

STRUCTURAL REHABILITATION

renovation and restoration of existing structures

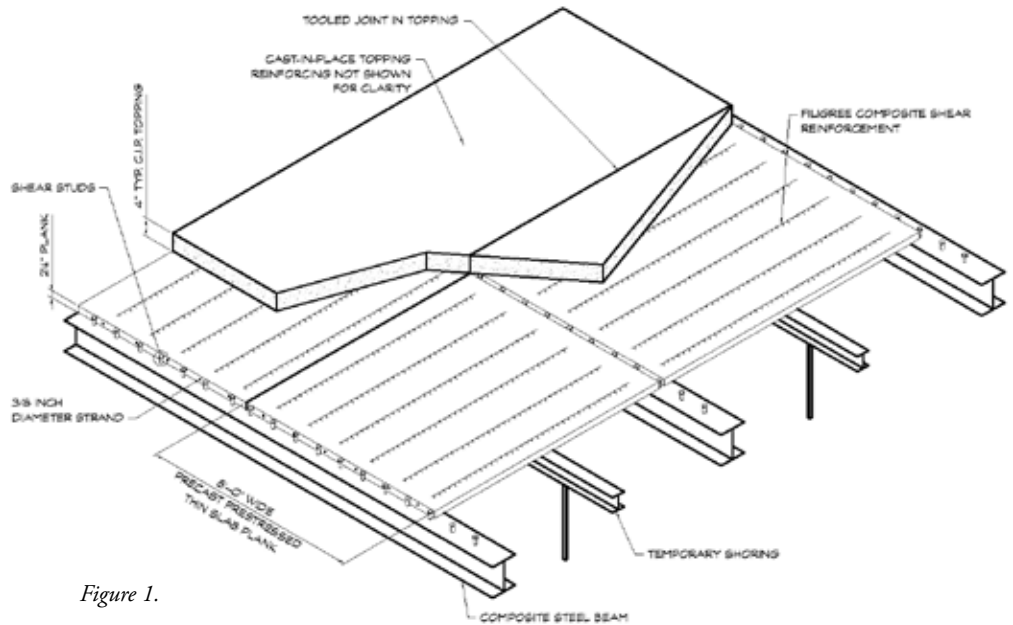


Figure 1.

Precast, Prestressed Thin Slabs in Parking Garage Structures

Or, When Thin is a Not a Win-Win

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Recently, Pennoni Associates was involved in the investigation and assessment of several existing parking garages constructed with precast, prestressed thin slabs. In this type of structural system,

precast planks function as stay-in-place formwork and become a part of an overall composite slab once a field-cast topping is placed and the shoring is removed. Although this type of construction is common in bridge decks, it is more unusual in parking garages, except perhaps in the Delaware Valley and surrounding region. In those areas, it is popular in cast-in-place concrete building construction as a voided system and is referred to as Wideslabs. There appear to be no similar precast, prestressed thin slab products available for commercial use in the remainder of U.S.

The System

The cross-section of the thin composite slab typically consists of a 2 1/4-inch-thick by 8-foot-wide solid precast, prestressed concrete planks in combination with a minimum 4-inch-thick cast-in-place concrete topping. The system is capable of clear spans of roughly 20 feet between beams that act compositely with the topping – either structural steel (Figure 1) or precast U-shaped beams that are infilled when the field-cast concrete is placed (Figure 2). The erection of the planks and beams requires the use of temporary shoring that remains in place until the field-cast topping is placed and has achieved adequate compressive strength.

The composite capabilities of the combined precast planks and cast-in-place topping is provided

primarily via vertical lattice or “filigree” reinforcing that is cast into the precast planks but protrudes above the top of them in order to engage the topping. The primary positive or bottom flexural reinforcing of the resulting system is provided by the prestressing strands (typically 3/8-inch diameter) in the precast planks, while the top or negative flexural reinforcing is provided via conventional deformed bars in the topping. Temperature and shrinkage reinforcing is also provided transverse to the slab span in both the precast planks and the cast-in-place topping.

Unlike similar thin precast components used in parking garage construction, such as double tee flanges, mechanical plank edge connections (e.g., embedded plate weldments) are not employed along the abutting joints of adjacent planks. As a result, the nominal transverse reinforcing in the topping and aggregate interlock of the cast-in-place concrete are the only mechanisms available for transferring moving, concentrated vehicular wheel loads across the open joints below, as well as the tooled joints in the topping that generally align with the plank joints. A search of the available literature indicated that the structural capability of this portion of the thin slab system to function properly in a parking garage appears to be untested.

