REPAIR AND REPLACEMENT OF PARTIALLY GROUTED EMBEDDED EXTERNAL TENDONS

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REPAIR AND REPLACEMENT OF PARTIALLY GROUTED EMBEDDED EXTERNAL TENDONS

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This paper discusses the removal and replacement of two partially grouted embedded external tendons in a two-span 220 ft (67 m) long viaduct. Embedded external tendons were used for cast-in-place viaducts for the Terminal Area Roadways Project (TAR) at Boston Logan Airport in Massachusetts. The project comprised more than 200,000 ft^2 (18,580 m^2) of viaduct. More than 70% of the viaducts were designed using external tendons partially embedded in the bottom slab of the box girder near midspan. The remaining viaducts had internal tendons inside the webs due to their tight curvature. The quality and integrity of grout is of prime importance for the structural integrity and long-term durability of post-tensioned concrete structures. Grout is one of several layers of protection against corrosion. It prevents corrosion of the strands by completely encasing them, it prevents water from collecting and freezing in the ducts by eliminating all voids, and it provides effective bond between prestressing steel and concrete. Improperly grouted tendons do not meet specifications or performance requirements and must be repaired or replaced. This paper discussed repair alternatives and successful replacement of two partially embedded external tendons that were improperly grouted. These tendons will be referred to as "partially grouted" hereafter.

KEYWORDS

bent pipes; deviation saddles; polyethylene ducts; repair, strands; tendon replacement; unbonded tendons.

INTRODUCTION

Early use of external prestressing dates back to the late 1920s when external tendons were first used in prestressed concrete bridges in Germany.[1,2] By the late 1960s, external prestressing was applied in some bridges in Belgium, France, and England. However, because of insufficient corrosion protection of these tendons in these early applications, many of the external tendons corroded.

There are multiple levels of protection for post-tensioned tendons. According to FHWA,[3] six possible protection levels can be provided depending on the post-tensioning (PT) system used and the surrounding environment. These include exterior protection to concrete member, concrete cover, PT duct, grout, sheathing/coating of strands, and corrosion resistance of the strands themselves. According to the FHWA recommendations,[3] a good practice requires at least three of these levels be properly applied from anchorage to anchorage.

Grout is a mixture of cementitious materials and water with or without mineral additives, admixtures, or fine aggregate, proportioned to produce a pumpable consistency without segregation of the constituents, injected into the duct to fill the space around the tendons.[4,5] The use of grouted PT tendons as a viable construction technique began in the 1950s. Since then, many post-tensioned systems have been used and grout and grouting techniques have improved. During the 1990s and early 2000s, prepackaged grout gained popularity in the United States. The grout material, testing, design, and application were first specified in 2001 in the first edition of PTI M55.1, "Specification for Grouting of Post-Tensioned Structures."[4] Those specifications helped improve grouting practices.

The quality and integrity of grout is of prime importance for the durability of PT concrete structures. Grout prevents corrosion of the strands by completely encasing them, prevents water from collecting and freezing in the ducts by eliminating all voids, provides effective bond between prestressing steel and concrete, and completes the concrete cross section. Potential problems in grout may arise from the quality of grout, application methods, joints and sealants in PT ducts, and vibration at early age.[6] Another factor that may contribute to inadequate strand protection is the draping of tendons. If bleeding occurs in the grout, voids may appear at the tendon high points.

According to the specifications for grouting of post-tensioned structures published by PTI,[7] the following factors can influence the quality of grout: 1) cement hydration rate, which affects working time and set time; 2) grout fluidity as a function of time and temperature; 3) volume control; 4) permeability; 5) strength; 6) bleed stability characteristics; 7) level of corrosion protection required; and 8) segregation of materials during mixing and placement. There are several ASTM specifications that control these factors, such as ASTM C953,[8] which specifies initial minimum and maximum set time at 3 hours and 6 hours, respectively, and ASTM C1202,[9] which specifies maximum permeability at 2500 coulomb. In addition, PTI requires certification for grouting and PT personnel in the field. The Virginia Transportation Center for Innovation and Research (VTIR) has made several recommendations[10] concerning grouting operations. These include design recommendations as well construction and material recommendations. VTIR[10] recommends mockup tests for major PT projects and, for the most critical tendon locations, to identify potential grouting problems prior to grouting operations.

