NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

August 21, 2008

MATERIALS LABORATORY FACTUAL REPORT Report No. 08-073

A. ACCIDENT

Place	:	Minneapolis, Minnesota
Date	:	August 1, 2007
Vehicle	:	I-35W Highway Bridge
NTSB No.	:	HWY07MH024
Investigator	:	Mark Bagnard

B. COMPONENTS EXAMINED

Erection Sequence

C. INTRODUCTION

This report presents the fabrication and erection procedure of the 3-span continuous deck truss of Bridge 9340 across the Mississippi River in Minneapolis, Minnesota. The deck truss was comprised in spans 6, 7, and 8 and included a small part of spans 5 and 9. The truss was supported on four piers; pier 5 at the southern end of the truss, pier 6 adjacent to the south bank of the river, pier 7 adjacent to the north bank of the river, and pier 8 at the north end of the truss. Span 6 consisted of the truss structure between piers 5 and 6, span 7 was the main river span between piers 6 and 7, and span 8 was between piers 7 and 8.

The steel fabrication and erection procedure for Bridge 9340 was engineered by Industrial Construction Division of Allied Structural Steel Company (Allied), Hammond, Indiana. This company was both the steel fabricator and erector for the project. The approved construction documents generated by Allied contained a detailed erection procedure with falsework[1] plans and closure details. This report summarizes the fabrication and construction procedures that were submitted at the time construction began. These procedures were revised twice prior to construction, and a discussion of these revisions is contained in section G of this report.

The technical documents that determined the construction methods and sequence of the bridge were contained in a construction planset, which included the Erection Scheme (ES), Falsework (FW) and Construction Stress (S) drawings. The Erection Scheme drawings are reviewed in this report. The Erection Scheme was contained on 4 sheets,

[1] Technical terms used in this report are defined in section D.

portions of which are reproduced in the figures. Drawing ES-1 detailed the erection sequence from node U0 to nodes L9 and U10 (primarily span 6, see figure 1) and from the U0′ to nodes L9′ and U10′ (primarily span 8, see figure 2). Drawing ES-4 detailed the erection sequence of the center portion, primarily span 7, as shown in figure 3. This drawing also contained a written Erection Procedure. As can be seen in figures 1 through 3, each main truss members was numbered according to the sequence that the specific member was erected. Drawing ES-2 detailed the erection of falsework Bents #1, #2, #3 and #4. Drawing ES-3 detailed the jacking arrangements at nodes L1, L1′ and L8, which are reproduced in figures 4 and 5.

The first set of Erection Scheme drawings was dated March of 1966. Problems with falsework locations in Span 6 resulted in revisions to Erection Scheme drawings ES-1.1, -2.1, and -4.1 in March 1967, as discussed in section G. The erection of the steel truss began on May 9, 1967 and was completed on August 11, 1967. This report focuses solely on the erection of the steel deck truss and does not address the construction of the piers, approach spans, or concrete deck.

D. DEFINITIONS

Specific terminology was used in the construction documents in reference to the erection process of Bridge 9340 and is similarly used in the body of this report. Definitions of some of these terms are provided:

Bent = transverse frame used to temporarily provide lateral and vertical support to the truss during erection, used to designate the falsework locations. The bents were numbered from 1 through 4 from south to north.

Close = completion of a specified node that created a stable structure. The closure of specified nodes indicate construction milestones during the steel erection.

Falsework = temporary framing used to support the truss structure during erection.

Fit Up = the act of positioning members, aligning holes, and installing bolts or rivets at a joint. Complete fit up was accomplished when the required number of fasteners were placed, allowing the erection to proceed.

Jack = hydraulic ram used to move truss horizontally or vertically.

E. FABRICATION

During fabrication, the main truss members were constructed using member lengths, shown on the design and shop drawings[2], that would result in an upward or positive camber of the truss between piers before the deck was added. This original length of a

[2] *Steel Details Bridge 9340,* (fabrication drawings), Industrial Construction Division Allied Structural Steel Company, March 9, 1966.

member is referred to as the cambered length. Addition of the full dead weight was intended to eliminate this upward camber such that the upper chord was approximately straight. The cambered lengths were shorter or longer, depending on the member, than required for the node-to-node designed dimensions to account for the elastic axial deformation each member experienced resulting from the self weight of the steel and concrete. Accounting for the deflection of the individual components due to dead weight resulted in a completed bridge with an upper chord that was approximately straight.

At an early step in the fabrication process, the rivet and bolt hole locations in the main truss members and gusset plates were punched to a diameter smaller than the specified final diameter. Then, using drawing sheets RA1 through RA6[3], the upper chord was laid out straight (without any camber) and the vertical and diagonal members attaching to the upper chord were laid out with an angle between the members corresponding to the orientation they would have in the truss with the dead load applied (final position). The rivet holes for the upper chord nodes were then reamed to the specified diameters. In a similar manner, the lower chord was laid out assuming that the dead load was applied, and the vertical and diagonal members attaching to the lower chord were laid out with an angle between the members corresponding to the orientation they would have in the truss with the dead load applied. The rivet holes for the lower chord nodes were then reamed to the specified diameters. The gusset plates were then attached to upper or lower chord members as denoted by a dark dot adjacent to one end of these members in drawings ES-1 and -4 (see figures 1, 2, and 3). Using this procedure, some distortion of the members would be needed to assemble the elements of the main truss without total dead load applied.

F. ERECTION PROCEDURE

Erection of the deck truss portion of the bridge began with construction of piers 5, 6, 7 and 8 (the supporting elements for nodes L1, L8, L8′ and L1′). The base plates, rollers, and temporary blocking were installed at piers 5 and 8 (the location of nodes L1 and L1′) in accordance with the drawing shown in figure 4. At this stage in the erection, nodes L1 and L1′ were to be constructed at an elevation 10 inches lower than their final elevation to assist with closure of the truss at midspan (nodes U14 and L13). Temporary jacks were also installed at L1 and L1′ at this time. Above piers 6 and 7 the complete bearing assemblies were erected; base plates, rollers and expansion bearing assemblies at pier 6 (node L8), as shown in figure 5, and the fixed bearing assembly joint at pier 7 (node L8′).

