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Journal

Thin Stone Marble Facade Systems

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Timeless, enduring, and stately, marble has been used since ancient Greece and Rome for the most important buildings of civilized society, from temples to bath houses to markets. The expense of quarrying and transporting the stone often constituted the bulk of construction costs, along with the workmanship of shaping and securing the heavy blocks. As the cost of labor increased, use of marble came to be reserved for the most socially significant buildings, such as courthouses and city halls.

With technological advances in the last half-century, marble became available not only as traditional dimension stone, but as thin panel cladding. As steel-framed structures grew in popularity at the turn of the century, taller buildings changed the landscape of urban architecture. By midcentury, marble veneers came into common use as a curtain wall material, enabling wide availability at a fraction of the cost of load-bearing stone. But marble panel wall systems are not without their drawbacks.

Without the benefit of long-term performance testing, marble veneers were installed at many buildings with little understanding of the material's behavior over time. A number of these buildings have since required partial or full wall system replacement,

a time-consuming, disruptive, and expensive endeavor.

If you are considering thin stone marble for your building, or if you have a building clad in marble panels, attention to fabrication, detailing, and signs of distress can make the difference between a minor repair project and complete wall system failure.

Material Properties and History

Marble is a metamorphic rock that derives from the transformation of limestone and other sedimentary carbonate rocks under high heat and pressure. Unlike slate or mica, in which differential stress creates planes of cleavage, marble is *non-foliated*, which permits its widespread use in sculpture and construction.

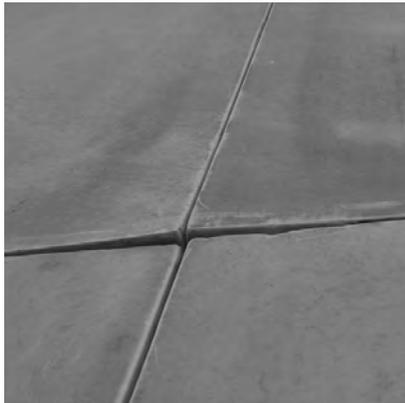
Hundreds of different types of marble are found throughout the world, including the United States, Europe, Egypt, and India. Characteristic veins and gradations in color result from impurities in the limestone, which move and re-crystallize as the stone metamorphoses into marble.

In commercial applications, the term "marble" may refer to a number of geologic formulations, including true calcite and dolomite marbles, as well as travertine, serpentine, and hard limestone, like Tennessee marble.



▲ New stone-cutting technology permits thinner marble panels—and brings new design challenges.

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Warping



Fractures



Spalls

The enduring presence of temples, arenas, sculpture, and monuments from antiquity is a testament to the durability of marble. However, while the physical properties and design principles of dimension marble are time-tested, thin stone veneers don't have centuries of refinement to guide their fabrication, engineering, and installation. In the 1950s, thin marble was combined with large structural pre-cast concrete panels as a cladding material. Due to its low cost, ease of installation, and aesthetic appeal, the panels grew in popularity. Since then, technologies for stone cutting, anchorage, and detailing have evolved considerably, offering owners more options and better understanding of the causes and prevention of deterioration.

Design and Installation Considerations

The thinness that makes veneers so economically appealing also makes them more fallible than their conventional dimension stone counterparts. Thinner marble is less resilient under the forces of changing temperatures, seismic loads, gravity, wind, and moisture. Connections require anchorage systems far more sophisticated than the metal fittings used to reinforce traditional marble construction, demand-

ing an exacting attention to design, engineering, and detailing.

However, new developments in the use of thin marble as a building material have opened up design options that were not possible with conventional stone blocks. The textural richness of marble can now be incorporated into curtain walls and shaped to achieve nearly any configuration.

To reap these benefits from the use of thin stone marble veneers without falling victim to the material's shortfalls, consider intersections, terminations, and physical properties of the selected marble variety when reviewing design options, whether for new construction, retrofit, or rehabilitation.

Anchorage

There are two basic methods for thin stone installation:

- **Hand-set method.** Each stone is individually attached to the wall framing system.
- **Panelized installation method.** One or multiple stone panels are factory installed on a steel frame or truss, or on a precast concrete backup. The composite panels are then secured to the building frame as a unit.

Panels must be secured to concrete

backup or to the structural frame by use of anchors. Selection of these anchors is critical to the performance of the marble veneer:

When precast backup is used, stainless steel hairpin anchors bonded into the concrete are used to engage the back of the marble panel. These pins are set on an angle, varying from 30 to 45 degrees. Each anchor should support about two to three square feet of wall panel, depending on weight and anchor load tolerance. To protect against cracks, anchors should be set about six to nine inches away from panel edges, with no more than thirty inches between them.

