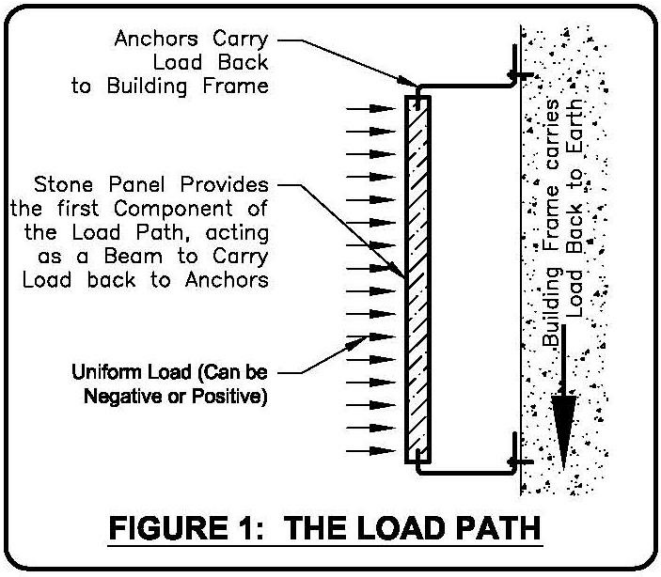

FIGURE 1: THE LOAD PATH

2.0 Stone Anchorage Devices

2.1. The next leg of the load path is the stone anchor. There are three elements to the stone anchor: the interface between the anchor and the prep cut into the stone panel, the anchor itself, and the connection of the anchor to the building structure.

2.1.1. The preparation machined into the stone panel that receives the anchor has a high level of influence on the strength of the entire assembly. The prep cut into the stone will usually be a hole,

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"plunge-cut" kerf, kerf of a determined distance, or a continuous kerf. In most cases, when anchors are tested to failure, the mode of failure is the fracture of the region of the stone panel that surrounds the anchor prep. For this reason, increasing the thickness or diameter of penetrating portion of the device can often lead to a decrease in strength, because it requires a larger prep to be machined into the stone, leaving less stone material surrounding the prep to resist the load. Increasing the length of the tab will generally increase the strength of the engagement into the stone.

2.1.2. The metal anchor itself requires analysis to ensure that it has sufficient strength to resist the loads to which it is subjected. In the case of a load bearing clip (or shelf) angle, the load is the gravity induced dead load of the stone panel acting to bend the horizontal leg of the angle downward. In the case of the lateral load strap anchor, the load is the negative or positive windload that acts against the engaged tabs (or pins) of the anchor attempting to bend them inward or outward, the positive windload that acts against the horizontal leg of the anchor attempting to buckle it, and the negative windload acting against the vertical leg of the anchor against the structure, attempting to pry it away from the building frame.

2.1.3. The connection to the building structure is generally the last component of the load path for which the stone installer is responsible. Common fastening techniques include expansion anchors into concrete, welding to embedded hardware in concrete, welding or bolting to structural steel, or installing self-drilling/self threading fasteners into light gauge metal frame.

3.0 Common Anchor Types

3.1. A myriad of different mechanical devices exist for anchoring stone, some of which are proprietary. Below is a partial list and brief description of the more common types traditionally used:

3.1.1. Clip (or Shelf) Angle: Similar to shelf angles used for brick masonry, sections of angle are commonly used for support of the deadload of stone (See Figure 2A).

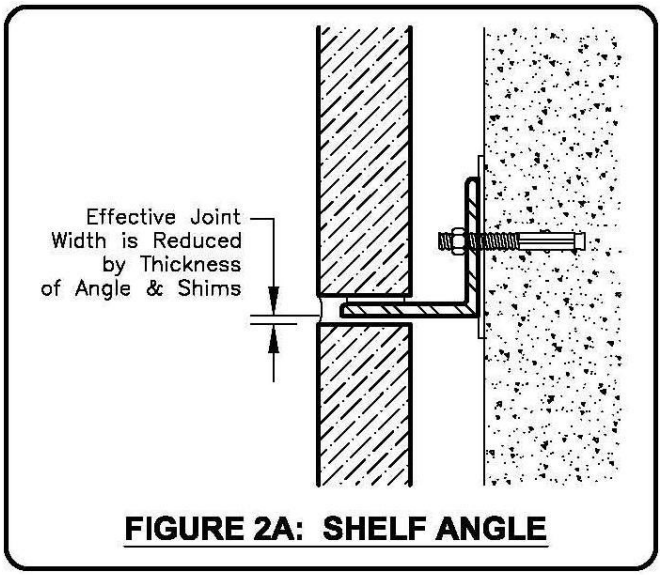

FIGURE 2A: SHELF ANGLE

Unlike their use in brick masonry, shelf angles are rarely continuous when used in stone, as it is more efficient to use short, thick sections of angle than long, lighter sections of angle, and it eliminates the need to compensate for the camber present in long lengths of steel sections. Shelf angles are commonly made of mild steel with appropriate corrosion protection, and in themselves, carry gravity loads only. Shelf angles can be converted into multi-directional load resisting devices by adding a small clip to them, which penetrates a kerf in the stone (See Figure 2C). Because the clip penetrates the stone, it must be of stainless steel. The clip is normally bolted to the angle and insulated from the mild steel by a dielectric separator. Depending on the joint size between the stone panels and the anticipated inter-panel movements, "rebates" are sometimes cut in the bottom edge of the stone panels to receive the shelf angles, thus allowing for the full, unrestricted movement capability of the joint (See Figures 2B, 2D).

