BNSF TRUSS ACCELERATED BRIDGE CONSTRUCTION OVER I-235

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BIOGRAPHY

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SUMMARY

The new Burlington Northern Santa Fe (BNSF) truss bridge over I-235 is located ½ mile south of the junction of I-235 with I-44 in Oklahoma City. I-235 carries 115,000 vehicles per day, connecting the northern suburbs to the Central Business District and the Capitol Complex. The truss bridge is composed of two 275-foot spans with a total bridge length of 558 feet. The Warren Truss with verticals has 10 panels per span. The single-track trusses are 21 feet wide and 45 feet tall.

The trusses cross 6 lanes of highway traffic and Deep Fork Creek. Immediately north of the BNSF Truss is the NW 50th Street Bridge over the interstate.

The I-235 and BNSF alignments are parallel through the heart of the city, with a crossing at NW 50th Street. To accomplish the crossing at NW 50th Street, the highway alignment follows a reverse curve to cross the railroad alignment at a 52 degree skew.

This is the first truss bridge erected by the Oklahoma Department of Transportation (ODOT) since the 1960's. Designing a truss bridge for the BNSF Railroad and bidding/ constructing what is now a very unusual structure for ODOT presented several challenges that were overcome through the partnerships that have developed over a number of years.

The use of Accelerated Bridge Construction techniques (ABC) minimized disruption to the BNSF rail traffic, averaging 49 trains per day, and 115,000 vehicles per day using the interstate. The contract documents were crafted carefully to ensure the contractors were fully aware the highway traffic would not be allowed to be reduced from four lanes to two lanes. The trusses could be launched or moved into place, but could not be stick-built in the final location.

The winning contractor elected to erect the trusses on the ODOT right-of-way and move them into place using Self-Propelled Modular Transports (SPMT). This creative method reduced the highway closure time for installing the trusses from months to a single three-day weekend. The use of SPMT resulted in no impact to rail traffic during the erection and installation of the trusses. In addition to the time savings, the use of ABC construction using SPMT's greatly improved safety of the traveling public, contractors, inspectors and the railroad personnel.

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Introduction

The I-235 Broadway Extension runs from suburbs north of Oklahoma City to the Capitol Complex and the Central Business District, carrying nearly 100,000 Average Daily Traffic. The interchange with I-44, NW 50th Street, and the crossing with the Burlington Northern Santa Fe (BNSF) Railroad is the next to last segment of a 10.6 mile stretch of interstate to be widened from four lanes to six lanes. See Figure 1.

The 1960's era Burlington Northern Santa Fe Railroad Bridge creates a bottleneck, with three piers tightly framing only four lanes of highway. A new structure which spans the new six lanes of highway and ramps and the triple cell reinforced concrete box carrying Deep Fork Creek through the junction is the solution to eliminating the corridor's bottleneck. See Figure 2. The truss is located on a 25-foot offset alignment east of the existing bridge, allowing continuous rail traffic until the tie-ins are made to crossover to the new track.

Each span is 275' long due to the 52-degree skew of the BNSF/I-235 crossing. The span length and railroad loading necessitate a truss bridge. The through-truss single track bridge measures 45' high and 21' wide, providing the proper proportions for a rail bridge. The Warren trusses incorporate vertical posts and hangers.

Figure 2: Bottleneck at existing BNSF Bridge.

The site requires a shallow superstructure below the top of the rail, which is satisfied by the truss. A shallow span structure is required because the railroad grade is bounded by the NW 50th Street Bridge crossing over the BNSF tracks and the close proximity of adjoining property owners to NW 50th Street and the I-235 entrance ramps. Additionally, I-235 could not be lowered further without creating a sump condition over the Deep Fork Creek during larger storm events.

Figure 1: Looking northeast towards the I-44 interchange.

The Contract Time for the interchange project was 850 calendar days, with a liquidated damages rate of $2,000 per day. The Notice-to-Proceed date was January 2, 2017, reflecting a project completion target of May 1, 2019. An A+B bid was provided in special provisions. The B portion of the bid was 700 days at $10k per day with the incentive capped at 180 days, moving the target forward to December 2, 2018.

The project was awarded in June 2016. The contract bid price for the truss bridge is $17.5 million. Shop drawing submittals began in June 2016, and fabrication began in October 2016. Truss assembly started in June 2017 and was completed by November 2017. Site-wide construction began in January 2017 and is scheduled to be completed in June 2018.

