DISTRESS AND REPAIR OF PRECAST PARKING STRUCTURE DECKS

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INTRODUCTION AND HISTORY

Precast/prestressed concrete is the structural system of choice for many multistory parking garages (Figure 1). Precast parking structures have desirable long spans and open floor plans with minimal interference from columns. In addition, the construction schedule of precast parking structures is typically significantly shorter as compared to the schedule of other structural systems.

Precast parking structures are comprised of prestressed double tees decks supported by inverted-tee beams, wall panels, or spandrel beams.

Precast double tees were first introduced in the construction of buildings in the early 1950s and were used shortly after in parking garages. Early precast double tee members were 4 to 6 feet wide with 14- to 15-inch deep stems. Since their introduction as a viable structural member, the size of double tees have progressively increased from a width of 8 feet in the 1960s to 12 feet in the 1980s. Twelve-foot tee widths are still commonly used today (Figure 2). Some double tees today are fabricated 15-feet wide to fit into a 30 foot by 60 foot or 45 foot by 60 foot bay scheme.

Figure 1. Precast parking structure during erection

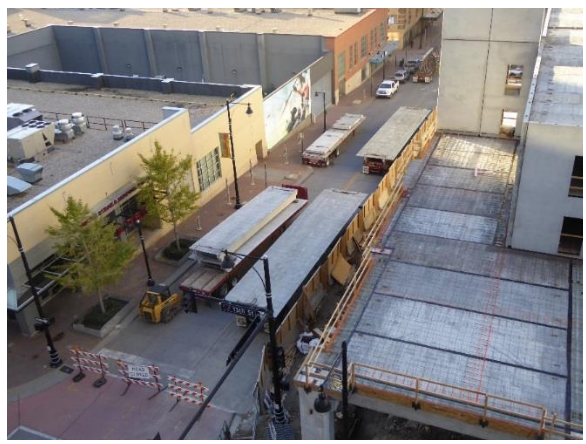

Figure 2. Precast double tee beams delivered to site prior to erection

The deck in precast parking structures is either "pre-topped" or "field-topped." A pre-topped deck is one in which the traffic bearing surface is part of the plant-cast, precast double tee flange. A field-topped deck is one in which the traffic bearing surface consists of a cast-in-place concrete topping. Double tee decks were field-topped until the early 1980s, at which time the use of pre-topped decks began to emerge. Beneficial features, which accelerated the use of pre-topped decks, include the potential for higher quality, plant-cast concrete and a shorter field construction schedule. Pre-topped double tee decks often have cast-in-place concrete pour strips located near the ends to conceal connections to wall panels or inverted-tee beams, accommodate field-installed reinforcing steel for diaphragm chord forces, and enhance drainage.

Adjacent double tees are connected together with flange-to-flange connections. Early versions of the flange-to-flange connector were fabricated from u-shaped reinforcing bars embedded in the opposing tee flange edges and welded together at the joint. Most of today's connections are proprietary corrosion resistant products. For a typical structure, the deck members are joined to each other by over a thousand flange-to-flange connections, and the joint between the double tees results in more than a mile of sealant joints.

Double tee beams and flange-to-flange connections are the work horse of precast garages. The sealant joints along the flange edges and over flange-to-flange connections are the first line of defense against moisture intrusion. Repair of flange-to-flange connections and double tee flanges is the focus of this paper, which includes a brief overview of common deck issues observed and review of repair techniques that have been used in the past. Repairs techniques presented in this paper are intended only to introduce basic concepts, and may not be applicable for project-specific conditions.

Maintenance of any open-to-the-weather structure is necessary to extend the service life of the structure. Precast parking garages are no exception, and maintenance should be done periodically during the life of the structure. The Maintenance Manual for Precast Parking Structures[1] by Precast/Prestressed Concrete Institute (PCI) provides a comprehensive guideline for maintenance and repair of precast garages.

Prior to any precast garage repair project, an assessment of the concrete structure is required to evaluate existing conditions and determine causes of distress and deterioration, which provides the basis for development of an appropriate repair and maintenance program. The assessment often includes document review, field investigation, field and laboratory testing, structural analysis, and an evaluation of findings. For additional information regarding concrete structure assessments, documents published by the American Concrete Institute (ACI)[2] and the International Concrete Repair Institute (ICRI)[3] provide specific guidance and recommendations.

