FIRE DAMAGE EVALUATION AND REPAIR OF PRECAST CONCRETE GARAGE

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Vehicular fires in parking garages are not an infrequent event. Research by the authors indicates that on average, one fire occurs each day in a parking garage somewhere in the U.S. When fires occur, the elevated temperatures and associated thermal shock associated with the fire and subsequent fire-suppression activities can result in damage to nearby structural components. Fortunately, concrete structures generally have the ability to perform well both during and after exposure to elevated temperatures. This is due to concrete's high capacity for heat absorption, its relatively low thermal conductivity, and the relatively short duration of such fires.

The evaluation of the extent of damage a concrete structure may have sustained from a fire, as well as the adequacy of affected members to remain in service, involves a systematic assessment of post-fire conditions. This article describes an evaluation of fire damage and subsequent development and implementation of repairs to the Woodlands Waterway Marriot Parking Garage located in Spring, TX.

The garage is a four-story parking structure built in 2003. The structural framing consists of precast concrete double tees, inverted tees, wall panels, and columns. The double tees were fabricated using lightweight concrete. A field-placed concrete topping slab is present over the double tees. In October 2008, a fire occurred in the northwest portion of the second level of the garage. The fire had a duration of 30 to 45 minutes and involved three parked vehicles. The fire caused readily visible surface damage to the double tees and supporting wall panels located directly above and adjacent to the conflagration.

Fig. 1: Double-tee flange soffit and stem affected by the fire

DAMAGE EVALUATION

An evaluation of the structural elements affected by the fire was conducted to determine the extent of the damage and to design required repairs. Elements indicating significant visible damage included three double tees, three wall panels, and six double-tee support haunches.

Detailed field observations revealed localized concrete spalls, cracks, and delaminations in the double tees, haunches, and wall panels. The most severe distress occurred in the double tee stems and flange soffits (Fig. 1). The flange soffit spalling was generally less than 1 in. (25 mm) and exposed portions of embedded welded wire reinforcement. Longitudinal spalls were noted at the corners of the stems, and lengths up to 10 ft (3 m) of welded wire reinforcement were visible. The spalls also exposed the bottom prestressing strand in several stems for lengths up to approximately 15 ft (4.6 m).

The spalling occurred due to the following material and structural response mechanisms[1]:

1. **Thermal gradient**: During the early stages of the fire, rapidly heated double-tee flange surfaces expanded at a greater rate than the cooler underlying material, resulting in a significant thermal gradient and buildup of stresses near the surfaces. When the shear/tensile capacity of the concrete was reached, a failure plane developed and an outer layer concrete was disengaged.
2. **Restraint**: Upon heating, the surface concrete of the stem or haunches expanded in all directions. At corners, this thermal growth resulted in expansion from two orthogonal

directions. This region of the corner was restrained by the relatively cooler, underlying concrete. Upon further heating, the tensile capacity of the concrete near the corner was reached, and cracking or expulsion of this portion occurred. A series of cracks, typically 1 to 3 in. (25 to 76 mm) from the corners developed, as the thermally growing member "shed" its corners.

Craze cracking was noted in vertical faces of the stems throughout the fire-affected area. Regions judged to have been located closer to the fire and thus to have experienced higher thermal exposure exhibited greater cracking. Craze cracking of surfaces reflect an irrecoverable shrinkage of a shallow zone of the paste matrix due to dehydration associated with the thermal excursion. This condition typically produces a fine, but very shallow and structurally inconsequential, network of cracks that does not impair the overall integrity of the affected member.

The detailed field observations were supplemented with soundings to aid in assessing the near-surface condition of the concrete. Based on results of the observations, soundings, and other evaluation, it was determined that the post-fire conditions were consistent with a normal anticipated response to a moderate fire exposure. Therefore, it was concluded that the affected members were able to provide future strength and serviceability by implementing appropriate repairs to address spalls and cracking, and to restore member geometry.

STRUCTURAL ANALYSIS

A limited structural analysis was performed to assess the possible effects of the damaged concrete on the overall load-carrying capacity of the double tees. The analysis was performing using design information indicated on fabrication drawings provided by the precast manufacturer. Flexural and shear capacities were determined using proprietary software for the analysis and design of prestressed concrete beams. The focus of the analysis was on the portion of the double tees within 20 ft (6.1 m) of the support. Of greatest concern was the possible detrimental effect of loss of bond at the bottom prestressing strand due to the corner spalls. To evaluate this possible effect of loss of bond, the bottom strand was modeled as being intentionally debonded, or blanketed, for a distance of 15 ft (4.6 m) measured from the support. In addition, the effect of the craze cracking in the stems was conservatively modeled by reducing the specified concrete compressive strength by 25%.

