POST-TENSIONING SYSTEM OF THE WEST 7TH STREET BRIDGE PRECAST NETWORK ARCHES

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The West 7th Street Bridge spans the Clear Fork of the Trinity River connecting downtown Fort Worth, TX, to the Cultural District. The 981 ft long (299 m) bridge consists of a series of six 163.5 ft (49.8 m) precast post-tensioned network arch pairs. The primary constraint for design and construction was the need to reduce on-site construction time so that the bridge was out of service for no more than 150 days. The Texas Department of Transportation (TxDOT) engineers designed the 280 ton (254 tonne) arches to be cast on their sides near the bridge, rotated into a vertical position, and hauled to the site. All post-tensioning (PT) stages occurred prior to setting the arches on columns. Once the arches were in place, the existing bridge was closed to traffic and then demolished. This case study of the West 7th Street Bridge focuses on the PT of the arches, including partial detensioning of the rib tendons.

KEYWORDS

Arch; bonded; bridge; concrete; detensioning; grouted; network; post-tensioned; precast.

INTRODUCTION

The use of prestressed concrete was vital to the success of the West 7th Street Bridge. Prestressing was used not only for concrete member design but also for temporary connections during construction. Strand PT systems were used for the precast concrete network arches and traffic rail, and bar PT systems were used for the floor beam to arch tie connection along with temporary construction connections including lifting frames, strongbacks, and horizontal bracing between arches. The floor beams and 4 in. (102 mm) stay-in-place concrete deck panels were precast and pretensioned in fabrication yards. While many prestressing applications were used on the bridge, this case study focuses on the PT of the network arches, including staged stressing and partial detensioning of the rib tendons.

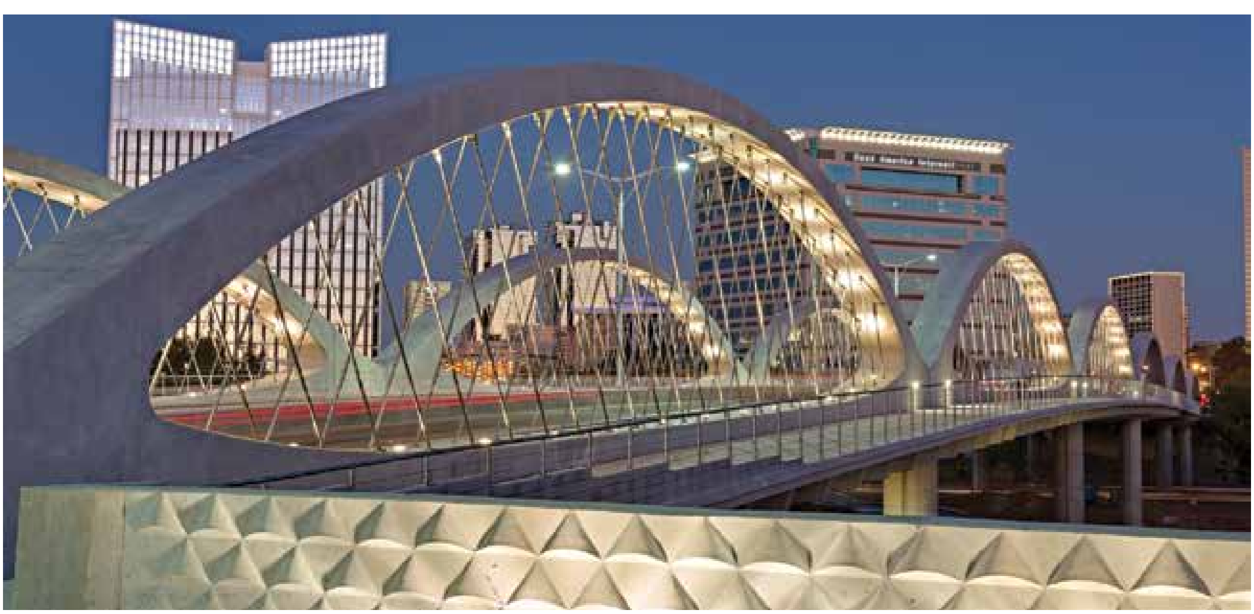

Fig. 1—Photograph of West 7th Street Bridge looking toward downtown. Photo courtesy of Liam Frederick.

