Building Stone Institute

RECOMMENDED BEST PRACTICES

CONTENTS

1. SCOPE

1.1 The following material is intended to provide basic guide lines for the architect, engineer, stone contractor, stone fabricator, anchoring device fabricator, and other interested parties for the safe and economical use of building stone in construction.

It offers guide lines for the design and application of building stone using metal gravity anchors and/or lateral anchors to: (a) clad solid concrete or masonry, (b) clad the structural frame of a building, either directly, or to subframes, or to curtain walls which are attached to the building structure.

It also includes guide lines for the design and application of paving stones.

2. GEOLOGIC CATEGORIES OF STONES FREQUENTLY USED IN CONSTRUCTION

2.1 Sedimentary stones (sandstone, limestone, dolomite) originally formed mainly in sea water, or lakes, from the remains of animals and plants, also from transportation and deposition of rock products.

2.2 Metamorphic stones (marble, serpentine, onyx, slate, quartzite, gneiss) are produced from sedimentary or igneous rocks by the action of heat and pressure.

2.3 Igneous stones (granite, syenite, diorite, gabbro, andesite and basalt) are formed when magma (molten rock within the earth) cools.

3. TRADE CLASSIFICATION OF STONE TYPES

The American Society of Testing Materials (ASTM) has issued standards for the physical requirements of the most frequently used natural building stones. These standards are reviewed every five years by their technical committee, and are subject to revision at any time.

3.1 Granite.

Fine, medium and coarse igneous rock, composed of quartz, feldspar, and mica with accessory minerals. Colors range from pinks, reds, grays, blues, greens, tans, browns, blacks and every color and shade between.

Granite supplied under ASTM C-615 Standard Specification for Granite Dimension Stone shall conform to the physical requirements indicated in the following table:

- Click here to see the Granite Table -

3.2 Marble.

A metamorphic recrystallized rock composed of carbonate minerals (calcite or dolomite) or of serpentine, capable of taking a polish. The range of color and texture is wide. For soundness marbles are classified in 4 groups:

GROUP A

Sound marble with uniform and favorable working qualities; containing no geological flaws or voids.

GROUP B

Marbles similar in character to the preceding group, but with less favorable working qualities; may have natural faults; a limited amount of waxing, sticking and filling may be required.

GROUP C

Marbles with some variations in working qualities: geological flaws, voids, veins and lines of separation are common. It is standard practice to repair these variations using polyester resin, or epoxy liners and other forms of reinforcement when necessary.

GROUP D

Marbles similar to the preceding group, but containing a larger proportion of natural faults, maximum variations in working qualities, and requiring more of the same methods of finishing. This group comprises many of the highly colored marbles prized for their decorative value.

3.2.1 Dolomite marble contains in excess of 40% magnesium carbonate.

3.2.2 Dolomitic marble contains not less than 5%, not more than 40% magnesium carbonate.

3.2.3 Travertine marble **-** a porous or cellularly layered, partly crystalline calcite of chemical origin.

3.2.4 Serpentine marble (popularly called Verde Antique) a rock consisting mostly or entirely of serpentine (hydrated magnesium silicate), green to greenish black in color, commonly veined with calcite, and dolomite or magnesite, or both.

3.2.5 Onyx marble **-** translucent, generally layered cryptocrystalline calcite with colors in pastel shades, particularly yellow, brown, and green.

Marble supplied under ASTM C503 Standard Specification for Marble Dimension Stone (Exterior) shall conform to the physical requirements indicated in the following table:

- Click here to see the Marble Table -

3.3 Sandstone.

Fine to medium grained sedimentary rock having a minimum of 60% free silica. Colors range from light grey to yellow and brown. Common commercial varieties are:

Bluestone. A dense, hard, fine grained commonly feldspathic sandstone of medium to dark greenish grey or bluish-grey color that may split readily along original bedding planes to form thin slabs.

Brownstone. A dense, medium-grained sedimentary stone, with a distinctive dark brown to red brown color.

3.3.1 Quartzitic Sandstone which contains at least 90% free silica.

3.3.2 Quartzite **-** Highly indurated, typically metamorphosed sandstone containing at least 95% free silica.

Sandstone supplied under ASTM C-616 Standard Specification for Quartz-based Dimension Stone shall conform to the physical requirements indicated in the following table:

- Click here to see the Sandstone Table -

3.4 Limestone.

Sedimentary rock predominantly composed of classic sand-sized grains of calcite, fossils or shell fragments.

Oolitic limestone: composed largely of spherical particles called oolites.

Dolomitic limestone: sedimentary carbonate rock consisting largely of the mineral dolomite.

Colors range from light grey, tan to light brown.

Limestone supplied under ASTM C-568 Standard Specification for Limestone Dimension Stone shall conform the physical requirements indicated in the following table:

- Click here to see the Limestone Table -

3.5 Bluestone.

Fine grained metamorphic sandstone. Colors range from shades of blues, grays, greens, buffs and red with random surface colors of gun-metal, gold and brown.

3.6 Slate.

Fine grained rock which splits easily along its cleavage. Colors are grey, black, purple, green, red, and brown.

3.7 Schist.

A foliated metamorphic quartz-feldspar containing rock characterized by minerals such as mica or chlorite. Schist splits readily along the planes of foliation.

4. NATURAL STONE USES

4.1 Interior use: marble, slate, hard limestone, quartzite and granite are most often used to build solid steps, platforms, treads, risers, saddles and paving.

Important considerations for selecting stone for this type of work are: surface finish, resistance to wear, slip resistance, resistance to staining, and maintenance. The use of porous limestones and soft clayey sandstones is not recommended. High traffic areas require less porous, harder stones as these are more resistant to staining and wear.

4.2 Exterior use: bluestone, granite and other igneous rocks are more appropriate as they are more durable, resist weathering, and wear well. Abrasion resistance of stone selected for foot traffic may be determined with test methods described in ASTM C-241. Stone may become slippery when wet, therefore the following finishes are preferred for exterior use: tooled, flamed, sandblasted or natural cleft.

4.3 For street curbing granite (sometimes bluestone) is used as it resists weathering and wears well. It is recommended that the top of street curb be flamed, or otherwise textured to make the curb more slip resistant.

4.4 Regarding natural stone sills, stools, and copings see the recommendations described in paragraph 4.1 and 4.2.

4.5 Open joint pavers may be used on a plaza, terrace, or on a roof where the designer prefers cavity under the pavers and where the rainwater or melted snow can be led along a sloping subsurface to concealed drain holes. Granite pavers with non-slip finishes are usually selected for such installations.

4.6 Load-bearing: rubble, ashlar, base, riser, lintel, arches. For interior use natural stones with high compressive strengths are preferred. The main requirements for exterior use are low water absorption rate, high compressive strength and flexural strength with resistance to weathering.

4.7 Non-load-bearing: veneer, wall facing, curtain wall panels, column covers, soffits, wainscots, and door jambs. For interior use mainly aesthetic requirements govern. For exterior application low water absorption rate and high flexural strength with resistance to weathering are the most important functional requirements.

5. FINISHES

5.1 Sedimentary stones:

(1) Smooth (machine finished by saw, grinder, or planer).
(2) Machine tooled (uniform grooves).
(3) Chat Sawn (non-uniform, shallow saw marks).
(4) Shot sawn (irregular and uneven markings).
(5) Split face (concave - convex).
(6) Rock face (convex).
(7) Natural cleft.

5.2 Metamorphic stones:

(1) Sanded
(2) Honed (medium to high honed)
(3) Polished
(4) Wheel abraded
(5) Bush-hammered
(6) Split Face
(7) Rock Face
(8) Natural cleft

Note: Slate and quartzite cannot be polished and may be sanded, honed or natural cleft. Gneiss will take all the finishes of marble and may also be flame finished.

5.3 Igneous Stones

(1) Sawn
(2) Honed
(3) Polished
(4) Machine tooled (4-cut, 6-cut, chiseled, axed, pointed, etc.)
(5) Flamed
(6) Sandblasted
(7) Split Face
(8) Rock face

Note: Diorite will not take a good uniform, flamed finish.

