DART ORANGE LINE – A SPLICED GIRDER SOLUTION FOR A FAST PACED DESIGN BUILD PROJECT

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ABSTRACT
Dallas Area Rapid Transit's (DART) Orange Line Light Rail extension provided a unique challenge crossing the Trinity River. The overall bridge length was more than 7000 feet, and crossed state highways, interstate highways, the Trinity River and the Trinity River levees. This project is located in Dallas, and connects the existing DART light rail network to the cities of Irving, Las Colinas, and the DFW Airport.

A particular challenge for this structure was crossing the West bank Trinity River Levee where the alignment is vertically constrained by nearby high voltage transmission lines above and a US Army Corp of Engineers (USACE) levee below. To avoid disturbing the levee, as required by the USACE, the structure needed to span 260 feet without any temporary supports or heavy machinery on the levee during construction. A number of alternatives were explored by the design/build KSWRP Joint Venture including CIP segmental balanced cantilever, through steel girders, arches, and standard girders, deciding on precast concrete spliced girders. The spliced girder provides an innovative use of common element types and post-tensioning, resulting in an economical and constructible design.

The completed dual track structure is a three-span continuous unit with span lengths of 145' – 260' – 145'. Each girder line is comprised of five girder segments. Segments B and D are balanced over the central piers and stabilized with a temporary support tower beneath the end spans. The remaining girder segments are supported using overhead steel strong-back beams. The unique construction sequence, developed in concert with the contractor during design, provides a means by which the levee remained undisturbed during construction. The typical section was derived from the existing TxDOT "Tx70" standard girder, and increased in depth and width to accommodate the post tension ducts while developing the necessary moment resisting capacities. The finished girder section was reviewed by TxDOT and incorporated into their standards and is now available as the "Tx82" for spliced girder applications. The 260' main span is the longest concrete span in Texas, and the 160' pre-cast "drop-in" span is the longest single cast girder in Texas history.

Construction afforded many challenges including site access, night work requirements, a massive crane resting on utilities, and a variety of temporary works, all of which were met by using an innovative design and construction procedure that were effectively integrated though the design/build delivery process. The cooperation and assistance of our pre-cast partners was instrumental in the successful completion of this structure. The DART Orange Line was open to revenue service in July of 2012.

Keywords:
DART, Trinity River Bridge, light rail bridge, spliced girder, post-tensioning, TX82 girder

GENERAL

A Kiewit-led joint venture, KSWRP (Kiewit, Stacy and Witbeck, Reyes, and Parsons), is constructing 9.3 - miles and six stations for Dallas Area Rapid Transit's (DART) new Orange line from Bachman Station on the Green line in northwest Dallas to Belt line Rd. on the southern portion of DFW Airport, as shown in Figure 1. Work began on the design/build (D/B) in June 2009 and the first segment is expected to open in the summer of 2010. The project consists of eight bridges, including a 7000-foot-long bridge over the Trinity River. One three span unit of that bridge is a spliced and post-tensioned precast concrete girder structure that spans the Trinity River Levee and is a key component of the structure.

The project provided a unique challenge in crossing the Trinity River Levee system. The alignment is vertically constrained by nearly adjacent power lines above and an US Army Corp of Engineers (USACE) levee below. To avoid disturbing the levee, as necessitated by the USACE, the structure needed to span 260 feet without any temporary supports or heavy equipment on the levee during construction. Because it was a D/B project, a constructible and economical solution was developed through an integrated approach utilizing input from both the construction and design members of the team.

A number of alternatives were explored by the D/B KSWRP Joint Venture. These included CIP segmental balanced cantilever, steel through-girders, steel arches, and standard precast girders before deciding on precast concrete spliced and post-tensioned girders. Standard precast girders would not work due to restrictions that the USACE had regarding placement of foundations within the levee. The 260 foot clear span was necessitated by the Corps requirement that no foundations be closer than 50 feet to the toe of the levee, as shown in Figure 2.

The precast concrete spliced girders and the CIP segmental were the only structure types that would realistically span the required 260 feet across the levee and fit within the clearance envelope between the overhead transmission wires and the top of the levee. The steel options had too great a section depth in order to meet the structure stiffness and live load deflection requirements. The chief concerns with CIP segmental, however, were the schedule impacts resulting from a rather lengthy construction duration. This was amplified even further by the time required at the start to get through the design and permitting process with the USACE. The precast concrete spliced girders provided an innovative use of common structural element types and post-tensioning, resulting in an economical and constructible design.