Among the other issues addressed in the third edition of PTI M55.1-12[7] are the chloride content and segregation of grout. Some of the practices that were allowed in the 2001 specification[4] were tried to remedy the grouting problems in this project. These practices are no longer acceptable in the 2012 PTI specifications.[7] The 2012 edition does not allow flushing of PT ducts to clean the ducts from debris or dust prior to grouting operations. It also does not allow flushing of ducts to remove grout in case of problems in grout materials or grouting operations. The 2012 specification[7] also recognized the impact of worker qualifications and skills on grouting quality and operations. The 2012 specification[7] requires grouting operations be performed and supervised by qualified personnel. PTI M50.3-12[11] requires the supervisory personnel of post-tensioning operations and the foreman of each installation and stressing crew to be certified as PTI Level 2 Bonded PT Field Specialist; and the foreman of each grouting crew to be certified as PTI Level 2 Bonded PT Field Specialist and ASBI Certified Grouting Technician. Also, at least 25% of each crew is to be certified in PTI Level 1 Bonded PT – Field Installation.

This paper discusses repair alternatives and replacement of two deficient partially grouted embedded external tendons.

GROUTING OPERATIONS

Grouting operations were specified in the TAR project specifications and special provisions.[12] These specifications primarily followed the 2001 PTI specification[4] and the Central Artery/Tunnel Project Specifications,[13] which were used for many cast-in-place (CIP) and segmental viaducts in Boston between 1990 and 2000.

PT ducts should be sealed from debris and intrusions prior to PT operations and grouting should start as soon as PT of the strands is complete. Before starting the grouting operations, the tendon ducts as well as all inlets and outlets must be checked for obstruction. This is typically done with oil-free compressed air. The ducts on this project were flushed with water to remove corrosion protection compounds or to clear debris and blockages consistent with the prevailing. This practice is no longer allowed by PTI.[7] In this case, the flush water should meet the same requirements of water used in the grout and any water left in the duct must be blown out with compressed air. When blowing out the water, any already-installed grout caps must be removed. Ducts, particularly those of thin metal, are often rendered non-tight by corrosion in transit, by tearing in handling, or when placing adjoining reinforcing steel. Duct joints may accidentally be pulled apart. Ducts may be inadvertently compromised by drilling holes for form ties or by rough use of internal vibrator. Such defects cause the grout to leak, resulting in unacceptable voids in the grout. All leaks must be filled to ensure proper grouting. Ducts may be sealed or repaired by several wraps of waterproof tape or even, more positively, by heat-shrink sleeve. When holes or gaps are larger sleeve than 1/4 in. (6 mm), they should be sealed by a metal strip taped in place over the hole.

When a blockage occurs during grouting, every effort must be made to ensure that the tendon duct will be grouted properly. A blocked duct should not be grouted from the other end because air or water would be trapped inside and the corrosion protection for the prestressing steel could no longer be guaranteed. If the tendon ducts cannot be properly grouted, the injected grout should be immediately flushed out with water from the opposite end until clear flush water emerges from the grouting point. Once the tendon duct has been flushed clear and compressed air blown through, grouting operations are repeated with a fresh mixture. Standby water-flushing equipment with a pressure capability of 200 to 300 psi (1.4 to 2.1 MPa), powered by a separate power source, should be available during all tendon grouting.

The project specifications[12] state that: *the exposure interval between strand installation and grouting shall be limited to 20 days for moderate atmospheric conditions (humidity between 40 and 70%), 40 days for very dry conditions (humidity less than 40%), and 10 days for humid conditions (humidity more than 70%), unless temporary corrosion protection measures are taken.*

DESCRIPTION OF PROJECT

The Terminal Area Roadways (TAR) project[12,14] is comprised of a series of viaducts connecting the terminals at Boston Logan Airport to the Sumner Tunnel to the city of Boston, to Route 1A north, and to the Ted Williams Tunnel and I-90. The project consists of approximately 200,000 ft^2 (18,500 m^2) of post-tensioned cast-in-place box-girder viaducts with span lengths varying from 90 to 160 ft (27.5 to 49 m). The substructure consists of single-column piers and straddle bents supported on drilled shafts. The column diameter varied from 5.5 to 7 ft (1.68 to 2.13 m). The foundations are 7 and 8 ft (2.13 and 2.44 m) diameter single-drilled shafts stepped at approximately 80 ft (24.5 m) below ground level. The superstructure is made of 6.5 ft (2.0 m) single and multiple-cell box girders. The roadway width is variable and ranges from 24 to 70 ft (7.3 to 21.5 m). The design of the cast-in-place box girders included both external and internal tendons. The external tendons were embedded in the bottom slab near midspan. The constraints imposed by the project site and the construction staging requirements required the design to consider several stages of construction, which increased the duration of construction.

GROUTING OF TENDONS T1 AND T2 IN SPANS EE11 AND EE12

Spans EE11 and EE12 are two equal spans each 119 ft (36.3 m) long simply supported at Bents EE12 and EE10 and continuous over Bent EE11, as shown in Fig. 1. The two-span structure is a three-cell box girder 6.5 ft (2.0 m) deep and 56 ft (17.1 m) wide. The box girder is post-tensioned with 12 tendons (T1 through T12), each having twenty-seven 0.5 in. (13 mm) diameter strands whose profile is shown in the elevation in Fig. 1. Each span has two deviation saddles (Fig. 2) and the tendons are partially embedded in the bottom slab. The anchorage locations at each end were 4.5 ft (1.4 m) from the soffit of the 6.5 ft (2.0 m) two-cell box girder. At midspan, the tendons were located 6 in. (152 mm) from the soffit of the box and the intermediate support (Bent EE11); the high point was located 5.75 ft (1.8 m) from the soffit. The connection details for the ducts at the deviation saddle locations are shown in Fig. 3. Strands were installed in Tendons T1 and T2 and the two tendons were stressed following the installation and stressing procedures specified on the contract drawings and in the project specifications. While grouting tendon T1, the Tendon developed multiple leaks. Leaks were identified at the rubber coupling connection between the galvanized deviation pipes and the high-density polyethylene (HDPE) exposed ducts. Leaks also occurred at a spalled location in the bottom slab. Once the leaks became evident, the grouting operations stopped and grouting remediation was attempted.

The tendon was not flushed while the repairs were being made. As it became clear that the repairs would not work, the tendon was flushed so that grouting operations could be resumed the next day. The grout was flushed from anchorage location EE12 through Bent EE11 and from anchorage location EE10 to Deviation Saddle DV4. The section from Bent EE11 to Deviation Saddle DV4 could not be flushed because grout had already set at the time flushing was attempted.

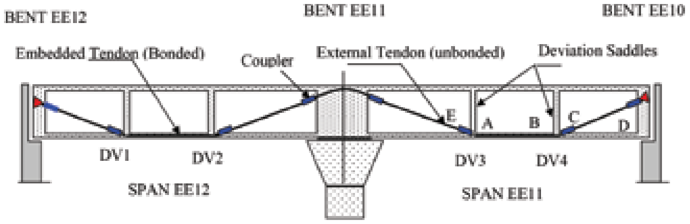

Fig. 1—External tendon layout for Tendons T1 and T2 in Spans EE11 and EE12.

Fig. 2—Deviation saddle and bottom slab reinforcement.

Tendon T2 also developed leaks during the grouting process. The grout was flushed from Anchorage EE10 to Deviation Saddle DV4 and from Anchorage EE12 to Deviation saddle DV3. The section of duct embedded in the concrete slab between Deviation Saddles DV4 and DV3 was flushed with good water flow but it was uncertain if the grout was completely removed.

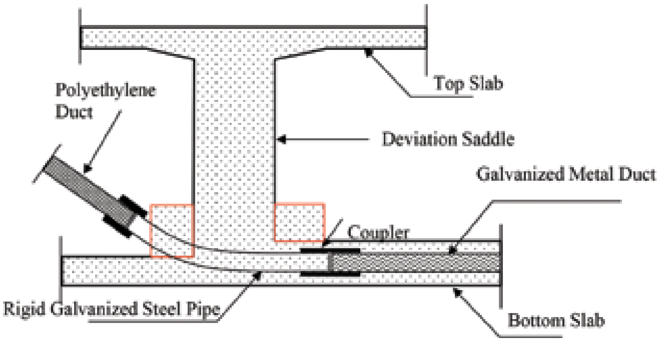

Fig. 3—Duct details at deviation saddles.

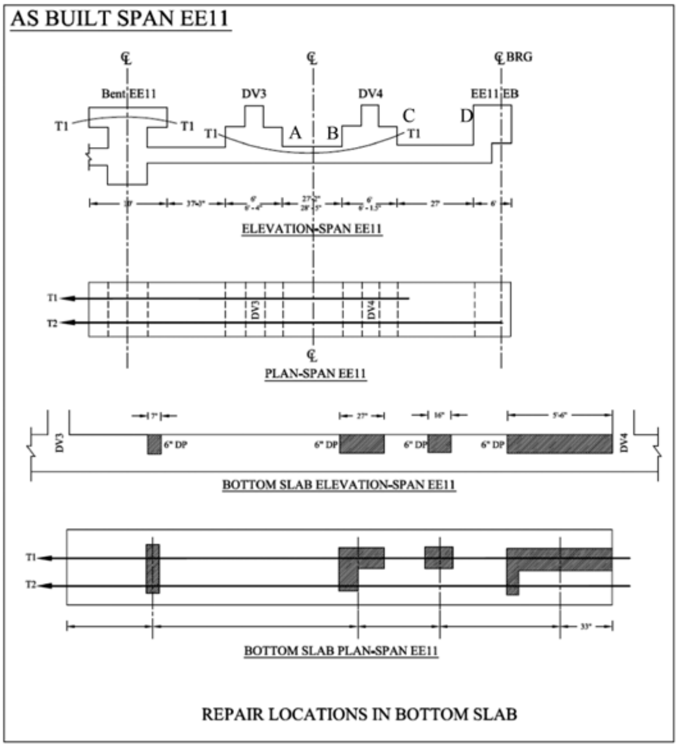

Fig. 4—Repair locations in elevation and plan in thickened slab in Span EE11.

PROPOSED REMEDIAL ACTION FOR PARTIALLY GROUTED TENDONS

It was initially proposed that for Tendon T1, the connection between the HDPE duct and the galvanized pipes on each side of Deviation Saddles DV4 and DV3 and the Span EE11 side of Bent EE12 be opened and visually inspected to confirm the completeness of the grouting of this section. If no voids were to be found, the connection would be closed and an additional grout vent would be installed on the EE10 side of Deviation Saddle DV4. This initial remediation proposal also required that the portion of the duct in the concrete slab between Deviation Saddles DV3 and DV4 be chipped away in small locations to verify that complete grouting was achieved; however, this may not be necessary if the galvanized pipes are filled with grout at each end of the bottom slab. If voids were found between Deviation Saddles DV3 and DV4, then the locations of the end of the void would be determined and the concrete would be chipped to expose the tendon near the end of the void. An additional vent would be installed at this location, and the excavated area would be sealed and patched.

For the two partially grouted tendons (Tendons T1 and T2), a majority of the length of the strands had been exposed without corrosion protection for periods exceeding the project-specified limits. In addition, there may have been standing water in the duct left behind after it was partially flushed out when grouting operations were stopped. As a result, it was likely that the steel strands in these ducts had developed an unacceptable level of corrosion. A region of Tendon T1 was found not completely grouted at Location C near Saddle DV4 in Fig. 4 (also refer to Fig. 1), so it was possible that other voids existed in the grout as well. There is no satisfactory method of verifying that a tendon is completely grouted without performing some destructive examination. However, because of the probability of existing corrosion of the steel strands, at this point, there seemed to be no acceptable remedial action repair but to remove and replace the two tendons.

REPAIR ALTERNATIVES

Removing and replacing partially grouted tendons has been successfully completed on other projects.[15] The procedure requires removal of the HDPE ducts; clamping the strands; chipping the grout; cutting the strands one by one, detensioning and removing the strands; and removing the wedge plates. Sudden detensioning of a large force should be avoided for safety reasons; it may cause damage in the deviation saddles and trigger unbalanced loading that could compromise the integrity of the structure. Extra care should be taken to avoid sudden release of large forces and individual strands should be removed using monostrand jack by breaking the bond between the strand and the grout. This may require cycling detensioning and tensioning of the strands to avoid breaking of the strand before breaking of the bond with the grout. After all strands have been removed, the remaining grout must be removed from the duct. The ducts were cleaned at the deviation saddles. The tendon was then re-installed using new strands and wedges. The tendons should not be removed by jack-hammering the concrete elements in which the tendons are encased. Several methods for the gradual release of the prestressing force (slackening) in partially grouted Tendons T1 and T2 in this project were considered.[12] The following methods were evaluated taking into account time considerations, safety, cost, and specific project requirements:

