MARBLE AND ONYX

1.0 GENERAL

1.1 Related Documents

1.1.1 Drawings and general provisions, including General and Supplementary Conditions of the Contract and Division I Specification sections, apply to this section.

1.2 Applicable Publications

1.2.1 The following publications listed here and referred to thereafter by alphanumeric code designation only, form a part of this specification to the extent indicated by the references thereto:

1.2.2 ASTM International (ASTM):

1.2.2.1 C503, Standard Specification for Marble Dimension Stone

1.2.2.2 C97, Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone

1.2.2.3 C99, Standard Test Method for Modulus of Rupture of Dimension Stone

1.2.2.4 C170, Standard Test Method for Compressive Strength of Dimension Stone

1.2.2.5 C241 Standard Test Method for Abrasion Resistance of Stone Subjected to Foot Traffic

1.2.2.6 C880, Standard Test Method for Flexural Strength of Dimension Stone

1.2.2.7 C1353, Standard Test Method for Abrasion Resistance of Dimension Stone Subjected to Foot Traffic Using a Rotary Platform Abraser

1.2.3 Natural Stone Institute (NSI):

1.2.3.1 Membership, Products, and Services Directory

1.2.3.2 Dimension Stone Design Manual

1.2.3.3 Additional publications may be available from the NSI Bookstore. Go online at www.naturalstoneinstitute.org.

1.3 Scope of Included Work

1.3.1 The work to be completed under this contract includes all labor and materials required for the furnishing and installation of all marble work shown or called for on the contract drawings, specifications, and addenda.

1.4 Definition of Terms

1.4.1 The definitions of trade terms used in this specification shall be those published by the NSI or ASTM International.

1.5 Source of Supply

1.5.1 All marble shall be obtained from quarries having adequate capacity and facilities to meet the specified requirements, and by a firm equipped to process the material promptly on order and in strict accord with specifications. The Specifying Authority (architect, designer, engineer, contracting officer, end user, etc.) reserves the right to approve the Material Supplier prior to the award of this contract. Stone and workmanship quality shall be in accordance with Industry Standards and Practices as set forth by the NSI.

1.6 Samples

1.6.1 The Marble Contractor shall submit through the General Contractor, for approval by the Specifying Authority, at least two sets of samples of the various kinds of marble specified. The sample size shall be 1'-0" x 1'-0" (300 mm x 300 mm) and shall represent approximately the finish, texture, and anticipated range of color to be supplied.

Where necessary to show variations in color and markings, larger samples or range sets of samples should be submitted. If marble is to be matched, a minimum of two sets each containing four matched samples showing proposed veining and range of color in each set must be supplied. Samples designating finished face shall be clearly labeled on the back with the name of the marble, the group classification for soundness, and the use for which the marble is intended. One set of samples shall be retained by the Specifying Authority, and one set shall be returned to the Marble Supplier for his/her record and guidance. It is noted herein that marble is a natural material and will have intrinsic variations in color, markings, and other characteristics. Depending on the marble selected and quantity required, a range mockup may be used to further define the characteristics of the material. Cost of mockup, if required, shall not be included in this section.

1.6.2 Prior to fabrication, an inspection and approval by the Specifying Authority and/or General Contractor and/or End User of the finished slabs is recommended to understand the finish and full range of the material.

1.7 Shop Drawings

1.7.1 The Marble Contractor shall submit through the General Contractor, for approval by the Specifying Authority, sufficient sets of shop drawings showing general layout, jointing, anchoring, stone thickness, and such other pertinent information. These drawings shall show all bedding, bonding, jointing, and anchoring details along with the net piece dimensions of each marble unit. One copy of approved drawings shall be retained by the Specifying Authority, one copy shall be retained by the General Contractor, and one copy returned to the Marble Contractor for fabrication. NO FABRICATION OF MARBLE SHALL BE STARTED UNTIL SUCH DRAWINGS HAVE BEEN FULLY APPROVED AND MARKED AS SUCH. The General Contractor shall furnish all field dimensions necessary for fabrication. If measurements are not established and guaranteed in advance, the Marble Contractor shall obtain and verify measurements at the building. The General Contractor shall be responsible for all reasonable assistance to the Marble Contractor, including the services of an Engineer, if required, for the establishment of levels, bench marks, and the like. The Marble Contractor shall not be responsible for determining, making, or verifying (1) design, structural, wind, seismic, or other design loads; (2) engineering estimates; (3) plans or specifications; or (4) the types, sizes, or locations of anchors, unless specifically added to the scope of work.

1.8 Defective Work

1.8.1 Any piece of marble or onyx showing flaws or imperfections upon receipt at the storage yard or building site shall be referred to the Specifying Authority for determination as to responsibility and decision as to whether it shall be rejected, patched, or redressed for use.

1.9 Repairing Damaged Stone

1.9.1 Small chips at the edges or corners of marble may be patched provided the structural integrity of the stone is not affected and the patch matches the color and finish of the marble so that the patch does not detract from the stone's appearance.

2.0 MATERIALS

2.1 Marble

2.1.1 General: All marble shall be of kind or kinds shown on the Architect's drawing or as specified herein, conforming to or within the range of approved samples and in accordance with the characteristics and working qualities set forth under their respective Soundness Group Classifications, A, B, C, or D, as defined by the Marble Institute of America. Care shall be taken in selection to produce as harmonious effects as possible. Patching and waxing, where permitted under the Marble Institute of America Group Classifications, shall be carefully done to conform to the marble's general character and finish. Texture and finish shall be within the range of sample(s) approved by the Specifying Authority.

2.1.1.1 ASTM C503 [C97] [C99] [C170] [C241/C1353] [C880] See the chart of applicable ASTM standards and tests in the Appendix.

2.1.2 Schedule: Marble shall be provided as follows:

2.1.2.1 For (*state location on building*) (*state name and color*) marble with a (*type*) finish, supplied by (*name company or list several approved suppliers*).

2.1.2.2 Provide information as in (1) for each different marble/finish combination in the project.

2.1.3 Finishes: Finishes listed in the schedule shall conform with definitions by NSI or ASTM International.

2.1.3.1 Polish Finish: A mirror-like, glossy surface which brings out the full color and character of the marble. This finish is not recommended for exterior or commercial floor use.

2.1.3.2 Honed Finish: A velvety smooth surface with little or no gloss.

2.1.3.3 Abrasive Finish: A flat, nonglossy surface usually recommended for exterior use.

2.2 Setting Mortar (And Adhesives)

2.2.1 Portland cement shall conform to the requirements of the Standard Specifications for Portland Cement, ASTM C150. White portland cement is recommended for white or light colored marble. Nonstaining cement shall conform to the requirements of the Standard Specifications for Masonry Cement, ASTM C91.

2.2.2 Sand. All sand shall be clean, free from organic and other deleterious matter likely to stain the finished work, and shall be screened as required for the desired results.

2.2.3 Portland cement shrinkage-reducing accelerator used with portland cement to give it the quick-setting characteristics of plaster of paris, shall be a nonstaining admixture that will not corrode anchors or dowels.

2.2.4 Nonstaining adhesive shall be of a type that will not stain the marble, that is not affected by temperature changes or moisture, and that adheres with strong suction to all clean surfaces.

2.3 Pointing Mortar

2.3.1 Mortar for pointing shall be Type N, as defined in ASTM C270 (Standard Specification for Mortar for Unit Masonry). All mixing, handling, and placing procedures shall be in accordance with ASTM C270.

2.4 Sealants and Backup Material (if Applicable)

2.4.1 Where specified (*state type or name of sealant*) shall be used for the pointing of joints. The backup material used with the sealant shall be (*identify material*).

2.4.2 Sealants, used for pointing to exclude moisture and provide a joint that will remain plastic for many years, shall be nonstaining.

2.5 Anchors, Cramps, and Dowels

2.5.1 Anchors, cramps, and dowels shall be made of corrosion-resistant metals. Special cramps, dowels, and the like shall be used where shown on shop drawings, but elsewhere, #8 copper or stainless steel wire anchors shall be used. It shall be the responsibility of the Marble Contractor to anchor all marble securely. For standing marble, the following practices usually prevail:

2.5.1.1 A minimum of four anchors should be provided for pieces up to 12 square feet (1 m^2), with two additional anchors for each additional 8 square feet (0.75 m^2) of surface area. Shims used to maintain joints shall be plastic.

