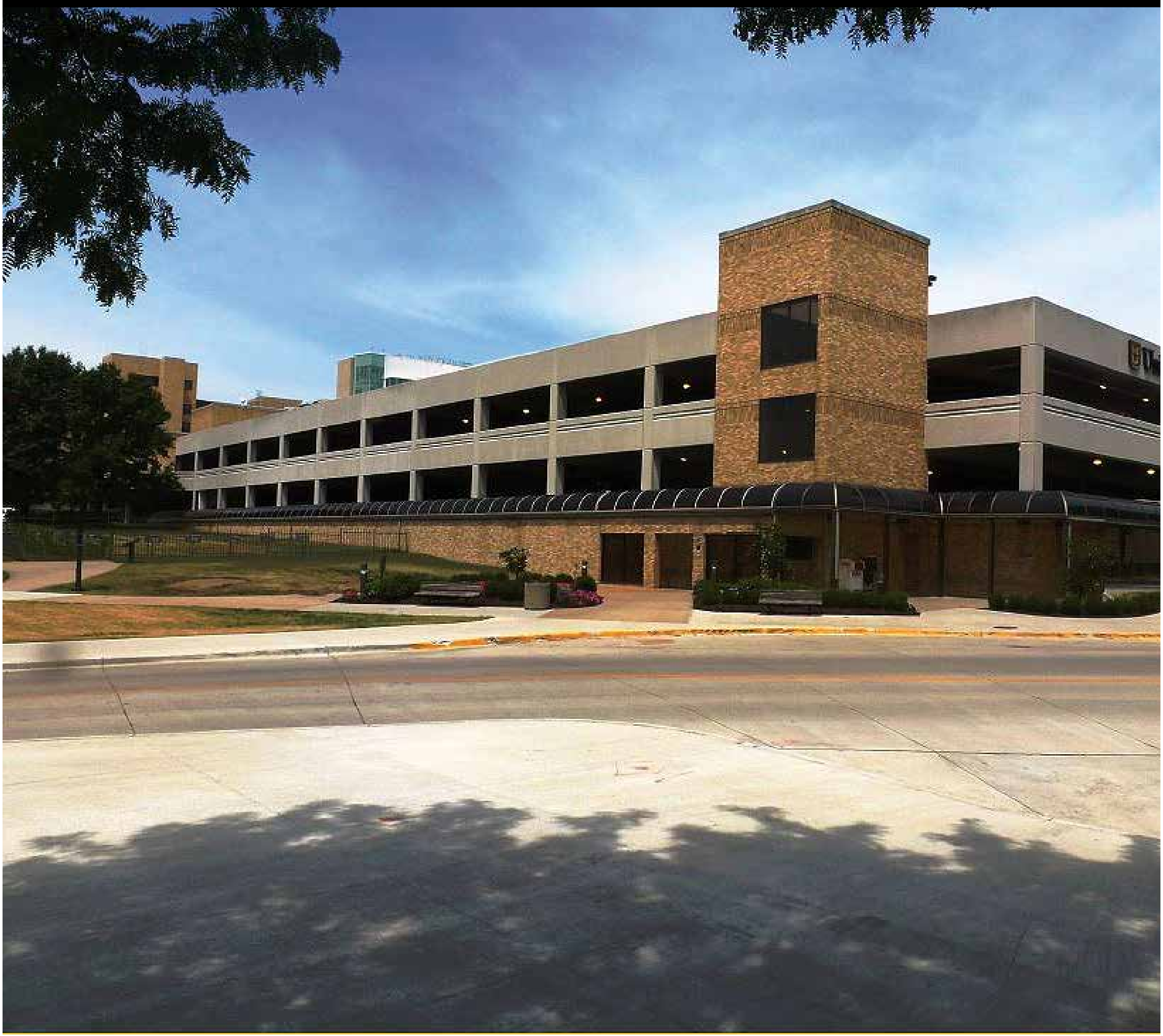
University of Missouri
Hospitals and Clinics

Structural Repair and Protection of Post-tensioned Parking Garage



University of Missouri Project

The University of Missouri Health Care Patient and Visitor Parking Structure (MUHC Garage) is a 448 car, four-level structure located in Columbia, Missouri. The MUHC Garage is the gateway to vital health services for hundreds of daily patients and visitors for the Health Care Facility while also serving as the hub for service providers, security and maintenance personnel, and students.

The parking garage, built in 1986, is a cast-in-place post-tensioned beam and slab structure consisting of three elevated post-tensioned decks over a slab-on grade level. The post-tensioning tendons were the plastic push-through type (stuffed) which are susceptible to having voids in the anti-corrosion grease.