The completed dual track structure is a three-span continuous unit with span lengths of 145' – 260' – 145'. Each of the six girder lines are comprised of five girder segments. Girder Segments B and D are balanced over the central piers and stabilized with a

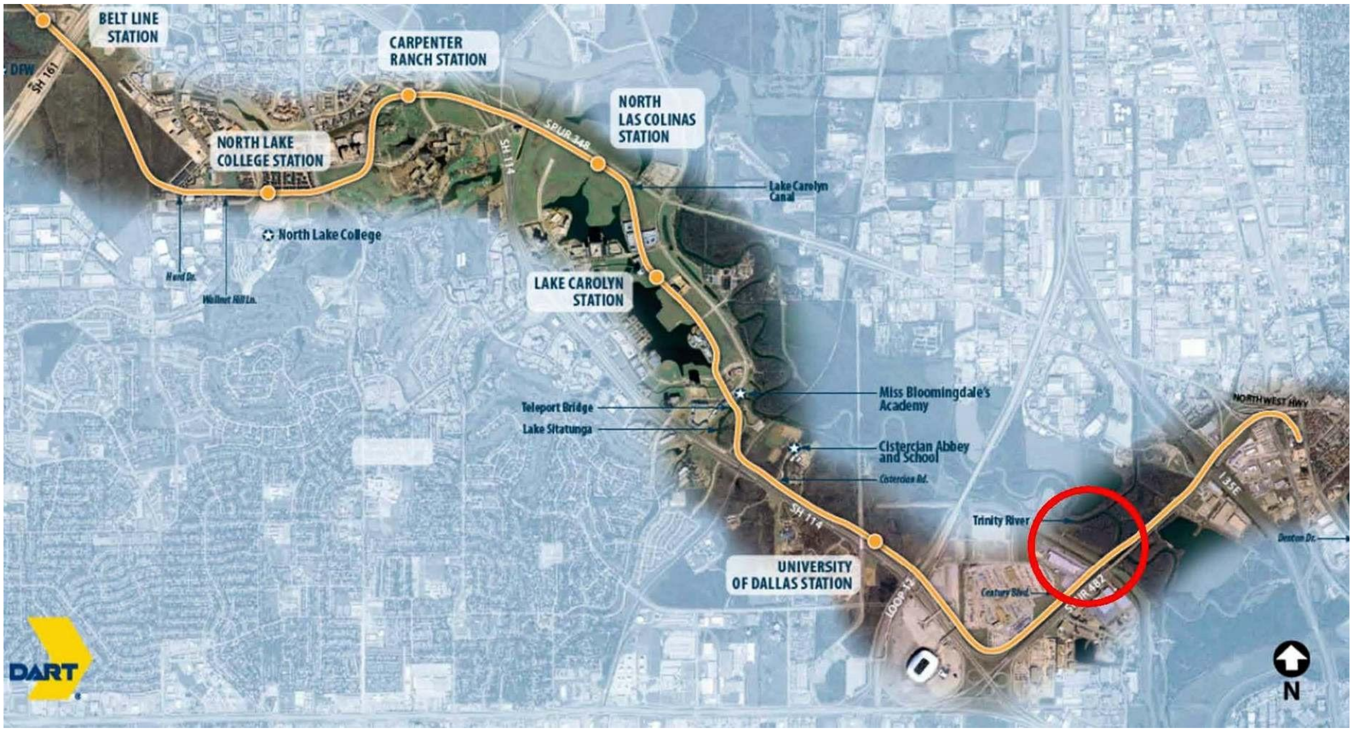

Figure 1 – DART Orange Line Expansion. Trinity River Bridge location shown at red circle.

temporary support tower beneath the end spans. The remaining girder segments A, C, and E are supported using overhead steel strong-back beams. The unique construction sequence, developed in concert with the contractor during design, provides a means by which the levee remained undisturbed during construction. The girder layout and construction sequence are shown in Figure 3.

