Precast Concrete Parking Structures

Durability starts at the joints

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Parking structures comprise the largest market segment for the structural precast, prestressed concrete industry, providing over 50% of the industry's annual sales revenue. In U.S. practice, a typical precast parking structure incorporates concrete double tees, inverted T-beams, columns, shearwalls, stair units, spandrel panels and beams, and flat panels that are manufactured in a plant, transported to the site, and erected (Fig. 1). Because these components must be joined together in the field, proper detailing and construction of the resulting joints, particularly those exposed to traffic, are critical for ensuring long-term performance and durability.

The Precast/Prestressed Concrete Institute (PCI), the American Concrete Institute (ACI), and the National Parking Association (NPA) have published recommendations and guides defining proper design, construction, and maintenance practices for parking structures.[1-5] This article provides recommendations, with particular focus on recommendations for joints at the flanges of double-tee elements.

Fig. 1: A partially-completed precast concrete parking structure consisting of key components including columns, double tees, inverted tees, and shearwalls

TEE TOPPING

For double tees used in parking structures, building code requirements for supporting concentrated loads as well as requirements for providing fire resistance necessitate a 4 to 5 in. (100 to 125 mm) total flange thickness. This total thickness can be obtained with a single placement in the plant (so-called pretopped double tees) or using two-course construction, with an initial, 2-in.-thick (50 mm) plant-cast flange supplemented with a 2 to 3 in. (50 to 75 mm) concrete topping installed after erection.

JOINTING PRACTICE

Precast elements must be joined together within defined horizontal and vertical tolerances, with provisions made for connection requirements, sealant requirements, and crack-control requirements.

The joints between the flanges of the double tees and between inverted T-beams and the ends of the tees are very important. These joints must incorporate diaphragm connections (to ensure overall structural stability as well

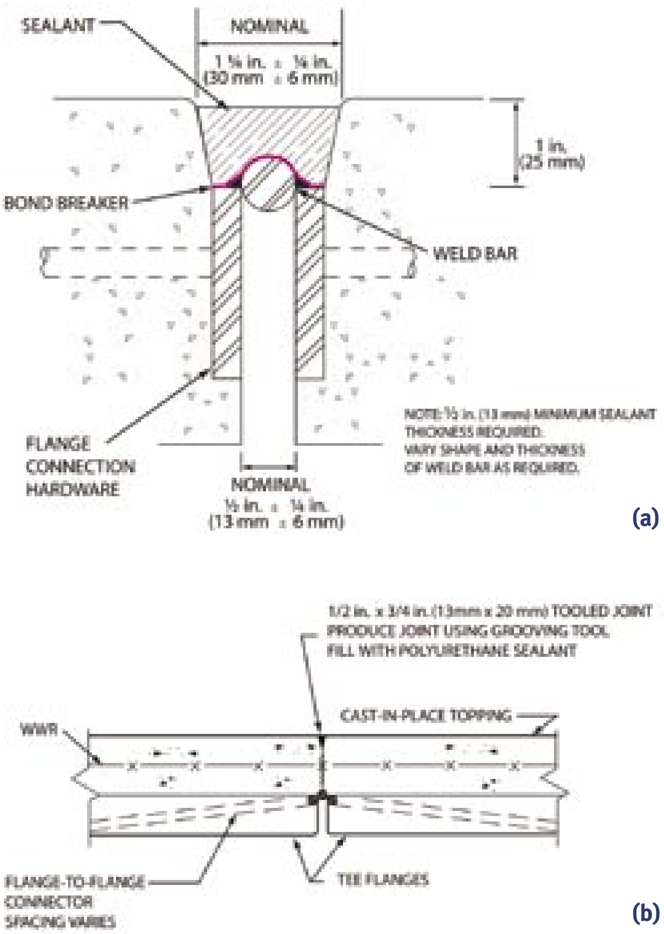

Fig. 2: Typical connection and sealant details at double-tee connections: (a) pretopped; and (b) field-topped

as to provide displacement compatibility), and they must be sealed to prevent water from entering or passing through the joint. How to effectively satisfy both requirements has been an ongoing topic of debate throughout the history of the industry, as joint failure comprises the most significant repair issue in precast parking structures.

To prevent excessive restraint of strains imposed by shrinkage and temperature changes, horizontal movement joints (expansion joints) are required in structures with large plan areas. These joints must be capable of transferring vertical shear and, as with other joints, must be sealed.

RELATIONSHIP BETWEEN CONNECTION DETAILING AND JOINTING PRACTICE

Precast concrete parking structures, whether pretopped or field-topped, require joining of the double tees at the flanges with welded connections. The locations where joints and connections come together are particularly vulnerable to performance problems. Connections are

Fig. 3: Cracking and edge spalling behind the flange connections can occur if the joints are not properly detailed

typically made using metal hardware cast into each component. After erection, the hardware is welded to complementary hardware cast into an adjacent component. Much of the following discussion focuses on the joints between double-tee elements.

