

Durability Considerations in the Design of Stone Facades

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INTRODUCTION

The design process for stone veneers typically involves a series of iterations that are focused primarily in the selection of the color, shape and texture of a particular stone type. In addition to aesthetics of the façade, another very important condition that, in the author's opinion, is frequently overlooked in many projects is the evaluation of the long-term durability characteristics of stone material as well as strength characteristics. Moreover, the use of thin stone veneers in exterior wall cladding resulted in types of failures in the stone cladding that did not take place in the thicker stone walls. This condition occurred because the use of thin stone cladding places greater reliance on design and on the physical long-term properties of the stone than it did previously for 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 this problem involving 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. This paper presents typical problems that have arisen from the use of natural stone veneers.

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 pre-existing 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 or pressure or of 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.

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

TABLE 1 – GENERAL DURABILITY OF NATURAL STONE [AFTER HECKROODT, 2002]

DURABILITY CONSIDERATIONS

In the context of this paper, durability is defined as the quality of a material to resist wear and decay and continue to be useful after an extended period of time and usage. All stones weather and change with time. The characteristics of the stone and the severity of the environment it must resist are factors that control the rate of weathering. The weathering of building stones is becoming an important issue. In the past, when stone was used in large and thick units as a masonry surface against a backup wall, a surface loss of 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 30 mm thick stone reduces the thickness by 10% to 15% and consequently the resistance to bending may increase to 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, weather, including stone cleaning. Weathering factors associated with stone are given below [Smith, 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 50 mm or less, planes of weathering weakness can pass through the entire thickness; and if the building is located where freeze-thaw cycles occur, the stone pieces can separate. Photograph 1 is representative of this type of defect.

Bowing of thin marble can occur as shown in Photograph 2. This is caused by a permanent hysteresis 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.



PHOTO 1- FISSURE IN STONE VENEER



PHOTO 2 - MARBLE BOWING DUE TO HYSTERESIS

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 which is 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
- 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 (i.e face bedding installation)
- Improper methods of quarrying and working

Photograph 3 shows a wall system where some of the anchors were missing.



PHOTO 3 - MISSING ANCHORS

Weathering Associated with Design

It is not uncommon to form a design first and to subsequently select the materials, whereas it would often be advantages to select the materials with due regard to their durability in the geographic location in which it is proposed to build, and to then design the building to suit their ideal use. But in instances where the design is already defined, 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 façade system comprised of 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 Photograph 4.

Another design problem occurs with the association of incompatible materials. It has been 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 sulphur gases. However, if calcium sulphate, resulting from the decomposition of a limestone, finds its way into such a stone, decay will most likely result. Calcium sulphate 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 Photograph 5.

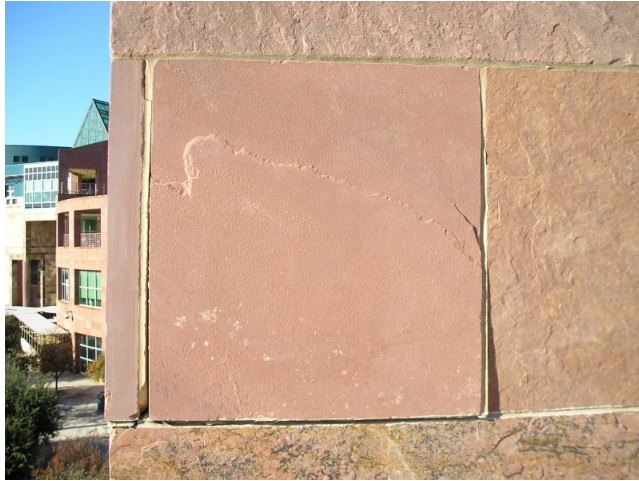


PHOTO 4 - INADEQUATE MOVEMENT JOINTS CAUSED STONE ROTATION



PHOTO 5 - DISINTEGRATION OF GYPSUM (MORTAR) BETWEEN STONE AND BACKUP WALL.

Weathering Associated with the Environment

Weathering and deterioration can result from chemical reactions between the stone material and substances which 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 Photograph 6.