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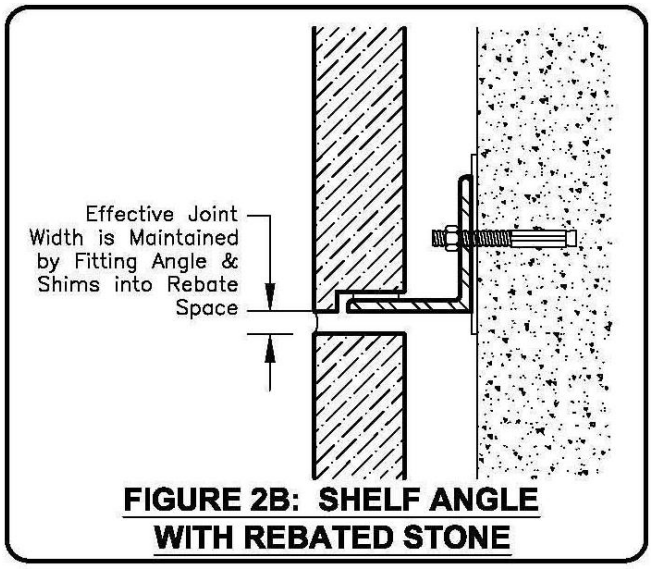

FIGURE 2B: SHELF ANGLE WITH REBATED STONE

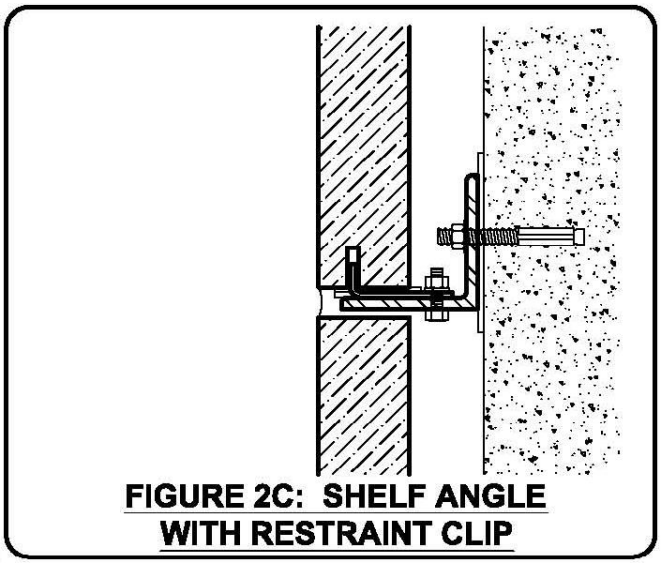

FIGURE 2C: SHELF ANGLE WITH RESTRAINT CLIP

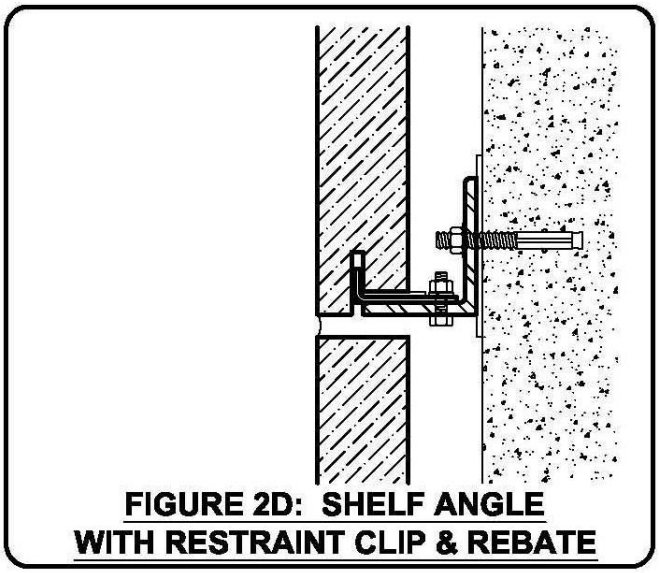

FIGURE 2D: SHELF ANGLE WITH RESTRAINT CLIP & REBATE

3.1.2. Bent Stainless Steel or Welded Stainless Steel T's: On projects where higher corrosion resistance is desired, mild steel shelf angles are replaced with stainless steel sections. (See Figure 3A, 3B)