6. INSTALLATION METHODS

6.1.1 Steps, platforms and copings are usually installed in cement mortar.

6.1.2 Pavers may be of regular or irregular shapes and dimensions. The thickness of pavers depends on the type and strength of the stone, on the designed sizes, and on the nature of the support. Thin tiles of 12" square or 18" square are mostly used in 3/8" to 3/4" thickness for interior flooring and are set either in full cement mortar bed or with a "thin set" method utilizing a Latex admixture in the cement mortar, which is spread on the concrete floor with serrated trowels in an average of 1/8" to 3/16" thickness. Hairline, or 1/16" wide joints are mostly used for interior thin-set applications. Exterior pavers are usually larger than 2' square in size and their thickness can vary from 1-1/4" to as much as 4" depending on the intended use. As a rule of thumb, the cement mortar bed should more or less equal the thickness of the stone paver. No air pockets should be left under any of the pavers installed in a cement mortar bed. The use of Lime in the cement mortar bed is **NOT** recommended. Application of any Plaster of Paris for any part of the exterior flooring will be

detrimental. Design of joint width for exterior pavers may vary from a minimum of 1/8" to 1/2", using cement mortar, or caulking. In case of cement mortar, expansion joints should be introduced approximately every 25 feet. The use of wire mesh reinforcing in the setting bed, and a slip sheet under the setting bed, is a matter of design consideration
(see Fig. 6.1.2).

6.1.2.1 Interior stone pavers installed on a wood structure on top of plywood need special treatment because movement of the wood structure must be anticipated. To prepare more rigid support, the use of two layers of plywood is recommended-with the plywood joints not lined up with one another, but staggered. Bituminized felt paper and galvanized wire mesh should be tacked down to the double plywood floor and not less than a 1-1/2" thick mortar bed should be prepared using a mixture of 1 bag Portland Cement, 3 cu. ft. of clean sand, mixed with 3 gallons of Laticrete or approved equal of latex admixture.

Before placing the stone floor tiles on a wet screed bed, an approximate 1/16" thick latex based skim coat shall be applied to the back of each floor tile. Uniform joints of not less than 3/32" wide shall be maintained. After each piece is laid, it shall be tapped down using a wooden block to level the surface and imbed the stone. Care must be taken not to crack the floor tiles during the tapping. Joints are filled with Portland cement with, or without Latex reinforcing, and sealed with a squeegee. Movement joints shall be applied between the walls and the floor tiles.

As described in paragraph 3.2 marbles are classified into 4 groups for soundness. Group C and D marble tiles are often reinforced with nylon mesh set in an epoxy (or polyester resin) film on the back of the tile. Unless this film is ground off, the cement mortar bed, or the thinset mortar often separates because it does not adhere to the epoxy film properly (see Fig. 6.1.2.1).

6.1.2.2 For exterior pavers the use of a sand bed may be considered. Pavers installed with a sand-set method can easily be replaced, repaired, or adjusted. However, the sand-set method shall be used only with soil conditions that drain well and are stable with no settling. Proper compaction of a well draining sub-bed and sand setting bed is critical to prevent settling and moving. For stability a maximum 1" thick sand bed should be used with 1/16" wide joints which are swept with sand. The sand set method is **NOT** recommended for interior use.

6.1.2.3 For the installation of conventional stone paving the preparation of both the sub-surface and the stone pavers is equally important.

If the setting bed between the concrete slab surface and the bottom side of the stone pavers exceeds 2", concrete fill should be provided by the General Contractor. Concrete fill must be properly bonded to the concrete slab.

Concrete surfaces to receive stone flooring must be thoroughly cured, and free from soil, oil, and other extraneous materials.

Concrete slab (or concrete fill) shall be saturated with water, but free water must be removed prior to installation of mortar mix.

Mortar shall be prepared using the approved ratio of Portland cement and clean, damp sand with a minimum amount of water to produce a workable mass. Mortar must be used within one hour after mixing, without any additions or re-tempering.

A thin coating of Portland cement grout shall be troweled to the bed of the stone pavers immediately before each stone is laid.

Pavers shall be tapped into final place and made level without any air pockets left under the pavers and while the setting mortar is still pliable.

6.1.2.4 For pedestrian traffic on exterior plazas, terraces, promenades and roofs a pedestal paving system may be used to obtain a perfectly level walking surface with open joints, so that the rainwater or melting snow can drain to the sloping cavity under the pavers and lead to the drain holes. Presently three methods are used to provide drainage between the pavers and the waterproofed structure below.

None of the 3 methods described here provide support for vehicular traffic.

Manually operated vehicles, dollies, rolling pipe scaffolds may be used within the calculated load capacity of the pedestal paving system.

(1) TREM proof King Pin Pedestals (by Tremco) have 4 adjustable stone supports with about 1-1/4" adjustability in 1/16" increments. It can provide a 10,000 lb working load (2500 lbs per adjustable support) with zero permanent deformation when supported by a non-compressible base. To insure uniform joints the use of 60 to 70 durometer neoprene cross spacers is recommended at the joint intersections. For prevention of "moving up" one side of the cross spacers could be self adhered, or silicon caulking may be installed above the cross spacers, flush with the finished stone surface (see Fig. 6.1.2.4 (1)).

(2) Terra System One (by Wausau Tile) is composed of a number of components such as tabs, shims, pedestals, reducers, spacers, extenders, etc. Designed to provide level surfaces above sloping sub-surfaces the pedestal cavities are filled with specially blended concrete to provide total and complete support.

(3) PAVE-EL (by Envirospec). This pedestal system also elevates the pavers to provide a drainage plane between the pavers and the supporting structure below. Pave-El pedestal is a grid-like structure of high density polyethylene with integral spacer ribs for either 1/8" wide joints or for 1/4" wide joints. It also has leveling plates over the pedestal to eliminate minor deck or paver discrepancies (see Fig. 6.1.2.4 (3)).

Each of the three types of pedestal methods described above may be installed directly to the membrane, using protection boards, or over high density (125 psi) rigid insulation board.
At larger joints burning cigarette butts may cause damage to the rigid insulation. Insulation is the weakest link of the pedestal system, when the pedestals are installed on rigid insulation.

6.2 Vertical Installation.

6.2.1 Thin tiles of 12" square, or 18" square pieces in thicknesses ranging from 3/8" to 3/4" are often used for interior cladding set in cement mortar bed on masonry backup, or set with a "thin-set" method using a Latex admixture in cement mortar spread on sheet-rock panels on studs, or set on thin cement board panels nailed or screwed to the studs.
For "wet" walls in bathrooms, plastic sheets shall be installed between the studs and the cement boards. Serrated trowels will provide an average of 1/ 8" to 3/16" thickness of thin-set backup to the thin tiles. Hairline, or 1/16" wide joints shall be used for natural stone tile cladding for interior application.
Marbles classified in Group C and D, reinforced with nylon mesh in an epoxy (or polyester) film on the back of the marble tile, shall be ground off for

proper adherence.

The "thin-set" tile application or cement mortar applied to thin tiles, without the use of mechanical anchors is **NOT** recommended for exterior wall cladding. Weathering resistance and durability of thin tiles exposed to hostile environment is limited. Freeze and thaw cycles, water entering into joints and behind the stone, installation imperfections, and numerous other hazards are good reasons to avoid exterior stone-tile without mechanical anchoring and without well designed weep slots and air ventilation.

6.2.2 Natural stones conventionally anchored to back-up structure or to masonry.

Anchoring devices are installed to resist lateral and gravity loads. Anchoring components shall be designed as simply as possible, with the fewest components and types to be adjustable, and with careful prevention of galvanic and chemical corrosion. Anchors for conventionally installed natural stone are usually designed to work laterally, on tension. To resist lateral compression, mortar spots are placed in the setting space, usually at the location of the anchors, and at mid-span between the anchors.

6.2.2.1 Thick stone veneer ashlar.

Approximately 4"-thick random rectangular shaped natural stone is often used to achieve a rustic appearance on exterior cladding. It is recommended that sufficient air space be left behind the stone veneer for air circulation, and to provide vent holes (or vent slots) near the bottom and the top of the wall. To stabilize such stone veneer, the use of mechanical anchors is necessary. Corrugated stainless steel strap anchors are acceptable with occasional cement mortar spots in the cavity near the anchors to resist positive lateral loads.