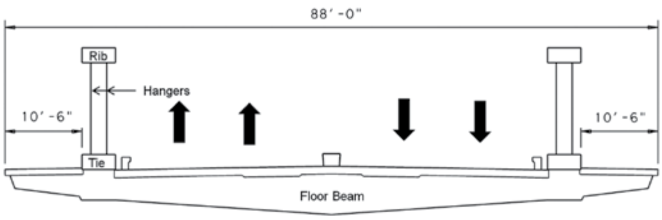

Fig. 2—Transverse section of bridge. (Note: 1 ft = 0.305 m; 1 in. = 25.4 mm.)

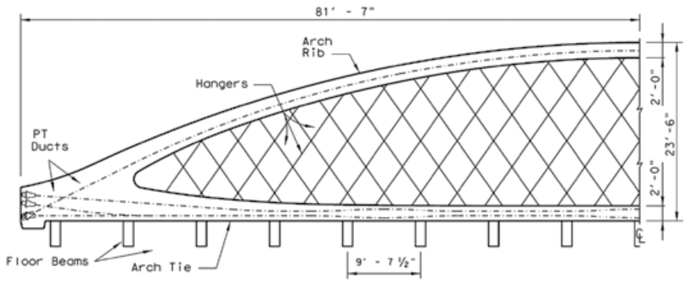

Fig. 3—Arch elevation. (Note: 1 ft = 0.305 m; 1 in. = 25.4 mm.)

BRIDGE DESCRIPTION

The West 7th Street Bridge is located in Fort Worth, TX (Fig. 1), connecting downtown to the Cultural District. Figure 1 is a photograph of the bridge taken facing downtown Fort Worth. The 981 ft (299 m) long bridge consists of six 163.5 ft (49.8 m) precast prestressed concrete network arch spans. The overall bridge width is 88 ft (26.8 m), as shown in Fig. 2. The bridge accommodates two lanes of vehicular traffic in both directions along with 10.5 ft (3.2 m) sidewalks located outboard the arches. The arch was kept shallow for ease of handling with a rise of only 23.5 ft (7.0 m) (Fig. 3). The arch width of 4.5 ft (1.3 m) was kept as narrow as possible to minimize hauling weight but wide enough to provide strength, stability, and room for embedded items. The arch tie and rib depths taper from the knuckle down to 2 ft (0.6 m) at midspan. The tight hanger spacing of 4.8 ft (1.47 m) was used to allow a transverse floor beam spacing of 9.6 ft (2.94 m) that eliminated the need for longitudinal stringers common to arch bridges. A typical slab cross section consists of 4 in. (102 mm) precast concrete panels with a 4.5 in. (114 mm) cast-in-place topping slab.

Fig. 4—Construction sequence.

CONSTRUCTION SEQUENCE

The primary constraint for design and construction was the need to reduce on-site construction time so that the bridge was out of service for no more than 150 days. The construction sequence for the bridge played a large role in how the arches were constructed. Multiple bridge elements, including the arches, were precast off site to minimize on-site construction time. The arches were constructed in a casting yard four blocks from the bridge site. Figure 4 illustrates the multiple stages of construction that are discussed in this section.

First, the arch was cast on its side to simplify the formwork and provide better quality control. While the arch was horizontal, the first stage of PT was performed. This stage of PT provided a uniform axial compression throughout the rib and tie to handle the bending stresses that would be induced by lifting and rotating the arch into a vertical position. Next, the stainless steel hanger bars were installed and the arch was rotated into a vertical position. The arch was lifted and rotated using six lifting frames and the lifting system shown in Fig. 5. Once vertical, the second and final stage of PT was performed, which included partial detensioning of the rib tendons. In this stage, the rib tendon stress was reduced by half and the tie tendon stress was doubled. This last stage of PT had to occur in the casting yard because the arches were ultimately set just 4 in. (102 mm) apart with no access for stressing jacks. After PT was completed, the hangers were tensioned using the weight of the tie rather than the typical method of stressing bars individually, which would have been difficult given the large number of hangers (52). The hanger tensioning process shown in Fig. 6 consisted of lifting the tie using 13 rams connected to one manifold; removing the slack in the bars; tightening the nuts under the tie; and then releasing the pressure in the rams, thus lowering the tie. This process effectively used the tie self-weight to simultaneously load all the hangers. The arch was then transported to the bridge site with SPMTs traveling across the existing bridge and set on columns located just outboard of the railings. Once all 12 arches were in place, the existing bridge was closed to traffic and then demolished. Next, the floor beams were hung from the arch ties. The floor beams provided the transverse bracing for the arches, which required a moment connection (Fig. 7). A stiff epoxy mortar was used at the floor beam to tie interface to accommodate the two precast nonplanar surfaces. After lightly squeezing out the mortar, the mortar was allowed to cure; then the 1.75 in. (44 mm) diameter PT bars were stressed to 105 ksi (724 MPa), securing

Fig. 5—Arch rotation.