Because the existing bridge required removal and replacement to accommodate the highway widening, the Oklahoma Department of Transportation (ODOT) was responsible for constructing the truss bridge for the BNSF Railroad. The agreement between these two parties resulted in the bridge being incorporated into the widening project to be bid and managed by ODOT.

The steel dead load of each new span totaled 950 tons and used 55,000 permanent bolts. The size and placement of this truss bridge required the implementation of special procedures to ensure the safety of the public, construction and inspection personnel and BNSF, in addition to facilitating acceptance of the bridge by BNSF. Key to the planning process was safety and to minimize impacts to the traveling public and rail traffic.

Site Constraints

As shown in Figures 1 and 2, the site is located south of the I-44 interchange on a curved alignment. The existing NW 50th Street Bridge crosses over the interstate, over Deep Fork Creek and over the BNSF track.

Deep Fork Creek crosses under the BNSF embankment in a triple cell 10’ x 10’ box, which is separated from the abutment for the BNSF Bridge by a drilled shaft wall extending ten feet above finished grade. The drilled shaft wall continues to the north behind the NW 50th Street Bridge pier. The north end of the truss stops just short of the NW 50th Street Bridge.

On the east side of the site, businesses are located along the BNSF right-of-way; therefore, the grade differential is managed by drilled shaft walls up to 35’ in height. During construction, the drilled shafts walls and the existing railroad embankment form a narrow pocket for the south end of the truss to rest on its abutment, as shown in Figure 3.

Figure 3: Looking southwest. The south “pocket” between existing rail and drilled shaft wall.

Drilled shaft walls are also an accelerated construction technique, in which retaining walls are formed without excavation of the native soils behind the wall for footings. Drilled shafts are placed close together in the native soils, with a space ranging between slightly overlapping to one diameter clear between the drilled shafts. The front side of the drilled shafts are excavated to the subgrade, and a drainage system installed between the drilled shafts. Precast fascia panels attach to the front face of the drilled shafts, connected between a leveling pad at the base and a connection cap at the top of the wall.

The Design Process

ODOT contracted with a consultant to design the widening throughout the corridor. ODOT entered into an agreement with BNSF to prepare plans for the bridge through the design consultant. A railroad design consultant was added to the team to perform a peer review and facilitate acceptance of the truss plans by BNSF. The railroad consultant’s role later expanded into the design of the truss, while the design consultant designed the floor system and substructure. BNSF contracted with an independent railroad consultant to review the calculations and plans to ensure that American Railway Engineering and Maintenance-of-Way Association (AREMA) criteria and BNSF design preferences were incorporated into the plans. In accordance with the ODOT/BNSF agreement, ODOT paid the fees for the independent railroad consultant review.

The BNSF independent railroad consultant prepared a spreadsheet with review comments, and the designer and reviewer responded back and forth until every comment was resolved. The review process was expedited through conference calls and meetings between the reviewer and designer to supplement the responses in the spreadsheet. A final railroad agreement for construction was not completed until all comments were resolved to BNSF's satisfaction.

The most expeditious way for a highway department to design a bridge for a railroad is to include an experienced railroad design consultant recommended by the railroad to prepare the bridge design and plans. In addition, the project design schedule should accommodate a few rounds of reviews by the railroad's independent consultant, with a minimum review period of three months each. Not all industry practices are codified, and the expertise of a railroad design consultant is key to having an approved design in a timely manner.

The Truss

Built-up box members comprise the top and bottom chords and end portals of the truss. The top and bottom flanges and webs of the box sections are steel plates varying from 1/2" thick to 1" thick, joined by 6 x 6 x 3/4 angles, made up to form a 2'-7" square section. See Figure 4 for the interior of the upper chord, with access holes in the top and bottom plates covered by bird screens. The bird screens were attached such that that a screen that vibrated loose would remain inside the box section, rather than falling onto the highway below.

The web members of the truss are plate girders, arranged in a Warren Truss configuration with vertical members. Each truss consists of ten panels, with vertical members called either posts or hangers, depending on the axial load carried. The plate girders have flanges varying from 1/2" x 1'-4" to 1 1/2" x 1'-8", with nominal 1/2" x 2'-5" webs.