DOUBLE TEE FLANGE CONCRETE DETERIORATION

The type of deterioration can be different for pre-topped and field-topped decks. Deteriorated concrete is often observed on double tee flanges in the form of cracked, raveled, delaminated, or spalled concrete (Figures 3 and 4). Deteriorated concrete is most often concentrated along double tee joints, at flange-to-flange connections, and near the ends of double tees along the drainage edge of the deck. For pre-topped decks, spalling of concrete in the flanges usually occurs near the joint where the welded wire reinforcing (WWR) is located near the top surface because of its placement over the flange-to-flange connections. Debonding, freeze-thaw deterioration and scaling of concrete are typically observed on field-topped decks. Breaches in the joint sealant and unsealed cracks in double tee flanges allow water and deicing salts to either run down the flange edge onto the exposed connections or to penetrate the flanges. Corrosion of embedded flange-to-flange connections and the embedded WWR in the flanges can result from repeated exposure to moisture. The deterioration is often most pronounced at the roof decks in colder climates that are subject to moisture from the elements, deicing salts used in the garage after snow storms, and snow removal equipment. When the embedded steel corrodes, it expands and the resulting stresses cause cracking of the surrounding concrete in a plane parallel to the concrete surface (a delamination). Delaminations that break away from the substrate concrete produce spalling. Spalling has also been observed below or adjacent to steel flange-to-flange connections that do not exhibit any signs of corrosion (Figure 5). Spalling observed near non-corroded connections is typically caused by localized stresses in the concrete associated with

[1] Maintenance Manual for Precast Parking Structures, 1st Edition (MNL-136-04), Precast/Prestressed Concrete Institute, Chicago IL, 2004
[2] Guide for Evaluation of Concrete Structures Before Rehabilitation, (364.1R-07), American Concrete Institute, Farmington Hills, MI, 2007
[3] Nondestructive Evaluation of Methods for Concrete Structures, (210.4-2009), International Concrete Repair Institute, St. Paul, MN, 2009

restrained volume change, vehicular traffic loading, insufficient concrete cover, or other mechanisms not associated with deterioration of embedded steel.

Figure 3. Concrete spall below flange-to-flange connection that is corroding in field-topped deck

Figure 4. Cracked and spalled concrete above flange-to-flange connection in pre-topped deck

Figure 5. Concrete spall below stainless steel flange-to-flange connection in pre-topped deck

Due to the relatively shallow thickness of the double tee deck, usually 4 inches for pre-topped systems and occasionally slightly thicker for field-topped systems, full-depth repairs are typically preferred to partial-depth repairs so as to provide a more durable cast-in-place repair with mechanical anchorage. Sometimes, full-depth repairs are required due to the aggressiveness of most concrete removal processes and partial-depth repairs are often not feasible because the thinner remaining concrete is susceptible to cracking from the concrete removal process. At deteriorated areas in the pour strip concrete, demolition is required around chord reinforcing to clean the steel and adequately anchor the patch which often results in a full-depth repair~~.~~

FLANGE-TO-FLANGE CONNECTION BEHAVIOR

Embedded flange-to-flange connectors are used universally to connect adjacent double tees. Flange-to-flange connections, in most installations, are made by aligning the connectors in two adjacent flanges and are joined by field welding a round or square "slug" bar between the two embedded steel connectors. A generic embedded connector and welded connection is shown in Figure 6.

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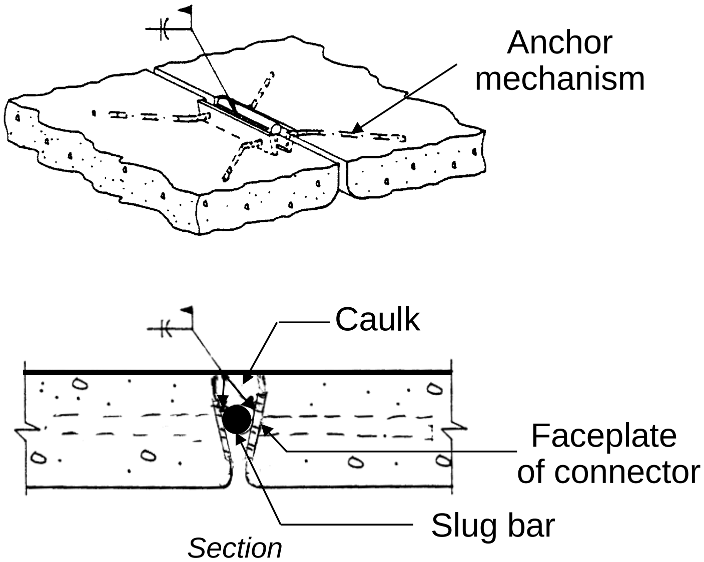

Figure 6. Sketch of flange-to-flange connection with sloping faceplates to hold the slug bar

Connectors of this type are usually subjected to multi-axes loading (Figure 7). Forces can be transferred between flanges in the following manner:

- Out-of-plane shear
- In-plane shear, also referred to as horizontal shear
- In-plane tension, also referred to as opening force or as tension

Out-of-plane forces, as indicated in Figure 7a, occur due to gravity load sharing between adjacent double tees, most commonly from vehicular traffic live loading. Out-of-plane forces may also be generated during erection alignment of adjacent double tees where a member may be jacked into place, welded and then released, allowing the dead load of the double tees to redistribute throughout the deck. In-plane shear forces in the longitudinal direction of the double tee, as shown in Figure 7b, are created when the floor system is required to act as a diaphragm in transferring lateral loads to the lateral force resisting structural elements (e.g. shear walls).

