AHTD TRC TRANSPORTATION RESEARCH COMMITTEE

TRC8901

Bridges Constructed from Railroad Cars

Thomas J. Parsons

Final Report

1991

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Technical Report Documentation Page

1. Report No. FHWA/AR-91/004	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: Bridges Constructed From Railroad Cars		5. Report Date: December, 1991
		6. Performing Organization Code
		8. Performing Organization Report No.
7. Author(s): Thomas J. Parsons		
9. Performing Organization Name and Address: Arkansas State University, Department of Engineering, P.O. Box 1740, State University, AR 72467-1740		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.: TRC-8901
12. Sponsoring Agency Name and Address: Arkansas State Highway and Transporattion Dept., P.O. Box 2261, Little Rock, AR 72205		13. Type of Report and Period Covered: Final Report, July, 1989 to April, 1991
		14. Sponsoring Agency Code

15. Supplementary Notes

This study was conducted in cooperation with the AHTD and U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The objectives of the study consisted of determining present to future usage of railroad car bridges, development of a railroad car data archive, and development of load ratings software for railroad cars.

A survey instrument was sent to all cities and county judges in Arkansas in 1988. Thirty-six of the 75 judges reported that railroad car bridges were being used in their counties, and that 167 railroad car bridges are in use, up from 74 reported in 1986.

Drawings and specifications were obtained for six box cars but none of the flat cars and a limited archive was developed. Software was developed which determined the load rating for a railroad car bridge. The program was checked by 1) building and testing a one-third scale model of a railroad car frame, and 2) testing four bridges in the field.

A one-third scale model of a typical box car frame was constructed, instrumented, and tested. The calculated strains by the analysis program were within ten percent of the measured strains for the model with single and tandem axle loads. It was found that the analysis did not accurately predict the behavior of the model when it was subjected to point loads which resulted in a torsion rotation.

A series of eight destructive tests were carried out on the scale model. The tests revealed that there was a good agreement between the strains measured in the model and the strains predicted by the finite element analysis when there was limited damage.

Four railroad car bridges were field tested and the results were compared to the load rating program. Reasonable accuracy was obtained by the program.

17. Key Words: Railroad car bridges, Field testing, Laboratory testing, Load rating program	18. Distribution Statement: No restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages: 278	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

BRIDGES CONSTRUCTED
FROM
RAILROAD CARS

BY

THOMAS J. PARSONS, Ph.D., P.E.

FINAL REPORT

SOFTWARE
BY
J. DAVID GILLANDERS, Ph.D., P.E.

HIGHWAY RESEARCH PROJECT - TRC 8901

CONDUCTED FOR THE

THE ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

December, 1991

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitute and appreciation to the following people for their efforts and assistance in the research project:

Dr. J. David Gillanders, who worked many hours in perfecting the data acquisition system and strain gauge boxes along with the load rating program software.

Mr. Greg Coldwell for the design and construction of the strain gauge boxes, development of related software and many hours in the field glueing strain gauges and trying to keep the computer systems in operation.

Dr. Larry Byrd for the hours spent checking the data acquisition system software and the calibration of the model.

Ms. Maxine Smith and Ms. Belinda Taylor for preparing the many drafts of the reports.

GAINS, FINDINGS, AND CONCLUSIONS

The wide range objectives of the study consisted of determining present to future usage of railroad car bridges, development of a railroad car data archive, and development of load ratings software for railroad cars. The following are a few highlights of the achievements.

A survey instrument was sent to all cities and county judges in Arkansas in 1988, and follow-up surveys with county judges were conducted. Thirty-six of the 75 judges reported that railroad car bridges were being used in their counties, and that 167 railroad car bridges are in use, up from 74 reported in 1986. The judges reported that 73 percent of the railroad cars used were flat cars and 24 percent were box cars with the sides removed. Field visits revealed different percentages.

Seventeen railroad car identification numbers were found during the field visits. Drawings and specifications were obtained for six box cars but none of the flat cars. This resulted in detailed information being obtained for four out of the 167+ railroad car bridges in Arkansas. A limited archive was developed presenting structural member spacings, member dimensions and member specifications.

Software was developed which determined the load rating for a railroad car bridge. The load rating was based on inventory and operating vehicles. The program was checked by 1) building and testing a one-third scale model of a railroad car frame, and 2) testing four bridges in the field.