The floor system consists of W30x357 floor beams with eight W21x182 stringers. The ballasted deck system anticipated up to 30 inches of ballast. The

Figure 4: Built-up box section.

deck plate is a 1" steel plate welded to the stringers. Flexibility is required for the connection of the floor beams to the truss, which was achieved using bent plates for the connection from floor beam to the truss. For the connection of the stringers to the floor beam, the top bolt adjacent to the stringer web on each connection angle was removed to add flexibility, as shown in Figure 5. Removal of these bolts help prevent fracture from occurring at the location of the greatest angle bending between the legs.

Figure 5: Flexibility in stringer connections.

To transfer the loads from the truss to the bearings, a stiffened bearing column was incorporated into the lower chord end point, as shown in Figure 6. The end floor beams incorporated stiffeners for jacking the bridge in the future to allow replacement of the bearings. Two of the jacking points were used in the week following swinging the truss into place, to allow one bearing to be adjusted.

Figure 6: Bearing column.

The chord members are spliced at every other panel point. Originally located at the center of the panel point, these were later offset to one end of the gusset plates to reduce the size of the gusset plates. Further economy in the size of the gusset plates was introduced by changing the web members of the truss from the original box sections to plate girders. The design modernization introduced by the railroad design consultant produced a more efficient design than the original go-by plans provided by BNSF.

The camber loading requirements for trusses are clear in the AREMA Manual. In this case, the resulting camber for the 275-foot simple span included the increasing length of the top chord members and decreasing the length of the bottom chord members to achieve the required camber shape. However, the camber requirements for the floor system were not provided on the plans or specifications. For span lengths up to 300’, it is common to shorten the floor system similar to the bottom chord members to account for the truss camber. As a result, the floor system now shares in the dead and live load resistance with the truss members. As the span lengths approach 300’, the amount of tension in the floor system increases during deflection of the truss. If the floor system is not shortened similar to the bottom chord members, significant force would be required to install the stringers during assembly of the truss and floor system, which was unacceptable. For truss spans 300’ or longer, an expansion joint is provided in the floor system to limit the additional tension placed into the floor system. Since this case was below the 300-foot span length, an expansion joint in the floor system was not utilized, but reduction of the tension forces in the floor system were desired. A solution was chosen to revise the stringer to floorbeam connections to incorporate short horizontally slotted holes, to allow the truss to deflect under self-weight prior to tightening the stringer connections and completing welds between the deck pan and the stringers. This solution resulted in lowering the amount of additional tension in the floor system. For shorter span, another consideration would be to incorporate a note to state that the floor system is shown as a horizontal projection and have the fabricator incorporate grade and camber into the detailing, in coordination with the erection contractor.

Construction Requirements

An offset alignment allows installation of the new bridge and removal of the existing railroad plate girder bridge with minimal interruption to rail traffic. Key to the project is maintaining two lanes of through traffic each way on I-235 during construction, limiting closure related to the BNSF Bridge to three weekends: one three-day weekend for erecting each of the two trusses, and one weekend for demolition and removal of the existing railroad bridge.

Plan notes specifically prohibited truss assembly over traffic, prohibited reducing the number of lanes on Broadway from two each way and limited closure to no more than two three-day weekends for erection of the bridge. This effectively allowed constructing the trusses on ODOT or BNSF right-of-way and moving or launching them into place.

Several large out-of-state contractors with truss experience were contacted during the design process to vet the site constraints for launching the truss from the BNSF embankment or for using Self-Propelled Modular Transports (SPMT). One SPMT contractor visited the site to review the grades and available space to maneuver the trusses into place, and deemed SPMT was a viable option. See Figure 7.

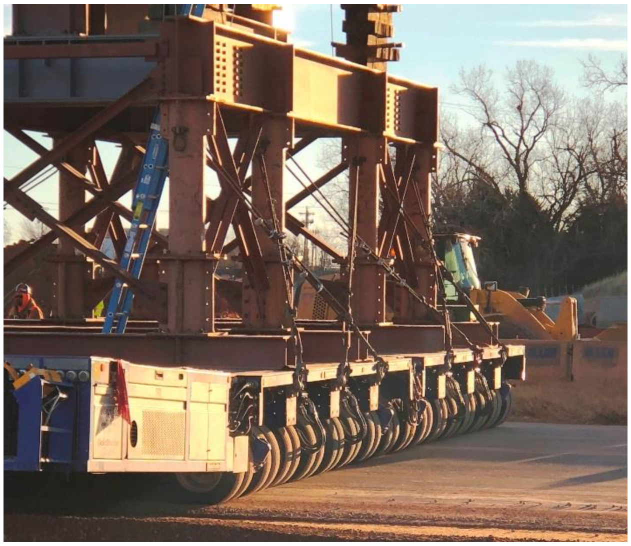

Figure 7: Self-Propelled Modular Transport.