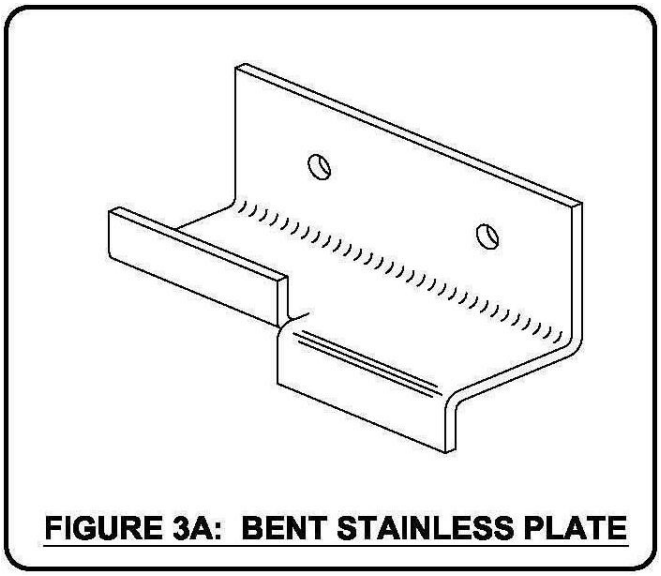

FIGURE 3A: BENT STAINLESS PLATE

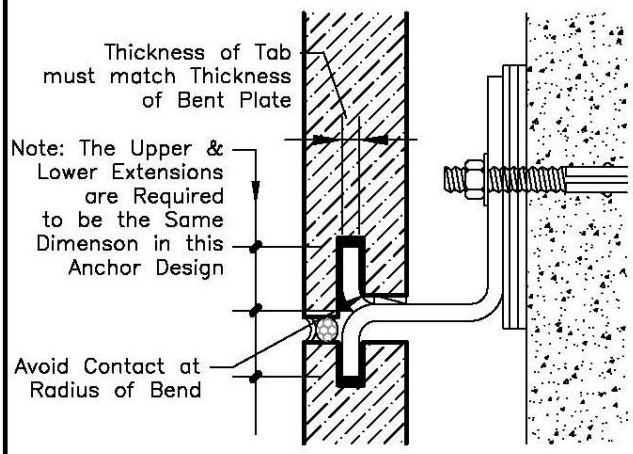

FIGURE 3B: INSTALLED BENT PLATE

Generally, the stainless section will be a bent plate, and the lateral load resistance will be accomplished by either "tabs" bent at the end of the plate, or a separate strip of stainless that is welded to the end of the plate. Welding a separate strip has the advantages of using a lighter thickness of metal for this portion (decreasing the width of the prep that must be machined into the stone), allowing for full length engagement into both the upper

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and lower stones, eliminating the radii of bending (which can be substantial in heavier sections) at the tabs, and accommodating asymmetrical relationships between the top and bottom embedment tabs (See Figure 3C & 3D). Depending on the joint size between the stone panels and the anticipated inter-panel movements, "rebates" are sometimes cut in the bottom edge of the stone panels to receive these stainless steel sections, thus allowing for the full, unrestricted movement capability of the joint.

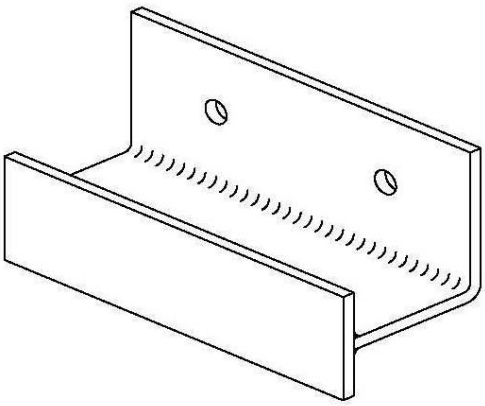

FIGURE 3C: WELDED STAINLESS STEEL "T"

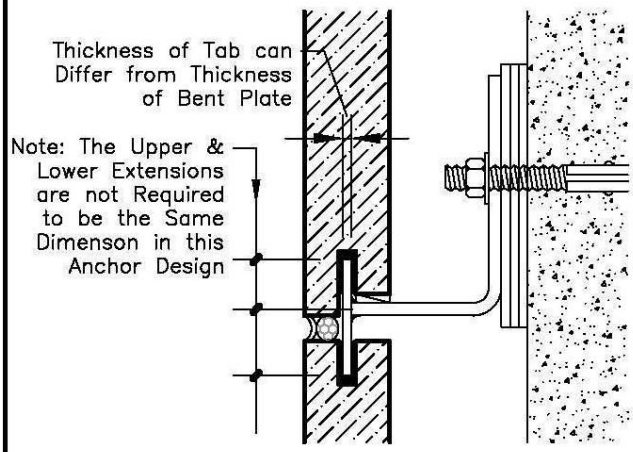

FIGURE 3D: WELDED STAINLESS STEEL "T" IN REBATED STONE

3.1.3. Similar to the anchors discussed in 3.1.2., bent stainless steel plates are also used in load bearing conditions with the restraint provided by a pin that is either swaged into or welded to the plate. (See Figures 4A & 4B)

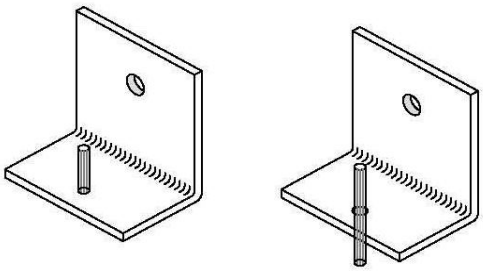

FIGURE 4A: BENT PLATE WITH PINS COMBINATION ANCHOR

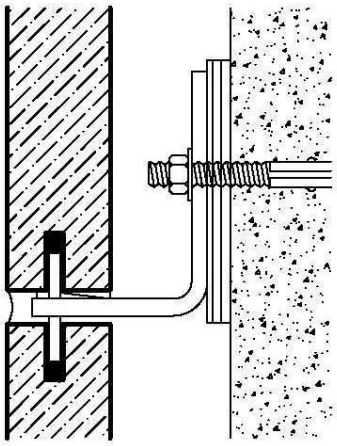

FIGURE 4B: BENT PLATE WITH PINS ANCHOR INSTALLED

Using the cylindrically shaped dowel to engage a drilled hole in the stone provides the advantage of less stone removal, and generally higher strengths. The hole diameter is necessarily oversized to receive the pin. The recommended oversizing is 1/8" (3 mm), providing and annulus region measuring 1/16" (1.5mm). Since this dimension creates challenges in alignment of preps between adjacent stone panels sharing common anchors, some fabricators oversize the holes by larger dimensions, albeit generally not recom-

