Hurricane Coastline:
Lessons Learned During Sliding Glass Door Replacement and Concrete Balcony Repairs

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Abstract

During an initial investigation of a 12-story condominium building, general conditions of the sliding-glass doors and concrete balconies revealed that they were in various states of deterioration and corrosion such that sliding-glass door replacement and concrete balcony repairs were considered to be necessary. The ongoing multiphase project also included new structural framing, new exterior cladding, concrete balcony re-sloping, and new waterproofing. The new sliding glass doors were water-tested in accordance with industry standards. However, unforeseen obstacles were experienced during the repair project and water testing that revealed the need for additional engineering and waterproofing research.

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INTRODUCTION

Coastal environments are considered some of the harshest conditions to which a building can be subjected. Over time, the combination of salt, humidity, and wind can significantly decrease the service life of important building envelope components. For example, aluminum-framed sliding glass doors exposed to these coastal conditions are prone to have a decrease in serviceable life. Even though typical maintenance will prolong the longevity of such building envelope components, it can be expected that these components will have to be replaced at some point.

Since the early 1980s, a 12-story oceanfront condominium building has been subjected to the harsh coastal environment of South Carolina. During a preliminary investigation of the building, general conditions of the aluminum-framed sliding glass doors and exterior concrete balconies revealed that they were in various states of deterioration and corrosion such that sliding glass door replacement and concrete balcony repairs was considered necessary.

The ongoing multi-phase project included the removal and replacement of all of the sliding glass door units, installation of new light-gauge metal framing, repairs and resloping to the concrete balconies, installation of new waterproofing on the concrete balconies, and installation of new stucco cladding. Additionally, several of the new sliding glass doors were water-tested in accordance with industry standards. Unforeseen obstacles were experienced during the project that revealed the need for additional engineering and waterproofing research. This paper will present this as a case study, discussing the technical highlights of the first phase of this project and identifying the issues experienced during the building project.

PRELIMINARY INVESTIGATION

The subject property includes two oceanfront condominium buildings. The Phase 1 building was constructed in 1986 and is 12 stories high, while the Phase 2 building was constructed shortly after and is nine stories high. Both of the buildings are supported by reinforced concrete foundations. The structural skeleton of the buildings is constructed with elevated reinforced concrete slabs and reinforced concrete columns. The exterior walls of both buildings include light-gauge steel infill framing that is covered by a combination of conventional stucco and brick veneer. The roofs of the buildings are low-slope configurations that are covered with a single-ply membrane.

Preliminary investigation of the subject property began with the Phase 1 building. This building is divided into two sections: the condominium units on the oceanfront elevation, and the hotel units. Each floor on the condominium side consists of three individual units that include an exterior cantilevered reinforced concrete balcony on the oceanfront elevation (see Figure 1). With the exception of the south elevation units, each unit has two sliding glass door units, which provide access to the exterior balcony from the living room and master bedroom areas. The south elevation units have an additional smaller cantilevered reinforced concrete balcony accessed from a bedroom area (see Figure 2). Each floor on the hotel...
side consists of eight individual units with a sliding glass door unit leading to a concrete balcony.

During the preliminary investigation of the Phase 1 building, the sliding glass doors and exterior concrete balconies’ assessment revealed that they were in various states of deterioration and corrosion. Specifically, the sliding glass door units were observed to show signs of distress and limited remaining service life due to the extent of gaps in the framing components (see Figure 3), the extent of gasket failure between the framing and glazing components (see Figure 4), and compromised waterproofing conditions.

The extent of corrosion observed on the framing components of the sliding glass doors varied significantly. Additionally, evi-
dence of modifications, repairs, and physical damage was observed on the framing components. Figure 5 and Figure 6 show significant corrosion and deterioration of the framing components at the bottom of the operable slider and sliding glass door threshold.

The concrete surface of the exterior balconies was observed to be spalling adjacent to several of the sliding glass door units. Additionally, localized areas of concrete cracking and/or delamination were observed.