In-plane tension forces, shown in Figure 7c, are often generated because of restraint to volume-change. Drying shrinkage of concrete and temperature change are the primary sources of in-plane tension, although such forces can also occur if the floor is a diaphragm and the connections act as chord reinforcement. In some cases, compression is possible from lateral-load induced diaphragm forces or extreme temperature changes.

Because the three directions (and sources) of load can occur concurrently, a combination of forces typically exist on the connections.

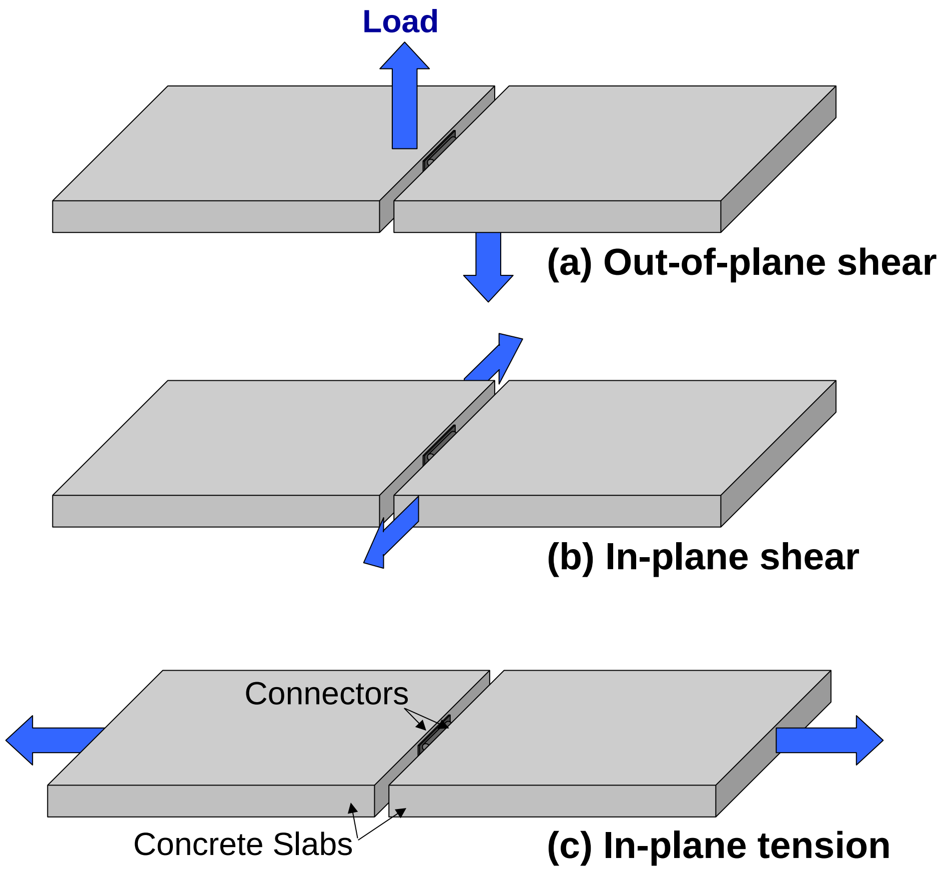

Figure 7. Types of forces on flange-to-flange connectors

Connection Deterioration and Distress

Several undesirable conditions are often observed at the flange-to-flange connections including poor welding, improper installation of connectors or slugs, and failed connection welds. Failed connections have been observed at both connections with corrosion related deterioration and connections with no corrosion related deterioration. Failed connections may involve a fractured weld or a fractured connector faceplate (Figure 8 and 9). Fractured welds are often the result of one or more of the following conditions: poor quality and/or undersized welds, corrosion related deterioration leading to a reduced section, or overloading. In addition, overload, impact loading from vehicles or snowplow blades, and repeated loading may contribute to fractured welds and failed connections. As discussed, stresses are also induced in the concrete and connectors from in-plane movement transverse to the joint between members of the deck due to drying shrinkage, temperature changes, and diaphragm action. If the width of ramp double tee joints at sloping ramps is not increased slightly to account for sloping geometry, the joints in the ramps will be slightly wider than the joints in flat areas of the garage, which can result in an increase of bending forces and stress on the connections. As individual connections fail, greater stresses are exerted on adjacent connections which can lead to progressive flange-to-flange connection failures.

Figure 8. Fractured weld at flange-to-flange connection

Figure 9. Fractured faceplate at flange-to-flange connection

The load demand on the flange-to-flange connections in field-topped double tees is much lower than in pre-topped double tees because a portion of the forces at the connection between members can be transferred through the cast-in-place topping. Due to greater spacing along the joint, the total number of connections in parking structures with field-topped decks in significantly less than for similarly sized structures with pre-topped decks. For these reasons, the incidence of flange-to-flange connection distress in field-topped decks is typically lower than in pre-topped decks.