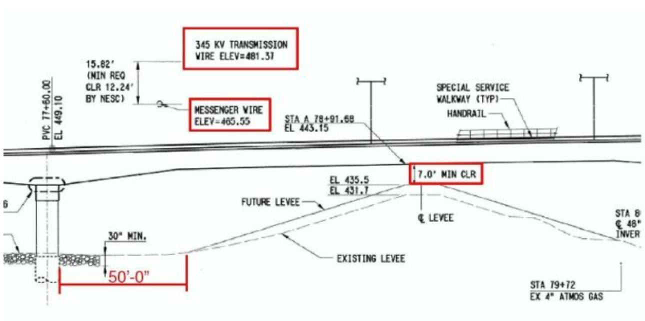

Figure 2 – Site Constraints

DESIGN

Because of the tight project schedule and the critical need to begin construction activities as soon as possible, it was necessary for the design of the foundations to be completed prior to the completion of the superstructure design. The foundations for all piers of this unit consisted of a single large diameter drilled shaft below each column. This foundation type proved to be an option that could be designed and constructed quickly, as well as economically. The foundations and substructure were designed, approved by the Owner and the USACE, and constructed well in advance of the girder erection schedule.

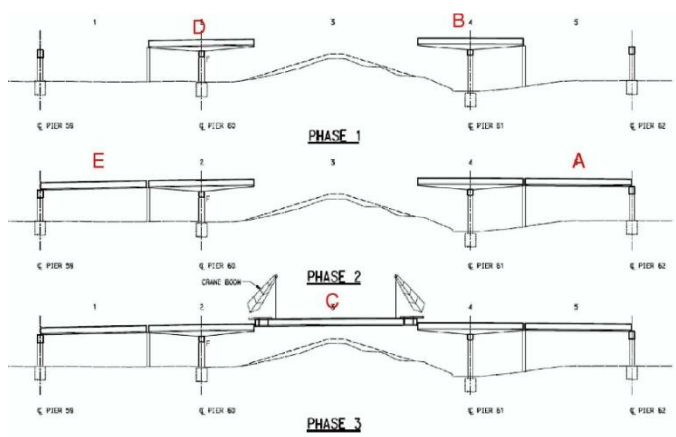

Figure 3 – Girder Layout and Construction Sequence

Although precast girders are used extensively in Texas, the deepest of the TxDOT standard girders was 70” and not sufficient for the selected structure requirements. Parsons modified the deepest standard girder by increasing the web height by 12 inches and the width by 1 inch, creating a new girder now called the TX82. The increased web width is used to help with shear capacity and, more importantly, to accommodate the longitudinal post- tensioning tendons located within the web. This girder section was used for Girder Segments A, C and E, as shown in the girder layout in Figure 4. The middle girder of the levy span is 160 ft. and at the time of construction was the longest precast girder ever erected in Texas. For Girder Segments B and D located over the main piers, the girders were once more modified by utilizing a variable depth that increased the maximum depth an additional four feet, resulting in an 11’-10” total section depth at the pier.