**RECOMMENDED SCOPE OF REPAIR**

Based on the preliminary investigation of the Phase 1 building, it was evident that the sliding glass door units were at the end of their service life, and repairs were necessary. The recommended scope of repair included the complete removal and replacement of the sliding glass door units and localized repair to the exterior concrete balconies. The repair would include the removal and installation of new light-gauge metal framing, corrective sloping of the exterior concrete balconies to drain, installation of a new waterproofing membrane on the exterior concrete balconies, and the localized installation of new stucco cladding. Additionally, approximately 10% of the new sliding glass doors would be subjected to water penetration testing.

Several factors were considered when deciding how the repair project would be broken down between the Phase 1 and Phase 2 buildings. Since neither the Phase 1 nor the Phase 2 building could be completely closed during repairs, the repair project would be divided into three phases. The first and second phases would consist of repairs to the condominium units and hotel units, respectively, on the Phase 1 building. The third phase would consist of repairs to the Phase 2 building. Repairs would be performed three floors at a time during the winter season to minimize full-time resident disturbance and financial impact. As repairs are currently ongoing, this paper will focus on the first phase of the repair project.
REPAIR DESIGN AND DETAILING

The design of the Phase 1 building was based on the applicable building code at the time of original construction. Since that time, the building codes have continued to progress and change due to construction practices and engineering research. Therefore, the design for the first phase of the repair project would be based on the 2012 International Building Code (2012 IBC), code-referenced standards, and manufacturers’ installation instructions.

Since the original sliding glass door units were being replaced, the engineering design consisted of coordination between the project engineer, sliding glass door manufacturer, and general contractor. The project engineers provided the sliding glass door manufacturer with the code-prescribed wind pressures that the new sliding glass doors would have to resist. Additionally, the project engineers also provided details to the general contractor regarding the new light-gauge metal framing, which was installed to transfer the code-prescribed wind pressures from the sliding glass doors to the reinforced concrete slabs.

The original sliding glass door units in the condominiums consisted of a combination of two fixed/one operable door (i.e., OXO configuration) and one fixed/one operable door (i.e., OX configuration). Additionally, the original sliding glass doors were non-full height (i.e., not slab-to-slab) at an opening size of 10 x 8 ft.

During design discussions with the homeowners’ association, it was decided that the new oceanfront sliding glass doors would be full height (i.e., slab-to-slab), and the remaining sliding glass doors would be the original size of the existing sliding glass doors. The opening size for the new full-height sliding glass doors was 10 x 10 ft.

Changes to the original-size oceanfront sliding glass doors consisted of simply designing the vertical jambs along each sliding glass door since the new sliding glass door would be anchored directly to the reinforced concrete slab at the top and bottom. A new light-gauge metal header was also designed for the new sliding glass doors that would remain at the original size (i.e., non-full height).

The concrete adjacent to several of the original sliding glass door units was observed to be spalling and cracked. The project engineers worked with the general contractors to come up with a design that incorporated a new waterproofing membrane with the new sliding glass doors. Many of the original sliding glass door thresholds were installed on shallow concrete curbs or on the surface of the original concrete balconies. This original design/detail was considered undesirable due to the vulnerability of water intrusion around the sliding glass door. Therefore, a new raised concrete curb would be constructed that would incorporate the new waterproofing membrane and provide support for the new sliding glass door. Figure 7 illustrates the new concrete curb and waterproofing details.

As shown above in Figure 7, a new concrete curb would be constructed to support the new sliding glass doors. A cant strip was installed at the transition from the horizontal concrete balcony surface to the vertical concrete curb surface. The waterproofing membrane was installed on the concrete balcony surface and continued onto the concrete curb.

