FIELD TESTING OF A RAILROAD FLATCAR BRIDGE

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ABSTRACT

The feasibility of using railroad flatcars (RRFCs) as the superstructure for bridges on low-volume roads has been investigated in two previous research projects at Iowa State University. The results of these projects verified that RRFCs are efficient and economical alternatives for low-volume road bridges.

Two county engineers involved with the RRFC project cited cost as the main factor for choosing to install more RRFC bridges in their counties. The last RRFC bridges built in their counties cost approximately $27 per square foot and $35 per square foot, respectively. Both of these figures are well below the typical IDOT standard slab bridge, the cost of which the engineers approximated to be $70 per square foot. Also, county forces can be used to install RRFC bridges, which saves time as well as money.

In order to gather more data on the behavior of RRFC bridges, and to refine the design methodology presented in the previous project, the strains and deflections of another RRFC bridge were measured as a tandem-axle truck crossed the bridge. From these results, the bridge was deemed satisfactory to carry Iowa legal loads. Also, live load distribution factors were determined for RRFC bridges composed of two RRFCs. Finally, these live load distribution factors were incorporated into a rating procedure for RRFC bridges.

INTRODUCTION

Background

Iowa is located between the Mississippi and Missouri Rivers, so a large number of tributary streams and creeks create the need for bridges throughout the state. The majority of these streams and creeks are crossed by secondary roads, thus, the majority of Iowa's bridges must be maintained by the counties. According to a list of deficient bridges in each state from the Federal Highway Administration in December 2003, Iowa ranked third behind Oklahoma and Pennsylvania *(1)*. However, Iowa ranks 30th in terms of population *(2)*. This lower tax base limits the funds that are available for Iowa counties to repair or replace the deficient bridges. Because of this, the Bridge Engineering Center at Iowa State University (ISU) has researched low-cost alternatives for use on low-volume roads (LVR). One such alternative is the use of recycled railroad flatcars (RRFCs) for the superstructure in bridges.

The viability of using railroad flatcars as an economical alternative for LVR bridges was examined in two research projects conducted by the Bridge Engineering Center: a 1999 feasibility study and a 2003 demonstration project. The feasibility study listed desirable qualities in RRFCs, and the demonstration project furthered that concept by providing a process for selecting RRFCs. Through experimental results from field load tests and theoretical results from analytical models, the two projects determined that RRFCs could efficiently carry Iowa legal loads *(3,4)*.

For this paper, the county engineers that participated in the demonstration project were questioned regarding their decision to continue using RRFC bridges and the benefits associated with RRFC bridges. Both Jim Witt, county engineer for Winnebago County, and Brian Keierleber, county engineer for Buchanan County, cited cost as the main factor for choosing to install more RRFC bridges in their counties. The last RRFC bridges built in Winnebago County and Buchanan County cost approximately $27 per square foot and $35 per square foot, respectively. Both of these values are well below the typical Iowa Department of Transportation (Iowa DOT) standard slab bridge, the cost of which the engineers approximated to be $70 per square foot. In addition to cost, Witt also explained that county forces can be used to install RRFC bridges, which saves time and money.

Based on the recommendations for further study from the 2003 ISU RRFC demonstration project, a research project to continue examining the behavior of various RRFC bridges was established. The primary objectives of the research were to: (1) obtain more data on the structural behavior of different RRFC bridges, (2) refine the design methodology presented in the demonstration project, and (3) develop a load rating process for RRFC bridges. To achieve the primary objectives, a previously constructed 56-ft RRFC bridge composed of two flatcars was field load tested.

Selected RRFC Bridge Site

Buchanan County in Iowa participated in previous RRFC research projects and was interested in developing the concept further. The Buchanan County bridge tested was designed by Buchanan County. This bridge crosses the Dry Creek about five miles southeast of Quasqueton, Iowa, on 290th Street. Figure 1a presents a map of a portion of Buchanan County showing the major highways in the area with a box around the general area of the bridge. The actual location of the bridge is shown in Figure 1b with a dashed circle. The stars in each map represent the same location, the approximate the location of Quasqueton, Iowa.

The bridge at this site, which was constructed two months prior to testing, consists of two 56-ft V-deck RRFCs, spans 54 ft – 0 in. from center to center of the abutments, and has a width of 20 ft – 7 in. As may be seen in Figure 2c, the 56-ft flatcars have three main girders, two exterior and one interior, and six small secondary girders, all W-shapes. The main girders are connected with C-shaped transverse members. Also, the interior girder is approximately 8 in. lower than the exterior girders, giving the deck a V shape. As seen in Figure 3, the longitudinal flatcar connection between the two RRFCs is a 22-in. reinforced concrete beam,.

Pea gravel was placed on the RRFC decks over the lower interior girders to aid drainage. A layer of gravel was placed over the RRFC deck and the pea gravel for the driving surface. The 290th Street bridge has a guard rail system that consists of guardrail posts welded to the flanges of the exterior girders and a thrie beam attached to the guardrail posts. Figure 4 shows the completed 290th Street bridge.

RRFC BRIDGE FIELD LOAD TESTING

The behavior of the RRFC bridge was determined through a field load test, which consists of a tandem-axle truck loaded with gravel driven slowly across the bridge. The width of the front tires was 15 in., the width of the individual tandem tires was 9 in., and the width of the rear tandem tires was 2 ft-0 in. Figure 5 shows more information on the truck used in the tests, and Figure 6 presents pictures of the instrumentation used on the 290th Street bridge. Strains in critical locations on the RRFC girders as well as in transverse members and the longitudinal connections were measured and recorded using strain transducers and a data acquisition system, respectively. Also, the deflections of the girders at midspan and the two quarter points were measured in the tests using deflection transducers. With the results of the field load test, a load rating for the bridge can be determined. This rating will dictate the weight limit for vehicles crossing the bridge.

Figure 7 illustrates the instrumentation plan for the 290th Street bridge test. Girders across the entire cross-section at the midspan of the bridge were instrumented with strain gages and deflection transducers to verify transverse symmetry and to determine the structural strength and behavior of the bridge. Likewise, the interior girder of the north RRFC was instrumented at critical locations along the entire length of the bridge to verify strength and longitudinal symmetry. The reinforced concrete beam acting as the longitudinal flatcar connection (LFC) was also instrumented with strain gages to determine the maximum strains and the load distribution effectiveness. Deflections and strains were measured continuously throughout each test; as the tandem axle of the truck crossed critical sections, the deflections and strains were recorded. The critical locations were: the centerline of the east abutment, 1/4 span, midspan, 3/4 span, and the centerline of the west abutment.

The 290th Street bridge was divided into three lanes, shown in Figure 8, to examine the behavior of the bridge under different load conditions. When in Lanes 1 and 3, the truck was positioned with the edge of the front tire 2 ft from the north and south edges of the bridge, respectively. Lane 2 centered the truck transversely on the bridge. Figure 9 shows photographs of the actual testing.