Fig. 6—Hanger stressing.

Fig. 7—Arch-to-floor beam connection.

the connection. Next, the precast concrete panels were placed and the deck cast. After the rails were completed, the bridge was reopened to traffic in October 2013, 30 days ahead of schedule.

ARCH POST-TENSIONING

General

Each arch has six PT tendons of nineteen 0.62 in. (15.75 mm) diameter strands: four in the tie and two in the rib. There are also two ducts located in the tie for possible future use that accommodate up to 12 strands each.

Design

Designing the PT layout proved to be challenging due to the need to keep the arch within stress limits at all stages of its construction and service. One of the challenges for design was that minor changes to the tendon layout in the knuckle region affected both rib and tie stresses due to the frame action of the arch. The three controlling stages outlined in orange in Fig. 4 were arch rotation, hanger tensioning, and the completed bridge in service with long-term losses. Stiffening elements were required on top of the rib near the knuckle during hanger tensioning to offset the high tensile stresses generated by reverse loading (Fig. 6).

CONSTRUCTION

Tensioning

To maintain more uniform stresses on the rib and tie, tendons were stressed in 52 ksi (359 MPa) increments alternating between all six tendons. The tendons were stressed from one end only. The arches were post-tensioned in two stages. The arch was horizontal for the first stage of PT and vertical for the second. Stage one PT stressed the rib tendons to 77% of minimum guaranteed ultimate strength (MUTS), or 208 ksi (1434 MPa), and the tie tendons to 38.5% of MUTS, or 104 ksi (717 MPa). Refer to Table 1 for tendon stressing sequence of Stage

Table 1—Stage 1 PT sequence

Increment No.	Tendon No.	Arch element	Jacking Stress, ksi (MPa)
1	1	Rib	52 (359)
2	3	Rib	52 (359)
3	2	Tie	52 (359)
4	4	Tie	52 (359)
5	5	Tie	52 (359)
6	6	Tie	52 (359)
7	1	Rib	104 (717)
8	3	Rib	104 (717)
9	2	Tie	104 (717)
10	4	Tie	104 (717)
11	5	Tie	104 (717)
12	6	Tie	104 (717)
13	1	Rib	156 (1076)
14	3	Rib	208 (1434)
15	1	Rib	208 (1434)

Table 2—Stage 2 PT sequence

Increment No.	Tendon No.	Arch element	Jacking stress, ksi (MPa)
Initial	1	Rib	208 (1434)
Initial	3	Rib	208 (1434)
Initial	2	Tie	104 (717)
Initial	4	Tie	104 (717)
Initial	5	Tie	104 (717)
Initial	6	Tie	104 (717)
1	2	Tie	156 (1076)
2	4	Tie	156 (1076)
3	5	Tie	156 (1076)
4	6	Tie	156 (1076)
5	2	Tie	208 (1434)
6	4	Tie	208 (1434)
7	5	Tie	208 (1434)
8	6	Tie	208 (1434)
After detensioning	1	Rib	52 (359)
After detensioning	3	Rib	52 (359)
9	1	Rib	104 (717)
10	3	Rib	104 (717)

1 PT and Table 2 for Stage 2 PT. The final stress level in each rib tendon was 104 ksi (717 MPa) and 208 ksi (1434 MPa) in each tie tendon. The tendon anchorage location is shown in Fig.8.

Detensioning

The rib detensioning set-up for the West 7th Street Bridge required six shims on each tendon—three shims per tendon end—with protection rings covering the shims as shown in Fig. 9. This assembly, shown in Fig. 10 through 12, was installed prior to the first stage of PT. The shims were not removed until the arch was rotated into the vertical position and all tie tendons had been stressed to their final stress of 208 ksi (1434 MPa). The shims remained on the arches for as little as 5 days to as long as 35 days. The shims had an 8 in. (203 mm) outer diameter and consisted of two half circles as shown in Fig. 11. The protection rings had an inner diameter of 8.25 in. (210 mm) to fit over the shims and limit their movement.

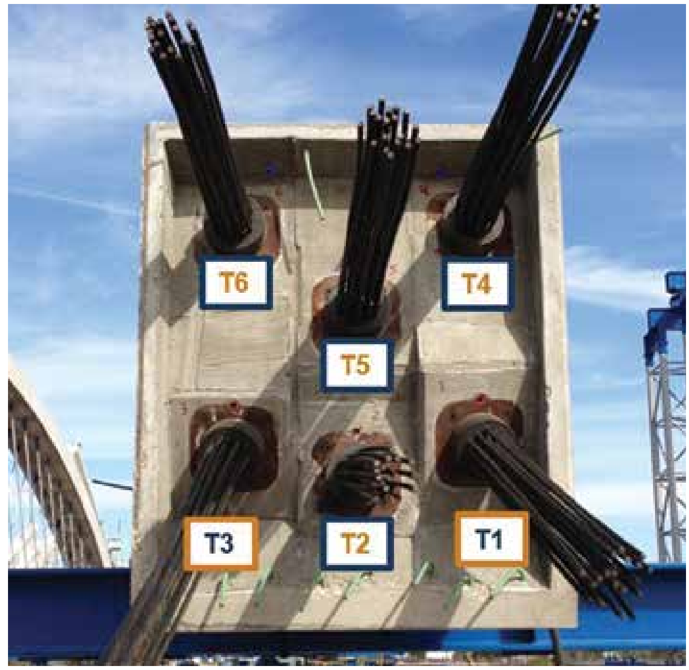

Fig. 8—Tendon anchorage locations.