6.2.2.2 Conventionally anchored thin stone veneer to back up structure or to masonry.

Cement mortar is used for exterior installations. Plaster of Paris may be used for interior application. Stainless steel strap anchors or rod anchors are used for exterior walls to resist tensional forces, with cavity between the structure and the thin stone veneer. Occasional cement mortar spots are used near the anchors, to resist lateral loads (compression). Vent holes or vent slots are provided for exterior installations near the bottom and the top of the wall. Interior thin stone veneer is usually installed using brass wire anchors and Plaster of Paris. No vent holes are used for interior stone veneer (see Fig. 6.2.2.2).

6.2.2.3 Mechanically installed stone veneer.

Stone slabs are anchored, piece by piece, to a metal grid system which in turn is secured to the building's structure. Such installations are made either from scaffolds or from the floor slab. Miscellaneous steel, such as rectangular tube, different types and sizes of uni-struts, clip angles and "Z" shapes may be used to substitute for a masonry backup. These miscellaneous steel components are supported by the structural steel and the anchors are attached to the miscellaneous steel members. Lateral and vertical adjustability is accomplished through proper design of the miscellaneous steel components and/or anchoring components (see Fig. 6.2.2.3).

6.2.2.4 Floor to floor panel installation.

Thicker stone slabs are used extending from floor slab to floor slab, usually without the use of scaffolds. Stainless steel seat angles are mostly used for gravity support, with welded tabs on the horizontal edge to resist lateral forces and adjustable stainless steel anchors are installed in the perimeter joints. At locations where some of the joints are exposed, concealed anchors are installed to replace perimeter anchors (see Fig. 6.2.2.4).

6 2.2.5 Stone veneer installed to curtain-wall components.

This is done similar to the glazing method or with the introduction of special aluminum extrusions for gravity and lateral supports. Matching kerfs are provided to receive the extrusions (see Fig. 6.2.2.5).

6.2.2.6 Pre-assembled systems.

Stone panels are built in a shop under controlled conditions. Such systems are sometimes built on to reinforced precast concrete backing. Such stone faced precast panels are often designed with reinforced concrete hunch for gravity and/or lateral support. A slip sheet is applied in between the precast concrete and its stone facing to accommodate differential movement. Stainless steel cross dowels, or hairpin anchors of different shapes are used to tie the precast and the natural stone together. A minimum of one pair of anchor legs is designed for every 3 square feet. The newest applications have rubber grommets installed on the anchors at the back of the stone panels to allow concrete shrinkage and differential movement, without any damage to the stone.

To pre-assemble lighter panels, stone slabs may be installed in a plant on metal trusses, or on frames of different sizes or shapes. Miscellaneous steel, such as tubes, channel sections, and angles are used to build the stone supporting frames which must coordinate the needs of all components to be housed within the pre-assembled panel such as flashing, drainage, or insulation (see Fig. 6.2.2.6).

6.2.2.7 Curtain-wall installations.

Stone, glass, and aluminum components offer cost effective cladding of high rise buildings.

Stick system. For field-assembled curtain-wall, aluminum vertical mullions and horizontal components are extruded, cut to size, pre-punched and pre-drilled for connections and weep holes. Properly numbered they are then shipped loose for job site erection. Glass and stone are used as glazed panels. Silicone sealant is used for watertight sealing and carefully designed bites and aluminum pockets are used to accommodate anticipated building movements and to prevent air and water infiltration (see Fig. 6.2.2.7 (1)).

Unitized curtain-wall systems may have glass and stone shop-installed into prefabricated frames. The size of the designed units is governed by shipping limitations and field conditions. Stone slabs of a minimum 1-1/4" thickness are either set in pockets similar to glass or are kerfed for mechanical anchoring. Extreme care is required to move, transport and field-erect unitized curtain-walls (see Fig. 6.2.2.7 (2)).

6.2.2.8 Field conditions shall be examined, if possible, before installation starts. An experienced foreman or supervisor shall lay out the necessary lines and grades from the engineering marks provided by the General Contractor.

Tools, anchoring devices, other materials and equipment shall be organized and lined up by the time installation starts.

Fabricating, shipping, unloading, and distribution shall be carefully planned so that sufficient stone arrives at the job-site in logical setting sequence. Stone should be stored reasonably close to the setting place, to insure trouble-free continuous installation.

6.2.2.9 Installation shall be in strict accordance with specifications and approved shop drawings. Safety regulations shall be strictly observed.

Erection tools, chain hoists, scaffolds, etc. shall be inspected and, if necessary, reconditioned for safe and effective use on the job.

6.2.2.10 Scaffolds generally used for stone cladding may be classified into four types:

(1) Frame scaffolding
(2) Suspended scaffold for material handing
(3) Suspended swinging scaffold
(4) Bosun's chair

(1) Frame Scaffolding is normally used for stone installation of limited height. It can be used above 30 feet in height, but must be tied back to the structure.

(2) Suspended Scaffold designed for material handling is normally used by brick masons for installing brick and block walls on high-rise buildings. Occasionally, they are also used for installation of stone cladding, where cladding units and materials must be stored on the scaffold.

These scaffolds are usually 5-feet wide and are suspended at four points from steel wire rope.

(3) Suspended swinging scaffolds are suspended only at two points, from steel wire rope, and are not designed for material handling. Swinging scaffolds have a better efficiency rating because one can raise or lower them with greater ease and in less time. Commonly used lengths are from 12' to 24' at 2-foot intervals. Stirrups are 28" wide. A safety line is required for each person riding a swinging scaffold.

(4) Bosun's Chair is normally used for minor repairs or limited stone installation. The operator has little control keeping the chair in a working position. It is **NOT** recommended for use if wind is over 5 m.p.h.

When using any type of scaffold, the safety rules and manufacturer's instructions shall be strictly complied with.

6.3 Preparation and supervision are the keys to successful installation. Clear, readable, logically numbered, and detailed shop drawings are essential.

Shop drawings shall give all necessary information to fabricate and install all stone requirements and should also indicate tolerances with all materials and components fully identified.

6.1 Horizontal installation.

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6.1 Horizontal installation.

7. RECOMMENDED TEST METHODS

AAMA 501.1 Test for Water Penetration using dynamic pressure.

ASTM E-283 Air Infiltration Test by static pressure.

ASTM E-330 Structural Load Test by uniform static pressure (positive and negative).

ASTM E-331 Water Infiltration Test by static pressure.

The four test methods listed above are used in the stone industry to test the performance of stone panels installed on a grid system, a strut system, or stone panels assembled on pre-fabricated steel frames, or trusses, or used as components of field-installed curtain-wall or shop-assembled unitized curtain-until failure occurs in the stone slab, or its anchor provisions. It is desirable that no failure take place until 4 times the design load is reached (see Example for shop-test chamber).

DURABILITY TEST There is no standard test procedure for the durability of natural stone. Until standard test procedures are developed, ASTM C-666 which describes the resistance of concrete to rapid freezing and thawing is often used with minor modifications (to be reasonably analogous to the conditions the stone will experience on the building) to test the durability and aging resistance of dimension stone on an accelerated basis. If such tests take 300 cycles, then it will require close to three months to perform. They are generally costly.

A control group of specimens is tested vs the cycled specimens. Increase in absorption of the specimens after cycling, weight loss, decrease of strength in compressive strength in modulus of rupture and in flexural strength shall be evaluated and any visual deterioration or erosion during the test should be recorded and reported including the number of cycles at which such defects were noted.

The dry-to-wet ratio of the modulus of rupture of a thin section of natural building stone could also give an approximate evaluation of the durability of the rock. Erhard Winkler in his paper "Durability Index For Stone" (1985), prepared for the International Conference on Deterioration and Conservation of Stone, gives the relationship of the general stone evaluation as function of dry-to-wet strength ratio based on the modulus of rupture (see E. Winkler Wet & Dry Ratio Durability Index).

SHEAR AND PULL-OUT TESTS of anchoring of stone facing to precast panels. Such tests are made to establish the resistance of the natural stone to separation from the back-up.

8. SELECTION OF STONE TYPE AND FINISH

8.1 Quarry assessment. Prior to selection of the stone, it is advisable to obtain reliable information to determine if the quantity and the largest stone sizes required are readily available from the quarry source. Rates of block production on seasonal basis shall be evaluated. The uniformity of the color, texture, and physical properties of the rock must be checked as well. It is also advisable to establish a mutually acceptable range of color and texture to prevent possible later dissatisfaction or dispute.