Hand-set panels may employ anchors inserted into *kerfs*, which are narrow slots at panel ends, or fasteners set in holes at the sides or rear of the panel. Care must be taken during fabrication to cut kerfs and holes neither too deep nor too shallow, so that they are large enough to hold the anchor but not so large as to weaken the marble panel. Incorrect placement too near the edge of the panel can cause breakage.

Anchors should be engineered based on pull tests and calculations to withstand lateral and gravity loads. Where precast back-up is used, the thin stone veneer must be directly



Cracks

connected with no annular (cavity) space between marble and concrete. Relieving angles incorporated into the anchorage system provide additional support.

Building Movement

Marble, sealant, concrete and steel respond differently to changes in temperature, wind pressure, and seismic forces. Unless facade design anticipates and responds to these varying degrees of change, the wall system will fail under the stress of restricted movement.

To improve tolerance for this differential movement, a bond breaker, usually a polyethylene sheet or foam pad, may be installed between marble panels and concrete back-up. Likewise, accommodate movement at anchor points by drilling kerfs and holes slightly larger than the anchor.

In the past, this anchorage space was often filled with epoxy to maintain water-tightness. However, epoxies restrict shear movement, which can cause the marble to crack. Instead, opt for rubber grommets or flexible sealants that balance the need for water protection with the requirement for movement tolerance.

Hysteresis

Midcentury thin marble was gener-



Sealant and anchorage failure

ally cut to a thickness of three or four inches. Developments in stone cutting allowed for ever-thinner panels, with the 1970s seeing marble as thin as a half inch. Lighter weight panels saved money in materials and installation, but brought with them new problems.

Thinner marble lacks the strength to resist intrinsic material stresses. Through a process known as *hysteresis*, some fine-grained marble veneers gradually expand with each thermal change, resulting in permanent deformation. The interior and exterior faces of the stone expand at different rates, causing the panel to bow outward, away from the plane of the wall. In turn, this warping causes stress on anchorage and perimeter joint systems.

Changes to the microstructure of the marble also affect its permeability and contribute to micro-crack generation. Over time, the panel sustains not only deformation, but structural disintegration as well.

Moisture Intrusion

Hysteresis increases the porosity of marble, permitting additional moisture to enter the panel. Damage to the marble from freeze/thaw cycling, salts, acid rain, and pollutants then occurs from the inside out, not just at the surface.



Hysteresis

Joint treatments are particularly critical in preventing moisture intrusion behind the panels, which can lead to heaving, displacement, and cracking. Water can also cause anchors to corrode. Not only does this compromise the strength of panel supports, the expansive forces of the deteriorating metal can crack the stone, creating further moisture entry points and accelerating the cycle of deterioration.

Controlling moisture egress through the appropriate use of flashings and weep holes, which channel wind-driven rain and condensation out of the wall system, are integral to the durability of the facade.

Environment

Rain water and rapid temperature changes can cause detail deterioration and surface erosion. As the surface of the marble deteriorates, bonds between mineral particles in the marble weaken, and the stone's *flexural strength*, or ability to resist loads without deformation, can become compromised. The weakened marble becomes pitted at the surface, developing a characteristic texture known as *sugaring*. At the same time, the more porous surface admits still more water, compounding the problem.

To extend the lifespan of marble veneers, clean thin stone facades



▲ Ground-Penetrating Radar (GPR) identifies anchor locations without removing panels.



▲ Replacement panel mock-up to assess anchor geometry and installation protocol.



▲ Penthouse marble panel replacement in process.

periodically to minimize contaminants. Flexural strength tests may also be conducted, both for existing marble and to evaluate potential replacement stones.

Resolving Deterioration

Where wall cladding distress is observed, often in the form of cracks, displacement, bowing, or leaks, it is important to address conditions promptly. Emergency measures to prevent loose stone from falling, such as face-pinning of marble panels, may be necessary as a safety precaution. As research develops in the field of thin stone technology, new mechanical and chemical treatments are becoming available to address hysteresis and loss of flexural strength, as well as to promote resistance to moisture intrusion and environmental stressors.

Visual Survey

Depending on the height of the building, observation from street level using binoculars may be a good place to start. However, use of a suspended scaffold or lift may be necessary for an accurate evaluation. In particular, hysteresis and other deterioration within the stone may not be detectable except by close examination and *sounding*, or tapping the stone to assess its integrity.

Using an accurate set of drawings, the architect or engineer should label evidence of damage, distress, or failure. Visual survey provides an overall picture of the condition of the marble wall system, such that remedial measures can be evaluated.