2.5.1.2 Use of copper wire for anchors to be installed over 12' (3.5 m) off the ground is not recommended.

3.0 FABRICATION

3.1 Beds and Joints

3.1.1 Bed and joint width shall be determined by analysis of anticipated building movements and designed to accommodate such movements without inducing undue stresses in the stone panels or joint filler materials. Expansion joints shall be designed and located to accommodate larger movements.

3.2 Backs of Pieces

3.2.1 Backs of pieces shall be sawn or roughly dressed to approximately true planes. Back surfaces shall be free of any matter that may create staining.

3.3 Moldings, Washes, and Drips

3.3.1 Moldings, washes, and drips shall be constant in profile throughout their entire length, in strict conformity with details shown on approved shop drawings. The finish quality on these surfaces shall match the finish quality of the flat surfaces on the building.

3.4 Back-Checking and Fitting to Structure or Frame

3.4.1 Stone coming in contact with structural work shall be back-checked as indicated on the approved shop drawings. Stones resting on structural work shall have beds shaped to fit the supports as required.

3.4.2 Maintain a minimum of 1" (25 mm) between stone backs and adjacent structure. (Note: many bolted connections will require more space than this; 2" (50 mm) space may be more desirable. Large-scale details should illustrate and control these conditions.)

3.5 Cutting for Anchoring, Supporting, and Lifting Devices

3.5.1 Holes and sinkages shall be cut in stones for all anchors, cramps, dowels, and other tieback and support devices per industry standard practice or approved shop drawings. However, additional anchor holes shall be drilled at job site by Marble Contractor to facilitate alignment.

3.5.2 No holes or sinkages will be provided for Marble Contractor's handling devices unless arrangement for this service is made by the Marble Contractor with the Marble Fabricator.

NOTE: It is not recommended that lewis pins be used for stones less than 3½" (90 mm) thick.

3.6 Cutting and Drilling for Other Trades

3.6.1 Any miscellaneous cutting and drilling of stone necessary to accommodate other trades will be done by the Marble Fabricator only when necessary information is furnished in time to be shown on the shop drawings and details, and when work can be executed before fabrication. Cutting and fitting, due to job site conditions, will be the responsibility of the Marble Contractor.

3.6.2 Incidental cutting such as for window frame clips, etc., which is normally not considered to be the responsibility of the Stone Supplier, will be provided only by arrangement by the General Contractor and Marble Contractor with the Marble Fabricator.

3.7 Carving and Models

3.7.1 All carving shall be done by skilled Stone Carvers in a correct and artistic manner, in strict accordance with the spirit and intent of the approved shop drawing, or from models furnished or approved by the Specifying Authority.

4.0 SHIPPING AND HANDLING

4.1 Packing and Loading

4.1.1 Finished marble shall be carefully packed and loaded for shipment using all reasonable and customary precautions against damage in transit. No material which may cause staining or discoloration shall be used for blocking or packing.

4.2 Site Storage

4.2.1 It shall be the responsibility of the Marble Contractor to receive, store, and protect the marble from damage by others after it is delivered to the job site and prior to its erection in the building. All marble shall be received and unloaded at the site with care in handling to avoid damage or soiling. If marble is stored outside, it shall be covered with nonstaining waterproof paper, clean canvas, or polyethylene.

5.0 INSTALLATION

5.1 General Installation

5.1.1 Installation shall be accomplished with competent, experienced Stone Setters, in accordance with the approved shop drawings.

5.1.2 All marble and onyx pieces shall be identified with a unique piece number corresponding with the number on the shop drawings. Interchanging of numbered pieces is not permitted.

5.1.3 Marble and onyx shall be free of any ice or frost at time of installation. Salt shall not be used for the purpose of melting ice, frost, or snow on the stone pieces.

Adequate protection measures shall be taken to ensure that exposed surfaces of the stone shall be kept free of mortar at all times.

5.2 Mortar Setting of Marble and Onyx

5.2.1 Floor Marble

5.2.1.1 Floor Preparation. It is the General Contractor's responsibility to clean all subfloor surfaces to remove dirt, dust, debris, and loose particles immediately prior to setting marble floor and to ensure that the area to receive the stone flooring meets the deflection standards of the industry.

5.2.1.2 Curing Compounds. Curing compounds of any kind shall not be used on the slab on which floor marble is to be directly set. If a curing compound is present, it is the General Contractor's responsibility to remove it by scarifying the slab.

5.2.1.3 Before being set, all marble shall be clean and free of foreign matter of any kind.

5.2.1.4 Mortar Bed. The mortar bed to receive the marble tile shall consist of 1 part portland cement to not more than 4 to 5 parts of clean, sharp sand mixed quite dry for tamping. White portland cement is recommended for light-colored marbles.

5.2.1.5 Marble Tamped. The marble shall be tamped with a suitable mallet until firmly bedded to the proper level of the floor.

5.2.1.6 Marble Removed. The marble shall then be removed and the back parged with wet cement or the bed sprinkled with water and cement. In the latter procedure, the back of the marble shall be wet. The method of fully buttering edges of the marble as it is laid is equally approved.

5.2.1.7 Joints. Joints between the marble pieces shall show an even width when laid and finished.

5.2.1.8 Traffic after Installation. The floor shall be roped off for 24 hours after installation and then grouted with water and white portland cement grout or nonstaining dry set portland cement grout.

5.2.1.9 Timeline for Additional Cleaning. Cleaning or additional surfacing, if required, shall not be undertaken until the new floor is at least seven days old.

5.2.1.10 Thin-set Method. The thin set method of installing marble tile employing the use of dry-set portland cement mortars is recommended for thin marble tiles [nominal 3/8" (9.5 mm) thick] where optimum setting space is not available. Subfloor shall be clean, smooth-finished, and level.

5.2.1.10.1 Stone dust must be washed off the back face of stone pavers prior to installation. Apply mortar with flat side of trowel over an area that can be covered with tile while mortar remains plastic. Within ten minutes, and using a notched trowel sized to facilitate the proper coverage, comb mortar to obtain an even-setting bed without scraping the backing material. Key the mortar into the substrate with the flat side of the trowel. Comb with the notched side of the trowel in one direction. Firmly press stone tiles into the mortar and move them perpendicularly across the ridges, forward and back approximately 1/8" to ¼" (3 to 6.5 mm) to flatten the ridges and fill the valleys. Ensure a maximum mortar thickness of 3/32" (2.5 mm) between stone tile and backing after stone tile has been tamped into place. Stone tile shall not be applied to skinned-over mortar. Alternatively, back butter the stone tiles to ensure 100% contact. In either method, ensure 100% contact on 3/8" (9.5 mm) tile; not less than 80% contact on ¾" (20 mm) or thicker material, noting that all corners and edges of stone tiles must always be fully supported, and contact shall always be 100% in exterior and/or water-susceptible conditions.

5.2.2 Interior Veneer Marble

5.2.2.1 The marble shall be set by spotting with cement mortar and the use of concealed anchors secured in the wall backing.

5.2.3 Marble Wall Tile

5.2.3.1 Individually set thin tile [nominal 3/8" (9.5 mm) thick] on vertical surfaces exceeding 15'-0" (4.5 m) is not recommended. Where thin marble tile is installed, nonstaining adhesives or thin-set mortars may be used as setting beds.

5.2.4 Toilet and Shower Compartments

5.2.4.1 Stiles and partitions shall be assembled with concealed dowel fastenings or corrosion-resistant angles, three in height of stall.

5.2.4.2 For ceiling-hung units, metal supporting members in ceiling are to be furnished and installed by the General Contractor.

5.3 Mortar Joints

5.3.1 Mortar joints shall be raked out to a depth of ½" to ¾" (12.5 to 20 mm). Apply pointing mortar in layers not exceeding 3/8" (9.5 mm) and allow each layer to get hard to the touch before the next layer is applied. Tool finished joints with a concave tool having a diameter approximately 1/8" (3 mm) greater than the joint width.

5.3.2 Care shall be taken to keep expansion joints free of mortar, which would compromise their function.

5.4 Anchorage

5.4.1 All marble shall be anchored or doweled in accordance with the approved shop drawings.

5.4.2 To the furthest extent possible, all anchor preparations in the marble units shall be shop-applied.

5.4.3 All anchorage devices and anchor hole/slot fillers shall be in accordance with ASTM C1242. Care must be taken to ensure that any holes capable of retaining water are filled after use to prevent water collection and freezing.

