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ASSESSMENT AND REPAIR OF EXTERIOR FACADES

Common problems in exterior facades include water infiltration, lack of proper details to accommodate volumetric changes of the façade materials and to accommodate differential movement between facade elements and the building structural system, improperly designed or built connections, deterioration of anchors and connections, material flaws and durability, and use of thinner than traditional wall systems. Safety issues during the assessment and repairs are briefly described. Methods and examples of repairs for brick masonry, granite, limestone and concrete facades are presented. Examples of retrofit of the precast concrete facade panel connections and recladding of building facades are shown.

Keywords: exterior facades, facade panels, granite, limestone, brick, concrete

1. INTRODUCTION

Common problems in exterior facades include water leakage, condensation at the interior of the building, cracking, displacement, fracturing, bowing and/or dislocation of facade elements.

Claddings on modern multi-story buildings usually include a combination of various materials. They include aluminum, concrete (cast-in-place, precast walls, panels), glass, masonry, mortar (joints), sealant (joints), steel and stone (granite, limestone, marble). Most of the older building facades were built by with brick masonry, terra cotta, granite and limestone. Unlike the floor structure of the building which is usually never exposed to its full design live load, cladding on buildings will most likely be exposed to the wind load, rain, and temperature ranges for which they were designed. Consequently, the cladding on a multi-story building has a greater potential to fail if it is not properly designed or constructed to meet design conditions.

The major causes of problems and failures in exterior facades include:

- Inadequate provisions for prevention of water leakage into the interior of the building
- Lack of proper details to accommodate volumetric changes of the facade materials

- Lack of proper details to accommodate differential movement between the facade and the building structure
- Improper connections and improper construction methods
- Material flaws and durability
- Use of thinner than traditional wall systems

Sometimes, corrosion of metal elements embedded in the cladding system can present a problem. Several examples of facade problems are shown in Figures 1 and 2.

Figure 1. Moisture expansion of brick

Figure 2. Bowed marble panel due to confined permanent expansion

2. SAFETY ISSUES IN FACADE REPAIRS

During the assessment of conditions and repair of exterior facades, access and personal safety were major issues. To access the facade, there is a need to install a suspended scaffold system which needs to be properly supported at the top of the building (Figures 3 and 4). In addition to the support, the scaffold needs to be tied to a different point at the building in case of failure of the supports. Special safety requirements exist for personal safety which includes a personal safety harness which is tied to a safety line tied to a different part at the building than the lines for the scaffold.

In the course of the investigation and repair, additional safety issues can arise. They can include finding cracks or expensive spalls that indicate structural distress in elements of the facade. That may require installing shoring before proceeding with a repair program (Figure 5).

Figure 3. Suspended scaffolds on the side of the building

Figure 4. Supports for suspended scaffold

Figure 5. Severely deteriorated balcony requires shoring

3. BRICK MASONRY CLADDING

Brick masonry cladding is usually installed over the building's concrete and steel framing with common brick masonry backing. Corrodible metal shelf angles and window and door steel lintels were used as a support for brick cladding. Moisture intrusion behind the brick masonry cladding have caused the corrosion of steel shelf and lintel angles. Cracking, spalling of brick masonry, as well as bowing out of sections brick clad walls above window openings and at parapet walls were common distress due to corrosion of embedded steel.

Staining in a form of efflorescence, atmospheric deposits, staining from various causes, and other contaminants are often present at the exterior walls, and façade cleaning is usually part of the restoration project in order to improve the appearance of the building.

3.1 TYPES OF DISTRESS IN BRICK MASONRY CLADDING

The most common distress observed at the exterior walls clad with brick masonry consists of deteriorated mortar joints; spalled brick and bowed out wall sections due to corrosion of embedded steel shelf angles and steel window and door lintels (Figure 6); cracks observed at building corners, and sections of walls that cannot accommodate movements; displaced wall sections due to inadequate or missing anchorage to the backing wall; deteriorated sealant in expansion joints; soiled walls; freeze-thaw damaged brick and deteriorated bricks due to applied unbreathable paint coatings over them.

Figure 6. Distressed section of brick masonry wall before and after removal of brick to expose corroded embedded steel lintel

In most of the cases during the investigation work, it is challenging to determine the condition of the embedded steel angles. The best practice would be to make exploratory openings during that time. The openings should be made in several distressed areas to determine the extent and severity of deterioration. This will ultimately determine the repair approach.