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mended. It is always necessary to test the anchor with a test specimen that has the same diameter hole as will be used in the production stock. In some cases, the hole will be field drilled, but whether a field or factory performed task, the drilling must be done with a diamond abrasive bit using non-percussive drilling equipment (no hammer drilling, please).

3.1.4. Aluminum Extrusion: Aluminum extrusions are commonly used as combination gravity & lateral load restraint devices (See Figure 5). They can be used as both short sections and as

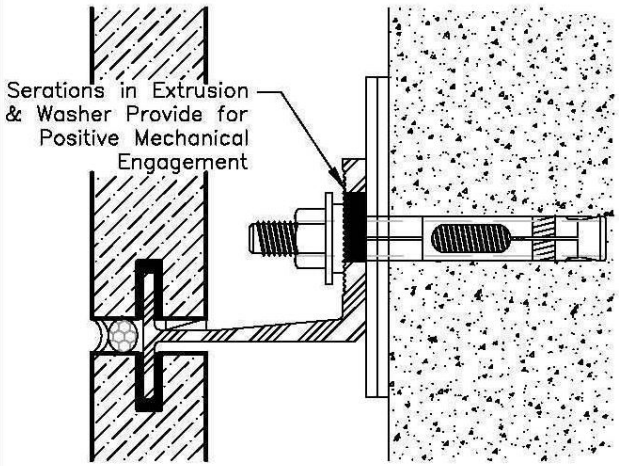

FIGURE 5: ALUMINUM EXTRUSION

continuous sections. When used in continuous sections, careful analysis of the connections of the aluminum to the structure is required. If the aluminum is allowed to deform substantially between connection points, the anchor will be effective only near the connection points, and not continuously along its length. One advantage of aluminum sections is that a die can be manufactured to extrude a custom-designed section, if the project quantity warrants it. This allows the designer to make a very specific cross section which will be as efficient as possible for the given project. This cross section can also include serrations, which when coupled with serrated washers, can provide positive mechanical vertical position security without shims or field welds. The in-out positioning usually relies on shims, and this requires a plumb surface on the structure on which to mount the hardware, otherwise the engagement into the stone kerf will be out of plumb. Continuous aluminum anchors obviously require continuous kerfs to be cut in the stone panel, and sometimes these kerfs must be rebated to allow for full movement capability of the specified joint width. Continuous kerfs and/or rebates consume significant amounts of abrasive during fabrication, and pose challenges in crating and handling due to their fragility. This is offset by their simplicity in that shop drawing coordination is less cumbersome due to the elimination of having to prelocate anchor preps to coincide with the anchor locations.

3.1.5. Strap Anchor: Perhaps one of the most frequently used devices is the strap anchor. This is a lateral load restraint device only, and gravity loads must be addressed by other means. The strap anchor is simply a length of stainless steel strap, which is cold bent at its end to provide a "tab", or two "split-tail tabs" in opposing directions that engage preps cut into the stone (See Figure 6A).

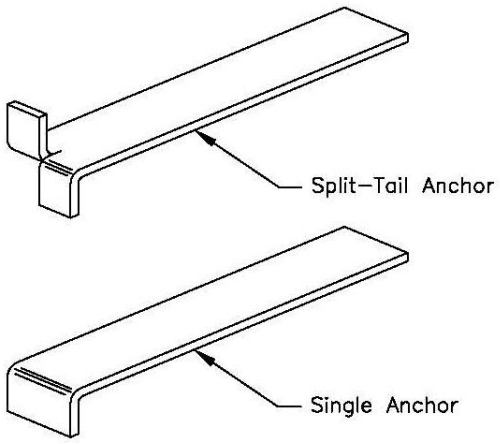

FIGURE 6A: STRAP ANCHORS AS SUPPLIED BY VENDOR

The opposite end is usually field bent to suit jobsite conditions. If a bolted connection is used at the building structure, the hole for the bolt is usually field punched to control the distance between the bolt location and the field bend (See Figure 6B).