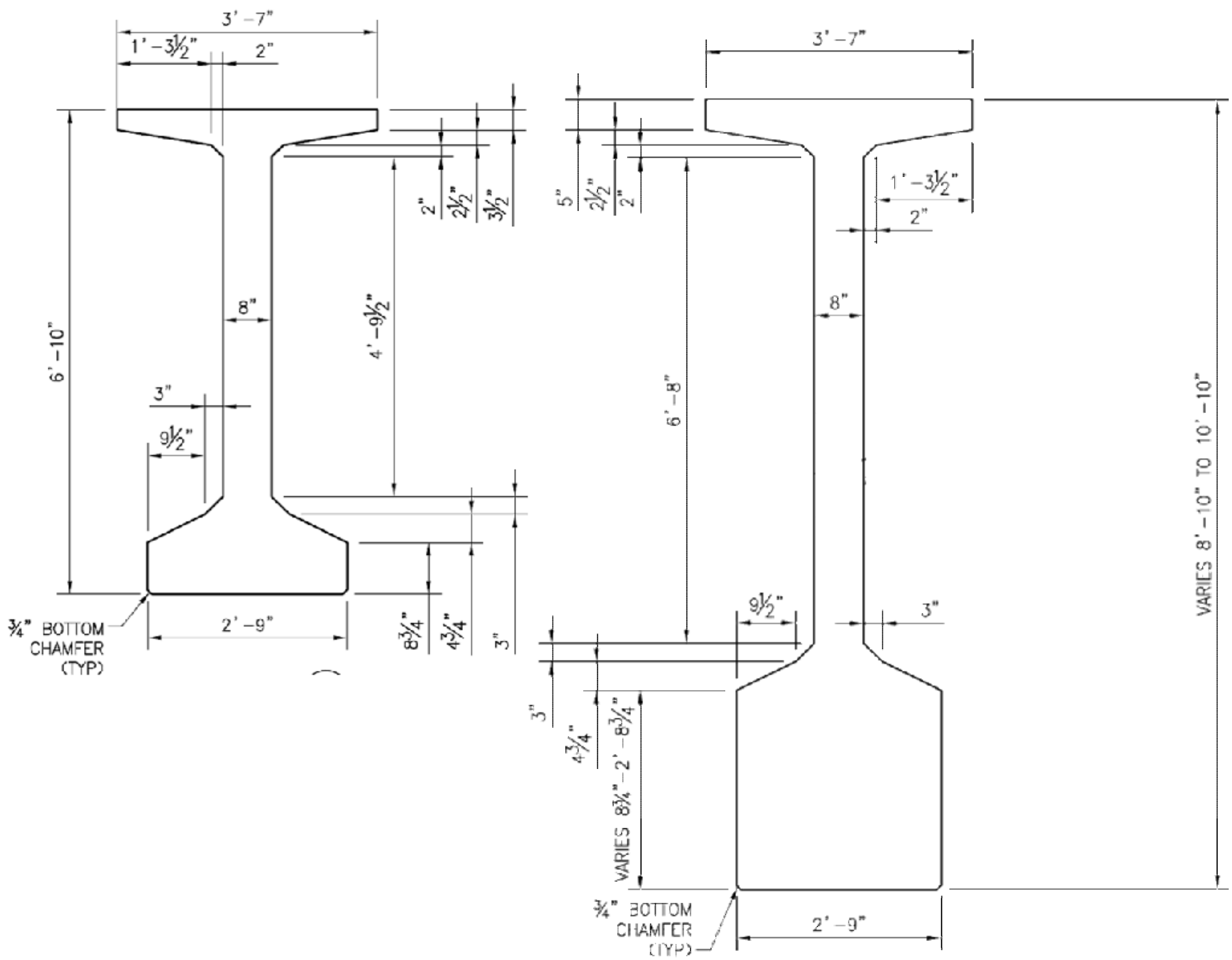

Figure 4 – Girder Dimensions (Segments A, C & E Left and Segments B & D Right)

Rider comfort and long term performance of the structure are a major consideration in the design of the structure and live load deflection and frequency requirements were specified in the project design criteria. The response of a structure to a moving train load is quite different for a long structure with many shorter spans from a shorter structure with a relatively long span in the center. To ensure that rider comfort was maintained across the relatively flexible structure and that dynamic structural stability was maintained, a rolling stock analysis was conducted to study the interaction of the dynamic structure deflections with the moving train loads. Also, from a deflection standpoint, long term creep and static live load deflections could not encroach into the clearance envelope above the levee. Additionally, the initial structure camber needed to ensure the vertical clearance to the overhead power lines was maintained. The multiple step construction process required that camber and erection geometry be carefully considered.

Transportation, construction, and final configuration of the girders posed a challenge for the prestressing design, requiring a combination of both pre- tensioning and post-tensioning, as well as temporary prestressing. The girders went through a number of different support conditions during transportation and erection requiring a delicate balance of stresses for each of the configurations. Standard precast girder pre-tensioning strand was used in all the prismatic girders to provide the compression needed for handling segments prior to splicing the girders once placed in the structure. For the variable depth girder segment over the pier, permanent post-tensioning is used at the top for the negative moments because of difficulties associated with pre- tensioning stressing blocks at the height of the top flange.

Figure 5 – Girder B & D Post-tensioning details

These tendons required the design of an anchorage end block at the ends of the pier girder, as well as a matching block at the end of the adjacent girder to ensure a straight flow of the high longitudinal stresses across the splice joint. A single temporary tendon was required in the bottom of the pier girder for the storage and transport support points, which were located closer to the ends of the girder. For the full length continuity tendons stressed after the closure joints are cast, the skewed main piers resulted in different girder lengths and thus a need for unique tendon paths for each girder line. Furthermore, those continuity tendons were fully stressed before casting the deck; an important accomplishment for ease of construction and future deck replacement.