Testing and Analysis

Depending upon the results of the initial inspection, the architect or engineer may elect to remove panels to identify concealed conditions and to evaluate the properties of the marble. When developing a removal and testing program, the design professional should endeavor to remove sufficient panels to provide a comfortable representation of the facade, and locate panel removals accordingly. Temporary protection or replacement is also a consideration, so as to protect openings from the elements. Weather events and seasonal variables should also be considered when scheduling invasive testing.

Removal of panels is disruptive, but it may be necessary to establish the marble's physical condition and life expectancy, as well as to facilitate development of proper repair details. Typical laboratory tests include:

- **Petrographic analysis** (American Society of Testing and Materials / ASTM C1721) describes the nature of the stone as regards its lithology, mineralogy, morphology, microstructure, and aging. Petrography enables classification of the marble and assists in the detection of defects.
- **Flexural strength testing** (ASTM C880) indicates the stone's ability to resist bending stress. Marble with higher flexural strength is less susceptible to hysteresis.
- **Absorption** (ASTM C503) tests the marble's porosity, or tendency to absorb moisture over time. More porous stones tend to sustain greater damage from freeze/thaw cycling.
- **Density** (ASTM C503) indicates weight per unit volume. Different classes of marble vary in acceptable density for construction.

The lightest, travertine, has a minimum 144 pounds per cubic foot, while the denser dolomite must achieve at least 175 pounds per cubic foot.

On-site testing commonly involves measuring resistance to lateral forces produced by wind loading. Transverse wind load tests simulate the vacuum pressures that cause deflection and bending, by subjecting marble panels to increasing levels of force until the stone sustains permanent damage. Planning for pull tests requires wind load analysis to determine necessary load values and factor of safety.

Wind Load Design

Most building codes provide prescriptive requirements regarding wind loads on building components and cladding, which vary depending upon building height. The American Society of Civil Engineers (ASCE) 7 standard is currently considered state-of-the-art for determining design loads on structures. Note that some older building codes do not consider ASCE 7, which could be significantly more conservative than the code requirement. For this reason, it is important for the architect or engineer to evaluate all applicable codes and standards, in order to provide the building owner with recommendations.

Another method for determining load values is a wind tunnel analysis, performed in a laboratory. While this approach can provide more accurate values tailored to the shape and location of the building, the cost to perform the analysis might be prohibitive.

Perimeter Waterproofing

Typically, thin stone marble panels are joined at the perimeter with sealant, although mortar has also been used. If the latter is the case, joint mortar should be evaluated for strength and

adhesion, while the stone should be examined for cracks or *spalls* (areas where the surface has broken away). Proper mortar adhesion is difficult to achieve, especially in high-rise applications. To avoid water pooling in the joints, tooling profiles should provide a path for moisture to drain.

“While some products do offer improved resiliency, they are not a replacement for correct design and detailing.”

For the more commonly used joint sealants, the design professional should consider properties such as adhesion (bonding to the stone), cohesion (resisting internal cracking), and flexibility. The sealant should resist moisture ingress and thermal degeneration, while providing enough tolerance for marble panels to move in response to changes in temperature and pressure. Adhesion tests should be performed to determine the appropriate product for the marble composition, as well as to evaluate whether or not a primer is necessary.

In general, silicones have a better performance record than do polyurethanes, which tend to revert to an uncured condition. However, silicones collect more dirt, such that light colors will turn dark over time without diligent cleaning.

Research and testing should be conducted to verify that the product and primer selected do not stain existing

or replacement stone. Sealant manufacturers usually provide this service; however, testing by an independent laboratory should be conducted whenever possible.

Even if an appropriate joint compound is selected, the system can still fail if the space between panels is too small to accommodate differential movement or too large for the sealant to span. Manufacturers' guidelines and industry standards provide requirements for width-to-depth ratios and minimum bond surfaces.

Repair

Although displaced, de-bonded, or heavily bowed panels will require replacement, it is possible to restore marble that has sustained only minor damage. This is good news both from a preservation point of view and from a practical one. With many quarries closed or depleted by the late twentieth century, finding suitable replacement marble can be expensive or even impossible.

After evaluating information gathered during the visual survey, the design professional should locate and catalog each deficiency. Small spalls less than half a square foot and small cracks less than a foot long can be repaired with patching material. Granular matter, including marble dust, can be added to improve the match in texture and color. Behavior of the patching compound in response to heat, UV radiation, moisture, cold, and pressure must be considered, so that the material is neither so rigid as to restrict the movement of the marble nor so pliable as to fail when exposed to the elements.