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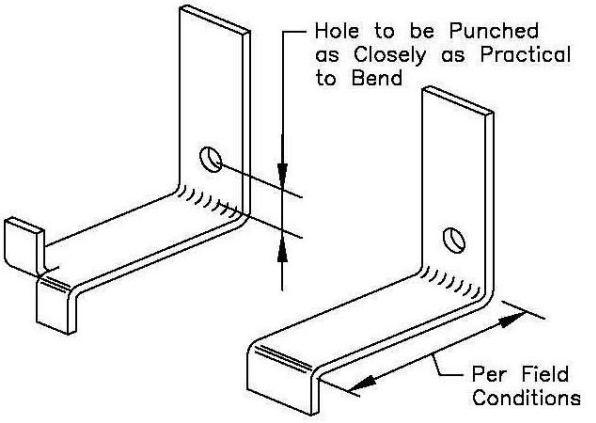

FIGURE 6B: STRAP ANCHORS AFTER FIELD BENDING & PUNCHING

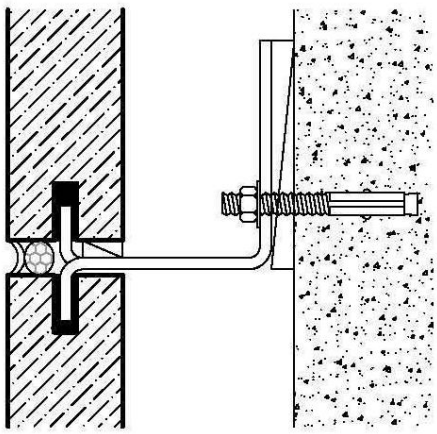

FIGURE 6C: INSTALLED STRAP ANCHOR

Excessive distance between the hole and the bend can result in a bending failure of the strap during negative lateral load experiences, and is one of the most frequent misapplications in the use of this anchor type. Maximum distances critical to the performance of the anchor should be specified by the design engineer and communicated to the field mechanics. The prep cut into the stone is usually a half-moon shaped local kerf, which is accomplished by "plunge-cutting" with a small diameter (≤6", ≤150 mm) diamond abrasive blade. Position of the kerf centerline relative to the face of the stone is critical, as this influences both the alignment of the installed pieces and the strength of the anchor assembly. Position in the other direction, parallel to the stone's face, is not as critical, since there is some adjustment available in fitting the tab into the kerf (See Figure 6C). The anchors are generally only used with relatively small panel sizes and low load conditions, since the capacity of them is usually somewhat limited.

3.1.6. Combined Pin & Strap Anchor: This device is similar to the strap anchor described above, with the exception of using a stainless steel dowel swaged or welded to the strap, in lieu of bending tabs on the end of the strap (See Figure 7).

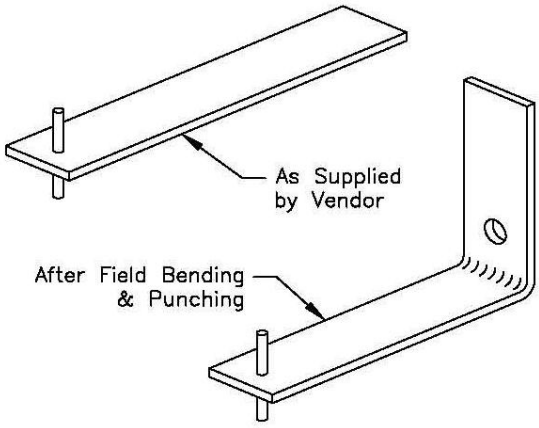

FIGURE 7: STRAP ANCHOR WITH PIN

Using the cylindrically shaped dowel to engage a drilled hole in the stone provides the advantage of less stone removal, and generally higher strengths. The hole diameter is necessarily oversized to receive the pin. The recommended over-sizing is 1/8" (3 mm), providing and annulus region measuring 1/16" (1.5mm). Since this dimension creates challenges in alignment of preps between adjacent stone panels sharing common anchors, some fabricators oversize the

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holes by larger dimensions, albeit generally not recommended. It is always necessary to test the anchor with a test specimen that has the same diameter hole as will be used in the production stock. In some cases, the hole will be field drilled, but whether a field or factory performed task, the drilling must be done with a diamond abrasive bit using non-percussive drilling equipment (no hammer drilling, please). The primary challenge of this anchor type is accomplishing the exact alignment between pieces when a common anchor engages two adjacent panels. Even a slight error in hole position can create alignment difficulties. This anchor type is generally a lateral load restraint only, although there are some anchor vendors that provide modified versions of it capable of addressing both gravity and lateral loads.