Additional critical design aspects that required close coordination between the D/B team design and construction groups was the determination of maximum size of girder segments, location of cranes for critical girder lifts, and the location of the temporary support frames. The construction sequencing, location of piers, and the location of girder splice points were all dependent on those constructibility items and were an integral part of the analysis model.

Figure 6 – Temporary Support Tower and Tie-Down

Due to the layout of the girder segments and the selected location for the temporary support tower at the side span end of the variable depth pier girder segment, the tower needed to resist a significant amount of uplift prior to the completion of the girder splicing and post-tensioning. A design for the tower utilized tie-down bars from the girders to the top of the frame where the uplift was then transferred through the steel frame and to the large concrete spread footing, as shown in Figure 6. The footing acted to distribute the compression loads in the tower in the phase prior to setting the drop-in center girder. Its weight was used as a dead-man to resist the uplift loading.

Another interesting aspect of the design needed for construction was the girder strong-back beams, used to support one girder end from the top of the adjacent girder without the need for supports below to the ground. This was critical at the levee, where construction loading of the levee was prohibited.

Figure 7 – Girder Strong-Back Beams

The design of the strong backs needed to be such that they could be assembled quickly when erecting the girders due to the limited schedule during the night erection periods. These strong backs needed to be as economical as possible given their temporary use; able to form and cast the closure joints with the system in place; and they needed to have the strength and stiffness required for stability and transfer of girder reactions from one girder to the next. A design that utilized standard steel rolled sections and post-tensioning bars was developed, as illustrated in Figure 7. The details of the process using the strong-back beams are given in the construction section below.

CONSTRUCTION

Construction afforded many challenges including a girder type new to Texas fabricators, transportation length, weight and height restrictions, constrained site access, night work requirements, and a substantial crane resting on existing underground utilities, very limited working room, a variety of temporary works, and a tight construction schedule.

The process of fully understanding these challenges and identifying feasible plans to mitigate each of them prior to finalizing the design of the girders and temporary works began with the development of a simple construction computer model. The modeling process began by deciding which of the segments B or D would be erected first. It was anticipated that the required bridge pier foundations on the wet side of the levee might take longer to construct than the foundations on the dry side of the levee due to the possibility of flooding or standing water within the floodplain after heavy rain events. All of the substructure foundations were contained in the same design package and were released for construction at the same time. Due to the aggressive schedule, it was determined that the dry-side substructure foundations would be constructed first, thereby allowing for Segments D and E of the precast concrete spliced girders to be placed while the wet-side substructure foundations were being completed.

The modeling effort helped identify the crane sizes that would be required by allowing the construction team to experiment with the crane placement. This also determined the reach required at each crane location with considerations made for the length of the girder segments, truck positioning, and the temporary support towers. The crane reach required equals the safe working radius within which the cranes would have to operate, and coupled with the beam weights allowed us to select the appropriate sized cranes for each of the girder segments. The modeling on the dry-and wet-sides of the levee largely mirrored one another.

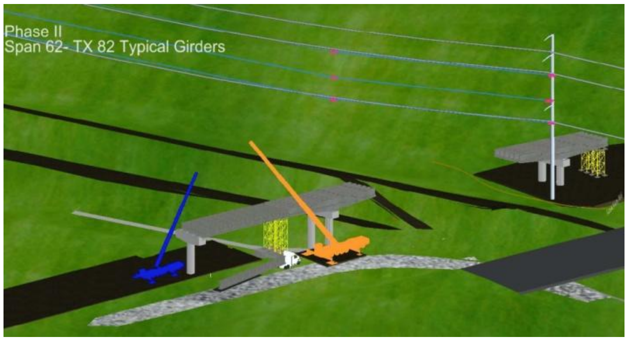

Figure 8 – Computer Modeling of Crane Placement

Segment C, the center drop-in girder, by far presented the greatest number of challenges. Concerns with the overhead transmission wires and several underground utilities, including an old and reported fragile 48" RCP City of Dallas water main and a 4" high pressure gas line, created limitations on where cranes could be placed Several different erection scenarios were considered for this segment. These included a 3-crane pick and pass, a single crane pick, and a launching system. The launching system was eliminated due to excessive costs. The 3-crane pick and pass was given consideration because of the ability it offered of using smaller cranes than would be required for a single crane pick which allowed for a smaller footprint nearby and greater clearance from the underground water main and high pressure gas line. It did, however, include risks that would be largely avoided using a single larger crane. namely the risks of passing a girder from crane to crane and having to locate a crane very near the high-voltage overhead transmission wires and the accompanying increased chances of operator error.