As previously stated, approximately 10% of the new sliding glass doors were subjected to water penetration testing. It should be noted that the new sliding glass doors were not tested for air resistance. The water penetration testing would be performed in general accordance with ASTM E-1105, Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cycle Static Air Pressure Difference and
Due to the location and functionality of the Phase 1 building, the coordination and execution of the first phase of the repair project would be performed during the winter months. Additionally, since all 12 floors could not be completely closed at the same time, the first phase was broken down into four groups of three floors; each group included nine condominium units. Repairs would commence at the top group (12th floor through 10th floor) and continue forward with each group section (9th floor through 7th floor, 6th floor through 4th floor, and 3rd floor through 1st floor) until completion. In order to complete the repair project on schedule, each floor group had to be completed within three to four weeks. The work to be completed for each floor group included the following:

- Grinding of concrete balconies
- Removal of existing sliding glass doors and components
- Repair of concrete balconies
- Installation of new concrete curb
- Installation of new light-gauge metal framing
- Installation of new exterior stucco cladding
- Installation of new sliding glass doors and waterproofing
- If applicable, water penetration testing of new sliding glass doors
- Cleaning of condominium units to preconstruction conditions

**Grinding and Repair of Concrete Balconies**

The repair project began with the grinding and repair of the exterior concrete balconies. Unlike current building codes and standards, the applicable building code at the time of original construction did not provide exterior concrete balcony slope requirements. Though drainage scuppers were installed at the outboard edge of the balconies, evidence of water ponding was observed on the balconies. For new construction, accepted industry standards and typical waterproofing manufacturer’s installation instructions require a minimum 1/8-in.-per-ft. slope-to-drain for balconies over a nonhabitable space. The repair project did not specify the installation of a new overlayment to provide adequate slope for drainage purposes, and the concrete balconies were ground in localized areas to assist with drainage. Additionally, since carpet was installed on the concrete balconies of several condominium units, grinding would remove any glue or impurities that otherwise would not allow the new waterproofing membrane to properly adhere to the concrete balconies.

Localized areas adjacent to several of the sliding glass door locations required repair. The majority of issues adjacent to the sliding glass door locations consisted of spalling and cracking of the concrete balcony from long-term water intrusion. In a few localized areas, the steel rebar was observed to be corroded; therefore, the exposed steel rebar was ground and treated with a corrosion inhibitor to prevent any further deterioration. After loose or broken pieces of concrete were removed from the spalled and cracked areas, a concrete rehabilitation repair mortar was used to patch the areas and provide a uniform and sloped surface (see Figure 8).

**Installation of New Concrete Curb**

Following the concrete balcony grinding and repair work, a new concrete curb was poured. Additionally, the new concrete curb...
would allow the installation of the cant strip to provide proper integration of the new waterproofing membrane (see Figure 7). When the concrete curb had properly cured, a urethane waterproofing membrane was installed from the top surface of the concrete balcony and past the interior face of where the new sliding glass door would be installed.

Installation of New Light-Gauge Metal Framing

The new sliding glass doors and metal framing were designed to resist the 2012 IBC wind loads. The new metal framing (i.e., jambs and headers) for the sliding glass doors consisted of 18 light-gauge metal studs and tracks. For example, the design pressure rating for the sliding glass doors at the twelfth floor was DP 100. Therefore, after the new sliding glass doors received the code-prescribed 100-psf wind pressure, the new metal framing has to transfer that load to the adjacent reinforced concrete slabs.

Due to the large wind pressures, the metal framing (i.e., jambs and headers) of the new sliding glass door units would consist of several framing members. The full-height metal framing configuration is shown in Figure 9, while the non-full-height metal framing configuration is shown in Figure 10.

For example, the metal built-up jamb framing at the 12th floor consisted of two studs and two tracks. Likewise, the built-up header framing consisted of three jambs and three tracks. A structural metal connector was installed to attach the built-up jamb framing to the reinforced concrete slabs. A similar-type connector was used for the attachment of the built-up header to the built-up jamb framing.

Once the metal framing was complete and the concrete curb was properly cured, the sliding glass door units could be installed. Before the sliding glass door units were installed, the door subcontractor had to install a metal subheader and sub-sill. Due to the large code-prescribed wind pressures, the subheader and sub-sill act as a stiffener to allow proper load transfer from the sliding glass door to the reinforced concrete slabs and metal framing. The new sliding glass doors are simply “snapped” into the subheader and sub-sill, which are connected to the reinforced concrete slabs (for the full-height units) and metal built-up header (for the non-full-height units). Figure 10 shows a non-full-height opening (on right) and full-height opening (on left) with the subheader and sub-sill installed.