A one-third scale model of a typical box car frame was constructed, instrumented, and tested. The objective of this task was to check the accuracy of the analysis program in predicting the behavior observed in the laboratory. The calculated strains by the analysis program were within ten percent of the measured strains for the model with single and tandem axle loads centered or positioned at the edge of the model (with respect to the width of the model). The worst loading case or maximum strains were determined to be when a single axle was positioned at mid-span and along the edge of the frame.

It was found that the analysis did not accurately predict the behavior of the model when it was subjected to point loads which resulted in a torsion rotation of the model. However, the results were not critical for it was determined that this loading case did not produce the maximum strains.

A series of eight destructive tests were carried out on the scale model of the box car frame. These tests were carried out to determine the accuracy of the finite element analysis in predicting the behavior of the model when it had been damaged. The tests revealed that there was a good agreement between the strains measured in the model and the strains predicted by the finite element analysis when there was limited damage.

Four railroad car bridges, each constructed from a different type of railroad car frame were field tested. The loading rating program did predict the behavior of the flat cars with reasonable accuracy. It should be used for each railroad car and the bridge loading based on the weakest car.

The analysis program was not as accurate when predicting the behavior of the bridges constructed from box cars. The sliding sill box car had a conservative estimate of the load capacity of the center sill. The bridge constructed from stationary center sill box cars was unique in that the side sills were bolted together. This had a major impact on the behavior of the bridge for point loads were uniformly distributed by the composite behavior of the box car frame.

EXECUTIVE SUMMARY

The purpose of the study was 1) to establish present and future use of flatbed railroad car bridges in Arkansas; 2) to establish a data base of railroad car frame technical literature, member sizes, section properties and materials strengths; and 3) if a sufficient data base could not be established, develop and verify a load rating software program for railroad car bridges.

A survey instrument was sent to all cities and county judges in Arkansas in 1988, and follow-up surveys with county judges were conducted. Thirty-six of the 75 judges reported that railroad car bridges were being used in their counties, and that 167 railroad car bridges are in use, up from 74 reported in 1986. The judges reported that 73 percent of the railroad cars used were flat cars and 24 percent were box cars with the sides removed.

Twenty-seven bridges were visited during field trips composed of 52 railroad cars; 41 were box cars, eight flat cars, and three gondola cars. Car identification numbers were found on nine box cars and eight flat cars.

Seventeen railroad car identification numbers were found during the field visits. Drawings and specifications were obtained for six box cars but none of the flat cars. This resulted in detailed information being obtained for four out of the 167+ railroad car bridges in Arkansas. A limited archive was developed presenting structural member spacings, member dimensions and member specifications.

A survey of the railroads and the American Association of Railroads revealed that prior to 1964 each railroad had its own design standards. In September, 1964 the American Association of Railroads developed the Specifications for Design, Fabrication and Construction of Freight Cars. The only noted change in the specifications between 1964 and 1987 was the design

loads. The draft load changed from 300,000 to 350,000 lbs and the compressive end load changed from 800,000 to 1,000,000 lbs. This would reflect the longer trains in use.

Software was developed which determined the load rating for a railroad car bridge. The load rating was based on inventory and operating vehicles. The program was checked by 1) building and testing a one-third scale model of a railroad car frame, and 2) testing four bridges in the field. The results obtained from the model and field testing were compared to the predicted results obtained from the load rating program. Corrections were made as necessary.

The load rating program is based upon performing a finite element analysis on each railroad car used in the construction of the bridge. The software was designed so that the data from a bridge inspection would be used to produce the required finite element data files. The data consists of beam spacing, type of structural members, dimensions of the beams and the location and a description of damage to structure.

A one-third scale model of a typical box car frame was constructed, instrumented, and tested. The objective of this task was to check the accuracy of the analysis program in predicting the behavior observed in the laboratory. The observed behavior consisted of measuring the strains at several locations in the model. This was achieved by developing instrumentation which sent noise-free singles from the strain gauge to a data acquisition system. The model testing consisted of loading the model with point loads, single axle loads, and tandem axle loads at several locations. Also, the effect of two railroad cars being bolted together was studied.

The calculated strains by the analysis program were within ten percent of the measured strains obtained from the model for single and tandem axle loads centered or positioned at mid-span and along the edge of the frame.

The effect of two railroad cars being bolted together was obtained by adding an additional side sill to the model. It was found that the analysis program did not accurately predict the behavior of the model when it was subjected to point loads which resulted in a torsion rotation of the model. However, the results were not critical for it was determined that this loading case did not produce the maximum strains.

