Case Studies in Structural Repair of Pretensioned Concrete Products

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Case studies show various types of repairs that are sometimes necessary to rectify precast, prestressed concrete products. The cases show types of damage that can be caused by overloading, underdesign, quality control errors, accidents, and unanticipated events. The types of repair methods discussed are epoxying cracks, applying patches, enlarging the member with steel, and adding supplementary structural members. A precast member that is only slightly damaged can simply be patched or epoxied once the source of damage is removed. One case is found to be not repairable and the member is recast due to the severity of the defect and the time and cost involved in repairing it. It is found that damage may be limited by meticulous production and quality control, good communication with erectors, and careful detailing and testing of new design concepts.

Because precast, prestressed concrete products are fabricated under carefully controlled factory conditions, such members rarely need to be repaired after fabrication. However, there are occasions when, precast, prestressed concrete members need to be repaired because they are miscast, accidentally damaged, or become deteriorated over time. This paper discusses methods to locate causes of damage, methods to prevent future damage, and repair options so that a quality product can be provided with the necessary structural capacity and durability.

Five case studies will show various repair methods. The damage may arise because of numerous causes. It is important to ascertain the cause and extent of the problem so the repair can be effectively executed.

Cracking in pretensioned concrete members can be organized into two categories, namely, those that affect the integrity of the entire structure and those that only affect the member itself. Cracks can be sealed using epoxy injection to prevent moisture intrusion. However, this measure may not remove the root cause of the cracking. All repairs must be directed to restoring the structural integrity of the overall structure and to preventing continuing damage.

The main causes of structural cracking are overloading, errors in design and design details, errors in construction, and accidents. The cause of cracking is found by looking at the location of the crack compared with the structure, the pattern of cracking, the relationship of the crack to the reinforcement (both prestressing and mild reinforcing steel), the depth of cover over the reinforcing steel, the direction of the cracking, and the member deflection.[1,2]

The case studies were gathered from more than one fabricator. It is shown that some defects need only epoxy injection or patching, some can be effectively repaired, and a few cases are too severe to be economically repaired. In general, the repair of pretensioned concrete is more challenging than for reinforced concrete. The biggest task is to get the patch material that is not pretensioned to actively resist the loads.


Fig. 2. Water Treatment Basin.

CASE 1: A PATCHED SPALL

A double tee stored in the fabrication plant was damaged when a storage yard tractor accidentally hit the double tee. The tractor hit the interior side of the stem causing a spall on the upper third of the stem as shown in Fig. 1. The stem was 30 in. (762 mm) high and the width varies from 4.75 in. (121 mm) at the bottom to 7.75 in. (197 mm) at the top.

The collision caused a spall 1.5 ft long x 8 in. wide x 1.5 in. deep (457 x 203 x 38 mm). An investigation revealed that there were no cracks in the stem or flange and no reinforcing steel was exposed. The pretensioning strands and the concrete around them were in good condition.

It was found that the spall did not affect the bearing capacity or the shear or anchorage strength of the double tee. The spall was patched using the following procedure:

First, all loose concrete and dust were removed. Then, the area was thoroughly saturated with water to prevent absorption of water from the repair mix. A bonding agent was brushed well onto the surface.

The concrete mix was placed in layers of less than 0.5 in. (13. mm) thickness and consolidated by hand tamping. Each layer was placed after about 10 to 15 minutes. The patching concrete was fast curing reaching 3000 to 5000 psi (21 to 35 MPa) in 24 hours so delays were limited. The double tee was repaired, shipped, and erected at the job site with no further problems.

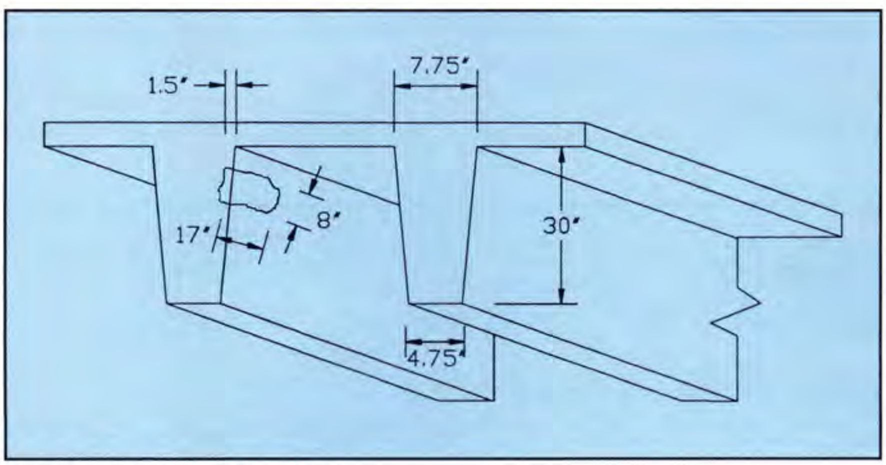

Fig. 1. Spall in a double tee stem.