Understanding the vital role of the structure to the University and the community, MUHC staff was immediately concerned upon discovering a broken post-tension tendon protruding from the underside of an elevated deck. MUHC promptly retained a structural engineering firm to investigate the exposed tendon, determine the cause of the failure, and develop a long-term repairs strategy.

Figure 1: Erupted Post-tensioned Tendon Discovered March, 2013

Investigation & Recommendations

Phase 1

Investigation: The initial investigation occurred at the location of the original tendon eruption (Level 1 North Bay) and included invasive inspections for further tendon breaks, live anchor condition at the expansion joint, and screwdriver penetration tests at mid-span. The penetration test involves wedging a flathead screwdriver between the individual wires which make up the strand. Screwdriver penetration can only be achieved if one or more wires are broken.

Results: 43% of the 39 post-tensioned slab tendons tested were broken, and moderate to severe corrosion of the live anchors was observed due to leaking expansion joints.

Phase 2

Investigation: With significant tendon problems detected, extensive forensics testing of representative sample areas was conducted to verify tendon condition at the remaining four expansion joint locations. The testing included post-tension corrosion evaluation to determine the level of moisture inside the tendons. A structural analysis of Level 1 using IBC 2012 (40 psf live load) was completed along with visually inspecting and sounding of the concrete decks.

Results: 80% of the 40 anchors inspected exhibited moderate to severe corrosion damage. Chloride profile testing indicated levels exceeding 400 ppm at 1” depth, a level considered sufficient to initiate corrosion for high strength steel under stress, which can be more susceptible to corrosion than conventional rebar. Corrosion potential testing along the expansion joints indicated 30% of the anchorage areas had a high probability of active corrosion (< -350 mV vs CSE) and only 25% of locations are passive (> -250 mV vs CSE). A large majority of the 64 tendons tested had excessive moisture, sufficient to maintain corrosion activity in the tendons.

Phase 3

Investigation: Based on the results of Phase 2, all remaining slab tendons were evaluated for strand condition and moisture content.

Results: A total of 27 out of 497 tendons that were exposed had broken or missing strands at the test locations. 65% of tendons were determined to be in good to fair condition. However, 62% had missing or degraded grease and 98% had excessive moisture levels.

Figure 2: Screwdriver Penetration Test Detecting Broken Wires

Figure 3: Severe Corrosion and Degraded Grease

Figure 4: Corrosion at Slab Grout Pockets

Figure 5: Corrosion at Beam End Grout Pockets

Understanding the severity of the corrosion problem, the Engineer identified the cause of the advanced degradation. A gutter system had been installed below the leaking expansion joints. This gutter system trapped debris, moisture, and chlorides from deicing compounds beneath the failed joints, established a corrosive environment at the post-tensioning anchors, and was an entry point for moisture into the tendons. Maintaining the long-term serviceability of the MUHC garage would require both repairing existing structural problems (which would worsen over time) and addressing the corrosion problem that was causing the deterioration.

Figure 6: Post-Tensioned Slab Corrosion Evaluation Procedure (moisture test)

Repair Plan

With the investigation complete, it was determined that voids between the sheath and strand and a lack of protective tendon grease allowed water and chloride ingress from the expansion joint. After completing a 20-year life cycle cost analysis, the engineer finalized the repair strategy which included following items:

- Repair damaged concrete and masonry
- Replace all live stressing anchorages at the expansion joints and 20’ of strands in bays adjacent to expansion joints
- Install galvanic anodes in repairs
- Repair 25 broken tendons and replace 3000’ of monostrand tendons
- Replace all expansion joints, re-caulk horizontal and vertical construction joints
- Apply heavy duty traffic bearing membrane to all levels
- Employ post-tension cable drying (dehumidification) to all slab tendons. After internal tendon moisture has been reduced, follow with post-tension grease injection process.

Project Delivery

With a comprehensive structural repair plan designed, it was decided to restore the structure in two phases. Given the volume of work, a compressed schedule, and the technical nature of the repairs, substantial involvement by the structural engineer (including prequalification of the specialty repair contractors) was critical to deliver a successful project. The first phase was completing structural repairs from May to September 2014. After the structural repairs were complete, the post-tension tendon drying and grease injection process was completed between August 2014 and January 2015.

For the structural repairs phase, the Owner faced the hard decision of phasing the work to maintain an operational garage. The Owner chose to close the entire garage for the massive repair scheme recognizing that maintaining an operational garage would increase the repair cost, extend the project duration, and create potential safety risks for their patients and visitors.

A closed garage also allowed replacement of existing garage systems to be added to the project. The Owner elected to install new LED lighting systems, updated dry fire sprinkler systems, new paint, and a new exterior canopy system covering the walkways between MUHC buildings.