8.2 Manufacturing plant assessment. Past and current performance on similar projects shall be evaluated. Fabrication capacity within the required time frame shall be examined. Crating and transportation facilities should also be examined. Quality control during fabrication must be insured.

8.3 In addition to aesthetic considerations, the selected stone has to resist possible present and future environmental attacks during the planned life span of the building. Exposure to weather may cause changes in shade or coloration. Polluted air, acidic and sulfuric rainwater may cause changes in appearance. Serious and repeated environmental attacks, combined with freeze-thaw action may cause spalling and slow deterioration if the improper type of stone and/or finish is selected.

8.3.1 Failure investigations and research work do not justify the use of thin marble veneer for exterior cladding high-rise buildings in an environment where air pollutants, carbon dioxide (C02) or sulfur dioxide (S02) are present.

Atmospheric water dissolves these gasses creating "acid rain" which, in turn, can cause degradation of the marble veneer.

8.3.2 Freeze and thaw cycles can also change the original characteristics of the thin marble veneer. Due to thermal expansion or contraction, and moisture, some of the thin (1" to 1-1/2", or 2.54 to 3.81cm) crystalline marble slabs will release their stress of geological origin and when cooling off or warming up, will not fully return to their original position (hysteresis).

The volumetric content of natural cementation in the marble and the size of the crystals may play important roles in the moisture activated bowing of the thin marble veneer.

8.3.3 Warping is also caused by unequal moisture absorption which happens when one side of the slab stays dry while the other side becomes wet. This type of warping can be prevented by providing adequate ventilation, using weep slots (weep holes) to keep the cavity, behind the marble veneer, dry.

8.4 In selecting panel sizes, consideration must be given to the capability of the quarry and the fabricating plant to economically produce the selected sizes and thicknesses.

The selected thickness shall be proportionally adequate for the panel size, anchoring system and the finish, without losing sight of economic considerations. Where wind loading criteria is established by the specification, the selected thickness as well as selected anchoring system shall be substantiated with calculations by a licensed Professional Engineer. Tests shall be conducted by an independent testing laboratory.

8.4.1 Thermal (flamed) finish will effect the strength and durability of thin granite veneer. Flame treatment of granite will produce a type of finish which is desirable to many architects and building owners. However, it will reduce the effective thickness of the thin granite slab, together with its bending strength. This may become critical for the long term durability of the thin granite veneer.

Freeze and thaw cycles of flame-treated thin granite may alter the always present micro-cracks to macro-cracks*, making it more vulnerable to further deterioration, permitting absorption of water to a depth of about 1/4" which may freeze within the flamed thin granite slab.

**MICRO FRACTURES were formed when the molten rock (magma) came to the surface of the earth and it cooled off. Micro fractures can not be seen by the naked eye.*

**MACRO FRACTURES have very limited depth and width, however they are visible with the naked eye. Macro fractures do not impair the structural integrity of the intended use of the rock.*

8.4.2 Functionally, a polished finish is the most desirable finish of thin granite veneer used for exterior cladding. Polishing procedures close the pores of the thin stone slab, protecting its surface from deterioration caused by hostile environmental weathering conditions.

8.4.3 Polished granite and marble are recommended for interior vertical walls.

For interior flooring, polished granite is preferred, but good quality polished marble is often used. The use of flamed, honed, sawn or sandblasted oolitic or dolomitic limestone for wet room flooring such as baths or showers is **NOT** recommended.

It is **NOT** desirable to combine granite and marble for a floor pattern due to the difference in abrasion rate. If repolishing is needed, it will be difficult to handle with mixed materials.

In the selection of marble flooring material for high traffic areas, the quality of the marble pavers and their resistance to heavy foot traffic should be carefully considered. Stratified marble or conglomerates are often contaminated with clay, sand, and other such minerals, which after being subject to foot traffic and maintenance procedures, may become fissures on the finished surface.

**FISSURES are narrow openings in the rock, having occasionally more depth than width. Fissures are very common in travertine marble and are caused by entrapped gases.*

9. DESIGN PRINCIPLES

9.1 Where specifications and contract drawings describe an engineered system of stone cladding, it is recommended that the Engineer of Record be consulted for:

(1) Maximum expected deformation and movement of the structure.

(2) Safe and economical suspension system.

In case of performance specification, the design criteria shall be established by the Engineer.

9.2 Stone panel suspension design shall be based on design criteria established by the specifications and applicable building codes. In addition, the architect, engineer and stone contractor (fabricator) shall take into consideration all other factors for a properly designed and functional stone suspension system such as:

(a) Expected windload.

(b) All building movements-sway, elastic deformation and creep, shrinkage of structure and"47or supporting back-up walls, thermal movements of structure and/or cladding.

(c) Connection design to accommodate combination of building movements, fabrication, erection tolerances and economy of erection.

(d) Dangers of freeze-thaw action.

(e) Prevention of corrosion of anchoring devices.

(f) Joint design.

(g) Possibility of water penetration.

(h) Ventilation requirements behind stone panels.

(i) Transportation and handling requirements.

(j) Coordination with requirements of adjoining building trades.

(k) Testing program.

9.3 Reinforced concrete buildings may have dimensional changes or a combination of dimensional changes due to the following:

(1) Shrinkage of concrete structure.

(2) Elastic deformation and creep of concrete structure under sustained load.

(3) Thermal movements.

(4) Sway (of tall buildings).

9.3.1 Drying shrinkage of cast-in-place concrete is perhaps the most important factor to be considered by the designer of the stone suspension system. Drying shrinkage is dependent upon many factors, such as the cement, aggregate, and water content of the concrete mixture, together with ambient temperature, humidity, etc. Certain aggregates may have very high shrinkage characteristics.

Under normal conditions, one can assume that cast-in-place concrete will shrink as follows:

During the first 2 weeks-approximately 33% of the total shrinkage.
During the first month-approximately 45% of the total shrinkage.
During the first 3 months-approximately 66% of the total shrinkage.
During the first year-approximately 90% of the total shrinkage.

The complete drying and shrinkage may take several years. However, since the major part of the shrinkage takes place within the first 3 months it is advisable, when possible, to start stone installation after the poured-in-place concrete structure is complete.

The average drying shrinkage value for non-reinforced concrete is in the range of 0.0005 to 0.0009 x length. Reinforced concrete may be calculated to half of that.

9.3.2 Creep of concrete under sustained load will cause permanent deformation, which is also a factor to be considered during the design stage.

9.3.3 Thermal movement of a poured-in-place reinforced concrete structure using normal stone aggregate is relatively low: 0.0006% per 100° F.

In calculating thermal movement of a stone clad concrete structure one can use a maximum of 70° F.

9.4 Tall steel-framed structures may also have dimensional changes or combinations of dimensional changes caused by the following:

(1) Thermal movement.
(2) Elastic deformation under sustained load.
(3) Sway.

9.4.1 Thermal movement of steel framing can be expected: 0.0007% per 100° F. In calculating thermal movement of a stone clad fire-proofed steel structure one can use a maximum of 70° F.

9.4.2 Elastic deformation of high-rise steel framed buildings should be taken into consideration.

9.4.3 If cladding is supported on the edge of the slab, or concrete beam, long term deflection should be considered.

9.5 Cladding may have dimensional changes caused by temperature. Cladding usually has substantially greater temperature changes than the protected concrete or steel structure of the building. In North America, one can expect temperature changes in the cladding as high as 170° F. depending on its color and texture.

9.6 Provide expansion joints to accommodate building and cladding movements. Make sure that joints under gravity supports are kept free from any debris, shims, etc. to avoid "stacking" of stone panels.

10. ANCHORING

10.1 All stone cladding panels anchored to a building are subject to:

(1) Gravity load (the weight of the stone panel).

(2) Applied load (wind load, structural and thermal movement, seismic movement). The location, shape, and size of all anchors must be designed and calculated to safely support the stone for all stresses to which they may be subjected (compression, tension, bending, torsion). Inducing excessive stresses in the stone must be avoided.

10.2 Loadbearing (gravity) anchors are recommended, if possible, to support stone cladding panels, under (or close to) the bottom bed (see Fig. 10.2).