5.5 Sealant Joints

5.5.1 Where so specified, joints requiring sealant shall be first filled with a closed-cell ethafoam rope backer rod. The backer rod shall be installed to a depth that provides optimum sealant profile after tooling.

5.5.2 If recommended by the Sealant Manufacturer, primers shall be applied to the substrate surfaces according to the manufacturer's directions prior to application of the joint sealant.

5.6 Expansion Joints

5.6.1 It is not the intent of this specification to make control or expansion-joint recommendations for a specific project. The Specifying Authority must specify control or expansion joints and show locations and details on drawings.

5.7 Caulking

5.7.1 Where so specified, joints shall be pointed with the sealant(s) specified in Section 2.4, after first installing the specified backup material and applying a primer if required, all in strict accordance with the printed instructions of the Sealant Manufacturer.

5.7.2 All sealants shall be tooled to ensure maximum adhesion to the contact surfaces.

5.8 Weep Tubes

5.8.1 Plastic or other weep tubes shall be placed in joints where moisture may accumulate within the wall, such as at base of cavity, continuous angles, flashing, etc., or as shown on architectural drawings.

6.0 CLEANING AND PROTECTION

6.1 Cleaning

6.1.1 Marble shall be shop cleaned at the time of final fabrication. It shall also be cleaned after installation and all pointing or caulking is completed. All dirt, excess mortar, weld splatter, stains, and other defacements shall be removed.

6.1.2 All cleaning methods shall be in accordance with ASTM C1515.

6.1.3 Stiff bristle fiber brushes may be used, but the use of wire brushes or of acid type cleaning agents and other solutions which may cause discoloration is expressly prohibited. Fabricator should be contacted before cleaners other than neutral detergents are used.

6.2 Protection of Finished Work

6.2.1 After the marble work is installed, it shall be the responsibility of the General Contractor to see that it is properly and adequately protected from damage or stains until all trades are finished. This responsibility includes the stone cleaning costs prior to the required final inspection. The Marble Contractor will outline the needs for protection, in writing, to the General Contractor. For the protection of projecting members, corners, window stools, and saddles, wood guards using lumber that will not stain or deface with marble shall be supplied, installed, and maintained by the General Contractor. All nails used shall be galvanized or nonrusting. Damage to finished marble by other trades shall be repaired or replaced at the expense of the General Contractor. Marble flooring shall be adequately protected by the General Contractor against traffic and other damage with nonstaining materials without cost to the Marble Contractor.

6.2.2 All marble work in progress shall be protected at all times during construction by use of a strong, impervious film or fabric securely held in place.

PRODUCT DESCRIPTION –
Marble and Onyx

1.0 GEOLOGICAL CLASSIFICATION

1.1 Marble is geologically defined as a metamorphic rock predominately consisting of fine- to coarse-grained, recrystallized calcite ($CaCO_3$), and/or dolomite, ($CaMg(CO_3)_2$), which has a texture of relatively uniform crystals ranging from very large (inches) to very fine, small, uniform sized crystals[1]. Two aspects of the definition are important to the stone industry professionals and scientists alike: It is *metamorphic* and, it is *recrystallized*; that is, many marbles are formed by processes of recrystallization and/or metamorphism and have recrystallized textures that obscure most previous texture and depositional features.

1.1.1 A commercial definition equally important and long used in the industry is that marble is any crystallized carbonate rock and certain types of limestone that take a polish and can be used as architectural or ornamental stone[2]. The dimension stone industry traditionally includes other types of stone, such as onyx, in the same classification as marble.

1.1.2 Almost all metamorphic marbles are developed by high pressures in the process of metamorphism, while recrystallization of limestone can occur under normal overburden pressures in thick sedimentary sequences. Obviously, due to the high pressures of metamorphism, it is expected that metamorphic marble is tighter, denser, and more fracture-free than other kinds of marble, and generally that is true. Metamorphic marble and recrystallized limestone will not be differentiated in the remainder of this discourse unless otherwise noted.

1.1.3 In commercial usage, descriptives may be added that refer to a marble's color, e.g., *white* or *blue* marble. More useful to the trade because of the necessity to judge the properties and behavior of the stone, is the scientific convention of referring to the mineralogical content of the stone, such as *dolomitic* marble or *sandy* marble, indicating marbles with some dolomite or sand content. Assuming the marble user knows something about the properties of the minerals, an idea of the stone's behavior can be anticipated.

1.1.4 Colors. In dolomitic marble, the dolomite often weathers to a tan or buff color from the oxidation of a slight amount of iron released from the marble. The chemical series of dolomite, with the end members of $CaMg(CO_3)_2$ to $CaFe(CO_3)_2$ is continuous from 100% Ca to 100% Fe, so many dolomitic marbles, while nearly white when cut, will probably weather slightly buff to tan due to the

[1] Adapted from: Bates, R. L. and J. A. Jackson, eds., 1980, *Glossary of Geology*, 2nd Edition, American Geological Institute, 1980.
[2] Ibid.

release of iron, which then oxidizes to iron oxides that yield the characteristic colors from off-white to tan, buff, yellow to red, and dark brown to the stone as a whole. In dolomitic marble these colors are often uniformly distributed. Bands, streaks, or swirls of distinct color may have other explanations relating to the stone's original deposition and subsequent geological formation.

1.1.5 Calcite, the dominant mineral of marble, occurs in many colors. Among the many common trace-amount impurities that color marbles are organic matter (generally gray to black), chlorite[3] (generally light green to yellowish-green), epidote[4] (the same green as above), and minor amounts of land-derived clays, silts, and sands. These clastic silicate sediments may already be stained with iron to yield any color from very light buff to dark brown, and almost any red color; or the silicate grains themselves may contain trace amounts of iron available by chemical release to stain and color. Other known coloring agents are too numerous to mention here. Iron is by far the most common.

1.1.6 Impurities are often confused with other features that can be found in marble, most of which are primary depositional features[5] or artifacts of chemical changes prior to, during, or subsequent to metamorphism and/or re-crystallization. Such features are intrinsic to the character of many exotic marbles, making some rare types quite valuable. Conversely, the same features could be detractions, weakening the stone or making it unattractive, thus rendering it unsuitable as a decorative dimension stone.

1.1.7 Geological origin. Limestone that begins as an accumulation of shelly debris, mostly fragmental but also including whole shells, is mostly the aragonite form of $CaCO_3$. Original sediment usually has a matrix of organically derived, clay-sized carbonate grains of aragonite. If buried, compacted, and cemented, it takes about 50 to 60 million years under standard conditions of temperature and pressure for aragonite to convert to calcite. In addition to fossils, other features, artifacts of deposition, may also be preserved. Examples include voids, often the internal void space of shells of clams and snails. Commonly, these are filled in with carbonate dust that has crystallized solid. Voids of any origin commonly contain calcite crystals totally filling in the void space.

1.1.8 Cross-bedding and ripple marks on the sea floor are visibly preserved, as are raindrop imprints and mud cracks from shrinkage during exposure and drying that form if the surface is exposed to air, for example at low tide, and then buried, preserving the features. There are many more examples, some of which are called "faults," but are entirely natural. Most of these features formed at the time of deposition disappear and are lost in the recrystallization process of limestone or in pressure-related metamorphism. Some of these primary features can be detrimental, as they could weaken stone.

1.1.9 Another kind of feature, known as a *stylolite*, is formed as a result of geochemical processes either after burial or cementation and long geologic aging. A stylolite is a spiked surface within and usually parallel or subparallel to a bedding planes. Stylolites are evidence of dissolution along fractures or

[3] *Chlorite* is a very complex hydrous silicate of magnesium, iron, and aluminum has a platy habit. It is soft, flexible (micalike, but not elastic), and usually an alteration product in igneous or low-grade metamorphic stone, or is transported into sedimentary sequences.

[4] *Epidote* is often found with chlorite and has about the same color range. It is a complex, low-grade, metamorphic hydrous silicate of iron, calcium, and aluminum. Being very hard, heavy, and insoluble, it weathers out of metamorphic terrain and can be deposited in near-shore marine deposits of carbonate debris, lending its green color to marble.