DEAD LOAD ANALYSIS

To determine the total stresses in the primary girders of the flatcar, the bridge was analyzed to determine the dead load stresses. To simplify this analysis, several assumptions were made. First, it was assumed that each primary girder supported its self-weight along with the weight of the secondary girders and transverse members within the contributory width of the primary girder. The weight of the steel was assumed to be 490 lb/ft^3.

Following conventional methods for bridge design, the connected flatcars were assumed to form a rigid cross-section such that any additional dead load could be considered uniform on the bridge. Thus, the total weight of the pea gravel and the gravel driving surface was assumed to be uniform on the bridge. Based on quantities and weights from the demonstration project, the total weight of the pea gravel and gravel was assumed to be 98.2 lb/ft^2. Using these assumptions and the section properties of the girders, the maximum dead load stresses at the midspan of the interior girders and exterior girders were determined to be 6.1 ksi and 11.0 ksi, respectively.

RESULTS

As previously discussed, deflections and strains were measured in longitudinal girders and secondary and transverse members. After reviewing the results of the bridge tests, it was determined that the critical deflections and strains occurred at midspan of the primary longitudinal girders. Thus, the RRFC bridge performance will be illustrated using the deflections and strains measured at the midspan of the primary longitudinal girders, and the discussion that follows will focus mainly on the behavior of these primary girders.

The maximum midspan deflections and strains that were measured in the three load tests on the 290th Street bridge are presented in Figures 10 – 12. These deflections and strains occurred when the center of the tandem axle of the truck was at the midspan of the bridge. For each test, the maximum deflections and strains occurred directly below the wheel loads and then decrease as the distance from the wheel load increased. For lateral load distribution, one would expect the entire bridge to “rotate” as one with linearly varying strain across the entire bridge. The girder deflection and strain patterns shown in Figures 10 – 12 indicate effective lateral distribution through the longitudinal flatcar connection. Also, transverse symmetry is shown with the deflection and strain patterns in Figures 10 and 12. This behavior indicates that the bridge has uniform transverse bending and torsional stiffness.

Also seen in Figure 10 is the maximum deflection of the bridge, 0.46 in. The 1994 LRFD and 1996 LFD AASHTO *Bridge Design Specifications* give an optional deflection limit of L/800 *(5)*. For a 56 ft-0 in. span, this optional limit is 0.84 in. To compare the deflection of the bridge under Iowa legal loads with this limit, a linear relationship between the weight of the truck and the maximum deflection was assumed. Increasing the weight of the truck to 72 k increases the maximum deflection to 0.67 in. Thus, deflections in the 290th Street bridge are acceptable.

Based on tensile tests on steel coupons from flatcars used in previous projects, the modulus of elasticity and a conservative yield strength of the flatcars used for this project were assumed to be 29,000 ksi and 36 ksi, respectively *(4)*. The maximum strains measured in the interior and exterior girders due to the live loads were 116 MII and 93.6 MII (3.4 ksi and 2.7 ksi, respectively). When combined with the dead load stresses from the theoretical analysis, the maximum stress in the longitudinal interior girder was 9.4 ksi, and the maximum stress in the longitudinal exterior girder was 13.7 ksi. As with the deflection, a linear relationship between the weight of the truck and the maximum stresses was assumed. Increasing the weight of the truck to the Iowa legal load of 72 k increases the maximum stresses in the longitudinal interior and exterior girders to 13.8 ksi and 20.0 ksi, respectively. Since the maximum stresses are less than the yield strength, stresses in the primary girders of the 290th Street bridge are acceptable.

DESIGN AND ANALYSIS OF THE RRFC BRIDGES

Recommendations for Live Load Distribution

In the demonstration project, equations for the live load moments were presented. These equations were developed for three-span bridges composed of three RRFCs connected with the LFCs described in the report *(4)*. Since the 290th Street bridge is a one-span composed of two RRFCs, the equations were modified to more accurately determine the live load moments in the interior and exterior girders.

As found from the results, the maximum stresses were recorded in the three primary girders of the RRFC. The live load moments in each girder can be determined with the following equation:

$$M_{LL} = \frac{2}{3}\psi\omega M_{SD} \qquad \text{(Equation 1)}$$

where:

M_{LL} = The actual, maximum midspan live load moment in the girder being investigated

M_{SD} = The maximum, midspan live load moment in the statically determinate RRFC bridge based on the live load

$$\omega = \text{Inertia ratio} = \frac{I_D}{\Sigma\, I_{RRFC}} \qquad \text{(Equation 2)}$$

I_D = Strong-axis moment of inertia for the girder being investigated

ΣI_{RRFC} = Sum of the girders' strong-axis moments of inertia in one RRFC
$= (2)(I_{EXT})+I_{INT}$ (Equation 3)

I_{EXT} = Strong-axis moment of inertia for the exterior girder

I_{INT} = Strong-axis moment of inertia for the interior girder

ψ = Adjustment factor to correct for the simplified analysis *(4)*

For interior girders in RRFC bridges like the 290th Street bridge,
$\psi = 0.9$

For exterior girders in RRFC bridges like the 290th Street bridge,
$\psi = 0.75$

The demonstration project uses the adjustment factor, ψ, to correct for the use of a single span bridge as opposed to the continuous span bridge actually built, but the bridge under investigation is a single span bridge. Thus, the adjustment factor does not make this correction. Instead, the adjustment factor makes corrections for the transverse load distribution.

The 2/3 fraction in Equation 1 represents the fraction of the total area under the deflection curve for one railroad flatcar when the truck is positioned over that car. This value was first determined in the demonstration project, though the actual fraction was slightly less than 2/3. The same method described in the *Demonstration Project Using Railroad Flatcars for Low-Volume Road Bridges* was used to determine the fraction for a two-car bridge, and the result was slightly larger than 2/3. The similar result is due to the minimal load carried by one exterior RRFC when the truck is positioned over the other exterior RRFC in a three-car bridge *(6)*. Because of this, although the values of the variables have changed, Equation 1 has remained unchanged.

Rating Procedure for RRFC Bridges

The rating procedure for a RRFC bridge is nearly the same as the procedure for a typical highway bridge. Following the AASHTO *Manual for Condition Evaluation of Bridges* (Rating Manual), the equation used to determine the rating of each member in a typical highway bridge is as follows:

$$RF = \frac{C - A_1 D}{A_2 L(1+I)} \qquad \text{(Equation 4)}$$

where:

RF = The rating factor for the live-load carrying capacity

C = The capacity of the member

D = The dead load effect on the member

L = The live load effect on the member

I = The impact factor to be used with the live load effect

A_1 = Factor for dead loads

A_2 = Factor for live load *(7)*

All of the variables, except for the live load effect, L, should be determined following the Rating Manual. Appendices are provided in the Rating Manual to find the live load effect of girders and stringers in typical highway bridges, but RRFC bridges are not composed of uniform girders at equal spacing like standard slab-on-girder bridges. Thus, a different method must be used to determine the live load effect. For RRFC bridges, the effect of the live load on a member, L, is determined by assuming the live loads act on one beam and then multiplying the resulting moment by a distribution factor.