3.2 TYPES OF REPAIRS IN BRICK MASONRY CLADDING

Repointing of mortar joints: includes grinding out deteriorated or cracked mortar joints, and installation of new mortar in order to prevent water infiltration into the building; replacement of damaged brick with new; installation of repair anchors to stabilize/secure the movement of displaced section of the brick wall; and repair/replacement of shelf angle/lintel includes removal of brick above the shelf angle/lintel as needed to expose the corroded portion of the embedded steel and repair/replace it based on percentage of section loss (Figure 7).

Additional type of repairs include resealing / repointing of crack; creating a new expansion joint; as repaired facade may also be cleaned. The type of cleaning solution to be used will depend on condition of brick, level of soil, efflorescence staining, atmospheric deposits, and other contaminants.

Figure 7. Repaired steel lintel with installed flashing over it

4. STONE MASONRY CLADDING

Stone masonry cladding is usually installed over the building concrete and steel framing. The limestone cladding was typically 10 cm (4 in.) thick and was supported or attached to a backing wall with corrodible angles and straps. The limestone pieces above the window openings are supported by steel angles. No flashing was installed over the steel window lintels typically. Granite panels 3 cm (1.2 in.) thick were supported with non-corrodible angles and brackets.

Moisture intrusion behind the limestone cladding caused the corrosion of concealed corrodible metal straps, dowels and shelf angles. Cracking, spalling, and displacement of limestone panels were typical forms of distress observed. Displacement of granite panels was found to be typical distress due to the inability of connections to accommodate movement of the panels, and failed epoxy adhesives. Sealant between granite panels was generally deteriorated.

4.1 TYPE OF DISTRESS IN LIMESTONE CLADDING

Distress observed at the exterior limestone walls consist of deteriorated mortar joints between limestone panels; spalled limestone due to corrosion of embedded strap anchors; spalled limestone due to corrosion of embedded shelf angles; cracks observed along the building corners; displaced wall sections with spalled limestone.

Figure 8. Cracked and spalled window mullions and rosettes

At locations of displaced and cracked limestone panels steel lintels, dowels and straps behind them were severely corroded. The expansion of corrosion build-up creates large expansion forces causing pressure on adjacent stone, which caused displacement and cracking of the limestone blocks at their back portion. Typical observed distress is shown in Figures 8 and 9.

Figure 9. Severely corroded steel shelf angle and cracked and spalled limestone block due to corrosion

4.2 TYPES OF DISTRESS AT GRANITE CLADDING

Displacement of granite panels was found to be typical distress due to the inability of connections to accommodate movement of the panels, and failed epoxy adhesives. At those instances connections installed to support granite panels were inadequate and different from designed. Instead of using metal clips at the bottom and top of the panels to provide for gravity and lateral support, panels were connected with wires glued with epoxy adhesive to the back of the panels and attached with anchors to the backing wall.

In case where epoxy was used as an attachment adhesive, it was discovered that granite inserts embedded into granite panels were debonded from the backing material, as shown in Figure 10.

Figure 10. Granite inserts attached with epoxy adhesive that has failed

4.3 TYPES OF REPAIRS FOR STONE CLADDING

Repointing of mortar joints includes grinding out deteriorated or cracked mortar joints and installation of new mortar; patching of spalled limestone with a hand-placed mortar patch, as shown in Figure 11.

Dutchman repair includes removal of sections of deteriorated or damaged limestone and repairing the removed area with limestone dutchman held in place with strap anchors and/or stainless steel pins, as shown in Figure 12.