With field-topped systems, the welds are covered with 2 to 3 in. (50 to 75 mm) of field-placed concrete. This inherent design feature provides the connection with some protection from chloride exposure, cracking of surrounding concrete, or other types of deterioration associated with the flange weld connections in pretopped structures (see Fig. 2). Tables 3.3 and 3.4 of ACI 362.1[1] provide recommendations regarding corrosion protection for the weld hardware itself, depending on the service environment.

Pretopped tees

Of all the jointing requirements in a precast parking structure, none is more challenging than the flange connections between the tee deck elements in a pretopped system. These connections are usually 4 to 6 in. (100 to 150 mm) long and occur every 4 to 5 ft (1.2 to 1.5 m). They must be small enough to fit within the joint space between tees (which is subject to tight tolerance controls). In addition, these connections have minimal concrete cover over their anchorage devices, will be subject to vehicular traffic, will be exposed to harsh weather, will be covered only with sealant, and must respect the sealant requirements.

The flange connections are also points of restraint to movement due to shrinkage, thermal cycling, and traffic exposure, and are vulnerable to microcracking of the surrounding concrete. The heat imposed from welding can also contribute to this potential problem.

If all of these variables are not properly taken into account, a pattern of microcracking or "halo cracking" behind the welds (Fig. 3) is likely to occur when the structure is exposed to traffic and thermal cycling. This condition can lead to extensive concrete spalling at the connection points, resulting in leakage, corrosion of the underlying connection hardware, and significant deterioration of the surrounding concrete.

With proper joint detailing at the tee-flange-weld connection, the connection hardware is embedded toward the middle of the concrete flange section, and significant concrete covers the anchorage. The weld plate itself, however, is left free at the top to allow for expansion from the heat generated during the welding process. This mitigates the tendency to introduce cracking stresses into the surrounding concrete from the expansion forces induced into the connection hardware from the heat generated by welding. The connection hardware itself should be stainless steel to provide corrosion protection if the service condition is to be exposed to chlorides. The weld anchor should be at least 1 in. (25 mm) below the deck surface to provide room for sealant over the weld and proper concrete cover.

In recent years, proprietary weld assemblies have been developed that resolve many of the issues associated with flange welds. These devices have won acceptance with many precast manufacturers despite their increased cost.

To seal the joint, a compressible backer rod is placed between the welded connections and a bond breaker tape is placed across the top of the weld hardware. The sealant is then applied in accordance with the manufacturer's recommendations. Good practice calls for recessing the sealant in the joint slightly below the deck surface to avoid direct contact with vehicular traffic. The edges of the joint should be beveled or tooled with a radius to avoid creating a 90-degree edge that can be subject to edge spalling and cracking under vehicular traffic.

Finally, the best joint performance is seen when the width of the joint is constant along its length, eliminating weld pockets that have been another source of leakage in many structures. This method reduces strain on the sealant by eliminating changes in sealant mass where the open joints transition to the weld conditions.

How the joints and welds are provided has proved to be as, or more, important to the successful performance of the sealed joints than the choice of sealant material or installation practice. Problems have been aggravated in the past because precast concrete manufacturers tend to emphasize how the welded connections and joints are provided during the manufacturing process, rather than how they will perform in the intended service condition. Service performance is a critical issue, and emphasis on proper design detailing should prevail over manufacturing concerns.

Field-topped tees

Most deck connections in precast parking structures with field-placed concrete toppings are protected by the concrete topping and therefore less vulnerable to the problems associated with deck connections for pretopped systems. Welded wire reinforcement is frequently used in the topping but is typically used as temperature steel and is not relied on for structural connections.

Field-placed concrete toppings or concrete pour strips have a strong propensity to crack in a predictable pattern over all of the intersecting planes of the underlying precast members. For this reason, joints should be tooled into the concrete topping while it is in its plastic state during finishing. The joints should be provided over the intersection of all underlying precast members using a common concrete groover similar to the tool used to provide sidewalk joints. The joint should be a minimum of 3/4 in. (20 mm) deep with a top width of 1/2 in. (13 mm) and a 1/8 in. (3 mm) radiused edge at the driving surface. These joints should be sealed with polyurethane sealant in accordance with the sealant manufacturer's recommendation. Bond breaker or filler rod is normally not required to successfully seal joints of this type because movement is restrained by the presence of reinforcement steel, welded connections, and welded wire reinforcement through the joints in the topping.

How the joint is provided is important to sealing practice. As a general rule, a sealed joint with a tooled, formed, curved, or chamfered edge will perform better than one provided by sawing. Sawed joints in concrete toppings and pour strips are not recommended because they are prone to edge spalling and random, uncontrolled cracking behind or along the sealant bond line. This is due to several factors: sawing of joints can be delayed until after cracking tendencies develop; joints may not be precisely located, leading to uncontrolled cracking parallel to the joint; and the sharp edge left does not perform well under vehicular traffic.

JOINT SEALING

Joint sealant performance is important in controlling leakage and prolonging the service life of the surrounding concrete and underlying connection hardware. Movement in the joint, exposure to weather or traffic, the type of sealant used, and the integrity of the substrate to which the sealant is applied all affect performance.

Joints should be prepared so that sealant will be applied to clean, dry, sound concrete substrates. Any curing compounds and form release agent should be removed prior to applying the sealant in compliance with the manufacturer's installation recommendations.