If cracks or spalls are large or close to the edges of the stone, a “Dutchman” repair may be used. The damaged area is removed, and a new piece, or “Dutchman,” is installed with appropriate anchors.



▲ Face-pinning is often used as a safety measure to prevent loose panels from falling.

Larger, continuous cracks should be evaluated on a case-by-case basis. Usually, face-pinning the stone and patching the crack is sufficient. However, multiple cracks on a single panel could be symptomatic of restraint and hysteresis stresses, which might require replacement of the panel and possibly the anchoring system.

Structural Considerations

Marble panel systems are a type of curtain wall cladding, which does not bear any building load other than its own weight. This weight must be transferred via anchors, and sometimes through secondary supports, to the building's main structural system. Additional loads from wind, seismic, impact, construction, and other forces must also be considered in the anchorage system design.

Due to hysteresis, anchorage details must consider the change in shape of the marble as it ages. Therefore, new or replacement anchors must not only contain the stone panel within the exterior wall assembly and comply with code requirements for lateral forces, they must also remain flexible enough to tolerate movement.

ASTM C1242 provides guidelines for the selection, design, and installation of stone anchoring systems, as does

the Marble Institute of America's *Dimension Stone Design Manual*. In general, the type of marble, its weight and thickness, and the composition and exposure of the structure should dictate the appropriate safety factor and anchorage method.

Re-Cladding

Where inadequate design, faulty installation, or widespread deterioration precludes repair of individual panels, complete replacement may be a viable option. Many cases exist of thin stone wall systems that have failed prematurely, and the building is stripped of the marble panels and clad with new material. Re-skinning the facade is a drastic and expensive approach, but for buildings exhibiting extensive failures, it may be the only feasible tactic.

Evaluating the Options

Before rushing to a decision, consider the technical viability and anticipated return on investment for each option, including repair; isolated replacements; anchorage rehabilitation, and re-cladding. Some factors to consider:

- **Condition of the existing substrate.** If the back-up or framing exhibits deterioration, it may be necessary to remove panels and repair the source of distress. Fixing cracks or replacing sealant won't help unless the underlying problem is resolved.
- **Load capacity.** Replacing very thin marble panels with thicker ones can resolve hysteresis issues, but may cause structural problems if the framing can't handle the increased weight.
- **Space between cladding and property line.** A cost-effective strategy for facade upgrades can involve retrofitting a new curtain wall over existing framing. However, the building face then moves outward by several inches,

which may be problematic if the structure already abuts the property line.

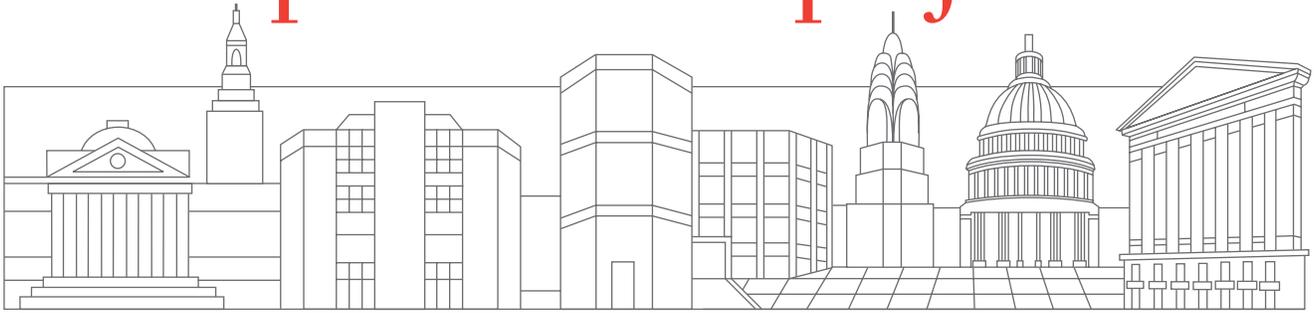
- **Presence of hazardous materials.** Where testing reveals PCBs in sealant or asbestos in insulation or adhesives, removal of the existing curtain wall may be cost-prohibitive.
- **Energy efficiency.** Unlike their load-bearing cousins, thin marble panels provide little insulating value. Thermal performance of stone veneers is derived primarily from insulation in the cavity or backup wall. Newer systems are designed for improved energy efficiency, which may help to offset the cost of rehabilitation or replacement.
- **Aesthetics.** Marble's sculptural quality and depth of light penetration makes it an aesthetically satisfying building material. Replicating this effect with patches or replacement panels can be difficult, and care must be taken to mimic the gradations and texture of the original stone as closely as possible. Likewise, full replacement of a marble facade demands thoughtful consideration, as the finished appearance of the building can alter dramatically.