The distribution factor is the fraction of the live load transferred to the member. These distribution factors for the RRFCs used in the bridge tested for this investigation were presented in the previous section as part of Equation 1 and now explicitly as Equation 5.

$$DF = \frac{2}{3}\psi\omega \qquad \text{(Equation 5)}$$

The variables in Equation 5 are the same as in Equation 1.

Because RRFC bridges differ from typical highway bridges, the rating procedure for RRFC bridges is slightly different than the procedure described by AASHTO. The majority of the RRFCs have three primary girders and several secondary members. As discussed in the previous sections, field testing has shown that the primary girders carry nearly all of the load. Because of this, the distribution of the live load assumes that the primary girders carry all of the load. Since the secondary members are assumed to carry no load, no distribution factors are presented for the secondary members. The secondary members are not critical load-carrying members in the RRFC bridge investigated; instead, they act more as stiffeners for the deck. For this reason, only the primary girders are given a numerical rating. All members of the bridge, including the secondary girders and the transverse members, should be visually inspected for damage as described in the Rating Manual.

To determine the rating of each bridge member, the Rating Factor, RF, from Equation 4 should be multiplied by the weight of the truck used in determining the live load effect, L. This will result in the bridge member rating in tons, and the actual bridge rating will be controlled by the bridge member with the lowest rating *(7)*.

SUMMARY

In this investigation, the behavior of a RRFC bridge composed of two flatcars was examined. The first objective was to obtain more data through the field testing of a RRFC bridge located in Buchanan County, Iowa. The strains and deflections of the main girders of the bridge were measured and recorded as a tandem-axle truck carrying Iowa legal loads traveled across the bridge. Through analysis of the recorded strains and deflections, it was determined that the longitudinal flatcar connections effectively transferred load between cars. Also, the deflections of the bridges were below the limit recommended by AASHTO, and the maximum girder dead plus live load stresses were below the yield strength of the steel assumed in the flatcars.

The second and third objectives were met using the results from the field load tests. Load distribution factors were determined for the interior and exterior members of the RRFCs. After the determination of the distribution factors, a procedure for rating RRFC bridges was established. All members of the bridge should be visually inspected, but only the interior and exterior primary girders are assigned a numerical rating. This rating should be found following the AASHTO *Manual for Condition Evaluation of Bridges*. However, due to the variation of girders and girder spacing, the live load effect of a member cannot be determined with the tables provided in the Rating Manual. Instead, the live load effect is determined using the load distribution factors developed in this investigation.

ACKNOWLEDGMENTS

The Bridge Engineering Center at Iowa State University conducted the investigation presented in this paper. The Iowa Department of Transportation, Highway Division, and the Iowa Highway Research Board sponsored the research as a phase of Research Project TR-498.

The author wishes to thank Brian Keierleber, Buchanan County Engineer, for his cooperation with this project. Thanks are also given to Doug Wood, ISU Research Laboratory Manager, for his assistance with the field tests. Finally, thanks to the following ISU graduate and undergraduate students who helped with the instrumentation and field testing of the bridge: Elizabeth Kash, Jon Greenlee, Travis Konda, and Ben Woline.

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8. Mapquest.com, Inc. *Mapquest.* http://www.mapquest.com. Accessed July 7, 2004.

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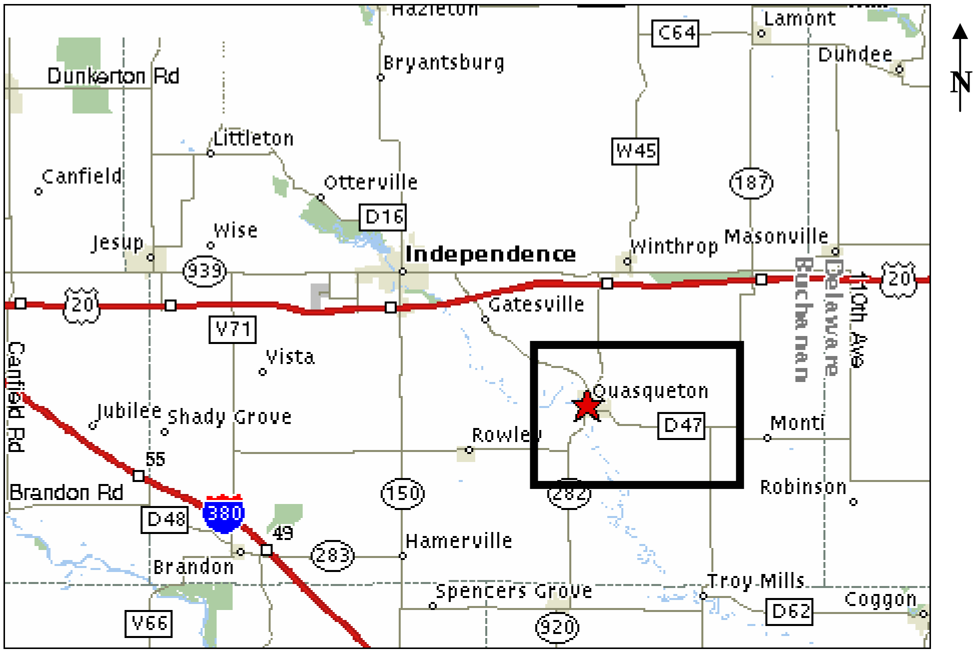
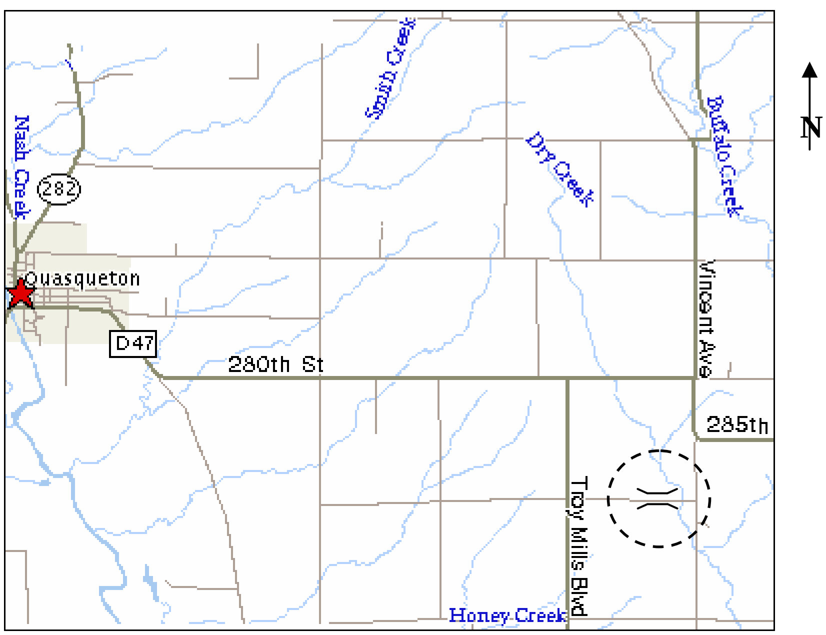


a. Map of a Portion of Buchanan County *(8)*.

