Stone cladding technology: Monitoring and intervention techniques for stabilization

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ABSTRACT: Stone cladding technology used to express the International Power Style of the 1950s, as coined by Robert Hughes in *The Shock of the New*, has required intervention over the past few years. The United Nations Headquarters and Lincoln Center for the Performing Arts, both in New York City, and the Governor Nelson A. Rockefeller Empire State Plaza in Albany, New York, range between thirty and fifty years old. Although these buildings are relatively young, constituents and historians argue that they are monuments that must be preserved. As a result, engineers, architects, and conservators have been commissioned to document and physically monitor these monuments, especially with regard to their exterior facades. The technology of stone cladding, as exhibited in these complexes, derived new expressions of monolithic textures expressed through weightlessness and smooth stone finished facades. Technically, these buildings present many challenges about how to maintain the original curtain wall and its elements that evoke such monumental power. The technical challenges include the difficulty of surveying large areas and collecting large amounts of data, testing stone panels to understand their behavior and designing technically viable repairs that respect the original aesthetic. Therefore, monitoring and intervention techniques, which may differ from those in the past, may be required to ensure the seamless continuance of the facades’ expression.

1 INTRODUCTION

This paper is part of a series dedicated to the new challenges in preserving buildings of the modern movement. Part 1 of this topic was presented at the International Millenium Congress in Paris, France, in September 2001, and focuses on the aesthetic challenges of preserving dimensional stone cladding. Part 2 of this topic (this paper) focuses on the technical challenges of preserving dimensional stone cladding.

The technical challenges of dimensional stone preservation not only involve finding aesthetically acceptable repair/replacement material, but also include addressing the behavior of the stone as an individual unit and as a monolith slab wall attached to the building structure via a multitude of various connectors. How do we address the dimensional stone curtain wall as it undergoes material and structural failure? What happens to these dimensional stone curtain wall systems when we cut, drill, pin, patch, and retrofit them as the “pristine planes” they often form? While mortar patches, Dutchman, and pins maybe appropriate for older handmade structures, they may threaten the technical well being of these dimensional stone curtain wall systems.
2 THE COMPLEXES

While the planning and design of individual buildings within each complex was done by world renowned architects, New York City architect Wallace K. Harrison is listed as the lead architect since he was appointed the director of planning at each of the complexes that are the subject of this paper. In total, the three complexes cover an area of over 60 hectares (150 acres) and consist of approximately twenty buildings. The first complex to be constructed was the United Nations Headquarters (UN), New York City, which was constructed between 1949 and 1953; followed by Lincoln Center for the Performing Arts (Lincoln Center), New York City, which was constructed between 1962 and 1968; and lastly, the Nelson A. Rockefeller Empire State Plaza (ESP), Albany, New York, constructed between 1965 and 1979 (Newhouse, 1989). The facades of all three complexes are finished either with an aluminum and glass curtain wall or a dimensional stone cladding, or a combination thereof, see Fig. 1.

3 IDENTIFICATION OF CURTAIN WALL TECHNOLOGY

The architectural conception and the structural elements of buildings of the International Power Style are manifest clearly in the construction of the exterior walls. The facade represents an independent architectural form which determines the aesthetic character of the building. Most exterior building wall components can be classified by their composition or by the “curtain wall system” that comprises the aesthetic massing of the building. Due to the complexity of most modern curtain wall systems, a thorough investigation is often required to identify all of the building’s components and the types of materials used. Identification of the exterior cladding system must be a priority if an appropriate assessment of the building is to be completed. If an intervention is required, a stabilization plan for the curtain wall system implementation may be required before a conservation program can be implemented. In addition, if the aesthetic character of curtain wall system is altered, both stabilization and repair measures must prove to maintain the character of the original building. This requirement may impose certain limitations on the potential scope of repairs or treatments, in order to maintain the original architectural expression and material components.

3.1 Dimension Stone Cladding

Dimension stone can be defined as natural rock material quarried for the purpose of obtaining slabs or blocks that meet specifications according to “size”, which includes width, length, and thickness. Other classifications include shape, color, grain texture, pattern, with a mechanically finished stone surface. The American Society for Testing and Materials (ASTM) has continued to establish guidelines for durability and strength (i.e. mineral composition, strength, and past performance). The principal rock types are granite, limestone, marble, sandstone, and slate, although a variety of igneous, metamorphic, and sedimentary rocks are also used as dimension figures 1: From left to right, United Nations Headquarters, Lincoln Center and Empire State Plaza.
stone. Other varieties of dimension stone that are normally considered to be special minor types include alabaster, soapstone, and various composite systems containing natural stone.