When analyzing cost estimates, consider not only the up-front price of repair or replacement, but the long-term expense incurred through maintenance and repair. Properly constructed marble wall systems require comparably less maintenance than do many other types of curtain walls. Sealant replacement every 10 to 20 years is usually the only major anticipated repair; depending on the type of sealant used.

Whether choosing rehabilitation or replacement, establish a routine cleaning program to remove stains and con-

(continued on page 8)

representative projects



Thin Stone Veneer

Solving stone panel distress demands technical know-how, practical experience, and aesthetic sensibility. When it comes to resolving anchorage, cladding, or structural framing problems, Hoffmann Architects has the expertise to get the job done. Our architects and engineers diagnose and correct deficiencies related to the unique material properties and design challenges of stone veneers.

Hoffmann Architects has developed thin stone wall system solutions at diverse properties, including:

Chase Manhattan Bank
New Rochelle, New York
Marble Panel Investigation

One Shell Square
New Orleans, Louisiana
Marble Panel Failure Consultation

The Phoenix Companies Headquarters
Hartford, Connecticut
Limestone Panel Rehabilitation

**School of Law Library
University of Connecticut**
West Hartford, Connecticut
Granite Veneer Stabilization

Office Park
333 Westchester Avenue
White Plains, New York
Marble Panel Consultation

Crowne Plaza Hotel Times Square
New York, New York
Granite Panel Replacement

MasterCard Headquarters
Purchase, New York
Travertine and Concrete Facade Rehabilitation

Verizon Building
240 E 38th Street
New York, New York
Granite Veneer Facade Repair

**Ralph S. O'Connor Recreation Center
Johns Hopkins University**
Baltimore, Maryland
Limestone Panel Investigation

**Bristol Myers Squibb Pharmaceutical
Research Institute**
Wallingford, Connecticut
Stone Panel Anchorage Rehabilitation

Office Building
110 South Bedford Road
Mt. Kisco, New York
Marble Panel Facade Rehabilitation



Corporate High-Rise at 1095 Avenue of the Americas in New York, New York.
Marble and Glass Curtain Wall Consultation.



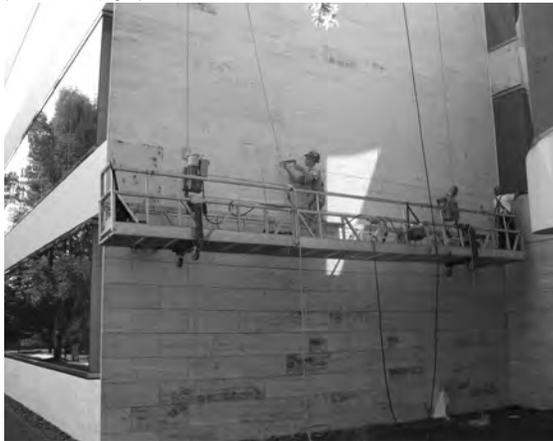
Blessed Kateri Tekakwitha Parish in Sparta, New Jersey. *Thin Stone Veneer and Roof Rehabilitation.*

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▲ Periodic sealant replacement should be part of a comprehensive maintenance program.

taminants, without being so aggressive as to damage the stone. Due to thin marble's propensity toward hysteresis, periodic inspection of the wall panels is recommended to evaluate loss of strength. Many of the problems inherent to thin stone marble wall systems can be avoided through appropriate maintenance and early detection.

The Future of Stone

Thin stone veneers offer the aesthetic benefits of traditional load-bearing stone at a more affordable price. As the industry develops, more buildings have come to adopt this technology. For thin marble cladding to last, however, it is necessary to understand and address the particular challenges

posed by this natural material in the built environment.

As more research is conducted into the relatively recent field of thin stone wall systems, products continue to emerge on the market that claim to improve resistance to environmental contaminants, moisture penetration, temperature fluctuations, hysteresis, differential movement, UV radiation, and other stressors. Some

have contributed to improvements in stone veneer construction; others are basically worthless.

As with any new technology yet to stand the test of time, treatments claiming to resolve deficiencies in design or material properties should be treated with caution. While some products do offer improved resiliency in marble panel systems, they are not a replacement for correct design, waterproofing, and detailing. To avoid the expense and inconvenience of repeat repairs—some of which can actually cause permanent, irreversible damage to the marble—work with your design professional to investigate, resolve, and, ideally, prevent underlying problems, before reaching for a quick fix. ■

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