The erection divided the deck truss into three sections. This discussion follows the order of erection until final closure of the truss at node U14.

[3] *Steel Details Bridge 9340,* (fabrication drawings), Industrial Construction Division Allied Structural Steel Company, March 9, 1966.

Section 1, node U0 to nodes U10 and L9

1. Falsework Bents #1 and #2 were constructed below nodes L3 and L5, in accordance to sheets ES-1.1 and ES-2.1.
2. The erection in this section (primarily Span 6) followed the sequence shown on figure 1, starting with lower chord L1/L3 between pier 6 and Bent #1. All members of the main truss were required to have 50% of the fasteners installed directly after the member was erected to maintain structural stability.[4]
3. The steel was erected from nodes L1 to L3 making closure at U2. Prior to closure at any node, all truss connections were required to be 2/3 pinned or bolted before proceeding with the erection.[5]
4. The floor trusses, sway and lateral bracing follow in sequence, except where noted in the Erection Procedure on drawing ES-4.1.
5. The erection proceeded with placing steel between U2 and U0. Steel was then erected from nodes U2 and L3 to L5, making closure at U4.
6. The erection continued in this section from L5 to L9 making closure at nodes U6 and U8. The erection of the truss between piers 5 and 6 was essentially complete.
7. Members within Span 7, between piers 6 and 7, were now erected by cantilevering outwards from the completed truss on the south shore. Following the numerical sequence on figure 1, lower chord L8/L9 was installed, followed by additional members through upper chord U9/U10 and diagonal L9/U10.

Section 2, node U0′ to nodes U10′ and L9′

1. On the north shore, the falsework Bents #3 and #4 were constructed below nodes L5′ and L7′, in accordance to sheets ES-1.1 and ES-2.1.
2. The erection of this section (primarily Span 8) followed the sequence on figure 2, starting with lower chord L7′/L8′ between pier 8 and Bent #3. Span 8 was erected between L8′ and L5′ making closure at U6′.
3. Members U8′/L9′ and L8′/L9′ were erected in Span 7, and then erection continued north from nodes U6′ and L7′, making closure at node U2′. The remaining members were erected in Span 8 between nodes U2′ and U0′ and in Span 7 between nodes U8′ and U10′.

Section 3, nodes U10 and L9 to nodes U10′ and L9′

1. The erection of this section (primarily Span 7) followed the sequence on figure 3, starting at nodes L9 and U10 on the south side. From this position, the truss was cantilevered north to nodes U12 and L13.
2. From nodes L9′ and U10′ the truss was cantilevered south to nodes U14 and L13 (past the center of Span 7).

[4] Drawing ES-4 specifies that “fit up a minimum 50% (1 pin, 1 bolt, 2 open holes)”, which is interpreted as a connection having 50% of fasteners in place before proceeding with the erection.
[5] Drawing ES-4 specifies that “fit up a minimum of 66.7% (1 pin, 1 bolt, 1 open hole)”, which is interpreted as a connection having 66.7% of fasteners in place before proceeding with erection.

3. From nodes U12 and L13 additional members were cantilevered northward to nodes U14 and L13.
4. The erection plans specified that locations L13 and U14 were to maintain a minimum separation of 1" prior to closure. Longitudinal adjustments were made by jacking Span 6 at L8.

Final Closure

1. When all main truss members had been erected, the truss was ready for final closure at midspan. Because nodes L1 and L1′ were constructed 10" below the final elevations, the two portions of the truss met in the center of span 7 at an angle to their final position. This misalignment at the center is shown exaggerated in figure 6.
2. To begin the closure process, node L8 was jacked to the north joining the north and south portions of the truss at node L13. A single bolt was installed at L13 to maintain alignment but allow member rotation at L13. This allowed partial connection of member L13/L13′ into node L13, as depicted in figure 7.
3. Nodes L1 and L1′ were jacked vertically until node U14 was joined, as indicated in figure 8. After node U14 was joined, the remaining bolts and rivets at nodes L13 and U14 were riveted. Closure at midspan was now complete.
4. The jacks and blocks at L8 were removed to allow horizontal expansion of the structure. Nodes L1 and L1′ were jacked to their final elevations as illustrated in figure 9.
5. The remainder of the steel was erected, which consisting mainly of floor trusses and deck stringers.
6. Upon completion of the erection, the expansion bearing assemblies at L1 and L1′ were installed and the jacks removed, as shown in figure 10.

G. TRUSS REACTIONS

As part of the erection process, the steel erector made measurements and determined the truss reactions at the final truss elevation. The contractor used calibrated hydraulic jacks and gauges to measure the truss reactions at the supports L1 and L1′. The measured values were compared to the estimated reactions calculated by the Minnesota Highway Department Bridge Office. The calculated values and the contractor measurements are provided in Table 1.

Table 1: Truss Reactions

Node	Pier	Calculated (kips) [6]	Measured (kips) [7]	% Difference
L1	5	245	285	16
L1′	8	257	259	0.8

[6] P. Swenson, Minnesota Highway Department, (letter regarding construction loads) addressed to W. Fryhofer, U.S. Department of Transportation, October 25, 1967. [9340_F024_027.pdf]
[7] M. Everson, Industrial Construction Division Allied Structural Steel Company, (letter regarding construction loads) addressed to R. Dobbin, Minnesota Highway Department, August 21, 1967. [9340_F024_027.pdf]

The calculated reactions were computed using the self-weight of the steel; all dimensions and material had been previously determined in the design stages. During construction, the reactions at L1 and L1′ were periodically measured using the calibrated vertical jacks. The as-built reaction at pier 8 was within 1% of the estimated. The reaction at pier 5 differed from the estimated by 16%, but a bridge engineer from the Minnesota Highway Department explained this was due to measurements being taken before all of the steel stringers on Span 7 had been erected.[5] According to structural mechanics of a three span, continuous structure, increasing the load on the center span of the truss will increase the reactions at piers 6 and 7 and decrease the reactions at piers 5 and 8.