CASE 2: FROZEN BEAM SLEEVES

Inverted tee beams and double tees were used to construct a water treatment basin in the Detroit, Michigan area (see Fig. 2). A few weeks after erection, it was noticed that three of the inverted tee beams were cracked in the bearing area on one end of each beam as shown in Fig. 3. All the cracks were located solely on the east end bearing area of the beam. The cracks were found in different directions on each beam and where the bond between the prestressing strands and concrete had been released.

The reason these beams were cracked was that water froze in the sleeves provided for the connections with the columns. The problem did not arise on the other beams and on the other ends of the damaged beams because all the other sleeves were covered with duct tape. Fabricators and erectors should be aware that water freezing inside a tube or duct is a problem. Rainwater and curing water can be kept out of sleeves by capping the ducts with tight fitting plastic caps or by grouting the ducts.

The beam was analyzed to find whether any repairs were required.

Fig. 3. Inverted tee beam cracks.

Fig. 4. Sealing cracks.

The loss of bond between the prestressing strands and concrete changed the moment capacity diagram by moving inward the point where the beams develop their full strength. The maximum ultimate moment strength at midspan was not changed since the beam length was sufficiently long to allow full strand development.

The debonding of strands at the ends of beams is sometimes intentionally done with sheaths or masking tape to reduce end tension and compression stresses as discussed by Kannel et al.[3] and Russell et al.[4] Rose and Russell[5] showed that strand end slip is an excellent indicator of bond or loss of bond. Civjan et al.[6] presented an instrument that uses slip to determine the amount of prestress in strands.

The shear capacity of the beam was not altered because the cracks were located over the support. However, an analysis showed that by neglecting the concrete shear strength, the reinforcing bar stirrup, acting alone was strong enough to support the load. The concrete shear strength need not be totally neglected when the concrete is cracked.

Shear strength after the concrete cracks is called shear friction. Shear friction relies on several mechanisms including aggregate interlock and dowel action. Tests are needed to find what portion of the strength remains after cracking. The authors recommend against patching a shear crack, but only epoxying it because a patch has lower shear friction capability than a crack in monolithically poured concrete.

The beams were badly cracked in the bearing area. However, the bearing plate was capable of carrying the forces to the concrete. These bearing plates are commonly designed assuming cracks have developed. Bearing loads are carried similarly in reinforced and pretensioned concrete. Therefore, if a patch is necessary, then re-prestressing a patch is not a concern.

All of the strength checks were satisfactory, so the cracks were repaired by epoxy injection. Note that the high-pressure injection can squeeze the epoxy out of the member through invisible cracks. Therefore, to seal the surfaces it is necessary to apply a sealant (such as Bondo) generously on and around the visible cracks as shown in Fig. 4.

Epoxy seals the cracks closed but its structural strength is neglected in these repair calculations. Epoxy is typically selected for repairs based on its viscosity, sealing, and durability properties. In order to use its structural strength, the epoxy selection needs to consider the tension and compression strengths of the material.

ACI Committee 503[7] recommends that to achieve proper bond, the crack must be free of loose and unsound material. The soundness needs to be tested by pull-out tests on core samples. However, prestressed concrete is often highly congested with reinforcement. It is difficult to get enough core samples to guarantee concrete soundness. The amount of loose and unsound material in cracks needs to be quantified in future tests. These tests will indicate the amount of epoxy that has proper bond with concrete. Therefore, the effective epoxy strength can be found.

CASE 3: CONSTRUCTION OVER-LOAD SHEAR CRACKS

A double tee at a water treatment basin in Detroit, Michigan failed (see Fig. 2). The double tees were required to support soil for a golf course. The double tee did not collapse but 1 in. (25 mm) wide shear cracks formed (see Fig. 5).

There were three reasons why the beam failed. First, the top of the double tee was used as a stacking area for the soil. The soil rose 8 to 12 ft (2.4 to 3.6 m) high. Second, heavy machines and bulldozers were used to distribute the soil on the slab. Their weight and the impact load exceeded the double tee's capacity. Third, the soil was compacted by at least 30 to 40 percent over the specification limit. The double tee was required by contract documents to support 4 ft (1.2 m) of soil but was designed to carry only 6 ft (1.8 m) of soil in anticipation of the uncertainties illustrated above.