Results of the structural analysis indicated that the flexural capacity of the affected double tees was adequate to resist code-required design loads. The analysis, however, also showed that the shear capacity of the double tees could be slightly inadequate. Therefore, it was decided to provide supplemental shear reinforcing over a portion of the double-tee span.

REPAIRS

The repairs consisted of concrete patches, double-tee stem strengthening, haunch extension, and neoprene pad replacement. The double-tee strengthening is a notable feature of the repairs and thus is described in greater detail.

CONCRETE PATCH REPAIRS

The spalled areas at stems, wall panels, and double-tee flanges were patched using conventional concrete repair methodologies. Patch repairs for corner spalls of the stems generally consisted of the removal of loose and unsound concrete, preparation of the exposed steel reinforcement, installation of stainless steel threaded rod anchors, and form-and-pour application of a polymer-modified portland cement-based patching material. The perimeter of the patch was saw cut to avoid feather edges. In addition to the threaded rod anchors, longitudinal threaded rods were installed along the corner spall repairs to control shrinkage cracking of the patch material. The spall repair at the flange soffit was accomplished using low-pressure spray-applied mortar (Fig. 2). Trowel-applied and form-and-pour repair techniques were considered; but given the overhead application, it was felt that the low-pressure spray technique would provide a higher level of assurance because the repair material was bonded to the sound concrete. Exposed steel reinforcement was cleaned by wire brush/hand methods and coated with an epoxy-modified cementitious material to improve bond with the repair material and provide enhanced corrosion protection.

Fig. 2: Application of spray-applied mortar on double-tee flange soffit

DOUBLE-TEE STEM STRENGTHENING

Common techniques for double-tee stem strengthening include steel plates and external post-tensioning (EPT). In the past several decades, repair techniques using externally bonded fiber-reinforced polymer (FRP) systems have emerged as an effective means to repair and strengthen concrete structures. For this project, it was decided that a FRP-based repair approach provided the needed structural enhancements while assuring an aesthetically pleasing solution as an added benefit.

Design of the FRP system was performed following guidelines presented in ACI 440.2R-08.[2] Two plies, or layers, of a bidirectional carbon FRP system were used. The first layer consisted of a "U-wrap" configuration along the portion of the stem located approximately 15 ft (4.6 m) from the support. This layer provided the necessary supplemental shear capacity. The upper end of the fabric was extended to within several inches of the flange soffit. In addition to providing the shear capacity, the fabric also served to confine the repair material for the corner spalls. The second layer consisted of a short section of fabric placed at the end of the stem. This layer was oriented in a plan view "U-shaped" configuration such that it extended around the end of the stem (Fig. 3 and 4) and for 3 ft (0.9 m) on each face toward the midspan of the member. The purpose of the second layer was to provide supplemental strength to a localized region of the stem exhibiting more extensive cracking.

In general, installation of the FRP system proceeded in the following manner:

1. Patch materials along the stem corners were allowed to cure, and cracks 0.01 in. (0.3 mm) and wider were epoxy injected.
2. Surface preparation was specified to achieve a texture equivalent to ICRI Concrete Surface Profile (CSP) 3. Corners at the end of the stems were ground to eliminate sharp edges.
3. Initial cutting of the FRP material was performed in the presence of the fabric manufacturer.
4. A solvent was applied to the concrete surface immediately prior to epoxy adhesive application.
5. The FRP material was saturated in the epoxy adhesive.
6. After allowing the solvent to flash off the concrete surface, the epoxy adhesive was applied to the concrete surface and allowed to set for several minutes.