In case of exposed heads above windows or in similar conditions where exposed gravity anchors are not allowed under the bottom bed of the stone panels, it is customary to use epoxied and doweled stone liners for interior work.

For exterior applications, stainless steel concealed supports should be designed (see Fig. 10.2 A). Epoxied liners for exterior use should be avoided.

If epoxied liners or other epoxied stone components for exterior use can not be avoided, then the following shall be carefully considered:

. keep the surfaces of the stone components to be epoxied together clean and dry

. use specified epoxy and follow manufacturers recommendations . use clamps until epoxy is cured

. use non corrosive mechanical connections (dowels) where possible, in addition to the application of epoxy, to prevent separation in case of improper workmanship, or failure of the epoxy.

For 2-12" thick or thicker cladding panels, the use of clip angles, or plates, placed in non-continuous slots, cut in the back of stone panels is recommended.

The veneer may be supported by properly designed stainless steel plug anchors drilled in the sides and engaged with stainless steel threaded rods supporting stainless steel clip angles.

If plug anchors cannot be used because the sides are exposed, then the use of properly designed stainless threaded bent rods (often called "J" anchors) set in epoxy fill, in back of thin stone veneer is also an acceptable practice.

Stainless steel threaded bolt (called Cold Springs #31 anchor) seated in a matching routed slot in the back of the stone veneer also provides an excellent concealed anchor, when the stainless steel threaded bolt is attached to a stainless steel (or aluminum) clip angle, which could serve as a gravity and lateral supporting member.

It is recommended that when using a metal clip angle in the back of the stone engaged to a plug anchor, or to a "J" anchor, or to a #31 anchor, a "stressless" stainless steel or aluminum disc with a threaded hole should be screwed on hand-tight, with epoxy film facing the back of the stone slab, so that when the metal clip angle (or other device) is attached, it is tightened against the metal disc and not against the stone slab, preventing inducement of stress into the stone.

10.3 Lateral anchors are recommended in the joints, between the cladding panels. For conventionally installed stones lateral anchors are usually round anchors, or pins fitted into drilled holes, or strap anchors fitted into anchor slots in the edges of the stone. Sometimes it becomes necessary to provide concealed lateral anchors into the back of the stone which is connected and adjusted at the back of the stone panel. It is difficult to provide "blind" (concealed) anchors into solid masonry and, if possible, should be avoided.

Some anchors may be designed as lateral and gravity anchors, such as plug anchors, "J" anchors, or #31 anchors.

Other customized anchoring is described under "Pre-assembled Systems" and "Curtain wall Installations".

The number and distribution of the anchors should be determined by calculations and by the applicable code. Calculations shall be based on the forces to which the cladding will be subjected.

Modern stone fabrication technology makes possible the production of thin (1/4" to 1/2") stone veneer, which is installed using a "thin-set" method for interior use. Very thin stone, epoxied or honeycomb-backed, is also marketed, mainly where the weight of the panels must be limited. None of these very thin stones should be used for exterior installations, because of their very limited resistance to aging and weathering. Based on today's knowledge of the state-of-the-art, it is recommend that all stone panels for exterior installations be mechanically anchored.

10.4 Anchoring design should be sufficiently adjustable to overcome expected tolerances in building construction and to overcome the tolerances in natural stone fabrication, or a combination of both. To avoid use of anchors at improper locations, it is recommended that anchors with similar functions be designed to resist forces at any location of the building.

Stone cladding panels and anchors shall be designed to resist positive and negative windloads. The height of the building, the velocity of expected wind gusts, and the topography of the surrounding area will determine the windload criteria. For information and guidance in design of structures to resist windloads, see: **WINDLOADS ON BUILDINGS AND STRUCTURES NBS BSS 30** issued by the U.S. Department of Commerce National Bureau of Standards, and **MINIMUM DESIGN LOADS IN BUILDINGS AND OTHER STRUCTURES - A 58.1** issued by the American National Standards Institute.

10.5 The shape, size and location of gravity and lateral anchors, as well as their attachment to the structure, shall be carefully designed and calculated for all mechanical stresses to which they could be subjected: compression, tension, shear, bending, and torsion.

Special attention is recommended in the design of horizontal joints under the gravity angles to avoid load transfer to the panel below.

The use of round holes in stone to receive anchors or dowels is preferable to the use of slotted holes (kerfs) to receive strap anchors, since stones with the same thickness, using round anchor holes, usually resist mechanical stresses better than stones with slots.

Individual anchors are preferable to "split-tail" anchors. When using "split-tail" anchors or "drop dowels" to connect two stone panels, it is recommended that the anchor or dowel cavity on one side in the first stone panel be grouted and the anchor or dowel cavity on the other side in the second stone panel be caulked with fast curing silicone or high modulus polyurethane sealant.

10.6 All metals in direct contact with stone should resist corrosion and be non-staining. Anchors not in direct contact with stone may be hot dipped galvanized for exterior work, electro-galvanized, or properly painted for interior work. Above all, care shall be taken to avoid galvanic corrosion using non-compatible metals together without a proper isolator.

Galvanic corrosion occurs when a more noble metal in contact with another metal in the presence of moisture, will impair the strength, or will gradually deteriorate the less noble one.

The ratio between the mass of the two dissimilar metals, the area of their contact, and the difference in their voltage potential will determine the degree of corrosion and deterioration.

10.7 For exterior gravity and lateral anchors in direct contact with stone cladding the use of 302 or 304-type stainless steel is recommended.

Hot dipped galvanized carbon steel gravity anchors have a heavy zinc coating which will prevent corrosion for many years. Drilled holes, or rethreaded holes are a potential source of corrosion.

Electro-galvanizing does not provide reliable protection for exterior anchoring. Electro-galvanized anchors are liable to scratch and rust.

The use of galvanized anchors in direct contact with limestone is NOT recommended.

Brass wire is widely used for interior natural stone installation.

Plaster of Paris, or Gypsum, has little resistance to water penetration and is considered unsuitable for use in exterior walls.

TABLE NO. 1

METAL	**1**	**2**	**3**	**4**	**5**	**6**
1. Galvanized Steel	Yes	No	Yes	Yes	No	No
2. Stainless Steel	No	Yes	No	Yes	CC	CC
3. Cast Iron	Yes	No	Yes	No	No	No
4. Aluminum	Yes	No	No	Yes	No	No
5. Copper, Brass	No	CC	No	No	Yes	Yes
6. Phosphor Bronze	No	CC	No	No	Yes	Yes

CC = Controlled Conditions: i.e., presence of moisture (electrolyte) is prevented.

10.8 Table No. 1 indicates recommendations for bi-metallic contacts for the most frequently used metals in natural stone construction.

10.9 All welding shall conform to the provision of the code for welding contained in "Building Construction of the American Welding Society."

11. RECOMMENDED SAFETY FACTORS FOR CALCULATING STONE SLAB THICKNESS FOR WINDLOAD AND FOR LATERAL ANCHORING IN STONE.

11.1 Due to the tolerances allowed for erecting steel structures and pouring concrete, and due to other field conditions, the setting space behind the stone panel may have large variations and other discrepancies such as misplaced or left-out inserts, etc.

Based on this, it is recommended that the design of all anchoring devices be for the worst possible condition and to follow A.I.S.C. specifications for allowable stresses.

11.2 When testing natural stones, test results in a close range indicate a stone with more consistent physical properties, while test results in a wider range show the weaker and stronger areas in that test specimen.

A wide margin of safety is needed not only to meet the varying strength of the building stones, but also to provide for possible deterioration in strength of the stone after it is placed in the wall due to environmental attacks and normal expansion and contraction, freeze-thaw cycles, or other external forces, and aging.

Since the basic chemical and physical characteristics of natural building stone are determining factors of its strength and durability, it is recommended that when calculating slab thickness for wind load, for handling and for lateral anchoring, different safety factors be used for the sedimentary, metamorphic, and igneous origin rocks, so that the safety factor will reflect not only the range of spread in the test results but will also agree with the general chemical and physical characteristics of the rock.

Using a minimum of five (5) test specimens, preferably from different blocks and slabs, it is recommended that the spread in these test results be converted into safety factors as described in Table No. 2.