[5] *Primary depositional features* are developed at the time of deposition of sedimentary particles.

partings, possibly initiated by a thin film of dark organic matter. Such dissolution can remove several feet of section in a carbonate sequence. These lines become increasingly irregular in a vertical plane as dissolution proceeds at varying rates from place to place along the surface. Stylolites can occur in any carbonate rock from limestone to metamorphic marble, and are purely a phenomenon of chemical dissolution. Stylolites are identifiable as a thin, spiky, or crenellated black line.

1.1.10 Other minerals found in marbles include the various common carbonate minerals previously mentioned. One, magnesite ($MgCO_3$), is characteristic of the metamorphic marbles and not usually found in recrystallized, limestone-type marbles. A generally undesirable mineral, pyrite (FeS_2) or iron sulfide may also occur in marble and are alteration minerals formed after deposition and during the metamorphism and recrystallization phase from small amounts of entrained sulfates or fluids containing dissolved, sulfur-bearing salts that enter the stone during its burial history.

1.1.11 Pyrite will occur as discrete cubic crystals, finely disseminated, or as masses in marble. It is hard (H=6+ on the Mohs scale[6]) and sometimes has an attractive, brassy appearance–it will bleed ugly stains from oxidation during repeated water incursion. Pyrite is often found disseminated throughout shelly limestone, a natural occurrence with biological materials deposited in anoxic conditions (without oxygen). Pyrite exposed on the face of cut and polished stone easily reacts with moisture to form the undesirable and difficult to remove staining. Its brassy metallic luster is not necessarily unattractive, but not for use in wet environments.

1.1.12 The accessory mineral variation found in marble is diverse and dependent on the geologic origin and burial history of the limestone or marble. If the marble was in contact with granite or volcanic igneous rock, then the accessory minerals may include a suite of complex carbonates and silicates. If the marble is in contact with, or influenced by other complex metamorphic stone, then it may have complex carbonate/metamorphic minerals other than the few already mentioned. It is geologic factors like these that can produce the highly colorful and complex marbles seen in both antique and modern works. Such stones may occur in limited deposits. The more common and universally used marbles from antiquity to the present are mostly calcite, many close to ±99% calcium carbonate, found in large deposits with adequate reserves for extended quarrying.

1.1.13 The great variety of colorful, often exotic marbles from Italy is formed in juxtaposition to intrusive and extrusive igneous rocks and/or a variety of metamorphics. Italy has an exceedingly complex geology, with active igneous activity and nearly every known level of metamorphism, as well as a variety of sedimentary deposits. Italy also has experienced remarkable dry periods clearly indicated by the kinds of sedimentary rocks surrounding the Mediterranean (e.g., mottled red marbles), dating from when the area was an empty, desert-like basin before the Straits of Gibraltar opened to flood the present Mediterranean Sea.

1.1.14 Physical and Chemical Properties of Calcite. To understand the stone, one must first understand the minerals. Many of the desirable qualities and many of the problems commonly encountered with marble are direct consequences of the properties of calcite, the dominant mineral, or in some cases, the less abundant accessory minerals. A review of the physical and chemical properties of calcite follows:

1.1.14.1 Crystals. Calcite crystals are found in several different and predictable crystal shapes exactly controlled by atomic geometry

[6] See Appendix for the Mohs Scale of mineral hardness.

of the $CaCO_3$ molecule. Crystals may grow in isolated free spaces or voids called "vugs[7]" or in open fractures or in masses like an entire sequence of stone. More geometrically complex crystals, if they occur, are generally unrecognizable from randomly oriented cuts on polished marble surfaces. Both fractures and vugs eventually fill completely with crystals, often obscuring their former existence. The most common calcite crystal shapes are parallelograms or truncated, faceted, or tapering prisms[8]. Fractures are generally identifiable even if filled, while a totally infilled vug is easily overlooked. Fractures may be a potential line of breakage, but a small, closed vug, being virtually unrecognized on a polished surface, is of little significance to the commercial quality of a stone.

1.1.14.2 Cleavage. Calcite has a definite geometric molecular structure; i.e., the atoms of calcium, oxygen, and carbon are always arranged in a fixed geometry such that three planes of weakness occur not at 90°, along which calcite crystals will generally break.[9] The result is a parallelogram-shape fragment with very flat sides. This is termed *cleavage*. It reflects atomic planes of weakness that predetermine how and where a mineral will break apart. Other minerals may have one, to as many as six, cleavages. Any two exactly parallel sides constitute one cleavage. Thus, a six-sided parallelogram of calcite exhibits three cleavages, with one for each pair of parallel sides. A cleavage face is very flat. It may be stepped but the stepped surfaces are exactly parallel and reflect light as a single surface.

1.1.14.3 Color. Calcite can be any color from black to white (the most common), and colorless clear or transparent. It can be almost any other color of the spectrum. Calcite is also easily dyed with proprietary dyes and techniques. Many are organic compounds that have limited longevity in sunlight and thus fade in time. Or these manmade dyes wash out from chemical spills and ordinary cleaning compounds. Dyed stone of any kind should be considered with extreme caution for these reasons.

1.1.14.4 Composition. Calcite is a carbonate of calcium or $CaCO_3$. While calcite is the most abundant component, carbonates of iron, manganese, magnesium, zinc, and strontium are sometimes present. Many other carbonates and hydrous carbonate minerals of various metals such as lead, barium, and copper are rarely seen in commercial marble.

1.1.14.5 Acid Reaction. Calcite effervesces—reacts and bubbles vigorously in dilute hydrochloric acid. This is a positive diagnostic chemical property of calcite. Calcite can dissolve without visible bubbling in the presence of other kinds of dilute acids or even acidic liquids, such as red wine and salad vinegars. In acidic atmospheres with sulfur, marble is not only etched, but will react with very dilute sulfuric acid in moist air to form a powdery calcium sulfate, the mineral gypsum.

1.1.14.6 Optical Character. Optically clear cleavage fragments–parallelograms–of calcite have the curious optical property of double refraction. Objects or print seen through the cleavage fragment will appear as a double image. The varietal name for optically clear calcite is *Iceland Spar*[10].

[7] *Vugs* are mostly small to microscopic, but some have been found large enough to walk into. A vug in limestone, dolomite, or marble may contain crystals of calcite in addition to some of the other mentioned accessory minerals.

[8] Calcite is rarely found in the unusual crystalline form of fibrous masses. Because the individual fiber-like bundles of crystals are so small, it is easily carved and has been mistakenly called alabaster, though it is not the true gypsum-based material.

[9] In addition to cleavage, any mineral can be fractured other than along known planes of weakness in atomic geometry. Such noncleavage breaks are always very irregular and rough. Fracture and cleavage may be microscopic in scale.

[10] Named after Iceland, where it is found in abundance. Some specialized 19th century microscopes utilized the optical characteristics of Iceland Spar and incorporated a pair of precisely cleaved parallelogram-shaped calcite crystals. Such instruments are now obsolete.

1.1.14.7 Anisotropy. Calcite is one of many minerals that exhibit different values of physical and chemical properties on different crystal sides or optical directions in its crystalline shape. These variable properties, changes in numerical values in different crystallographic directions, are known as *anisotropic* properties. The differences, although very slight numerically, add up from thousands to hundreds of thousands of crystalline mineral grains, to significant totals that profoundly affect stone performance when dealing with polished slabs of fine-grained crystalline calcite. These slight, but important differences and behavioral characteristics must be dealt with in the engineering design of marble installations. The anisotropic properties of calcite that most seriously affect marble performance are:

1.1.14.7.1 Solubility. Slight differences of solubility on one or more of the three calcite cleavages in the crystalline parallelogram-shaped crystals. The differential number may be very small, but the cumulative effect can be a serious problem in an installation.

1.1.14.7.2 Ease of Cleavage. The ease of cleaving may be minutely different for each of the three cleavages of a cleavage fragment, thus allowing preferential slippage to occur. Although slight, in total it allows visible and permanent dislocations to accumulate, ultimately leading to failure in some thinner sheets of marble.

1.1.14.7.3 Thermal Expansion and Contraction. Varies with the various faces and optical direction in crystals. For example, calcite thermal expansion occurs in one crystallographic direction, while thermal contraction occurs in crystallographic directions normal to the direction of expansion.