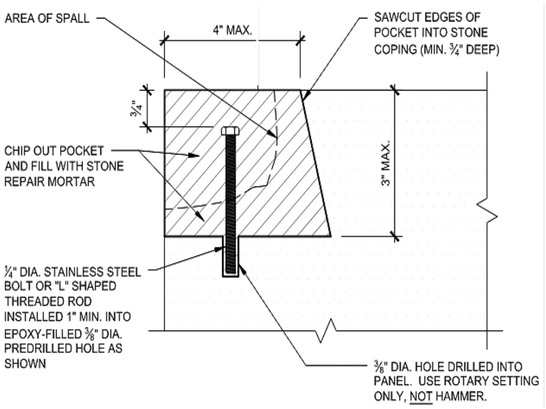

Figure 11. Limestone patch

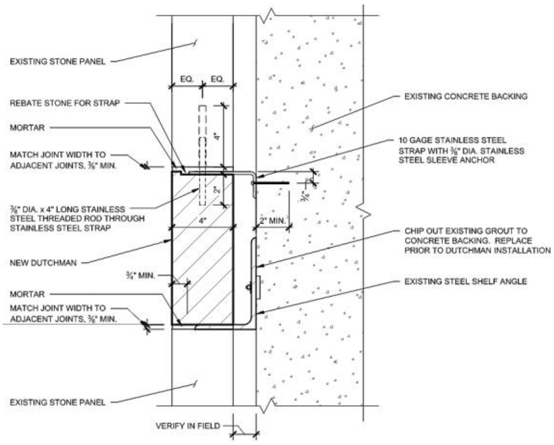

Figure 12. Dutchman limestone repair

Repair option also included replacement of damaged limestone with new; installation of repair anchor to stabilize/secure the movement of displaced stones; repair of shelf angle/lintel. Based on the percentage of section loss it is determined is shelf angle/steel lintel would be repaired or replaced; installation of flashing with a drip edge over steel lintels (Figure 13).

Figure 13. Repair of steel shelf angle/window lintel

Other repairs included replacement of deteriorated sealant in joints between stone panels; replacement of inadequate connections at granite panels included installation of new stainless steel angles anchored into the backing wall and reattaching granite panels to them; and reattaching of granite inserts using epoxy adhesives included removal of existing failed adhesives and backing material and installation of new.

5. PRECAST CONCRETE PANELS AND THEIR CONNECTIONS

The controlled manufacturing environment allows the facade panels to meet exacting tolerances for dimensions and anchorage placement that are generally not attainable in the structural frame to which they are being attached. Consequently, the facade panel connections must allow not only for structural load transfer, creep, shrinkage and thermal movement of the facade elements and the structural frame, but also for field variation in connection location and alignment. The installers of the panels often try to overcome these alignment difficulties by adding supplemental shims or by field welding or bolting supplemental connection plates to make up for poorly matched connectors. However, these field installed connectors do not perform well because the field installers do not fully understand the design and implications of varying the connection. In some instances these failures can be catastrophic as shown in Figure 14.

Figure 14. Failure of facade panel connection

Figure 15. Inadequate bearing of façade panels

The most often observed cause of exterior facade panel failures was the improper construction of panel connections to the building frame. Construction deficiencies included using the originally designed connections for connecting the panel to the building frame even though the frame connections were not located at the intended elevation and location; improper placement of the connection plates, bolts or welds; misalignment of panel; using erection shims and bolts as permanent connection as shown Figure 15; and welding connection plates when they were intended to be bolted to allow for volume changes. Most of these problems could have been easily and inexpensively solved if the erector, after realizing that the connections did not fit the as-built frame, would have alerted the design engineer or had his own engineer modify the connections with due consideration to the forces and the actual dimensions involved.

The design deficiencies in the exterior facade panel connections involve the lack of adjustable connections that may be required for panel erection even for a building frame and facade panels built to the design tolerances, not providing for volume changes in the panels and building frame (welding both ends of a long panel, for example), and not considering the full extent of eccentricities in the connection plates and bolts.

Figure 16. Typical gravity load connection repair

The retrofit design for typical gravity connection included welding fairly thin steel plates on each side of the haunch flange and to the steel bearing plate, as shown in Figure 16. This connection provided transfer of gravity load, restrained out-of-plane movement of the panel, and allowed for the volume change movements along the length of the panel through flexibility of thin steel plates. The interesting aspect of this repair project was that the repairs had to be performed without interruption of the hospital operations. Up to three patient rooms were emptied each day, the inspection openings were cut in the wall finishes to expose and inspect the as-built connections, the connection repair was designed based on the condition found, and the repair contractor performed required retrofit.

Another example of improperly built connections were the supports for 10 m high facade panels of a four-story police/jail facility. These very heavy panels had the type of the panel built as a haunch which rested on the roof slab of the building. Unfortunately, all the panels were rigidly connected to each other by steel connection plats welded to adjacent supports. This prevented normal volume change movements and caused all panels to crack at and around their bearing supports (Figure 17). The repair included attaching supplemental steel brackets to the panels away from the original supports and transferring through them the weight of the panels to the roof (Figure 18).

