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I am submitting herewith a thesis written by Christopher Thomas Schmidt entitled "Measured Deflections of a Four Girder Bridge Under Varying Bracing Conditions." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Dr. James H. Deatherage, Major Professor

We have read this thesis
and recommend its acceptance:

Edwin G. Burdette

Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

Measured Deflections of a Four Girder Bridge Under Varying Bracing Conditions

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Christopher Thomas Schmidt

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ABSTRACT

This thesis reports a study comparing measured vertical girder deflections, twisting of bottom flange, impact factors on girders, and lateral load distribution from two different bracing conditions under a controlled load and normal traffic loads on the Holston River Bridge located in Knoxville, TN. The two controlled load tests performed were a crawl (static) and speed (dynamic) tests. In the first bracing condition the bridge girders were laterally braced. In the second condition the bridge had some lateral bracing removed. This thesis describes in detail how data were obtained for the comparisons of results between the two bracing conditions. Measurements of the girder deflections were achieved by using small apparatuses that resemble cantilever beams.

The static test results show that when lateral bracing was removed, the changes in girder deflections were not significant; however, the dynamic test results showed a significant change. The lateral load distribution was essentially unchanged by the removal of bracing. The static test results also showed that the bottom flange angle of twist on an unbraced girder increased significantly after removal of the lateral bracing.

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LIST OF ABBREVIATIONS

HRB	Holston River Bridge
DG	Deflection Gage
LVDT	Linear Variable Differential Transformer
ε	Strain
D1	Parallel Deflection Gage on Girder #1
D1S	Perpendicular Deflection Gage on Girder #1
C2	Parallel Deflection Gage on Girder #2
D3	Parallel Deflection Gage on Girder #3
D4	Parallel Deflection Gage on Girder #4
MPH	Miles Per Hour
RMC	Root Mean Cubed
PC	Personal Computer

Chapter 1

Introduction

Description of the Bridge

The Holston River Bridge (HRB) or Ralph K. Adcock Memorial Bridge, which lies east of Knoxville, TN on Interstate Highway 40, supports three lanes of traffic and a shoulder in both east and west directions. HRB has eight continuous spans over the Holston River and is 1190 feet in length (Figure 1-1).

The bridge is constructed of four continuous steel plate girders (Figure 1-2). The four girders are evenly spaced at 26 feet. The girder depths range from 70 to 94 inches at the mid-spans, and 73 to 142 inches at the supports. The girders' flanges vary from 22 to 28 inches wide.

The roadway on the bridge is 109 feet wide and includes three lanes and a shoulder for both east and west bound traffic with a concrete barrier separating the two traffic directions (Figure 1-2). Each lane is 12 feet wide and the shoulder is 11.25 feet wide. The bridge deck is a 7.5 inch thick concrete slab, with a 3 inch thick asphalt topping, which

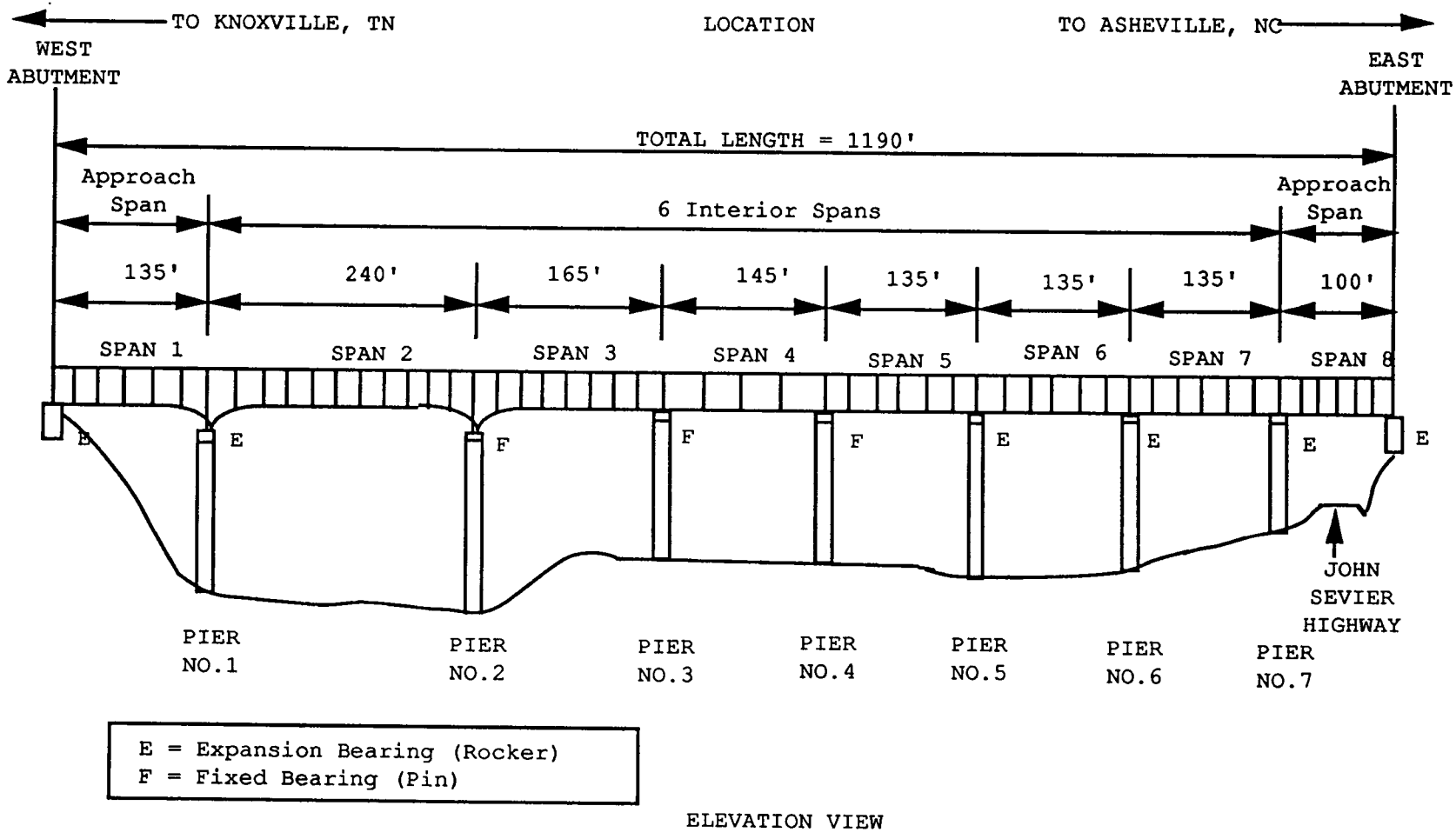


Figure 1-1 - HRB Elevation View

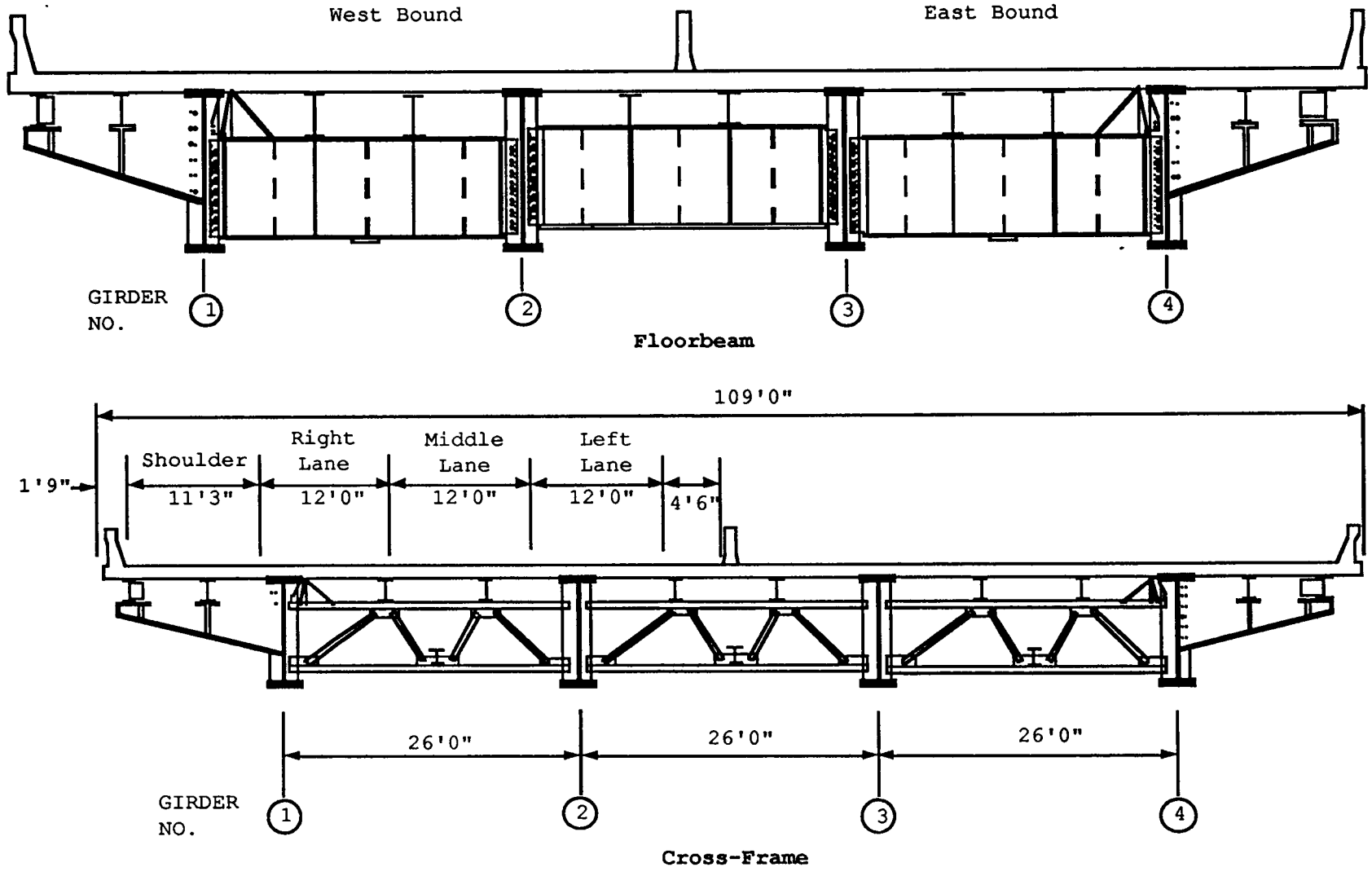


Figure 1-2 - HRB Cross-Sections

acts compositely with the girders in the positive moment regions of the bridge.

Cross-frames are connected laterally to the girders in the second span (Figure 1-3) from the west end of the bridge. These cross-frames are spaced at 20 or 22.5 feet along the span. The other seven spans have the girders connected laterally with floor beams spaced at 20 or 22.5 feet apart (Figure 1-4). Both the floor beams and cross-frames support two wide flange stringers, which act as supports for the bridge deck between girders.

The exterior girders have cantilevers attached to their webs at the same locations where the cross-frames and floor beams frame into the webs (Figure 1-5). The cantilevers support the shoulder of the roadway.

Lateral cross-bracing is connected to the web of a girder near the bottom flange and to the bottom chords of the cross-frames. The lateral cross-bracing is made of a T and W-Sections. The lateral bracing is connected to plates that extend from the webs of the girders and the cross-frames (Figure 1-6).