In the end it was determined that a single crane pick would provide the best option and fewest risks. In particular, this scenario provided the furthest clearance off the overhead transmission wires. It did however, carry with it the largest footprint and bearing pressure against the underground utilities, as well as consume the largest amount of overall space in an already extremely tight area which complicated truck access in and out. A 750 ton CC 9600 Versa Crane engineered, manufactured, and operated by a crane supplier out of Louisiana was the most suitable single crane for the work. The crane would require 240 feet of boom and 624 kips of auxiliary counterweight to safely perform the pick.

Because of the uniqueness of these girder segments and the need to get the girder fabricator closely involved with the project early, the process of selecting a fabricator began several months ahead of the scheduled start of fabrication. While similar spliced girder segments are fabricated and erected commonly in other parts of the country especially along the Gulf Coast, none of the 3 largest fabricators within Texas had direct experience with these girders. Their concerns included time and expense to fabricate specialty formwork, prestressing and post tensioning, and delivery of the girder segments. The variable depth Segments B and D girders are nearly 11 foot at greatest depth and would require specially fabricated trucking components to haul them. Segment C girders are over 160 feet in length and also required specialty haul equipment be fabricated. Because of height and length restrictions and the specialty haul equipment requirements, haul routes would have to be chosen carefully. The transportation would be slow due to low clearance bridges along the route or tight turns and equipment limitations dictating a delivery pace of only one to two girder segments a day.

After extensive discussions were held with each of the possible fabricators a precaster out of San Antonio, Texas was chosen to perform the fabrication for the precast concrete girder segments. They were selected six months ahead of anticipated delivery dates. These six months of lead time were extremely busy and tight as Bexar began producing shop drawings for the formwork and prestressing, fabricating the forms, and modifying haul equipment to handle the large girders. The forms themselves took almost 3 months to design and produce and getting them on line quickly was crucial as the cost prohibited fabricating multiple forms for these unique girders. A single form was fabricated for the A, C, and E girder segments and another for the B and D girder segments. The required fabrication schedule would be met with just these two form sets, but there was no room for error. The precaster did an excellent job involving the KSWRP design and construction personnel throughout the process asking many questions, making numerous suggestions, and offering multiple visits to their plant site as the forms, rebar, and prestressing/post tensioning ducts were assembled and readied for the first concrete placement.

Figure 9 – Variable Depth B & D Girder Segment Casting

While the formwork was designed and fabricated, the precaster and KSWRP worked closely to identify the best haul route and staging area for the girder delivery trucks. The precaster's project manager and trucking boss made several trips to the project site to identify the most appropriate delivery route. It was determined that because of the height of girder segments B and D, those girder segments would have a slow haul up from the San Antonio fabrication site and avoid many low clearance bridge structures by taking off-ramps through frontage road intersections then re-entering the freeway at the next on-ramp. Ultimately, this made a six hour trip nearly ten hours and, combined with only 2 haul trucks with the needed specialty modifications with which these segments could be hauled, would prevent KSWRP from setting more than 2 girder segments every other night.

Once near the project site, the girder segments would have to be temporarily staged and repositioned to make the final pull into the setting location. Because the girders were of such height and length, they could not make the turnaround under the existing highway bridge at the set site in the normal flow of traffic. Once in the staging area and repositioned to face the correct direction, the girders would travel under a temporary traffic blockade in a pattern against normal traffic flow eastbound down westbound Spur 482 and off at the normal on ramp onto the westbound frontage road and through to the set site, as shown in Figure 10. The permissible traffic closures were extremely limited, due to the set site's proximity to a major Federal Express hub facility. The hours that the turnaround lanes could be shut down to through traffic were limited from 11 pm to 5 am.