TABLE NO. 2

Safety Factor for Calculating Stone Thickness

Spread in Test Results	For Windload	For Lateral Anchoring
IGNEOUS ROCK		
Up to 10%	3.0	4.5
l0 to 20%	4.0	6.0
Over 20%	6.0	8.0
METAMORPHIC ROCK		
Up to 10%	4.0	6.0
10 to 20%	5.0	7.5
Over 20%	7.0	10.0
SEDIMENTARY ROCK		
Up to 10%	5.0	7.5
10 to 20%	6.0	9.0
Over 20%	8.0	12.0

It is recommended that, when possible, the full scale anchoring system be laboratory tested in lieu of relying solely on calculations. Based on a minimum of five (5) pull-out test results for anchoring stone, one can use the same safety factors which are shown in Table No. 2 for calculating the stone thickness for windload.

As a general rule, natural building stones possess higher strength in the direction at a right angle to the bedding plane than to any other direction. Therefore, it is recommended that when testing natural building stone to establish safety factors, the tests should be performed on specimens which are fabricated for testing at parallel direction with the bedding plane.

Stone specifications shall specify, and inspection shall control, the fact that all stone blocks are slabbed at the parallel direction with the bedding plane.

Where natural building stone is used as load bearing material, a 100% increase to the safety factors is recommended as shown in Table No. 2 for stone thickness.

The previously mentioned safety factor recommendation is reasonably conservative. It is written as a guide to users in the stone industry for the avoidance of potential failure and litigation. The factor of safety depends upon the Building Code and the judgment of the engineer.

The physical and chemical characteristics of the stone determine its durability, resistance to moisture and atmospheric pollutants (after it is placed in the wall). Consequently, it is not advisable to use the same safety factors for rocks of igneous, metamorphic, and sedimentary origin.

The physical and chemical characteristics of the rock also vary widely within these three groups. Nevertheless, such a simplified grouping will provide some degree of guidance to engineers, architects and designers who are calculating stone thickness for wind and anchoring, but are not thoroughly familiar with all its physical and chemical characteristics.

The basic chemical and physical properties of natural building stone vary according to its geological origin. These characteristics determine:

- elastic properties, compressive and flexural strength
- hardness and resistance to erosion
- resistance to attacks of acidic solutions (weathering)
- resistance to attacks of freeze/thaw cycles
- internal structure, coherence of the minerals

In addition to the wide variation of the weak and the strong zones of the natural building stone, there is an endless list of occasions when damages have caused substantial weakening in some of the installed stone panels, and the stone has become substantially weaker than the previously received test results would indicate.

It is common knowledge that most of the failures occur at, or near, the anchors. Unless properly conducted anchor pull-out tests suggest differently, it is reasonable to use more conservative safety factors when calculating stone thickness for anchoring, than for calculating stone thickness for wind. Of course the flexural and shear strength of the homogeneous metal anchors may be safely calculated regardless of the origin of the loads. However, natural stone is heterogeneous, therefore weak zones at, or close to, the anchors could lead to failure much before the life expectancy of the rock.

12. JOINTING DESIGN

The specification, design and detail of joints and sealants should be done by qualified persons.

12.1 Loadbearing joints in vertical walls transmit loads to the stone below. Shims are used to provide the designed joint width until the cement mortar cures. Cement mortar is also used for pointing or grouting horizontal surfaces such as paving, steps, and copings, etc.

12.2 Sealants applied in joints of vertical walls accommodate movements of the stone cladding and movements of the structure which may be transmitted to the cladding. Sealants need back-up materials which compress easily and do not bond to the sealant. Most sealants require primers for good adhesion. Particular care is necessary to have clean joints to insure proper adhesion.

12.3 Expansion joints with sealants are designed to accommodate vertical, as well as horizontal, building movements. Expansion joints are needed in stone joints beneath supporting steel angles to prevent stress concentrations due to differential vertical movements between the stone veneer and the building structure, or due to deflection of the spandrel beam, thermal movement or sway. Utmost care is needed to make sure that shims, or any other rigid objects, are not left in the expansion joints. Vertical expansion joints shall be designed to accommodate thermally or otherwise induced horizontal movements of the stone veneer or its supports.

Adequate expansion joints are needed on roof parapets which are open to the weather on two sides, to roof copings, and to expansion joints between intersections of a stone base course and a horizontal sidewalk where lack of properly designed and executed expansion joints may cause serious failure.

When designing joint widths the fabrication and installation tolerances shall be considered. For prefabricated panels such as stone faced precast or stone on trusses, unitized curtain wall panels, joints between the stone slabs should be caulked in the shop under controlled conditions. Only the joints between the prefabricated units should be caulked at the jobsite and using the same caulking compound which was used in the shop. When designing joints the potential problems due to handling, loading, transportation, unloading and erection should also be carefully considered.

Joint sizes should be designed realistically. Aesthetic considerations should not be more important than the functional requirements. Designing joints too small, could create serious functional problems.

12.4 Sealants are classified as single component or multi-component.

Single component sealants have a slower curing time.

Non-sag type sealants are applied with a gun. Self-leveling type sealants are poured into paving joints and do not require tooling.

Silicones cure fast and resists ultraviolet light. Urethanes show good resistance to abrasion and are preferred for use in paving joints. To avoid smears in critical areas masking tape may be used along the joint edges.

Part of the jointing design is the selection of the proper joint filler which controls the depth of the sealant in the joint and can also act as a secondary barrier in case of sealant failure.

Closed cell joint fillers are non-absorbent. If the ambient temperature is very high, some closed cell joint fillers may cause bubbling of the sealant. Puncturing or over-compression may also lead to bubbling of the sealant.

Open cell, sponge type joint fillers have water absorption characteristics.

Kerfs, or holes in the tops of stones must be filled with a high quality compatible sealant.

Sealant application shall be according to manufacturer's recommendation, and prior to the expiration of shelf life of the sealant. If stone thickness and setting conditions allow, the use of double sealing (back and front) is recommended.

Gaskets are usually extruded or pre-formed for joints where pressure will compress the gasket for efficient water protection.

12.5 Water leakage may lead to such serious problems as damaging the anchoring system. Due to the effects of freeze-and-thaw cycles, water trapped in anchor slots may crack the stone and cause failure of the anchoring system.

Therefore exterior stone joints must be designed and properly sealed to prevent leakage.

After the support structure and stone slab supporting system is reviewed, the stone joints should be examined.

The taller the building, the more flexural deflection, shrinkage, and creep or thermal movement of the structure may be expected.

When designing joints between the cladding units, it is important to take into consideration the expected dimensional changes in the parts of the building to which the stone cladding is applied.

The larger the stone slabs the more stress is put on the small stone joints by the mechanical and thermal movements of the structure. However, reducing the stone panel size will increase the number of joints. Potentially, more joints also mean the greater possibility of human error and imperfection in installation, as well as more erosion of joint sealants due to exposure to the elements.

12.6 Applications shall comply with the specifications, with design details, and with the sealant manufacturer's recommendation.

The most common problem during the application is the change in the joint sizes, due to tolerances of stone dimension. Such field conditions may result in undesirable deviations from the jointing design and may lead to leakage and failure. Therefore, before sealant application begins, qualified persons should inspect joint conditions and either remedy improper joints, or re-design the joint treatment.

13. CONTROLLING WATER PENETRATION

Flashing.

No cladding is perfectly waterproof. Wind driven rain will find its way behind stone panels where pointed cement mortar or caulking separates the stones. Porosity, which is the volume of voids related to the apparent volume of the stone, under pressure of wind driven rain could let water seep through. Condensation can also produce moisture on the back side of the stone panels. Therefore, a second line of defense is necessary to collect and let the water out of the cavity behind the stone panel, and ventilate the cavity to keep the stone and the back-up masonry dry.

Properly designed weep holes, weep slots, and flashing serve this purpose. Flashing is a flexible material installed at one end, higher up against the structure, and turned at the other end, into the stone joint. Waterproof, rubberized fabric, polyethylene, or soft neoprene sheets, or soft thin-gauge stainless steel flashings are the most widely used.

An experienced, qualified person, with a thorough understanding of the cladding system, including the windows, is needed to design the flashing and the components of the secondary water defense. Leaving it only to the person installing the flashing is **NOT** recommended.