3.1.7. Dowel Anchor: Perhaps the simplest anchorage device in use is the dowel anchor (See Figure 8).

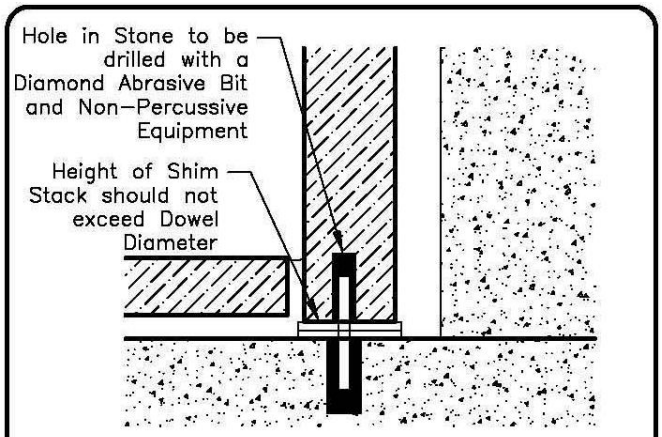

FIGURE 8: DOWELED CONNECTION AT BASE COURSE

A stainless steel dowel is used to control alignment of a stone panel to an adjacent material, or less frequently, to an adjacent stone panel (which has been secured by other means). It is most often used to anchor the bottom of a stone panel to a concrete shelf or floor, although it can also be used on structural steel with the dowel welded to the steel. In its simplest analysis, the dowel appears to be in pure shear under load, but substantial bending forces can occur due to the separation of the stone from the floor via shimming. As a general rule, the height of the shim stack shall not exceed the diameter of the dowel. As in the case of the pin anchor discussed above, the dowel anchor enjoys a minimally sized, cylindrical prep cut into the stone panel's edge, which will be oversized to accommodate fitting the anchor. In many cases, the hole will be field drilled, but whether a field or factory performed task, the drilling should be done with a diamond abrasive bit using non-percussive drilling equipment. The dowel is generally secured in the stone by either a resinous or non-staining elastomeric sealer. The holes in the concrete will always be field drilled, and generally with percussive equipment.

3.1.8. Wire Tie Anchor: This style of anchorage is the traditional "marble setter's" anchor and has been used for decades. A small diameter wire (In the US, commonly 8 gauge, or 0.1285" [3.264 mm]) of corrosion resistant metal (sometimes copper, stainless steel preferred) is fitted into a slightly oversized hole in the stone panel, and attached to the structure either with a fastener or via a pocket embedment (See Figure 9).

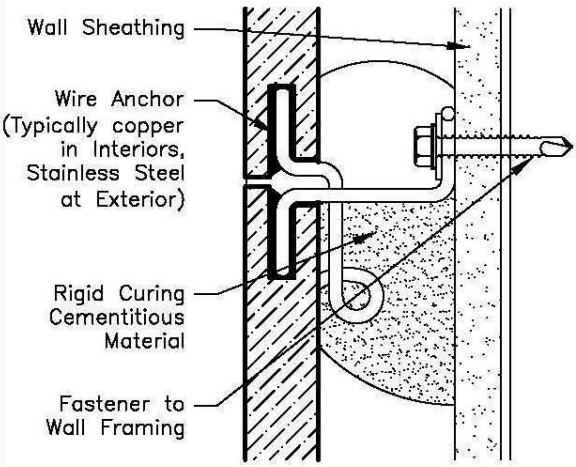

FIGURE 9: WIRE TIE ANCHOR

After securing the wire, the stone setter encapsulates the wire with a portion of rigid curing material, which prevents the wire from buckling in compression. Historically, the material used to encapsulate the wire was plaster, which was both low in cost and rapid setting. In modern construction, plaster may only be used in areas that

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are not subject to any moisture, even incidental or condensation induced moisture. A portland cement based mortar is recommended for all other applications. Many designers prohibit the use of gypsum based products in any area, citing its lack of moisture resistance as a reason. Historically, wire tie anchorage was used in both interior and exterior cladding. Currently, its use in exterior applications is discouraged other than for limited areas of very lowrise (≤ 1 story) construction. One of the concerns with this anchorage system is that it is very craftsman dependant, in that an experienced mechanic can likely make very reliable connections, while an inexperienced mechanic is much less likely to maintain the same level of quality control. A second concern is that due to its dependence on experience level, there is reduced confidence that the anchor assembly specimen that is tested will be accurately replicated in the field condition. There are several advantages to this anchorage system, one being the use of economical components, a second being the speed of installation, which further contributes to economy by reducing labor. An additional advantage of this system is that it requires only small diameter holes to be drilled in the stone panels, which preserves as much stone material as possible surrounding the anchor penetration. This makes this system well suited for anchoring low strength stones used as ¾" (20 mm) interior panels.

3.1.9. Plug Anchor: Plug anchors were the original method used to provide a threaded rod attachment point on the rear surface of a stone panel (See Figure 10). Due to the development of other types of back anchors, which accomplish the same thing at a lower cost, they are not seen as frequently as in the past. However when used in the softer stone varieties in cubic (≥3", ≥ 75 mm) thicknesses, they will generally produce significantly higher strengths than other back anchor varieties. Plug anchors are a two component device, and require two drilled holes of different diameters from perpendicular faces. Into one hole, a smooth plug is inserted which has a threaded hole in it, and through the perpendicular hole, a smaller diameter threaded rod is fitted which engages the threaded hole in the plug.

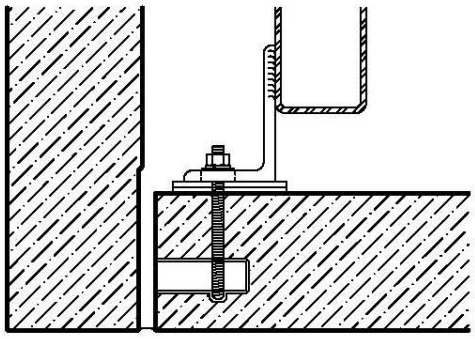

FIGURE 10: PLUG ANCHOR

3.1.10. Back Anchor: Back anchors, as their name suggests, are those anchors which extend from the back surface of the stone panel (See Figure 11B).