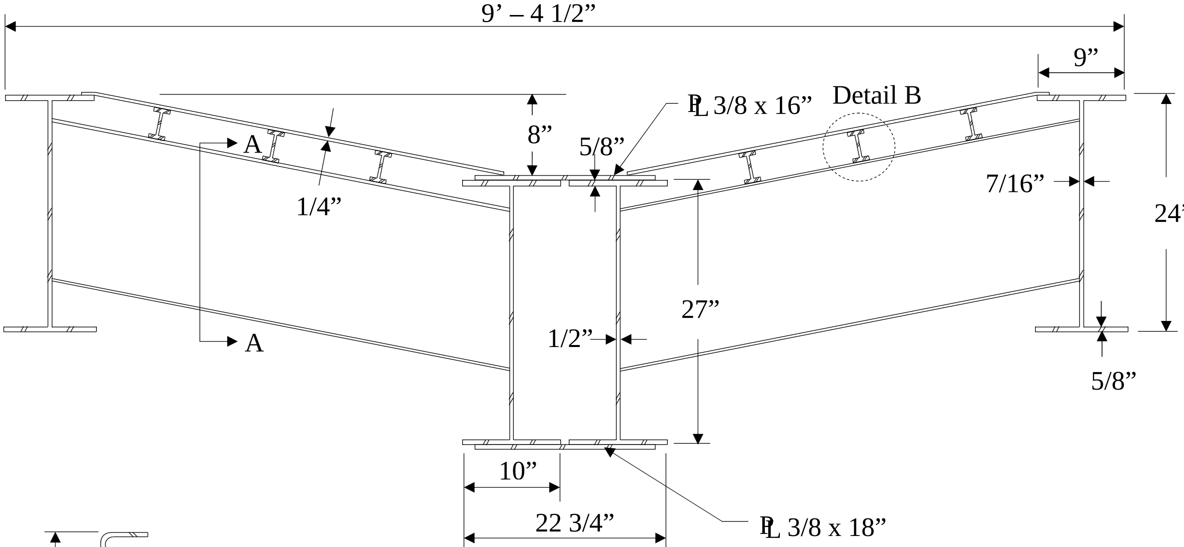


b. Location of 290th Street Bridge *(8)*.

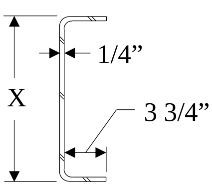
FIGURE 1 Location of 290th Street Bridge.

a. The 56-ft RRFC at the Erman Corporation.

b. The V-deck.



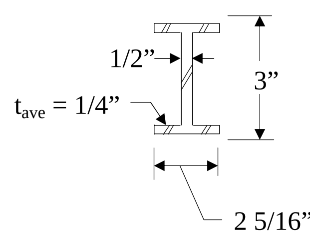
c. Cross-section at midspan.



X = 12” for the Small Transverse Member.

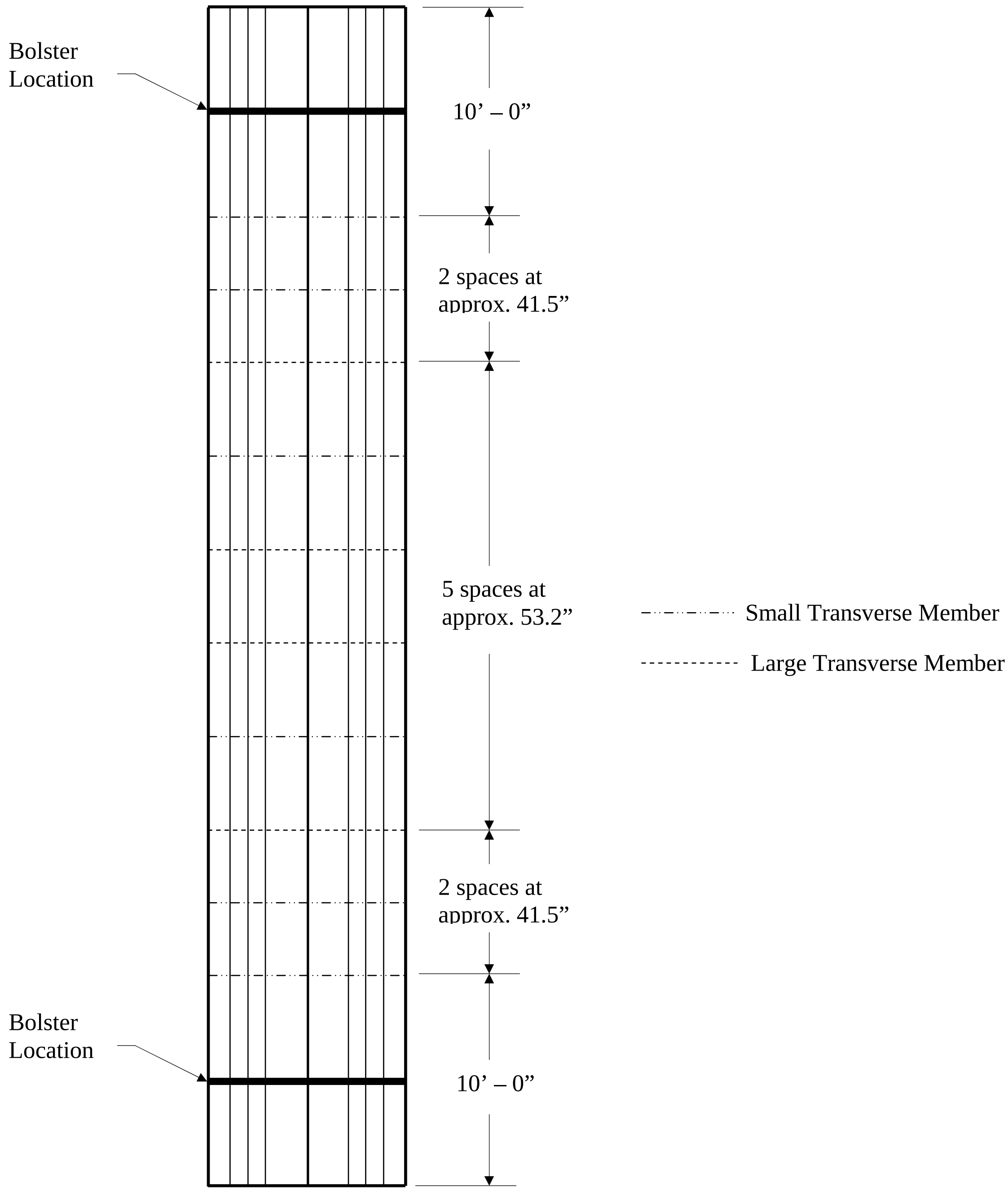
X = 16 3/8” for the Large Transverse Member.

d. Section A – A.



e. Detail B.