Prefabricated systems, such as stone on trusses, or stone on unitized curtainwall panels require a galvanized sheet metal water defense designed

behind the stone slabs, including gutters and weep-tubes to collect and discharge water from the cavity
(see Fig. 13).

14. QUARRYING AND FABRICATION

14.1 For large projects it is prudent for members of the design team to visit the quarry and the manufacturing plant to check on the availability of the stone required.

To obtain a more uniform and aesthetic appearance, as well as more uniform strength, all blocks should be quarried to dimensions which will allow uniform slabbing in relation to the bedding plane of the rock. Most stones have higher flexural strength if slabbed parallel with the bed. Sedimentary rocks, such as limestone and sandstone, should always be slabbed parallel with the bed.

14.2 Fabrication shall be in strict accordance with specifications and approved shop drawings. Tolerances described in the specifications must be followed. Shop inspection of fabricating is strongly recommended to protect all parties from possible later disputes about color ranges, marking, structural defects, or improper thickness. Anchor holes, cut outs for other trades, and lifting holes shall be provided in the shop and **NOT** on the job site.

For large projects a mock-up sample wall should be erected in the fabrication plant as a guide to control the uniformity of the stone color and texture. If this is not done, stone slabs with improper coloration or texture may be cut to final dimensions and shipped to the job site where they may be installed. At this point, the removal of rejected pieces and re-installation can be very costly.

To prevent the installation of slabs with improper quality, coloration, or texture a mock-up sample wall, or floor, should be erected at the jobsite, for the approval of the Architect. Once the quality and the appearance of the stone and its method of installation is approved, it is critical that proper supervision be maintained to insure against sub-standard installation, or against the use of stone slabs beyond the approved range of color, texture, and quality of the mockup.

For controlling the consistent quality of the stone, it is prudent to apply specially designed shop tests for a certain percentage of the slabs to be used on the project. Such shop testing is usually done by applying uniformly loaded weight on the slabs, or by using a small test chamber for applying static pressure. (see paragraph 7 - Chamber Tests).

14.3 For composite panels, such as precast concrete faced with natural stone, or stone slabs pre-assembled on steel frames or trusses, inspection of the assembly is recommended to insure the specifications and design details are followed. In many cases the anchors, shelf angles, reinforcing steel, insulation, slip-sheet and other components are not exposed to view. The consequences of improper assembly may only become evident years after the panel erection.

Special care shall be taken in handling and storing composite panels to prevent bowing, chipping freeze-thaw, and other damage.

- Click here to see Table 14.4 -

15. HANDLING, STORING AND TRANSPORTATION

15.1 Special care is needed in handling and storing stone slabs to prevent bowing, cracking, chipping, and staining. Supports shall be designed to avoid over-stressing or cracking of stone panels during storage and transportation. Stress concentration due to improper handling may interconnect micro or macro fractures of geological origin which may be present in the stone slabs. Moisture and thermal cycles may cause later distress and failure of such panels on the building facade.

Stone slabs should be properly palletized or crated on edge for safe transportation and for economic unloading and distribution. Non-containerized crates should be marked "fragile" and packed and handled with increased care due to the higher breakage hazard.

Pallets, crates, or pre-assembled panelized stones on trucks or in containers shall be carefully secured to prevent them from shifting. Pre-assembled panels for storing and shipping shall be designed so that the frame supports the stone and no load is transmitted through the connections to the stone slabs.

Unless stone slabs or pre-assembled panels are erected directly from the truck or trailer, ample room will be needed at the job site to distribute them reasonably close to where they will be installed. They should be distributed so their identification numbers are visible. Double handling, moving stone at the jobsite, will greatly increase the possibility of breakage or chipping.

Unloading of trucks or containers at the job site should also be done carefully. If a "cherry picker" or a mobile crane is used for unloading, a permit is usually required. Forklifts or monorails are also often used to unload trucks or container shipments.

The method of storing stone on structural floors should also be carefully planned. Unpolished slabs, in particular, should be protected from staining. The storage areas should be adequate, accessible, and the moving of materials of other trades should be limited. Pre-loading floors should be in accordance with requirements set forth by the engineer of record.

When stone slabs are stacked, they should be separated with two non-staining skids placed approximately one-quarter of the way from each end of the slab. Skids should be placed directly above one another to prevent cracking or breakage (see Fig. 15.1).

15.2 Pre-assembly of stone on steel frames, curtainwall components or precast concrete is done in a shop under controlled conditions.

If possible, pre-assembled panels should be shipped in a position similar to the one in which they will be installed. For supporting seats, the use of special hard rubber pads is recommended. It is prudent to protect the stone from possible staining during transportation.

15.3 All cladding stone above the first course shall have lifting holes. Type and location of lifting holes shall be carefully designed for safety and clearly defined on the shop drawings or shop diagrams. Cutting lifting holes on the job site should be avoided. All stones shall have identification numbers for erection purposes and shall be shipped and stored in the sequence of erection.

16. SURVEY, LAYOUT, AND FIELD MEASUREMENTS.

16.1 If location of walls, door bucks, window frames, etc. cannot be guaranteed, the job for the interior stone installation shall be field measured, or certain critical slabs shall be shipped over-sized for field cutting.

Exterior stone shall be prefabricated in compliance with approved shop drawings.

Perimeter offset lines, column center lines, benchmarks, and other necessary survey marks shall be provided to the stone contractor for the stone layout on each floor. Where possible, cuts or nails shall be provided in the concrete floor rather than paint or crayon marks.

17. SUPERVISION

17.1 All critical phases of the installation procedure shall be performed by qualified mechanics under the supervision of a registered architect, engineer, or consultant, who understands the anticipated mechanical and thermal movements of the supporting structure, the function of the gravity and lateral anchors, and who knows the physical properties of the stone being used. Supervisor shall be able to recognize field conditions which deviate from the specifications and/or shop drawings, and shall make substitutions to meet field conditions or, if necessary, stop installation until acceptable measures or changes may be taken.

Close coordination is needed between the General Contractor, the Stone Cladding Subcontractor, Architect, Engineer, Stone Consultant, and Field supervision personnel to make certain that all components (inserts, gravity, and lateral anchors) are located and installed as designed, within allowable tolerances and that the type and number of anchors used for stone cladding is in strict accodance with the specifications and approved shop drawings.

18. PROTECTION, CLEANING, AND MAINTENANCE

18.1 Stone cladding contractor shall protect stone slabs during storage and installation, including protection of exposed surfaces from scaffold tie backs, hanging scaffold rollers, and possible damage from erection tools and equipment. General Contractor shall protect all stone set in place from possible damage from other trades.

It is recommended that all exposed stone paving surfaces and facing surfaces (minimum 8 feet high above ground level) be protected with Homosote, or non-staining plywood.

18.2 Removal of excess mortar, dust and dirt from the exterior stone shall begin at the top, and be worked down. Stone cladding shall be thoroughly washed down using clean water and fiber brushes. Stonework with accumulated dirt or substantial damage from industrial air pollution may be cleaned by an approved cleaning process employing properly pressurized steam and water.

For removal of particular oil or grease stains, organic stains, rust, or other miscellaneous stains, seek the advice of a qualified experienced stone restoration firm. It is recommended that all exterior exposed natural building stone surfaces be washed down once every five years. It is recommended that you contact Building Stone Institute (BSI) for names of qualified firms experienced in cleaning exterior stone.

During washdown, pointed or caulked joints which may be damaged shall be raked and repainted or recaulked.

18.3 Cleaning and maintenance of marble and limestone require different preparation than granite. To prevent injury to marble or limestone, avoid the use of solutions containing salts.

Generally clean water is all that is needed. However, from time to time, when such treatment does not leave a clean and fresh looking surface, a mild detergent and rinsing may be used.

18.4 A periodic inspection and maintenance program can prevent expensive renovation work or potential removal and replacement of stone slabs.

The findings of every inspection should be recorded so that any progress in deterioration can be measured and evaluated.

Particular attention should be given to stone joints, lips between stone panels, cracks or spalls.

19. STONE REPAIR

19.1 In the stone industry it is understood that in the process of fabricating, shipping, and erection stone panel damage and/or breakage may occur. It is an accepted practice to repair damaged stone within certain limitations.