Figure 10 – Site Staging Lane Closures

With the design of the structure complete and girder segment fabrication underway, KSWRP began preparing for the initial erection of Segment D girders. In early April 2010 the temporary shoring tower foundation on the dry side of the levee was constructed. The first shore tower for the temporary support of these girders went up the same day that the Dallas Cowboys' old Texas Stadium was demolished. With the shore tower in place and inspected for full compliance with the design drawings, it was time to take delivery of the first of the Segment D girders and see all the design and planning efforts come to fruition. The first two girder segments arrived and were set on April 14, 2010. Each segment was set using a 2-crane pick.

The traffic closure restrictions proved very challenging on the initial set of girders. While there was a tremendous planning effort that went into preparation, there was still a learning curve and the first girder set proved slower than had been hoped. Each girder had to be tied down with post-tensioning to the pier cap at the center and temporary shoring tower on one end and properly torqued before releasing the cranes from the girder. By the time it was released from the cranes there was only about an hour and a half window remaining in the permissible traffic closure. With one girder up however, as the second girder had to be set as well in order to stabilize the girders through the use of temporary steel diaphragm bracing. These braces were tied off to the second girder such that they would be hoisted with the girder and then once the second girder had been tied down to the pier cap the temporary shoring tower would then be positioned by hand and bolted to each girder as required. Fortunately the second girder was set in place onto the cap and the delivery truck was able to pull out of the way shortly before the traffic closure had to be lifted and the tie- down and diaphragm bracing work continued unimpeded.

Segment D girders were successfully set at the pace of 2 every other night for a 5 day total duration. The setting operation then moved next to Segment E girders which would be suspended off of the Segment D girders at one end through the use of overhead steel strong-back beams, and set on the pier cap at the other end.

Figure 11 – Setting the First Girder Segment E

While the Segment E girders themselves allowed for delivery of all six girders on the same night, the strong-backs added another element of time constraint. Due to vertical height restrictions along the haul route, only once the girders arrived within the set area could the steel strong-back beams be fastened to the top of the girders and made ready for set. It took an additional crew to install the beams and once the first was ready the girder set crew would hoist the girder in place and secure the strong-backs to the Segment D girders while the strong-back crew moved on to the next Segment E girder. The Segment E girders were set at the pace of 3 a night in consecutive nights.

Once all the Segment E girders were set in place, they were connected to Segment D girders with a cast-in-place concrete closure pour. The post tensioning ducts were joined together and then the wood formwork and reinforcing steel were placed. The wood soffit formwork was suspended from the underside of the girders using the same tie-down rods that secured the strong-backs to Segments D and E. Once the closure pours had been made, Segments D and E were complete and ready for Segment C girder placements.

By this time the substructure foundations were finished on the wet side of the levee, and the girder setting operation moved over to set girder segments B and A. These girder sets closely mirrored the setting operations for Segments D and E, but were further complicated by their immediate proximity to the high-voltage overhead transmission lines. Fortunately on this side of the levee there was no traffic closure restrictions as there were near the Fed Ex facility. However, there was a restriction on hours that the overhead transmission lines could be powered down to allow for the work to take place so closely. Particularly the extended crane booms. Work still had to be completed at night and within a window of 10 pm to 7 am. Close coordination was required with Oncor Transmission to both schedule the outages and visually verify the power-down and tag-out/lock- out procedures prior to extending the crane booms in the air. Nevertheless the work to set Segments B and A proceeded quickly and was completed successfully, including the closure pours joining each of these girder segments together. They too were now ready for Segment C girder placements.

The Segment C girder erection posed the most challenges, with a girder length of just over 160 feet and a weight greater than 214,000 pounds. Additional complications includes the physical site constraints , a 48” water main and 4” high pressure gas line underground, very limited working space between the set location against the levee and the adjacent roadway. The first challenge was identifying the right crane for the job that could safely make the lift and offer the smallest footprint and ground bearing pressure possible. As mentioned above, KSWRP selected a CC9600 750 ton Versa Crane for this work. This crane had a reasonable footprint of 40 by 25 feet, smaller in comparison to other cranes that were explored. The design of the crane pad went through extensive analysis and peer review to ensure that we would not overload the underground utilities below, as the crane would exert a total ground pressure of 1.6 million pounds. Should the water main be overloaded and fracture or rupture, the result would have been catastrophic under full load with the crane hoisting a girder segment in the air near the 345 kV overhead transmission lines, while shutting down water service to a large portion of the Cities of Dallas and Irving.