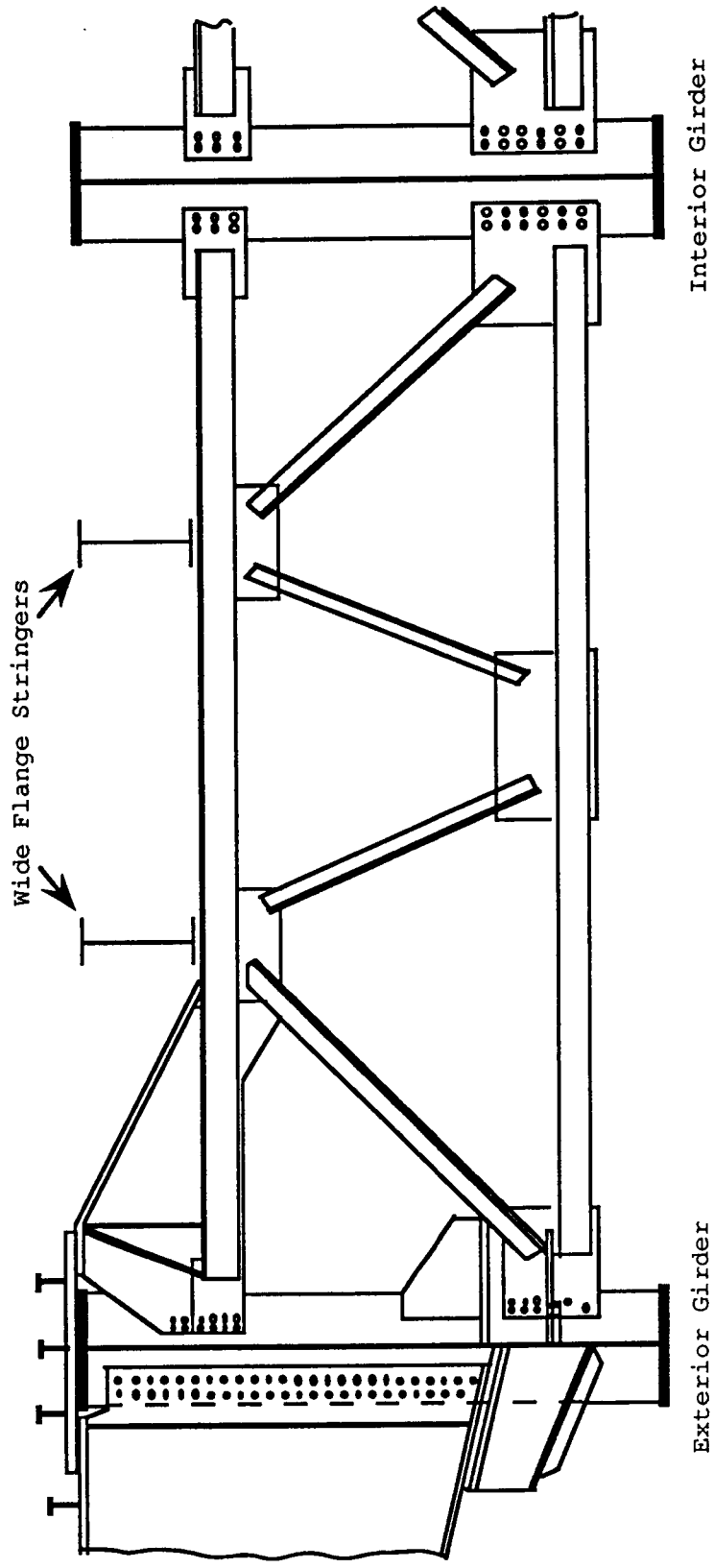


Figure 1-3 - Typical Cross-Frame

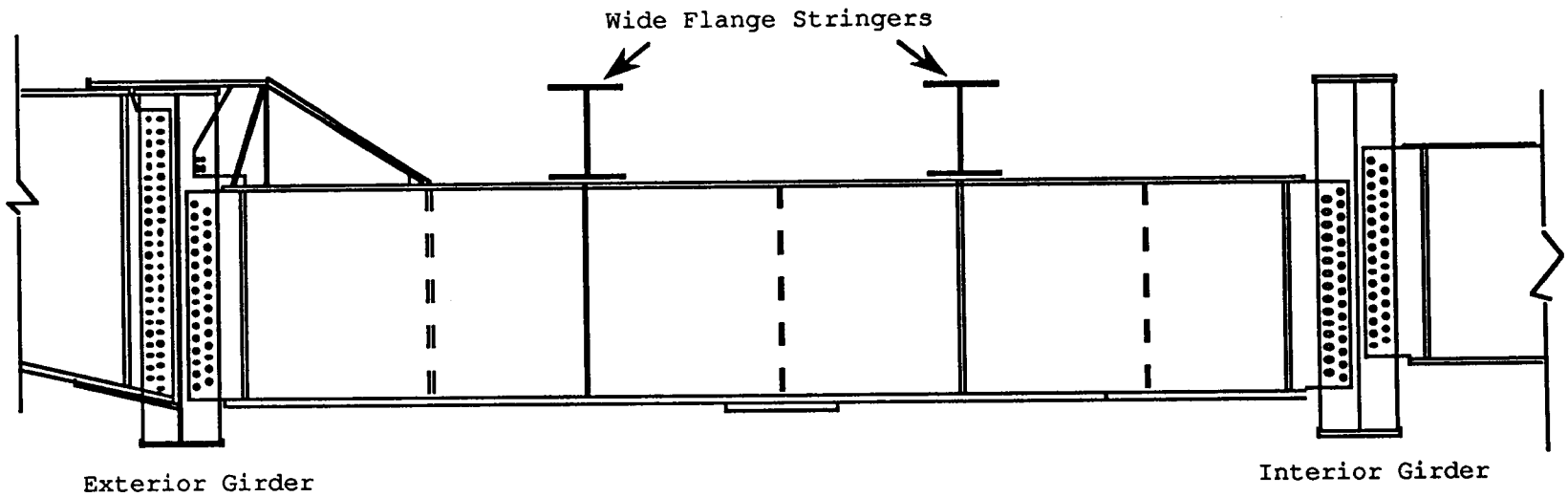


Figure 1-4 - Typical Transverse Floor Beam

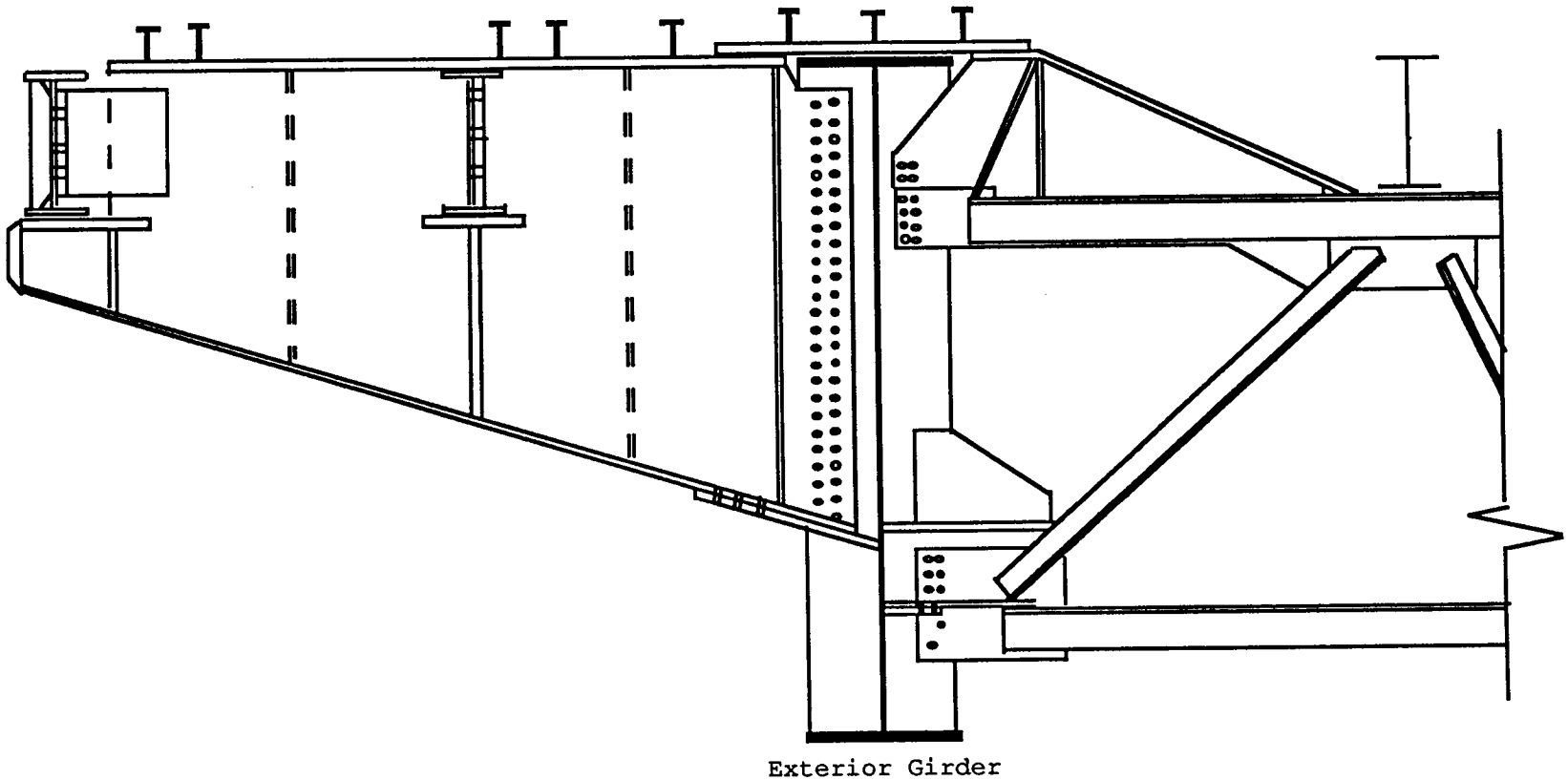


Figure 1-5 - Cantilever to Girder Connection

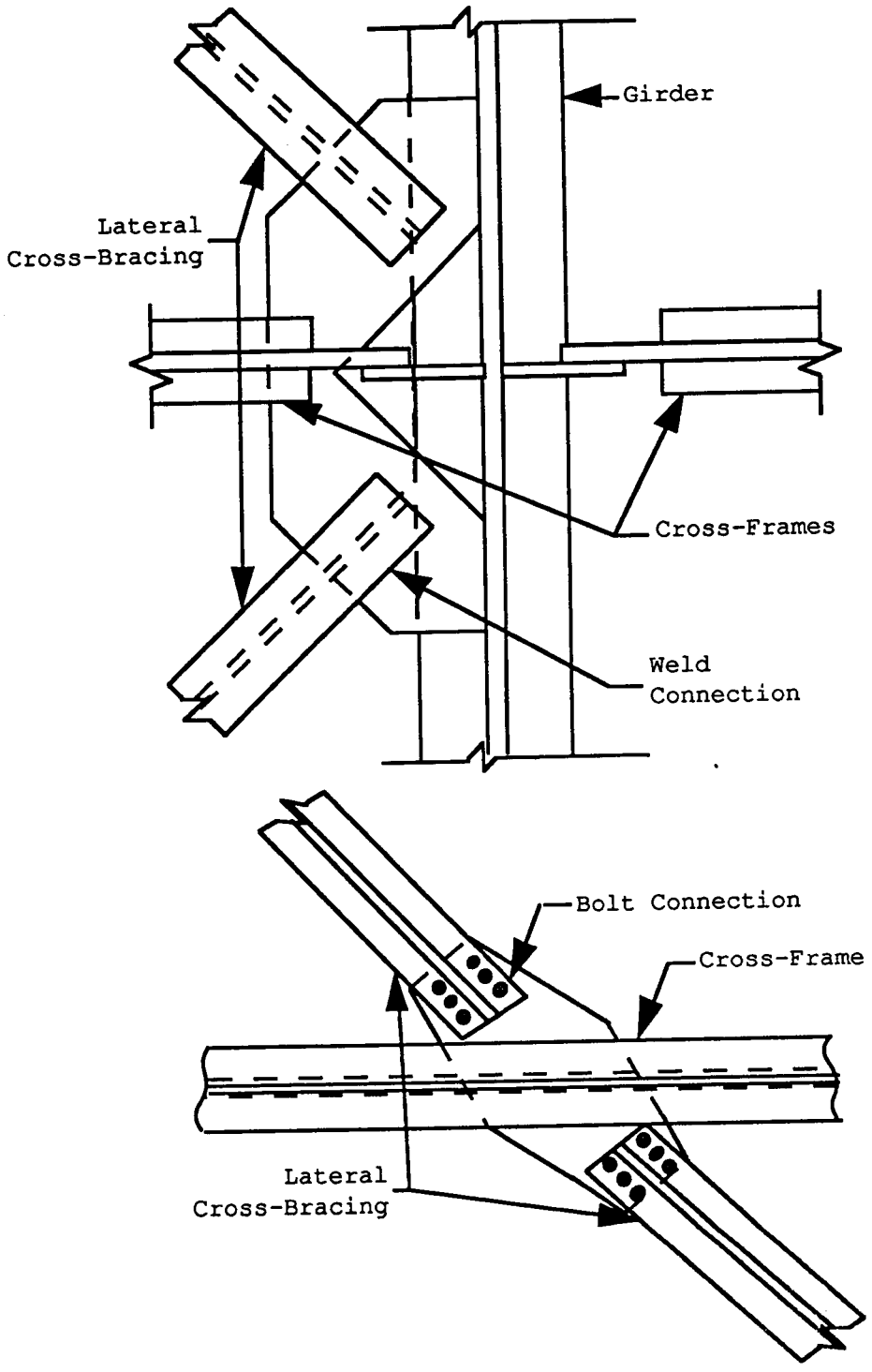


Figure 1-6 - Lateral Cross-Bracing Connections

Objective

An objective of the research project described in this thesis was to measure the deflections of the four girders of the HRB. The HRB was subjected to a controlled load applied at specific locations on the bridge. The response of the girders was measured under two lateral bracing conditions: (1) with the lateral cross-bracing in place and (2) with the lateral cross-bracing effectively removed from a portion of the bridge where deflections were measured. The displacements of the four girders reflects how the truck load was distributed to each girder. Since it had been postulated that the presence or absence of lateral bracing would not alter the load distribution on the bridge, field tests were needed to either verify or reject this hypothesis.

Static, dynamic, and normal traffic tests were performed to verify this hypothesis. The static tests used a three axle tandem dump truck to apply known loads at various locations on the bridge. The dynamic test consisted of the same truck moving at a velocity of approximately 55 mph under controlled traffic conditions. The speed test allowed the evaluation of the effects of impact on the girder responses. The normal traffic tests consisted of obtaining data as the bridge was subjected to normal traffic loading.

Chapter 2

Literature Review

The effects of removing lateral bracing on the behavior of bridge structures has not been reported extensively in the literature. Stallings (1996), Azizinamini (1994), Kostem (1977), and Tarhini (1992) have recently reported the results of removing diaphragms on highway bridge structures.

The effects of removing torsional bracing were measured experimentally (Stallings, Cousins, Stafford 1996) on a five lane bridge having nine girders. The study by these researchers examined girder deflections and stresses under controlled load and normal traffic. The speed of the controlled load truck was not discussed in the report. Under the controlled load, the stresses increased 8 to 10% for side-by-side trucks and 6 to 15% for a single truck. The girder deflections under the controlled loads increased, meaning that the diaphragms do indeed enhance the lateral load distribution. Wheel load distribution factors were used to examine the data from the normal traffic tests. The results from the normal traffic showed that the removal of diaphragms increased the girder wheel load distribution

factors 8 to 17% for the heavily loaded girders. The researchers concluded that the diaphragms did enhance lateral load distribution.

Another experimental study was done on a simply supported three girder bridge for two lanes of traffic (Azizinamini, Kathol and Beacham 1994). The researchers measured the effects removing diaphragms from this bridge. The bridge was loaded by hydraulic rams to simulate static truck loads. From their results the researchers concluded that the slab alone was sufficient to laterally distribute loads.

One analytical study on how diaphragms affect lateral load distribution was done on two bridges (Kostem and deCastro 1977). The analytical study was on a five and six girder prestressed concrete I-beam bridge using finite elements to model the two bridges. The study examined the two modeled bridges separately and varied the number of diaphragms and loaded lanes on the six beam bridge. A part of the study examined the effects of having no diaphragms and one to five diaphragms spaced equally. The researchers concluded that using more diaphragms did not necessarily mean that the load would be equally distributed and that the diaphragms contributed a small portion to lateral load distribution.

The researchers also said that diaphragms did not meet the expectations of bridge designers in lateral distribution.

Another analytical computer model study was performed on a four girder, four lane bridge (Tarhini and Frederick 1992). The computer model used a configuration of finite elements for the girders and composite slab along with space trusses as the torsional bracing. The researchers' study looked at different parameters that affect the distribution of a load. One of those parameters was the absence of torsional bracing. The results from the study indicated that removing the torsional bracing had a negligible effect on the distribution of the loads.

Three of the four studies mentioned in this chapter concluded that torsional bracing does not enhance lateral load distribution. None of these studies considered dynamic effects. The fact that dynamic effects were not considered for those studies and the insufficient information on effects of removing lateral bracing led to the study that is presented in this thesis.

Chapter 3

Data Acquisition

Deflection Gages

Girder deflections were measured using deflection gages (DGs) (Figure 3-1) that had been developed for a previous research project. These DGs consist of a tapered cantilever beam that is sandwiched between two support plates which can be clamped to a girder at a desired location. At the free end of the tapered beam, an eye bolt was installed to provide a means to pretension a wire that would be connected to an anchor below the bridge.

Strain gages were placed on the top and bottom of the tapered beam, directly opposite each other. The strain gages used were 0.25 inch, 350 ohm foil gages, manufactured by Micro-Measurements (type CEA-06-250UW-350). The center line of each strain gage was placed 1 inch away from the face of the support plates. Each strain gage had two terminals, and each terminal had a soldered lead wire. The strain gages were wired (half Wheatstone bridge) such that their outputs were additive, thus increasing the sensivity of a DG. Figure 3-2 shows the wiring diagram of a DG's strain gages.

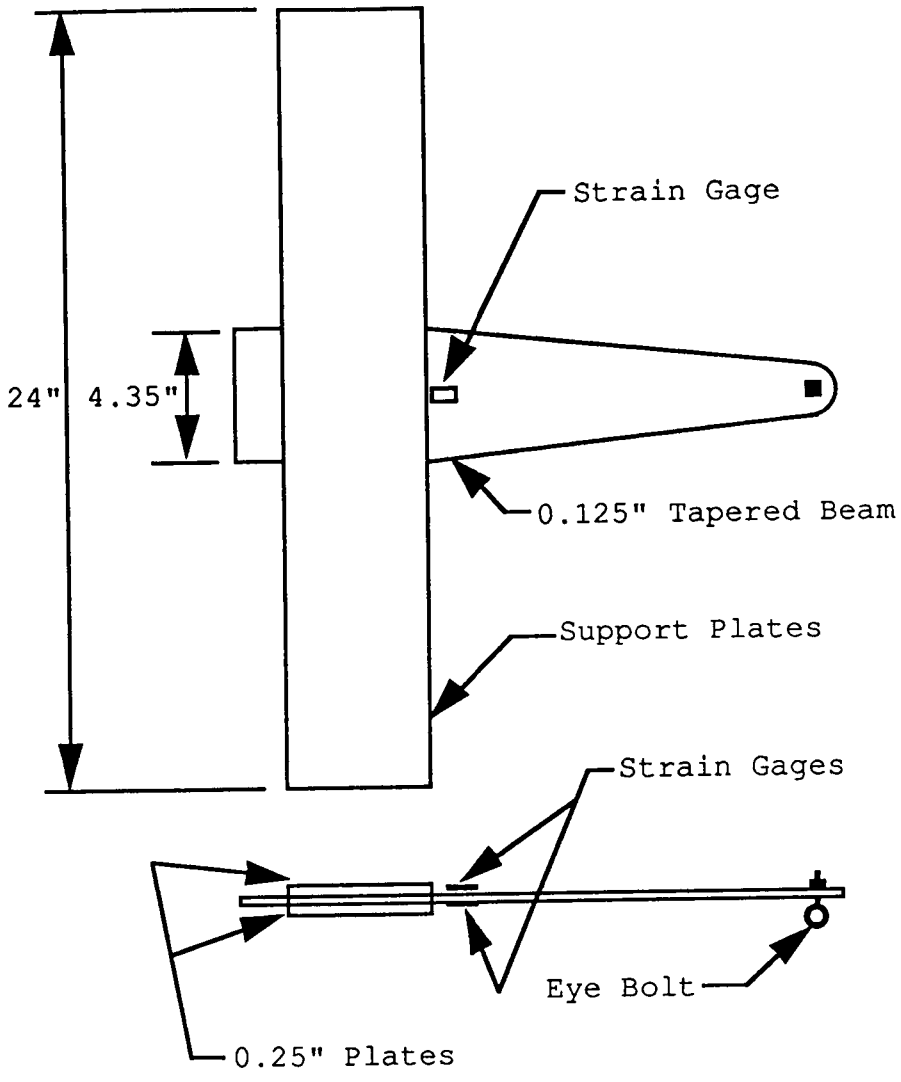


Figure 3-1 - Deflection Gage

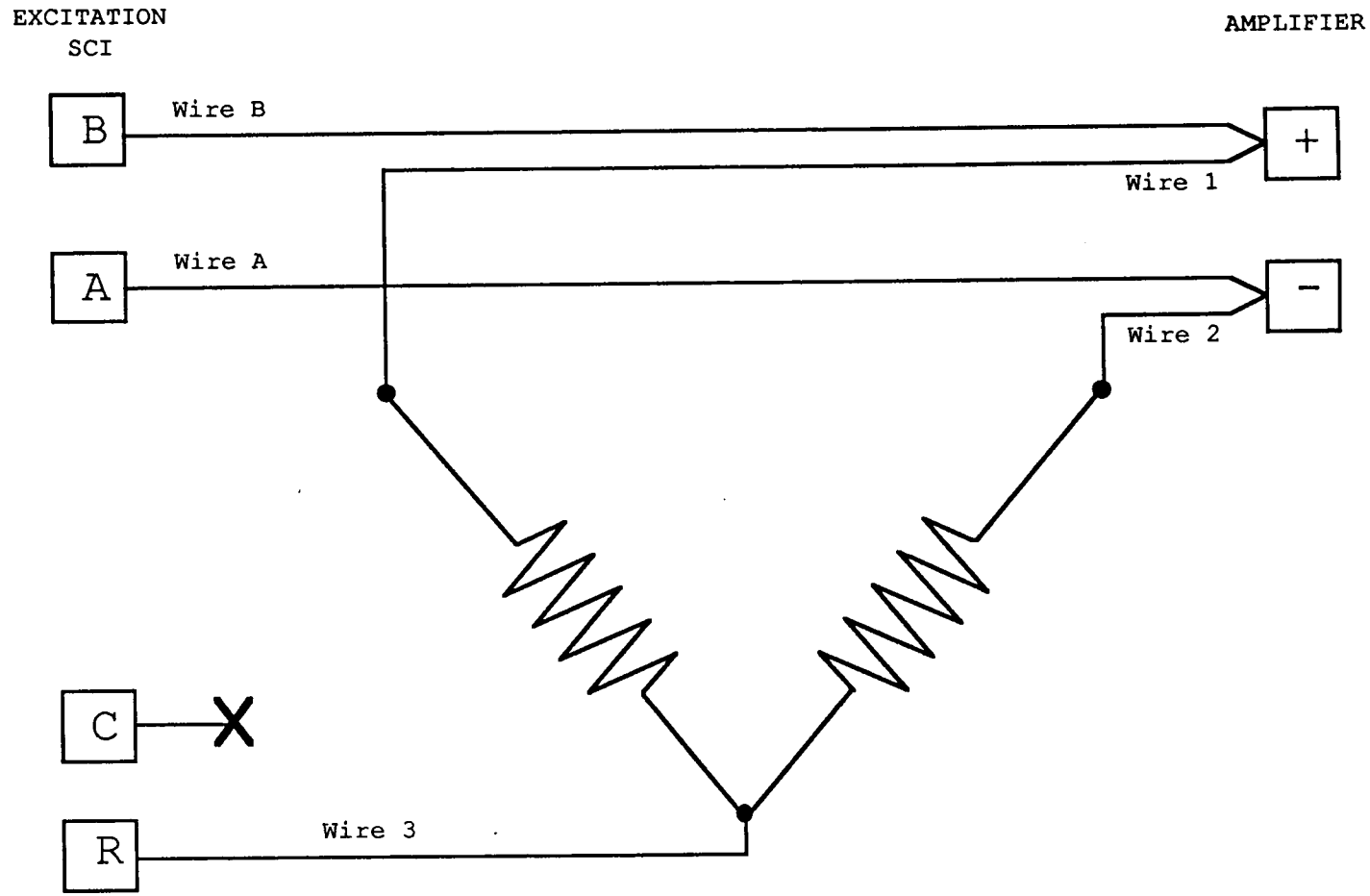


Figure 3-2 - Deflection Gage Wiring Diagram

Calibration of Deflection Gages

Each DG was calibrated prior to being used to collect data. The output from a DG was a measure of the strain on the tapered beam, and the strain was correlated to the measured displacement.

The calibration of the DGs was done in a laboratory. The necessary equipment for the calibration tests included a Linear Variable Differential Transformer (LVDT), an Optim MEGADAC (data acquisition system), a personal computer (PC), pretensioning wire, and a winch (Figure 3-3). The LVDT was Model Type LDG3000A, Serial No. 436 manufactured by RDP Electronics. The LVDT was put near the eye bolt of the triangular plate. A pull wire was attached to the eye bolt and to the winch. The support plates of the DG were clamped to a fixed support. The output strain measurements from the DG and the displacement values from the LVDT were recorded using a TCS 3000 software program on the PC.

Each calibration test was repeated three times which consisted of increasing the strain output for a given deflection and plotting the data as shown in Figure 3-4.

A linear regression was done for each DG by combining the strain and displacement data points from three calibration

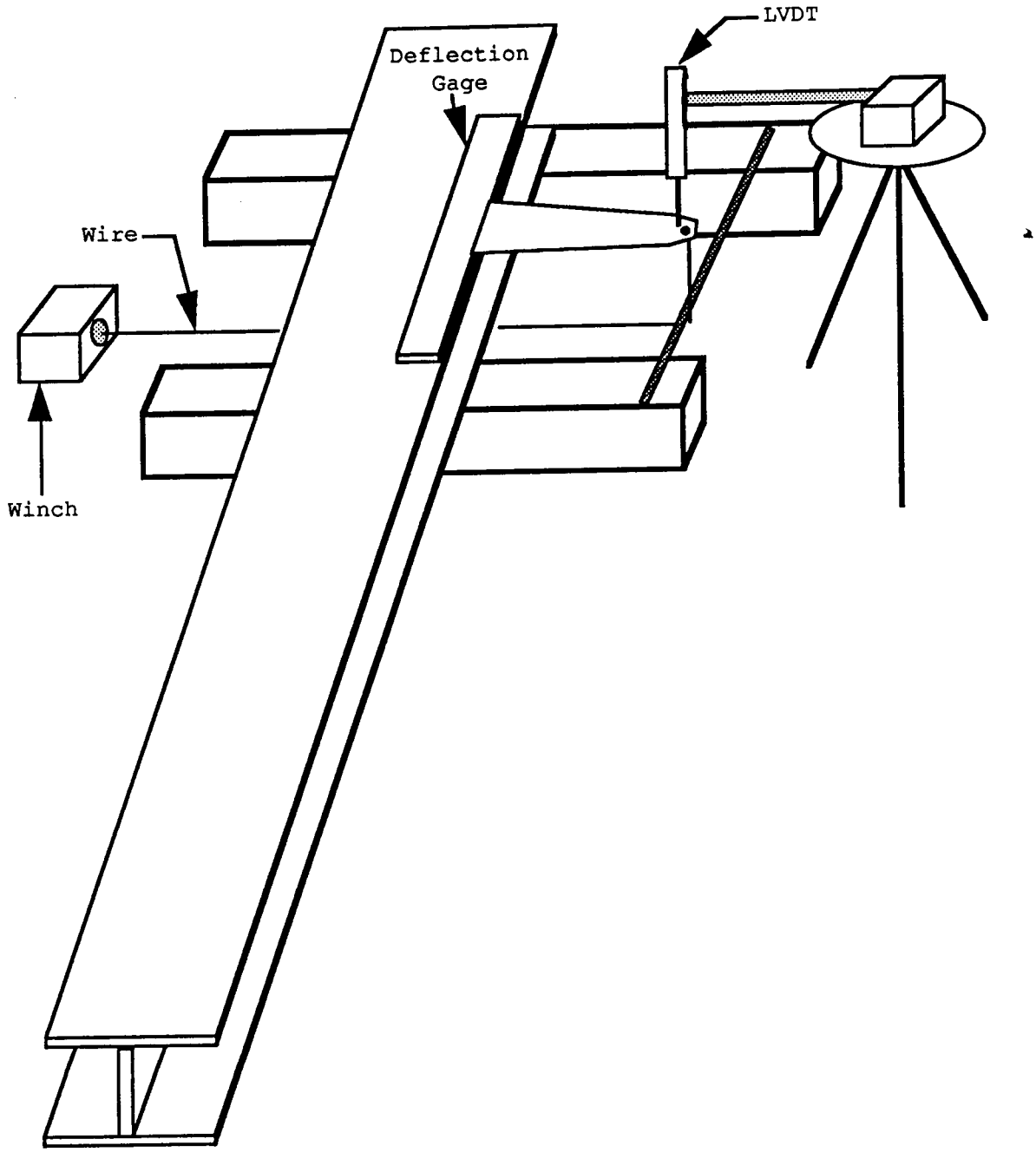


Figure 3-3 - Deflection Gage Calibration Test Setup

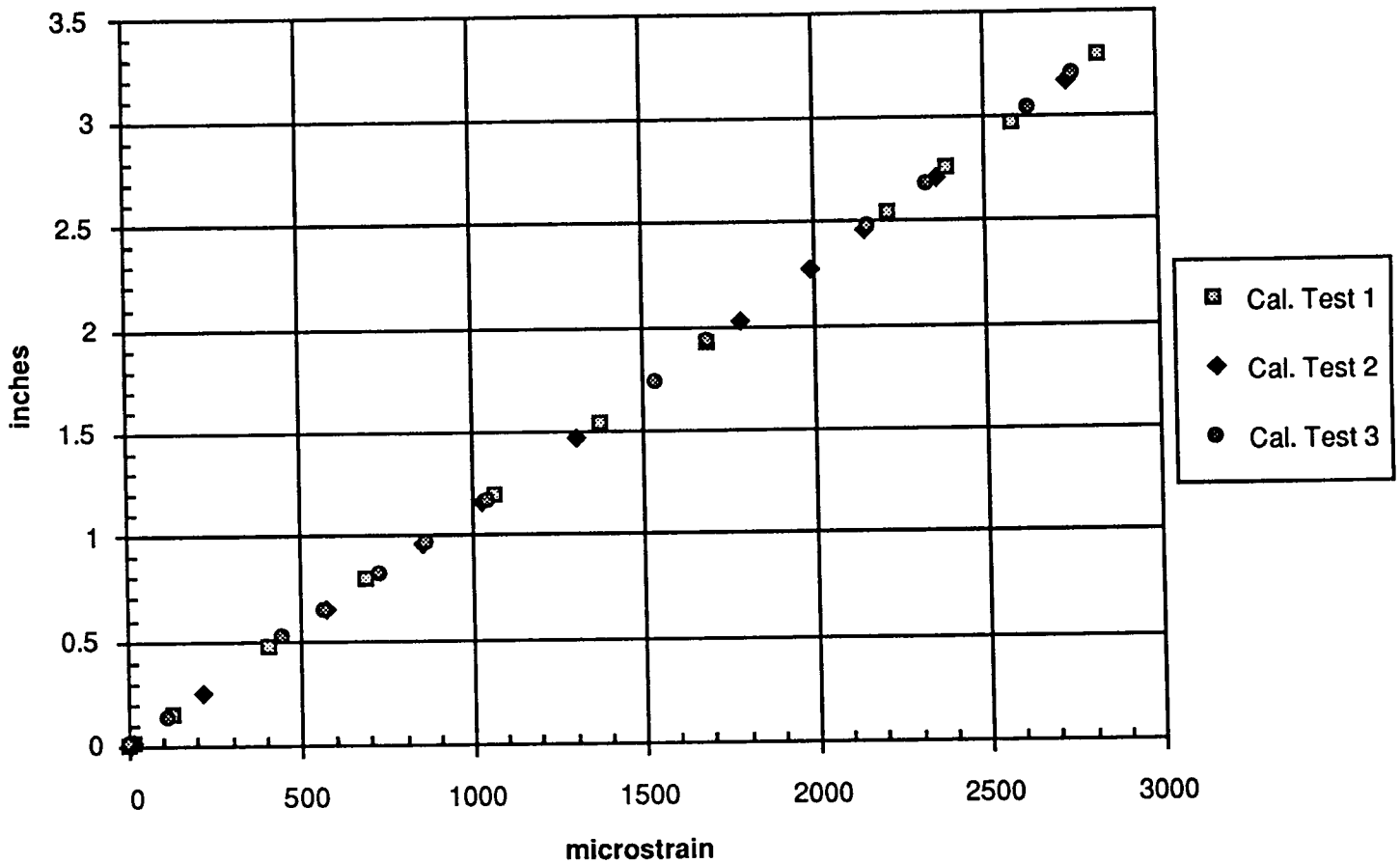


Figure 3-4 - Typical Deflection Gage Calibration Test Plot

tests of each DG. This linear regression allowed the conversion of a reading of strain to a displacement value for the controlled load and normal traffic tests. The linear regression slopes for the DGs varied between 800 and 900 με per inch of deflection.

Two DGs were mounted on Girder #1. Girders #2, 3, and 4 had only one DG. On Girder #1, one DG was placed parallel (D1) to the girder, while the other was placed perpendicular (D1S) (Figure 3-5). The parallel DG measured the deflection in the middle of the flange (girder deflection), while the perpendicular DG measured the outside flange deflection. A comparison of the gage outputs of the perpendicular DG provides an indication of the bottom flange's twist. The remaining DGs on Girders #2, 3, and 4 (C2, D3, and D4 respectively) were placed parallel to the girders.