1.1.15 Thermal Hysteresis. Thin sheets of certain marbles can sometimes fail under the combined effects of the aforementioned anisotropic properties. Engineering practice recognizes the collective phenomena as *thermal hysteresis*. *Hysteresis* is defined as "a lag in the return of an elastically deformed body to its original shape after the load has been removed. One of the effects of anisotropy and repeated thermal cycles is to defer and/or arrest the elastic rebound that would normally occur with hysteresis.

1.1.15.1 Events that can occur in calcite crystals in marble because of anisotropy and thermal hysteresis include:

1.1.15.1.1 Measurable extension on a surface due to repeated, cyclic heating from the sun or some other heat source.

1.1.15.1.2 Differential linear increases across the front of thin panels vs. the back sides can yield bowing, pillowing, or dishing of the sheet if too thin.

1.1.15.1.3 Changes of intracrystalline pressures, either increased or decreased, from distorted shape, induces growth of calcite crystals or dissolution of calcite (on different crystal surfaces). Both chemical effects tend to reduce strength and induce failure.

1.1.15.1.4 Strained or distorted crystals accumulate from repeated heating cycles and become permanent.

1.1.15.1.5 Microfractures develop from expansion or distortion of crystals and slippage on cleavage.

1.1.15.1.6 Microfractures allow entrance of moisture and/or acid rain, which enlarges fractures by solution, and in some cases, loosely re-cements some areas and may at the same time initiate formation of gypsum and granulation inside the stone and on the surface. Both effects weaken stone, particularly on the backside of bowed or pillowed sheets when moisture is present.

1.1.15.1.7 Reduction in strength of marble sheets from the above microfractures and growth of softer, in-filling minerals.

1.1.15.1.8 Permanent distortion of shape: bowing, pillowing, and dishing, ultimately causing fractures and catastrophic failure.

1.1.15.1.9 Reduced aesthetic appearance.

1.1.15.2 Such events do not occur in all marbles. Anisotropic/hysteretic effects are most pronounced in the finer-grained, highly compacted, truly metamorphic marbles. Anisotropic- and thermal-hysteretic problems generally are not seen with marbles of large grain or crystal size, nor are they seen where the slabs are thick enough to counteract the forces and negate thermal differential between front and back sides of the stone when effective moisture control is practiced for back sides.

1.1.15.3 Problems with marble arising from anisotropy and thermal hysteresis can be avoided by intelligent stone selection, careful design, and engineering practices that recognize known chemical and physical properties and the effects of the variable properties in calcite.

1.1.15.4 An excellent and complete discussion of thermal hysteresis including actual test data and thickness recommendations has been written by Bernard Erlin[11] and published by ASTM International.

1.2 Onyx originates in the dripstone deposits of limestone caverns, where it forms stalactites, stalagmites, and other formations that can fill an entire cavern or void space. It is deposited by gentle, dripping water movement followed by evaporation between drops that deposits calcium carbonate from the water onto the formation, incrementally enlarging formations by thousandths of an inch or less per drop. Thus onyx is also a chemical sedimentary stone, and may envelop terrestrial fossil remains. Prehistoric human remains have been found encased in cavern onyx. Although this process of drop-by-drop addition of material does take time, large deposits of onyx begin to mature (filling caverns or fractures) in a relatively short period of geologic time.

1.2.1 Although onyx is occasionally called travertine, commercial practice generally distinguishes the two stones because of obvious differences that relate to their respective attractiveness. Onyx tends to be more crystalline, strongly banded and colored in browns to yellows and clear. It can be translucent, and light-colored varieties sliced thin are used for attractive backlit display panels or even light-admitting windows. By contrast, travertine displays large void spaces and abundant, visible porosity, and is in all cases an opaque stone. Onyx, like most limestone, will recrystallize in time (not a metamorphic process), often enhancing translucency. It is the material that cameos are made from, and cameo makers use the stone's colored bands to achieve artistic effects. Italy produces much onyx, and the cameos carved in Tuscany from highly-colored, banded onyx are world-renowned.

2.0 COLOR AND VEINING

2.1 The color, veinings, clouds, mottlings, and shadings in marble are caused by substances included in minor amounts during formation. Iron oxides make the pinks, yellows, browns, and reds. Most grays, blue grays, and blacks are of bituminous origin. Greens are caused by micas, chlorites, and silicates.

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[11] Erlin, Bernard, "Contribution to a Better Understanding of the Mechanism Causing Dishing Failures of the Carrara Marble When Used for Outside on Building Facades." *Dimension Stone Cladding: Construction, Evaluation, and Repair*, ASTM STP 1394, ASTM International, 2000.

3.0 TEXTURE

3.1 The term "texture," as applied to marble, means size, degree of uniformity, and arrangement of constituent minerals. Grains of calcite, the chief constituent of most marbles, are crystalline and have definite cleavage that show bright, reflecting faces on a broken surface. In most marbles, however, the grains are elongated in one direction by the folding and placation of the beds.

4.0 FINISHES

4.1 Marble's surface may be finished in a number of ways. In general, smooth finishes tend to emphasize color and veining, whereas rough finishes tend to subdue the veining or markings.

4.2 Typical finishes for marble are:

4.2.1 Polished: A glossy surface that brings out the full color and character of the marble. It is not generally recommended for exterior use or commercial floors.

4.2.2 Honed: A satin-smooth surface with little or no gloss, recommended for commercial floors.

4.2.3 Abrasive: A flat, nonreflective surface, usually recommended for exterior use.

4.2.4 Other finishes, such as **axed**, **bush hammered**, **rock faced**, **rough sawn**, or **tooled,** are also available.

5.0 THICKNESS

5.1 Standard nominal thicknesses for marble veneer are ¾", 7/8", 1¼", 1½", and 2" (20 mm, 22 mm, 30 mm, 38 mm, and 50 mm). When a marble thinner than ¾" is specified, the ratio between thickness and overall size and the use of reinforcing backup materials must be considered. Marble thicker than 2" (20 mm) is usually regarded as cubic stock.

6.0 SIZES

6.1 Marble is a product of nature with hundreds of varieties available, each possessing distinct characteristics. Little can be done to alter the condition in which nature presents these varieties to us. Therefore, size may become a limiting factor to consider in the selection of marble. Check with the Stone Supplier as to the sizes that are available for the specific marble.

6.2 Selection and delivery can be greatly facilitated by a jointing scheme that permits the use of smaller sizes. A final jointing scheme should be agreed upon after the marble has been selected and the Marble Contractor has been consulted.

7.0 PRODUCT SAMPLING

7.1 Marble is formed by nature; thus, there are variations in the tonal qualities of the stones. However, it is these natural variations that make marbles unique, valuable, and highly desirable. Because of these variations, selection of marble should never be made on the basis of one sample only. It is recommended that selection be based on viewing sufficient samples to show the complete range of colors of the desired stone.

8.0 PROPER USAGE TIPS

8.1 Recommendation for commercial floors:

8.1.1 Minimum ¾" (20 mm) thickness.

8.1.2 A honed finish.

8.1.3 A minimum hardness value of 10 as measured by ASTM C241/C1353.

8.2 Avoid the use of gypsum or molding plaster setting spots for the installation of stone.

8.3 Avoid using Soundness Classification C and D marbles in wet areas, saunas, and steam rooms.

8.4 Certain green colored marbles may warp when installed with water based adhesives. Ask the Supplier for instructions.

9.0 VENEER CUTTING

9.1 Quarry blocks are reduced to slabs by a gang saw. The gang saw consists of a series of steel blades set parallel in a frame that moves forward and backward. The most productive and precision gang saws have diamond-tipped blades with individual hydraulic blade tensioners.

9.2 Marble blocks can be sawn either parallel or perpendicular to the bedding plane. The perpendicular cut is referred to as an across-the-bed or vein cut. The parallel cut is with-the-bed or fleuri cut. Some marbles produce a pleasing surface when sawed in either direction, and are available as either vein or fleuri. Other marbles produce a pleasing surface only when sawed in one direction, and are generally available only in that variety.

10.0 SOUNDNESS CLASSIFICATION

10.1 As a result of knowledge gained from extensive practical experience in the dimension stone industry, marbles have been classified into four groups known as the Marble Soundness Classification.

10.2 The groupings–A, B, C, and D–should be taken into account when specifying marble, for all marbles are not suitable for all building applications. This is particularly true of the comparatively fragile marbles classified under Groups C and D, which may require additional fabrication before or during installation.