FIGURE 2 The 56-ft V-deck RRFC used in 290th Street Bridge *(4)*.



f. Locations of small and large transverse members.

FIGURE 2 Continued.

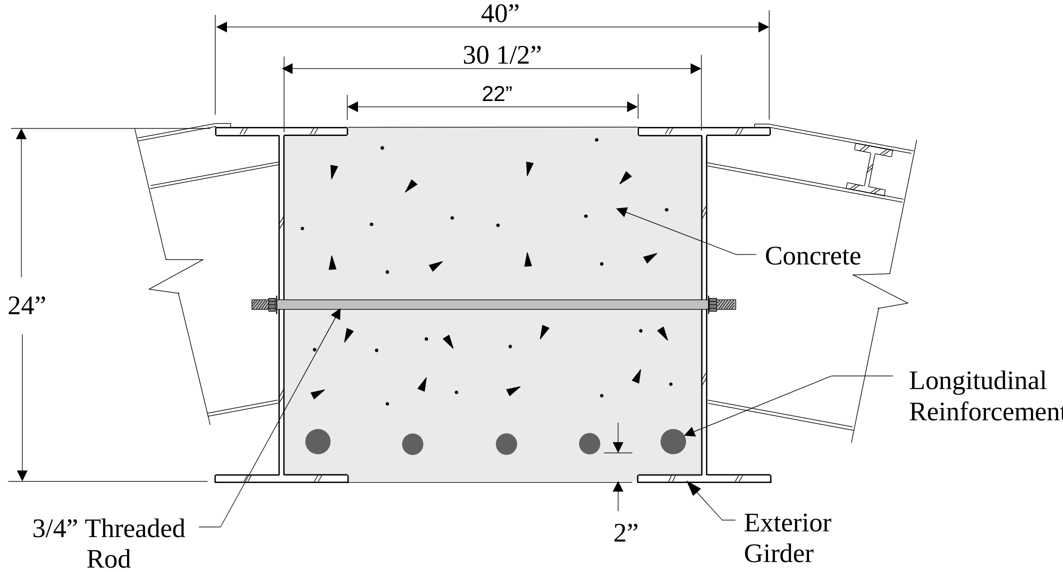
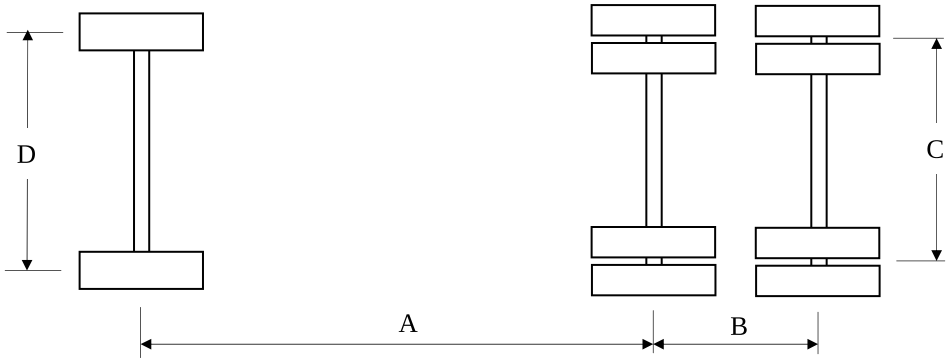
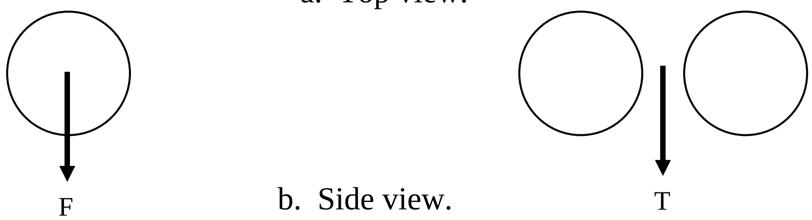


FIGURE 3 Longitudinal RRFC connection used in the 290th Street Bridge.

FIGURE 4 Completed 290th Street Bridge.



a. Top view.



b. Side view.

Bridge	Dimensions				Load (lbs)		
	A	B	C	D	F	T	Gross
290th	13' -11"	4' - 5"	6' - 0"	6' - 9 1/2"	15,200	34,320	49,520

c. Photograph of Test Truck.

FIGURE 5 Dimensions and weights of test truck used in RRFC bridge field tests *(4)*.

a. Strain transducer on concrete longitudinal RRFC connection.

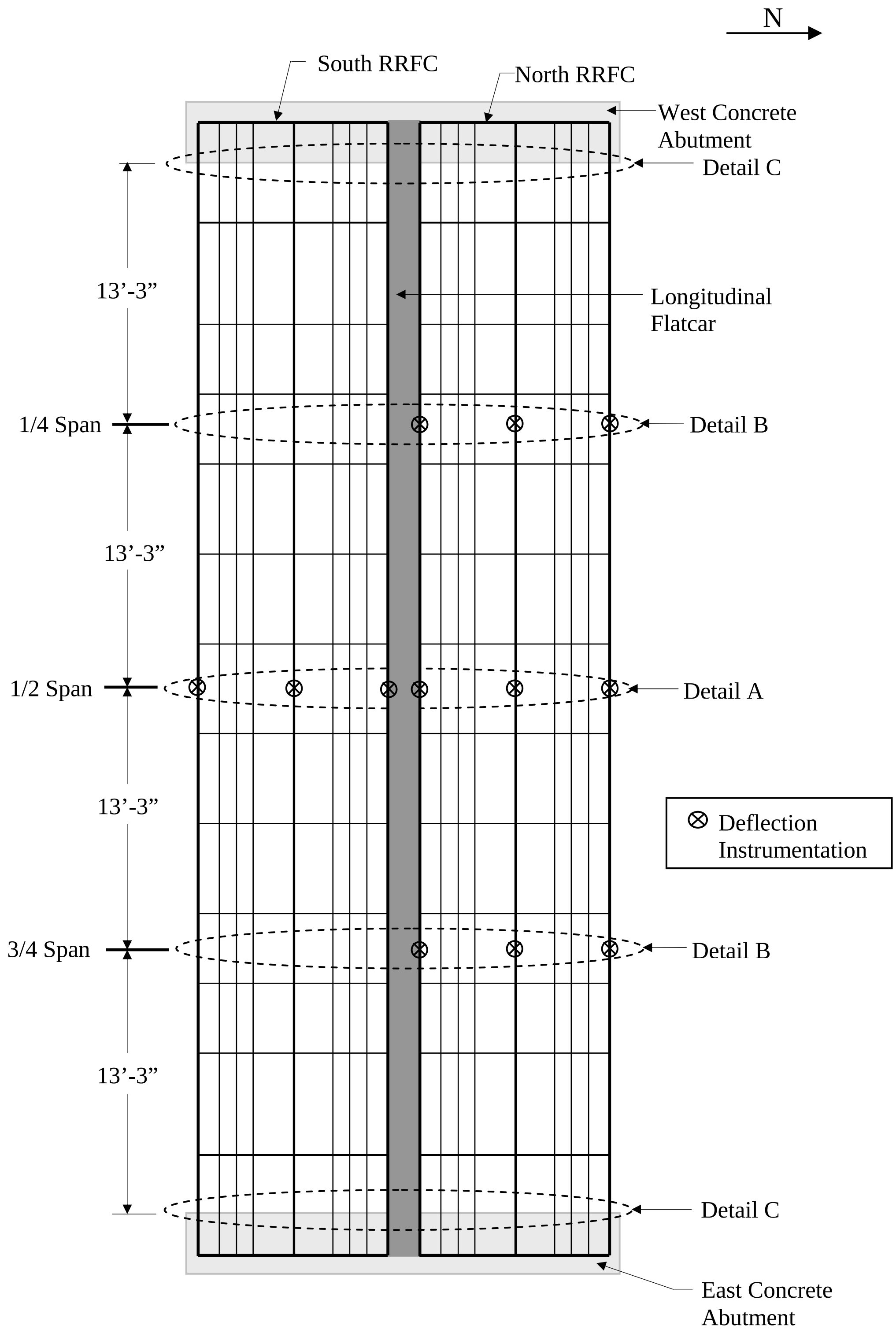
b. Strain transducer on guard rail.