The DGs on Girders #1, 2, and 3 were located 90 feet away from the first pier in the second span (Figure 3-6) from the west end of the bridge. On Girder #4 the DG could not be placed 90 feet from the pier because a gusset plate on the bottom flange had a bolt pattern that restricted placing the DG flat against the flange. Therefore, a DG was placed at the end of the gusset plate 96.3 feet away from the first pier in the second span (Figure 3-6).

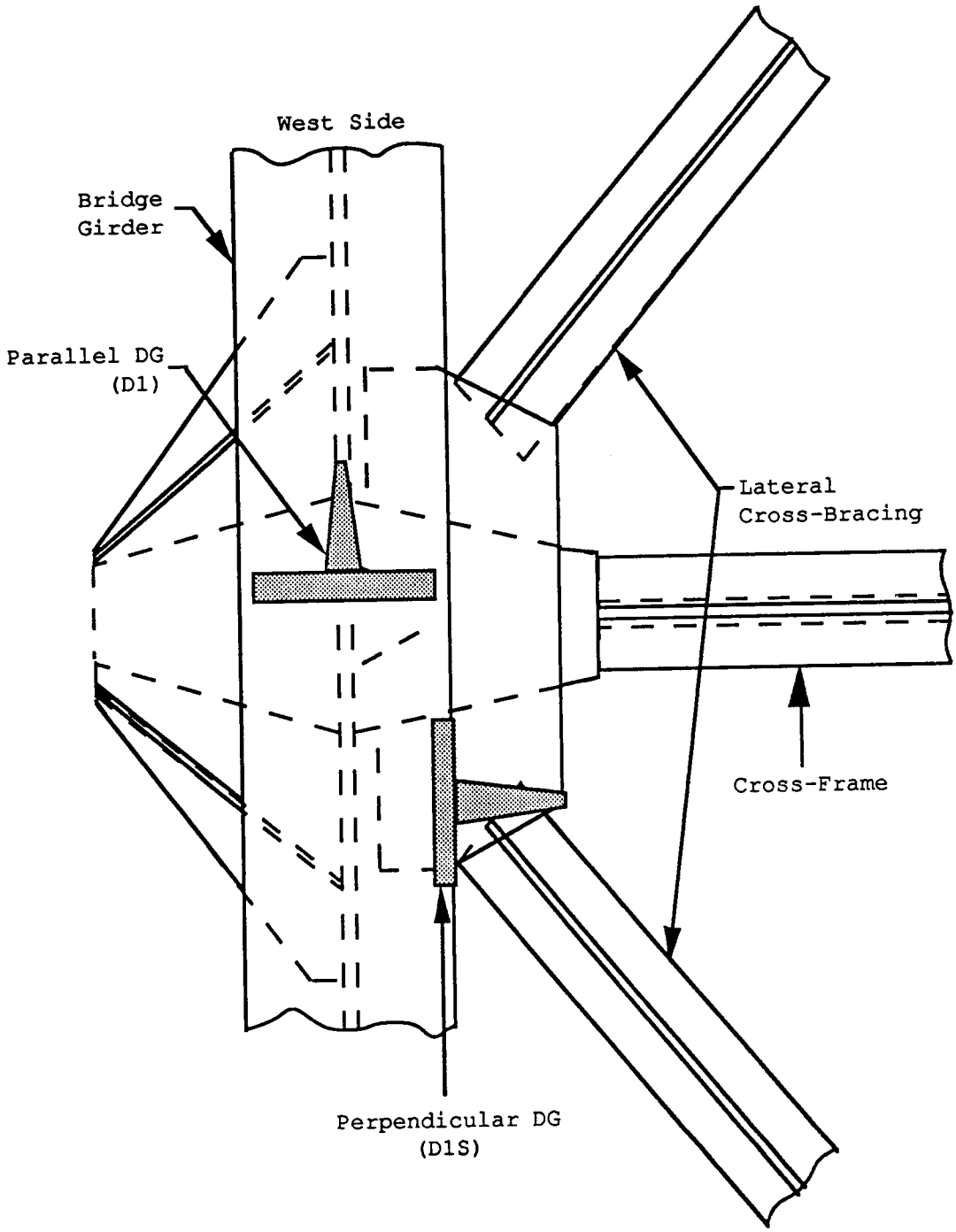


Figure 3-5 - Orientation of Deflection Gages

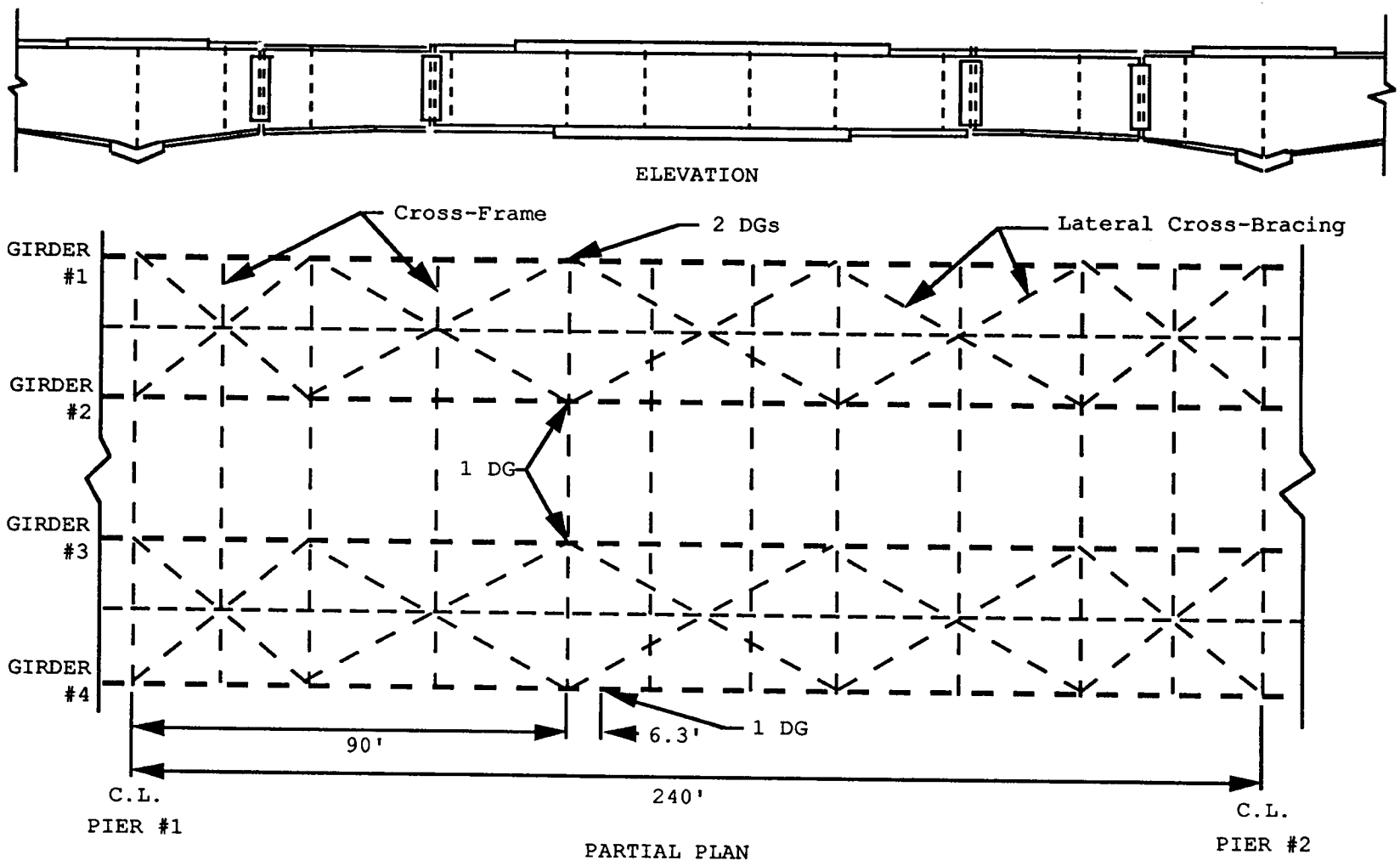


Figure 3-6 - Second Span Partial Plan and Elevation Views

Each DG's support was clamped to the girder's bottom flange using C-clamps. One end of a pull wire was tied to the DG's eye bolt with the other end tied to a weight resting on the bottom of the river. The weight was made of a welded wide-flange section and a steel tube (Figure 3-7). The wide-flange section was used as the base while the steel tubing had the pull wires tied to it. The pull wire was pulled taunt so that the DG's plate deflected approximately 2 inches at the eye bolt. The plate was deflected 2 inches because it was anticipated that a girder would not deflect more than 2 inches. The pull wire was attached to the tube, above the water level, so that the running water would not vibrate the pull wire and increase the vibration in the DGs (Figure 3-8).

Test Data Equipment

The controlled load and normal traffic test data were recorded using the same equipment as used in the DG calibration tests except that the LVDT and winch were not used. During the tests, the recording equipment was in a vehicle located near the west abutment off the bridge on the east bound side in the shoulder. The wires from the MEGADAC were hooked up to the DGs at a junction box.