Neither the highway department nor the contractor expressed difficulties or problems associated with the erection of the deck truss that would result in overstress in the truss members.[4] Additionally, the agreement of the estimated and measured reactions at L1 and L1′ gave the bridge office confidence that an overstress condition did not occur.[5]

H. ERECTION PROCEDURE CHANGE

The erection procedure was revised two times. As noted in Section C, the original erection scheme positioned falsework at nodes L5, L7, L5′ and L7′, per Drawing ES-1, -2 and -4.[8] The falsework locations for span 6 were located on a service road and over a storm drain and needed to be relocated.[9] Bents #1 and #2 were relocated to below L3 and L5 for Span 6, per the revised ES-1.1, -2.1, and -4.1 in March 1967.[10] After this revision, but prior to steel erection, the steel erector requested a second change to the procedure. The erector requested that falsework remain in place during the erection of Spans 6, 7 and 8, as opposed to removing the falsework after completing the truss at each span, as ES-4.1 specifies.[11] Approval was given to the contractor to proceed in this manner.[12]

Samuel Pond
Civil Engineer

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[8] *Erection Scheme Spans 6 and 8,* (construction drawing), Industrial Construction Division Allied Structural Steel Company, March 9, 1966. [9340_F022_001.pdf]
[9] M. Everson, Industrial Construction Division Allied Structural Steel Company, (letter regarding falsework) addressed to R. Dobbin, Minnesota Highway Department, April 10, 1967. [9340_F026_034.pdf]
[10] *Erection Scheme Spans 6 and 8,* (construction drawing), Industrial Construction Division Allied Structural Steel Company, March 7, 1967. [9340_F022_001.pdf]
[11] P. Swenson, Minnesota Highway Department, (letter regarding falsework change) addressed to W. Fryhofer, Bureau of Public Roads, May 16, 1967. [9340_F026_031.pdf]
[12] A. Ranta, U. S. Highway Department, (letter regarding falsework change) addressed to J. Jamieson, U.S. Department of Transportation. [9340_F024_001]

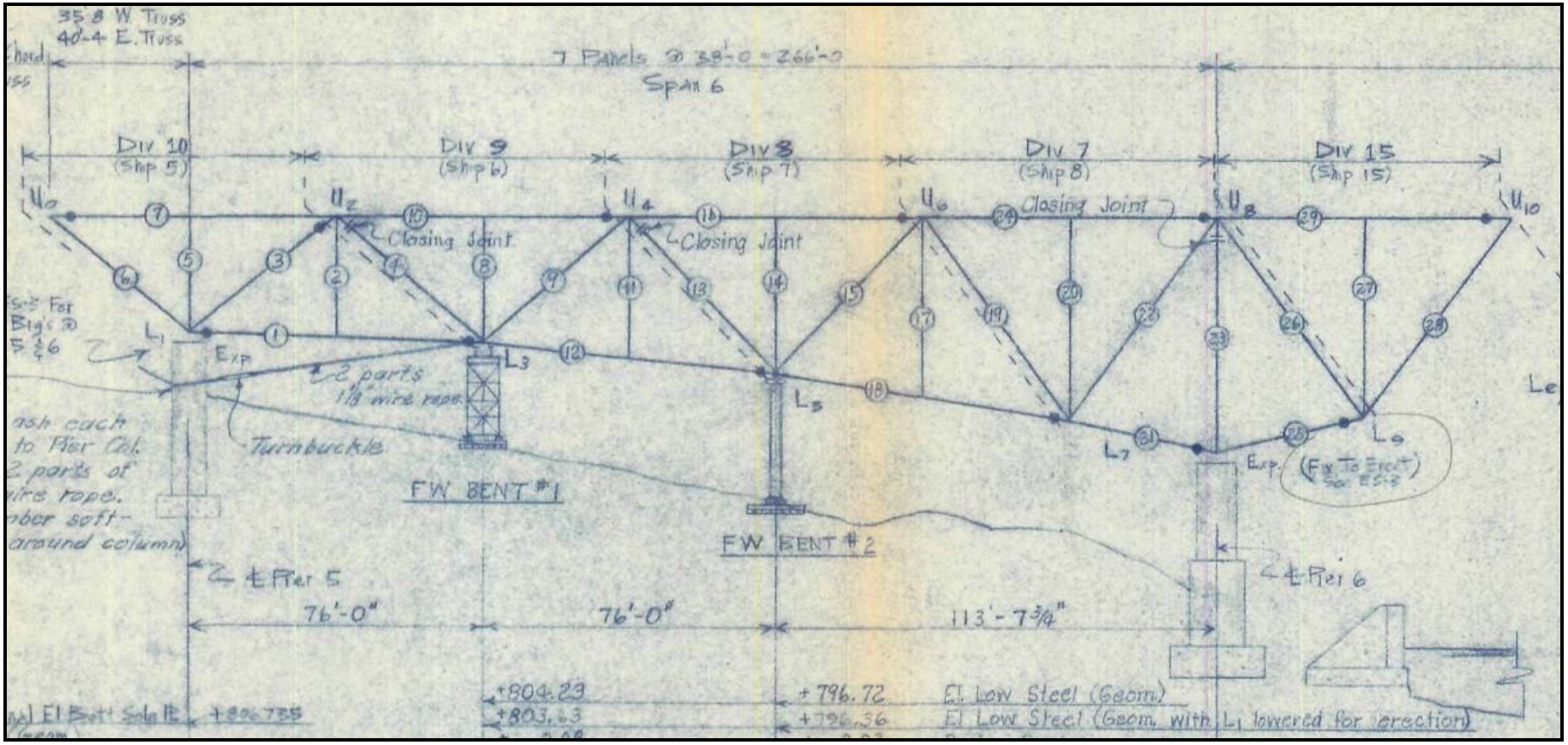

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Figure 1: Erection Sequence Span 6

