2020 PROJECT OF THE YEAR

HIGH-RISE CATEGORY

The Austonian: Slab Edge Repairs

AUSTIN, TEXAS

SUBMITTED BY PIVOT ENGINEERS

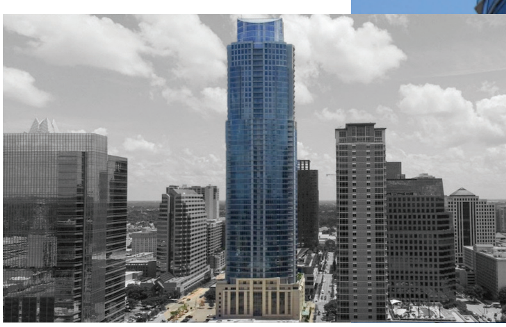

Fig. 1: The Austonian building

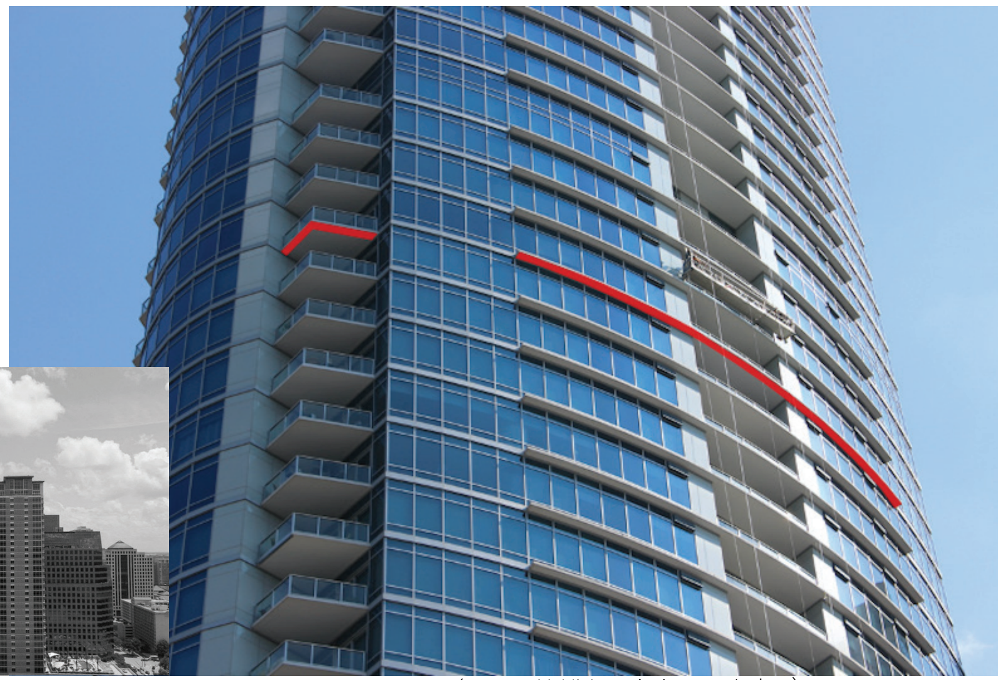

Fig. 2: Slab edges at the Austonian (red lines highlight typical exposed edges)

The Austonian is a 59-story, 683 ft (208 m) tall high-rise condominium that was completed in 2010 and is located in downtown Austin, Texas (Fig. 1). The building is comprised of reinforced concrete structural elements and unbonded, post-tensioned (PT) concrete slabs. The majority of the slab edges in a typical floor are covered with aluminum cladding, while the remaining slab edges are exposed to the elements. The building has approximately 1.75 linear miles (2.8 km) of exposed slab edges distributed over the entire height of the structure (Fig. 2).

Six years after construction, a 5 ft (1.5 m) long concrete segment (Fig. 3) detached from a balcony edge, fell more than 200 ft (60 m), and almost hit a staff member. Fortunately, no one was injured, and the spalled concrete caused limited property damage. Immediately after the incident, a visual survey identified 31 slab edge locations with evidence of severe cracking and distress (Fig. 4). The distressed slab edges were distributed throughout the building and were not concentrated in any particular area. To mitigate the risk of falling hazards, temporary protective measures were installed at the distressed locations to secure the concrete in place until permanent repairs could be performed. Understandably, the residents were concerned about the possible danger to people and property from falling debris.