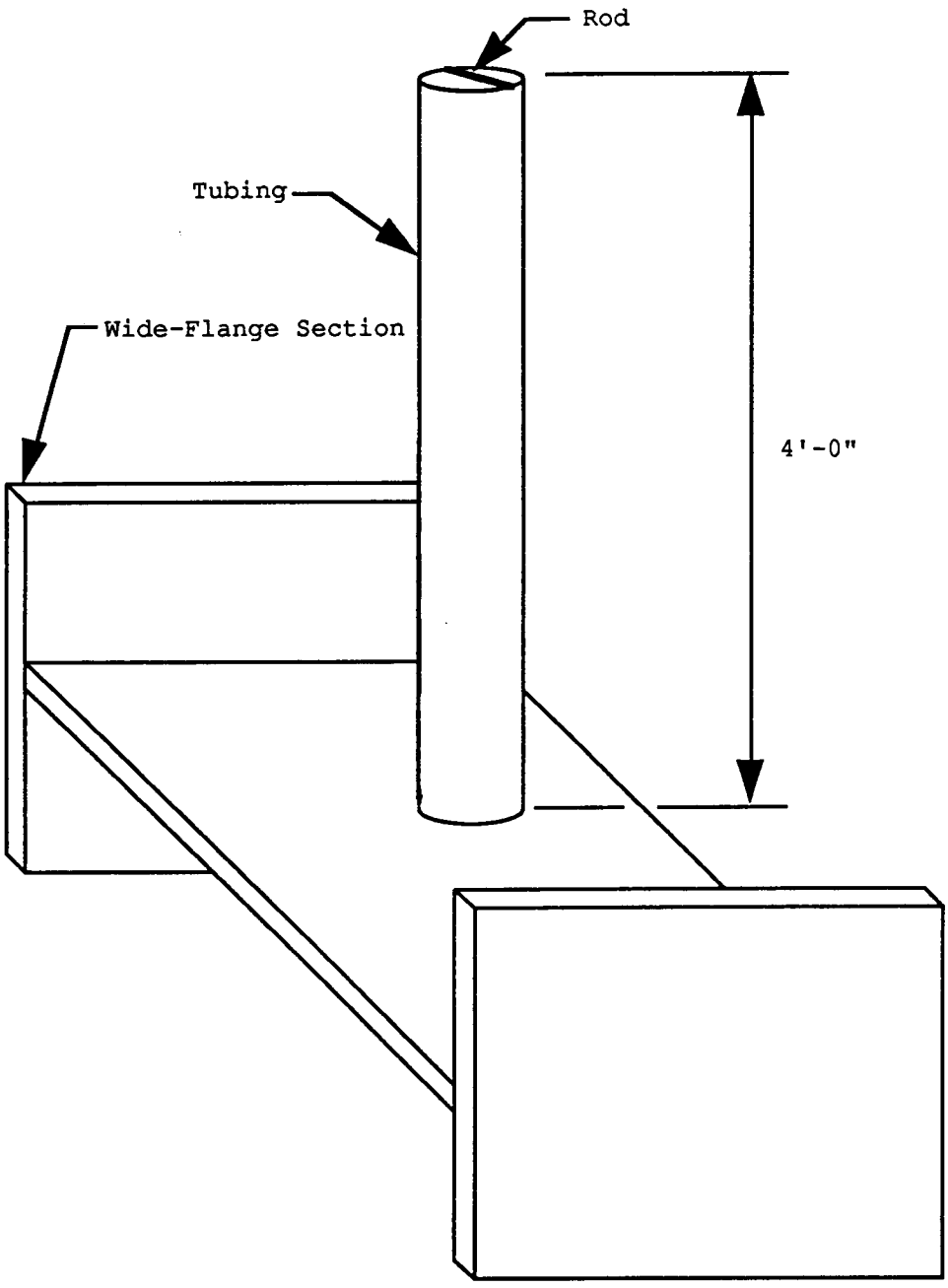


Figure 3-7 - The Weight

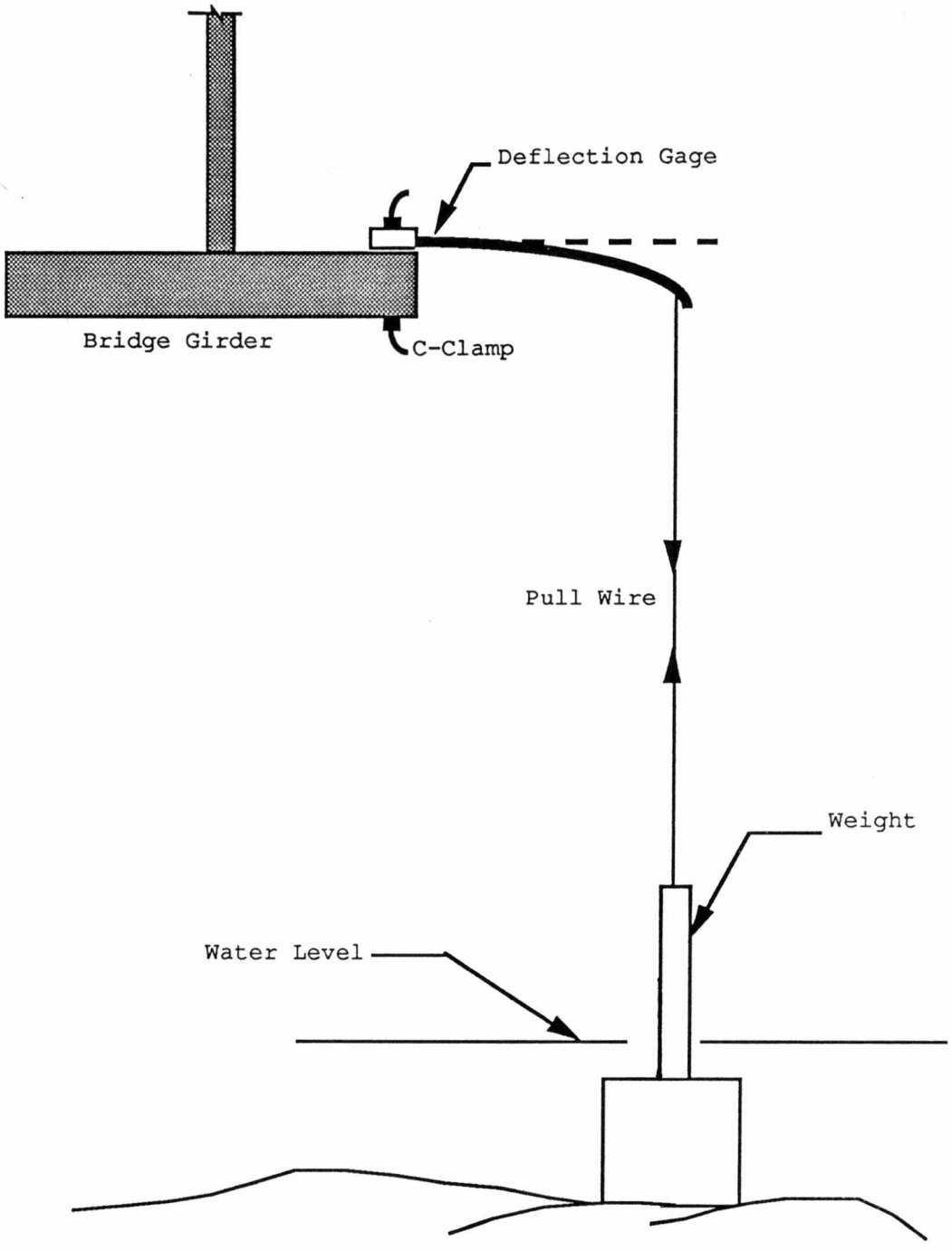


Figure 3-8 - Deflection Gage Setup for Tests

Test Data Recording

Before conducting the controlled load test, the DGs were balanced to zero strain reading when the bridge was closed to traffic. Also, before recording normal traffic data, the DGs were balanced to zero strain reading when the bridge had no tractor trailer trucks on the bridge. Test data were recorded using the same software program that was used for the DGs calibration tests.

Chapter 4

Testing Conditions

Deflection data were obtained for various test conditions to evaluate different aspects of the bridge's behavior with and without the presence of lateral bracing. Deflections of the bridge were measured with the lateral bracing in place and with the lateral bracing effectively removed around the cross-frame 90 feet from the first pier (Figure 4-1).

Truck

The test load truck used for the controlled load tests was provided by the Tennessee Department of Transportation. The truck was a tandem dump truck with a single front axle and dual rear wheel axles with an additional rear axle that was raised during testing. Figure 4-2 shows the truck geometry and axle weights. The gross truck weight was 79,200 lbs. for the braced condition and 81,420 lbs. for the unbraced condition. During the controlled load tests, a member of the research team rode in the truck to instruct the driver on which lane to use and what speed to drive.