The erection sequence of Span 6 was detailed on drawing ES-1.1. The main truss members are numbered to indicate the sequence of erection. The floor trusses, sway and lateral bracing follow in sequence, except where noted in the Erection Procedure on drawing ES-4.1.

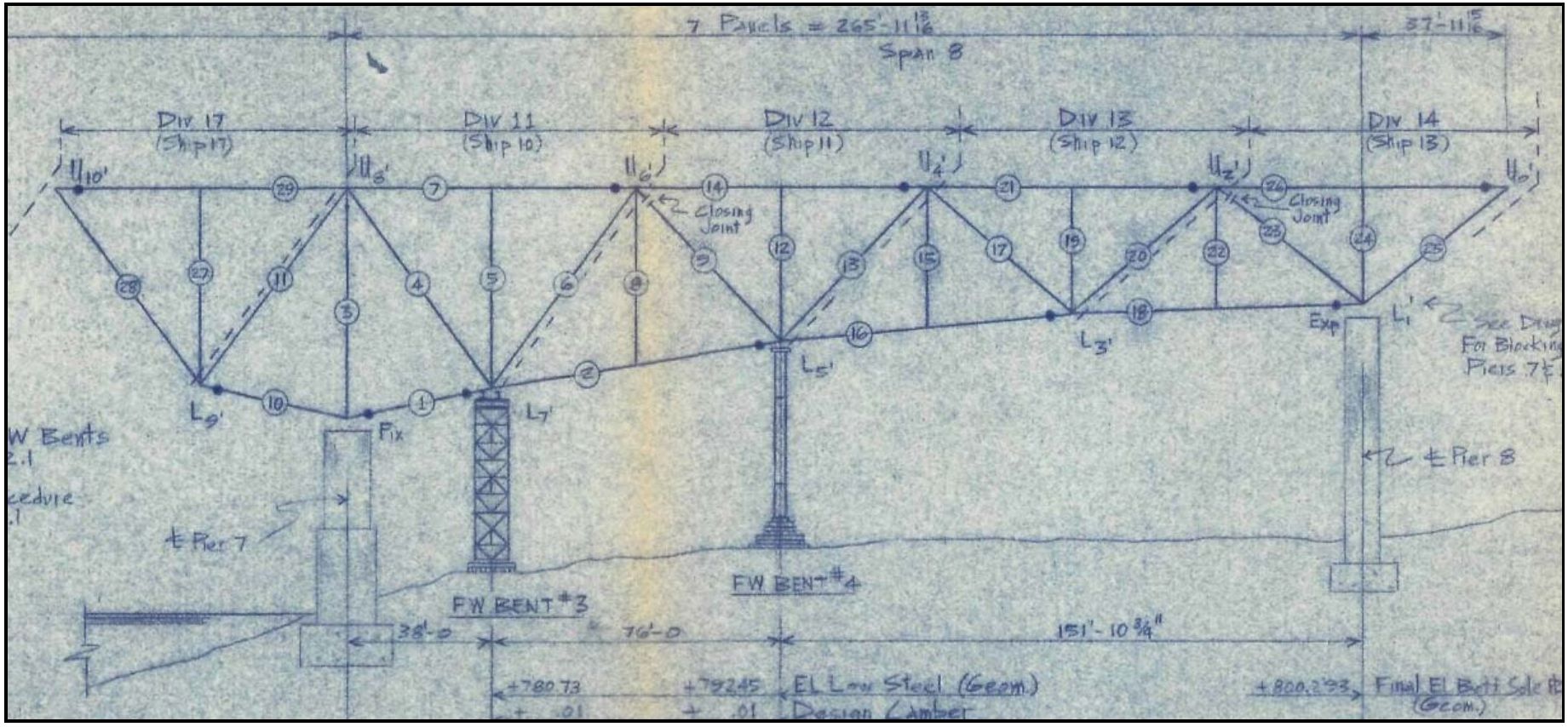

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Figure 2: Erection Sequence Span 8

The erection sequence of Span 8 was illustrated on drawing ES-1.1. The main truss members are numbered to indicate the sequence of erection. The floor trusses, sway and lateral bracing follow in sequence, except where noted in the Erection Procedure on drawing ES-4.1.