1. Heating of tendons to release as much as possible of the prestressing force to avoid sudden release of force when the strands are cut. This method requires removing the PE duct and as much grout as possible around the tendon. The tendon is then heated along its entire length to release as much PT force as practical. However, although this method will save time, it requires significant heat to release the tendon force and the heating will not be uniform along the tendon. Also, to heat the portion of the tendon embedded in the bottom slab, the top concrete cover over that portion of the tendon would have to be removed. The bottom portion of the tendon would still not be fully exposed, as the heat would only be on the top of the tendon. In addition, inducing such high temperatures inside a confined space of a box girder may be hazardous and unsafe.
2. Removal of concrete around anchorages, and burning wedges to remove tendons. Although this method could have saved time, it was thought to be unsafe.
3. Controlled release of prestressing force (slackening of strands) and removal of individual strands after chipping as much grout as possible. This method, although time-consuming, involved less risk than the other methods, used successfully on other projects[15] and was proposed for the removal of partially grouted tendons T1 and T2; it is described in detail in the tendon removal section that follows.

REMOVAL AND REPLACEMENT OF TENDONS T1 AND T2

Removal of partially grouted Tendons T1 and T2 in Spans EE11 and EE12 by slackening the strand alternatively on each side of the deviation saddle was recommended. This procedure is similar to the one used for the removal of corroded external tendons of the Mid-Bay Bridge in Florida in 2001.[15] The difference between the tendons in the Mid-Bay Bridge and those in Spans EE11 and EE12 of this project was the embedded portion of the tendons in the bottom slab near midspan. This portion was approximately 45 ft (13.7 m) long in each span between deviation saddles and it was difficult to remove it.[14] The removal and replacement of this portion was time consuming. Portions of the slab had to be chipped away at various locations to allow for the tendon removal and the contractor was able to do that without removing any portions of the deviation saddles or causing damage in the saddle. In Span EE11, approximately 30% of the of the bottom slab had to be chipped away to allow for the removal of Tendon T1 and 8% for the removal of Tendon T2, as shown in Fig. 4. In

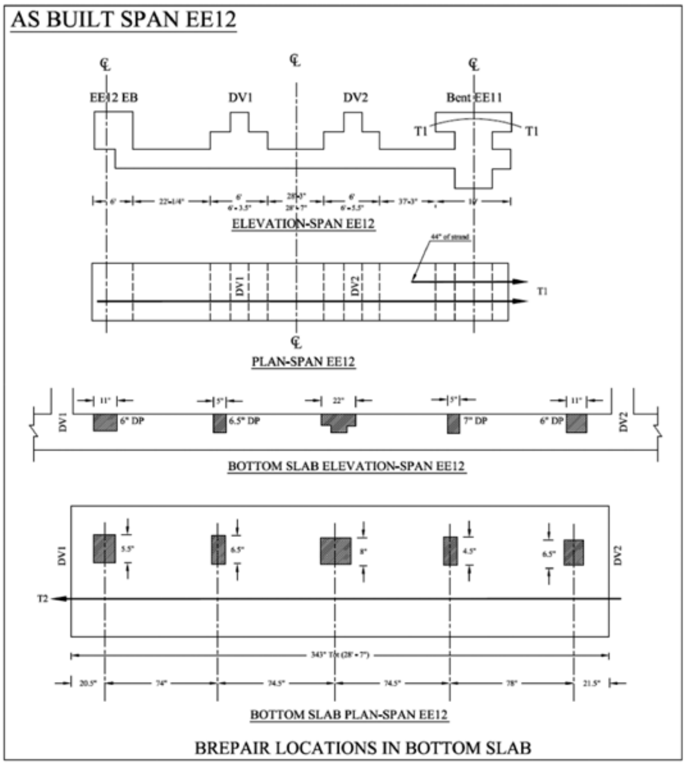

Fig. 5—Repair locations in elevation and plan in thickened slab in Span EE12.

Span EE12, approximately 16% of the of the bottom slab had to be chipped away to allow for the removal of Tendon T1 and only minor chipping was needed for the removal of T2, as shown in Fig. 5. The procedure used for the removal and replacement of Tendons T1 and T2 is described in the following sections.

