DURABILITY ASPECTS IN THE DESIGN OF MASONRY STONE FAÇADES

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The design process for masonry stone veneers typically involves a series of iterations focused primarily in the selection of the color, shape, and texture of a particular stone type. In addition to aesthetics of the façade, another important condition that is frequently overlooked is the evaluation of the long-term durability characteristics of masonry stone material, as well as its strength characteristics. Moreover, the use of thin stone veneers in exterior wall cladding can result in types of failures in the stone cladding that do not occur in the thicker stone walls. This condition occurs because the use of thin stone cladding places greater reliance on design and on the physical long-term properties of the stone than on the successful performance of the veneers, and failures often occur whenever the design, the construction, and/or the stone material of the veneer system is inadequate.

The importance of considering the durability of building stones is becoming widely recognized by building owners. The restoration of stone veneers involves an additional appreciable financial burden to owners; and in many situations, the façade deterioration conditions can endanger public safety.

STONE TYPES

It is important to have a basic understanding concerning the geology of the dimensional stone being used commercially. Stones are made up of a mosaic of interlocking mineral grains that have definite chemical compositions. Rocks have been divided into three major groups: igneous, sedimentary, and metamorphic.

- **Igneous**—This group has been formed by the cooling and consequent solidification of molten material. Granite and related rocks are igneous rocks that have cooled and crystallized below the earth's surfaces, having a fine- to coarse-grained mineral crystal structure. Granite and related rocks have a variety of colors and textures.
- **Sedimentary**—Sedimentary rocks are of a secondary origin. Many of them originated directly from the disintegration of igneous rocks or of preexisting sediments, but some are of an organic origin and others were formed by chemical precipitation from solution. Limestone, sandstone, travertine, and cantera are samples of sedimentary rocks.
- **Metamorphic**—A metamorphic rock is a rock, either igneous or sedimentary, which has been changed from its original form by the effects of heat, pressure, or both combined. With the exception of slates and marbles, metamorphic rocks are not commonly used for veneers.

Table 1 summarizes some of the most important characteristics of stone, taking into consideration the type of stone.

DURABILITY CONSIDERATIONS

In the context of this article, durability is defined as the quality of a material to resist wear and decay and continue as designed and constructed after an extended period of time and usage. All masonry stone elements weather and change with time. The characteristics and the severity of the environment the stone must resist are factors that control the rate of weathering. In the past, when stone was used in large and thick units as a masonry surface against a backup wall, a surface loss of 0.12 in. (3 mm) was negligible. With the advent of new framing systems, the use of thick load-bearing walls gave way to thinner non-load-bearing walls. Therefore, a similar surface loss for a 1.2 in. (30 mm) thick stone reduces the thickness by 10 to 15% and, consequently, the resistance to bending may increase up to 40%.

MECHANISM OF WEATHERING

The weathering of building stone has an important impact on the long-term costs of façade maintenance. Factors that influence decay include stone properties, adjacent materials, pollution, stone cleaning, and weather. Weathering factors associated with stone are given below (Smith and Turkington 2000).

WEATHERING ASSOCIATED WITH NATURAL DEFECTS INHERENT IN THE MATERIAL

Building stones are liable to suffer from inherent natural defects, which become apparent when the material in the building is exposed. Planes of weather weakness may exist along the veins in metamorphic marble stone and throughout the open texture of travertine, a sedimentary limestone. These material anomalies were less important in earlier, thicker stone. With stone 2 in. (50 mm) or less, planes of weathering weakness can pass through the entire thickness; and if the building is located where freezing-and-thawing cycles occur, the stone pieces can separate. Figure 1 is representative of this type of defect.

Bowing of thin marble can occur, as shown in Fig. 2. This is caused by a permanent hysteretic growth in the stone due to a differential temperature or moisture change throughout its thickness. Generally convexed outward, the phenomenon can be concaved inward depending on boundary and gradient conditions.

WEATHERING ASSOCIATED WITH WORKMANSHIP

In some instances, decay results from faulty workmanship. Defects may occur as the result of lack of skill in manipulation or from the lack of intimate knowledge acquired by experience and from a long association with the materials. A stone might also happen to be used in such a manner as to predispose it to deterioration. Some of the most common workmanship problems are:

- Careless cutting of stone kerfs;
- Missing anchors (refer to Fig. 3);
- Failure to remove temporary shims or spacers;
- Inadequate cleaning of vertical and horizontal expansion joints;
- Application of mortar or sealant to drainage systems;
- Inadequate installation of stone (that is, face bedding installation); and
- Improper methods of quarrying and working.

WEATHERING ASSOCIATED WITH DESIGN

It is not uncommon to create a design first and to subsequently select the materials, whereas it would often be advantageous to select the materials with due regard to their durability in the geographic location where the project will be built, and to then design the building to suit their ideal use. In instances where the design is already defined, however, adequate care should be taken to ensure that the material selected is suitable for use in the design.