In addition, cracks and/or breakage sometimes develop - or may be discovered - after the stone has been installed. It is the accepted practice to repair such stones under the supervision of an experienced and responsible stone expert. Such repair work should be done by qualified mechanics who have been instructed in the proper procedure, usage of specified materials, and recommended methods.

19.2 What cannot be repaired.

Any stone that has a crack, chips or break that compromises or in any way affects the structural integrity or the structural anchorage of the unit to the backup is NOT to be repaired - but is to be replaced.

19.3 What can be repaired.

Damaged stone that is determined to be repairable by an expert may be repaired by one of the following methods:

Patching: for breaks less than 3/4" in depth.
Filling & Patching: For breaks larger than 3/4" in depth.
Bonding: Adhesion of stone to stone.

19.4 Patching

This is a process where chipped or broken out areas of stone are repaired by patching the void with an epoxy mortar mix. This method is used where the broken off pieces of stone are either not available and/or the size of the chipped area is under 3/4" in depth (see SK #1).

The subject area is to be examined to determine if the size of the break warrants, or can accommodate, "tie-in" dowel pins (see SK #1& SK #2).

a) If the condition to be patched is of a size where steel dowel pins cannot be properly encapsulated with the patch mix, provide an alternative "tie-in" by drilling several 3/16" diameter "key-in" holes, using diamond bits, at alternate approach angles (plus or minus 1-1/2" o.c. plus-or-minus 3/8" deep). This will provide a mechanical tie-in that is in addition to the adhesion obtained by mortar mix (see SK #1).

b) At conditions where the size of the patch can properly encapsulate steel dowel pins, prepare the area by drilling 3/16" diameter holes, using diamond core bits, at alternating approach angles (see SK #2).

Fill the holes with epoxy mortar mix and insert 1/8" diameter stainless steel dowel pins, allowing the dowel pins to project out into the area to be filled.

c) If a limited break occurs on the exterior portion of a continuous kerf, dowel pins are to be used (see SK #3).

Note: Only exterior portions of continuous kerfs may be repaired.

d) Place and secure edge plywood framing as, and if, required (see SK #1 & SK #2).

e) The area to be patched is to be clean, free of dust and dry. The subject area should be kept free from exposure to moisture for a minimum of 24 hours prior to the repair operation. As an added precaution, the subject area may be further dried by the use of a hot air blow dryer for a minimum of 5 minutes just prior to proceeding with the patching.

f) Prepare an "epoxy mortar mix" consisting of an approved bonding agent, and ground stone particles, to a non-sag-consistency; fully fill "key-in" holes and then fill in the balance of the chipped or broken area. Texture the surface of this patch to resemble the adjacent finish. Once the epoxy has fully set, rough up or hone the surface to match the flamed or honed finish to produce a matching texture.

When repairing polished surfaces, use a wrinkle-free polyethylene sheet to obtain a smooth shiny finish, or hand polish if necessary.

19.5 Filling and patching

Where the chipped or broken out area is larger than 3/4" in depth and the broken off piece of stone is not available, the area must be prepared by filling in or building up the void area with a material especially manufactured and formulated for this particular application. Then, the final surface area is to be patched and dressed using an "epoxy mortar mix" as previously described.

a) Prepare the area to be filled by providing a mechanical tie-in by installing 1/8" diameter bent dowel pins at alternating approach angles in the base stone (see SK #5).

b) Place and secure edge plywood framing as required.

c) Clean and dry the area.

d) Prepare a "fill mixture" of an approved bonding agent (without any aggregate) and fill the void area completely except the top, plus-or-minus 1/2". Allow some of the dowel pins to penetrate out into this 1/2" area.

e) Allow the "fill mix" to cure for a minimum of 24-hours. Then patch the remaining area using an approved bonding agent (see SK #5).

19.6 Bonding.

Bonding is used when an actual piece of the broken stone is available to be reattached and bonded back into place.

a) The broken off piece of stone is to be placed, and temporarily held, in proper position on the unit, and several 3/16" diameter holes are to be drilled through the broken off piece directly into the main base piece. The holes should be located in the "meaty" portion of the broken off stone. The depth penetration of these holes into the base piece is to be plus-or-minus 3/4" (see SK #6).

b) After drilling the holes, both pieces of stone are to be cleaned and thoroughly dried using a hot air blow dryer.

c) Prepare an "adhesive mix" of an approved bonding agent without any aggregate. Fill all the pre-drilled "key-in" holes with the adhesive mix, as well as both surfaces of the stone that will come in contact with one another. Press fit the pieces to be bonded together and insert stainless steel dowel pins so that the pin engagement is approximately 50% in each of the two pieces of stone. The exposed access holes are to be patched using an approved epoxy mortar mix with the appropriate colored granulated aggregate to match the adjacent area. Clean off any excess overflow and attach retaining clamps if necessary.

d) Broken non-continuous kerf (single anchor kerf) shall **NOT** be repaired. The stone should be replaced. Continuous kerf (full length anchor kerf) broken at the outside portion can be repaired only if the broken part can be properly re-attached with the use of stainless steel dowel pins. Such kerf repair shall be analyzed and substantiated with signed and sealed calculations by a licensed professional engineer.

19.7 Stitching.

When a cracked or broken stone is discovered on a building **-** after installation **-** it can be repaired by "stitching" if it is determined to be repairable by an expert (see SK #7).

To stitch a hairline crack in a vertically installed stone facing, provide a kerf cut in the exposed face of the stone, to a depth half of the stone thickness, using a diamond blade tool.

The cut should be in the direction perpendicular to the hairline crack to receive a 1/8" diameter, 2" long stainless steel dowel.

Install the dowel in knife-grade epoxy mixed with stone powder which will color the epoxy as close as possible to the original color of the stone.

A minimum of one stainless steel dowel is recommended for every 6" length of hairline crack in the stone.

If the crack is 1mm thick or more, then in addition to the stainless steel dowel stitching of the slab, provide a "V" grove 1/4" deep along the crack, and fill it with epoxy mixed with stone powder.

19.8 Pinning.

In addition to, or in place of,"stitching," cracked, broken or loose stone can be pinned, if determined to be repairable by an expert
(see SK #8).

To pin a vertically installed stone facing, drill a half inch diameter hole sloping down approximately 22°, through the stone and its setting space into the concrete backup structure.

Clean the hole with air and inject low consistency epoxy in the hole in the stone.

Dip pre-cut stainless steel rod in epoxy and place it in the hole of the concrete and the stone approximately 1/4" short of the finished face of the stone.

Fill the last 1/4" with epoxy and stone powder.

19.9 Materials and tools.

a) Patching: Use an "epoxy mortar mix" consisting of an approved bonding agent with fine to medium grade aggregate consisting of ground particles of the actual project stone for the purpose of obtaining and matching the original project stone.

b) Filling and Patching: "Fill mix" to be an approved bonding agent with no aggregate added.

c) Bonding: Adhesive mix is to be made of an approved bonding agent.

d) Stone Aggregate: Pre-packaged, dry, stone aggregate of the project stone, of a color to produce a mortar mix that matches the project stone.

e) Factory pre-packaged proportional units of an approved bonding agent with the appropriate mixing containers.

f) Stainless Steel Type 302 or 304 solid dowel pins or threaded rods of various lengths - straight or bent.

g) Other Equipment: Diamond drill bits, hot air dryer, clamps, spatulas, polyethylene, tapes.

20. REFERENCE LIST

American Architectural Manufacturers Association (AAMA)
1827 Walden Office Square (#104), Schaumburg, Illinois 60173
(847) 303-5664
www.aamanet.org

American Institute of Architects (AIA)
1735 New York Avenue, NW, Washington, D.C. 20006-5292
(202) 626-7300
www.aia.com

American Institute of Steel Construction (AISC)
1 East Wacker Drive (#3100), Chicago, Illinois 60601
(312) 670-2400
www.aisc.org

American National Standards Institute (ANSI)
11 West 42nd Street, New York, New York 10036
(212) 642-4900
www.ansi.org

American Society for Testing & Materials (ASTM)
100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428
(610) 832-9500
www.astm.org

American Welding Society
550 N.W. LeJeune Road, Miami, Florida 3312
(305) 443-9353
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Building Stone Institute
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www.buildingstoneinstitute.org

Construction Specifications Institute (CSI)
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