Close-up inspection from the bottom at flange-to-flange connection can be performed. However, connection distress or failure is not always obvious without removal of sealant in the top of the joint to enable visual observation of the underlying connector components and adjacent concrete surfaces. In addition, corrosion is not always visible and the expansion of corrosion scale doesn't not always deteriorate the surrounding concrete if the corrosion scale has room to expand within the joint. Hammer sounding should be performed to aid in assessing the presence of incipient delamination near the connections. Relative displacement of the flanges as vehicles travel across the joints can be observed. If appropriate, the relative displacement can be measured using dial gauges. Excessive displacement is an indicator of failed connectors.

FLANGE-TO-FLANGE CONNECTION REPAIRS

Connection repairs are necessary to maintain the lateral load diaphragm element of the structure, maintain a solid and smooth driving surface, and transfer gravity loads across the joints, which reduces the stress on the outstanding flanges of the double tees. Therefore, failed connections should be identified and repaired in a timely manner.

Flange-to-flange connection repairs can be separated into the following four categories:

1. In-kind repairs
2. Externally attached steel members
3. Concrete shear-friction repairs
4. Joint doweling repairs

In-kind Repairs

In-kind repairs generally consist of rewelding the slug to the connector faceplates. For more severely distressed connections, complete replacement of the connector becomes necessary (Figures 10 and 11).

Typically, a rewelding repair addresses a fractured weld or other adverse conditions present in the originally installed slug. The rewelding repair generally consists of a new slug bar, sized to fit the joint opening, and welded to the faceplates. The heat generated during welding needs to be controlled so that the heat does not cause cracking in the adjacent concrete. Welding can be a quick, easy, and inexpensive repair but may not necessarily address the cause of the weld fracture or other shortcomings of the original connection.

Connection replacement entails creating a full-depth repair and installing a new flange-to-flange connection between the double tee flanges. The wings (anchor mechanism) need to be anchored back into the double tee flanges which can be accomplished by using hooked reinforcing bars adhesively anchored into the tee flanges at the edge of the opening. The joint between the double tees is maintained and a slug is welded between faceplates after the concrete is placed and has cured. Connection replacement is not a simple repair and multiple trades are necessary. Also, proprietary flange-to-flange connections, if used, were developed for new construction, and installing a new flange-to-flange connection into an existing structure is an invasive repair method that may require project-specific modifications to perform as intended.

In-kind repairs can be successful if the root cause of the distress or deterioration has been identified, and the rewelding or connection replacement directly addresses the cause. One advantage with an in-kind repair is that there is minimal change to the behavior of the structure. Potential, repeated poor performance can be expected with in-kind repairs unless changes in the original design are implemented.

Figure 10. Rewelding slug to faceplate at flange -to-flange connection

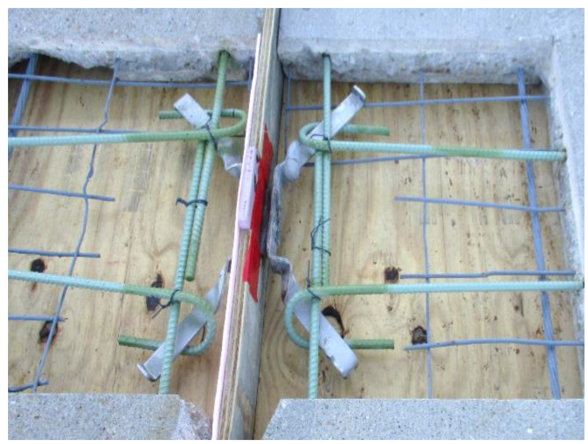

Figure 11. New connection installation in-progress

Externally Attached Steel Members

Externally attached steel members generally consists of fastening structural steel members to the undersides of the double tee flanges across the joint between adjacent flanges (Figures 12 and 13). The steel member is used to transfer forces across the joint that were previously transferred by the flange-to-flange connection that has failed. Angles and channels are commonly used for this type of repair. If a more structurally robust repair is desired, the steel member can consist of a stiffer steel shape (e.g., HSS) that is fastened to the double tee stems to distribute load directly to the stems, as shown in Figure 13.

Flange-to-flange connection repair using external steel members circumvents repairing the flange-to-flange connection. Using external attached steel members has a long history of field use, especially in regions of the country where the environmental exposure is not aggressive. External steel members can mitigate weaknesses of the original connection when designed and installed properly. However, supplemental steel repairs can be vulnerable to damage, loosening, and even dis-engagement from repeated loading, especially if they are attached to the deck using fasteners that do not extend through the entire deck thickness. For this reason, it is recommended that all externally attached steel members be anchored into the deck using through-bolts. In addition, spoiling of the bolt threads or other measures should be employed to minimize progressive loosening of nuts. External steel members are used primarily to address out-of-plane shear transfer. It can be difficult to design supplemental steel repairs to carry in-plane shear and in-plane tension. In parking garages with large diaphragm forces, supplemental steel repairs may not be adequate to transfer in-plane shear forces. Fit-up can be difficult due to mis-alignment of flange soffits. Also, the durability of the steel member can be compromised if the repair is exposed to moisture directly below the joint. In addition, the existing flange-to-flange connection remains in place and can cause additional damage to the surrounding concrete in corrosive environments.