TENDON REMOVAL

The HDPE duct was removed from the entire length of the tendon between anchorages and deviation saddles, as shown in Fig. 6. The grout was then removed from accessible locations throughout the entire length of the tendon. Portions of the bottom slab were chipped way around the tendons, as shown in Fig. 7 and 8. Heavy-duty U-shaped clamps were used and were placed approximately every 4 to 6 ft (1.2 to 1.8 m) to control strands' sudden release of force and energy when the strand was cut, as shown in Fig. 6. A power saw was used to cut strands. The process started by chipping concrete in the bottom slab portion between the deviation saddles to expose strands, as shown in Fig. 7 and 8. One strand was then cut at Location C (refer to Fig. 1 and 4), leaving a sufficient length of strand so that it can be gripped by a monostrand jack to remove it later after all strands were cut. The force from the cut strand was transferred to the remaining strands due to bond transfer over the length of the tendon on both sides of the cut. The stress in the remaining strands slightly increased due to force transfer over the bond length. The cut strand resulted in overall reduced tendon force over bond length of the tendon. One strand was then cut at Location B on the other side of the deviation saddle, as shown in Fig. 1 and 4. Cut strands were then checked to make sure they shortened to release force. If not, the clamps were allowed to release some force to allow cut strands to shorten. Strands in the tendon were then cut in an alternating pattern at Locations C, B, A, and E. Strands were not allowed to be out-of-balance at the deviation saddles by more than one strand at any time during the cutting process. Figure 9 shows all strands cut in Tendon T1. Once all strands were cut at locations C, B, A, and E, high-pressure hydroblasting was used

Fig. 6—Removing HDPE duct around strands and installing clamps.

Fig. 7—Exposing strands in portion of tendon embedded in bottom slab.

Fig. 8—Close-up of exposed strands in portion of tendon embedded in bottom slab.

to remove as much grout as possible in the bottom slab and near the deviation saddles, as shown in Fig. 10. The strands between the deviation saddles and at Bent Cap EE11 were then pulled out using a monostrand jack. Hydroblasting was then used to remove the remaining grout in the bottom slab and at Bent EE11 and near anchorages.

Concrete around the anchorage locations was chipped away to expose the bearing plates. The bearing plates were carefully removed using precision cutters so as to minimize damage to anchorage locations and the surrounding concrete.

Fig. 9—Tendon T1 with completely cut strands.

Fig. 10—Hydroblasting grout from around strands in bottom slab.

TENDON REPLACEMENT

After all strands were removed and all concrete was chipped away, unsound concrete and debris were removed. The bottom half of the corrugated duct that remained embedded in the bottom slab was trimmed and removed. The full length of the duct was then cleared from debris and loose grout. An inflatable tube (mandrel) was installed through the steel pipes at the deviation saddle through the duct path in the bottom slab to maintain the same size and geometry of the ducts, as shown in Fig. 11

Fig. 11—Inserting inflatable tubes (mandrels) into bent steel pipes.

Fig. 12—Inserting inflatable mandrels in cleaned ducts path in bottom slab.

Fig. 13—Mockup tests for mandrels.

Fig. 14—Interior of PT corrugated duct after using mandrels.

Fig. 15—View of terminal-area roadway viaducts, Spans EE11 and EE12.

and 12. Mockup specimens were built to check the effectiveness of the inflatable bladder in maintaining the duct path and geometry, as shown in Fig. 13 and 14. The ducts were cleaned and checked for any obstructions after the mandrels were removed. The bottom slab was repaired in those areas where concrete had spalled or cracked, and epoxy grout was injected at some locations in the bottom slab and at deviation saddles. Ducts were flushed along the full length, water blown out with oil-free air before strands were installed. The strands were then anchored and the tendons stressed. Grout vents were capped and tendon tails cut within a few hours of stressing. Grout was mixed and injected under pressure into the ducts within 7 days, according to project specifications.

CONCLUSIONS

Two external tendons partially embedded in the bottom slab were successfully removed and replaced by cutting and detensioning of individual strands. This example demonstrates that it is possible to remove and replace grouted tendons that are partially embedded in concrete if there is access to the tendons, as was the case with the embedded tendons in the bottom slab, to remedy situations such as voids in the tendon grout.

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