A series of eight destructive tests were carried out on the scale model of the box car frame. These tests were carried out to determine the accuracy of the finite element analysis in predicting the behavior of the model when it had been damaged. The tests revealed that there was a good agreement between the strains measured in the model and the strains predicted by the finite element analysis when there was limited damage.

Four railroad car bridges, each constructed from a different type of railroad car frame were field tested. The frames consisted of flat cars with tapered and trussed floor beams and box cars with stationary or sliding center sills. The bridges were constructed by placing two flat cars side-by-side with a center spacer or bolting the side sills of box cars together or just laying box cars next to each other.

The loading rating program did predict the behavior of the flat cars with reasonable accuracy. The spacer between the cars permitted the cars to act independently of each other. Thus, the load rating program should be used for each railroad car and the bridge loading based on the weakest car.

The analysis program was not as accurate when predicting the behavior of the bridges constructed from box cars. The program over estimated the strains in the bridge constructed with sliding center sill frames. It was assumed that the sliding sill would not carry load in the analysis program and the field data revealed that it did carry a significant percentage of the load. This resulted in a conservative estimate of the load capacity of the center sill.

The bridge constructed from stationary center sill box cars was unique in that the side sills were bolted together. This had a major impact on the behavior of the bridge. When trucks were positioned so that they directly loaded the inside side sill, the field results showed the outside side sill across from the truck had an equal or greater strains. Therefore, the load was uniformly distributed by the composite behavior of the box car frame. However, the maximum strains in the bridge were produced when the truck was centered on the car at mid-span.

One of the loading tests performed in the field was measuring the strains in the bridge as a truck drove under normal operating conditions across it. In all cases, the maximum static strains were greater than the observed strains. One reason for this was that the truck was carried by the two railroad cars for the dynamic test and for the static tests it was positioned on one car.

IMPLEMENTATION STATEMENT

A major objective of this research project was to develop a mechanism which would result in load rating for railroad car bridges. This objective was achieved by the development of software which aided in the analysis and ratings of these bridges. It is recommended that the software be used for this purpose. The accuracy of the ratings have been checked by laboratory and field tests.

Field visits revealed that the majority of railroad car bridges consist of two railroad cars placed side by side. The normal driving lane consist of straddling both cars as one drives across the bridge. However, there exists a possibility that a vehicle may occupy one car only. Therefore, the software should be implemented for each car used to construct the bridge. The load rating should be based on the lowest rating obtained from either car. Also, if a spacer is used between the cars, the load capacity of the spacer should be checked and compared to the load rating obtained from the software programs and the smaller value used.

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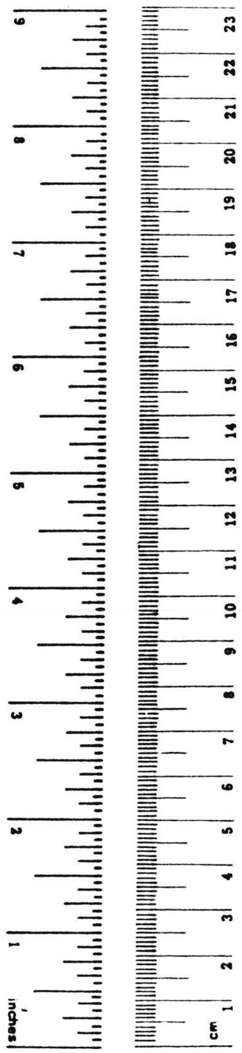
Approximate Conversions to Metric Measures

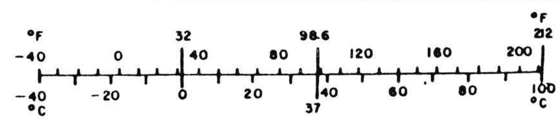
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



METRIC CONVERSION FACTORS

CHAPTER 1
INTRODUCTION

1.1 The Problem

In recent years many county and city governments have begun using salvageable railroad cars as highway bridges on low volume roads. This type of bridge provides an economical means of replacing seriously deficient bridges. However, the federally mandated National Bridge Inspection Program requires that load ratings be made for all bridges in the public highway system including roads with low traffic volumes. At present only limited technical data is available to the engineers for use in establishing load capacity ratings for these bridges.

1.2 Project Objectives

The study was divided into two phases. The first phase consisted of 1) establishing present and future usage of flat bed car bridges in Arkansas and, 2) establishing a data base of technical literature, member sizes, section properties and material strengths. The second phase consisted of the development of a load rating software program for railroad car bridges.