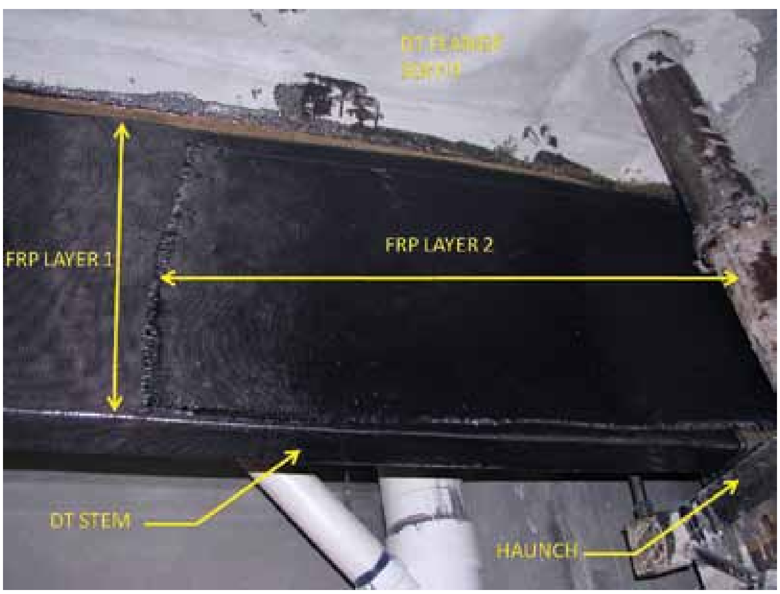

Fig. 3: Double-tee stem FRP repair

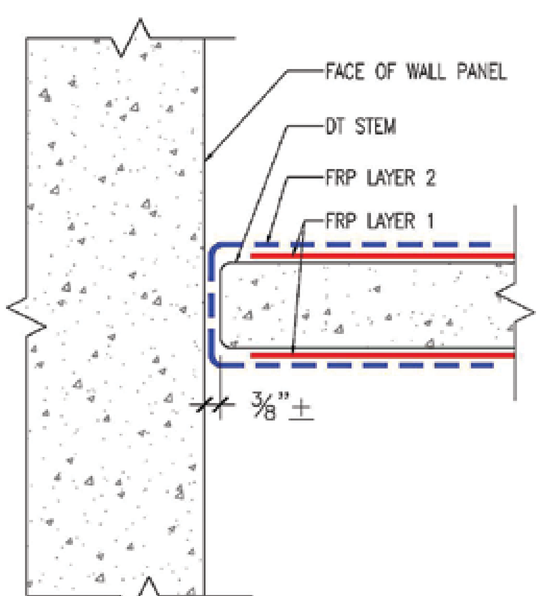

Fig. 4: (a) Schematic plan view of end of double-tee stem showing FRP layers; and (b) installation of FRP Layer 2

7. The first layer of FRP was installed and pressed into place.
8. The second layer of FRP was installed immediately after the first layer. Epoxy adhesive was applied to the end of the stem prior to the application of the second layer. Due to the tight gap between the end of the stem and the face of the wall, a sacrificial FRP extension wrapped on a piece of cardboard was used to facilitate pulling the FRP around the end of the stem.
9. All repaired areas were painted with acrylic-latex coating.

HAUNCHES

The double-tee support haunches were repaired by removing unsound concrete, installing repair mortar, and installing a haunch extension. The extension consisted of cast-in-place concrete located beneath the original haunch, effectively lengthening the haunch. Stems of supported double-tees were shored during this repair.

NEOPRENE PADS

Some neoprene bearing pads located on the haunches were damaged by the fire and required replacement. Pad replacement was performed by slightly jacking and lifting the double-tee to allow removal of the damaged bearing pad and creation of a gap into which the new pad could be inserted. Lifting of precast double tees for bearing pad replacement could lead to minor cracking of the topping, so the design drawings specified routing and sealing of all cracks in the topping slab located above the lifted members.

QUALITY ASSURANCE

A quality assurance program was implemented to verify that the repairs performed were in general compliance with the intent of the design drawings. The quality assurance procedures included preconstruction inspections of surfaces to be repaired, periodic observations, bond testing of concrete surfaces, and inspection and sounding of completed repairs.

Tensile pulloff tests were performed following ICRI Technical Guidelines.[3] The purpose of the tests was to quantify the near-surface tensile strength of the concrete substrate and to evaluate the quality of surface preparations prior to the installation of the FRP. Measured tensile strength

Fig. 5: Woodlands Waterway Marriot Parking Garage

of the concrete surface was determined to be adequate and failure modes observed indicated satisfactory surface preparation.

Mechanical sounding was performed at selected locations of completed spall repairs to qualitatively assess intimacy of repair mortar applications. In general, sounding revealed adequate bond between the patch repairs and sound concrete.

FIRE DAMAGE CAN BE REPAIRED

Concrete-framed parking structures generally experience relatively minimal damage during and after exposure to car fires. Nonetheless, a systematic assessment is needed to identify the nature, extent, and structural significance of any damage. As indicated by the conditions resulting from a car fire at this facility, a number of elements required evaluation. Structural modeling was performed to aid in assessing the possible reduction in strength of the double tees. As a result of the assessment, it was determined that the damaged members could provide satisfactory strength and serviceability after implementation of repairs. The result was a repair solution that is expected to be structurally functional and aesthetically pleasing for users of the facility.

REFERENCES

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Woodlands Waterway Marriot Parking Garage Evaluation and Repairs

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