FORENSIC INVESTIGATION

A comprehensive forensic investigation of the conditions at the exposed slab edges was performed to: 1) determine the cause and extent of the observed distress; and 2) develop an appropriate repair plan. The investigation examined a statistically representative and spatially distributed sample that included more than 15% of the exposed slab edges in the building, which ensured a high confidence level in the investigation results.

The investigation used several non-destructive and destructive evaluation techniques to estimate the in-situ concrete cover and evaluate the risk of ongoing corrosion activity. For the concrete cover survey, a cover meter (Fig. 5) and surface penetrating radar were used to locate the steel reinforcement and estimate the concrete cover.

Small-diameter holes were performed at select locations to verify the non-destructive testing results. The corrosion assessment included half-cell corrosion potential surveys and testing of carbonation depth and chloride content in the concrete cover.

The investigation determined that more than 85% of the examined slab edges contained reinforcing bars with inadequate concrete cover. More than 40% of the examined edge reinforcement had concrete cover that was less than 0.5 in (13 mm), which is the minimum cover allowed by the building code, including tolerances. The concrete cover deficiency was systemic throughout the building. The results also demonstrated improper placement and support of the edge steel reinforcement during original construction.

The investigation determined that carbonation-induced corrosion was the primary cause of the premature damage. Due to poor concrete consolidation around reinforcement with shallow concrete cover, the carbonation process progressed rapidly and initiated corrosion activity.

REPAIR DESIGN

Given the widespread nature of the issue, immediate repairs were needed to restore the safety and durability of the exposed slab edges. Full-depth repairs of the exposed slab edges were used to address the deficient slab edges and involved concrete removal of approximately 3 in (75 mm) into the slab. This removal depth limit was selected to preclude concrete removal in front of PT anchors, which could cause dangerous and uncontrolled release of PT tendons. The removal was sufficient to expose the improperly placed reinforcing bars, which were then cut and removed. Repair details specified roughening the concrete substrate to a concrete surface profile of CSP 7[1] to ensure adequate bond between the original concrete and the new repair material.

The repair included installation of glass fiber reinforced polymer (GFRP) dowels to anchor the new repair material to the concrete substrate. Given the dimensional constraints of the repair, the GFRP dowels selected for the repair had 180-degree hooks, which alternated orientations and were installed between 30 degrees above and below horizontal. Stainless steel helical anchors were also installed to provide supplementary mechanical anchorage. To mitigate excessive shrinkage cracking along the narrow and relatively long repair, the design incorporated longitudinal top and bottom GFRP bars that went through the hook dowels.

The concrete repair specifications limited the concrete strength and stiffness to mimic the characteristics of the existing concrete substrate. In addition, shrinkage tests and a specialized curing regime were specified to help reduce the severity of shrinkage-induced cracking of the repair material. The replacement slab edge extended 2 in

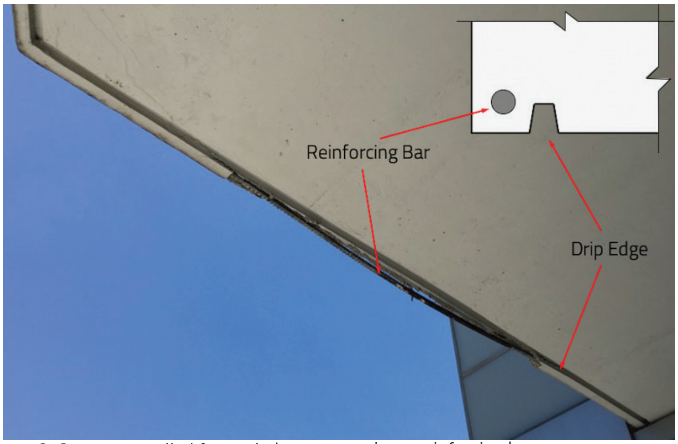

Fig. 3: Concrete spalled from a balcony, exposing a reinforcing bar


Fig. 4: Corrosion-induced damage at an exposed slab edge


Fig. 5: Obtaining concrete cover measurements

(50 mm) beyond the original slab edge (i.e. the final repair width was 5 in [125 mm] as compared to the 3 in [75 mm] removed during demolition work) to mitigate congestion inside the forms and accommodate new reinforcement.