Figure 12. Supplemental steel channels attached to the underside of double-tee flanges

Figure 13. Supplemental steel tubes attached to the underside of double-tee flanges and stems

Concrete Shear-friction Repairs

Cast-in-place, shear-friction concrete repairs have been implemented over the past 10 years to repair failed flange-to-flange connections. The repair details have ranged from minimally invasive, partial-depth small repairs to full-depth, core-hole repairs (Figures 14 through 17). Most of the cast-in-place shear-friction repairs are designed to remove the existing flange-to-flange connection and place new concrete between the flanges to transfer design forces through the concrete by shear friction. Shear-friction repairs generally involve the following steps.

1. Removing the existing connection.
2. Roughening and cleaning the perimeter of the repair area where the new concrete is bonded and reinforcement crosses the previous joint.
3. Inducing a vertical crack along the shear-friction plane, at the location of the previous flange-to-flange joint which can be accomplished by reducing the depth along this plane by tooling a joint at the topside of the repair and installing a chamfer strip along the bottom of the repair.
4. Sizing the crossing shear-friction reinforcing and cross section of concrete to meet shear friction and other design load requirements.

5. Sizing of epoxied-in dowels into the flange on either side of shear-friction plane, if required. The dowel bars and embedment should be sized to be considerably stronger than the shear-friction crossing bar.
6. Installing a bond breaker around the crossing shear-friction bar to provide a stretch length if loaded in tension and reduce dowel action of the crossing bar.
7. Installing sealant in the joint bonded to the existing or new sealant for continuity.

Shear-friction repairs can address the deterioration or distress in the original connection. This repair method has been installed and field load tested for out-of-plane shear forces (Figures 18 and 19). Often deterioration of the surrounding concrete is associated with failed connectors. This shear-friction repair method can remove the original corroded or failed connection, address concrete deterioration, and provide a load-transfer mechanism between the flanges.

The shear-friction repair method has a relatively short history of field use, and some of the movements and stresses at the shear-friction interface are not fully understood at this time. For example, the necessary aggregate interlock could be compromised if greater-than-expected in-plane joint opening occurs. WJE has installed monitoring gauges to measure in-plane joint movement at recently installed repairs. Preliminary review indicates that the cast-in-place, shear-friction repairs appear to be performing well. Raveling at the joint adjacent to the repaired joint connector was observed a few locations.

Figure 14. Stainless steel bar with sleeve installed in slotted opening, named "dog-bone" repair

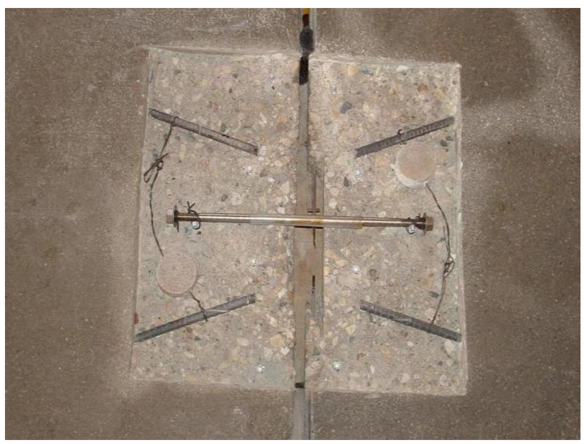

Figure 15. Partial depth repair with stainless steel crossing bars with sleeve

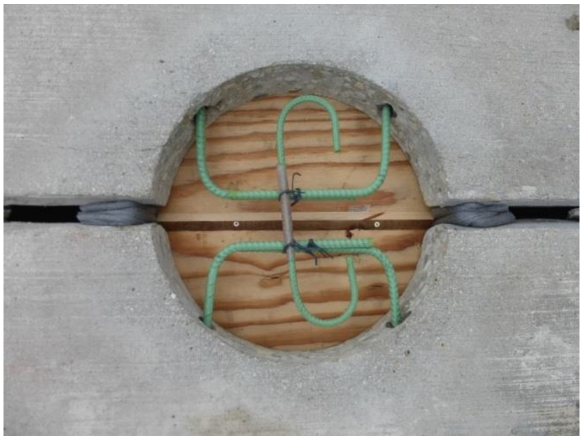

Figure 16. Core-hole repair in-progress with debonded epoxy-coated crossing bar with hooked ends