The crane supplier developed a lift plan for the safe rigging and execution of the Segment C girders. The weight of the Segment C girders required the use of an auxiliary counterweight pack. This auxiliary counterweight would only be used after the crane made the initial girder pick off the delivery truck and turned to face the set position. The auxiliary counterweight would then be attached and the crane boomed down to the maximum radius required to set the girders. The auxiliary counterweights could not be used without the load of the girder to counter the load of the added counterweight. This necessitated two separate lift plan calculations to ensure that whether with or without the auxiliary counterweight attachment, everyone involved with the crane pick knew the limitations and the safe working radius to stay within.

The crane was brought on site a week ahead of the scheduled set date for the Segment C girders. Because of the weight and quantity of the individual components and the need to stay within legal haul restrictions on the highways, the crane required 68 truckloads to get all the components on site. The crane supplier needed 5 days to haul in and assemble the crane, and this operation required its own 240 ton support crane.

Once the crane was fully assembled and readied, the Segment C girders were loaded and hauled to the jobsite. Only two trucks had been modified to manage this length and load of girder, so only 2 girders could be delivered every other day. Two, however, would prove very challenging to get into position, place the strong-backs at each end, rig, and set the girders, all within the allotted traffic closure time frame. Delivery of the Segment C girders followed the same route into the set site as did the others, with an against-normal traffic flow pattern. The girders were stopped short of the set position to allow ample space around the girder for the strong-back crew to make the necessary assemblies and then the girder was pulled ahead to the crane and into its pick position. The temporary steel diaphragm braces where also tied off to the girder at each of the required bracing locations before picking the girders.

Once the truck was positioned properly so that the girder segment lifting points were within the safe working radius of the crane, the crane was rigged to the girder. The rigging weight alone required a 240 ton support crane, and the rigging process took about 30 minutes per girder. Once rigged and readied, the crane hoisted the girder into the air and boomed up so that the load was no longer over the delivery truck. Because of the concerns with the hairline cracks at the girder lift points, a ten minute hold policy was implemented whereby the crane would make the initial hoist off the haul truck, boom up and lower the girder to just several feet off the ground so that each lift point could be inspected under load. This time also enabled the truck driver and team to get the haul truck collapsed and out of the way before the crane would be hoisting and swinging the girder load overhead.

After the ten minute hold and lift point inspections were completed, the girders were maneuvered into position.. The hoisting took considerable time due to the many parts of cable required in the crane to make the pick safely. It required approximately 1 hour from the time the girders were hoisted and turned and lowered into place so that the strong-backs rested on the Segments B and D girders. Many precautions were taken due the high risk of the pick and its proximity to the overhead transmission wire. Of chief concern was maintaining control of the girder segments as they were in the air. This was accomplished through the use of air tuggers that were mounted on the crane counterweights and cabled to each end of the girder segment so that girder positioning could be manipulated as needed.

Once each Segment C girder was set into place such that the strong-backs were squarely resting and supported from the Segments B and D girders, the

Figure 12 – Erecting Girder Segment C

set crew installed the tie-down rods and applied the required torque to each rod. Only once each rod had been both torque as required and independently verified by the design team was the crane released from the girder segment. The lifting operation took a total of 5 nights to set all 6 girders, including the delivery and turn around times. Once all the Segment C girders were set in place, they had to be joined to the Segments B and D girders with similar cast-in-place concrete closure pours as had been done for the other girder segments. Along with the closure pours, the segments required cast-in-place concrete diaphragms as various locations, and these were constructed in much the same manner as were the closure pours.

Figure 12 – Completed Bridge

After all cast-in-place closure pours and diaphragms had been constructed including the required cure time and concrete strength attainment, the work of post tensioning the girder segments was begun. There were over 40 miles of post tensioning strand consumed in the project. DSI performed all the post tensioning work, which took 3 weeks to complete.

SUMMARY

The DART Orange Line project had many key aspects, but none more so that the design and construction of the Trinity River Levee crossing. The difficult horizontal and vertical clearance restrictions due to the levee and the overhead power lines, the limited access available for large girders, and the need to get the structure done early to allow for rail installation, all combined to make this bridge a challenging design task and critical to the overall success of the project. Construction also afforded many challenges including site access, night work requirements, a substantial crane resting on utilities, and a variety of temporary works. Meeting all of the design and construction challenges could not have done without using an innovative design and construction procedure that were effectively integrated though the design/build delivery process.