Experience has shown that the use of backer rods and the cross section of the sealant geometry are not particularly important to joint sealant performance in cases where joint movement is restrained by underlying reinforcement or connections through the joint.

Preparation methods and adequate depth of sealant and adhesion area are more important considerations for successful performance in these applications. Sealant geometry and backer rod practice is important, however, for joints that are left unrestrained and allow movement to occur by design intent. Traditional sealant practice should be followed for these conditions.

Polyurethane sealants are typically used to seal the joints. These products have properties well suited to the application and have a long history of providing cost-effective service. Silicone sealants are sometimes used, but cost approximately three times as much as urethane sealants and are not well suited for traffic exposure. They do offer some potential performance enhancements where directly exposed to intense sun, however, such as in the southern and southwestern regions of the U.S., as they are more resistant to UV-related deterioration.

Joint sealant failure allows intrusion of water and chlorides into and through the structural elements. This can lead to a variety of problems including nuisance leakage, corrosion-related concrete deterioration, and accelerated structural deterioration that may shorten the service life of the structure.

Deterioration of the substrate directly behind the sealant—due to concrete edge spalls or cracking behind flange connections or elsewhere along the joints—is a more common cause of leakage and deterioration than premature sealant failure. If sealant failures and related leakage problems are left unrepaired for extended periods, concrete deterioration will likely occur.

CONCRETE SURFACE PROTECTION

The precast, prestressed concrete elements used in parking structure construction are produced in manufacturing plants with practices that provide very durable concrete. When concrete toppings and pour strips are to be used in combination with precast elements, it's important to also use concreting practices that produce durable concrete. The use of air-entrained concrete with a water-cement ratio of 0.40 or less to complement the durability of the precast members and proper curing practice are important.

In geographic areas where freezingand-thawing cycles and chloride exposure are likely, a silane sealer is typically applied in the field to the deck surface. These sealers further enhance the durability of the precast deck elements and decrease water absorption of field-placed concrete toppings and pour strips. A traffic deck coating is also commonly used to provide additional positive waterproofing protection in areas of the structure located over occupied space.

MAINTENANCE

All parking structures require periodic maintenance. For precast parking structures, the emphasis should be on maintaining the joints to keep them as watertight as possible. A yearly inspection is recommended to locate sources of leakage (typically along joint lines or through cracks), followed by spot repairs consisting of cutting out damaged or failed sealant back to sound substrate and replacing with new sealant. Leaking cracks should be routed out and filled with sealant. These actions, taken on a regular basis, will minimize the potential for deterioration of the concrete and corrosion of the embedded metal hardware at connections. These conditions can require significant repair expenses if they are allowed to reach an advanced state.

The expected service life of joint sealant systems is dependent upon weather exposure, tolerance control of the precast members, vehicular traffic conditions, and snowplowing procedures. High-quality polyurethane sealants should last 7 to 10 years before requiring general replacement in conditions where they are directly exposed to the sun, rain, and snow and twice that time where they are protected from the weather. Replacement of the joint sealant systems during the service life of the structure should be expected and planned for accordingly.

PCI,[3] ACI,[4] and the Parking Consultants Council of NPA[5] have all produced helpful maintenance guides with specific recommendations for developing and administering maintenance programs for parking structures of all types.

DURABILITY STARTS AT THE JOINTS

The advantages of precast, prestressed concrete for use in parking structures are well known as confirmed by the widespread use of these systems. Precast, prestressed concrete is extremely durable and resistant to the corrosion problems common in parking structures. Because the distinctive feature of these structural framing systems is their segmental nature, jointing practice is critical. Failure to properly provide, detail, and maintain the joints and joint-sealing materials can result in extensive leakage, corrosion of the connection hardware, and deterioration of the concrete substrate, reducing the expected service life. The welded connections between double tees are an especially vulnerable location, requiring care in both the weld detail and sealant practice to minimize the potential for leakage and related deterioration.

Properly addressing the issues outlined in this article, as well as those provided in the ACI[1] and PCI[2] design guides, will minimize these potential problems. Joint maintenance and joint system replacement at scheduled intervals should be planned for to ensure satisfactory service.

References

1. ACI Committee 362, "Guide for the Design of Durable Parking Structures (ACI 362.1R-97)," American Concrete Institute, Farmington Hills, MI, 1997 (Reapproved 2002), 40 pp.

2. PCI Committee on Parking Structures, "Precast Prestressed Parking Structures: Recommended Practice for Design and Construction," Precast/Prestressed Concrete Institute, Chicago, IL, 1997, 141 pp.

3. PCI Committee on Parking Structures, "Maintenance Manual for Precast Parking Structures," Precast/Prestressed Concrete Institute, Chicago, IL, 2004, 25 pp.

4. ACI Committee 362, "Guide for Structural Maintenance of Parking Structures (ACI 362.2R–00)," American Concrete Institute, Farmington Hills, MI, 2000, 15 pp.

5. "Parking Garage Maintenance Manual," National Parking Association, Washington, DC, 2004, 111 pp.

Selected for reader interest by the editors.

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