The Owner determined that the MUHC Garage must be repaired and returned to service before students return for classes. This restricted the post-tension repairs to just 91 calendar days, with the remainder of the work to be completed within 206 calendar days. The Engineer-established contractor prequalifications and aggressive schedule ensured that the Owner would contract with a highly experienced post-tension repair team who was up to the task.

Structural Repairs & Waterproofing

The primary focus of the structural repairs was to re-establish the integrity of the elevated post-tensioned slabs. The immediate task would be to replace 206 live stressing anchorages at the 4 failed expansion joints. The existing live anchorages would be replaced by new, fully encapsulated anchorages. This replacement would require installing various lengths of new tendon as well. Secondly, 29 tendon breaks throughout the garage also required location, splicing, and re-stressing. To round out the complete structural repair, all columns, walls, beams, and overhead concrete delaminations would be repaired by ICRI standards.

The selected Contractor focused all pre-construction efforts on the scheduling and coordinating of the multiple scopes of work planned for every garage level. The preliminary schedule was established so each trade started at the top of the garage and worked down to the entrance on Level 1. The Contractor's goal was to turn over 100% of the garage on the required opening date. Achieving this goal would require meticulous manpower organization to perform the post-tension repairs on each level within 3 weeks, on average.

The post-tension repair method was to "lock-off" the tendon lengths that did not require repair and maintain the structural capacity of the level still tensioned while the end anchors were replaced. This method limited the required shoring which in turn kept valuable areas of the garage open for other repairs to be performed simultaneously.

Figure 7: Post-tension Splicing with Center Stressing Chuck

Once the problem of deterioration was addressed, the cause of those problems would have to be eliminated to ensure an extended service life for the structure. The failed expansion joints and gutter systems on each level were removed and replaced with watertight elastomeric wing compression type expansion joints. Following the replacement of the joints, a heavy duty vehicular traffic waterproofing membrane to protect the repaired slabs from further moisture and chloride intrusion was installed. This protection included a pedestrian membrane in stairs, a slab-on-grade deck coating, and re-striping to conform to current ADA standards.

Figure 8: Completed Post-tensioned Slab Repairs

Figure 9: Application of Waterproofing Membranes

Post-tension Corrosion Mitigation

After the post-tension repairs were complete, the corrosion mitigation specialist mobilized to site. The scope of work was to complete the post-tension cable drying then install new anti-corrosion grease to protect the tendons from future corrosion.

On each of the 421 tendons to be dried, input and exit ports are installed using custom designed shut-off drills such that the post-tensioned strand would not be inadvertently damaged. Then manufactured dry air is transported to each tendon through temporary piping and passed through the tendon under controlled flow and pressure. The exhaust is monitored at the exit port until it has been determined that all bulk water and moisture from the grease and the interior spaces of the 7-wire stand has been reduced to sufficient levels.