The repair design included measures to enhance the long-term performance of the executed repairs. For example, a corrosion inhibiting admixture was specified to protect the PT anchors exposed during repair execution. The design documents also specified treatment of cracks wider than 0.016 in (0.4 mm) using gravity-fed high molecular weight methacrylate. To mitigate moisture ingress through the newly formed construction joint, a flexible sealant joint was specified at all construction joints. Finally, an elastomeric waterproofing membrane was installed over repair surfaces, extending past the newly formed construction joints. The selected waterproofing membrane was compatible with the original system, which remained in areas outside the scope of the repair. The repair design complied with the requirements of ACI 562.[2]

Fig. 6: Off-site mock-up showing conditions after reinforcement installation

Fig. 7: Overhead protection installed around the site

Fig. 8: Swing stages were used for access and material transportation

REPAIR EXECUTION

Prior to the commencement of repair work, the contractor performed large scale mockups, both off-site and on-site (Fig. 6). The repair mock-ups allowed for: 1) early coordination between the repair team members; 2) identification of execution obstacles; and 3) fine tuning of the repair details. The findings of the mock-ups led to changes in the design and execution plans which benefitted the project. For example, the geometry and orientation of the GFRP dowels were adjusted due to installation difficulties observed during the off-site mock-ups. Similarly, the contractor also elected to use conventional concrete instead of the originally selected self-consolidating concrete, due to: 1) the long setting time; 2) finishing difficulties encountered in the mock-ups; and 3) sensitivity to variations in mixing conditions. The mockups strengthened the collaborative approach between the design team and contractor.

Given the busy downtown setting and the substantial risk of falling hazards, the contractor worked with local businesses and several city departments to build overhead protection structures to protect the public prior to demolition (Fig. 7). The contractor also installed nets around work areas to catch debris and mitigate the falling hazard. Given the limited space at ground level, the contractor erected overhead protection and a work deck over the building podium to provide a staging area while also protecting property.

The contractor used swing stages to access repair areas and transport repair materials (Fig. 8). This allowed for repairs to be performed without the need to access the residential units which remained occupied. The height of the structure and the seasonal variation in wind patterns created logistical and access challenges. To limit delays due to high winds, the contractor divided the building perimeter into twelve independent drops. This allowed the contractor to continually perform the repair work, regardless of wind direction.

Concrete removal was performed using lightweight electric chipping hammers to prevent damage to adjacent PT tendons. The edge reinforcement with shallow concrete cover was exposed and removed. To avoid logistical challenges associated with media blasting hundreds of feet in the air, needle scaling was used to prepare the concrete substrate without weakening the bond by introducing microcracks. Once surface preparation was completed, a pressure washer was used to clean the concrete surface. The GFRP dowels and bars were then installed and secured in place using plastic ties (Fig. 9).

The concrete removal exposed numerous non-encapsulated PT anchorages. Because concrete placement often lagged behind concrete removal at a given location, some PT anchorages remained exposed for extended periods of time. To mitigate moisture ingress into the exposed PT tendons due to wind-driven rain and pressure washing, the project specifications required installation of temporary protective assemblies that sealed the ends of the anchors. The contractor developed PT protection systems that were evaluated using a mock-up assembly (Fig. 10).

Given the height of the structure and the limited volume of repair concrete needed at each location, the contractor selected a prepackaged material. The concrete was mixed in small batches at balconies located near the placement locations to prevent stiffening of the fresh concrete during transportation from the building podium to the intended repair location. Form and pencil vibrators were used to ensure adequate consolidation of the repair material. After curing, shrinkage cracks were treated, and a sealant joint was installed along the construction joint (Fig. 11).

