INNOVATIVE DOUBLE-TEE REPAIR SOLUTION

BY CHRISTOPHER M. MORGAN

In 2006, the damaged stem of a concrete double-tee roof structure required a unique repair. The roof structure supported a parking and plaza area over an underground parking garage. The structure was built in the 1970s and consisted of internally-reinforced concrete, precast double-tee beams with a clear span of approximately 53 ft (16 m), bearing on cast-in-place concrete foundation walls. At midspan, an opening had been cut through one flange of one double-tee to allow for the installation of a ventilation shaft. Over the years, water and deicing salts had reached the internal prestressed tendons within the double-tee stem through typical flexural cracks, causing corrosion and resulting in failure of the tendons (refer to Fig. 1).

Due to the extensive deterioration of the tendons, conventional external post-tensioning repair methods could not develop sufficient forces to meet the requirements of the given conditions. An innovative method of repair was developed using high-strength anchor bars (instead of tendons) to provide adequate strength to replace the damaged tendons without reducing the 53 ft (16 m) clear span.

THE PROBLEM

One of the stems of a concrete double-tee beam for a roof structure developed a significant structural flexural crack. It was discovered that all six of the prestressed reinforcing tendons within the stem had failed due to corrosion. Shoring, which had been placed underneath both stems of the double-tee, was immediately reinforced to provide emergency support for the entire weight of the double-tee and the associated parking and plaza area above. The challenge was to repair the damaged double-tee beam without reducing the clear span and without reducing the headroom clearance within the underground parking garage. Conventional external post-tensioning repair methods could have been used if only one tendon had failed, but they could not be used to provide sufficient strength to replace six tendons, or the equivalent of approximately 180,000 lb (81,650 kg) of force.

REPAIR CONCEPT

Common repair concepts for a failed prestressed tendon within a double-tee stem include external post-tensioning of the double-tee stem to restore its capacity or reducing the span of the distressed double-tee by the addition of new columns. For this project, the installation of new columns was not possible because the clear span of the double-tee beam could not be reduced. Furthermore, the headroom could not be reduced in the drive lane, and only minimally reduced elsewhere. Large diameter, high-strength steel bars were used that could be tensioned to very high stresses (or the equivalent of six prestressed tendons). By placing one of these bars on each side of the damaged double-tee stem, the necessary tension forces could be developed in these two bars to replace all six tendons. Each high-strength bar provided a design yield strength of 150,000 psi (1034 MPa), and the threaded ends could develop the tension loads by tightening nuts at each end (refer to Fig. 2).

Transferring the 180,000 lb (81,650 kg) of external post-tensioning tensile force from the high-strength bars back into the undamaged portion of the double-tee beam was another challenge. Steel plates and through-bolts are commonly used to transfer loads from external post-tensioning back