The BNSF and AREMA material and construction specifications differ from those of ODOT and American Association of State Highway and Transportation Officials (AASHTO). Additionally, AASHTO and the National Steel Bridge Alliance (NSBA) coordinated the effort of industry professionals from the fields of design, fabrication, and construction to develop a series of collaborative guidelines, including one for the erection of structural steel. The project was bid by ODOT as part of the largest construction package in ODOT history, combining the BNSF Bridge, the NW 50th Street Bridge, retaining walls, and highway drainage, grading, and surfacing, at a contract bid price of $81 million. To accommodate the BNSF/AREMA requirements, plan notes dictated the order as follows:

1. Plans and Plan Notes
2. Special Provisions
3. Appendix B - BNSF Standard Construction Specifications
4. AASHTO/NSBA Steel Bridge Erection Guide Specification
5. AREMA Manual
6. ODOT Standard Specifications for Highway Construction

Key portions of the BNSF construction specifications and the AASHTO/NSBA Steel Bridge Erection Guide Specifications were incorporated into the plan notes, because these are not typically heavily referenced in ODOT construction documents, and the project was bid under ODOT contracting procedures. This ensured the contractors bidding the project and the inspectors overseeing construction were aware of the major requirements. For example the project specified that the substructure would be paid under ODOT's Class AA Concrete bid item, ensuring the 28-day strength of 4000 psi concrete, but that the concrete would meet BNSF material and construction specifications.

The last truss bridge constructed in Oklahoma was erected in the 1960's. The specialized skills necessary for the safe erection of a truss bridge of this magnitude were limited. The contract documents required pre-qualification of the erection contractor. The General Contractors submitted the qualifications of the proposed erection contractor for evaluation by a team including the ODOT Bridge Engineer, Office Engineer, Division Engineer, Chief Engineer, and the design consultant.

The erection contractor was required to show a project reference list verifying the company's experience. The experience was also required for the foreman, job superintendent, and registered professional engineer preparing the erection plans and calculations and overseeing the construction and erection. A minimum of three projects consisting of railroad, city, state, or federal highway through-truss spans, or other significantly complex bridge structures were required. American Institute of Steel Construction (AISC) certification as an Advanced Certified Steel Erector (ACSE) was also required. The plan notes required the personnel submitted and approved through this process be on-site at all times when work was performed requiring erection team oversight.

ODOT engaged the design consultant and railroad design consultant, both of whom are the Engineers of Record, to perform the shop drawing reviews, erection plan reviews, and to respond to the Requests For Information (RFI). BNSF approved of this plan, and designated the railroad design consultant to also be their representative in the shop and erection plan review process, and responding to RFI's.

In addition, BNSF provided on-site inspectors for the fabrication and construction process. Ideally, the same railroad design consultant would perform shop drawing review as well as inspection services, having intimate knowledge of the design. In this case, a different railroad consultant was hired by

BNSF to provide inspection services for fabrication and construction.

Fabrication

Several members of the truss are Fracture Critical Members (FCM), including the lower chord, hanger members of the truss panels, floor beams, and connections of the floor beams to the truss. The stringers were marked to indicate Impact Testing Required (ITR), that the stringers must meet the criteria for Notch Toughness, with impact tests per Charpy V-Notch (CVN) tests per American Society for Testing and Materials (ASTM) A673/A673M.

The FCM designation indicated to the mill that the following requirements and procedures must be followed:

- softened slings used for handling,
- rolling defects cannot be repaired at the mill,
- any defects would be inspected at the shop prior to acceptance, and
- specified CVN requirements would be ensured.

The thick flanges of the W30 floorbeams and their use as flexural members in critical applications required additional CVN testing. The heavy hot-rolled shapes can have a coarser grain structure in the web-to-flange intersection, which could result in cracking when in tension. Notch toughness at service tension is recommended per ASTM A6/6M, supplement S30 for the “alternate core location”, found at the intersection of web and flange.

The computerized tracking system at the mill could accommodate one type of material testing, but not two. The normal order for FCM weathering steel members was “ASTM A709-50WF2”. For these heavy shapes, additional length to accommodate a second CVN test was not available. The semi-finished pieces had already been cast weeks prior to the realization that two tests could not be specified with an order. In this case, the maximum length of the “as-rolled” sections for beams of this size from the semi-finished castings was 120’. At this length, three ordered lengths of 36’-4” could be produced from one rolled section. From each of the ordered sections, the fabrication shop has sufficient room for two squaring cuts and a third cut to produce two floor beams from each ordered length. The drop pieces are possibly two or three inches long, but are not guaranteed to be long enough for the coupons for

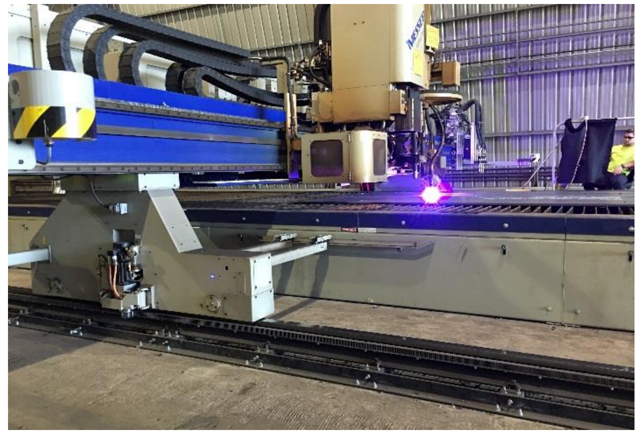

Figure 8: Computer Numerical Control Machine**.**

the ASTM 6/6M testing.

The steel mill accommodated the special request by pulling the core CVN test specimens from the same drop section they used for pulling the standard flange CVN specimens. The core specimens were fully certified, documented, and traceable to their particular heat. The mill shipped the core specimens and full documentation to the fabricator, who then provided the same to an independent testing lab who performed and certified the CVN test per ASTM A6/6M. BNSF agreed to this plan, and agreed to the reduced testing frequency H for the core specimens, rather than the originally specified P frequency, as the steel was not produced from ingots.

Computer Numerical Control (CNC) machining was permitted upon approval of BNSF. Acceptance of CNC machining saved several months of fabrication time. The CNC machine provided pin-dot marking, plasma cutting of members, and drilling of holes for

Figure 9: Pin dot marking.

the assembly of the box sections and connections. See Figure 8.

The CNC machine produced a pin dot marking which was light enough for FCM members, while being durable enough for use throughout fabrication and erection. See Figure 9.

The construction specifications required shop fit-up of the trusses in the horizontal plane, with a minimum of three continuous panels assembled at a time. The fabricator assembled each entire truss panel in the shop before shipping, as well as assembling the floor system shop in two parts.

Off-Site Erection

The truss members were assembled 1/4 mile north of the final location. The erection contractor chose to erect the truss members in the vertical position starting with the center verticals. This eliminated the need for special bracing to raise the truss from horizontal to vertical, and allowed the floor system to be installed in conjunction with the trusses. Construction progressed panel point by panel point in each direction. The panels were blocked to no-load conditions, matching the shop assembly position. See Figure 10.

Figure 10: Truss erection from the center point with blocking at each panel point.

Accelerated Bridge Construction

The general contractor and erection contractor elected to use SPMT's to move the trusses into final position. SPMTs consist of multiple transports tied together into a single remote controller. Each transport module has two axles, with four wheels per axle. For this move, two units were joined together to support the truss from the two closest panel points to the center panel point. Each unit consisted of eight

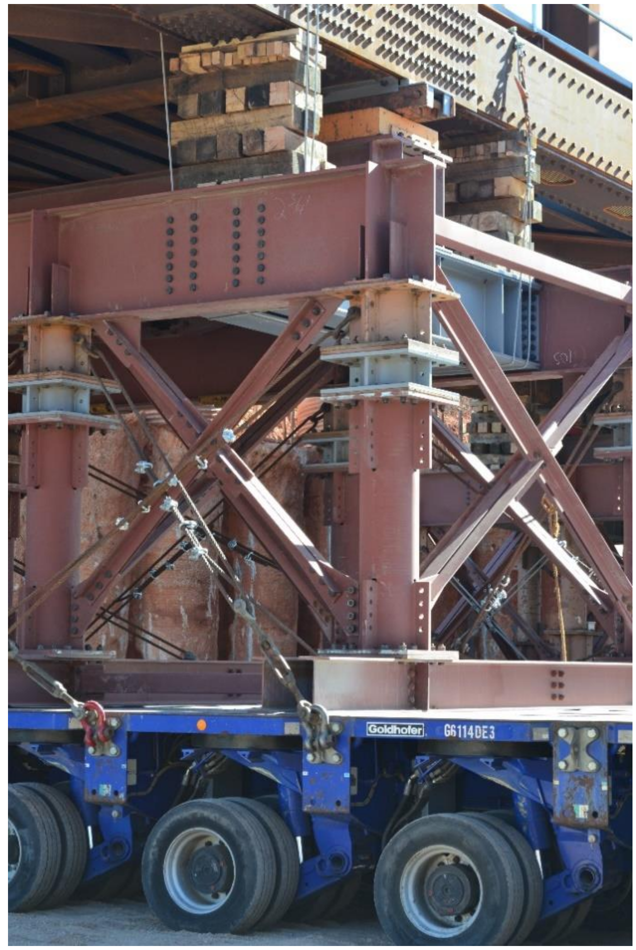

Figure 11: Cribbing on the SPMTs.

transport units. The total steel dead load of one truss unit is 1.9 million pounds. With a total of 256 wheels, each wheel carries almost 7,500 pounds. Temporary struts attached to the truss panels distributed the loads from these bearing points into the truss members.

The axles rotate in unison, and are capable of rotating 360 degrees. The hydraulics on the transports have a lifting range of 18 inches, requiring the trusses to be lifted and placed on cribbing above the transport units. They were moved along the highway approximately 16' in the air, which was slightly higher than the final in-place height. This allowed use of the hydraulic lifting range to move upwards to clear the bearings if needed. They were then allowed to lower the truss into the final position using the hydraulics. See Figure 11. (Note: The current roadway surface is higher than the final roadway surface, to avoid exposing the footings of the existing BNSF bridge.)

The move-in was performed with full closure of the highway over a planned 3.5 day-weekend starting at 7:00 pm on a Friday in January 2018 and ending by 6:00 am Tuesday. The plan was to begin moving the first truss Saturday from 8:00 am to 5:00 pm, followed by the second truss from 5:00 pm Sunday to 4:00 am on Monday. The time from highway closure to the first move, in between moves, and after the last move was for moving traffic barrier, compacting gravel pads where needed to level the grade, and replacing traffic barrier and restoring the driving surface.

The first truss was moved into place in four hours on Saturday, requiring a highly skilled operator for the SPMT's. The south truss was swung around the pier and backed into a tight pocket at the south abutment bordered by the existing railroad embankment on the west side and a 30-foot tall drilled shaft wall retaining the properties along the east side. The maneuver was accomplished with approximately two feet to spare from the drilled shaft wall, as shown in Figure 12.

Figure 12: Truss being moved past the drilled shaft wall into south "pocket".

The second truss was moved in place on Sunday morning, in approximately three hours, due to a much more direct route to the pier and north abutment. The northbound lanes were re-opened to traffic on Sunday night and the southbound lanes mid-morning on Monday. Traffic was opened approximately 32 hours and 24 hours early for northbound and southbound traffic, respectively. Trains passed throughout each day unhindered by the moves, with the SPMT's stopping when a train was due to pass by. An average of 49 trains traverse the track per day.

For both trusses, fine tuning the placement of the truss on the bearings took as long as the entire movement from the erection site to the pier and abutments. One bearing was misaligned in comparison to the truss, requiring adjustments prior to acceptance. The design intent was for the anchor bolts to be grouted into place after setting the truss, to allow more leeway to bring bearings into the necessary tolerance. This is a common detail for truss installation during a short railroad closure period, using a flowable non-sanded grout.

The first Accelerated Bridge Construction of this type in the state of Oklahoma went smoothly, reflecting the general contractor's philosophy was fully implemented: "If there is no room for error, then there is no error. Plan accordingly!"

Positive Public Support

ODOT hosted a media event for the move-in with approximately 700 spectators observing the move-in from a high vantage point and another 1,700 viewers watching live-stream from the ODOT website. ODOT provided numerous interviews of ODOT and construction personnel to provide updates on the move-in progress, explain the process, and to answer questions from the public and media. Countless others watched the event from news channel coverage, Facebook, and Twitter links. The feedback to ODOT was overwhelmingly positive, with the public understanding that the short-term closure saved them additional months of traveling through construction zones and lanes reduced to one lane each way.

Lessons Learned

Several lessons from this project, some of which were incorporated, some of which would have improved the project process include the following:

- A large size construction project can better accommodate the costs of specialized construction.
- When two large projects originally designed to be constructed in sequence are instead bid together, the construction sequence should be evaluated and modified where possible to reduce the construction time.

- A+B+C bidding procedures can further reduce the construction time.
- Properly developed incentives/disincentives minimize disruption to the traveling public.
- Contract documents need to incorporate sufficient clauses to ensure that the desired outcome is provided.
- Particularly when specialized construction is to be employed, what is allowed and what is disallowed needs to be clearly presented.
- When the project will involve construction specifications unfamiliar to the department of transportation inspectors and contractors, additional notes highlighting the key points are helpful to ensure their implementation.

Additionally, the inclusion of an industry expert in the design process is imperative for streamlining the railroad review of the design calculations and drawings. Ideally, the same industry expert is involved in the design, shop drawing review, and shop/field inspection, with the railroad designating the expert as their representative. The design schedule needs to allow sufficient time for three or four cycles of review and comment and resubmittal of the calculations and drawings.

When specialized construction is necessary for a region, a pre-qualification process or other methods must be employed to ensure safe and sound construction.
Electronic shop drawing submittals, with digital approval stamps and locked files expedites the shop drawing review process. By using an industry expert with the authority to review on behalf of the railroad, several months were cut from the schedule. CNC machining likewise cut several months off the schedule for fabrication.

Acknowledgements

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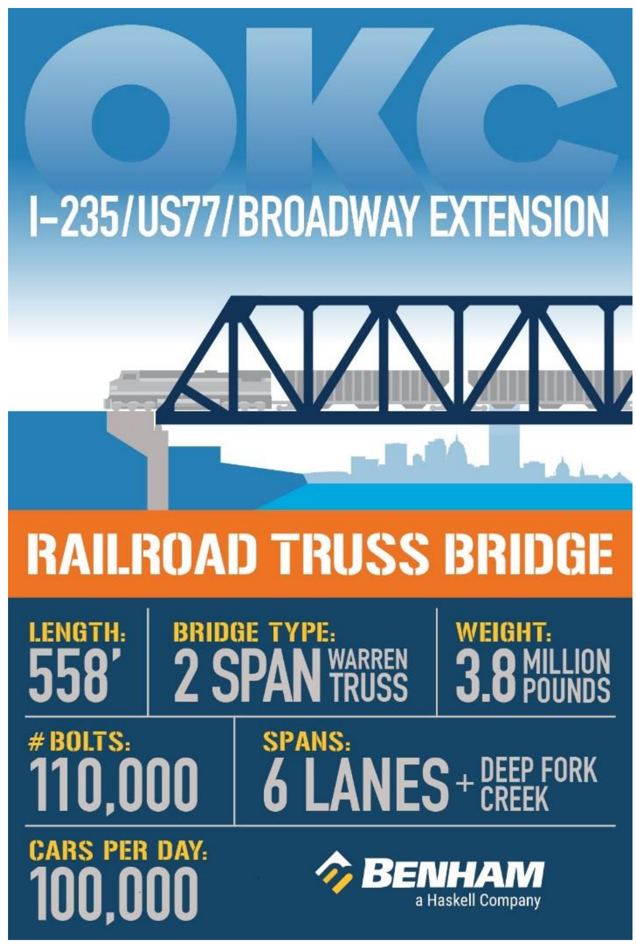

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1. Aerial Photography courtesy Jamin Yeager/Aerial Oklahoma, LLC; AerialOK.com.