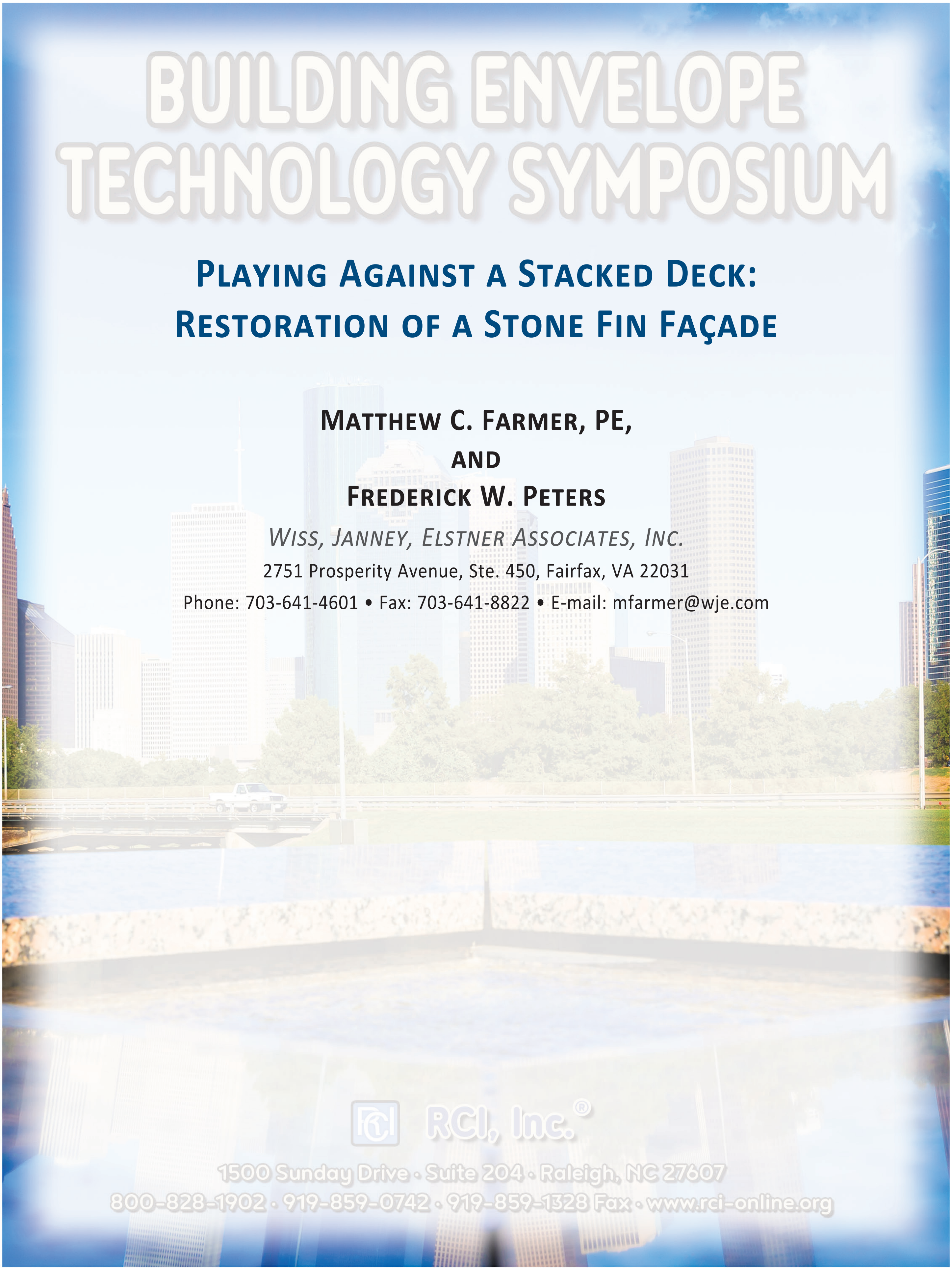

BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

Playing Against a Stacked Deck: Restoration of a Stone Fin Façade

Matthew C. Farmer, PE,

and

Frederick W. Peters

Wiss, Janney, Elstner Associates, Inc.

2751 Prosperity Avenue, Ste. 450, Fairfax, VA 22031

Phone: 703-641-4601 • Fax: 703-641-8822 • E-mail: mfarmer@wje.com

RCI, Inc.®

1500 Sunday Drive · Suite 204 · Raleigh, NC 27607

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Abstract

A popular architectural style of the late 20th century embraced alternating vertical "fins" of stacked stone cladding and strips of glazing. One of the best examples of this aesthetic is the National Geographic Society Building in Washington, DC. Due to the load-bearing panel configuration, conventional practice would have required destruction of several undamaged stone panels to access one needed repair. An innovative pre-tensioned cabling system used to temporarily support the intact panels enabled targeted removal of only the damaged portions of the panels. This innovative method offered a time- and cost-effective repair strategy using only suspended scaffolding.

Speakers

Matthew C. Farmer, PE — Wiss, Janney, Elstner Associates, Inc.

MATTHEW FARMER has served as principal investigator on numerous evaluations of buildings and monuments, and he has concentrated his practice in the areas of masonry building enclosure systems engineering, design, investigation, analysis, and repair. Farmer's projects have included institutional, commercial, and historic landmarks. He is a registered professional engineer in Washington, DC; Maryland; and Virginia. Farmer holds a bachelor of science degree in architectural engineering and a bachelor of environmental design degree from the University of Colorado, as well as a master of civil engineering degree from Cornell University.

Nonpresenting Coauthor

Frederick W. Peters — Wiss, Janney, Elstner Associates, Inc

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INTRODUCTION

Prior to the advent of individually anchored stone veneer systems, stacking multiple stone cladding panels was a common practice in high-rise construction of the modernist era in architecture. In the late 20th century, a popular architectural vernacular of alternating vertical "strips" of cladding and glazing was embraced by many post-modern designers. This aesthetic both lightened the massing of formal stone façades by piercing them with contrasting windows or other materials, and accentuated the verticality of the structure. One of the most widely recognized practitioners of this style was the architect Edward Durell Stone (1902-1978). *Figure 1* is a photograph of Stone taken in 1964 with his model of the NASA Electronics Research Center (located in Cambridge, MA, and renamed the John A. Volpe National Transportation Systems Center in 2011). During the latter part of his career, Stone and his firm were responsible for several buildings that incorporated this distinctive aesthetic, including the Palo Alto City Hall (circa 1967) in Palo Alto, CA; Aon Center (formerly the Standard Oil Building, circa 1974) in Chicago, IL; the General Motors Building in New York, NY; and the National Geographic Society Museum and Headquarters (circa. 1961) in Washington, DC.

The National Geographic Society Building in Washington, DC is the subject of this paper. It incorporates solid marble panels "stacked" to form fins that project from the plane of the façade (see *Figure 2*). Stacking of stone panels two or three panels high between gravity supports is advantageous due to the reduced number of gravity support points and because the gravity load is directly transferred to the floor slabs of a typical building, eliminating the need for a more structurally robust backup support system capable of carrying gravity load between floors.

A significant disadvantage to stacking stone panels as part of a façade becomes apparent if replacement or major repairs are necessary; to access the lowest of the stacked panels, the panels above must also typically be removed or temporarily supported, complicating the repair and increasing its cost. In the case of the NGS building, restoration of this iconic building possessed similar challenges. Due to the stacked panel configuration of the fins and the inaccessible lateral and gravity connections, conventional practice would have required destruction of several undamaged fin panels to access the ones needing repair, making the cost of the work prohibitive and time-consuming. Valuable historical building fabric from this architectural landmark would have also been lost in the process.

In response to these concerns, an innovative stone repair approach was developed as part of the NGS façade restoration to address widespread damage to the marble fin panels. Along with more traditional stone repairs, a system of pre-tensioned chains was utilized to temporarily support the intact panels and allow removal of discrete sections of the damaged marble fin panels. This technique resulted in the ability to restore the existing connections (consisting of dowels and stiffened bearing seats), target only the damaged portions of the marble fin panels, minimize loss of the intact marble fin panels, and enable cost-effective repair access using only suspended scaffolding.

BACKGROUND

The NGS Headquarters expanded over the years to occupy a multibuilding campus located in downtown Washington, DC. The original NGS building designed by Stone is part of the campus and remains a historical

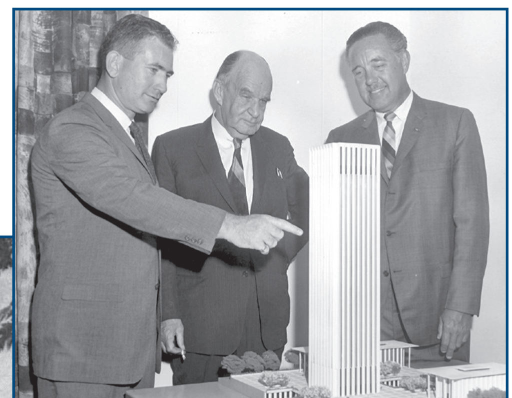

Figure 1 – Architect Edward Durell Stone (left) with his model of the NASA Electronics Research Center, circa 1961. (Photo by Great Images in NASA.)

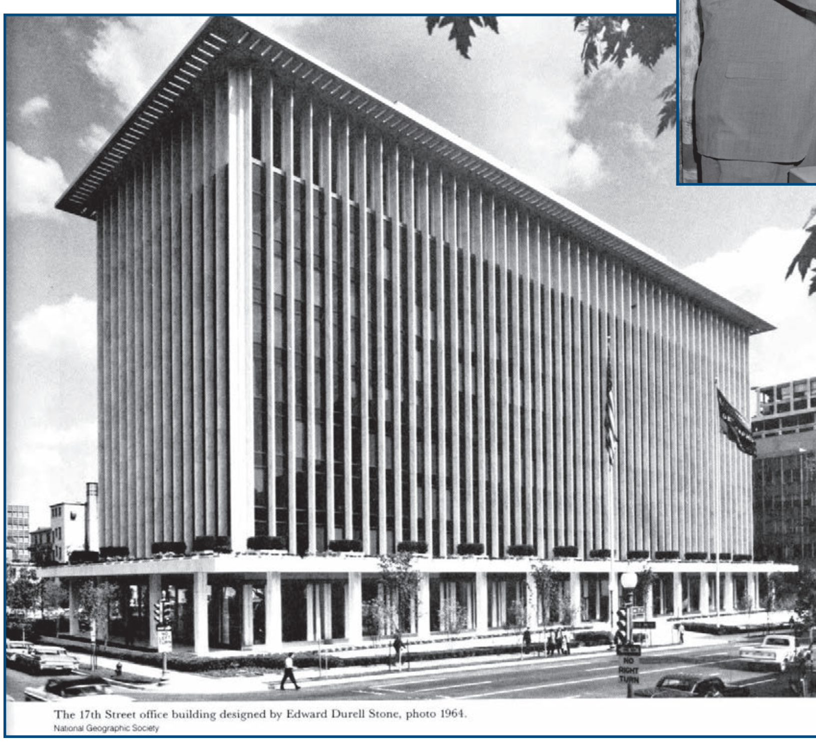

Figure 2 – National Geographic Society headquarters building, circa 1964. (Photo by National Geographic Society.)

Figure 3 – National Geographic Society Headquarters from M Street. (Photo by Mark Thiessen.)

icon for the organization (see *Figure 3*). The building houses editorial and administrative offices on the upper floors, plus a museum on the first floor that is open to the public and displays exhibits chronicling scientific expeditions, explorations, and issues affecting our world and its diverse population.

On August 23, 2011, at approximately 1:51 PM, a 5.8-magnitude earthquake occurred within the "Central Virginia Seismic Zone" near Mineral, Virginia, approximately 84 miles southwest of Washington, DC. Significant ground motion from this earthquake was experienced throughout the DC metropolitan area and in many states across the eastern portion of the United States. As a result, numerous buildings in the DC area experienced distress resulting from the seismic event, ranging from minor interior finish cracking to major structural damage.

As a precaution following the earthquake, NGS retained a structural engineer to conduct an assessment of the NGS campus. The assessment identified several instances of distress at the NGS Building that were potentially the result of the earthquake or that may have predated the seismic event. Among the distress identified were several cracks in the stacked marble fin panels of the façades. NGS engaged Wiss, Janney, Elstner Associates to further assess the damage to the fin panels in an effort to determine their current stability and any long-term risk associated with damage. NGS also requested recommendations for repair of the fin panels, should they be necessary.

CONSTRUCTION

The NGS building is ten stories in height and rectangular in plan. All four façades of the building are similarly comprised of vertical "fins" made of solid marble panels that extend the height of the building and terminate at the soffit of an overhanging flat roof. The overhang itself is perforated by slots that align with the fins below. Between the fins are sections of glazed aluminum-framed curtainwall with vertically alternating lites of vision and nonvision glass. The ninth and tenth floors are recessed from the building fins, creating a terrace around the entire perimeter. The fins continue to the roofline, supported by concrete-encased steel columns where the façade steps back at the terrace levels (see *Figure 4*). There is a low roof above the lobby level that extends beyond the façade at the base of the building, creating a visual plinth for the tower and an arcade along all four elevations.

The NGS building fins are made of 17 stacked individual panels of solid white marble. The approximate spacing between fins is 63 inches horizontally; every fifth marble panel fin is aligned with a building column in plan. The dimension of each marble panel is approximately 24 inches deep, 88 inches high, and 6 inches wide. In total, the fins consist of approximately 2,244 individual marble panels.

The original drawings indicate the marble fin panels are supported at floor lines by supports consisting of a galvanized steel bar 1½ in. thick by 3 in. wide by 30¾ in. long, with a ½-in.-thick galvanized steel stiffening plate perpendicular to the bottom of the bar, field-welded to an angle embedded in the concrete floor slab (see *Figure 5*). This assembly cantilevers outward to

Figure 4 – Marble fin panels continuing past the ninth-floor terrace.

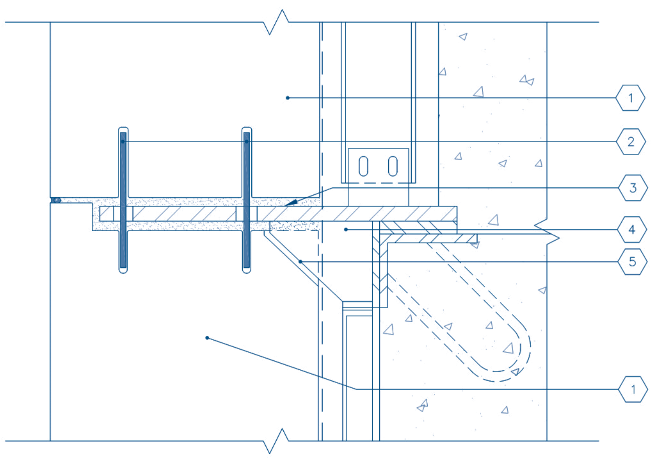

Figure 5 – Section of the marble fin panel at gravity support at floor lines.

KEYNOTES:
1. *Stone panels.*
2. *Steel dowels.*
3. *Bearing joint at stone panels at typical floors.*
4. *Steel-bearing support anchorage for stone panels with holes to accept dowels.*
5. *Slot and rebate in stone panel to accommodate support anchorage bearing plate and stiffener plate.*

support the gravity load of two fin panels. The bar has two 9⁄16-inch-wide by 1¾-in.-long slotted holes cut for the dowels that secure the fin panels above and below to the bar. Two noncorrosive ½-in.-diameter by 1-ft.-long dowels are shown centered in the slotted holes of the steel bar.

The marble fin panel directly below the stiffened bar is rabbeted to receive the bar and slotted to receive the plate; the space around the hardware is filled with mortar. The two marble fin panels at each floor meet at an intermediate joint between the floor lines. They are secured to each other at this joint with two or three steel dowels (depending on location) to create a rigid connection, but there is no attachment back to the structure (see *Figure 6*). The joints between fin panels at both the gravity support and the intermediate connection are filled with mortar, with sealant applied to the outer surface of the joints.

OBSERVATIONS

The façade fins were evaluated using a combination of high-power optics from the ground, roof, terraces, suspended scaffolds, and mobile personnel lifts. Cracks were observed in the marble fin panels at the ninth and tenth floors, typically emanating from the intermediate joints (see *Figure 7*). These cracks aligned with the locations of the dowels that connected the fin panels at the intermediate joints, suggesting that the

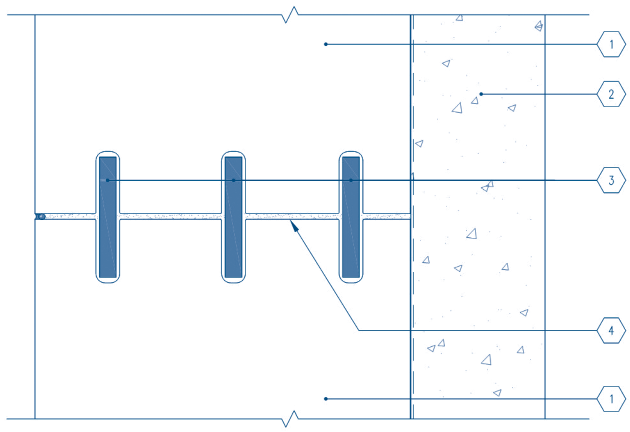

Figure 6 – Section of the marble fin panel intermediate joint between floor lines.

KEYNOTES:
1. *Stone panel.*
2. *Concrete column at the ninth and tenth floors supporting stone panels.*
3. *Steel dowels.*
4. *Mortar joint between stone panels.*

Figure 7 – Vertical crack approximately 4-5 inches in length, emanating from the intermediate marble panel joint at the ninth-floor marble fin panel.

Figure 8 – Rust-colored staining observed at the ninth-floor intermediate joints.

Figure 9 – Corroded dowel exposed by removal of a spall at ninth-floor intermediate joint.

Figure 10 – Removed incipient spall at marble fin panel below the floorline gravity support. The steel bar of the panel support is corroded.

Figure 11 – Cracks and an incipient spall in a marble fin panel above a floorline joint previously repaired with sealant.

Figure 12 – Typical shallow spall observed at the edges of the marble fin panel joints.

dowels were inducing stress in the stone. Also common at the ninth and tenth floors were rust-colored stains above or below the intermediate joints (see *Figure 8*). The staining indicated corrosion of the embedded dowels that could be compromising their capacity. But more importantly, the staining also indicated that the corrosion was present in the space between the dowel and the stone, potentially exerting pressure on the surrounding stone that would lead to cracking, connection failure, and eventual instability of the marble fin panels (see *Figure 9*). The fin panels adjacent to the intermediate joints at the lower floors (eighth floor and below) were largely undamaged, because the dowels used at these connections were composed of a noncorrosive material.

Also of concern was the discovery of significant cracks associated with incipient spalls near the floorline joints between panels at numerous façade fins, particularly at the panels directly below the floorlines (see *Figure 10*). Further close-range inspection was performed at several of these locations, revealing the gravity support connection was corroding. The corrosion was exerting pressure on the side of the rabbet in the stone, causing it to fracture. After identifying this condition, it was discovered that numerous repairs were completed prior to the earthquake, using sealant (see *Figure 11*). Upon further examination, these repairs were also unstable.

Because the joints between the stone panels were solidly filled with mortar, the joints could not accommodate volume change of the panels over time, due to thermal cycling or hysteresis of the marble[1]. The mortar enabled load to transfer between fin panels due to the accumulation of gravity load (stacking pressure), which increased the stress at the edges of the stone where the stone panel was rabbeted and slotted to accommodate the gravity support connection. The increased stress at these edges often led to shallow spalls in the stone near the joints (see *Figure 12*).

THE CHALLENGE

Overall, the marble panels that comprise the vertical fins of the façade were in good condition with minimal erosion, deterioration, or other visible material-related degradation. However, a large number of the panels were cracked, spalled, or otherwise damaged in the vicinity of the panel-to-panel joints, the majority at joints that align with the building floorlines. Major cracks and spalls were observed at fewer of the intermediate joints that fall between the floorlines. Several large fragments of stone were removed from the individual panels during the façade investigation, and numerous new cracks were observed. Previous repairs were also evident at several cracks and incipient spalls; however, these repairs were not successful in stopping progression of the distress or in stabilizing already displaced stone fragments. Over 164 panels (7%) of the fin panels were damaged and in need of repair; these panels were spread throughout the four principal building façades, necessitating repairs around the entire building perimeter.

Conditions at the Floorline Joints

The marble panel damage was largely concentrated at the floorlines where steel structural elements project from the floor slabs to support the weight of the marble panels. The original drawings indicated the support components are mild steel with a galvanized coating, and the dowels are a noncorrosive (though not identified) material. The observations of the gravity support connections clearly indicate that the galvanizing on the steel plate and bar failed or was not present at all, allowing these elements to corrode. The marble panels would have to be repaired by removing the damaged portions of the stone near these connections and then reintegrating the connections into new stone, all while maintaining stability of the undamaged panels above.

Conditions at the Intermediate Joints

At the intermediate panel joints between floors, the marble panels are joined by three large-diameter dowels at the upper floors and two dowels at the lower floors. Damage was largely limited to the ninth and tenth floors where the dowels were severely corroded and damaged the surrounding marble panels. This damage compromised the structural connection between panels and reduced their capacity to resist lateral loads when compared with their as-built condition. The dowel distress observed was limited to the ninth and tenth floors due to a modification of the dowels used at these locations (either in size, material, or position) that made them more prone to corrosion. Repair would require removal of portions of the stone panels that were damaged and replacement of the damaged connection hardware, without removal of the intact panels above and below the damage area.

Panel Joint Conditions

The joints between marble panels that comprise the fins were originally filled with mortar and struck flush with the marble surface. Mortar joints degrade over time due to erosion, shrinkage, and cracking associated with movement of adjacent materials. As a result, mortar allows moisture to pass the joint surface and reach the interior of the joints at an increasing rate over time. As the moisture levels increase, the deterioration of the mortar correspondingly increases as well.

The mortar between marble fin panels had undergone multiple repair efforts. At some point in the past, the original mortar was removed from the joints to varying depths and replaced with a new, harder mortar used to fill the void or "point" the joints. When a hard mortar (in relation to that of the original mortar) is used as a repointing mortar, the harder mortar can cause stress concentrations at the face of the adjacent stone, causing them to chip or spall. Subsequent to the installation of the new mortar, sealant was applied in a thin layer over the mortar. This material is in poor condition, with frequent separations from the stone panels and severe oxidation of the surface (see *Figure 13*). Despite the application of sealant over the mortar, water could continue to reach the underlying steel (either the gravity supports at the floor line joints, or the dowels at the intermediate joints of the ninth and tenth floors), enabling corrosion to develop. It was clear from the condition of the mortar and

Figure 13 – Typical example of deteriorated sealant at a marble fin panel joint. The sealant was thinly applied over the existing mortar.

Figure 14 – Substantial corrosion observed on the steel bar and stiffener plate at the location of a removed incipient spall.

sealant, as well as the stone damage resulting from load transfer through the mortar, that all of the panel joints would have to be addressed in some manner to reduce the accumulated stresses damaging the stone and to limit water from reaching the steel connection hardware.

Corrosion Damage or Seismic Damage?

Detailed examination of this building was initiated by concerns regarding seismic damage of the fins and the appearance of "new" distress. Closer examination of the distress revealed that it was initially caused by corrosion and that much of the damage predated the "Mineral event," as evidenced by the many pre-existing repairs. However, it was likely that the earthquake worsened some of the existing damage or initiated cracking at areas already highly stressed where distress was not yet evident.

The corrosion observed was initiated by exposure of the steel elements to water and oxygen during prolonged periods of wetting and drying, attacking the steel at defects in the galvanizing. The alkalinity of the mortar used in the slot also provides some protection against corrosion; however, over time, the mortar is exposed to atmospheric carbon dioxide (the process of carbonation), which reduces the alkalinity and the mortar's ability to protect the steel.

As time passes, the corrosion of the steel increases, leading to further degradation of the galvanizing and conversion of the base metal to iron oxide. Iron oxide (commonly referred to as rust scale) can occupy many times the volume of the deteriorated base metal. When confined, the iron oxide formation exerts expansive stress on the surrounding material, causing it to spall or crack. At the NGS building, moisture had reached the stone panel gravity support elements through failure of the joint mortar between the marble panels at each floorline. Water was absorbed and retained in the cementitious mortar that fills the rabbet cut into the lower panels to accommodate the steel bar and plate, then was held against the steel with no provisions for drying. Iron oxide that formed on the steel bar and stiffener plate had exerted expansive forces against the portions of the marble that form the rabbet and slot that conceal the steel elements (see *Figure 14*). Once the force exceeded the tensile capacity of the marble, it cracked or spalled, leading to more ingress of moisture and oxygen, thereby accelerating the corrosion process. There was no marble distress evident beyond the extent of the steel bar and stiffener plate because the dowels used as part of the gravity support hardware were noncorrosive as the drawings indicated, and better protected from corrosion than the other elements.

Given that the steel elements comprise the primary support for the marble panels that make up the fins, it was necessary that these elements be fully evaluated, repaired, and protected where stone damage was evident to limit the risk of subsequent stone damage or repair failure. It was also recognized that while the level of corrosion observed at the majority of steel elements does not sufficiently compromise their load-carrying capacity or warrant direct strengthening of the steel elements, the ongoing corrosion would potentially continue to cause distress in the marble panels, as it had for the past several years. A combination of repairs was needed to repair the marble panels where they had fractured, restore the structural integration between the marble panels and the gravity support hardware, re-establish the intermediate joint connections between panels where compromised, and limit future water infiltration into the joints between marble panels to slow the rate of corrosion at gravity support connections and dowels that would remain unrepaired.

THE SOLUTION

Access Limitations

Based on the condition of the marble panels that comprise the fins and the panel joints, comprehensive repairs were recommended to address all currently damaged stone and to address the joint condition between every fin panel. Access to 100% of the fin panels was necessary to address the joints and also to evaluate the soundness of every panel at close range to ensure all damage was identified. But because the stone damage was scattered throughout the four main façades of the NGS building, fixed scaffolding was not an economical option for access. Scaffold platforms could not be used due to ground conditions and the low roof surrounding the façades, so it was determined that the work had to be conducted from suspended scaffolding.

Temporary Support of Undamaged Fin Panels

The fins were constructed by stacking the marble panels from the bottom up, including gravity supports at every other

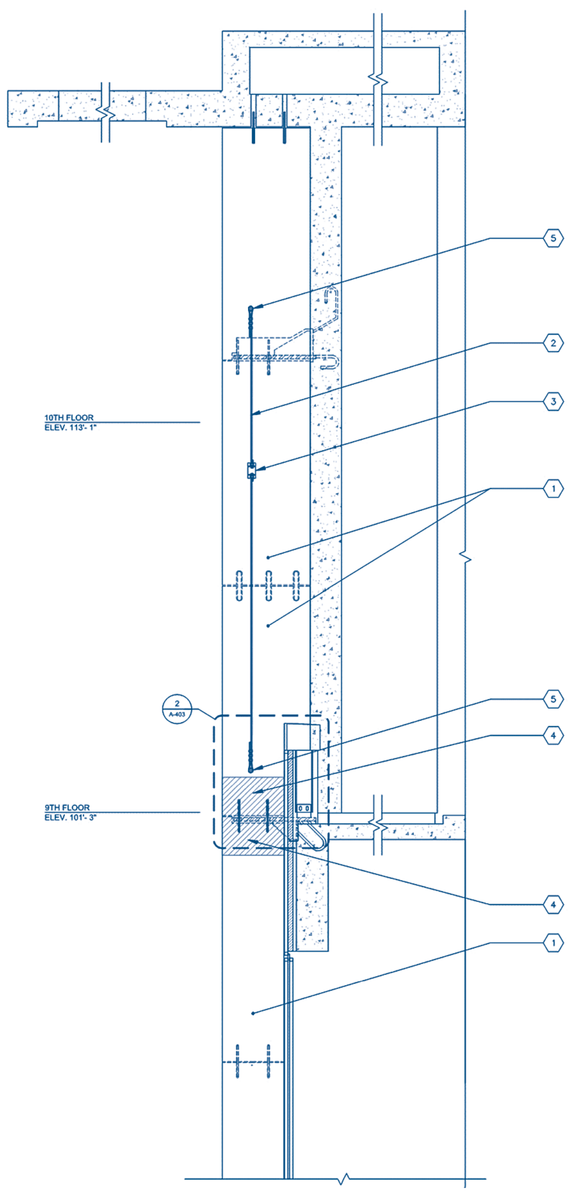

Figure 15 – Conceptual drawing of proposed suspended panel support system.

KEYNOTES:

1. *Marble panels to be supported during work*
2. *Cable or other supporting method*
3. *Tensioning element for cable*
4. *Damaged section of marble fin panel*
5. *Steel bar support dowel through panel to support the panel during suspension*
8. *Additional location for cables or other support methods*

Figure 16A (above) – Custom-built steel support frame installed on both sides of panel and anchored into the concrete column and overhang.

Figure 16B (left) – Trial installation of stone support system, which included a steel frame (Figure 16A), chain, chain hoists, tensioner, and chain anchored to steel dowels installed through the stone.

panel vertically; therefore, to access the panels bearing on the gravity support, the panel above would typically have to be removed. The dowels used at the gravity supports and at the intermediate panel joints to connect the panels vertically were inserted into holes at the top of the panels, then the next panel above was slipped over the protruding dowels. Dowel placement also made removal of at least one panel above a damaged panel necessary in order to perform repairs. Removing an entire fin panel was not a viable option due to the weight limits of suspended scaffolding and also the risk associated with removing and reinstalling the panel intact. Also, due to the geometry of the fin panels, partial depth dutchman repairs were not practical, aesthetically acceptable, or cost-effective. So it was necessary to remove the entire cross section of the fin panel where it was damaged, removing any remaining opportunity to maintain load transfer into the gravity support.

After considering several options such as material hoists, independent gantries, and other methods of removing the panels needed to effect the repairs, a novel concept was developed in which the undamaged panel supported by a damaged panel would be temporarily supported by the next highest gravity support connection. The undamaged panel could be "suspended" from the panel above the gravity support, transferring its weight to the gravity support above, allowing work to be performed on the damaged panel below (see *Figure 15*). Structural calculations of the gravity support connection demonstrated that there was sufficient capacity for the connection to temporarily carry the additional panel weight (a 50% increase in dead load).

Trial repairs were conducted to confirm the stone suspension system would perform; however, the contractor requested that the marble fin panels above the damaged fin panel be suspended from the exposed columns at the ninth floor, due to concerns that stacking pressure had accumulated over the fin height that could overwhelm the single gravity support being loaded once the damaged section of fin panel was removed. The change was agreed to, and the work proceeded (see *Figure 16*). Chains were suspended from the columns at the tenth floor and secured to a pipe section that was installed through the fin panel to be supported. The ultimate capacity of the assembly exceeded the weight of an entire fin. Load cells in line with the chains on either side of the fin monitored tension applied through turnbuckles, allowing the load to be equalized. Once the pre-tension load equaled the weight of the fin panel being supported, the damaged portion of the stone below was safely removed with no deflection.