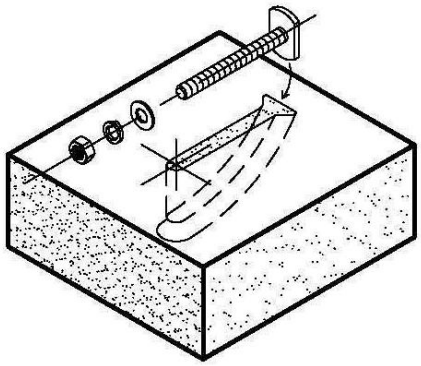

FIGURE 11B: EXAMPLE OF A COMMON BACK ANCHOR

Back anchors are sometimes used for blind connections (only when blind connections are unavoidable), or used when access to the rear face of the panel is available. Back anchors are frequently used in preassembled systems, soffits, or when exposed edge conditions prohibit the use of perimeter anchorage (See Figures 11C & 11D).

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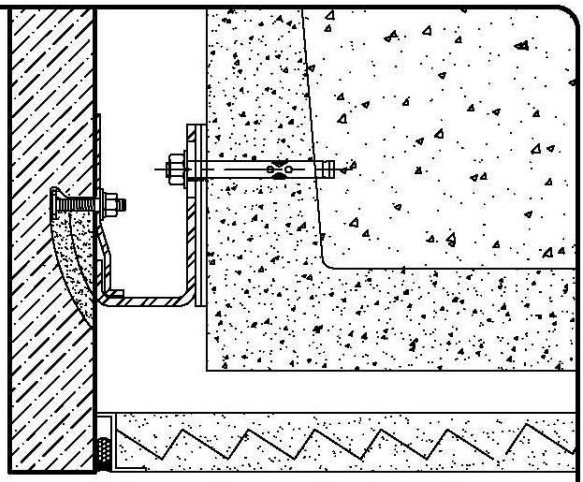

FIGURE 11C: BACK ANCHOR USED IN BLIND CONNECTION

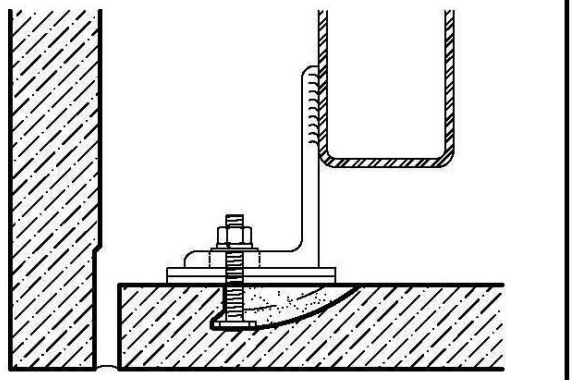

FIGURE 11D: BACK ANCHOR USED FOR SOFFIT SUPPORT

In addition to their concealment, a secondary advantage of using back anchors is the reduction of span. With optimal placement of the back anchor, the span is not only reduced, but the contraflexure of the stone panel over the anchor locations further reduces the bending stresses in the stone panel (See Figure 11A).

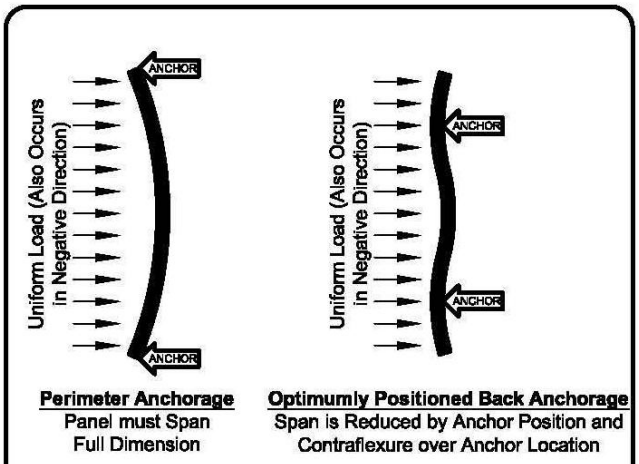

FIGURE 11A: PANEL SPANS

Within the stone industry, it is not considered acceptable practice for any anchor to rely on adhesive bond alone, so all back anchors must have some type of dovetail, conical, or bell-shaped prep machined in the stone to provide a positive mechanical engagement.

3.1.11. Hairpin Anchor: A specific variety of back anchors is the "hairpin" anchor, which is used to anchor stone veneer panels to precast concrete backings. Resembling a hairpin in its profile, this anchor is fitted into two angled holes drilled in the back surface of the stone panel (See Figure 12).

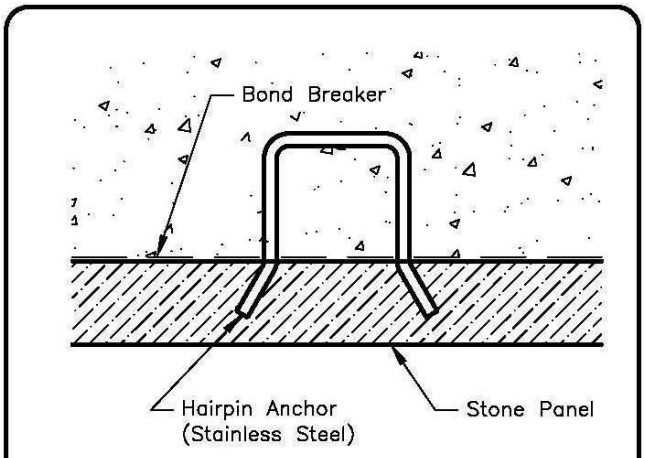

FIGURE 12: HAIRPIN ANCHOR

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A sheet applied bond breaker is applied to the stone, after which the concrete is cast in a factory setting. The concrete encapsulates the anchor, preventing it from springing out of the holes in the stone. The bond breaker allows the stone to move very slightly, independently of the concrete, which is necessary to accommodate differential thermal expansions and dynamic building movements. Quality control in the precasting facility must be closely monitored, since once the concrete has been cast, this anchor is fully concealed and cannot be inspected without highly sophisticated diagnostic equipment.