Phase 1 Specific Objectives

1. Survey all counties and cities in Arkansas to determine their use (such as number in use and plans for future use) of railroad car bridges.
2. Survey various railroads and railroad car manufacturers to obtain all available technical literature regarding railroad cars.
3. Determine railroad car design load and specifications, from 1935 to present, as specified by the American Association of Railroads.

4. Obtain information for the development of an archive of railroad car bridges existing in the state. This archive will include member sizes, sectional properties and material strengths for primary structural elements. Also included should be prints of original design drawings and design specifications.
5. Survey the railroads to determine the present analytical models in use for railroad cars. Also, determine the analysis schemes used for the original designs.
6. Organize the information obtained in Objectives 2-5 into a useful archive with a format easily understood and usable by AHTD.

Phase 2 Objectives

1. Develop a software program which would be capable of determining load ratings for railroad car bridges.

2. Construct and test a one-third scale model box car frame. The results should be used to calibrate the software program and to study the effect of selected damage to structural members.

3. Perform field tests on four railroad car bridges. The results should be used for final calibration of the software programs.

1.3 Methodology

In order to develop the comprehensive archive data base as outlined in Phase I, the following tasks were accomplished.

Task 1 - Surveyed Arkansas' city engineers and county judges to determine present and future use of railroad car bridges. Requested information included the source of the cars, serial numbers and problems encountered with their use.

Task 2 - Obtained a list of flat bed and box car manufacturers and attempted to obtain technical literature on the cars.

Task 3 - Reviewed American Association of Railroads specifications from 1935 to present to determine recommended design loads and specifications for flat bed and box cars.

Task 4 - Obtained information for the development of an archive of technical information on cars used to construct railroad car bridges. Through car registration numbers, the railroads were able to supply design specifications, material strengths and member sizes used in car construction along with prints of original design drawings. Since the cars are generally custom designed and purchased in a series, serial numbers of all cars in a series were requested.

Task 5 - A survey of railroad companies identified in Task 4 yielded analytical models of the cars to be used to analyze the car's structural soundness. In addition, we obtained historical data to determine analytical schemes used in car design for the past 50 years.

Task 6 - Information obtained in Tasks 1-5 was organized into a data archive consisting of all available information.

Task 7 - Prepared Phase I written report.

In order to develop and calibrate the load rating program in Phase II, the following tasks were accomplished.

1. A data entry software program was written which developed the finite element data files needed for the railroad car frames with minimum input. Programs for box car and flat car frames, member and support modifications, and a load rating scheme were written.

2. Strain gauge electronics and related software were developed which measured strains and recorded the data. The strain gauge electronics consisted of thirty boxes of electronic components which completed the strain gauge bridge, and sent a noise free signal to a data acquisition system. The software monitored up to thirty strain-gauge signals and a load cell output.

3. A one-third scale model of a typical box car frame was constructed and instrumented in the laboratory. Strain gauges were placed at one-quarter, center-line, and one-third point along the length of th model. The model was tested using point, single axle, and tandem axle loadings. The results of the model loadings were compared to the results of the load-rating program and corrections to the load rating program were made which improved the accuracy of the software.

4. The scale model was also subjected to various deterioration effects such as removing beam flanges and cutting beams. The software program was used to simulate the recorded strains and recommendations were developed for modeling the deterioration.

5. Four railroad car bridges were instrumented and tested in the Ozark Mountains. The bridges were constructed from a flat car with tapered floor beams, a flat car with trussed floor beams, a box car with a stationary center sill, and a box car with a sliding center sill. The load rating program was used to simulate the recorded strains and necessary modifications were made.

1.4 Literature Review

1.4.1 Background

Economic growth and transportation are closely related. State and interstate highways connect and are used to transport goods from one population center to another. County roads must support transportation of people and goods from the country to state highways and on to population centers. County roads and bridges must be maintained and in many cases there are limited funds and time for these operations. If a bridge is lost due to age, flooding or overweight vehicles, it needs to be replaced with a minimum amount of time and cost. The replacement bridges are generally short span bridges and can be constructed in various forms.

1.4.2 Short Span Bridges

In general, short span bridges are constructed by placing stringers between abutments and covering them with a deck. Most short span bridges are single span, but in a few cases they have a double or triple span. They are constructed from timber, steel, concrete, stone or other materials. The bridges are either built in place, that is, the stringers placed and a deck placed on top of the stringers, or prefabricated. For example, pre-cast concrete sections are set and tied in place. This results in reduced construction time.