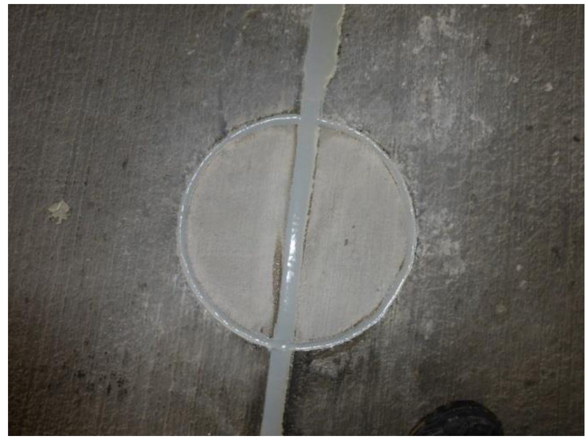

Figure 17. Completed core-hole repair

Figure 18. Load test on core-hole repair

Figure 19. Close-up view of load test on core-hole repair

Joint Doweling Repairs

This repair method consists of embedding reinforcing bars (Figure 20) or proprietary FRP composite biscuits (Figure 21) in saw-cut slots crossing the flange-to-flange joint. Load is transferred from one double tee to the adjacent tee by placing the bar or FRP biscuit into the slot and bonding it to the slot walls. Installation procedure generally consist of the following:

1. Saw cut a slot in the double tee flanges crossing the joint. For FRP biscuits, the slot is 1/4-inch wide; 18 inches long by 3 1/2 inches deep; for reinforcing bar dowels, the slot should be at least 1/8 in. wider than the bar diameter.
2. Clean slot surface with water and oil-free compressed air. Sandblasting should also be considered instead of water if the slot is wide enough.
3. Mask surfaces adjacent to slot.
4. Fill slot with mortar for the reinforcing bar or inject epoxy paste for FRP biscuit. Fill the void with sufficient mortar/epoxy to encapsulate the bar/biscuit after it is inserted into the slot. Ensure the epoxy is not moisture sensitive if the slot is not completely dry.
5. For the FRP biscuit, apply epoxy paste on both surfaces of biscuit.

6. Insert biscuit or reinforcing bar into slot and recess the dowel below top of concrete.

Joint-dowel repairs have a relatively limited history of field use. FRP composite biscuits were first used in 2009 and, therefore, their long-term performance is unknown. The manufacturer of the FRP composite biscuits has performed limited laboratory testing using monotonic loading. However, detailed test data is not readily available. Use of embedded reinforcing bars have been used prior to the emergence of FRP biscuits, but in-place service history is not documented in the literature. Possible disadvantages of dowel bar repairs include damage to edge longitudinal reinforcing steel within the flange from the saw-cut slots, ongoing corrosion-induced damage from existing connections (if left in place), and for the FRP biscuits, questions regarding the performance of the FRP dowel under exposure to fire.

Positive features of joint dowel bar repair include its minimally invasive installation procedure, quick installation, and potentially lower cost, all relative to other repair methods. Possible applications include those previously discussed to address deteriorating connections or cases of connector overloading. Use of joint dowel-bar repairs may not be appropriate for parking structures with large diaphragm forces, field-topped systems with poor bonding between topping slab and underlying precast flange, with deteriorated toppings, and decks with large volume change or in locations where a high number of cyclic loadings are anticipated, like transitions between flat and sloping ramps. The epoxy and mortar can also be susceptible to cracking at the joint.

Figure 20. Embedded dowel repair using reinforcing bars

Figure 21. FRP composite biscuit installation

CRACKING IN DOUBLE TEE FLANGES

Longitudinal Cracks

Longitudinal cracks in the top surface of the flanges, parallel to the direction of the double tee span, can occur near the supporting double tee stem (Figure 22). Double tee flanges are typically designed as propped cantilever beams with the joint as the location for the prop support and as continuous beams between stems. It has been our experience that these flange cracks typically occur at locations where flange-to-flange connections have already failed and the applied moment on the flange exceeds the cracking moment of the flange. Once the connections have failed, the stresses in the double tee flange increase when the load is placed near the tip of the flange. After the crack develops, the WWR engages, but may not be adequate for the cantilever bending moment. The cracking in the flange starts on the top surface of the flange where the tensile stresses are greatest but can progress, with time, to full-depth cracks from repeated loading of the flanges and loss of reinforcing steel cross section from corrosion. Therefore, longitudinal flange cracking should be a sign that it is necessary to repair the cracks and the connections. If the reinforcing steel has not lost a significant amount of cross section, the cracks can be repaired by routing the cracks and filling the cracks with sealant or a gravity fed epoxy after the flange connector is repaired.