Repair Damaged Portion of Marble Fin Panels at Floorline Joints

Once it was determined that the unsupported panels could be safely suspended, work began on the damaged panels below. The damaged section of the marble fin panels above and below the gravity support was removed in its entirety. The exposed connection hardware was inspected, and surface corrosion was removed. A corrosion-inhibiting coating was then applied over all the exposed steel. New pieces of stone cut to match the existing void were installed using new stainless steel dowels to connect the new stone panel sections to the remaining sections and to the gravity support (see *Figure 17*). The new stone was fabricated to accommodate the gravity support components, similar to the original stone panels. The new stone joints were filled with mortar, raked back, and filled with sealant to reduce stress on the outer edges of the panels.

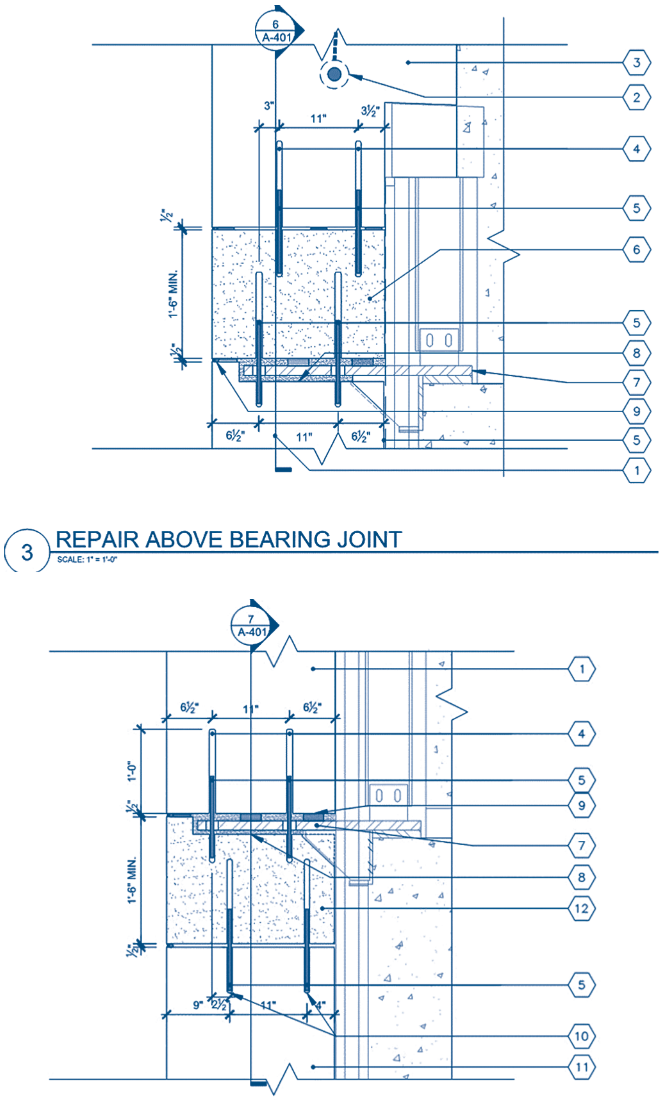

Figure 17 – Repair details for stone panel section replacement above and below the bearing support.

KEYNOTES:

1. *Stone panel to be inspected to determine required repairs*
2. *Suspended panel support system (Figures 15 and 16)*
3. *Stone panel with damage above bearing*
4. *Holes to be drilled into stone to remain*
5. *New dowels inserted into new holes*
6. *New stone panel Dutchman to match*
7. *Steel bearing support anchorage of panels*
8. *Slot and rebate in existing stone panel*
9. *Bearing joint at stone panels. Fill with mortar.*
10. *Drill new holes into existing stone.*
11. *Stone panel damaged below bearing*
12. *New stone panel Dutchman*

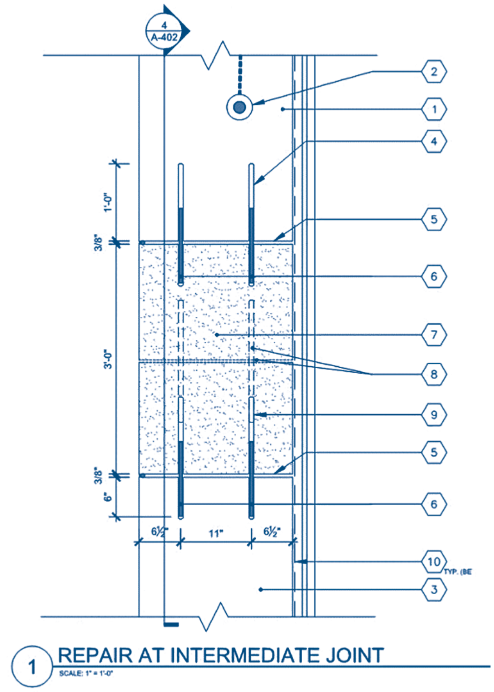

Figure 18 – Repair details for stone panel replacement at intermediate joint.

KEYNOTES:

1. *Stone panel with damage above joint*
2. *Suspended panel support system (Figures 15 and 16)*
3. *Stone panel with damage below joint*
4. *Holes to be drilled into stone to remain*
5. *New intermediate joints, filled with mortar*
6. *New dowels into new holes in existing stone*
7. *New stone panel Dutchman*
8. *Existing intermediate joint and dowels*
9. *New holes into new Dutchman*
10. *Replace deteriorated sealant.*

Repair Damaged Portion of Marble Fin Panels Adjacent to Intermediate Joints

A similar repair approach was performed at the intermediate joints. Once the panels above were supported, the damaged sections of marble fin panels were removed above and below the intermediate joints, along with the corroded or otherwise damaged dowels. A new single piece of stone cut to match the existing void was installed using new stainless steel dowels to connect the new stone panel section to the remaining sections above and below (see *Figure 18*). The new stone joints were filled with mortar, raked back, and filled with sealant to reduce stress on the outer edges of the panels.

Figure 19 – Completed repair of damaged marble fin panels at a floorline joint (gravity support).

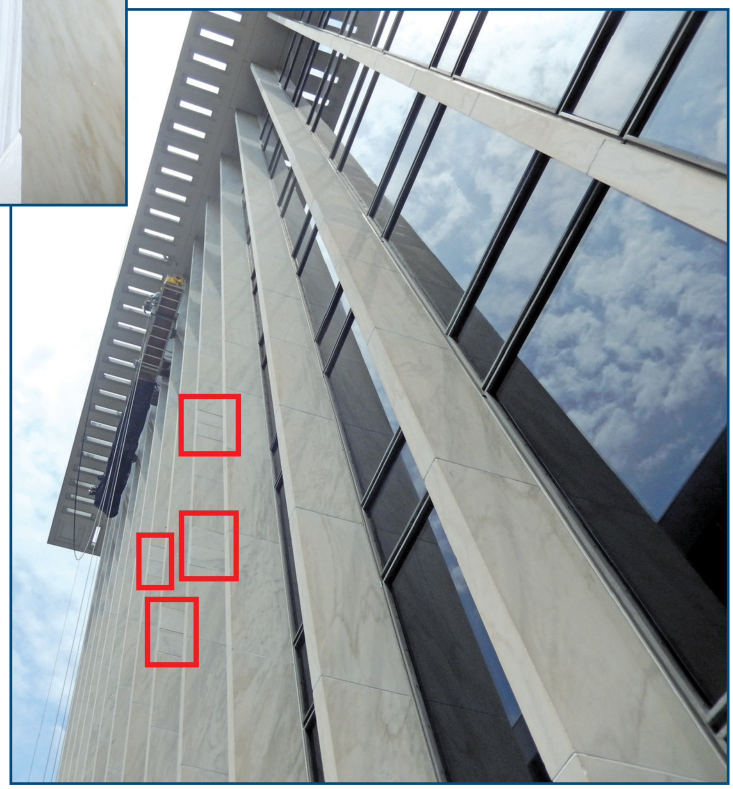

Figure 20 – Completed repairs of damaged marble fin panels at floorline and intermediate joints.

Replace All Joint Sealant

The mortar and sealant from all fin panel joints was removed to a depth of ¾ in. and then filled with sealant to reduce stress at the panel edges and to limit the potential for water to reach the concealed steel elements within the stone.

Monitor Marble Fin Panel Conditions

Because not all of the gravity supports could be inspected for corrosion, the marble panels of the vertical building fins will be inspected periodically by NGS staff familiar with the repairs performed to determine if any new damage occurs due to corrosion of either the gravity support hardware at the floorlines or the dowels at intermediate joints. If additional damage is observed as part of a subsequent inspection, they will contact a consultant familiar with the stone conditions and perform any necessary measures to make the building safe.

SUMMARY

The architectural style of the NGS building clearly places it in a class of post-modern architecture that was popular in the late 20th century and was repeated in other projects by Edward Stone and his contemporaries. While they are stylistically striking, the geometry and construction of the marble fins at the NGS building make them difficult to repair discretely. Faced with necessary repairs, an innovative means was needed to address the stone panel damage without added cost and risk associated with more comprehensive stone panel removal or deconstruction of the fins.

Collaboration between the design and construction team resulted in an efficient and cost-effective repair approach that utilized only suspended scaffolding and that is readily repeatable, should additional damage to the fin panels occur in the future. The resulting repairs are structurally sound, minimize loss of original material, restore the original load path for the fins, and are discreet in appearance (see *Figures 19* and *20*). Ultimately, the procedures developed for this project struck a desirable balance between essential repairs and pre-emptive intervention.

REFERENCES

1. Hysteresis is a phenomenon that affects certain "true" marbles. Unlike most stones, which return to their original volume after exposure to higher or lower temperatures, these marbles show small permanent increases in volume after each thermal cycle. This can result in differential expansion within the stone, which is more likely to be accommodated or restrained in thick veneers than in thin ones. If it is not restrained, bowing (and strength loss) of the marble panels ensues. Bowing also stretches the face, which makes stones more porous and increases their vulnerability to corrosion from acids in the atmosphere and deterioration from freezing and thawing effects. If marbles with this tendency are selected, research should be performed to determine the minimum thickness needed to overcome effects of hysteresis. *Ref: Vertical Surfaces, Dimension Stone Design Manual, Version VIII (May 2016), Marble Institute of America.*

NOTES