FIGURE 6 Instrumentation on 290th Street Bridge.

c. Strain transducer on RRFC beam.

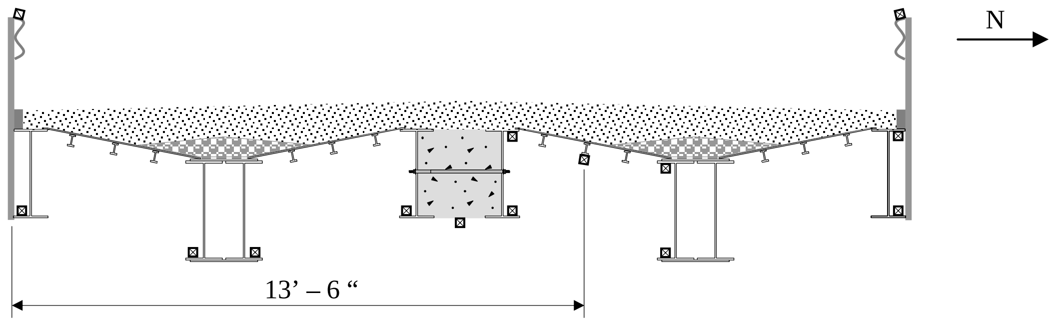
d. Deflection transducer.

FIGURE 6 Continued.

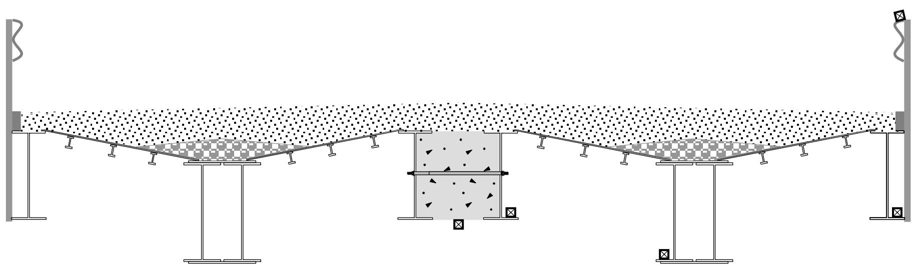


a. Plan View.

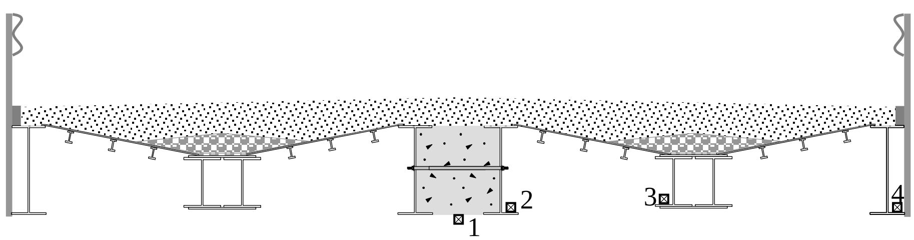
FIGURE 7 Location of instrumentation in 290th Street tests.



b. Detail A.



c. Detail B.

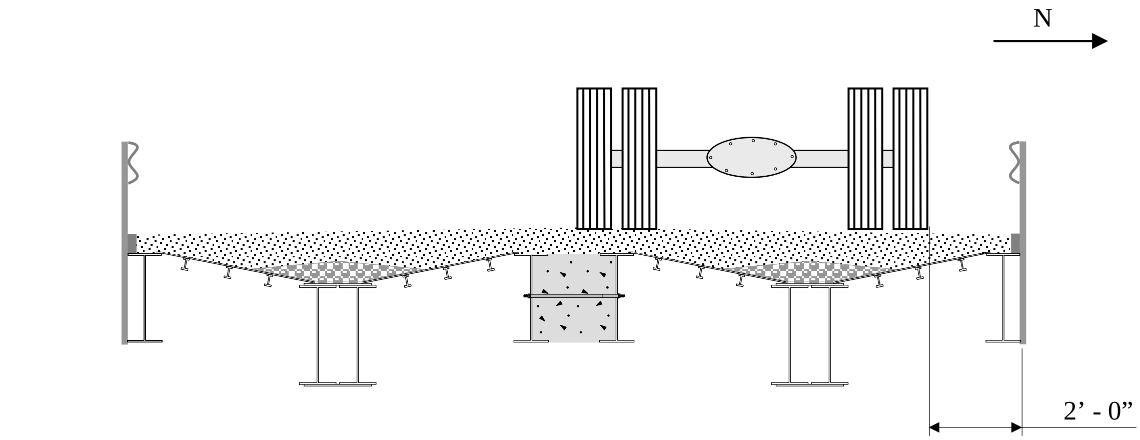


d. Detail C.

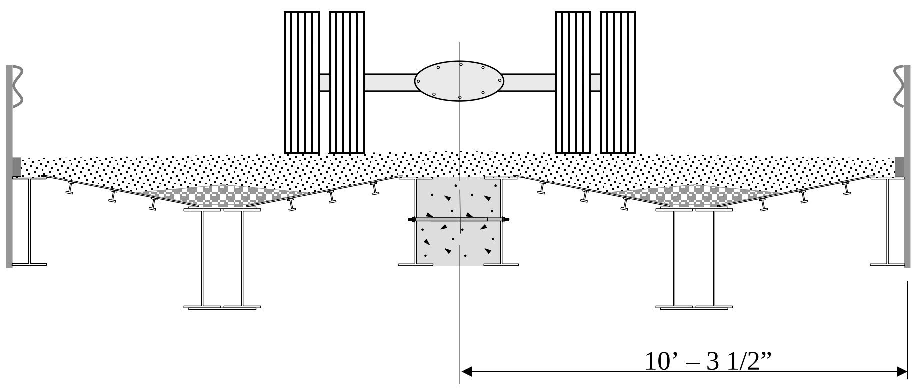
<u>Notes:</u>

- Transducers 1, 2, and 4 are on the East Abutment only
- Transducer 3 is positioned on both abutments.
- Strain transducers oriented with longitudinal axis in the East-West direction.