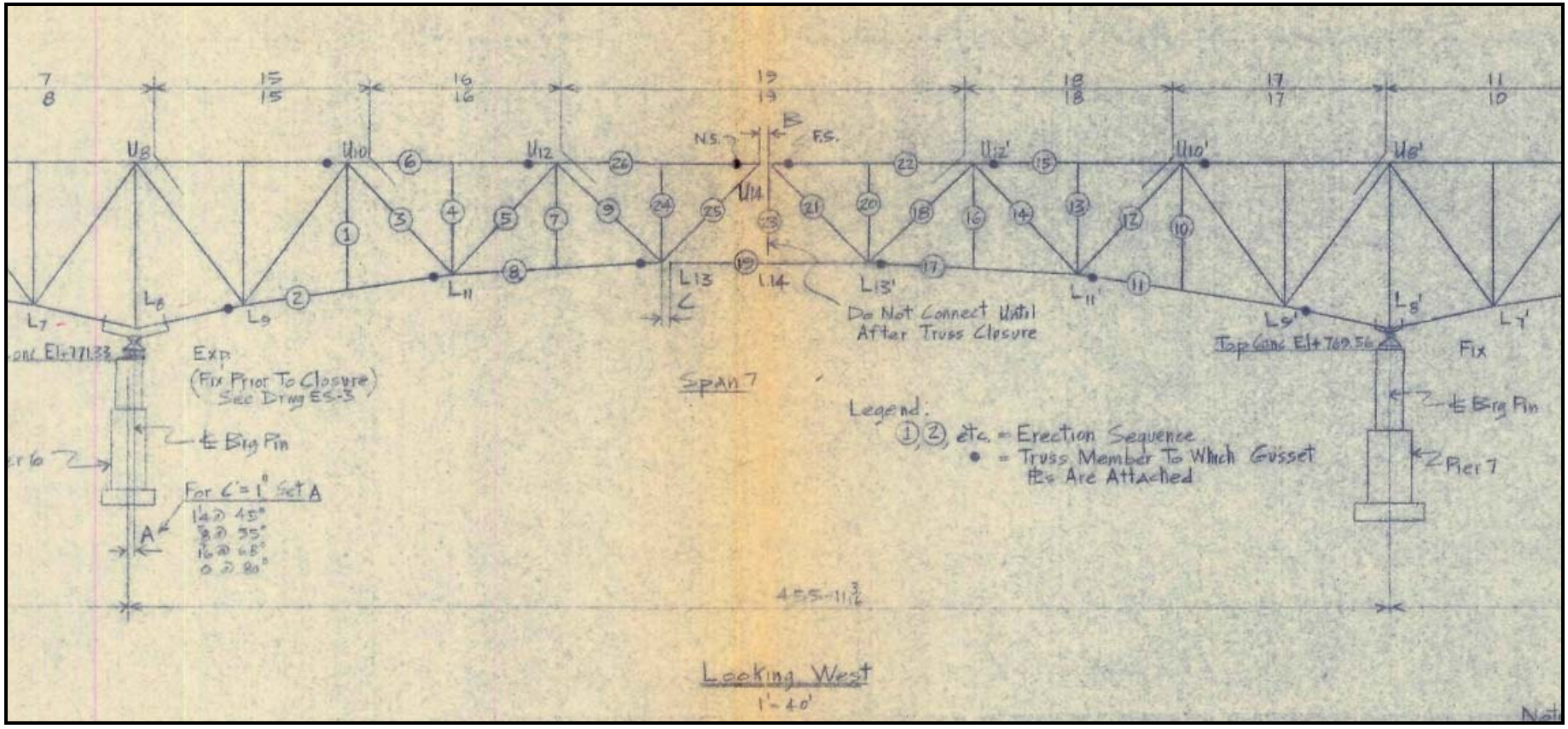

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Figure 3: Erection Sequence Span 7

The erection sequence of Span 7 was illustrated on drawing ES-4.1. The main truss members are numbered to indicate the sequence of erection. The floor trusses, sway and lateral bracing follow in sequence, except where noted in the Erection Procedure on drawing ES-4.1.

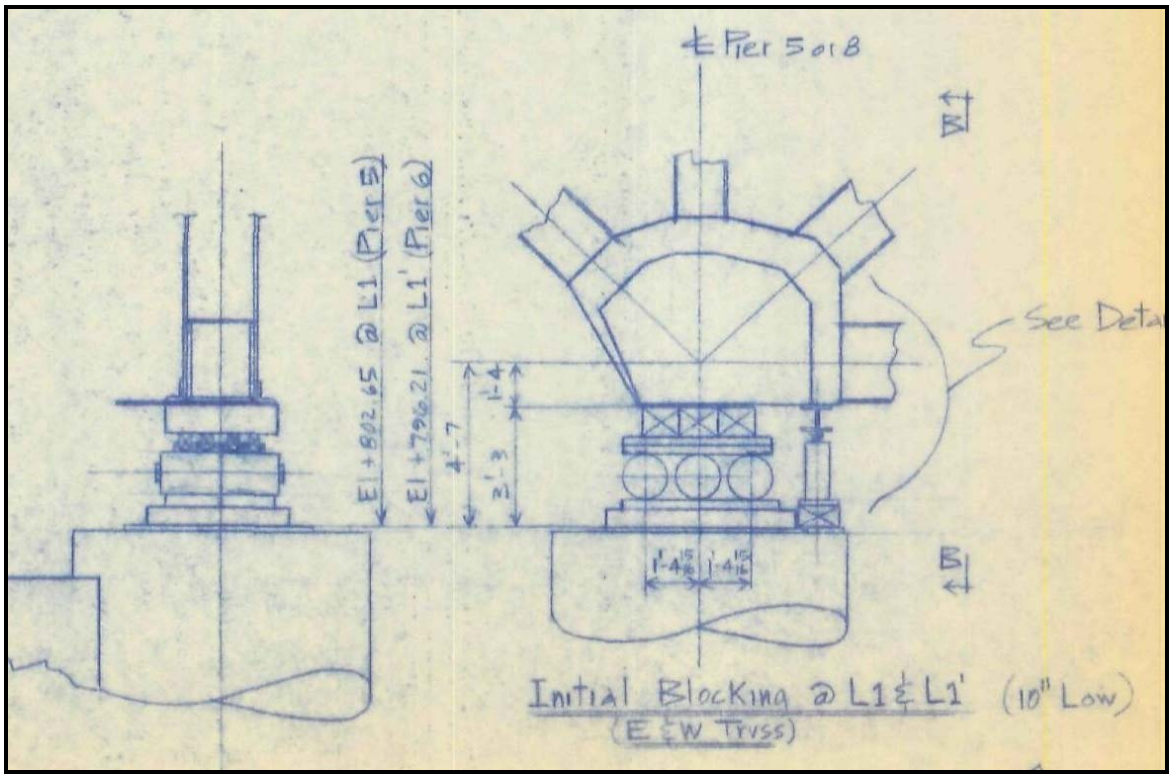

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Figure 4: Initial Blocking of Nodes L1 and L1'

The initial blocking of nodes L1 and L1' as detailed on drawing ES-3. The truss was constructed 10" lower then the final elevations at these nodes to allow closure at midspan.