Deterioration of natural stone due to frost action, commonly referred to as freeze/thaw cycles, occur 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 freeze/thaw cycles produces micro-fissures, cracks, flaking and spalling. Refer to Photograph 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 UNITED STATES

The durability of natural stones has been the subject of many studies both in Europe and in the United States. 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, 1999].

In the United States 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 ASTM (American Society of Testing Materials) standard to test the durability of a natural building stone. However, a testing protocol that has been accepted by practitioners as a measure of stone durability 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 23°C to 77°C at a rate of three cycles per day while being immersed on the finished face down 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 since it was determined that the greatest changes generally occur in the first 50 cycles for most types of stone.

Figure 1 present a typical weathering test graph for a limestone that was subjected to 300 cycles and was 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 as well as granite, limestone and sandstone has been reported in various studies [Bortz, 1999]. The strength of all the specimens tested in the above referenced studies, indicate a permanent reduction in its compressive strength. Refer to Table 2.



PHOTO 6 - STONE DETERIORATION DUE TO MINERAL DEPOSITS WITHIN THE STONE



PHOTO 7 - FREEZE-THAW DAMAGE EXACERBATED WITH THE USE OF DE-ICING PRODUCTS

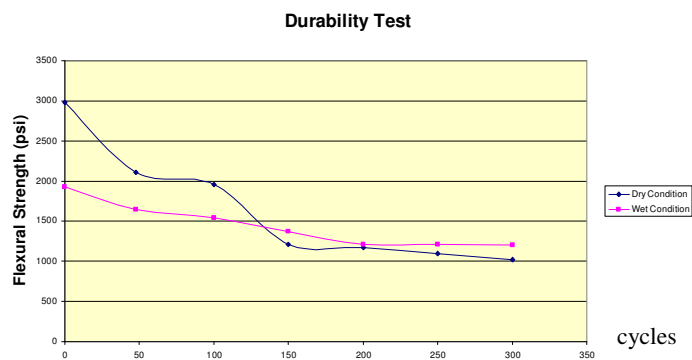


FIGURE 1 – NATURAL WEATHERING TEST RESULTS FOR A LIMESTONE

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

TABLE 2 - SUMMARY OF STRENGTH REDUCTION AFTER WEATHERING TESTS [CHIN, 1999]

RECOMMENDATIONS AND CONCLUSIONS

Some of the most common causes of stone deterioration have been presented within this paper. These common causes 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:

- 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 test recommended for stones are:
 - Stone classification
 - Chemical properties and composition
 - Abrasion resistance
 - Permeability and rate of absorption
 - Specific weight
 - 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
 - Color stability
- 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 for the mutual goal, which is the timely completion of a functional façade, free from problems, in an economic manner.

REFERENCES

- [1] Bortz, S.A., Wonneberger, B. (1999). *“Review of Durability Testing in the United States and Europe”* STP 1394, Dimension stone cladding: design, construction, evaluation and repair, West Conshohocken
- [2] Heckroodt, R.O. (2002). *“Guide to deterioration and failure of building materials”* Thomas Telford, London
- [3] Schaffer, R.J. (2004), *“The Weathering of Natural Stone”* Donhead, Dorset
- [4] Smith, B.J., Turkington, A.V. (2000) *“Stone Decay: Its Causes and Controls”* Donhead, Dorset
- [5] Miglio, B.F. et al. (1999). *“Assessment of the Durability of Porous Limestones: Specification and Interpretation of Test Data in UK Practice”* STP 1394, Dimension stone cladding: design, construction, evaluation and repair, West Conshohocken
- [6] Gere, A.S. (1988). *“Design Considerations for Using Stone Veneer on High-Rise Buildings”* STP 996, New Stone Technology, Design, and Construction for Exterior Wall Systems, Philadelphia
- [7] Chin, I.R. (1999). *“Common Causes of Failures of Stone Claddings on Buildings”* STP 1394, Dimension stone cladding: design, construction, evaluation and repair, West Conshohocken