The Problem

Similar to an aged and failed, tooled and sealed topping joint in a typical double tee parking garage structure, joints in a thin slab garage structure will allow for moisture intrusion into the joint. The moisture, which is typically contaminated with chlorides from deicing salts either applied to the surface or brought in from the road by vehicles, tends to migrate through the

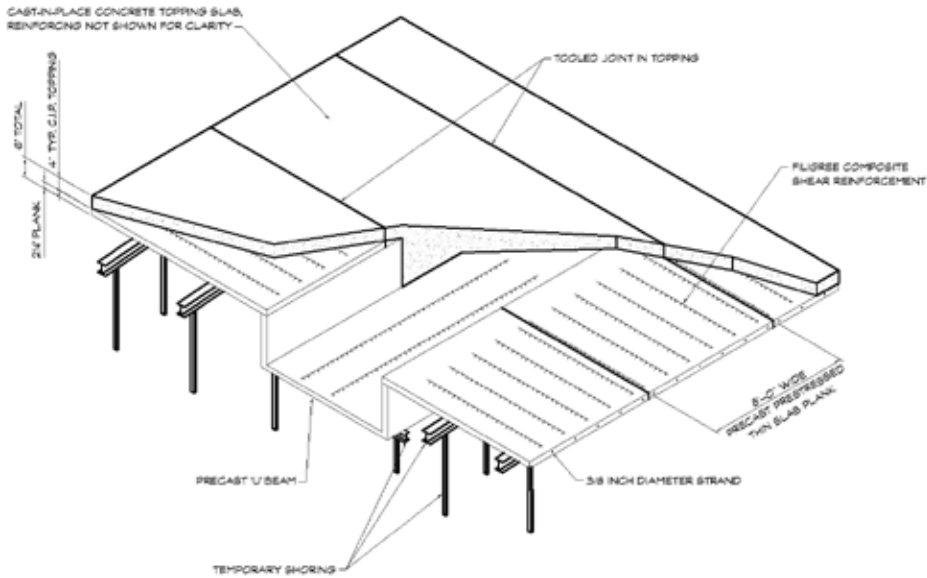


Figure 2.

joint. The moisture flows horizontally into the interface between the topping and precast via capillary action, and across the bottom surface of the soffit of the precast (Figure 3). As a result, any reinforcing steel that is adjacent to the joint will begin to corrode, causing the surrounding concrete to deteriorate.

In a double tee flange edge, this can result in isolated damage to the connectors and mesh reinforcing, which can often be repaired conventionally. In a thin slab plank, however, the proximity of the outside strand to the joint edge can result in the corrosion of a portion of the primary positive flexural reinforcing in the composite slab system. If the two outside strands of a typical 6-strand plank become corroded to a point at which a considerable amount of cross-sectional area is lost, or the strand is completely consumed – which is frequently the case because of the relatively

small diameter of the strand (Figure 4) – the associated 8-foot-wide section loses 33% of its positive moment capacity.

This vulnerability of the thin slab system is exacerbated by the lack of an adequate vertical load transfer mechanism at the joints. This susceptibility was evident even in garages that were only 5 to 10 years of age in which the condition of the tooled topping joint sealant appeared to be in very good condition. Test results indicated that the same level of contamination existed at both the driving surface above and the plank soffit joint edge below, with water-soluble chloride content as high as 2.63% by mass of cement versus an ACI-recommended limit of 0.06% for prestressed members. Similar planks in bridge decks do not appear to exhibit this phenomenon, primarily because tooled and sealed joints in the topping are not routinely used in such construction.

Petrographic testing of thin slab planks revealed additional susceptibilities of the product, including the lack of sufficient air-entrainment and concrete cover beneath the strands that was less than the 1-inch minimum recommended by ACI for precast slabs. In addition, laboratory testing revealed significant coarse aggregate segregation due to high-slump concrete and/or over-vibration, as well as carbonation as deep as 1 inch from the bottom of the soffit.