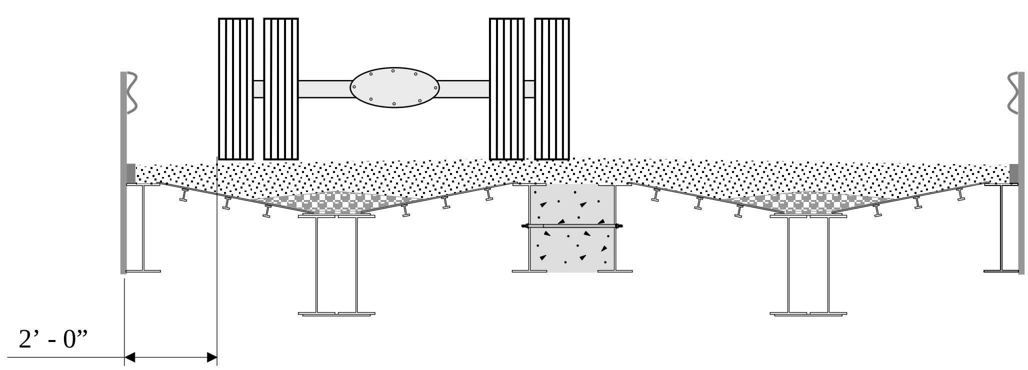
FIGURE 7 Continued.



a. Test 1.



b. Test 2.



c. Test 3.

FIGURE 8 Transverse location of truck in the 290th Street Bridge tests.

a. Loading bridge with truck on south RRFC (Lane 3).

b. Truck centered on bridge (Lane 2).

FIGURE 9 Photographs of the truck location in the 290th Street Bridge tests.

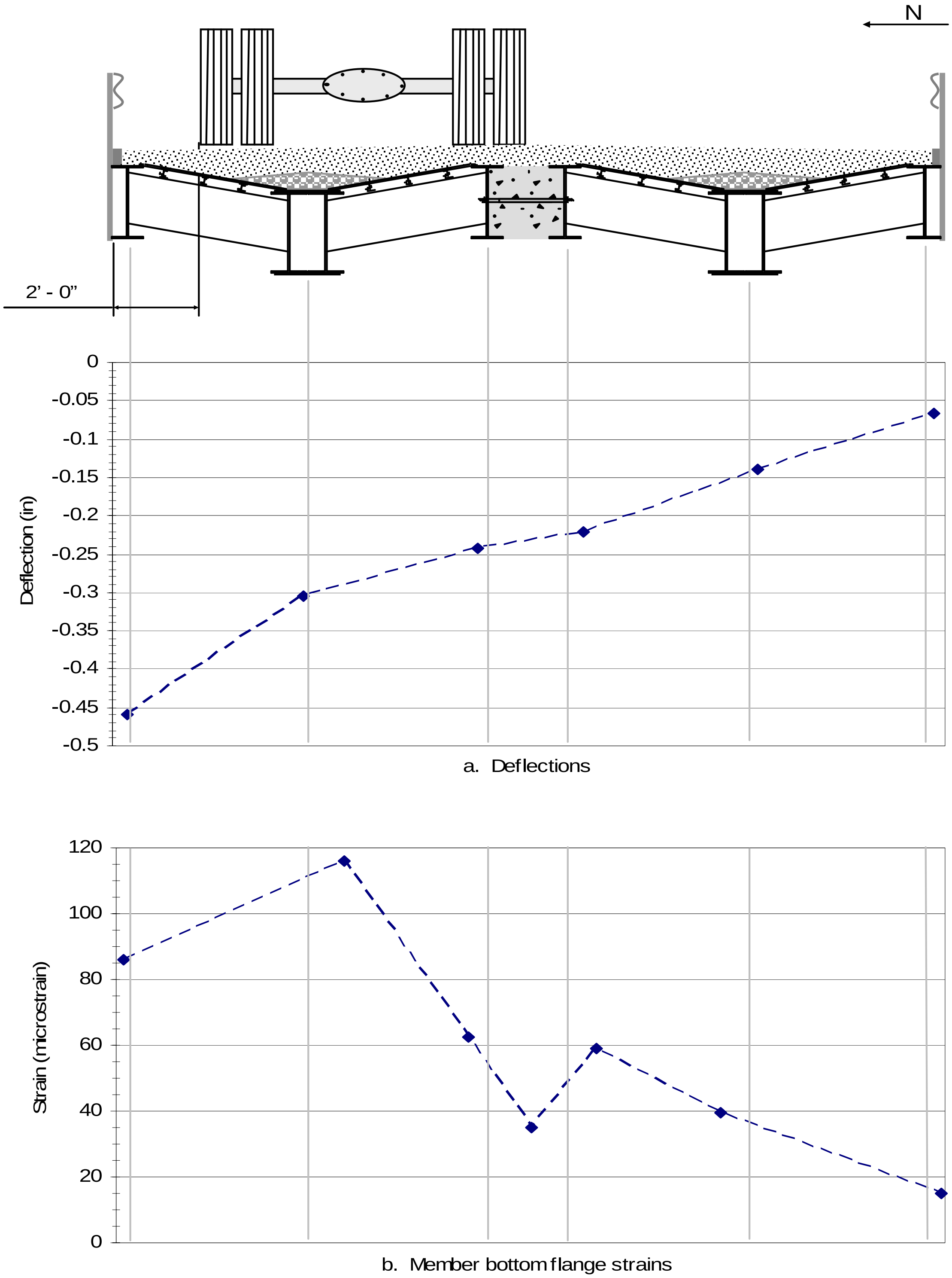


FIGURE 10 290th Street Lane 1 midspan deflections and strains.