3.2. Basic Metallurgy: As metallurgy of stone anchorage is an involved and complex topic in itself, a subsequent Marble Institute of America technical bulletin is planned to address that specific topic in more detail. In general, the industry advocates the use of mild steel with a corrosion protective coating only for components that do not penetrate, or have direct contact with the stone (such as a shelf angle which is insulated from the stone by means of a stainless steel or plastic shim material). Metals in direct contact or penetrating anchor preps of stone must be corrosion resistant metals, and the degree of corrosion protection varies slightly with the type of stone. Stainless steel is the preferred material for any penetrating device. Aluminum is also acceptable, although mill finish aluminum may cause corrosion with some calcareous stones (particularly limestone), so in those applications it must be painted. Copper is also used in applications that are not subjected to moisture.

4.0 Filling the Anchor Prep: Since the anchor prep is necessarily oversized relative to the anchor device, it is a requirement to fill the excess volume of the prep with another material. This material is typically one which is in a plastic or viscous physical state during installation, then cures to a solid or elastomeric state. Discussion of the various types is below:

4.1. Gypsum Based Fillers: Despite their popularity in this role a few decades ago, gypsum based products are currently not recommended as anchor prep fillers in any applications. Low strength, coupled with the vulnerability for swelling or erosion with even modest amounts of moisture, make these products inappropriate for this use.

4.2. Cementitious Fillers: Portland based anchor setting grouts are commercially available from a variety of sources. Most of these are rapid curing mixtures, which will achieve initial set in less than 30 minutes. These products also have some degree of vulnerability to swelling or erosion, and may be inappropriate for certain applications.

CAUTION: Never mix gypsum based products with portland based products. This will result in a hybrid material known as "ettringite", which has a greater volume than the sum of the two parent components. The pressure created by this reaction within the anchor prep can fracture the stone, created an immediate public safety concern.

4.3. Resinous Fillers: Resinous adhesives, commonly epoxy, have been used successfully, although their higher cost and slow cure times are not favored by stone mechanics. Additionally, the high level of rigidity of their cured state is a concern as it may increase stresses near the anchor prep due to its limited flexibility. These products are used frequently for securing dowels in cubic stone sections, such as coping and stair pieces. They are generally not appropriate for thin stone cladding.

4.4. Elastomeric Fillers: Both Silicon and polyurethane sealants, typically medium modulus varieties, are used for the purpose of filling anchor preps. These products share the advantage of remaining quite flexible after curing, so they accommodate dynamic movements in the assembly extremely well. This post cure flexibility makes them a preferred product in many applications. Care is advised in the selection of the product to avoid any sealant that could potentially stain the stone.

5.0 Shims: Historically, shims were of a malleable metal, most often lead. Lead is no longer

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used for environmental reasons. While stainless steel is an acceptable shimming material, most installers prefer high density, high impact plastic shims. Shims shall be full bearing and of solid construction. The height of the stack of "horseshoe" shaped shims used in a stack around bolts or dowels should generally not exceed the diameter of the bolt or dowel. Engineering details should address and note limits of allowable shim spacing. Note that some shims by design are temporary and must be removed after curing of the setting components.

6.0 Testing Anchors: Stone anchors are tested via two common methods. ASTM C1354 Strength of Individual Stone Anchorages in Dimension Stone is the test method used to test a particular anchorage device in a prepared stone specimen. This is a small scale "bench top" type test to establish the ultimate capacity of a given anchor in a given stone. One often overlooked requirement of this test procedure is that any filler used in the anchor slot must either be omitted, or intentionally prevented from bonding to the stone or anchor for the test. This is done as a precaution to guarantee that if this bond should fail during the service life of the building, the anchor will still demonstrate its tested capacity. The second method used, albeit less frequently due to greater cost, is ASTM C1201 Structural Performance of Exterior Dimension Stone Cladding Systems by Uniform Static Air Pressure. This method involves mocking up the full sized panel of stone with its anchorage, including related components of the anchorage assembly, and then applying a simulated windload via an air pressure chamber. The advantage of this test is that it is a simultaneous test of both the stone panel and the anchorage, so it proofs several components of the load path in one test. It also models whether deformations of any of the components during load will influence the performance of the system.

7.0 References:

7.1. Marble Institute of America Dimension Stone Design Manual, Version 7.1

7.2. ASTM C1201 Structural Performance of Exterior Dimension Stone Cladding Systems by Uniform Static Air Pressure

7.3. ASTM C1354 Strength of Individual Stone Anchorages in Dimension Stone

7.4. ASTM C1242 Standard Guide for Selection, Design, and Installation of Exterior Dimension Stone Anchoring Systems

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This bulletin is intended as an educational tool for natural stone professionals and other stakeholders (e.g. architects, interior designers, etc).

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