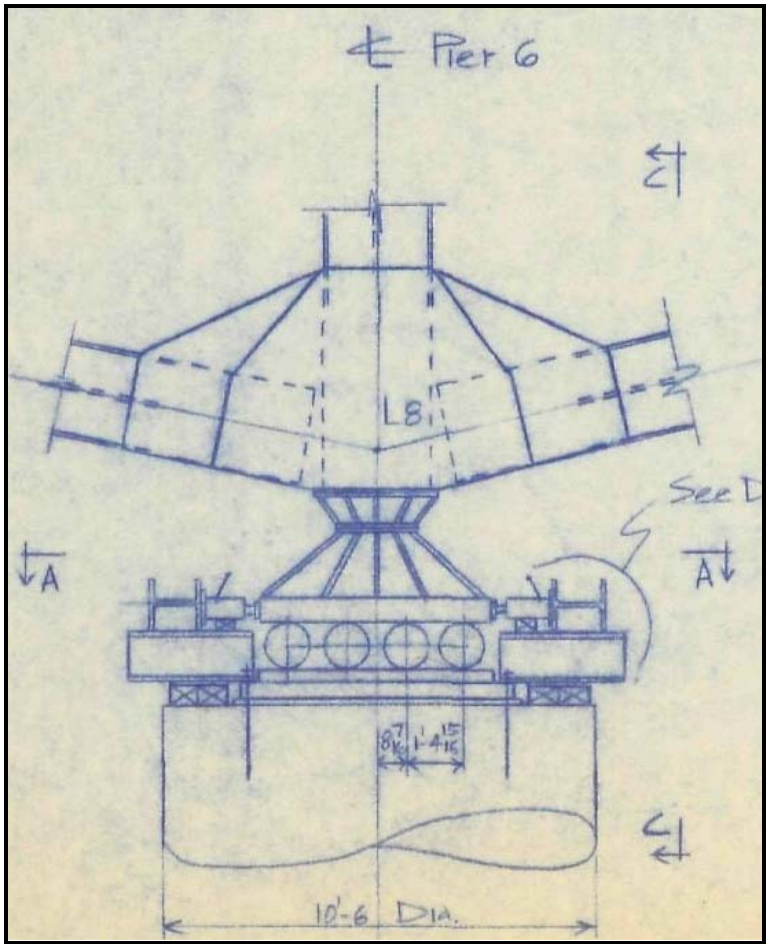

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Figure 5: Blocking at Node L8

Drawing ES-3 detailed the blocking and jacking configuration at node L8.
Longitudinal adjustments to Span 6 and cantilevered portion of Span 7 were made with the hydraulic jacks located at node L8. This jacking set-up was also used to close the truss at node L13.

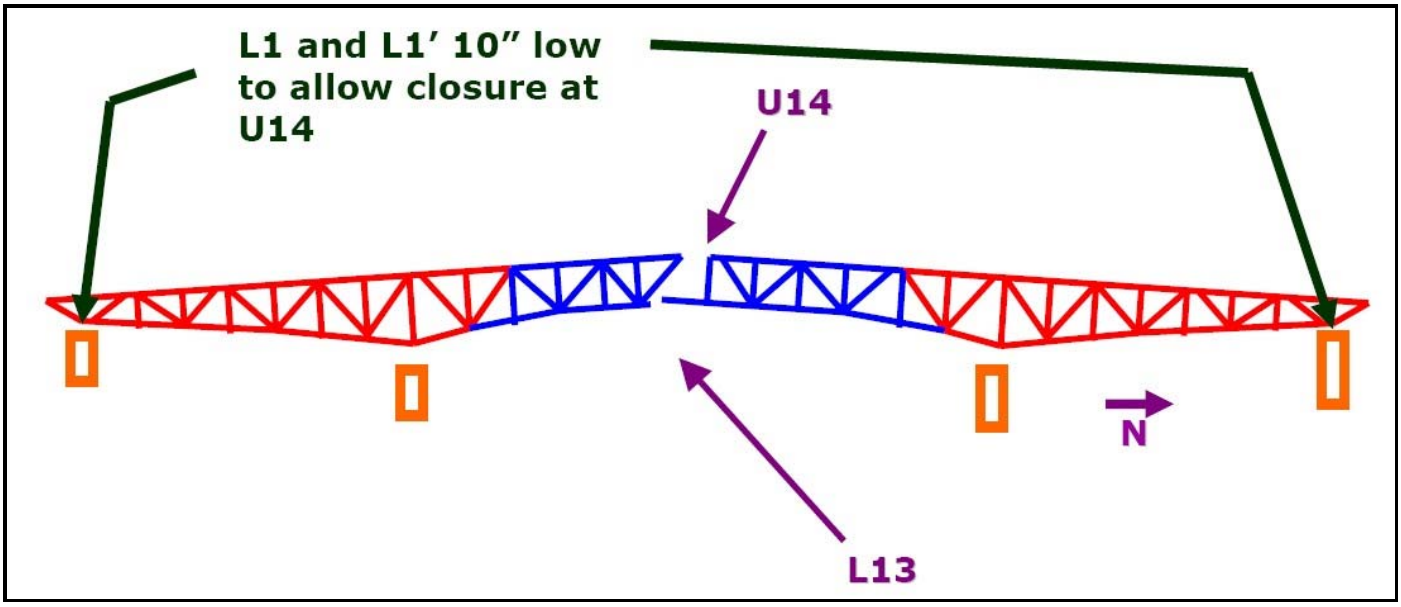

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Figure 6: Truss Orientation Prior to Closure

After Span 6, 7 and 8 had been erected according to the Erection Procedure on drawing ES-4.1, the two truss portions had the exaggerated configuration because nodes L1 and L1' were constructed 10" below their final elevations.