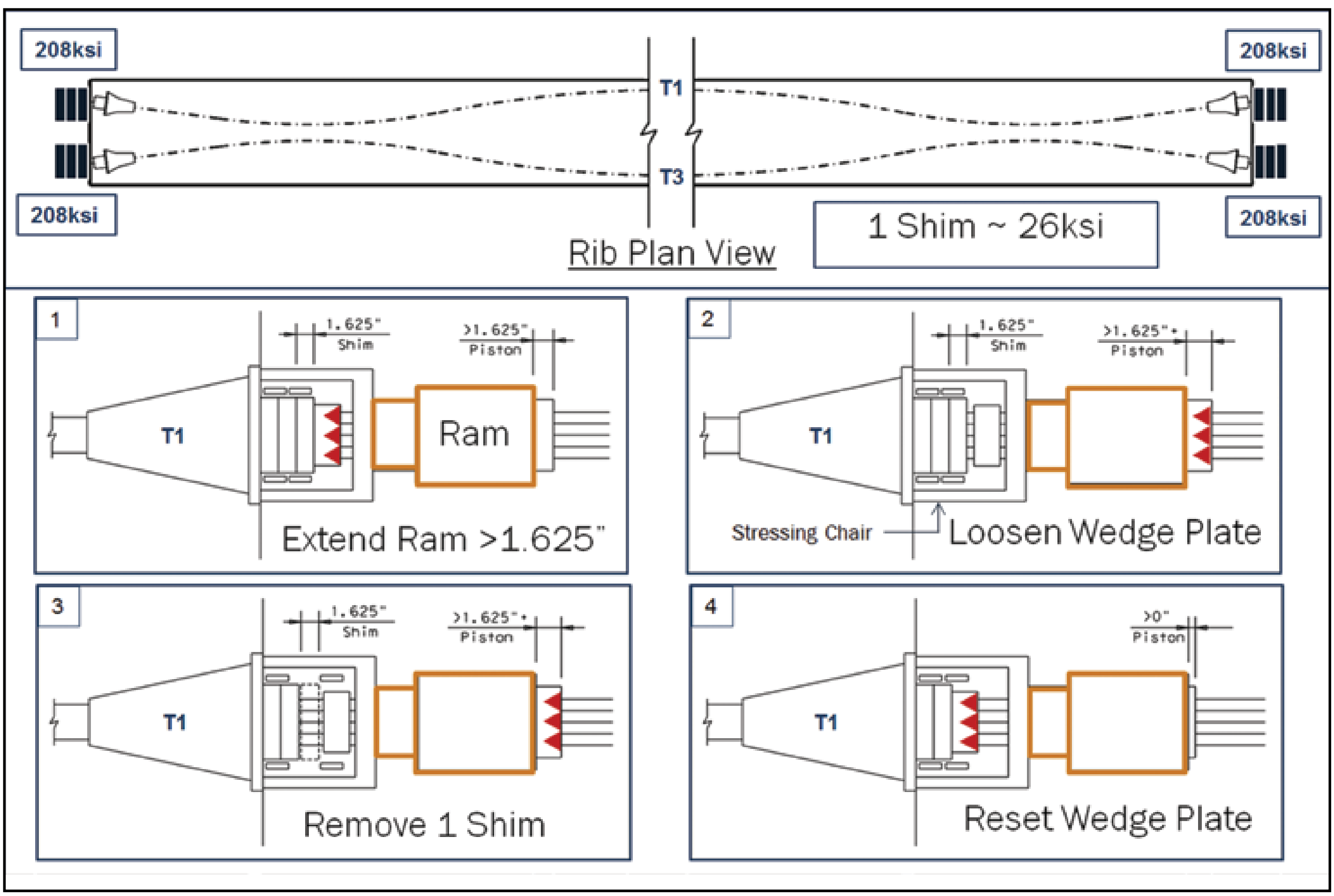

Fig. 9—Detensioning cycle. (Note: 1 ksi = 6895 KPa; 1 in = 25.4 mm.)

Fig. 10—Rib tendon anchorage with detensioning hardware.

The detensioning procedure used a series of prescribed reductions in tendon length that corresponded to desired stress levels. The arch rib tendons T1 and T3 start out the detensioning process fully stressed to 208 ksi (1434 MPa) from the first stage of PT. The shims were 1.6 in. (41 mm) thick; therefore, removing one shim equated to a stress loss in the tendon of 26 ksi (179 MPa). By removing all six shims on a tendon, the stress was reduced by 156 ksi (1076 MPa), leaving a stress of 52 ksi (359 MPa) in the tendon. The rib tendons were then restressed to 104 ksi (717 MPa) based on the pressure gauge to more accurately ensure the final stress level was as intended. During the detensioning process, the tendons were destressed in increments not to exceed a 52 ksi (359 MPa) differential between T1 and T3 to keep near-uniform lateral stresses

Fig. 11—Detensioning shims.

Fig. 12—Protection rings.

Table 3—Detensioning sequence

Increment No.	Tendon No.	Arch element	Arch end	No. of shims removed	Jacking stress, ksi (MPa)
Initial	1	Rib	Both	0	208 (1434)
Initial	3	Rib	Both	0	208 (1434)
1	1	Rib	Right	1	182 (1255)
2	3	Rib	Right	2	156 (1076)
3	1	Rib	Right	2	130 (896)
4	3	Rib	Right	1	130 (896)
5	1	Rib	Left	1	104 (717)
6	3	Rib	Left	2	78 (538)
7	1	Rib	Left	2	52 (359)
8	3	Rib	Left	1	52 (359)

in the arch. A typical shim-removal cycle is illustrated in Fig. 9. Each rib tendon started with three shims on each end and the tendon load held by the wedge plate as indicated by the red triangles in Fig. 9. The ram was then extended a distance greater than the thickness of one shim without loading the strands. Next, the ram bore against the chair and transferred the load from the wedge plate to the ram, in turn loosening the wedge plate. Then, while the ram was holding the load, the protection rings were separated to facilitate the removal of the shim closest to the wedge plate. Finally, the load was transferred back to the wedge plate, reducing the stress in the tendon. Refer to Table 3 for the detensioning sequence. At the end of the detensioning process, both rib tendons had a stress of 52 ksi (359 MPa). The rib tendons were then restressed to a final stress of 104 ksi (717 MPa).

Grout

Masterflow 1341 grout was used due to the vertical rise of the rib ducts. The rib tendons were grouted from both ends simultaneously upward, while the tie tendons were grouted from one end only.

CONCLUSIONS

The West 7th Street Bridge had unique aspects in design, construction, and PT application. This case study focused on the PT system of the arches and only briefly discussed the other aspects of the bridge. This bridge is a unique structure that was excellently executed with the bridge out of service for only 120 days and for a cost of $209 per square foot. Prestressed concrete played a major part in the success of the West 7th Street Bridge.

Courtney E. Holle *graduated from the University of Texas at Austin, Austin, TX, in 2005 with her degree in architectural engineering. She spent her first year in Houston working in the oil industry designing on- and offshore structures. In the past 8 years, she has worked on a wide variety of bridge projects for the Texas Department of Transportation in the Bridge Division. She performed the analysis of the West 7th Street Bridge in Fort Worth, TX.*

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