The costs for three repair options were estimated. The first option was to

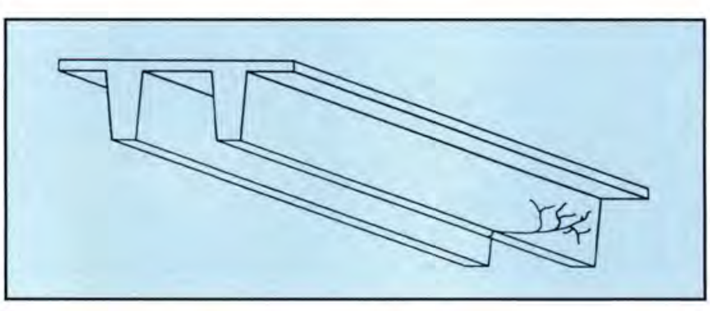

Fig. 5. Shear cracks in double tee.

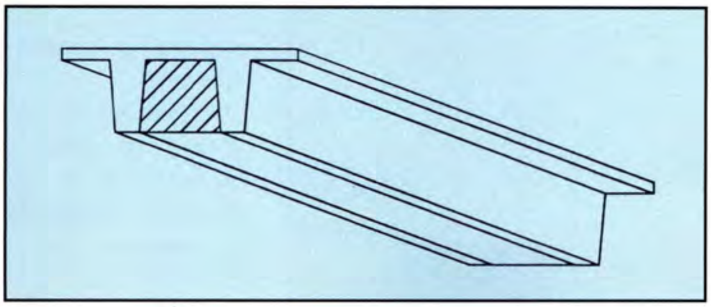

Fig. 6. A cast-in-place repair option.

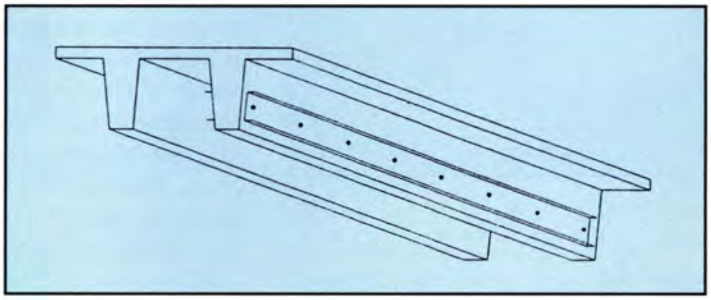

Fig. 7. A steel channel repair option.

replace the double tee. This was rejected because of high cost and time delays. The replacement would involve removing all the soil from the top of the double tee, cutting all the welds and removing the double tee, replacing the new component and welding it, and recompacting the soil. One major difficulty was removing the compacted soil from the top of a broken double tee without using any machines that could cause its collapse.

The second option was to cast-in-place a filler beam as shown in Fig. 6. This is costly because it is hard to pump the concrete into and vibrate the concrete inside the basin.

The third option was to strengthen the broken stem of the double tee with two steel channels as shown in Fig. 7. This was the most cost-effective method because it was easy to design and construct. The beam was jacked up and the cracks were epoxied. The channels and connecting bolts were galvanized because no exposed steel is allowed in the high humidity basin.

All of the repair options involved replacement or enlargement. The jacking and epoxying may have been able to fully repair the double tee and restore its shear strength. However, the flexural strength of the double tee could not be restored considering that Shahawy and Batchelor[8] found that strand debonding occurs as shear cracks open. Broken or debonded strands may be spliced but splicing would have been a more difficult repair option.[9]

CASE 4: PARKING STRUCTURE

A parking garage was built with precast, prestressed concrete columns, walls, beams, spandrels, and double tees. The double tees had 2 in. (51 mm) flanges with 3 in. (76 mm) of topping. After the topping was placed, the erector noticed cracks in several places in the shear walls and double tees.

The shear walls are shown in Fig. 8. The walls had 5 x 5 ft (1.52 x 1.52 m) cut-outs to reduce a driver's blind area. Brackets to carry ledger beams were inserted on top of each opening. A plan view of the ramp is shown in Fig. 9.