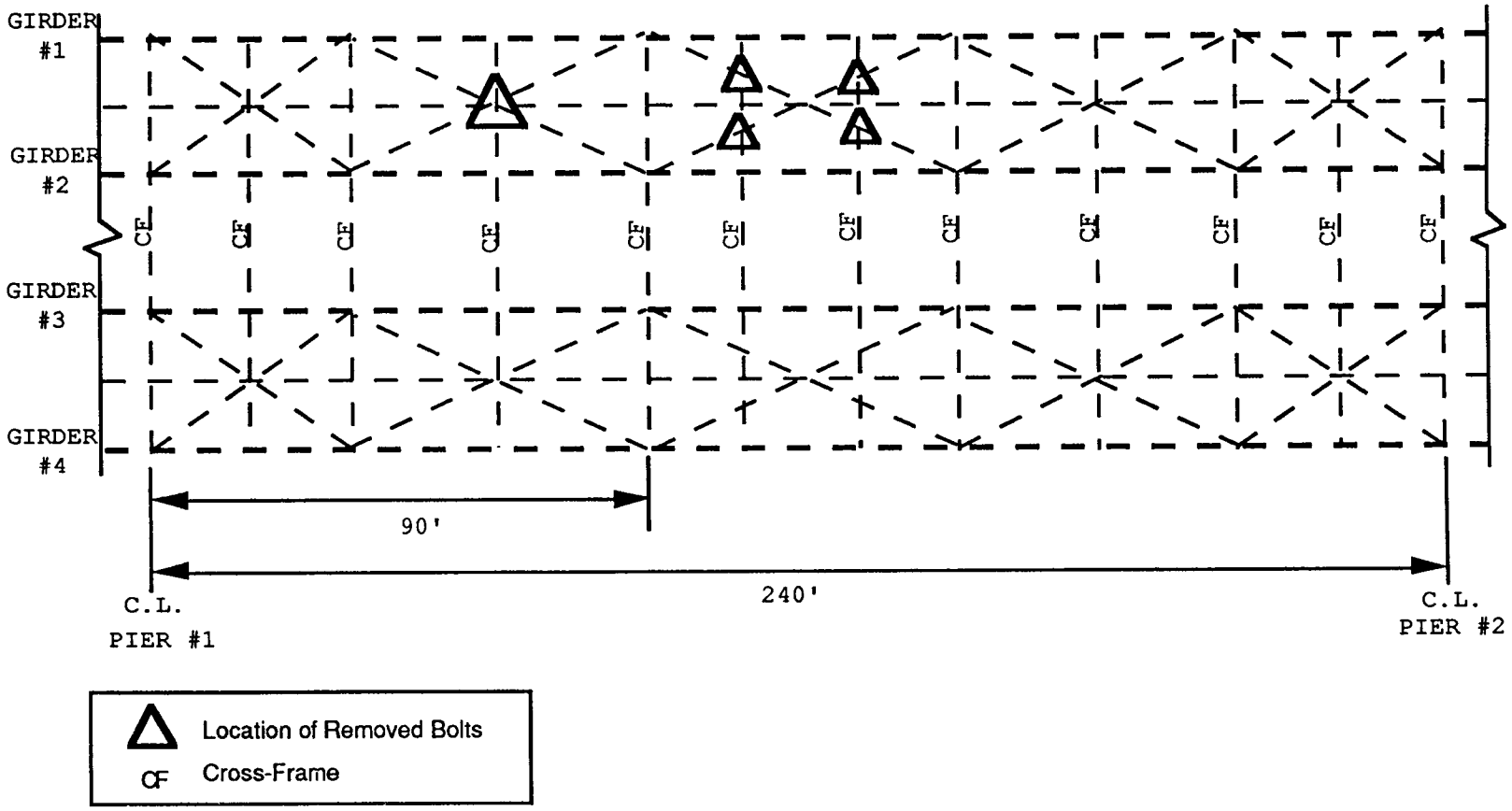


Figure 4-1 - Location of Unconnected Lateral Cross-Bracing

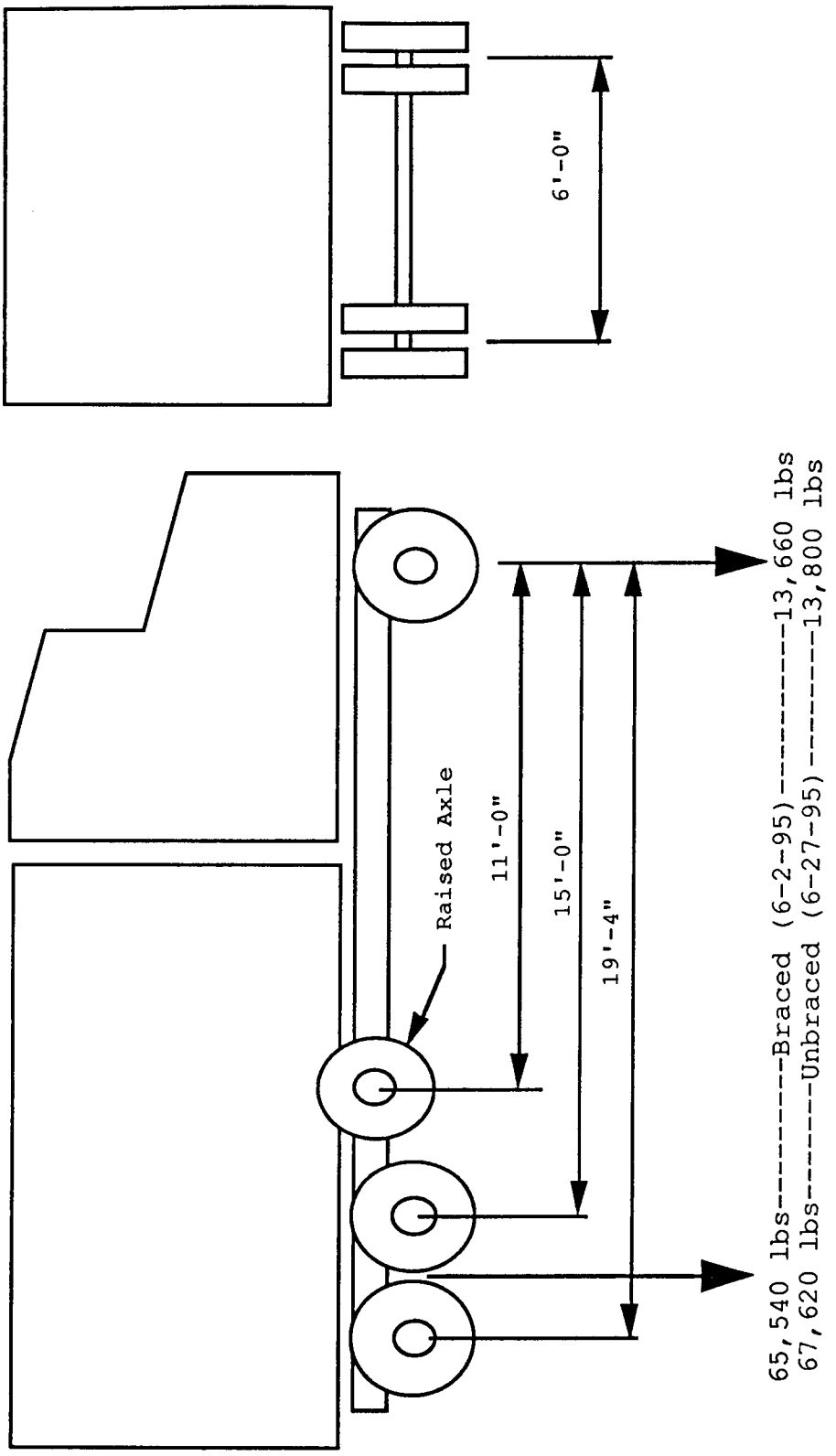


Figure 4-2 - Test Load Truck

Traffic Control

It was desirable that deflections of the bridge be measured which were attributable solely to the control load. Therefore, the controlled load tests required that the bridge be closed to traffic. The testing was done shortly after midnight to minimize inconvenience to the public. Traffic to the bridge was stopped at the nearest exits for both the west and east bound traffic. After the crawl test was completed, the bridge was opened to relieve the backed up traffic. When the congestion was relieved, the bridge was again closed to traffic while the speed test was being conducted.

Crawl Test

The crawl test consisted of the truck moving at very slow speed to resemble a static load. The crawl test was performed for both lateral bracing conditions.

The crawl test consisted of the test load truck traveling at a velocity of 5 mph to simulate a static load. The truck was positioned in the fourth span on the west bound direction approximately 600 feet from the west end of the bridge. The truck moved forward at a speed of no more than 5 mph. After proceeding to the end of the bridge in one lane, the truck would back up in the same lane at no more than 5 mph and stop when it reached the 600 foot mark. This procedure was

followed for the left, middle, and right lanes. The shoulder of the west bound direction was traveled only in the forward direction (Figure 4-3).

Speed Test

Deflections of the girders resulting from the control load vehicle crossing the bridge at various velocities were measured. The test load truck would cross the bridge in the west bound direction at a speed of approximately 55 mph in one of the three traffic lanes and then repeat the procedure for the two remaining lanes (Figure 4-3).

Normal Traffic Test

The normal traffic data were recorded prior to June 26, 1995 for the braced condition and on June 27 for the unbraced condition. These tests consisted of recording data under the two bracing conditions with the bridge opened to traffic and no test load truck. A total of 1.553 hours of data were recorded for the braced condition on two dates: May 30, beginning in the late evening and on May 31 beginning in the late afternoon. A total of 1.032 hours of data were recorded for the unbraced condition on June 27 beginning in the late evening.

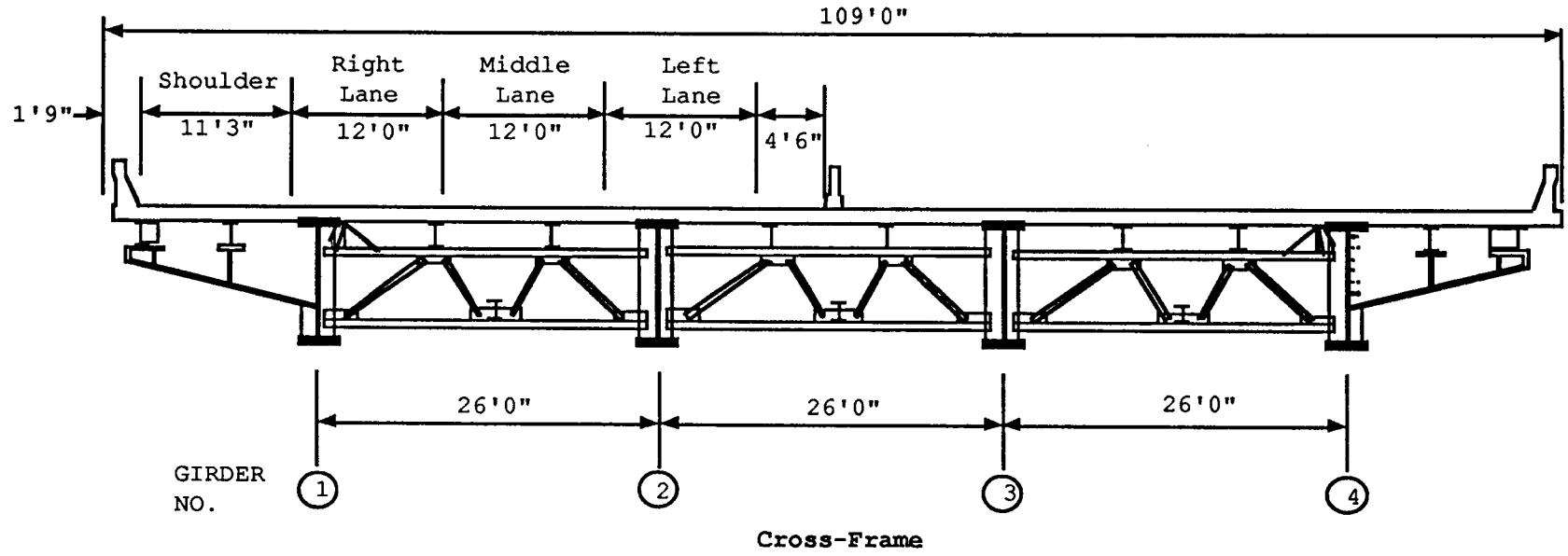


Figure 4-3 - HRB Traffic Lanes

Chapter 5

Test Results

The data from the controlled load and normal traffic tests are given in the folowing eight tables. The normal traffic data was reduced using a rainflow counting method (Downing 1992). From these tests it was possible to calculate, the load distributions, angles of twist, frequencies, and impact factors on girders.

Controlled Load Test Results

Table 5-1 presents the results from the crawl tests for both bracing conditions. The largest increase in deflection for Girder #1 was 0.04 inches or an increase of 8.8% after removing the bracing. Girder #2's largest increase in deflection was 2.4%. The load of the truck increased 2.8% for the unbraced condition. Since the girders' deflections are affected linearly by the load, the deflections of Girders #1 and #2 should be reduced by 2.8% for the unbraced condition. This reduction results in a change of 5.8% and -0.5% for Girders #1 and #2 for the unbraced condition. Therefore, the deflections of Girders #1 and 2 did not significantly change after the lateral bracing was removed.

Table 5-1 - Measured Deflections from Controlled Load Tests

Crawl Tests					
Truck Location	Bracing Condition	Girder No. (in.)			
		1	2	3	4
Left Lane	Braced	-0.20	-0.28	-0.16	-0.09
	Unbraced	-0.19	-0.27	-0.19	-0.10
Middle Lane	Braced	-0.29	-0.27	-0.12	-0.02
	Unbraced	-0.29	-0.27	-0.15	-0.03
Right Lane	Braced	-0.37	-0.26	-0.08	0.04
	Unbraced	-0.38	-0.26	-0.10	0.04
Shoulder	Braced	-0.43	-0.25	-0.05	0.10
	Unbraced	-0.47	-0.26	-0.06	0.11

Speed Tests					
Truck Location	Bracing Condition	Girder No. (in.)			
		1	2	3	4
Left Lane	Braced	-0.19	-0.29	-0.16	-0.08
	Unbraced	-0.24	-0.34	-0.19	-0.10
Middle Lane	Braced	-0.29	-0.27	-0.12	-0.02
	Unbraced	-0.34	-0.31	-0.18	-0.03
Right Lane	Braced	-0.35	-0.24	-0.08	0.04
	Unbraced	-0.45	-0.29	-0.12	0.05

Table 5-1 also presents the results of the speed tests for both bracing conditions. The results of these tests indicate that the deflections of Girders #1 and #2 are increased significantly after removing the bracing because of the impact on the girders. For example, the deflection of Girder #1 increased 0.10 inches or had an increase of 29% when the truck was in the right lane.

The load distribution to the girders remained the same for both bracing conditions and for both controlled load tests (Table 5-2). The lateral load distribution was calculated, assuming that each girder had the same flexural stiffness, as the ratio of a girder's deflection to the sum of the four girders' deflections for a particular load condition. The lateral load distribution only differed by at most 3% between the two bracing conditions. For example, Girder #2 had a difference of 3% when the truck was in the middle lane for the speed test. The 3% difference is a small enough value to conclude that the lateral bracing does not influence the lateral load distribution.

Table 5-3 presents the calculated angle of twist of the bottom flange of Girder #1. The angle of twist for a particular loading condition was calculated as the ratio of

Table 5-2 - Load Distribution from Controlled Load Tests

Crawl Tests					
Truck Location	Bracing Condition	Girder No. (%)			
		1	2	3	4
Left Lane	Braced	27	39	22	12
	Unbraced	26	36	25	13
Middle Lane	Braced	41	39	17	3
	Unbraced	39	37	20	4
Right Lane	Braced	56	39	12	-7
	Unbraced	55	37	14	-6
Shoulder	Braced	67	40	8	-15
	Unbraced	69	38	9	-16

Speed Tests					
Truck Location	Bracing Condition	Girder No. (%)			
		1	2	3	4
Left Lane	Braced	26	40	23	11
	Unbraced	28	39	22	11
Middle Lane	Braced	41	39	17	3
	Unbraced	39	36	20	4
Right Lane	Braced	55	39	12	-6
	Unbraced	55	36	14	-6

Table 5-3 - Calculated Angle of Twist for Bottom Flange of Girder #1

Truck Location	Bracing Condition	Deflection Gage No. (in.)		Angle of Twist (in./in.)
		D1	D1S	
Left Lane	Braced	-0.196	-0.211	0.0011
	Unbraced	-0.194	-0.225	0.0022
Middle Lane	Braced	-0.287	-0.304	0.0012
	Unbraced	-0.286	-0.337	0.0036
Right Lane	Braced	-0.372	-0.386	0.0010
	Unbraced	-0.384	-0.451	0.0048
Shoulder	Braced	-0.430	-0.438	0.0006
	Unbraced	-0.468	-0.583	0.0082

Gages are shown in Figure 3-5

the difference in deflection between D1 and D1S and the lateral distance between the two DGs which was 14 inches (one-half the flange width). Removing lateral bracing had an effect of increasing the angles of twist. The angles of twist were approximately 0.0010 in/in for the braced condition. However, the angles of twist for the unbraced condition increased as the load approached Girder #1 from the left lane to the shoulder (0.0022 in./in. to 0.0082 in./in.). Based on those two observations, the lateral bracing does influence significantly the angle of twist of a bottom flange.