The term dimension stone is in contradistinction to crushed and broken stone, such as is used for aggregate, roadstone, fill, or chemical raw materials. In common practice, some dimension stones are reinforced, filled, or surface treated (ASTM, 2000). Another important selection criteria is the ability of the stone to take a polish. However, definitions applied to dimension stones differ from country to country, as well as from region to region. For example, in certain stone-producing areas, travertine is considered a limestone even though it is sometimes classified with other marbles.

3.2 Stone Cladding Typology and Classification

Classification of modern stone cladding systems should be defined not only by the building style but also by aesthetic elements or components within a given stone cladding or curtain wall system. The building “typology” should be defined by (1) the building aesthetic, (2) the curtain wall system, (3) the cladding material (stone type), and if possible, (4) the specific anchor design. All too often, discussion focuses on common repairs or conventional selection of repairs to “match” the stone or cladding material. In other cases, a systemic repair using pin anchor hardware, epoxy adhesives, patch fillers, or even a stone dutchman, may not solve the inherent problem in the cladding or curtain wall system, and in fact may do more harm than good. As such, identification of the building typology, building components, and how they perform with the building structure must be studied to provide informed recommendations regarding structural and aesthetic issues when preserving the original design of the building.

3.3 Monolith Slab Wall

Common to most of the building structures at all three complexes is what was commonly referred as the idea of the “slab” wall construction. The Secretariat “slab” at the U.N. Headquarters is distinguished by the diagrammatic clarity of its cladding – two walls of glass and two of stone. LeCorbusier and Harrison selected dimension stone cladding comprised of Vermont marble panels to drape the concrete vertical slab walls. LeCorbusier believed that each monolithic wall would yield a soaring monumental appearance. The massive 39-story polished marble wall reached a total height of 166 m (544 feet). The monolithic slender appearance of each end wall and the contrasting glass curtain became the successful icon of the modern skyscraper, the symbol of innovation and pure engineering (Stern, 1997).

The massive slab wall configuration was a signature symbol of power during this phase of modernism. Philip Johnson utilized a similar scale with the massive side walls at the New York State Theater at Lincoln Center for the Performing Arts in New York City. The design of alternating sizes of travertine stone panels appear monolithic on the back and side walls of the State Theater facade. Here, alternating 2’-6” wide x 4’-6” high, 2-1/2” thick travertine stone cladding units were assembled and set atop slotted stainless steel shelf angles bolted back to the concrete structural frame. Stone panels were loaded on shelf angles at each floor, with alternating stone panels between each floor tied back with 18 gauge stainless steel dovetail and split-end tie backs. The stone cladding did not appear to be constructed using so many stones, however, due to the textured effect of the travertine, panels appeared as a single monolithic load-bearing masonry stone wall reminiscent of classical antiquity.

The monolithic stone wall was carried through in the design of the Agency Buildings at Empire State Plaza by architect Wallace Harrison. The stone clad concrete slab walls create a triangular shaped spinal tower to house the elevators and mechanical systems of four 19-story buildings. At the Agency Buildings, the repetition of four identical towering stone walls forms a collonade of buildings along the plaza. Harrison utilized 7.5 cm (3”) thick Vermont marble panels to clad the monolithic towers. The stone dimensioned panels measure approximately 182 cm (6’-0”) in width by 202 cm (6’-8”) in height. Stone cladding panels are set atop and lined up along a continuous stainless steel shelf angle bolted back into a stainless steel anchor insert embedded into the concrete substrate. A stainless steel dowel inserted through the angle is set into a vertical slotted hole in the panel approximately 1.87 cm (¾”) from the face of the panel.
3.4 Vertical Clad Fins

One of the key components used to describe the tower structures at the Empire State Plaza are the ‘vertical fins’ clad in Vermont marble. The design of the fins at the Agency Buildings and Corning Tower, as well as at Harrison’s Metropolitan Opera House, is comprised of a vertical fin element that emphasizes the verticality of the buildings. The stone clad vertical fins at the Agency Buildings and Corning Tower are constructed of two panels set on stainless steel shelf angles; each panel measures approximately 182 cm (6'-0") in height. Each clad fin flares toward the face of the glass window. The weight of two panels is carried at each floor slab as every other panel directly bears on a stainless steel shelf angle, see Fig. 2. At each edge of the panel, two stainless steel dowels laterally brace the panels together. These dowels and connectors are attached using dovetail anchors set into steel tracks embedded into the concrete substrate.

3.5 Composite Marble Panels

In the early 1960s, stone was successfully used to face precast concrete units. The use of the “composite stone panels” (concrete panel clad with a thin stone veneer) was popular due to the rapid production and deployment of precast concrete units. These precast concrete units faced with marble (2 cm stone at Juilliard School and 2.5 cm stone at Cultural Education Center) came in various prefabricated sizes to provide an infinite number of marble pattern possibilities; moreover, these units provided the possibility to erect ‘modular’ elements of a particular building. Depending upon the type of system, marble stone faced precast panels could have a minimum thickness of 2 cm (7/8") up to approximately 5 cm (2"). Typically, stainless steel anchors were embedded in 7 cm (3") to approximately 18 cm (7") of concrete backing. Marble panels were attached to the concrete backup using 32 mm (1/8") stainless steel clip anchors.

Erection of the marble-faced precast elements was a relatively simple process. Stainless steel connectors were attached to exterior framing embedded in the concrete substrate. Composite walls were hung on the outside of a building typically at a spandrel beam. Corrosion resistant fasteners were used due to their ability to resist weathering and retain strength over a long period of time. Marble panels were placed in vertical coursing and tie-back anchors were used to support the panels underneath. For example, the literature of the Vermont Marble Company listed types of anchorage supports to attach stone panels to the concrete structure, to which allow a sound section of stone to be dowelled and epoxied into place. For example, both the Juilliard School at Lincoln Center in New York and the Cultural Education Center at the Empire State Plaza, large assemblies of precast composite panels were hoisted into place to reduce construction cost and utilize the speed of erection of the composite paneling system; this was known to be one of the “cost saving” primary advantages of this construction method.

Figure 2 : At left, over photo of Agency Building with fin element. At center, plan section view of panel clad fin. At right, typical section at joint location of slab wall. Note stainless steel shelf angle resting in a connector that was cast with the concrete structure.
4 THE CHALLENGE IN MONITORING STONE CLAD FACADES

Methods developed to monitor massive stone clad facades may involve various visual observation techniques. The use of high powered binoculars and spotting scopes can give a preliminary evaluation. Close-up observations are performed via hung scaffolds or rope rappelling techniques. Data collection devices such as hand-held pocket personal computers (PDAs) aid in organizing field data. Other monitoring methods may include selective non-destructive testing (NDT) and using a borescope through small probe openings between joints to photograph conditions behind the stone panels.

As pointed out above, most of the cladding on all three complexes was designed to present a "slab" or mass of stone. As individual pieces of a monolith, each panel can have a deficiency that is unique to itself. In the case of ESP, there are approximately 125,000 panels on all nine buildings. This requires keen observation on a panel by panel basis to record and quantify the deficiencies. The challenge is developing the eye to observe deficiencies. The greatest asset to visual observations is light. In viewing these monolith type facades it is critical to understand the light source. Daylight, direct sunlight and tangential light (light that washes across the façade at less than a five degree angle) play large roles in what the naked eye perceives. In daylight, finer cracks tend to be more noticeable while in direct sunlight, spalls tend to be more noticeable. In tangential light, bowing and shifting of panels are more noticeable through the shadows they cast on adjacent panels, see Fig. 3.

Visual surveying from a distance is acceptable for establishing the overall condition of the facade, but it should be supplemented with close-up surveying. Access to these monolith facades is usually achieved with hung scaffolding, or a personal lift or “bucket truck” at lower elevations. Access can also be achieved with rope access. Rope access was used at Lincoln Center along the entire perimeter of the New York State Theater because of recognized limitations in distant visual observations. Travertine, the cladding used at Lincoln Center, has a rough surface with many voids. What may appear from a distance as a natural feature of the stone may actually be a crack. Rope rappelling techniques facilitate quicker access to the vast amount of wall space. During close-up examination, the stone panels can be measured and sounded with a plastic mallet to detect delaminations or voids, see Fig. 4. In addition to tape measurers, a bow measuring device customized to the typical panel size can be used to measure deflection of individual stone panels.

As mentioned above, stone clad walls typically contain many panels. Since each panel can have one or more types of deficiencies, the amount of data recorded can be overwhelming. The method used at ESP involves the use of hand held computers. Using hand held computers and a simple database, data fields can be customized for the observer to use in inputting data while performing visual observations. The fields in the database permit each of the 125,000 panels in the complex to be uniquely identified. Prior to recording the data, facade drawings of each building were prepared so that panels can be numbered. Depending upon the way the drawing is set up in Autocad, automatic numbering of the panels is possible. Once the data is recorded, queries can be written to extract statistics, or the history of an individual panel when surveys are conducted over a period of time. Additional information can also be added to the database as further surveying dictates.
Nondestructive techniques used on stone clad walls include impact echo and pulse velocity. Both techniques can provide useful information when correlated with visual observations and laboratory testing. Deficiencies that occur on the backside of stone panels, which are not visible from the face, can be detected with impact echo. Because each impact echo reading is limited to a small area of the stone unit, many readings may be required to locate specific deficiencies, see Fig. 5. However, a lower anomalous frequency reading, such as low frequency or signal velocity, may be an indication of a disruption in material. This disruption may be caused by veining in the marble and not necessarily by a crack or spall. Although pulse velocity is typically used across a specimen, with two sides exposed, it has also been successfully used on one side of panels by inducing the pulse at the top of the panels and receiving it at the bottom. However, thin panels, such as those 3 cm or less in thickness, may present a challenge because the period of the pulse velocity wave is narrow. In either technique, it is important to reiterate that correlation of the findings with visual observations and laboratory testing is necessary.

One other method to inspect stone clad walls involves localized intrusion into the facade. Fiberoptic borescopes are available with light sources and cameras so that the condition of the connectors behind the cladding can be identified. Use of the borescope typically requires that a small hole be drilled into the joint between the stone panels. In most cases a 3/8” diameter hole is sufficient. The borescope is inserted, the light source turned on, and the concealed anchorage or other interior wall conditions can be observed and photographed. Observations may be disorienting at first because the observer may not realize the direction of the view.

Figure 4: Industrial rope rappelling technique used for close-up observations and sounding at a travertine clad wall.

Figure 5: Impact Echo, one of several NDT methods that can be used in assessing the quality of the stone. Interruptions of sound waves through stone typically indicate discontinuity in the composition of the stone unit.
Petrographic examination and physical tests

Over past fifteen years, material studies were conducted at Lincoln Center for the Performing Arts in New York City. This project has provided an opportunity to assess material behavior of thin travertine cladding for a stabilization and repair program to be developed at Lincoln Center. Although there may be other material studies appropriate to this study, our findings set a precedence for us on how to evaluate appropriate techniques for stone evaluation. For example, representative samples of stone were extracted from various locations of the building for testing and analysis. Petrographic examinations were performed on representative travertine stone samples. The petrographic examination consisted of a microscopic visual study and geological study of the stone materials by a material scientist. Stone specimens of travertine were removed from most of the buildings, including unweathered travertine samples removed from interior and protected areas. Both unweathered and weathered samples were subject to procedures such as x-ray diffraction analysis to determine the physical characteristics and properties of the stone. Methods of x-ray diffraction were used to identify crystalline compounds including aggregates, efflorescence, paste components in mortar, grout, and any possible deleterious components. Many of the tests performed followed procedures outlined by the American Society for Testing and Materials (ASTM).

5.1 Physical Properties of Natural Building Stone

Through the materials study selected, representative samples were removed from various locations at the Lincoln Center complex to determine the water absorption properties of the stone. Consideration was taken to extract select samples from rain exposed locations as well as sheltered locations. In addition, freeze-thaw exposure of the travertine samples was conducted and periodic dynamic modulus and weight loss measurements were taken based on a modified ASTM C666 test. This test covered the resistance of stone samples to rapidly repeated cycles of freezing in air and thawing in water. Material degradation was not detected at 300 cycles of freeze-thaw testing for weathered samples eventhough existing deterioration of panels on the building was judged to be from cyclic freezing of critically saturated travertine.

While overall strength properties of more uniform materials such as marble, granite, limestone, etc., may be effectively represented by sampling and testing, travertine’s extreme variability made it difficult to select an adequate random sample that was representative. Due to the variability that may exist from panel sample to sample, the lack of uniformity can result in quite a range of test values that are relatively meaningless (Beasley, 1988).

6 ASSESSMENT OF ONGOING REPAIR PROGRAM

The challenges of stone cladding stabilization are numerous and their assessment cannot be fully described in this paper. However, over the last fifty years, stone cladding has developed considerably and continues to change especially in regard to the methodology for developing a repair program. In order to properly assess the condition of stone cladding, a trial repair program should be undertaken to recommend an appropriate stabilization program. A stabilization program has been underway at Lincoln Center for the Performing Arts since 1986, and includes periodic on-site inspection and ongoing monitoring of the travertine stone cladding. Although there are different types of repairs that can be implemented for thin dimension stone cladding, a few types of repairs are described here that still appear to be in sound condition and also maintain the aesthetic integrity of modern stone construction.