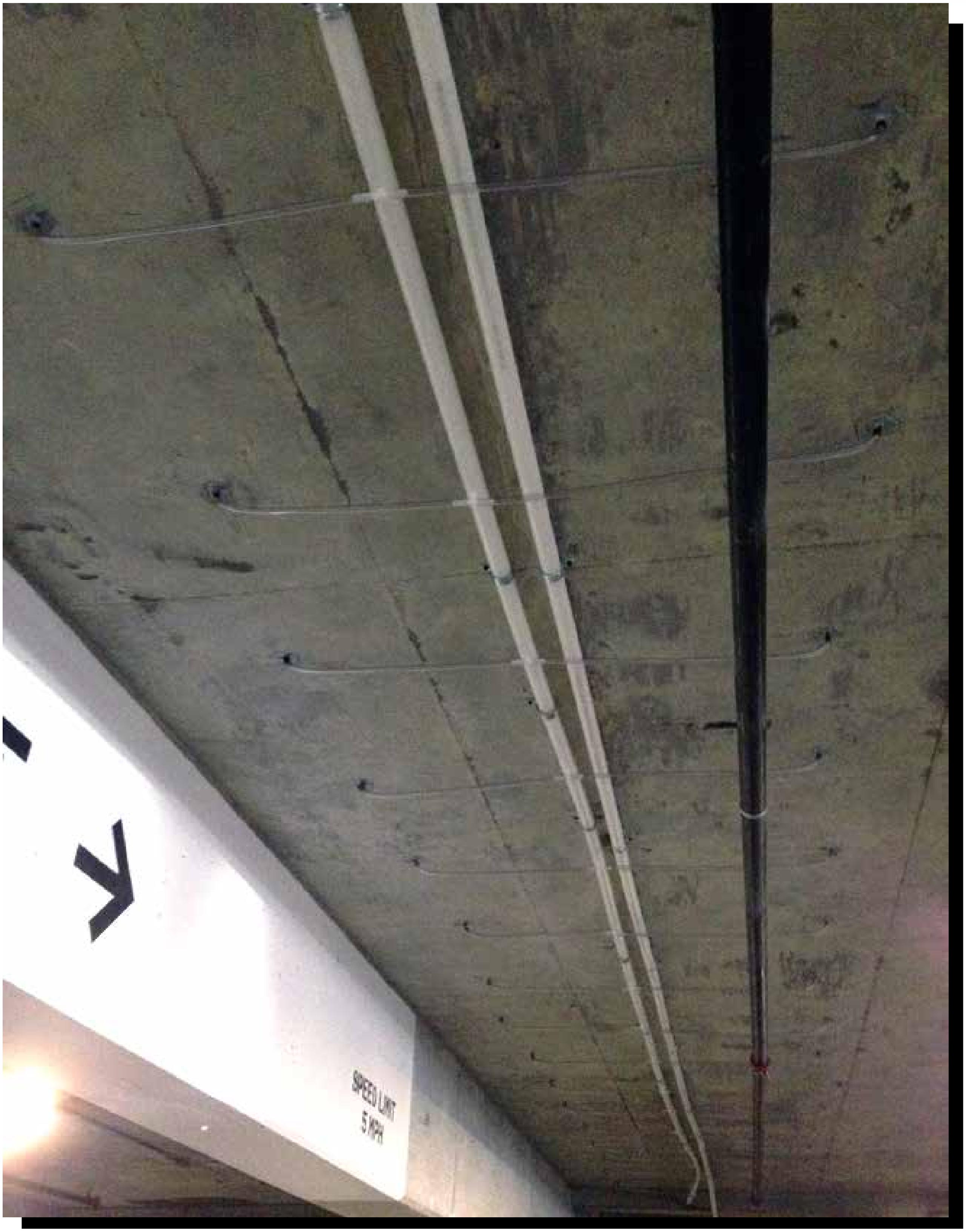


Figure 10: Manifold System and Input Air Ports for PT Cable Drying

Corrosion Evaluation Testing Classification:

	Classification Code	Potential for Corrosion	Moisture Content
	1	Low (Dry)	< 0.3%
Dry	2	Moderate (Moist)	0.3% to 0.7%
Wet	3	High (Wet)	> 0.7%

Figure 11: Potential for Post-tension Corrosion based on Moisture Content

The post-tension cable drying criteria for moisture content is based upon previous studies performed for the National Research Council of Canada. Prior to the post-tension cable drying, the tendons were in a Wet-3 condition with moisture content greater than 0.7% with several of the tendons even holding bulk water. After the post-tension cable drying process was completed, 98% of the cable groups were classified as Dry-1 with moisture content less than 0.3%. The remaining cables, classified as Dry-2 with less than 0.7% moisture, typically have airflow restrictions possibly caused by built-up corrosion.

After the post-tensioned cable drying process was completed, new anti-corrosion grease was placed in the individual tendons to eliminate any existing voids and to improve the corrosion resistance of the post-tension system.

Unforeseen Challenges

Pre-construction planning was essential to the success of the project and meeting the aggressive schedule. Missing the opening date was not an option for any of the team members, but as with all restoration projects, there would be many unforeseen conditions and circumstances requiring flexibility.

While repairs were keeping pace with the preliminary schedule, it was realized with 26 calendar days remaining before the garage opening deadline that just completing the post-tension repairs would not be sufficient. The Owner determined that their parking needs required that all garage repairs and coatings be complete before opening all 4 levels of the garage.

The entire project team had to combine efforts to find collective solutions and accelerate production for the remaining 5 weeks. The team's fortitude was again tested after uncovering 21 severely deteriorated end anchors that would require replacement with 10 days remaining prior to the opening deadline. On the opening day deadline, the Contractor and team of Sub-Contractors completed the traffic coating and striping on all 4 levels, finished the fire suppression systems, and turned on the new LED lighting; all items necessary to opening the MUHC Garage for patient and visitor parking.

Figure 12: Post-tension Re-Greasing at Grout Pockets

Figure 13: Post-tension Grease Injection Operation

Summary

The MUHC Garage Repairs project is an excellent example of how an experienced and cohesive project team can work together to overcome obstacles and find mutually beneficial success while facing difficult circumstances.

The keys to the successful MUHC Parking Garage Repair included:

- An owner with a long term outlook and commitment to high life safety standards
- A comprehensive condition assessment to determine the extent and magnitude of the corrosion problem, repair priorities and options
- Innovative project design to repair the current structural problems and mitigate the possibility of future widespread corrosion problems
- An experienced team of qualified engineers and contractors
- Innovative project delivery to meet owner's requirements for life safety and sustainability