10.3 The basis of this classification is the characteristics encountered in fabricating and has no reference whatsoever to the comparative merits or value of each type of marble. The classification indicates what method of fabrication is considered necessary and acceptable in each instance as based on standard trade practice and applies only to marble.

10.4 Classification of marble is done by NSI Member producers. A written warranty should be obtained from them prior to installation.

10.5 The four groups of Marble Soundness Classification are:

10.5.1 Group A marbles

Sound marbles with uniform and favorable working qualities containing no geological flaws or voids. They include completely metamorphosed limestone or dolostone, in which impurities such as clays and silt have reacted chemically with the calcite or dolomite to form other minerals. These stones have uniform working qualities, can be used on the exterior or interior, and do not require any filling or patching.

10.5.2 Group B marbles

Marbles similar in character to Group A, except that all the impurities have not changed into other minerals. Occasional small holes and voids are to be expected, and are characteristics of this group of marbles. The holes or voids are filled by the Marble Craftsman with epoxy, shellac, or polyester resin. (The terms "waxing,"[12] "sticking,"[13] and "filling" are common industry terms.) Filling is

[12] *Waxing* refers to the practice of filling minor surface imperfections such as voids or sand holes with melted shellac, cabinetmaker's wax or certain polyester compounds. It does not refer to the application of paste wax to make surfaces shinier.

[13] *Sticking* describes the butt edge repair of a broken piece, now generally done with dowels, cements, or epoxies. The pieces are "stuck" together; thus "sticking."

not intended to be noticeable to a great degree, perfectly color matched, or "glass" smooth. May be used on the exterior or interior.

10.5.3 Group C marbles

Marbles with some variations in working qualities. Geological flaws, voids, veins, and lines of separation are common. Many of the impurities have not changed into other minerals, and metamorphosis is not complete. This is the largest and most colorful group of marbles, and also contains significant holes, voids, lines of separation, and structural flaws. It is standard practice to repair these variations by use of reinforcing, liners, sticking together, filling with resin or cement, fabricating corners or missing stone with terrazzo and resin, and doing all other work necessary to hold the stone together to yield a finished product that is usable for architectural purposes. On completion, most repairs are visible and apparent, with a difference in light reflection. With few exceptions, these marbles are not suitable for exterior installation.

10.5.4 Group D marbles

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. Few stones carry this designation at this time; it is reserved for very laborious Group C stones.

10.6 The Marble Soundness Classifications indicate what method and amount of repair and fabrication are necessary prior to or during installation, as based on standard trade practices.

TECHNICAL DATA - Marble

1.0 PROPERTIES OF MARBLE DIMENSION STONE

1.1 In centuries past, relatively little importance was attached to the ultimate physical capabilities of most building materials. Rule of thumb was a common structural design criterion. As a result, the widely used materials of the day, for the most part natural rather than manmade, were seldom stressed to their ultimate limits.

1.2 In present-day construction, however, this is far from being true. Performance requirements are daily becoming more demanding. In striving for taller structures, greater spans, firmer foundations, thinner walls and floors, stronger frames, and generally more efficient buildings with more usable space, today's Architects and Engineers must get the most out of the materials with which they work.

1.3 Marble is a product of nature and not always subject to the rules of consistent behavior that may apply to manufactured building materials. It may not be proper for certain applications.

1.4 Physical property values of marble may, however, be measured using the standard test methods approved by the Dimension Stone Committee C18 of ASTM International. The values found when stone is tested for absorption, density, compressive strength, abrasion resistance, and flexural strength should be useful for the Designer and Engineer when preliminary construction calculations are being made. However, these tests should be made before the project specifications are written, not after. Member companies of the Marble Institute of America are represented on this committee and are active in its technical work of establishing proper test methods and specifications consistent with the latest technology.

1.5 The data shown in the following table is the result of testing sixteen domestic marble varieties at the Illinois Institute of Technology Research Institute, as well as historical data and information established and provided by ASTM International. Final design should always be based on specific values for the marble variety ultimately to be installed. These values may be obtained from the Marble Supplier.

1.6 Physical Properties of Marble*

Property	Range of Values
Compressive Strength (C170) lbs/in²	6,000-35,000
Recommended (min): 7,500	
Flexural Strength (C880) lbs/in²	600-4,900
Recommended (min): 1,000	
Modulus of Elasticity** (in millions) lbs/in²	1.5-5.0
Density, lb/ft^3 (C97)	140-185
Recommended (min): 162 (calcite), 175 (dolomite)	
Thermal Conductivity "k" Btu/in/hr/ft^2/°F	10.45-15.65
Water Vapor Permeability Perm-inch	0.324-4.460
Coefficient of Thermal Expansion in/in/°F	$3.7 \times 10^{-6} – 5.0 \times 10^{-6}$
Modulus of Rupture (C99) lbs/in²	1,000-4,000
Recommended (min): 1,000	
Absorption, by weight % (C97)	0.060-1.0
Recommended (max): 0.20	
Abrasion Resistance H_a/I_w (C241/C1353)	5.0-50.0
Recommended (min): 10	

* Test methods described in current ASTM standards.

** Also known as Young's Modulus.

2.0 STRENGTH (ASTM C170, ASTM C880)

2.1 The strength of a marble is the measure of its ability to resist stresses. This strength depends on several factors: the rift and cleavage of the crystals, the degree of cohesion, the interlocking of the crystals, and the nature of any cementing materials present.

3.0 FIRE RESISTANCE

3.1 Marbles are not combustible, according to underwriters' ratings, and so are considered a fire-resistant material. Because of its thermal conductivity, however, the heat transfer through marble is fairly rapid. Marble is not considered a highly rated thermal insulator.

3.2 Underwriters' fire resistance ratings evaluate whether or not a material will burn, as well as how long it will keep surrounding combustible materials from reaching temperatures which will cause them to ignite. Pilot plant tests at The Ohio State University Pyrotechnics Laboratory indicate that a 10-minute rating could be expected from 7/8" (22 mm) thick marble.

3.3 The use of an insulating material with marble substantially improves the fire rating, as shown below.

7/8" (22 mm) marble with 1" (25 mm) core of:

Paper Honeycomb.....................½ hour
Cement-Bonded Wood Excelsior......1 hour
Autoclaved Cellular Concrete.......1½ hour

3.4 Methods of estimating fire resistance periods of masonry walls and partitions utilizing component laminae are given in "Fire Resistance Classifications of Building Construction," BMS92, National Bureau of Standards.

4.0 ABRASION RESISTANCE (ASTM C241/C1353)

4.1 Abrasion resistance is a property of stone that should be tested per ASTM C241/C1353 to provide an indication of the stone's wearing qualities when exposed to foot traffic.

4.2 The hardness and uniform wearing qualities of most marble varieties make them extremely desirable and economically practical for floors and stairs. Varieties with an ASTM C241/C1353 abrasive hardness rating (Ha) of 10 or more are recommended for use as flooring. A minimum abrasive hardness of 12.0 is recommended for commercial floors, stair treads, and platforms subject to heavy foot traffic. Surfaces of floors constructed with two or more varieties, with Ha differences more than 5, will not wear evenly and uniformly.

5.0 FACTORS AFFECTING PROPERTIES

5.1 The ultimate test of a building material is its ability to have and maintain the necessary structural strength, as well as beauty of appearance and low cost of maintenance over the useful life of the structure. Experience has proven that marble meets this test as few other building materials can.

5.2 Illinois Institute of Technology Research Institute's studies have shown that the durability of marble is little affected by cycles of weather. This is because of marble's low rate of moisture absorption. The rates of absorption of all the marbles studied were less than 1 percent by weight. Other masonry materials range upward from 4% to 12%.

6.0 SAFETY FACTORS

6.1 Good engineering practice requires that allowable design stress must provide a margin of safety in any structural element. As a necessary precaution against such conditions as wind, ice, snow, impact, temperature changes, and imperfect workmanship, these allowable stresses must be smaller than those which produce failure.

6.2 Within the accepted limits of safe design practice, the closer the allowable load is to the ultimate failure load, the more efficient is the use of the material, and the less the cost of the construction.