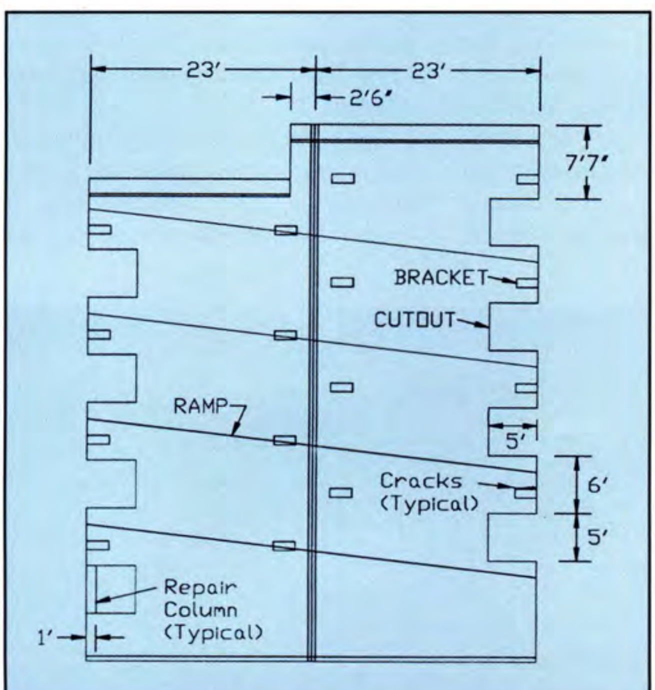

Fig. 8. Elevation view of shear wall.

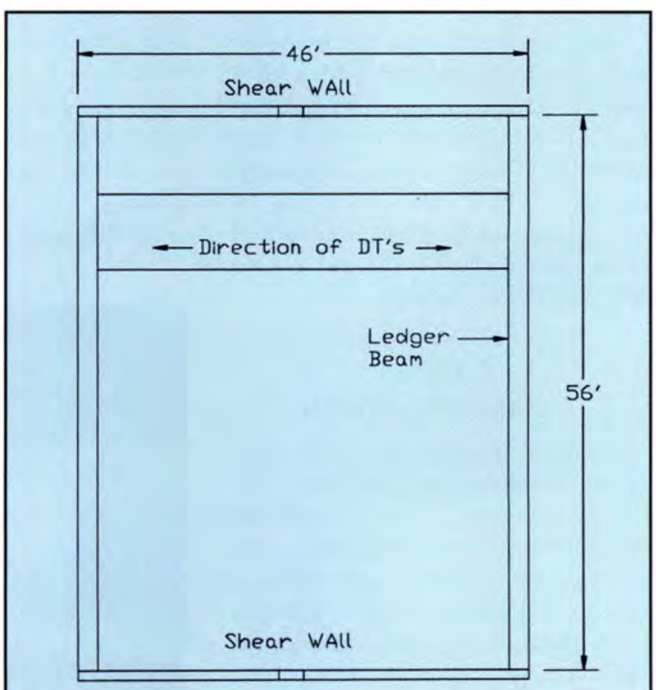

Fig. 9. Plan view of parking structure ramp.

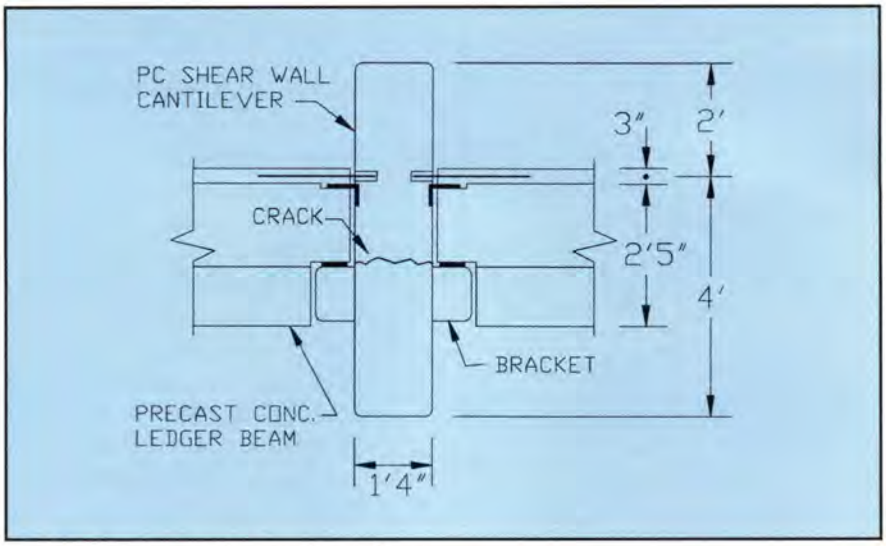

Fig. 10. End view of shear wall cantilever.

The shear walls cracked at the top of the brackets as shown in Fig. 10. Some double tees carried by the ledger beams were cracked due to induced torsion. The projection of the shear wall acts as a cantilever. This failed to carry the superimposed dead load. The cracks did not affect the strength of the main portion of the shear wall.

The repair options were either to enlarge the cantilever area or to add columns in the cut-outs. It was more economical to cast 1 ft (0.305 m) wide columns in the cut-outs. An example of this is shown in the bottom left cutout of Fig. 8.

The load was carried alternatingly through the columns and walls until it reaches the foundation. The columns partially reintroduced the blind area although much visibility was still available. The columns were cast by jacking the cantilever up. Note that all cracks in the shear walls and double tees were epoxy injected.

CASE 5: A CASTING ERROR

A manufacturer began casting large bridge box beams 4 x 4 x 120 ft (1.22 x 1.22 x 36.6 m). A casting problem occurred in the production of the first beam. Upon removal of the forms, it was noticed that there was no concrete cover along a 25 ft (7.6 m) segment and in two smaller areas (see Fig. 11).

The voids had shifted to one side under the pressure of the poured concrete. The voids shifted because an insufficient number of cover clips were provided. Holes were drilled to find the cover in other places. The cover varied from the design value of 6 in. down to 1 in. (152 to 25 mm).

At first, it was considered to repair the box beam by bending the stirrups into the voids and recasting the web. Shear could have been carried in the recast web. Thus, the shear forces would be transferred across the joint by shear friction. The web need not be prestressed to carry shear.

There are several things to consider when evaluating the bending strength. The recast web will not be prestressed. The effective section modulus for evaluating the prestress does not include the patch but includes a doubly thick web on the other side. This asymmetry causes variations in the prestress from side to side. Secondly, since the recast web is not prestressed, tension stresses cause cracking in the web due to superimposed dead and live loads.

To validate the strength of the beam, a load test would have to be done. Based on these considerations, the beam was judged not repairable and a replacement was cast.

FURTHER STUDY

One purpose of this paper is to clearly document repair methods. This is needed so that such methods can be shown to the owner's representative or inspector to convince them that precast, prestressed concrete can be effectively repaired. Owners' representatives frequently lack training in precast, prestressed concrete and become unreasonably fearful when confronted with an unusual situation. Beyond this paper, further efforts such as convening a PCI Task Force on recommended repair methods could standardize such procedures.

The design of repairs would be simplified if certain tests were done. First, in most cases, the strength of the epoxy is neglected in the design of repairs. It should be quantified by testing repaired prestressed concrete to failure and evaluating the soundness of the epoxy bond. Secondly, the shear friction strength and aggregate interlock on cracks are usually neglected if the cracks have opened. The effects of jacking cracks closed should be quantified since it will improve aggregate interlock.

Cracks cause debonding of strands and mild reinforcing steel that may or may not be significant depending on the region of the beam being affected.

Fig. 11. Exposed voids in a box beam.

The effects of epoxing and crack opening on strength should be investigated in the bending shear and bearing/anchorage regions of beams. With this knowledge, repair methods can be addressed more effectively.

CONCLUSIONS

Repairs to precast, prestressed concrete products are expensive and time consuming. They cause job delays and disruption to plant and project schedules. Repairs also affect profits because the costs incurred are not budgeted due to their irregular occurrence. In extreme cases, they may lead to litigation and poor customer relationships.

The best ways to prevent a repair is to have meticulous quality control in the plant, to have good communication with erectors, and to thoroughly check design features focusing on new design concepts. However, on occasion when these measures are not sufficient, the repair methods discussed in this paper need to be utilized.

Spalls may be simply patched if the spall does not cause cracks that reduce the strength of the member. Cracks may indicate loss of strength depending on the amount of crack opening. Prestressed concrete design often assumes that cracks form. Therefore, steel is designed to carry all the tension stress. Hairline cracks may simply be sealed to ensure durability due to environmental exposure. However, when a crack opens it indicates that some form of debonding has occurred.

In such cases an analysis should be performed to see if this debonding significantly affects the strength of the member in the controlling zones. When a structural repair is necessary to increase strength, a variety of options are available. Cost, obviously, is a factor that should be considered in choosing the best option.

In each of the illustrated cases the damage was visible to either the plant crew or to the erectors. However, the cause of the damage was not always immediately apparent. If the cause of damage is not obvious, then the first step should be to look for any unexpected loads affecting the member. A second step is to compare the as-built structure to the specifications, and to check the engineering assumptions.

In conclusion, it is apparent that much work remains to be done in procedures leading to the repair of precast, prestressed concrete members.

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