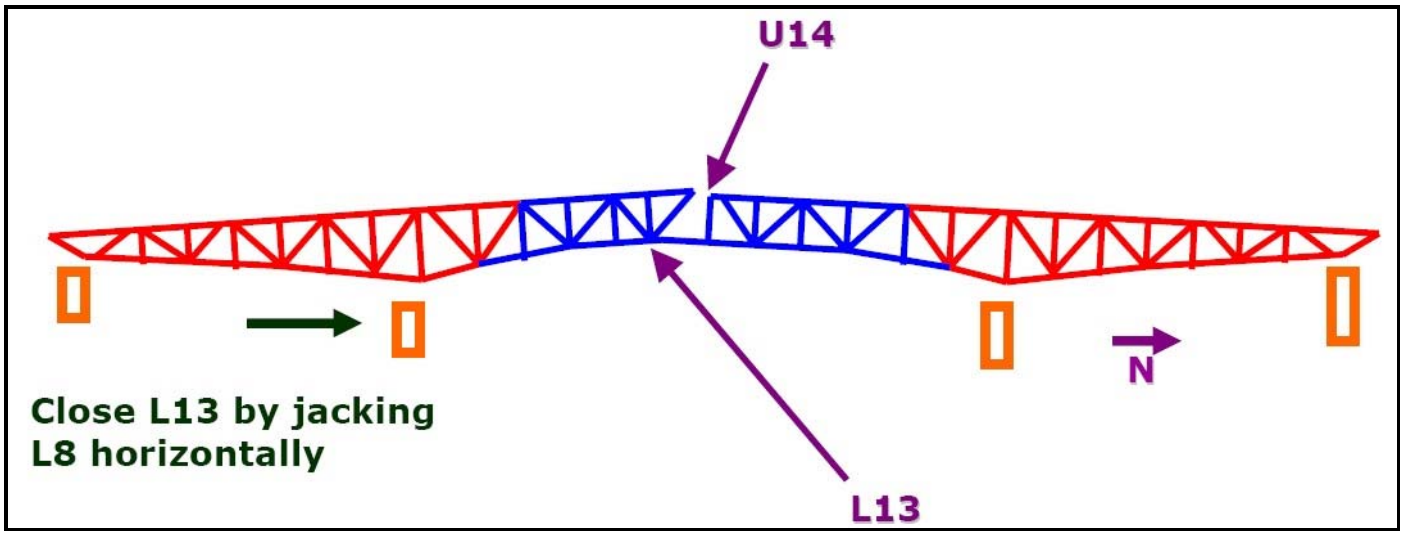

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Figure 7: Joining Node L13

The truss was joined at midspan by first closing L13. Node L8 was jacked horizontally until the south portion of the truss met the north portion at L13. A single bolt was installed to maintain connection but allowed member rotation at L13.

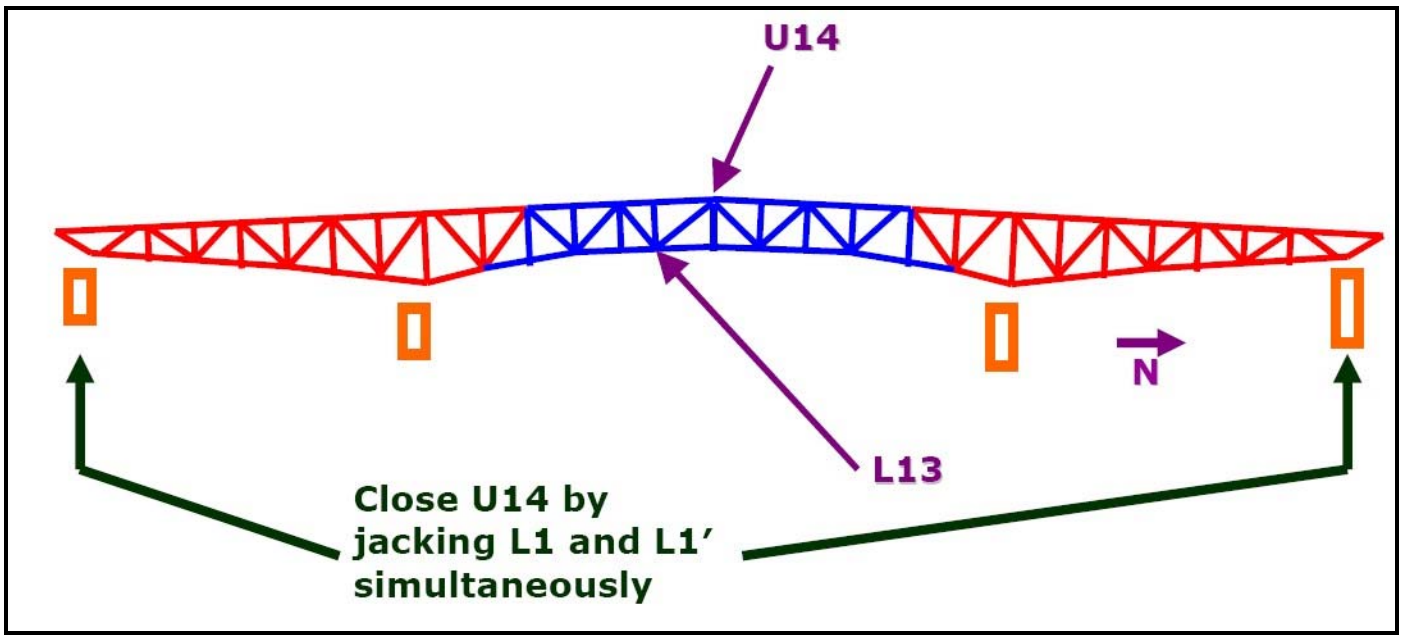

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Figure 8: Joining Node U14

Nodes L1 and L1' were jacked upwards simultaneously to make the connection at node U14. Following alignment of U14, both L13 and U14 were riveted.