6.3 Contemporary design of buildings, exclusive of the monumental type, does not usually employ marble as part of the structural frame, but rather as an independent unit, a curtain wall, or veneer. Therefore, the primary concern in such cases is with wind load, and a safety factor of 5.0 is recommended. Where the marble is to be subjected to concentrated loading, such as stair treads or lintels supported only at the ends, a factor of 10.0 should be used.

As buildings become taller and individual stone slab veneer becomes larger in area, the lateral forces due to wind loads must be considered. Wind tunnel tests are often used on major structures to determine wind dynamics and force magnitude. Reinforcement is sometimes necessary for large-dimension slab veneer in critical areas.

7.0 SEISMIC CONSIDERATIONS

7.1 Seismic considerations generally require that low buildings be stiff, and that tall buildings be relatively flexible. Design of connections must account for seismically induced horizontal loading. Local building codes vary and must always be checked to determine specific requirements for each area.

7.2 Additional Readings:
The National Bureau of Standards has published two documents on the topic: "Earthquake Resistant Masonry Construction," NBS Science Series 106; and "Abnormal Loading on

Buildings and Progressive Collapse: An Annotated Bibliography," NBS Science Series 67.

The U.S. Army Corps of Engineers also published TM 5-809-10, "Seismic Design for Buildings."

8.0 EFFLORESCENCE AND STAINING

8.1 Efflorescence is a salt deposit, usually white in color that appears on exterior surfaces of masonry walls. The efflorescence producing salts found in masonry are usually sulfates of sodium, potassium, magnesium, calcium, and iron. Salts which are chlorides of sodium, calcium, and potassium will sometimes appear, but they are so highly soluble in water that they will be washed off by rain.

8.2 The water-soluble salts causing efflorescence come from other materials in the wall. The salts exist in small amounts and are leached to the surface by water percolating through the walls. The most feasible means of prevention is to stop the entrance of large amounts of water. Absorption from the face will not cause efflorescence unless there are open joints.

8.3 Marble is not injured by efflorescence. However, some of the salt crystals may form in the pores near the surface. Crystal growth (recrystallization) in the pores can put stress on the walls of the pores and cause the stone to flake off. If the conditions bringing about this action persist, scaling may continue and flake off one layer after another. For this to happen, large amounts of water must enter the wall and must contain large amounts of salts.

8.4 Research indicates that staining or discoloration occurring on new buildings is caused by the action of water percolating through concrete from which soluble alkali salts are leached. The salts are then carried through the marble, where partially oxidized organic matter is picked up. This is then transported to the surface of the stone, where it is deposited as a stain as evaporation of the water takes place.

8.5 This staining phenomenon is similar to efflorescence except that it involves organic material. It does not harm the marble other than leaving an objectionable appearance during or soon after erection. However, if left alone, the stain is removed naturally by the action of the elements, usually in the course of a few months.

8.6 A considerable amount of water passing through the stone is necessary to bring out conspicuous discolorations. Proper precautions taken during construction of the walls will usually prevent such troubles. A simple and helpful expedient is to provide frequent weep holes in the base course and above shelf angles. These should be placed in the vertical joints so they can be sloped upward from the front to back.

8.7 Stains sometimes appear on the base course when marble is in contact with soil, or on interior and exterior horizontal surfaces, due to the carrying of soluble salts and some colored soil constituents up through and to the surface of the stone by capillary action. Almost all soils and most of the veining in marble contain soluble salts. Therefore, this staining phenomenon is similar to the discoloration described previously, and will disappear when the source of moisture is eliminated. However, materials from the veining may remain on the stone's surface. In walls, provide venting so that moisture can escape through the venting rather than through the stone. On horizontal surfaces, the use of a vapor barrier between the setting bed and the concrete slab, or between the setting bed and the ground, is recommended.

9.0 HYSTERESIS

9.1 Hysteresis is a phenomenon that affects certain "true" marbles. Unlike most stones, which return to their original volumes after exposure to higher or lower temperature, these marbles show small increases in volume after each rise in temperature above the starting point. This can result in differential expansion within the stone, which is more likely to be accommodated or restrained in thick veneers than in thin ones.

9.2 If it is not restrained, bowing of the marble panels ensues and produces compressive forces in the backs of panels. This causes creep, which in turn leads to permanent deformation. "Dishing" also stretches the marble's face, which makes stones more porous and increases their vulnerability to corrosion from acids in the atmosphere and deterioration from freezing and thawing effects. If marbles with this tendency are selected, it is important to determine the minimum thickness needed to overcome effects of hysteresis by testing under conditions which simulate in place temperature gradients of the wall.

10.0 THERMAL EXPANSION

10.1 The thermal expansion of marble is an important consideration where marble is used with dissimilar materials to form large units which are rigidly fixed.

Laboratory tests for the coefficient of thermal expansion of marble indicate that after several cycles of heating and cooling, a residual expansion of about 0.20% of the original increase can be expected. This should be taken into account when computing clearances. The coefficient of thermal expansion varies from one variety to another, so the actual thermal characteristics of a specific marble should be obtained from the quarries or fabricator before making a final selection.

11.0 TRANSLUCENCE

11.1 The translucency of marble is one of its most intriguing attributes. Not all marbles possess this translucent quality, nor is the degree of translucence the same in all varieties that transmit some light.

11.2 Translucence is dependent, to a greater or lesser extent, on the following factors:

11.2.1 Crystal Structure: Marbles of certain crystal structure are especially adaptable to transmitting light.

11.2.2 Color: The white and lighter-colored marbles are generally more translucent.

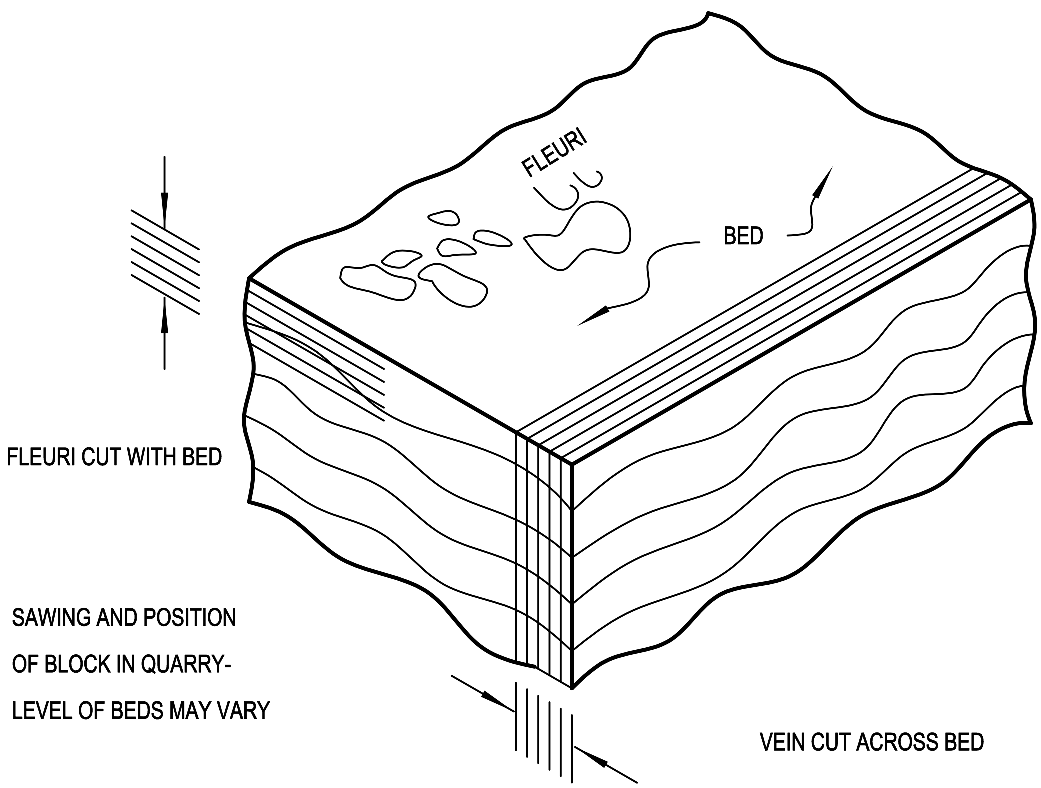
11.2.3 Thickness: The light transmission diminishes as panel thickness increases.