A frequently encountered design problem is inadequate differential movement accommodation. A masonry façade system comprising thin stone veneer experiences both horizontal and vertical movement, relative to the supporting building frame to which it is anchored, due to temperature and moisture changes in the stone itself as well as in the frame. Inadequate movement joints may produce the type of distress noted in Fig. 4.

Another design problem occurs with the association of incompatible materials. It has been

TABLE 1: GENERAL DURABILITY OF NATURAL STONE (AFTER HECKROODT [2002])

Class	Group Sample	Durability
Igneous	Granite (coarse grained)	Highly durable
Metamorphic	Marble (massive) Slate (strongly bedded)	Very durable Low to zero porosity: generally suitable for severe exposures
Sedimentary	Sandstone (siliceous) Limestone (calcareous) Shale (argillaceous)	Variable durability Porous with a relatively rough surface and variable resistance to salt and frost attack

Fig. 1: Fissure in stone veneer

Fig. 2: Marble bowing due to hysteresis

Fig. 3: Missing anchors

Fig. 4: Inadequate movement joints caused stone rotation

Fig. 5: Disintegration of (gypsum) mortar between stone and backup wall

Fig. 6: Stone deterioration due to mineral deposits within the stone

documented (Schaffer 2004) that stone decay can occur between certain types of building stone. For instance, the association of a limestone with a sandstone frequently results in the deterioration of the sandstone. Sandstones in which the grains are cemented with siliceous material are not liable to direct attack by atmospheric sulfur gases. If calcium sulfate, resulting from the decomposition of a limestone, however, finds its way into such a stone, decay will most likely result. Calcium sulfate may be carried from the limestone by direct washing resulting from rain. Therefore, it is important to give careful consideration to the selection of the type of stone as well as to its interaction with other selected construction materials.

Material incompatibility may also occur through the use of materials possessing dissimilar thermal expansion characteristics. This condition is severe at the connection between the stone and the substrates. Forces resulting from differential volumetric changes from stone and adhesives can result in debonding of connection along with cracking of stone panels at their connections. Therefore, the use of epoxy should be avoided. Gypsum-based mortars are sometimes used in stone connections at kerfs at the top of stone panels to eliminate pockets in the kerfs where water can enter and freeze. Gypsum-based mortar, when coming into contact with moisture, tends to expand and can cause cracks and fractures to develop in the stone at the connection kerfs. In addition, the material can disintegrate, making the connection unstable and vulnerable for additional decay (refer to Fig. 5).

WEATHERING ASSOCIATED WITH THE ENVIRONMENT

Weathering and deterioration can result from chemical reactions between the stone material and substances that are present as constituents of the atmosphere. Due to pollutants in the atmosphere, such as sulfates and carbon dioxide that form sulfuric acid and carbonic acid, rainwater can become corrosive to stone. Studies concerning the interaction between natural stone and pollutants indicate that silicates in granite erode at a much lower rate than the carbonates in the limestone and marble. Acid waters and fumes can leach carbonate minerals into limestone and marble relatively quickly (10 to 50 years), whereas the same corrosive materials could alter feldspar minerals in granite at a much slower rate (25 to 100 years). Oxidation occurs when the oxygen assisted by moisture combines with iron-bearing minerals (refer to Fig. 6).

Deterioration of natural stone due to frost action, commonly referred to as freezing-and-thawing cycles, occurs when water within the pore structure or cracks freezes to ice. It has been estimated that when water freezes it expands approximately 10%. The expansion force created by the freezing action combined with repeated freezing-and-thawing cycles produces microfissures, cracks, flaking, and spalling (refer to Fig. 7).

Another chemical process of weathering is due to salt crystallization. Salts are some of the most destructive agents to stone. Salts manifest themselves forming unsightly deposits, commonly known as efflorescence. The most common form of efflorescence is the appearance of salts at the surface, visible in the form of a gray or white powder. This occurs when the stone, substrate, or other sources of soluble salts are in contact with moisture and move to the surface by capillary action.

DURABILITY TESTING IN THE U.S.

The durability of natural stones has been the subject of many studies in Europe and the U.S. A common European practice has been to observe the reaction of similar dimension stones to exposure on existing buildings. Different laboratory tests have also been reported (Bortz and Wonneberger 2000).

In the U.S., there has been an effort to find a test procedure that will assess the durability of stone under natural weathering conditions. Currently, there is not an ASTM International standard to test the durability of a natural building stone. A testing protocol that has been accepted by practitioners as a measure of stone durability, however, is as follows.

Representative samples of a particular stone type are subjected to an accelerated weathering testing using ASTM C880, which determines the flexural strength of the specimens before, during, and after 300 cycles of exposure to temperature cycles of 73 to 170 °F (23 to 77 °C) at a rate of three cycles per day while being immersed on the finished face down in 0.24 in. (6 mm) deep solution of a weak sulfurous acid solution to simulate acid rain. In recent years, the consensus is to use 100 cycles because it was determined that the greatest changes generally occur in the first 50 cycles for most types of stone.

Figure 8 presents a typical weathering test graph for a limestone that was subjected to 300 cycles and then tested considering the flexural strength in both dry and wet conditions. An important conclusion that can be drawn from this study is that natural stone loses strength over time with the most significant changes during the first 50 cycles. The potential for the reduction in strength of marble, granite, limestone, and sandstone has been reported in various studies (Bortz and Wonneberger 2000). The strength of all the specimens tested in the above referenced studies indicates a permanent reduction in the specimens' compressive strength (refer to Table 2).

RECOMMENDATIONS

Some of the most common causes of stone deterioration discussed may be minimized when emphasis is placed on the performance of design, material testing, and the use of adequate drainage systems. The following schematic procedure for the design of stone veneers is recommended:

Fig. 7: Freezing-and-thawing damage exacerbated by the use of deicing products

- Select the color, grain, and finish of the stone using the generic name and the identification from the quarry;
- Determine physical characteristics of the stone. Procedures for testing should be developed on case-by-case basis as to how the stone is to be used. Some of the most typical tests recommended for stones are:
  - Stone classification;
  - Chemical properties and composition;
  - Abrasion resistance;
  - Permeability and rate of absorption;
  - Specific weight;

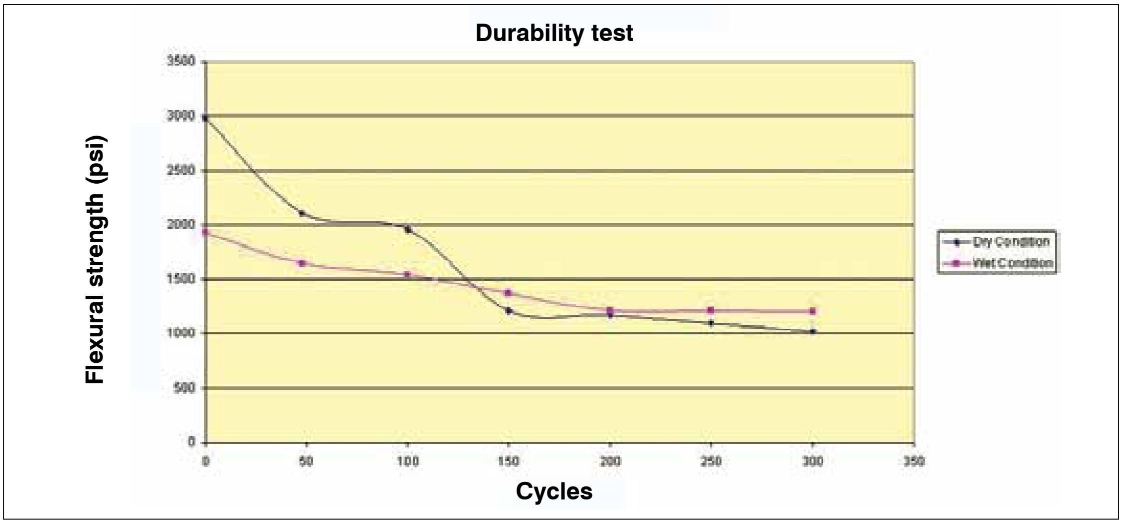

Fig. 8: Natural weathering test results for a limestone

TABLE 2: SUMMARY OF STRENGTH REDUCTION AFTER WEATHERING TESTS (AFTER CHIN [2000])

Stone Type	Percentage of Reduction of Compressive Strength
Granite	16.3%
Limestone	41.2%
Marble	53.8%
Sandstone	33.1%

  - Determination of the stone's rift;
  - Mechanical strength (wet/dry conditions and parallel/perpendicular to the rift):
    - Compression
    - Flexure
    - Rupture
    - Impact
  - Accelerated weathering tests;
  - Expansion, contraction, and warp in different conditions of temperature and humidity;
  - Resistance to fire;
  - Resistance and extraction of mechanical anchors used to attach the stone;
  - Compatibility with adhesive, fillers, and anchors; and
  - Color stability; and
- Determine the long-term maintenance needs for the stone and procedures for cleaning.

In closing, keep in mind that the stone will always vary in color, grain, strength, and availability. The design team (architect, engineer) must work closely together with the stone contractor and owner to achieve their goal—the timely, economic completion of a functional, problem-free façade.

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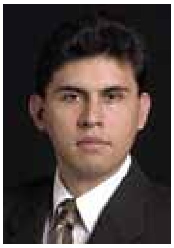

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