Table 5-4 presents the results of calculating the frequency of the four girders using the data from the speed tests. The results show that the frequency of each girder is approximately the same, ranging from 1.08 to 1.15 Hz, indicating that the girders have approximately the same flexural stiffness.

Table 5-5 presents the impact on the girders after increasing the truck speed from 5 mph to 55 mph. The impact factors were approximately equal to 1.00 for the braced condition. However, for the unbraced condition the impact factors were significantly larger than 1.00. When the truck was in the left lane, Girder #1 had an impact factor of 1.23. Based on

Table 5-4 - Calculated Frequencies from Speed Tests

Truck Location	Bracing Condition	Girder No. (Hz)			
		1	2	3	4
Left Lane	Braced	1.14	1.10	1.09	1.10
	Unbraced	1.08	1.09	1.09	1.09
Middle Lane	Braced	1.12	1.10	1.08	1.09
	Unbraced	1.14	1.10	1.10	1.14
Right Lane	Braced	1.12	1.08	1.12	1.13
	Unbraced	1.12	1.10	1.09	1.15

Table 5-5 - Calculated Impact Factors for Girders

Bracing Condition	Truck Location	Girder No.			
		1	2	3	4
Braced	Left Lane	0.97*	1.04	1.02	0.97*
	Middle Lane	0.99*	1.00	1.02	1.07
	Right Lane	0.93*	0.95*	0.96*	0.90*
Unbraced	Left Lane	1.23	1.24	0.99*	0.97*
	Middle Lane	1.19	1.16	1.21	1.06
	Right Lane	1.17	1.12	1.18	1.18

*Values should be equal or greater than 1.00

those two observations it can be concluded that the bracing influences the impact factors for the girders.

Normal Traffic Test Results

Table 5-6 presents the deflections under normal traffic for the braced condition, while Table 5-7 presents the deflections for the unbraced condition. Under the braced condition, the number of cycles for D1 was 944, and the Root Mean Cubed (RMC) value was 0.26 inches for D1. However, for the unbraced condition, D1 had a greater number of cycles, and a larger RMC value. The fact that the RMC value was significantly larger for the unbraced condition indicates that lateral bracing has an influence on the girder deflections.

Table 5-6 - Deflection Results Under Normal Traffic for Braced Condition

Deflection Range	Gage Number				
(inches)	D1	D1S	C2	D3	D4
0 - .05	5358	4909	5131	3657	4429
.05 - .1	483	490	423	1148	652
.1 - .15	127	132	146	425	147
.15 - .2	59	63	86	178	67
.2 - .25	59	54	64	96	31
.25 - .3	50	53	57	66	32
.3 - .35	41	39	44	40	36
.35 - .4	47	40	48	12	27
.4 - .45	27	35	21	9	33
.45 - .5	29	30	18	1	42
.5 - .55	10	12	6	1	29
.55 - .6	1	6	4	2	19
.6 - .65	5	4	4		15
.65 - .7	3	2	1		11
.7 - .75	2	3	0		6
.75 - .8	1	1	1		2
.8 - .85		1			1
.85 - .9					1
.9 - .95					1
.95 - 1					0
1 - 1.05					0
1.05 - 1.1					1
1.1 - 1.15					
1.15 - 1.2					
1.2 - 1.25					
Time (hrs)	1.55	1.55	1.55	1.55	1.55
No. Cycles	944	965	923	1978	1153
RMC (inches)	0.26	0.27	0.25	0.16	0.31
EB 3S2	423	423	423	423	423
EB 2D	68	68	68	68	68
EB DT	22	22	22	22	22
EB Other	39	39	39	39	39
EB TRUCK TOTAL	552	552	552	552	552
WB 3S2	470	470	470	470	470
WB 2D	64	64	64	64	64
WB DT	29	29	29	29	29
WB OTHER	38	38	38	38	38
WB TRUCK TOTAL	601	601	601	601	601
TRUCK TOTAL	1153	1153	1153	1153	1153

Table 5-7 - Deflection Results Under Normal Traffic for Unbraced Condition

Deflection Range	Gage Number				
(inches)	D1	D1S	C2	D3	D4
0 - .05	2481	2514	2289	2615	2971
.05 - .1	198	288	165	176	294
.1 - .15	74	76	75	76	63
.15 - .2	26	41	37	45	37
.2 - .25	26	18	39	37	11
.25 - .3	17	20	32	30	12
.3 - .35	22	14	34	23	12
.35 - .4	19	20	24	24	13
.4 - .45	34	11	14	16	11
.45 - .5	12	28	9	8	20
.5 - .55	16	23	4	1	15
.55 - .6	9	9	2	1	10
.6 - .65	8	12	1	3	12
.65 - .7	2	9	2	1	5
.7 - .75	3	6	0	1	8
.75 - .8	2	6	1	1	3
.8 - .85	0	0			0
.85 - .9	1	2			1
.9 - .95		3			0
.95 - 1		1			0
1 - 1.05		0			1
1.05 - 1.1		0			0
1.1 - 1.15		1			1
1.15 - 1.2					0
1.2 - 1.25					1
Time (hrs)	1.03	1.03	1.03	1.03	1.03
No. Cycles	469	588	439	443	530
RMC (inches)	0.32	0.36	0.27	0.26	0.35
EB 3S2	339	339	339	339	339
EB 2D	25	25	25	25	25
EB DT	25	25	25	25	25
EB Other	15	15	15	15	15
EB TRUCK TOTAL	404	404	404	404	404
WB 3S2	335	335	335	335	335
WB 2D	28	28	28	28	28
WB DT	23	23	23	23	23
WB OTHER	16	16	16	16	16
WB TRUCK TOTAL	414	414	414	414	414
TRUCK TOTAL	818	818	818	818	818

Chapter 6

Conclusions

This study has shown that the removal of lateral bracing affects different aspects of a bridge's behavior under controlled load and normal traffic loads. The bracing affects vertical girder deflections, the twisting of the bottom flange, and the impact factors of girders; however, the bracing does not appear to affect the lateral load distribution.

The lateral load distribution was unchanged (largest difference 3%) by the removal of the lateral bracing as postulated in Chapter One. The velocity of the test load truck did not have an effect on how loads were distributed. Azizinamini's study on the effects of torsional bracing did not consider dynamic effects. This thesis which did consider dynamic effects on lateral bracing supports Azizinamini's conclusion that the slab/deck is sufficient to distribute loads to the main structural members of a bridge.

The bridge responses that were affected by the absence of lateral bracing were vertical girder deflections, impact

factors, and the twisting of the bottom flange. The girder deflections were significantly increased for the speed (dynamic) test but not for the crawl (static) test, but both tests' results influenced the impact factors for the girders. The girder impact factors were consistently larger than 1.00 for the unbraced condition and approximately equal to 1.00 for the braced condition. The bottom flange angle of twist on an unbraced girder increased significantly after removal of the lateral bracing. This increase is the result of the lateral bracing providing some torsional resistance for the bottom flange.

The results show that the absence of lateral bracing affects several aspects of a bridge's behavior. Vertical girder deflections, twisting of the bottom flange, impact factors on girders, and lateral load distribution were dependent on the type of test (static, dynamic or normal traffic) that was being conducted. The deflections of the bridge under static loading were not affected by the bracing. The dynamic test results show that the bracing does affect the dynamic impact loading on the bridge. Any future related studies of bridges should consider that during a bridge's lifetime it typically experiences dynamic loads during normal traffic conditions. Thus, dynamic testing should be considered more relevant to analyzing a bridge's true response to these loads than static testing.

BIBLIOGRAPHY

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Azizinamini, A., S. Kathol, and M. W. Beacham. (1994, September). "Steel Girder Design: Can it be Simplified." Modern Steel Construction. Vol. 34, No. 9, pp. 44-46.

Bakht, B., and F. Moses. "Lateral Distribution Factors for Highway Bridges." Journal of Structural Engineering. Vol. 114, No. 8, (1988, August), pp. 1785-1803.

Downing, S. D. and D. F. Socie. (1982, January). "Simple rainflow counting algorithms." International Journal of Fatigue. pp. 31-40.

Keating, P. B., and A. R. Crozier. Evaluation and Repair of Fatigue Damage to Midland County Bridges. Texas Department of Transportation Research Report No. 1313-1F. (1992, October).

Kostem, C. N., and E. S. deCastro. (1977). "Effects of Diaphragms on Lateral Load Distribution in Beam-Slab Bridges." Transportation Research Record No. 645. pp. 6-9.

MEGADAC Series 5000A Release 1.1. Technical Manual. 1990. Optim Corporation.

Moore, M., K. A. Strand, M. A. Grubb, and L. R. Cayes. "Wheel-Load Distribution Results from AISI-FHWA Model Bridge Study." Transportation Research Record No. 1275. (1990). pp. 34-44.

Phillips, B. A. "Bracing Requirements for Elastic Beams." Thesis submitted in partial fulfillment for the requirements for the degree of Master of Science. University of Texas, Austin, TX. 1991.

Sanders, M. D. "Controlled Load Tests on a Four Girder Steel Bridge." Thesis submitted in partial fulfillment for the requirements for the degree of Master of Science. University of Tennessee, Knoxville, TN 1994.

Stallings, J. M., T. E. Cousins, and T. E. Stafford. (1996, January). "Effects of Removing Diaphragms from a Steel Girder Bridge." Transportation Research Board 75th Annual Meeting, Paper No. 960985, Washington, D.C., 7-11.

Tarhini, K. M. and G. R. Frederick. (1992, May). "Wheel Load Distribution in I-Girder Highway Bridges." Journal of Structural Engineering. Vol. 118, No. 5, pp. 1285-1294.

Walker, W. H. "Lateral Load Distribution in Multi-girder Bridges." Engineering Journal. Vol. 24, No. 1 (1987), pp. 21-28.

Yura, J., B. Phillips, S. Raju, and S. Webb. (1992, October). Bracing of Steel Beams in Bridges. Texas Department of Transportation Research Report No. 1239-4F. pp. 1-7.

VITA

Christopher Thomas Schmidt was in born in Bartlesville, OK on May 20, 1971. Chris attended the Bartlesville School District where he received his High School Diploma in May of 1989. In August of the same year he enrolled at Northeastern A&M College in Miami, OK, where he pursued an Associates Degree in Pre-Engineering for two years. He then enrolled at The University of Oklahoma in August of 1991, where he received a Bachelor of Science Degree in Civil Engineering in May of 1994. He enrolled at the University of Tennessee, Knoxville in August of 1994 as a graduate teaching assistant in the Civil and Environmental Engineering Department. He then served as a research assistant on the Holston River Bridge project from January of 1995 to March of 1996. He received a Master of Science Degree in Civil Engineering in May of 1996.