11.2.4 Surface Finish: Translucency is more apparent in smooth finishes than in rough finishes.

VENEER CUTTING

Quarry blocks are commonly reduced to slabs by a gang saw. The gang saw consists of a series of steel blades set parallel in a reciprocating frame.

Stone blocks can be sawed either parallel or perpendicular to the bedding plane. The perpendicular cut is referred to as am across-the-bed or veiny cut. The parallel cut is with-the-bed, or fleuri cut. Some stones produce a pleasing surface when sawed in either direction, and are available as either vein or fleuri. Other stones produce a pleasing and/or structurally sound surface only when sawed in one direction, and are therefore only available in that direction.



NATURAL STONE INSTITUTE 380 East Lorain Street, Oberlin, OH 44074 USA www.naturalstoneinstitute.org	REV	DATE	RIFT & SAWING DIRECTIONS DIMENSION STONE DESIGN MANUAL 2022
	0	MAR 2022	
			DRWG NO: 7-D-1
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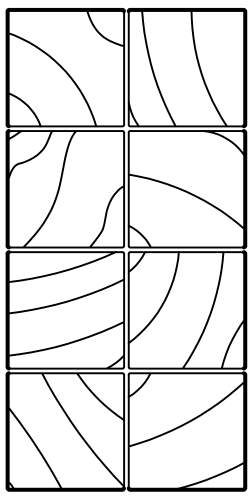
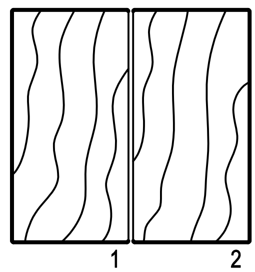
VENEER PATTERNS

Only certain stones lend themselves to specific veining pattern arrangements, such as side slip or end slip. This is because not all stones exhibit the near constant natural marking trend throughout the block that is required to accomplish these effects. Formal patterns require careful selection which often increases the costs of producing the stone veneer. Usually, a stone sawed in a veiny direction can be matched, while a stone sawed in a fleuri direction must be blended. Any desired pattern other than "blended" must be indicated on the contract bid documents to inform the stone contractor of the additional labor required.



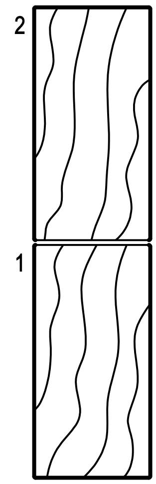
BLEND PATTERN

Panels of the same variety but not necessarily from the same block arranged at random. This scheme is followed when no other pattern is specified.



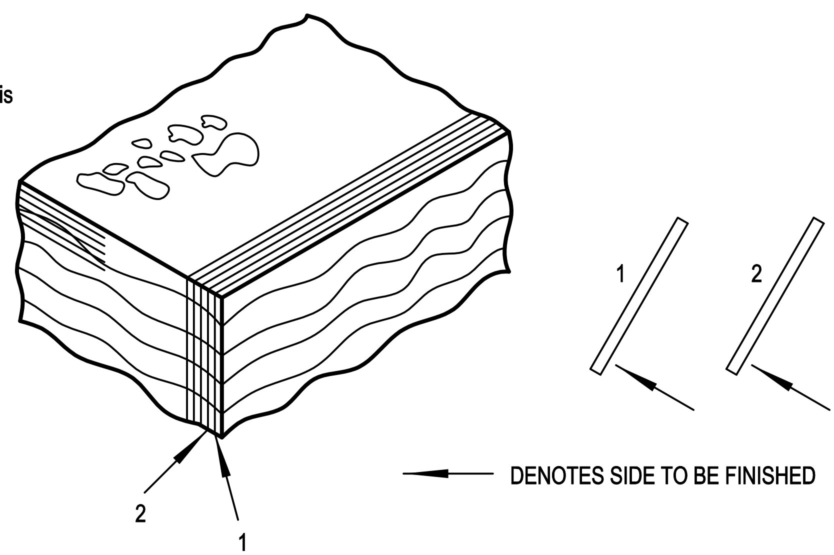
SIDE SLIP PATTERN

Panels are placed side by side to give a repetitive pattern and blended color in the horizontal.



END SLIP PATTERN

Panels from the same block are placed end to end in sequence to give a repetitive pattern and blended color in the vertical.



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380 East Lorain Street, Oberlin, OH 44074 USA
www.naturalstoneinstitute.org

REV	DATE
0	MAR 2022

VENEER VEIN PATTERNS

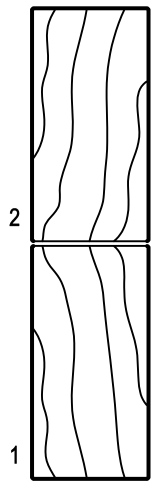
DIMENSION STONE DESIGN MANUAL 2022

DRWG NO: 7-D-2

SCALE: NOT TO SCALE

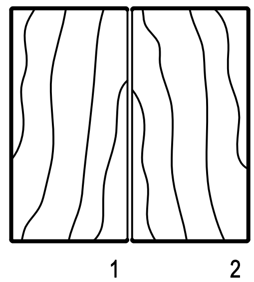
VENEER PATTERNS

Although the illustrations below depict a perfect match or mirror image of veining, such perfection is not realistic in actual stone veining. A portion of the block is lost due to the width of the saw kerf when the slabs are cut, and the veining position is likley to shift slightly across this offset. Brecciated marbles, for example, are extremely difficult to accurately cut into matched patterns. Ideally, jointery of the wall should plan for 4 panels of equal size.



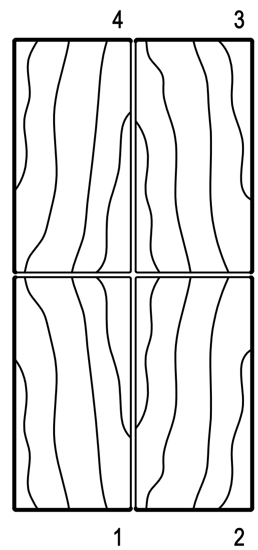
END MATCH PATTERN

The adjacent faces of panels 1 & 2 are finished.Panel 2 is inverted above panel 1.



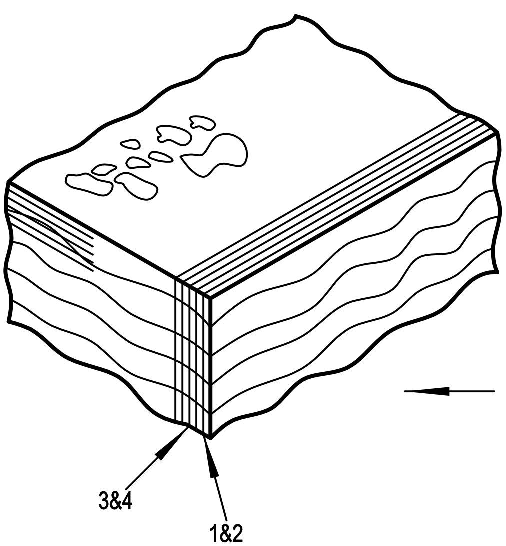
BOOK MATCH PATTERN

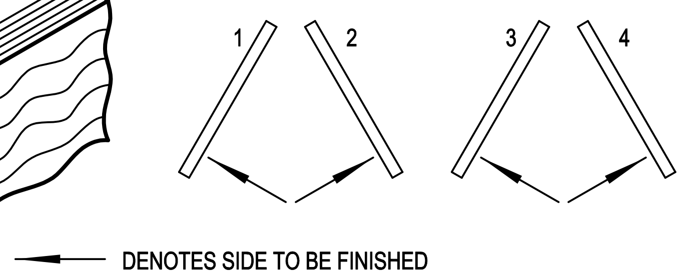
The adjacent faces of panels 1 & 2 are finished. Panel 2 is placed next to Panel 1 as the pages of a book are opened.



QUARTER OR DIAMOND MATCH PATTERN

Panels 1 & 2 are book matched. Panels 3 & 4 are book matched and then inverted over the top of panels 1 & 2.





NATURAL STONE INSTITUTE 380 East Lorain Street, Oberlin, OH 44074 USA www.naturalstoneinstitute.org	REV	DATE	RIFT & SAWING DIRECTIONS
	0	MAR 2022	DIMENSION STONE DESIGN MANUAL 2022
			DRWG NO: 7-D-3 — SCALE: NOT TO SCALE

NOTES: