DIMENSION STONE SELECTION

1.0 INTRODUCTION

1.1 Stone Selection Options. Architects and builders throughout the ages have chosen stone for its permanence and beauty. Where selection was once limited mainly to what was locally available, today's stone marketplace is virtually worldwide. With the broad and growing array of options, the stone selection process has become more complex under the weight of multiple considerations.

1.2 Stone Is A Product Of Nature. Dimension stone has its own unique qualities that not only distinguish it from man-made materials, but also should be considered in selecting it for a particular project. Stone is not manufactured; it is a product of nature. Blocks are removed from the quarry, slabs are cut from these blocks, and the slabs are further fabricated into the final stone to be installed. Each block is different; each slab is different. Skillful blending or matching of the dimension stone blocks, veneer panels, tops, etc., results in a beautiful blending of nature's variety and man's design. In contrast to the uniformity of materials produced by machine or assembly line, dimension stone's naturally varied appearance has wonderful character. "Uniformity of material," when applied to natural stone, is a term of relative value that needs to be understood when making a selection.

1.3 Exterior vs. Interior Installations. The factors to be weighed in selection may not be equally applicable to exterior and interior installations. The following discussion is therefore divided, as appropriate, between exterior and interior uses if the factors do not readily apply to both.

1.4 Selection Influencers. While any number of stipulations may direct selection of a particular stone for a specific application, there are several significant influencing factors. Among them are aesthetics, color, strength, durability, design, texture, finish, size, thickness, availability, stone testing, stone sampling, and cost. The effects any of these factors may have on another can influence the final choice. But aesthetic considerations nearly always drive the selection process.

2.0 AESTHETICS & APPEARANCE

2.1 Factors beyond Appearance. A palette of colors and a variety of textures provide ready options in the aesthetic choices among dimension stones. Yet, as the following pages suggest, it is advisable to examine and apply other factors that may recommend alternatives to a selection based purely upon aesthetic appeal, particularly on exterior applications. A stone that is most desirable in appearance, for example, may lack needed strength or durability for a particular application.

2.2 Exterior Cautions. The cautions regarding exterior applications are of far less concern when considering interior installations. Aesthetics can be allowed much freer rein for stone that is not subjected to the elements.

2.3 Variegated or veined materials, especially marbles, that offer interesting colors and patterns and that are by their nature "faulted" and not generally suitable for exterior use are often highly valued for their decorative qualities in interior installations.

2.4 Translucence occurs in some white or very lightly colored marbles and onyxes having a crystal structure that will transmit light to varying degrees depending upon stone thickness and finish. Translucence can be an aesthetically intriguing decorative attribute.

2.5 Sample Variations. Assuming that all critical factors support the desired choice in a given application, expectations as to final appearance must be realistic. Unless a choice is made and marked on an actual slab, variation from a submitted sample is a fact and should not come as a surprise.

2.6 Fleuri Cut Stones. Many dimension stones today are being cross cut or fleuri cut. This is true in travertines and some granites, for example. Many times, the reason this is done is to avoid a directional vein and achieve a more "cloudlike" effect. In any case, the Specifier and the Stone Supplier should know if this is done and investigate the test data, as it may change from normal, conventional means. See illustration at the close of chapter 7.

2.7 Filling Might Be Required. Another issue is where cross cut (fleuri cut) stones are used. As in the case of travertine, a limestone, it may require filling with cement or epoxy, which may or may not hold up under heavy traffic conditions, and the fills may come out.

2.8 Choosing a Finish. Choosing the manner in which stone will be finished is an integral part of the selection process. Finish can be anything from saw cut to high polish. A high polish will bring out the color of the stone to its fullest, because it will optimally reflect the light. Conversely, a textured finish will always appear lighter. A combination of finishes can add interest to a chosen stone. New finishes are appearing on the market yearly, so check and investigate all finishes available with your Stone Supplier.

2.9 Finishes commonly available are:

2.9.1 Polished: Mirror gloss, with sharp reflections.

2.9.2 Honed: Dull sheen, without reflections, achieved by abrasive heads. The degree of honing depends on the stone, but may vary from light to heavy.

2.9.3 Fine Rubbed: Smooth and free from scratches; no sheen.

2.9.3.1 Flamed or Thermal: Plane surface with flame finish applied at high temperature by mechanically controlled means to ensure uniformity; changes the color of the stone.

2.9.3.2 Water-jet Flamed Finish: Gives a more uniform, textured finish and allows more of the natural color to show.

2.9.3.3 Sandblasted: Coarse plane surface produced by blasting an abrasive, allowing a fine-textured finish; may lighten the color.

2.9.3.4 Bush-hammered: Coarsely textured surface produced by hammering, and may vary according to the metallic head used, from fine point to very coarse, and may leave high, lighter-colored markings.

2.9.3.5 Natural Cleft: A cleavage face formed when the stone is split into any thickness.

2.9.3.6 Picked, Hand-hewn Rock Face: Using a chisel or other metallic object that gives deeper indentations and cleavage to the stone.

2.9.3.7 Sawn: Usually refers to slabs coming from a gang saw, with blades that are applied to the block of stone using water and fine grit.

2.9.3.8 Gauged: Done by a machine, usually with circular abrasives to grind the material to a specific thickness.

2.9.3.9 Planed: Usually refers to slate, where a metallic scraper peels a layer of stone, making the stone flat and smoother.

2.9.3.10 Acid Washed: Usually applied to a sawn finish to lower the degree of sawn marks showing, yet maintain a natural textured finish.

2.9.3.11 Tumbled: Method of putting tiles in a mixing container with sand and rotating them, allowing the edges and corners of the tiles to chip.

NOTE: Many new finishes are being applied to stone as the market demand increases and new uses for stone are being conceived. In some productions, combinations of finishes on the same stone are being made. Check with the Supplier to verify the finish and how it was made in order to specify properly.

3.0 DESIGNING WITH DIMENSION STONE

3.1 Design Considerations are nearly equal among the factors of aesthetics, strength and durability. This is particularly true of interior applications. The imagination of Designers is boundless, and it is the Fabricator or Supplier who must counsel the design professionals as to what is feasible and what is not. Stone is not a plastic material. It is rigid and breakable when handled in fabrication.

3.2 Yield. Before making final selection of a stone, particularly on a larger project, take wastage into account to make certain there will be enough material to complete the project. An often-forgotten fact is that the material from a quarry today may be different from what was available six months ago. Further, there may be more than one quarry of the material. The criteria of the Producer to select stone also vary from quarry to quarry.

3.3 Modular Stone Tiles. For ease and economy, modular stone tiles offer a good alternative to stone panels for walls and level floors. Thin stone tiles, varying in thickness from 1 cm to 1.5 cm, are available in modular sizes of 12" x 12" (300 mm x 300 mm), 16" x 16" (400 mm x 400 mm), 18" x 18" (450 mm x 450 mm), and other sizes, up to a maximum of 24" x 24" (600 mm x 600 mm). The proper tile thickness for the installation will depend upon the stone type selected and the modular size of the tile specified.

3.4 Mixing Tiles. The final look of mixed tiles may fall short of appearance expectations, especially if the stone is variegated and veined. The Installer should mix tiles from different boxes during the installation to achieve a more even, visually pleasing result in the finished surface.

3.5 Matched-vein Patterns. In contrast to modular tiles, panels cut from the slab usually will give the best results aesthetically. There are different ways that veined dimension stones or other stones can be matched to form a pattern, and stones must be of types that lend themselves to specific pattern arrangement. Patterned and matched panels require that the material be selected and thus, often increases the cost of the stone. See diagrams at the close of chapter 7 for a detailed description of vein patterns.

3.6 Mixing Types of Materials. Designs calling for a mixture of stones with different physical properties, while aesthetically interesting, can give rise to problems of wear and of maintenance, mainly on floor areas. Re-polishing will pose problems, should that need arise. The Specifier should be aware that mixing types of stones means there will be different abrasion resistance levels as well as different densities of stones that must be considered in the long-term maintenance of the stone and its wearability.

4.0 EXTERIOR APPLICATIONS

4.1 Strength. A most important concern when selecting stone is strength. This is particularly true in cases of exterior stone cladding for buildings over two stories high. Strength in those situations should be the determining factor in the final selection of the stone.

4.2 Exterior Stone Stresses. Exterior stones must be able to withstand the stresses that will be imposed upon them, such as the following:

4.2.1 Gravity load, which must be borne by the anchorage system.

4.2.2 Windload, which exerts both positive and negative pressure on the panels and is typically higher at building corners and other areas of discontinuity.

4.2.3 Water vapor, which must be released to prevent condensation and efflorescence problems.

4.2.4 Freeze/thaw cycles, which can cause stone to crack and joints to fail.

4.2.5 Structural contraction, which occurs during the curing stage of the concrete.

4.2.6 Creep, or permanent structural distortion, which takes place progressively over the years until the structure has settled.

4.2.7 Elastic distortion, which is caused by movement produced by load charges on the structure.

4.2.8 Thermal expansion and contraction, which affects stone and other structural elements

4.2.9 Absorption or porosity of the stone is a factor, as it will affect the durability and life of the stone, as well as its appearance.

Note: The durability of the installation method for walls is determined by the substrate it is being applied to and the anchoring method being used. Consult an engineer to evaluate all installation issues.

4.3 Test Data. Where structural capability is critical, test data for compressive strength, flexural strength, modulus of elasticity, and sheer strength should be studied. Where weather is a factor, absorption, porosity, and permeability studies should be made. Freeze/thaw compressive strength testing should also be carried out. For walls, the type of anchoring, and performing an anchorage pull-out test, are important.

4.4 High-traffic Floor Areas. For high-traffic floor areas, abrasive hardness testing should be a requisite. The absorption or porosity is important, as well as the density of the stone. The finish applied to the stone will be a factor in the slip resistance specified for the area.

4.5 Durability. For durability, exterior stone should be free from structural defects and varying characteristics of vein structure, scaling planes, hairline cracks, earthly parts, and cavities. Panel dimensions should be controlled in size for optimal results.

4.6 Granites have been historically favored for exterior use. Their composition makes them both resistant and stable, and surfaces will hold a high polish longer. As a rule, weaker stones require greater and more costly reinforcement.

4.7 In dry and temperate climates, softer stones like limestones can also be used successfully in thicknesses appropriate to the job. However, exteriors of gray or black limestones with a bituminous or carbon composition should be avoided because the action of atmospheric agents will rapidly cause the surface to deteriorate. Other stones considered inappropriate are the ophicalcites and the breccia in general, as well as all stone containing pyrites, which may produce rust spots when exposed to air and moisture.

5.0 INTERIOR APPLICATIONS

5.1 Selection Criteria. The fact that interior stone is sheltered from the action of the elements makes all types of stone, from the hardest granite to the softest limestone, suitable for application. Criteria for the selection of interior stone for both commercial and residential projects tend to be similar. Selection considerations focus on whether the application will be on vertical or horizontal planes.

5.2 Interior Vertical Surfaces. Nearly any stone may be chosen for interior cladding of commercial buildings. Practical considerations for highly used areas, however, lead to stones that are dense, resistant, and easily maintained. These prove to be the best choice when aiming for a long-term investment.

5.3 Water Resistance. The action of water in areas such as fountains and showers is a factor to be reckoned with. Stones must be able to withstand frequent or continuous water projections, and in the case of showers, the presence of hot steam. Again, the best results are obtained with a dense, resistant stone, such as a granite, or a compact stone with a low absorption coefficient. The action of water on polished marble or limestone might cause surface dulling, spalling, warpage, or deterioration of stone over time.

5.4 Interior Horizontal Surfaces. Traffic is obviously a major consideration in selecting floor stone, whether for heavy, medium, or light duty. In heavy-traffic situations, floors need to withstand vehicles or carts, stiletto heels, mud and sand, salting compounds, spilled high-acidity liquids, and other pollutants and indignities.

5.5 Heavy-volume traffic and abuse require stone of maximum resistance–granite, quartzite, or highly compact marble, depending on the degree of punishment it must take. Testing for hardness as measured by ASTM C241 or C1353 and discussed elsewhere in this manual can help in the selection process.

5.6 For medium-volume traffic, stones can be somewhat softer. Many dimension stones will perform well, if properly maintained. There are good methods and maintenance products available to preserve the stone's appearance. Generally, it is recommended that a dimension stone floor receive a honed rather than a highly polished finish in commercial applications. Etching, scratching, and traffic paths will be far less obvious on a honed surface, thus making for easier maintenance.

5.7 In light-volume traffic and residential areas, where problems of etching, scratching, and staining are minimal, it is quite acceptable to make a selection based mainly on aesthetics and choose a highly polished floor if desired. In all cases, proper maintenance must be done.

5.8 Countertops. Stones for kitchen and lavatory tops should be chosen with regard to functionality. Foods and their handling will affect long-term appearance as acids and grease come in contact with the surface. Not all stones are resistant to staining; therefore, selection should be carefully considered. In all cases and regardless of the type of stone, spills should be wiped up immediately and cutting knives not used directly on the surfaces. There are also nontoxic sealers (necessary in food preparation areas) that can improve the performance of a stone to a great degree.

5.9 Lavatory Tops. As a rule, lavatory tops in residential bathrooms can be chosen according to taste, since the surface receives little abuse other than pollutants that might be contained in cosmetics.

5.10 MIA Statement of Position on Sealing Natural Stone Countertops. Most granite countertops do not need to be sealed. Before 1995 there were very few quality penetrating sealers on the market and there were very few cases of staining. Both prior to and after the availability of penetrating sealers, no cases of food poisoning, radon, or food preparation issues associated with treated or untreated granites have been reported. If a homeowner cleans their countertops after each meal, they will rarely, if ever, have staining or cleanability issues with granite. All this being said, many granite countertops receive additional benefit from being sealed. That benefit is the further reduction of moisture migration into an already moisture resistant surface.

Should natural stone counters be sealed? In many cases it makes sense to seal marble and granite countertops with a quality sealer. The product should have a life expectancy of ten to fifteen years and be of an oliophobic (resistant to water and oil based stains) nature. Once properly sealed, the stone will be more resistant against everyday dirt and spills.

In today's natural stone industry, many species of granite receive a resin treatment at the factory where the blocks of granite are cut into slabs and then polished. The treatment is used to fill microfissures, indentations and other minor characteristics that are found in many natural stones. The reason for the resin treatment is to address what most consumers consider as imperfections, but in reality are "birth marks." The consuming public gravitates to perfection, defined as no "birth marks," and so the marble and granite industry tries to fulfill the desire. Both resined as well as unresined slabs will outlast most of our lifetimes. Granite should, and in most cases will, be the last countertop surface a person will buy, providing a strong return on investment. The bottom line: Sealing resin treated countertops may increase the resistance of the already resistant nature of stone (adopted 11/8/06).

6.0 TESTING FOR PHYSICAL PROPERTIES

6.1 ASTM Tests. Stone is tested under a rigorous set of standards developed by the ASTM International, the world's largest voluntary standards development organization.

6.2 Purpose of Tests. The tests apply standard methods to uniformly evaluate stone characteristics and performance. ASTM standards are the recommended guidelines for installation in the stone industry. See Chapter 2 for more information about this organization and a list of ASTM specifications and standards.

6.3 Original Test Data. The Specifier has the right to request from the Supplier original test data on the stone to be used and verify the age of the test and its validity. In some cases historical data is sufficient on small jobs, but on larger jobs historical test data should only be taken as indicative, and new tests should be run on the specific stone from the specific quarry to be used.

7.0 SAMPLING

7.1 Stone Samples and Mockups. Preparation and supply of dimension stone samples and mockups are often expensive and time-consuming, but an essential part of stone projects. Samples and mockups help ensure that materials meet contract requirements.

7.2 Promotional samples are for color consideration only, but must be representative of the color and finish being proposed for use. They should be supplied in small sizes, such as 3" x 4" (75 mm x 100 mm), 4" x 6" (100 mm x 150 mm), or 6" x 6" (150 mm x 150 mm).

7.3 Project samples should be 1' x 1' (300 mm x 300 mm) in size or larger. Care must be taken to select samples that accurately reflect the shades, markings, and anticipated ranges of color, texture, finish, veining, filling, and other characteristics of the variety of stones specified.

7.4 Large Projects. For very large projects, multiple samples are needed in order to show the range of variations. These are normally assembled by selecting from the blocks that best meet the requirements at that point in time. Sometimes visits to the quarries become a necessary step in the selection process. Selecting slabs to be cut for the project is necessary to see the overall variation of the stone and finish to be used. In all cases, availability of the material should be secured.

7.5 Number of Samples. The number of sample submissions required on a specific project depends primarily on the amount and particular use of the stone required. However, there should never be fewer than two sets of samples submitted. Control samples should be kept by the Architect, Contractor, and

Producer for verification of the selection approved.

7.6 For stone that will be matched, prepare at least two sets of four matched samples each, showing proposed veining, flows, movements, texture, and range in each set.

7.7 Support Documentation. Depending on the stone selected and quantity required, a mock-up containing a full range of colors may be needed to further define the texture and characteristics of the stone. The Specifier or Buyer should request all samples and submission of stone be accompanied by the following in writing:

7.7.1 Actual name of stone and name of stone as applied by the Quarrier, as well as alternate names of stones in the marketplace, if any are known.

7.7.2 Country or state of origin.

7.7.3 Quarrier, if known.

7.7.4 ASTM test data or European equivalent for first evaluation purposes.

7.7.5 Age of sample, if known.

7.7.6 References of where this stone has been used near where the job may be located.

7.7.7 Photos of slabs showing more range of the material and other finishes available. Define whether there is more than one quarry and bed level of quarry where this stone is located.

7.8 This information will assure the Specifier of writing a specification that will control that the material being specified will indeed be the stone to be used on the job.

Note: As an example, specifying White Carrara (a generic name with over 30 quarries, and each quarry having possibly 4 selections) is meaningless if all the other information is not supplied.

7.9 Viewing Samples. When natural stone samples are viewed for approval, the viewer should be no closer than 6 ft. (2 m) from the sample surface and viewing from an angle normal to the surface. Natural light is preferred, striking the samples at an angle normal to the surface.

8.0 COST

8.1 Pricing Stone for the Job. A key factor in determining which stone to use will be the price. Today, thanks to the development of new technologies, stone is plentiful and competitively priced. There are many alternatives in stone selection, with a range of prices to fit any budget. The Specifier should ask for a budget price when initially considering a stone for the stone only. In the final consideration and determination, the Specifier should know the real cost of the stone based on the design and its installation costs to see if the stone fits into the budget of the job.

8.2 Size of stone is also important. Not all stones are available either in the size being designed or to get the best yield from the blocks or boulders. Price will be determined many times by the size and waste factor of the blocks in relation to the finished project.

8.3 Stone Thickness. In the past, buildings were erected using blocks or thick slabs. Now, cladding systems make it possible to use panels only ¾" or 1¼" thick, and with a notable reduction in the cost of stone. The thickness of the stone will be determined by engineering and the anchoring system for the specific stone.

8.4 Modular thin stone tile, a product of modern technology cut to a thickness of only 1 cm, is suitable for many applications and is competitive in price. These panels and tiles compare very favorably with other natural and manufactured products available for construction, and have the added advantage of conferring character and durability to the structure.

8.5 Multiple Factors Affect Price. Many factors determine the price of a particular stone. Availability, ease of extraction, market demand, quality, and transportation are a few of the variables that will affect the price. This is an advantage when cost is important, for there is always the possibility to select alternatives offering essentially the same desired characteristics. Availability is important to check to determine whether the stone is still quarried, is available in the quantity required, and in the time frame of installation of the project. Sometimes the more limited the availability, the higher the cost. If the stone is only available from one company, the Producer can demand a very high price and the Specifier should be made aware of this.

8.6 Other factors affecting the cost on large projects may include:

8.6.1 Quantity allowed for storage or attic material.

8.6.2 Extra material needed in the event of damages, improperly fabricated material, or other reasons replacement material might be needed.

8.6.3 Determination of who will pay taxes may be an issue and should be clarified.

8.6.4 Availability of a storage facility at the jobsite that is of adequate size to properly and securely store material until job is complete.

8.6.5 Consult with your local MIA Member to review these and other costs that factor into the overall project budget.

9.0 MAINTENANCE

9.1 General. Maintenance of the stone after it is installed is commonly forgotten. The Specifier should be aware of the maintenance required to maintain the color and finish of the stone for years to come. Ask the Stone Supplier and Salesperson for maintenance suggestions or requirements. Investigate with authoritative maintenance companies what they recommend for a specific stone and the cost factors involved in maintaining the stone. The more knowledgeable the Specifier and End Buyer are about stone maintenance, the longer and happier all parties will be in giving the Owner a quality finished job that will last for years to come.

9.2 Sealers. If sealers are to be used, have the stone tested to ensure in writing the sealer's performance for the stone and application of the stone intended. New surface and penetrating sealers are becoming available on the market every year.

9.3 Maintenance and Cost. The maintenance issues for a specific stone and the cost attributed to it can vary from one type to another, and may impact the decision to use that stone in a particular application.

STONE TESTING

1.0 INTRODUCTION

1.1 General. Testing evaluates the suitability of a specific stone for a particular application. The strength of the stone is tested to determine its resistance to crushing and bending. The density, or specific gravity, is tested to design a support system capable of carrying the weight of the stone. The amount of water the stone will absorb (absorption rate) will help determine the resistance of the stone to staining and freezing. The stone's wear resistance and slip resistance are crucial in flooring applications.

1.2 ASTM tests, many of which are conducted within engineering parameters, do not include petrographic and other geologic tests useful to evaluating stone behavior through time in adverse environmental settings. If and when a failure occurs, questions about what went wrong and why are asked; however, test data reviewed frequently may not reveal information useful to answer these questions. Stone behavior is directly related to the behavior of the mineral or minerals that make up the stone. Knowing something about physical and chemical characteristics of the common minerals found in stone can be very useful in understanding its behavior.

1.3 Petrography is the science of description and classification of rocks. A petrographic analysis can be arranged through most construction material laboratories. A comprehensive petrographic analysis will often suffice to answer many behavioral questions. Other, more sophisticated analyses performed in well-equipped chemical laboratories to determine exact chemical and trace element content can also be useful.

1.3.1 Perhaps the most common and time-tested petrologic studies use thin sections of stone. These are prepared by polishing small samples very flat, gluing them to glass microscope slides [1" x 3" (25 mm x 75 mm) to 2" x 3" (50 mm x 75 mm)], and slicing the stone thin with an ultraprecision, thin-blade diamond saw. The stone slice on a slide is then precision-ground to a precise thickness of about 20 to 30 microns. At that thickness most minerals, regardless of color, are translucent and can be studied under a microscope. In this way minerals can be identified, the crystal or fragment boundaries can be evaluated, and incipient microfractures can be seen, as can any chemical degradation that may weaken stone, permit water entry, or allow unanticipated breakup.

1.3.2 Exact identification of the minerals by thin section is a subjective, experience-based skill and is largely being replaced by exact methods of chemical analysis. Having both the thin section and chemical analysis is the preferred procedure, as the physical features can be seen documented on known mineral crystals or grains.

1.4 X-ray diffraction (XRD) analysis is one of the tried-and-true analytical techniques used for decades in petrology and remains the preferred technique in certain situations. However, more modern analytical techniques have evolved that are far more precise, analyze far more compounds and elements, and are rapidly replacing XRD for most routine purposes.

1.5 Lithogeochemistry, the chemical analysis of stone, relies on many new procedures too numerous to attempt explanation here. The following are just a few notable lithogeochemical analysis procedures:

1.5.1 Instrumental Neutron Activation Analysis (INAA)

1.5.2 Atomic Absorption Spectroscopy (AA)

1.5.3 Inductively Coupled Plasma Emission Spectroscopy (ICP-OES)

1.5.4 X-ray Fluorescence Spectroscopy (XFS)

1.5.5 Inductively Coupled Plasma Emission Mass Spectrometry (ICP-MS)

1.5.6 A few grams of a stone can be qualitatively and quantitatively analyzed accurately for bulk stone chemical content plus more than 53 trace elements–some to fractional parts per billion.

1.5.7 Although the ASTM Committee on Stone, C-18, has yet to include petrologic tests in their repertoire, lithogeochemistry is already quality-standardized by the International Organization for Standardization (ISO). ISO/IEC Guide 25 is an accreditation that many laboratories have because of the importance of these studies in the global mineral-extraction industries.

2.0 ASTM STANDARD TEST METHODS AND SPECIFICATIONS

2.1 ASTM International, formerly known as the American Society for Testing and Materials, has developed several standard test methods to evaluate stone characteristics so that stones can be compared on a uniform basis. The Marble Institute of America recommends ASTM methods and standards for dimension stone as guidelines for specification and installation. ASTM International is the world's largest voluntary standards development organization. Note that stone testing according to European methods and conditions may use different procedures that give different results than do ASTM methods for the same stone. This is particularly true of tests for abrasion (wear). The ASTM Standard Test Methods are listed in Chapter 2.

2.2 Current Standards. ASTM standards are revised from time to time. A revised version is indicated with a hyphen followed by a two-digit number after the basic designation of the standard, e.g., ASTM C119-20, showing that it was revised in 2020. An additional number in parentheses, e.g., ASTM C1527-11(2018), indicates that the 2011 edition was formally reaffirmed without change in 2018. The latest edition should be used. Copies of ASTM standards can be obtained from ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959 U.S.A. Telephone 610.832.9585. Copies can also be ordered through ASTM's web site and downloaded electronically. The Internet address is www.astm.org.

2.3 ASTM Standard Specifications. In addition to the standard test methods, ASTM has developed a series of standard specifications prescribing the minimum performance of each kind of stone when tested in accordance with the standard test methods. The ASTM Standards and Specifications are listed in Chapter 2.

2.3.1 These specifications are the standard methods for determining the characteristics of building stone needed for proper design for a particular application. They should be performed with care and the results used with an understanding of their intent and limitations. An independent testing laboratory properly equipped and capable of performing the tests should perform all tests. Stone Producers or Distributors, Associations, and other Promotional Organizations may publish typical test values. While these values can serve as a guide, current tests should be conducted on the actual stone to be used for a particular project.

2.4 Review for Suitability. ASTM test results for various stones are guidelines and information on the stone characteristics. In many cases, an Engineer should be employed to review the results of the test data and compare with actual installation methods to determine if the stone is suitable for the application in the specified thickness suggested, and if not, what changes should be employed to make the stone work as intended for the job in question. Evaluation and/or testing of compatibility of grouts, sealers, setting methods, and anchoring must be performed along with the stone.

3.0 OVERVIEW OF STANDARD TEST METHODS

3.1 Stone Uniformity. Stone is a product of nature, and as such, it varies. The properties of stone from one part of a quarry may not be truly representative of the same stone from a different part of the quarry. Some Architects specify strength-testing specimens from each quarry block to verify sufficient uniformity for the application. At the very least, current test results should be used because they are more apt to reflect the stone currently being quarried.

3.2 Wet/Dry Testing. For most tests, the stone specimens are tested dry. However, since the strength may vary when the stone is wet, the strength tests (i.e. compressive strength, flexural strength, modulus of rupture) are sometimes performed using wet stone specimens. For the dry condition, the stone specimens are dried in an oven at 60°C ±2°C (140°F ±4°F) for at least 48 hours or until the weight does not change with additional drying. For the wet condition, the stone specimens are soaked in water at 22°C ±2°C (72°F ±4°F) for 48 hours, wiped, and immediately tested. For general "catalog type" information, the stone is usually tested in a dry condition. The Specifying Authority may specify additional wet testing for a particular project to ensure that the stone will have adequate strength for the application.

3.3 Testing Parallel/Perpendicular with the Rift. The strength of stone also varies with the relation of the load or force to the direction of the "rift" of the stone. The rift is the plane of easiest splitting of the stone. Consider that a block of stone is like a deck of cards with rift direction corresponding to the plane of the cards. The cards are like the layers of the stone. The stone will be weaker if the applied loads tend to make the cards (layers) slide against each other than if the load is applied to squeeze the cards against each other. The variation in strength is likely to be greater in a stone with a more pronounced rift, like a sedimentary stone such as slate, than in a stone with a less definite rift, such as some igneous stones. The variation also depends on how strongly the layers are cemented or adhered to each other. To determine the variation, strength tests are conducted with the load parallel and perpendicular to the rift. For general information only one direction is tested, but the Specifying Authority may specify testing in both directions to ensure that the stone strength is adequate for the application. When specimens are submitted for such testing, it is important that the rift be clearly marked. The strength tests can be conducted by four conditions, wet or dry, and with the load parallel or perpendicular to the rift.

3.4 Horizontal Applications. ASTM C99, Standard Test Method for Modulus of Rupture of Dimension Stone, ASTM C170, Standard Test Method for Compressive Strength of Dimension Stone, and ASTM C880, Standard Test Method for Flexural Strength of Dimension Stone test results are not suitable to use for horizontal (floor) applications where the thickness of the stone tile being used is less than 1¼" (30 mm).

3.5 Limitations of Thin Stone Pavers. It is the position of the Natural Stone Institute that stones less than 1¼" (30 mm), when used for paving, do not possess any structural qualities other than abrasion resistance. The flexural, compressive, and breaking strengths these thin stones have will not materially improve the engineering quality of the designed surface. These thin stones are furnished for their aesthetic appearance and to supply abrasion resistance only.

4.0 ABSORPTION AND BULK SPECIFIC GRAVITY TESTING OF DIMENSION STONE

4.1 Water absorption is a measure of the porosity of a stone and can be an indicator of its susceptibility to damage during freezing. A stone that has greater water absorption will also tend to absorb liquid stains more readily. In general, the lowest water absorption is desired. The absorption is expressed as the percent weight change due to absorbed water. The maximum allowable water absorption for each type of stone is prescribed in the standard specifications for that specific stone. The required values range from 0.20% for marble to 12% for low-density limestone. According to ASTM C97, at least 5 specimens, as described for the density determination, are dried and weighed. It is important that the surface not be fractured by the cutting process because these fractures will increase water absorption. The specimens are then soaked in water for 48 hours, wiped dry, and weighed again. The difference in weights is divided by the dry weight and multiplied by 100 to give the percentage of water absorption. Variations in the wiping of the wet specimen before weighing will cause variations in the result. The standard test method describes removing the specimens from the water and surface drying with a damp cloth, but this is still somewhat subjective. A dryer wet specimen will result in a lower absorption number.

4.2 Specimen Thickness. This standard requires that the specimens have minimum dimensions of 2 inches (50 mm). However, sometimes the stone is not available in that thickness, especially flooring material, which may be only 3/4" (20 mm) or 3/8" (10 mm). Depending on the porosity of the stone, testing these thinner specimens may result in an "apparent" water absorption higher than if the standard-sized specimens were used. During the soaking, water may not be absorbed to the center of the standard specimen, but water might be absorbed to the center of the thinner specimens.

4.3 Slate. The water absorption test for slate, ASTM C121, uses different-size specimens. They should be 4" (100 mm) square and the "as cleft" thickness, which is typically ¼" to 3/8" (6.5 to 9.5 mm). Otherwise, the procedure is the same.

4.4 Stone Density. The density of the stone indicates the unit weight of the stone, which is necessary for the Architect or Engineer who is designing the structure to support the stone. The standard specifications prescribe minimum densities. The minimum densities are used to classify stones. For example, there are three classes of limestone, with each class having a different density as well as different strength requirements. Generally, a higher-density stone is probably harder, less porous, and stronger, but this is not always the case. Note that there is no density for slate specified in ASTM C629, although it could be determined, if desired, using the procedure of ASTM C97.

4.5 Specific Gravity is the ratio of the density of the stone to the density of water. If a stone has a specific gravity of 2.6, it is 2.6 times as heavy as water. Density is expressed as pounds per cubic foot (lb/ft^3) or kilograms per cubic meter (kg/m^3). The density in lb/ft^3 can be determined by multiplying the specific gravity by 62.4 (the weight of 1 cubic foot of water) or by multiplying by 1000 for the density in kg/m^3. One lb/ft^3 equals 16.02 kg/m^3. The specific gravity is the same in both measurement systems.

4.6 Stone Dry and Wet Weights. The dry weight of the stone specimen is divided by the volume. The specimen should be a cube, cylinder, or other regular solid with the dimensions between 2 and 3 inches (50 and 75 mm). The surface should be reasonably smooth, e.g., saw, core drill or better, but no chisels or tools which tend to fracture the stone. At least 5 specimens should be tested and the results averaged. The dry weight of each specimen is determined after drying 48 hours. The stone is then soaked in water for 48 hours, wiped almost dry, and weighed. It is then suspended in water by fine wire and the suspended weight is measured. The difference between the two weight measurements in grams is the volume in cubic centimeters (one cubic centimeter of water has a mass of 1 gram). The dry weight in grams divided by the volume in cubic centimeters is the specific gravity. The specific gravity is multiplied by 62.4 to obtain the density in lb/ft^3. Subtracting a tare weight of the suspended wire in water provides a correction for the mass of the fine wire.

4.6.1 This method of measuring the volume is based on the principle that a body suspended in water has an apparent weight loss equal to the volume of water displaced. In the metric system, the 1 cubic centimeter of water has a weight of 1 gram. In other words, there is a buoyant force on the object equal to the weight of the water displaced.

5.0 STRENGTH TESTING OF DIMENSION STONE

5.1 Compressive Loads and Strength. The loads on a material such as stone are expressed as the applied force divided by the area which must bear the material. For example, the compressive (crushing) load on a floor caused by a flat-bottomed round planter is the weight of the planter (including the soil and plants) divided by the area of the bottom of the planter. The compressive strength of the floor is the maximum compressive load the floor material can bear without crushing or deforming more than is allowed. In practice, the allowable loads in actual use are less than the maximum loads that a material can withstand during testing, to provide a safety factor. In all structural design, the maximum material strengths are reduced by a safety factor to establish the allowable design strengths. The safety factor allows for variations in the material strength, possible overloads in use, and similar considerations.

5.2 Strength Units of Measure. The strengths are expressed as pounds/square inch (psi) or pascals (Pa). A pascal is a force of 1 newton per square meter. Occasionally, the strength is expressed as kilograms/square meter (kg/m^2), which is technically incorrect because the kilogram is a unit of mass while the newton is a unit of force (or weight). In the U.S. system, we tend to think of mass and weight interchangeably. Therefore, when a weight or force is intended, the term used is pound force (lbf).

The following conversions can be used:
1 lbf/in^2(psi) = 6,895 pascals (Pa)
1 lbf/in^2 (psi) = 4.882 kilograms/square meter (kg/m^2)
1 kg/m^2 = 9.807 Pa
The terms kilopascal (kPa) and megapascal (MPa) are used for 1,000 Pa and 1,000,000 Pa, respectively.

5.3 Compressive Strength of Dimension Stone. Compressive strength is a measure of the resistance to crushing loads. If one were to build a stone wall, for example, the stone at the bottom would have to withstand the compressive load of the weight of the stones above. A stone floor must be able to bear the crushing loads of people, furniture, and other objects on the floor. The compressive strength is the maximum load per unit area that the stone can bear without crushing. A higher compressive strength indicates that the stone can withstand a higher crushing load. The required values range from 1,800 psi (12.45 MPa) for marble to 19,000 psi (131 MPa) for granite. To determine the compressive strength, at least 5 specimens are tested in ASTM C170. They should be cubes at least 2" to 3" (50 to 75 mm) on each side. Each face must be perfectly flat and they must be parallel or perpendicular with each other. Faces must be smooth with no tool marks and there should be no nicks at the corners. The faces must be honed or polished with no saw marks or other tool marks remaining. Any flaws in the specimens can result in a lower compressive strength. In some instances, the testing laboratory may have to refinish the specimens to produce surfaces sufficiently flat for testing.

5.3.1 The compressive strength can be determined in the dry or wet condition and with the load parallel or perpendicular to the rift. For the dry and wet conditions, the specimens are dried or soaked for 48 hours as described in the density test. For the compressive strength testing, the specimen is placed on the flat plate of the testing machine and increasing loads are applied to the top of the specimen through another flat plate. The test apparatus allows the top plate to swivel on a ball joint to adjust for any slight slope on the top of the specimen. The rift of the specimens should be vertical for the load to be parallel to the rift, or horizontal for the load to be perpendicular to the rift.

5.4 Bending Strength. The tests for modulus of rupture, ASTM C99 and ASTM C120 (Slate), and for flexural strength, ASTM C880, determine the strength of the stone in bending. A stone or door lintel must resist the bending loads from the weight of the stone. A veneer must bear bending loads, between anchor points, from exterior wind loads or persons leaning against interior veneers. Floor stone must bridge possible gaps in the grout or thin-set support. For all three tests, the stone specimens are supported near the ends and a downward load applied to the top. The modulus of rupture tests, ASTM C99 and ASTM C120, prescribe applying the load to a single point at mid-span. The flexural strength test, ASTM C880, prescribes applying the load simultaneously to two points, each one quarter of the span from the end support. The flexural strength is expressed as lb/in^2 or Pa. A higher flexural strength or modulus of rupture indicates a higher bending strength. The required minimum values range from 400 psi (2.8 MPa) for low-density limestone to 10.3 MPa for granite.

5.5 Modulus of Rupture of Dimension Stone. ASTM C99 requires a minimum of 5 specimens that are 4"x 8"x 2¼" (100 x 200 x 60 mm) thick. All of the faces, except the ends, must be flat and be parallel or perpendicular with each other. The faces must be smooth with no tool marks and there should be no nicks at the corners. The faces should be honed or polished with no saw marks or other tool marks remaining. Any flaws in the specimens can result in an apparent low modulus of rupture strength. The flexural (bending) strength may be tested in a dry or wet condition and with the load parallel or perpendicular to the rift. The specimens must be dried or soaked for 48 hours. For the modulus of rupture test, the stone specimen is laid flat on two crosswise parallel steel edges 7" (175 mm) apart. The 7" (175 mm) span allows the 8" (200 mm) long specimen to overhang the supports by ½" (12.5 mm) at each end. The supports of the fixture are gimbaled to accommodate any warp of the test specimen and prevent the introduction of torsional stresses applied to the stone. The test load, or force, is applied to the center of the top of the specimen through another crosswise edge. The load is increased until the specimen breaks. The flexural strength is then calculated from a formula based on the geometry of the test condition.

5.5.1 If the specimens are to be tested with the load perpendicular to the rift, then the rift plane must be parallel to the 4" x 8" (100 x 200 mm) faces. Returning to the card deck analogy, the "deck" of the specimen must be placed flat on the supports. If the specimens are to be tested with the load parallel to the rift, the plane of the rift must be parallel to the 2¼" x 4" (60 x 100 mm) ends of the specimen. In the analogy, several decks would have to be stacked up to a height corresponding to the 8" (200 mm) specimen length, and the card stack or specimen would be placed so the cards are on edge with each card parallel to the supporting edges. This is illustrated in ASTM C99.

5.5.2 In general, the flexural strength with the load parallel to the rift will be less than that with the load perpendicular to the rift. The variation would be greater for a stone with a more pronounced rift than for a stone with a rift less distinct.

5.6 Flexure Testing of Slate. The modulus of rupture testing for slate, specified in ASTM C120, is somewhat different than

C99. The specimens are 12" x 1½" x 1" (300 x 38 x 25 mm) thick. Rubbing or sanding the cleft faces achieves the specified 1" (25 mm) thickness. Six specimens are required: 3 with length parallel to the rift, and 3 with length perpendicular to the rift. For the test, the span between the supporting knife edges is 10" (250 mm).

While these test methods are useful, they have certain limitations. Since the specimen for ASTM C99 is always 2¼" (60 mm) thick or 1" (25 mm) for ASTM C120, the test does not indicate any reduction in the strength for thinner stone when used as a veneer or for flooring. They are valid for thicker sections. Because of the midspan loading, any weakness that is not in the center third (approximately) of the specimen will usually not affect the strength value determined by the test. These limitations are overcome by the flexural strength test of ASTM C880.

5.7 Flexure Testing of Dimension Stone. The flexural strength test of ASTM C880 is similar to the modulus of rupture tests, with two significant differences. First, the stone is tested at the thickness at which it will be used. The test span is proportional to that thickness by a ratio of 10:1. Thus any reduction in the bending strength due to the stone structure, e.g., grain size, grain cementing, etc., will be reflected in the test results. The test span is 10 times the thickness, but the actual length of the specimens should be about 12 times the thickness to allow for some overhang. The width is 1½ times the thickness, but, if the thickness is less than 2.67" (70 mm), the width is 4" (100 mm). If specimens for an exterior building veneer are 4" x 1¼" x 15" (100 x 30 x 380 mm), the test span should be 12.5. For a 3/8" (10 mm) floor tile, the specimens would be 4" x 3/8" x 4½" (100 x 38 x 120 mm) and the test span would be 3.75" (95 mm). As for modulus of rupture specimens, all faces, except the ends, must be flat and be parallel or perpendicular with each other. The faces must be smooth with no tool marks, and there should be no nicks at the corners. Faces should be honed or polished with no saw marks or other tool marks remaining. Any flaws in the specimens can result in a lower flexural strength. Since the length of the specimens serves only to provide sufficient overhang, exact length is not critical to the results.

5.7.1 The second difference that distinguishes the ASTM C880 flexural strength test from the modulus of rupture tests is that the flexural strength test is conducted with quarter-point loading. That is, the test load on the top of the specimen is not applied to a single location at midspan, but rather, the total test load is split, with half of the load applied at each of two points one quarter of the span from the supports, In this way, the entire center half of the specimen is subjected to the same maximum bending forces. Thus any local weakness, as from a vein, is more likely to be reflected in the resulting flexural (bending) strength.

5.7.2 The flexural strength test can be performed in the dry or wet condition and with the load parallel or perpendicular to the rift. The stone specimens are dried, or are soaked in water, for 48 hours. The rift directions are the same as described for the modulus of rupture test. At least 5 specimens are tested for each condition, and the results averaged.

5.7.3 As in the modulus of rupture test, the load is increased until the specimen breaks. Then the flexural strength is calculated using a formula based on the geometry of the test conditions.

5.8 Flooring Applications. There are two additional considerations for stone used for flooring: the wear or abrasion resistance, as measured by ASTM C241, and slip resistance as measured by its coefficient of friction, formerly evaluated according to ASTM C1028. This test method was withdrawn in 2014 and no replacement method was offered. See section 5.11, below, for an explanation.

5.9 Abrasion Resistance of Stone Subjected to Foot Traffic. Wear resistance is an essential characteristic that will determine whether a stone is suitable for use as a floor. The abrasion test of ASTM C241 results in an index number proportional to the volume of material abraded or worn off the stone during the test. The abrasion index numbers are scaled to generally range between 0 and 100. The ASTM specifications for stone list a minimum abrasion index for each type of stone. Marble and limestone, for example, should have an index of at least 10 (12 in heavy traffic areas); quartzitic sandstone and slate should have an index of 8; and granite, 25.

5.9.1 During the test, the weight loss of stone specimens is measured before and after being abraded, and then the density of the specimen is determined. The abrasion index is calculated using the average weight, the abrasion weight loss, and the density.

5.9.2 The test requires 3 specimens, 2"(50 mm) square and 1" (25 mm) thick. One 2" (50 mm) square face should have the finish to be evaluated, e.g., polished, honed, etc. The others may have saw marks, but should not be cut in a manner that fractures the stone because the fractures would affect the density determination.

5.9.3 The stones are abraded using a machine developed by Kessler. The machine includes a horizontal, round, cast iron "lap" about 9" (225 mm) in diameter, which rotates at a speed of 45 revolutions per minute (rpm). The specimens are mounted in a holder that rotates in the same direction as the lap, but at a different speed. While the lap and the specimen rotate, an abrasive flows onto the lap to abrade the bottom of the specimens. Each specimen supports a load of 2,000 grams, which includes the weight of the specimen holder, but not the specimen itself.

5.9.4 For the test, the stones are dried for 48 hours and weighed. The specimens are then abraded in the Kessler machine for 5 minutes (225 revolutions at 45 rpm), dusted off, and weighed. Knowing the dry weight of the specimens, they are soaked in water for at least 1 hour, and a bulk density is determined in the same way as the density procedure of ASTM C97. However, the abrasion specimen is thinner than that required by ASTM C97 and the specimen is not soaked for 48 hours. Consequently, the density may not be exactly the same as determined by ASTM C97.

5.10 The abrasion resistance index, which is proportional to the volume abraded, is calculated for each specimen using the average weight (before and after abrading), the weight loss, and the apparent density. An abrasion resistance index will usually be in a numeric value less than 100, but not always.

5.10.1 There are two concerns regarding this test method. First, it is not always possible to obtain specimens that are 1" (25 mm) thick. Although the ASTM method does not indicate it, specimens of other thicknesses can be determined by adjusting the 2,000-gram load on the specimen so that the load on the bottom of the specimen, the abrading face, is the same as it would be if the specimen were actually 1" (25 mm) thick. For a specimen ¾" (20 mm) thick, the 2,000 grams would be increased by the mass of the missing ¼" (6.5 mm) thickness of the specimen.

5.10.2 The second concern is the abrasive. ASTM C97 specifies a particular abrasive that is no longer being produced. The ASTM committee is currently conducting round-robin tests among different laboratories to determine a possible correction factor or a different test method which will produce abrasion index numbers that are the same as from the methods of ASTM C241, so that new test results can be compared with earlier results. In the meantime, test laboratories have had to develop a correction factor by comparing the results for stones having different abrasion resistances, e.g., soft and medium marble and granite, using the old and currently available abrasives.

5.11 Coefficient of Friction Testing. Slippery floors are a safety hazard, thus some measure of slip resistance is needed to evaluate stone and its finish as a floor material. Traditionally in the stone industry, slip resistance was evaluated by measuring the static coefficient of friction (the force required to initiate slipping divided by the normal force) per the ASTM C1028 method. This test method was withdrawn in 2014, for two reasons:

1. The load application is not automated, and therefore substantial operator influence is experienced in the load application rate, directional bias, and uniformity.
2. Since the test apparatus takes some time to set up, wet condition tests can produce a suction, referred to by many as "sticktion", preventing it from providing reliable data for testing in wet conditions. It can in fact produce data suggesting that frictional properties are improved by the wetting of the substrate and no replacement method was offered.

To address these concerns, the ANSI accredited standards committee A108, of which the Tile Council of North America (TCNA) is the secretariat, developed an entirely new procedure which measures not static, but dynamic friction to assess walkway safety. The new procedure first published in the ANSI A137.1-2012 document was entitled the "DCOF AcuTest^{SM}" method. It uses a commercially available instrument, the BOT-3000 (Binary Output Tribometer), but with very specific protocols regarding the redressing of the test foot between tests to ensure reliability and repeatability. Building on a large collection of data previously obtained by German researchers, substantial additional data was collected to develop the new more reliable and repeatable method of COF measurement. In 2017, the test procedure, which was originally part of ANSI 137.1, was published as a standalone document entitled ANSI A326.3 *Standard Test Method for Measuring Dynamic Coefficient of Friction of Hard Surface Flooring Materials*. Its primary improvement versus the previous version is that the procedure now specifically addresses in situ testing in addition to laboratory testing.

5.12 Other Stone Selection Considerations.

5.12.1 Other considerations for selecting exterior stones are the freeze/thaw capabilities of the stone in extreme climates. Also, the effect of ultraviolet light on the fading or changing of color of certain dimension stones. Tests are available for these considerations.

5.12.2 Sealants, seals, and gaskets for exterior applications are also considerations in the overall design of the building, and terminologies relating to these are available from ASTM under C717, and specific tests are also available.

5.12.3 Considerations for testing and evaluating stone must include petrographic and mineralogical data. The use of stone can be a factor directly related to whether it is an igneous rock like granite, a sedimentary rock like limestone, or a metamorphic rock like marble. The petrographic information may indicate a stone's elastic condition to change, or absorption degrees, or determine its strength and durability, as does the mineral content of the stone. The mineralogical information is important to see if the stone contains any minerals that may cause rust (as with stones containing ferrous minerals), exfoliation like some carbon stones, or minerals that may decompose and change due to weather conditions. The silicates in granite weather better than the carbonates of marble or limestones. The performance of a stone is related to its composition, and this is why some stones are more brittle than others, and why some stones, like common limestone, become harder when exposed to air through a process called "curing."

5.12.4 In designing stone exterior facades, consider the environmental conditions: rain, snow, hail, freezing and high temperature variations, and others. The stone must be resistant to weathering and decay. Carbon monoxide, sulfates, and other atmospheric pollutants form an acid, and with rainwater, can corrode certain stones over the course of time.

6.0 OTHER ASSOCIATIONS FOR ADDITIONAL INFORMATION

American Geosciences Institute (AGI)
www.americangeosciences.org

American Society of Civil Engineers (ASCE)
www.asce.org

American Concrete Institute (ACI)
www.concrete.org

American Institute of Steel Construction (AISC)
www.aisc.org

American Iron and Steel Institute (AISI)
www.steel.org

American Society of Landscape Architects (ASLA)
www.asla.org

Construction Specifications Institute (CSI)
www.csiresources.org

International Masonry Institute (IMI)
www.imiweb.org

Masonry Institute of America (MIA)
www.masonryinstitute.org

National Association of Architectural Metal Manufacturers (NAAMM)
www.naamm.org

National Tile Contractors Association (NTCA)
www.tile-assn.com

Precast/Prestressed Concrete Institute (PCI)
www.pci.org

Tile Council of North America (TCNA)
www.tcnatile.com

Special Note: A worldwide directory of ASTM-approved testing laboratories is available from ASTM International, www.astm.org.

NSI Bookstore Resources:
Reprints of this chapter, along with the Dimension Stone Selection chapter, can be purchased in a separate publication from the NSI Bookstore. The "Stone Selection & Stone Testing" technical module includes the contents of both chapters and additional illustrations and pictures.