Figure 17. Cracking of panel bearing

Figure 18. Connection retrofit with steel bracket

6. CONCRETE FACADE

Inadequate concrete cover over the reinforcing bars can result in moisture from the rain penetrating to the steel rebars which will begin to corrode. Expansion forces of the corrosion by-product (rust) will result in cracking and spalling of concrete (Figures 19 and 20). Standard concrete repair techniques include chipping deteriorated concrete around corroded rebar, sandblasting rebar and concrete surfaces, epoxy painting the rebar and pouring or hand applying concrete patches. It is recommended to install stainless steel wire anchored in the concrete substrate to help hold the patch in place if the bond between the substrate and patch weakens (Figure 21). Similar repairs are used for exposed slab edges.

Figure 19. Spalling and cracking of the concrete façade

Figure 20. Spalling and cracking of the concrete façade

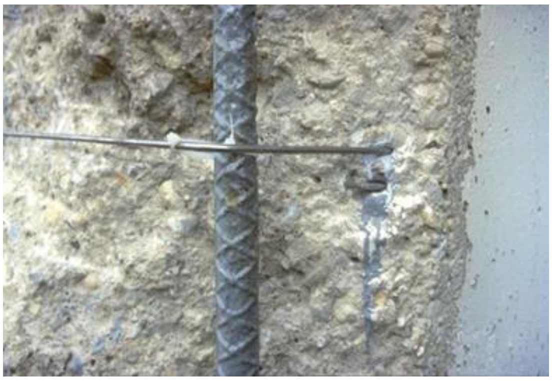

Figure 21. Facade patch repair

Concrete balcony slabs usually have additional deterioration due to the presence of steel railing posts embedded in the concrete slab. The deterioration of balcony slabs is accelerated if there is carpet present on the balcony (Figure 22). Painting the repaired facade with a breathable acrylic paint will improve the appearance and durability of the repair.

Figure 22. Deterioration of concrete balcony

7. RECLADDING OF FACADES

In the latter part of the last century, new, thinner facade systems were developed. They included thin composite panel systems where traditional materials like marble or limestone were reinforced to make them thinner. Also, traditional materials were used thinner than before. Using a rational design, the thickness of the non-load bearing wall was reduced down to 4-10 cm.

Currently, in order to reduce the weight and cost of the exterior façade veneer, the thickness of the veneer systems has been reduced down to 2.5 cm. and non-load bearing walls to 4 cm. A reduction of the thickness of the exterior façade cladding resulted in some new problems. In some instances, composite panel systems experienced failures due to unexpected interaction of different materials.

Outward bowing on thin brick bonded to cement board is shown in Figure 23. Connections of thinner marble and granite façade panels to the structural system of the building had smaller safety factors and cracks were occurring in the stone at locations of the connections. Bowing of marble panels is shown in Figure 24.

Figure 23. Outward bowing of thin brick bonded to cement board

Figure 24. Bowing of new marble panels on Finlandia Hall, 2005

As the facades with thin marble panels were beginning to age, bowing of the panels as shown in Figures 25 and 26, and failure of their connections were observed. Loss of flexural strength due to exposure to heat from the weather became evident. While this loss of strength was not affecting the performance of the thicker marble panels in the past, now with thin marble panels it became a major factor in their performance. It also became evident that details and connections for the panels that worked well in the past with thicker panels needed to be revised to accommodate the behavior of the thinner stone panels.

These conditions required removal of the existing cladding, and the design and installation of the completely new different façade system. The new system and connections should be tested with mock-ups before proceeding with the project. Figure 31 shows recladding of the tallest marble clad building in the world.

Figure 25. Recladding of the 82-story tall marble clad Amoco building

Figure 26. Bowing of panels

8. CONCLUSIONS AND ACKNOWLEDGEMENTS

The common causes of failures of exterior facades on multi-story buildings are: lack of provisions to prevent water leakage into the interior of the building, lack of proper details to accommodate volumetric changes of the façade materials and to accommodate differential movement between the façade and the building structure. Improperly designed or built connections, and use of thinner than traditional wall systems. Guidance on how to repair these conditions is presented.

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