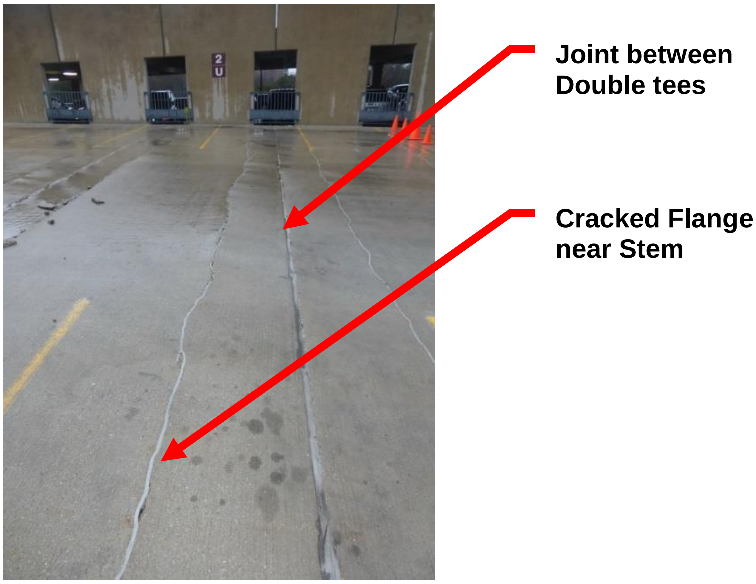

Figure 22. Longitudinal cracks at adjacent double tee flanges

At cracked locations, the WWR can corrode and not show signs of distress because the wire is located near the center of the flange and does not have enough cross-sectional area to create internal tension stresses in the concrete that cause delaminations. The corrosion of the steel is often only detectable by making destructive openings. Full-depth cracks at the supporting stem with evidence of water leakage and rust staining can be an indication that corrosion and loss of the steel cross section may be occurring. At locations where the WWR has lost cross-sectional area, it may be necessary to repair the reinforcing steel by increasing the cross-sectional area of developed reinforcing steel that crosses the crack. Reinforcing steel can be stitched across the crack (Figures 23 and 24). Stitch repair can be completed by removing a partial depth strip (slot) of concrete across the crack, preparing the surface of the concrete slot, installing an epoxy-coated reinforcing bar or stainless steel dowel, and recasting the concrete. The dowel bar should be developed on both sides of the crack, and if required, lap spliced to existing bars or wires.

Figure 23. Stitch repair using stainless steel dowels

Figure 24. Completed stitch repair

At locations with longitudinal cracks in adjacent double tees, where the WWR has lost a significant amount cross-sectional area and most of the connections are failed, full-depth flange replacement has been performed successfully. Prior to attempting this repair, a time-history of stresses on the double tee needs to be analyzed for various stages of the repair when a portion of the flange is removed. Movement of the double tees should be monitored and removing both flanges of one double tee at the same time is not recommended. The full-depth flange repair could consist of designing the flange as a cantilever, restoring the sealant joint at its previous location, and transferring forces across the joint between adjacent flanges by shear friction similar flange-to-flange connection repairs previously discussed.

Figure 25. Full-depth flange repair in progress

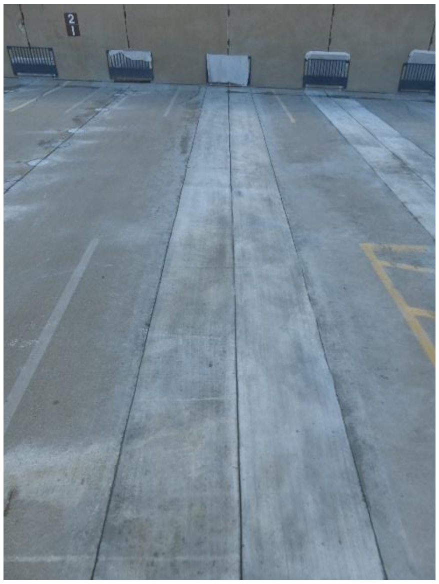

Figure 26. Completed full-depth flange repair

Cracks at Ends of Double tee Decks

Other cracks are often observed at the ends of double tee flanges. Some flange cracks at the ends of the double tees are through-thickness and observed to start near the welded connections between the double tee and supporting member where the tee flange can develop restraint against transverse movement (Figures 27 and 28). Movement occurs in the double tee flanges from drying shrinkage of the concrete and temperature changes which leads to the cracking. Welded plate connections between the double tee and the supporting member (inverted tee beam or spandrel) can create a fixed point in the support member that does not accommodate the flange movement. These cracks are more likely to develop in the flange on the inside face of the stem as opposed to the outside face because the flange-to-flange connections can accommodate some lateral movement. These cracks typically do not continue the full length of the double tee likely because the restraint of movement diminishes toward the center of the tee.

Some of the flange cracks observed are oriented diagonally from the ends of the double tee member, or start straight and then propagate diagonally. Diagonal cracks in the double tee flanges located between the two stems are often attributed to the result of warping the member to pitch water to the drains. These warping (torsional) stresses, if high enough, can exceed the tensile strength of the concrete and may result in these diagonal cracks. Diagonal cracks outboard of the stem are often due to stresses during stripping, handling and erection.