Installation of New Sliding Glass Doors and Waterproofing Membrane

The final stage in the repair project was the installation of the new sliding glass doors and waterproofing membrane. The new sliding glass doors were simply “snapped” into the subheader and sub-sill. Additionally, the jambs of the sliding glass doors were attached to the metal built-up jambs. The new sliding glass doors were properly sealed with engineered sealant joints around the perimeter. Lastly, the liquid-applied waterproofing membrane was...
installed. The waterproofing membrane consisted of small aggregate that provides slip resistance and keeps the concrete balcony surface cooler.

**WATER PENETRATION TESTING**

Due to the magnitude of the repair project, it was imperative that the new sliding glass doors be tested in place to replicate the harsh coastal environment. As the subject building is located on a hurricane-prone coastline, the new sliding glass doors would very likely be subject to hurricane-force wind speeds and wind-driven rain during its serviceable life. One of the best ways to subject the new sliding glass doors to these conditions is to perform an in-situ water penetration test to simulate these conditions.

During the repair project, ten new sliding glass doors were water-tested. The water penetration testing was performed in accordance with ASTM E-1105, *Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cycle Static Air Pressure Difference*, and AAMA 502, *Voluntary Specification for Field Testing of Windows and Sliding Glass Doors*.

To simulate a high wind-driven rain event, the laws of thermodynamics are used to draw exterior air and water toward the interior. Specifically, since pressure will always flow from high pressure to low pressure, an internal vacuum (i.e., low pressure) is created to force air from the exterior (i.e., high pressure) toward the interior. The simplest way to create this condition is to construct a frame around the interior perimeter of the sliding glass door and install a vacuum to draw the air out (see Figure 11). This method simulates a pressure differential by equilibrating the interior air pressure to a high-wind event. Additionally, a grid of water spray nozzles was constructed on the exterior side of the sliding glass doors to simulate rain (see Figure 12). The combination of the spray nozzles and interior pressures created the conditions of a high wind-driven rain event.

The interior chamber used during the repair project was constructed from structural wood framing and sealed with duct tape to prevent any air leakage. Clear heavy-duty plastic was installed on the interior face of the chamber to allow for water penetration observations. The water spray rack was constructed from PVC pipe and copper spray nozzles. Based on the above-referenced industry standards, the new sliding glass doors would be subjected to a constant water spray of 5.0 gallons per feet squared per hour (gal./ft²/h) and a static vacuum air pressure for 15 minutes. The static vacuum air pressure was based on the design pressure rating of the sliding glass doors. Therefore, the static vacuum air pressure at the 12th floor for a DP 100 sliding glass door is 1.92 inches of water column, or ten pounds per square foot (10 psf).

**THE UNFORESEEN OBSTACLES DURING REPAIRS**

In a perfect construction world, all of the contracting trades would work in harmony and construct an effortless structure with no imperfections or issues. However, in the real world, whether it is new construction or repair of an existing structure, this is never the case, and technical issues will arise. During the course of the repair project, several technical issues and unforeseen
obstacles were experienced that required additional engineering and drew on the expertise of the project engineers.

**Light-Gauge Metal Framing Modifications**

With any type of construction, it is always good practice to “measure twice, cut once.” During the preconstruction phase of the repair project, all of the existing sliding glass doors were field-measured for exact dimensions. On paper, it seemed the new sliding glass doors would fit into the existing openings. However, as the repair project progressed, it became evident that several structural reinforced concrete columns were not in the exact location as depicted on the original construction plans.

The depth of the new sliding glass doors increased from approximately four inches to six inches, but the length of the new sliding glass doors remained the same. Additionally, the number of light-gauge metal framing members increased at the jambs and headers of the new sliding glass doors. Though it appeared on the original construction plans that new built-up jambs would fit into the existing openings, this was not the case at several locations. Specifically, due to the location of the existing structural column, the built-up jambs had to be redesigned or completely omitted.

At some locations, we were able to omit the built-up jambs because the existing structural column was close enough such that the new sliding glass door could be directly attached. At locations with headers, the connection hardware could still be used; however, the fasteners had to be changed to be compatible with the reinforced concrete columns (see Figure 13).

At other locations, the required number of light-gauge metal framing members would not fit between the location of the new sliding glass door and existing reinforced concrete column. At these locations, only a few framing members that would fit the new sliding glass doors were then attached directly to the existing reinforced concrete column. The fasteners used were driven through the few metal framing members, with the metal framing members acting as a filler between the new sliding glass door and existing reinforced concrete column.

**Issues During Water Testing**

Water penetration testing is a method to observe whether or not a fenestration product (i.e., windows or doors) was properly installed to prevent water from entering the building. However, if a fenestration product does fail (i.e., allows water intrusion), then the water leak must be traced back to its origin to determine a proper repair.

During the water penetration testing for the repair project, ten new sliding glass doors were tested over the duration of the repair project as groups of floors were completed. Unfortunately, three of the ten sliding glass doors failed the water penetration testing.

During the first water penetration test, water appeared at the wall-to-floor intersection, adjacent to the right jamb of the sliding glass door (see Figure 14).
glass door. The observed water intrusion was caused by a crack/void in the exterior stucco cladding in the same area as the failed location. It should be noted that the new sliding glass door was not isolated from the exterior cladding. Since the intent was to test the installation of the sliding glass door only, subsequent water penetration testing would involve isolating the sliding glass door with clear plastic.

Of the remaining sliding glass doors to be tested, two additional sliding glass doors failed during water penetration testing. The failure mechanism of both sliding glass doors was observed to be similar. Specifically, water was observed to come up and over the back dam of the threshold at the intersection of the fixed panel and operable panel (i.e., sliding door). The operable door was removed so that the area where the water penetration was observed could be inspected. Upon inspection, a pinhole void in the field-applied concealed sealant joint was observed at the intersection (see Figure 14).

It was determined that the sealant had not had sufficient time to set prior to normal construction traffic pressure being applied to the threshold. It should be noted that unlike the water penetration testing, the pressure differential from the exterior to the interior and volume of water experienced during a high wind-driven rain event (i.e., hurricane) are not constant over an extended duration. Therefore, the author believes that it would be very unlikely that the failed sliding glass doors would fail under a high wind-driven rain event.

Issues With Waterproofing Membrane

The repairs to the cantilevered exterior concrete balconies consisted of localized repairs and grinding of the surface to assist with drainage. After the localized repairs and grinding were completed, a new waterproofing membrane was installed to protect the concrete balconies and assist with keeping water from entering the interior of the subject building. The new waterproofing membrane installed on the exterior concrete balconies was a two-part water-based epoxy primer/sealer that included an aggregate textured finish. The textured finish provided a slip-resistant surface and additional cooling during hot, sunny days. The new waterproofing membrane is marketed to be insensitive to humid conditions, therefore making it a suitable product in a coastal environment. Since the repair project was being performed during the winter months, the environmental conditions had to be suitable before the new waterproofing membrane could be installed (i.e., minimum temperatures, excess moisture conditions, proper curing). However, a few issues occurred during the installation of the new waterproofing membranes that had to be corrected.

The installation schedule of the waterproofing membrane was modified several times during the repair project because of weather. Due to the timing of subsequent weather events, curing problems in the waterproofing membrane occurred. Specifically, the localized areas of the waterproofing membrane did not have adequate time to properly cure from temperature and rain events. Therefore, many of the concrete balconies were recoated with a finishing layer to provide a uniform product.

Several months after the installation of the new waterproofing membrane, small voids or pinholes were observed at localized areas on the finishing layer of several concrete balconies. The initial prognosis was that either moisture off-gassing or pockets left from dislodged aggregate particles caused the imperfections (see Figure 15).

After further investigation among the project engineers, general contractor, and manufacturer representative, it was observed that the small voids did not penetrate through the base layer of the waterproofing membrane. Though the likely cause of the small voids may be from off-gassing (from excess moisture), the base layer of the waterproofing membrane was not damaged.

LESSONS LEARNED DURING REPAIR PROJECT

Regardless of the type or size of the construction project, there are always takeaways that can be applied to the next one. This repair project was no different. Several takeaways are being implemented into the next phases of the repair project, and others are being improved. Though there were several technical issues identified during the repair project, there were other lessons learned from a construction administration viewpoint. Many of the key lessons learned during the first phase of this repair project are outlined below.

Technical Lessons

- Perform a more comprehensive survey to verify existing conditions. During our preliminary investigation, a comprehensive survey was performed of the existing conditions for the sliding glass doors and concrete balconies, but not of other items, such as the location of reinforced concrete columns. The verification of the reinforced concrete column may have saved some time and engineering during the course of the repair project.
- Be able to adjust and redesign engineering components during repairs. On paper, it appeared that there would not be an issue with the new light-gauge metal framing. However, when the issue with the reinforced concrete column was encountered, the repair project could not be stopped to come up with a solution. Therefore, the project engineers had to rapidly come up with an adequate solution that would not delay the repair project.
- Identify and correct water intrusion during water penetration testing. Having a new sliding glass door fail the first water penetration test may have been expected. Conversely, having two additional sliding glass doors fail was definitely not expected. After each failed water penetration test, we were able to identify the cause and determine if a

Figure 15 – Small voids in waterproofing membrane.
repair was considered necessary.

• **Investigate potential issues with the new waterproofing membrane.** Several issues were experienced—either during the repair project or after completion. After correctly identifying the problem, whether from curing issues or post-installation voids in finishing layer, we relied upon research and experience to determine if repairs were required.

• **Work with the general contractor.** When general contractors work on similar projects over time, they figure out what products and methods work best for them. This repair project was no different. After the initial project plans were sent out, the general contractor requested a few minor changes to the connection hardware. Therefore, the project engineers researched and reviewed the requests to determine if those products could be used.

**Construction Administration Lessons**

• **Work with homeowners.** Though the majority of the condominium units at the subject property were rented out to vacationers during peak months, there are some residents who live at the subject property full-time. These people had to be temporarily relocated until repairs were completed in the units. Fortunately, the subject property is large enough such that those people could be easily relocated. Additionally, those full-time residents were able to observe the progression and completion of repairs.

• **Work with homeowners, again.** Though the majority of the homeowners were in favor of the repair project, some homeowners were not. Therefore, the project engineers, homeowners’ association, and project management worked with those individuals to come up with acceptable solutions.

• **Coordinate with all the different parties.** Due to all of the parties involved and the rapid pace of the repair project, weekly conference calls were started to keep everyone informed and to discuss any potential issues. Though at times there were not many items to discuss, the conference calls became especially convenient during periods when scheduling water penetration testing and to keep all parties informed.

• **Share project information.** Early on in the repair project, much of the project information was being shared via email with all parties. However, this process became cumbersome and difficult due to the volume of project information that was being shared. Therefore, a project website was setup in the virtual “cloud” that would allow all of the parties to access the project information.

**CONCLUSIONS**

Through the duration of the first phase of a multi-phase repair project, several unforeseen technical obstacles and construction administration issues were experienced that required additional engineering, research, and problem-solving. Since the repair project is located on a hurricane-prone coastline, the products used had to withstand the harsh environmental conditions over a long period of time, in addition to the wind pressures produced during hurricanes. It was proven during the repair project that not everything on paper goes according to plan. Ultimately, having the ability and experience to adjust and redesign components in a short amount of time was crucial to keep the project progressing. The lessons learned during the repair project have been valuable in that many aspects can be used for the remaining phases of the project and for future projects. The ability to work with different parties (i.e., engineers, contractors, management, and homeowners) is critical with regard to sharing project information, problem-solving, and meeting project deadlines while attaining appropriate customer satisfaction.