The Solution for Older Garages

The inability of individual deteriorated planks with completely corroded strands to share the support of imposed vertical loads with adjacent intact planks, due to the lack of mechanical connections at the thin slab joints, caused concern for the structural integrity of these planks. Furthermore, it was also not unusual for adjacent strands in adjoining planks to be corroded as well. This led to the development of the following mitigation strategy for the unsafe conditions created in garages, that were approximately 30 years of age, by the loss of one or more strands out of the available six in each plank.

Based on the age of these older garages, the original design live load was probably 50 psf. Comparing this with the current minimum garage live load of 40 psf suggested a reserve capacity of 10 psf, or 20% of the assumed original live load capacity of the planks. A loss of only one out of six strands equated to a strength reduction of approximately 17%, which was less than the 20% reserve capacity. Therefore, planks that had only lost one strand were deemed to be still capable of safely supporting the minimum imposed live load.

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Figure 3.



Figure 4.



Figure 5.

The loss of two out of six strands, which was the maximum strand loss documented in any of the 30-year-old planks, equated to a strength reduction of approximately 33%, which was greater than the 20% reserve capacity. These planks required the installation of aluminum shoring beams immediately below the location of the corroded strand, which were shimmed tight to the underside of the plank soffit. The shoring beams spanned between, and were supported by, the existing steel beams that provided the original support of the planks (Figure 5).

The composite nature of the plank and topping, made possible by the vertical lattice shear reinforcing, also makes it difficult to facilitate conventional repairs to both the precast and cast-in-place components of the slab system. This is because the vertical shear reinforcing is not robust enough to avoid being significantly damaged when subjected to the renovation demolition of the surrounding concrete. Supplanting the existing shear reinforcement with alternate means of providing composite action was also not considered practical or economical. As a result, any repairs from the top surface or bottom soffit that encountered the shear reinforcement would cause a loss of composite action between the planks and topping.

This condition meant that practical options for conventional concrete repair were extremely limited. Additional challenges in the older garages included the absence of a chloride extraction or re-alkalization system that would not risk hydrogen embrittlement of the strands, insufficient concrete cover over the reinforcing, and non-uniform

air-entrainment and the resulting susceptibility of the concrete to freeze-thaw damage. Because of these impediments, the most practical and cost-effective method of renovating the older garages involved the complete demolition, removal, and replacement of the existing composite slab system. A review of several options led to the selection of a 3¼-inch-thick cast-in-place slab on top of a shored 3-inch-deep composite metal deck, for a total thickness that matched the original slab system.

The Solution for Newer Garages

The mitigation strategy for the newer garages, where the extent of chloride contamination and carbonation had not yet resulted in corrosion of the plank strands, was different. Due to the limited ability of the filigree vertical lattice reinforcing to withstand renovation demolition of the CIP topping and the difficulty of replacing it with an alternate method of ensuring composite action between the prestressed planks and the topping, the success of repairs to the surface delaminations was difficult to predict. This led to the recommendation to conduct a limited test program at one of the deteriorated surface areas in order to assess the potential for successful repair. In order to prevent further moisture intrusion at the plank joints and the subsequent introduction of road salts, the top wearing surface would be coated with a waterproofing membrane after such repair.

The presence of significant chloride contamination of the plank soffits at the joint edges, even with the elimination of further

chloride-contaminated moisture migration due to the presence of a new surface membrane, would result in the eventual corrosion of the affected strands. This potential existed because of the exposure of the concrete to ambient conditions, which would allow for enough humidity in the concrete to be present to enable corrosion cells to develop. The recommended solution was installation of a surface-applied, metalized cathodic protection system on the plank soffit at the area of chloride contamination.

The recommended proprietary system was capable of providing long-term galvanic protection without damaging the prestressing steel via hydrogen embrittlement. The location and extent of the metalized cathodic system was established based on the results of an Electrical Resistivity survey. This allowed for the extent of the potential for corrosion to be mapped in areas not immediately adjacent to the plank joints, to ensure that the protection system did not have to be installed over the entire soffit.

Conclusion

The results of the investigation revealed the susceptibility of precast, prestressed thin slab parking structures to corrosion and resulting loss of strength over the life of this type of construction. It is interesting to note that the International Parking Institute began discouraging the use of this type of product in parking garages in 2004. In addition, a number of reputable consulting engineering firms that specialize in the design of parking structures do not recommend the use of precast, prestressed thin slab members in garages. ■