6.1 Full Panel Replacement

A full panel replacement requires installation of a new stone, dimensioned and cut to match the original stone to be removed. Typically, a new panel replacement is recommended when a significant distress condition is identified in the original stone panel, although this replacement may also be a desirable solution in order to maintain the original design aesthetic of the building. Examples of significant distressed conditions include large eroded pockets, large
voids, continuous interconnecting cracks, or fractures in the travertine that jeopardize the structural integrity of the panel, see Fig. 6a. A full panel replacement requires removal of the existing panel and existing dowels. New dowel holes are drilled into the adjacent panels and in the new panel. New 10 cm (4” in length) stainless steel dowels (typically 1.25 cm or 3/8” in diameter for a 1.9 cm or 3/4” thick stone panel) are selectively positioned into the new panel prior to setting of the panel. A mock-up of a sample panel replacement is recommended in order to test the integrity and aesthetic effectiveness of the repair.

6.2 Dutchman Repair

A dutchman repair requires a new prismatic shaped piece of stone cut to match the original portion of stone to be cut away and removed, see Fig. 6b. Typically, a dutchman is recommended in a select, isolated and distressed area of a stone panel. Some distress conditions that require dutchman repairs include small eroded or decayed pockets and panel cracks in the travertine that result in an isolated material failure in the panel. Often times, dutchman repairs are selected and considered more desirable in order to reduce the amount of material to be replaced. Dutchman repairs to travertine stone can visually provide a closer match and the resulting repair is usually less apparent because of travertine’s varied texture and color. However, a dutchman repair to marble stone may prove to be more difficult in that the requirement to match texture and color is more challenging. A field test of a sample dutchman repair is required in order to evaluate the integrity and aesthetic effectiveness of the repair.

6.3 Stitch Repair

A stitch repair requires that a large crack be routed and mechanically connected. The stitch repair is generally recommended over a deep crack that is continuous across the panel. Large cracks should be routed out 0.62 cm wide and 0.62 cm in depth upon which 1.2 cm diameter holes are drilled perpendicular to the face of the subject panel. Stainless steel U-cramps are then inserted into notched holes perpendicular to each side of the fracture. The notch is then patched solid with mortar compatible with the physical properties of the travertine, see Fig. 6c. Although these repairs were evaluated and tested prior to installation, considerable discussion occurred prior to implementation of the stabilization program to evaluate both structural and aesthetic issues related to this repair. Consideration of the aesthetic appropriateness of these stabilization methods was a major concern over the course of the project. A number of mock-ups for this repair were performed to evaluate the mechanical and aesthetic effectiveness of the repair.

![Figure 6: Repair Assessment](image)

Figure 6: Repair Assessment - from left to right; (Fig. 6a) a full panel replacement; (Fig. 6b) dutchman repair in progress at marble fin; (Fig. 6c) and a ‘Stitch’ repair in progress with ‘U’ clamps at each end of crack.
7 CONCLUSION

In considering measures appropriate to repair and stabilization of modern buildings constructed within the International Power Style, there remain many challenges in delineating the range of repairs appropriate for buildings at Lincoln Center, the Empire State Plaza, and the U.N. Headquarters. We have had the opportunity to implement repair programs at Lincoln Center for the Performing Arts and we intend to utilize this experience with the travertine stone cladding in the development of other repairs for marble stone cladding. Although these buildings clearly will require intervention to stabilize the stone cladding systems, the question remains: what types of repairs will be most effective with the minimal amount of intervention? In the case of Lincoln Center, the sample list of repairs were a challenge to develop and to implement. In addition, one of the more significant aesthetic issues was obtaining a proper color match of the stone. For example, it was difficult to match the honed surface of the new stone to the weathered existing stone.

Through the development of a stabilization repair program for the Metropolitan Opera House, other concerns rose out of the use of a dutchman or patch repair versus a full panel replacement. Under both instances, recommendations were made to replace the entire panel for both structural and aesthetic reasons: (1) structurally, the full replacement of a panel with new stainless steel dowels is a more appropriate long term repair, and (2) aesthetically, the full replacement of a stone panel maintains the original design intent of the dimension stone cladding system. In the case of these repairs, the dutchman repair of the travertine stone at Lincoln Center proved to maintain a unified aesthetic appearance due to the weathered appearance of the travertine. In most cases, the textural and porous appearance characteristic of the travertine stone cladding permitted the repair stabilization to eventually blend in well with the original stone cladding elements. Equally challenging will be to develop a comprehensive repair program for the Vermont (Pearl) marble stone cladding at ESP. Due to the higher compressive strength of marble and its visible veining characteristics, the stone properties may be more difficult to match both physically and aesthetically.

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