Because the repairs were performed while the building remained operational, all residents were affected by the noise, vibrations, and inconvenience of the repairs. However, the project team worked closely with building management to coordinate the schedule, manage expectations, and keep the residents updated.

HIDDEN DEFECIENCIES

During repair execution, several unforeseen construction deficiencies were discovered at discrete locations. At 15 balconies, railing post anchorages did not have code-specified anchor reinforcement. To address this issue, near-surface-mounted GFRP hairpins were installed around the deficient railing anchors (Fig. 12).

At seven locations, the demolition exposed significant bursting cracks around PT anchors. The repair team devised a unique solution that included epoxy injection of the cracks and installation of carbon fiber reinforced polymer thru-thickness splay anchors (Fig. 13). The splay anchors were designed to arrest existing cracks and in-plane delaminations.

QUALITY CONTROL

A comprehensive quality control program was implemented during repairs and included the following four-point inspection system:

- Surface preparation and dowel holes inspection by ICRI CSRT[3] trained inspectors;
- Reinforcement and formwork inspection by ICRI CSRT trained inspectors;
- Concrete placement and finishing inspection; and
- Waterproofing and final condition inspections.

Fig. 9: Slab edge prior to concrete placement

Fig. 10: Mock-up of temporary PT anchor protection

Fig. 11: Repaired slab edge after placement (note sealant joint and filled cracks)

In addition to common concrete material testing, pull-off bond strength testing was performed at least once every 250 linear ft (75 m) of repaired slab edge. Given the orientation of the repair, horizontal coring of the repaired slab edges was needed for the testing. To reduce the effect of uneven coring on the results, a modified slab edge geometry with reduced thickness was used in areas selected for pull-off bond testing (Fig. 14). After testing, the test area was repaired to match the adjacent slab edge repairs.

Fig. 12: Strengthening of a deficient railing anchorage

Fig. 13: Splay anchors installed to arrest existing PT bursting cracks

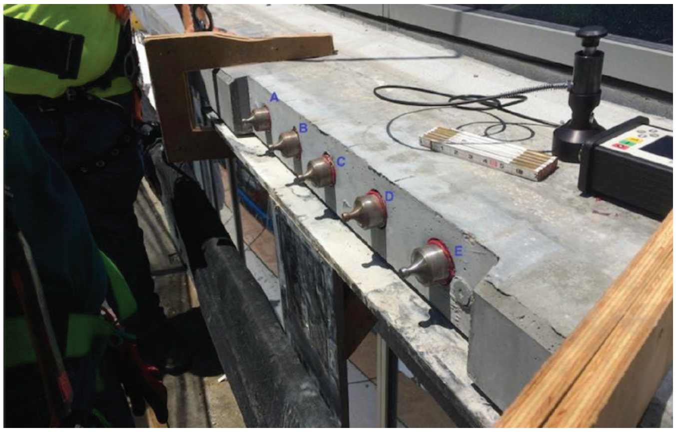

Fig. 14: A typical pull-off bond testing area

SUMMARY

A systemic concrete cover deficiency led to full-depth removal and replacement of 1.75 linear miles (2.8 km) of exposed slab edges over the height of a 59-story building in a downtown environment. Due to existing PT reinforcement, the concrete removal was limited to the exterior-most 3 in (75 mm) of the building slabs. This game of miles and inches necessitated the use of a myriad of repair and strengthening technologies, including GFRP dowels and reinforcing bars, near-surface mounted (NSM) reinforcement, and surface applied CFRP anchors and sheets. The slab edge repairs took place over a 16-month period and restored the safety and durability of the exposed slab edges. The collaborative nature of the project greatly contributed to its success.

REFERENCES

1. ICRI 310.2R, *Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair*, International Concrete Repair Institute, St. Paul, MN, 2013, 48 pp.

2. ACI Committee 562, *Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary* (ACI 562-16), American Concrete Institute, Farmington Hills, MI, 2016.

3. Concrete Surface Repair Technician (CSRT) Program, International Concrete Repair Institute, St. Paul, MN.

The Austonian: Exposed Slab Edge Repairs

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