Cracks are commonly observed in flange soffits near ends of double tees, at the flange-to-stem fillet joint, and most commonly the inboard fillet joint. These cracks originate at the end of the member and may extend several feet toward mid-span. Possible causes of these cracks include stresses induced during stripping, handling, and erection. In many instances, these cracks are partial depth and have no significant effect on the structural performance of the overall double tee. For field-topped decks, repair of these cracks is typically unwarranted.

Regular spaced cracking in the top surface of the pour strips is often observed and likely caused by shrinkage of the concrete. The pour strips are typically long and narrow and prone to cracking at regular spacing along their length because of the restraint of the adjacent concrete. The crack width is often small in the pour strips because of the increased amount of chord reinforcing steel crossing the cracks.

Cracks are also occasionally observed on the bottom surface of the flange in-line with the reduced thickness of the flange for the above pour strip. These cracks may be the result of the reduced section of the tee at its end or overstressing in tension of the tee flange during fabrication.

Open through-thickness cracks in the tee decks, if not protected from moisture, can lead to corrosion of the embedded reinforcing steel or prestressing steel in the stems, long-term deterioration of the concrete, and leakage into the lower levels of the garage. Although these cracks are typically not a structural concern, the cracks should be repaired to minimize water infiltration.

Figure 27. Crack at end of double tee that starts at stem connection to wall

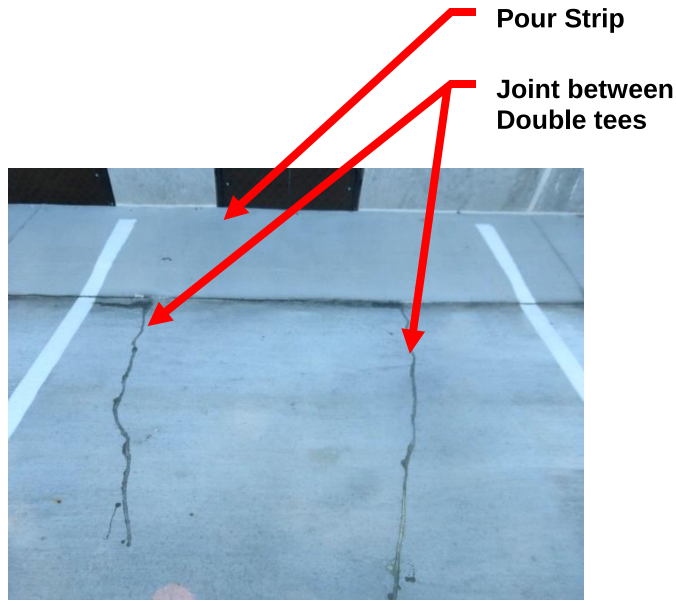

Figure 28. Cracks at end of double tee in line with at stem connections to wall (cracks in pour strips are not visible)

Waterproofing

Increased movement between the flanges as a result of failed connections often contributes to premature failure of the sealant. Sealant joints between double tee flanges prevent moisture and water from traveling between the flanges to the connections and lower levels of the garage. Water leakage can cause corrosion at flange connections and embedded reinforcing steel with the flanges. In order to provide protection to the concrete and extend the useful service life of parking structures, the sealant joints, cracks, and expansion joints should be maintained in a watertight condition. In addition, a vehicular traffic-bearing membrane system should be considered in the repair design to prevent water leakage thought the flanges and joints and to protect repairs. In our experience, given the extensive quantity of joints in precast parking structures, it is difficult to achieve a 100 percent, watertight structure without the redundancy provided with a membrane system.

Vehicular traffic-bearing membranes provide additional protection for the concrete against infiltration from moisture and deicing salts, as well as provide protection for parking spaces located directly below the decks (Figure 31). Vehicular traffic-bearing membranes can minimize future deterioration of the structure. The most vulnerable locations include the roof level which is not protected from environmental elements, along the flange edges and joints, and the cast-in-place pour strips. Membrane systems also require regular maintenance.

Figure 29. Vehicular traffic membrane on roof level ramp

CLOSING

The inherent features of precast/prestressed concrete make it a solid choice of structural systems for parking structures. With proper engineering design and detailing, high quality materials, and good construction practices, today's precast parking structures can be expected to serve owners and users for many decades. As with any type of structural system, a repair and maintenance program is necessary for precast parking structures to maintain structural serviceability and integrity, reduce uncontrolled water penetration, minimize deterioration, and extend its useful service life. Double tee flanges and their connections represent a common component of precast parking structures that benefit from proper repair and maintenance.

The conditions and repairs described in this paper are techniques that have been successfully used to repair double tee flanges and connections. Trial installations of repairs are recommended prior to implementation on a production basis. Often adjustments must be made to the scope of work, repairs, or the procedures to improve constructability of the repair, as well as accommodate unanticipated field conditions. Trial repairs also provide an opportunity to evaluate the performance of the repairs on a limited basis to evaluate their effectiveness in correcting the observed deficiencies.