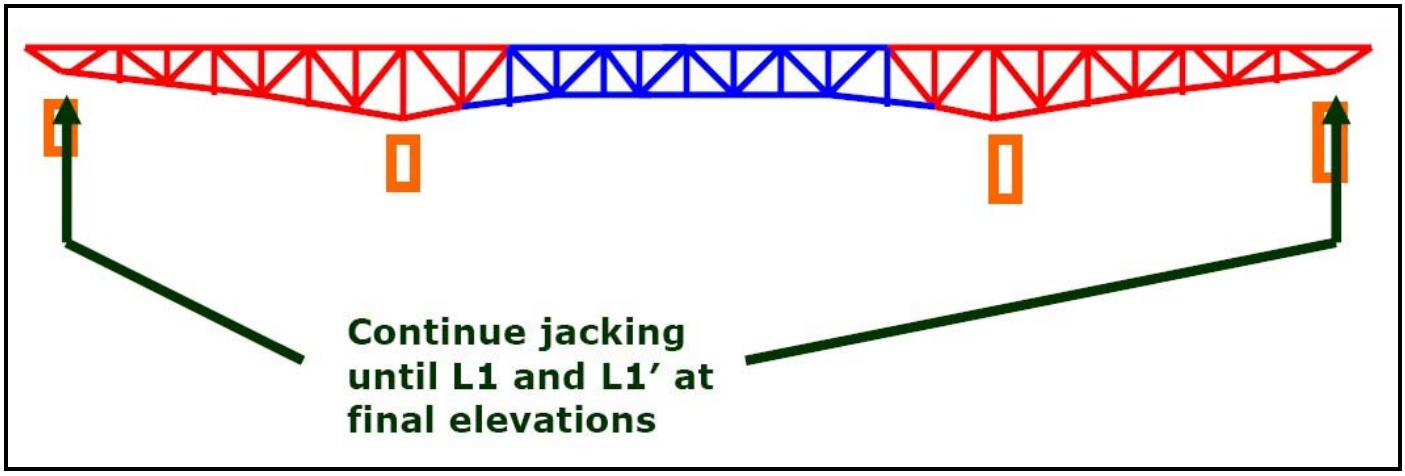

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Figure 9: Completing the Erection

After closure was complete at midspan, nodes were fit-up 66.7% and blocking removed at L8. L1 and L1' were jacked to their final elevations, remaining steel erected and expansion bearing castings placed.

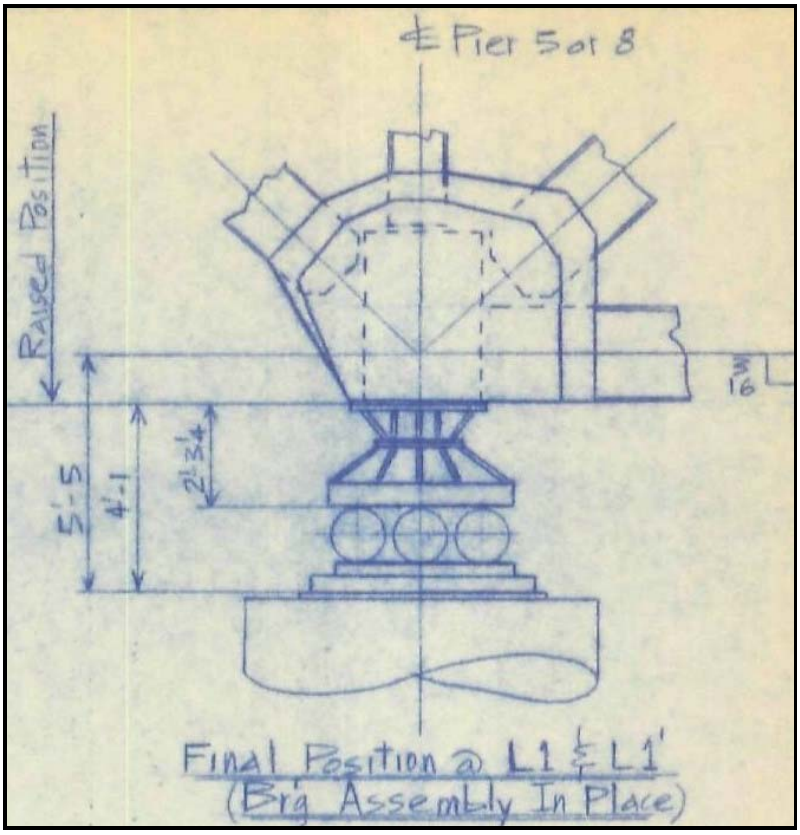

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Figure 10: Final Elevation Nodes L1 and L1'

The final elevation of nodes L1 and L1', with expansion bearing assemblies in place, as detailed on drawing ES-3.

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Figure 11: Span 6 Under Construction

Still image from video footage of Bridge 9340 during construction of deck truss superstructure. Image shows erection of Span 6 has been completed, including the deck stringers. Falsework is at the appropriate locations and still in place as requested by the contractor.

ImageNo: 0806A00853, Project No:2008060009

Figure 12: Span 8 Under Construction

Still image from same video file showing the erection of steel in Span 8. The progress in Span 8 appears to be near the closure at node U6'.