Fig. 1

Fig. 2

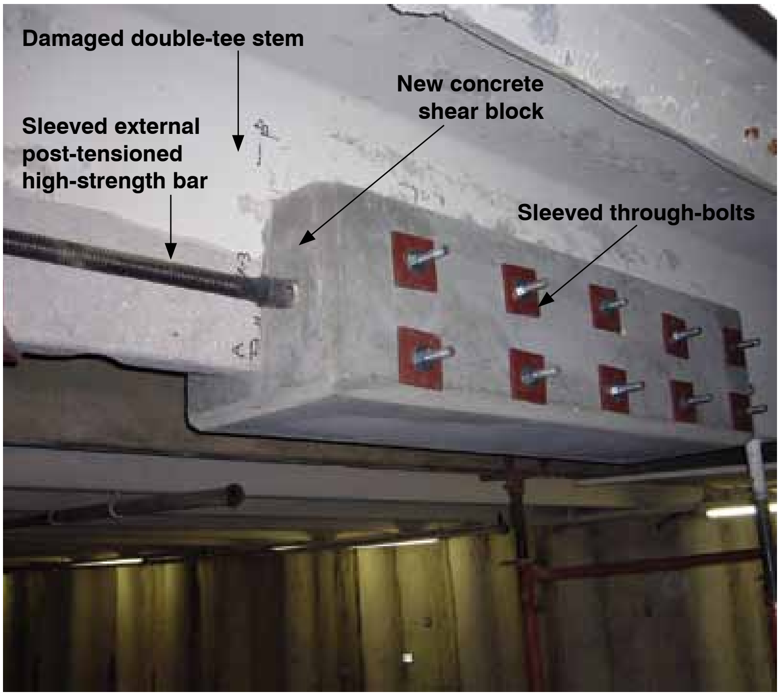

Fig. 3

into the double-tee stem. This type of connection, however, was not capable of transferring the large shear forces required for this repair. By using a reinforced concrete shear block cast against the original double-tee stem, the shear forces could be developed along the length of the beam. These shear blocks were used to anchor the external post-tensioned bars to the existing undamaged portion of the double-tee stem. Sleeved through-bolts were used to achieve the interlock between the newly placed concrete shear blocks and the roughened concrete surface of the double-tee stem. The shear blocks were cast low on the stem to position the external post-tensioning bars at the approximate elevation of the prestressed tendons (refer to Fig. 3).

To balance the new external post-tensioning forces in the development area (the portion of the double-tee stem where the new external forces are transferred back to the double-tee), the flange of the double-tee needed additional reinforcement. Additional deformed mild-steel reinforcing bars were embedded into a new concrete topping slab above the flange above the repair area.

During the design process, multiple design checks were performed for the new shear anchor blocks, which included allowable bearing pressures, shear transfer, and bursting stresses. During the repair work, multiple sections were checked for crack propagation before and after stressing. Flexural stresses were checked both in the top and the bottom sections of the double-tee to verify that the stresses were within allowable live- and dead-load conditions. Finally, constructibility was reviewed by the repair contractor.

REPAIR INSTALLATION

Installation of the repairs took place over a 6-week period, during which the initial structural cracks and deteriorated portions of the double-tee were repaired using epoxy-injection and high-strength patching materials. Sandblasting and surface preparation of the existing concrete double-tee stem to receive the new concrete shear blocks was performed. Through-bolts were installed and grouted into the double-tee stem and then sleeved within the formwork for the new shear blocks. New high-strength steel bars were installed with bursting steel and sleeves around the bars to allow movement within the shear block. Shear steel, bursting steel, and carrier bars were also installed within the shear block formwork. The concrete was hand-placed in the forms and consisted of high-strength, small-aggregate concrete.

Once the concrete for the shear blocks had achieved its required strength and the formwork had been removed, the through-bolts were tensioned to maintain interlock. Using a calibrated torque wrench, the bars where loaded to approximately 90,000 lb (40,825 kg) each to restore the original 180,000 lb (81,650 kg) of tensile force of the prestressed tendons in the double-tee stem. Monitoring of the shear blocks for signs of cracking or distress during loading was accomplished by painting critical locations with a brittle acrylic paint and inspecting the painted areas during tensioning for cracks. In addition, the shear blocks were monitored visually for cracks and the deflection of the double-tee beam was measured to verify when the original camber was restored. Upward deflections during the tensioning process were less than calculated; however, this was attributed to boundary conditions where adjacent double-tees were attached to the repaired double-tee (refer to Fig. 4).

PROOF LOADING

Once the newly installed external post-tensioning system settled in overnight, a proof-load test was performed on the repaired portion of the structure. This testing consisted of adjusting the shoring jacks down approximately 0.75 in. (19 mm), allowing the weight of the structure to be carried by the new post-tensioning system, and loading the structure with barrels of water to simulate live load conditions. Deflection of the double-tee was monitored from below at midpoint. The results of the proof-loading produced a 0.375 in. (9.5 mm) maximum deflection, which was well within the calculated 0.5 in. (12.7 mm) deflection. Once the structure was proof-loaded, the water was removed and the rebound of the structure was measured. Within 30 minutes, the structure had regained 85% of its original camber prior to loading (refer to Fig. 5).

The use of the high-strength steel bars in the external post-tensioning repair along with the shear blocks to tie the post-tensioning to the beam proved to be an effective and low-cost repair for the failed prestressed tendons in the stem of the double-tee beam.

Fig. 4

Fig. 5

Double-Tee Roof Structure Repair

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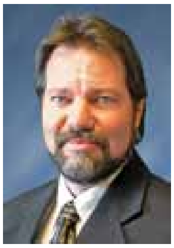

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