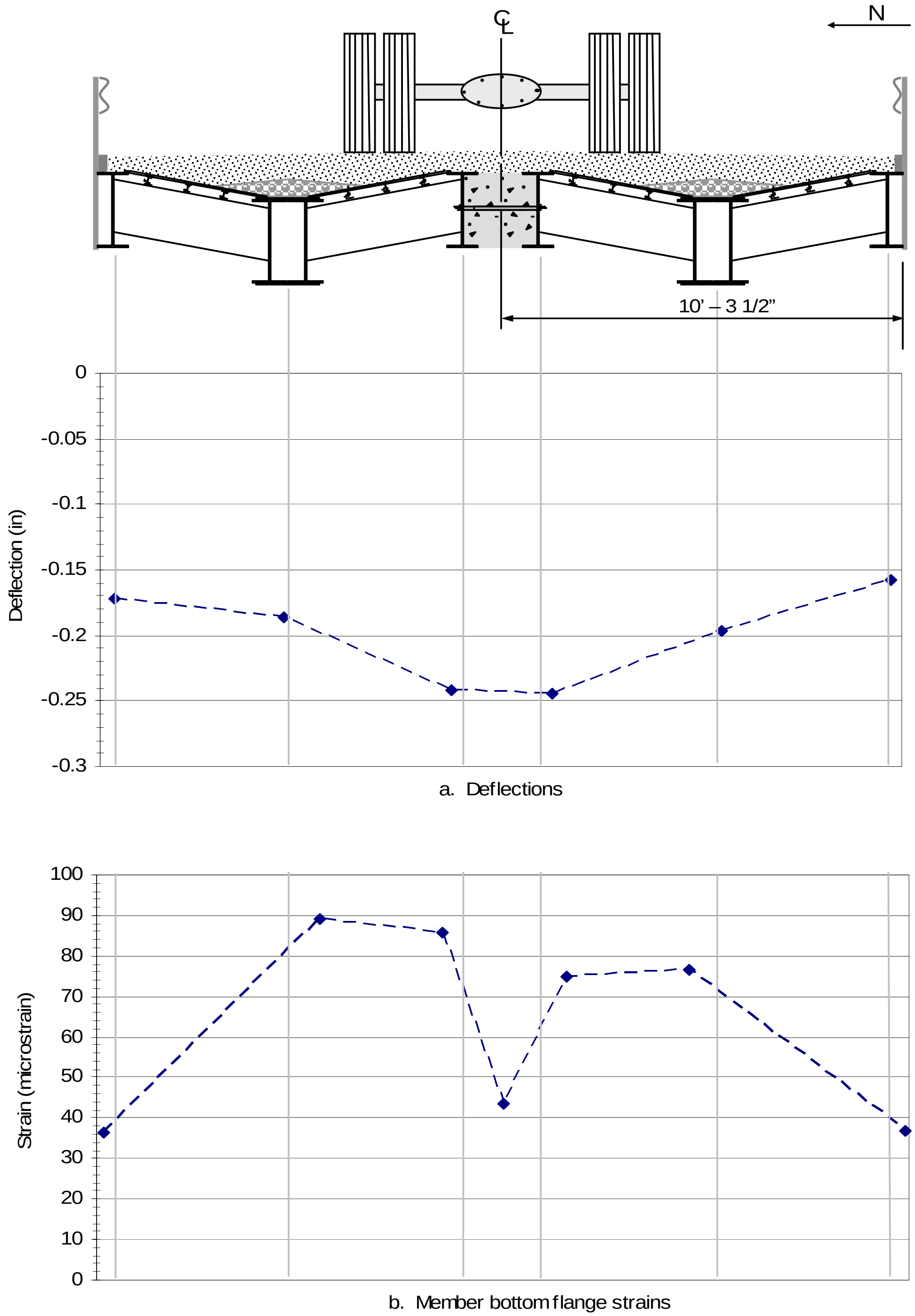


FIGURE 11 290th Street Lane 2 midspan deflections and strains.

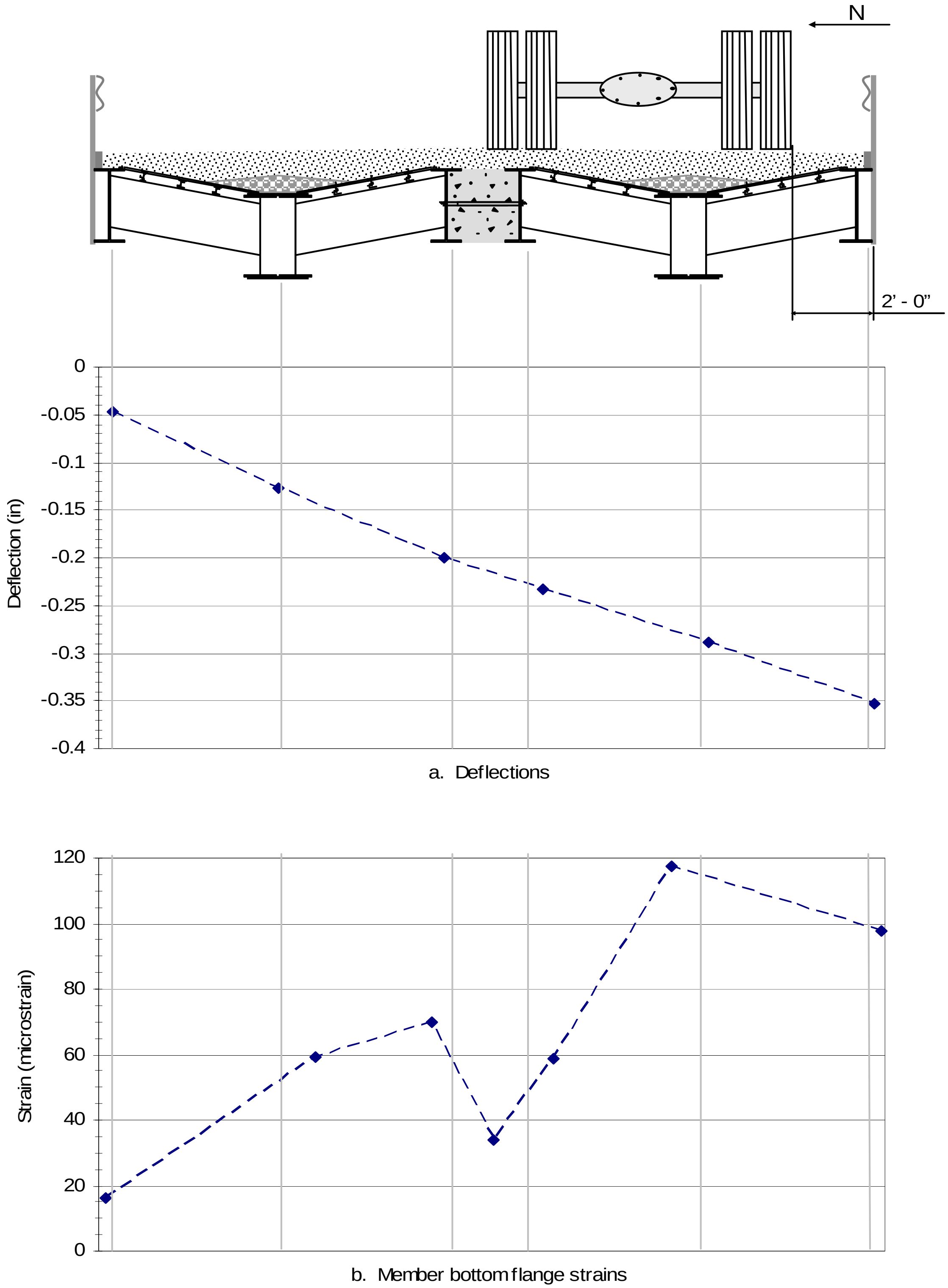


FIGURE 12 290th Street Lane 3 midspan deflections and strains.