1.4.3 Noncomposite Bridges

A bridge is considered noncomposite when the stringers do not act as an integral part of the deck. In this type of construction the stringers are designed to carry the dead load, the bridge deck and stringers self weight, and the live load or truck loadings. An example of this type of construction is a timber bridge. The stringers are heavy timbers and the deck timbers transmit the load to the stringers. The stringers are sized to carry the live load, decking and self weight. Other examples would be steel stringers, wide-flange beams covered with a timber, steel grid or concrete deck.

1.4.4 Composite Bridges

In a composite bridge the stringers act as an integral part with the deck. By design, the dead load is carried by the stringer and the composite section carries the live load and the weight of the curbs and railings. The most common example of this type of construction is a bridge constructed from steel stringers covered with a concrete slab. The composite action is ensured by fastening stud shear connectors to the stringers (Fig. 1.1). The advantage of composite bridges is that smaller stringers are required, thus producing a cost savings.

1.4.5 Modular Bridges

Modular bridges are constructed from pre-fabricated panels which could be composed of a variety of materials. The panels are lifted into place by a small crane. The Bethlehem Steel Corporation has designed and markets a modular steel bridge system (1). The most common forms are precast and prestressed concrete sections. The sections come in shapes of box-beams, T sections, double T sections and U sections (Figures 1.2-1.5). The sections come in varying widths, lengths and depths and have proven to be effective, however, some maintenance problems have appeared in the joints between sections.

1.4.6 Railroad Car Bridges

A fast growing modular bridge system is the railroad car bridge constructed from salvaged railroad cars. The frame acts as the bridge stringers and the steel or timber deck as the road surface. Bridges have been constructed from box, gondola and flat cars which are approximately nine feet wide and come in lengths up to 86+ ft.

Two common bridge decks used on railroad car bridges are 1) asphalt placed on timber decks and, 2) reinforced concrete placed on steel decks (Figs. 1.6 and 1.7)(3,4). Special care should be used when connecting the bridge to existing foundations. The connection needs to 1) resist longitudinal and lateral forces and, 2) prevent tipping about the main longitudinal beams. One suggested connection detail is given in Fig. 1.8.

Selection of the car requires an evaluation of material strength, fatigue strength, brittle fracture, effect of broken or damaged members, previous overloading and cyclic loadings (3,4). It is suggested that a condition survey be conducted to determine: 1) length and width of the car, 2) spacing and dimensions of all members and, 3) location and

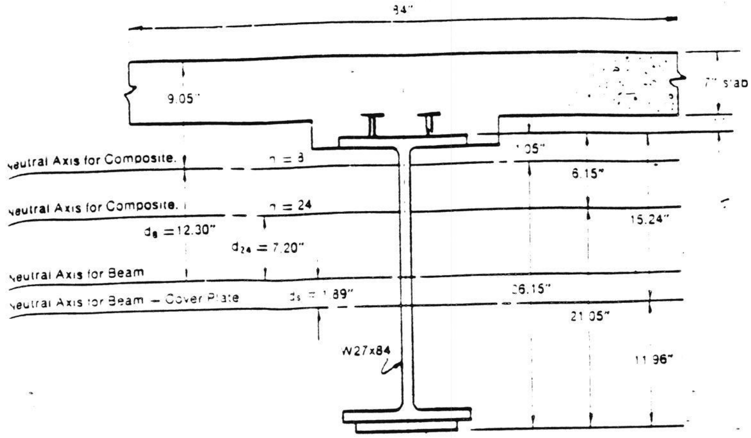


Fig 1.1 Composite Bridge (2)

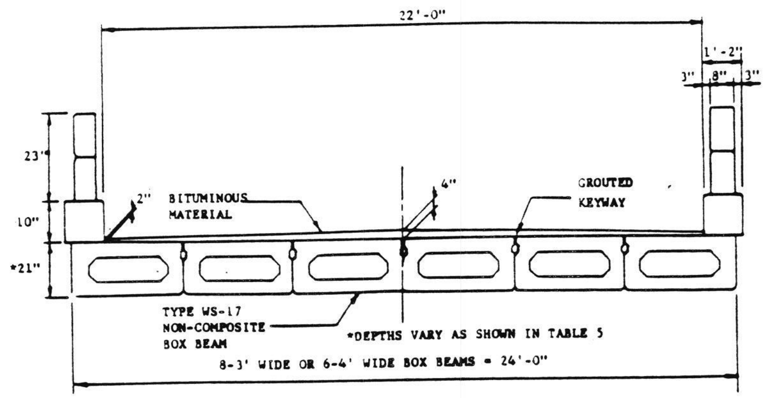
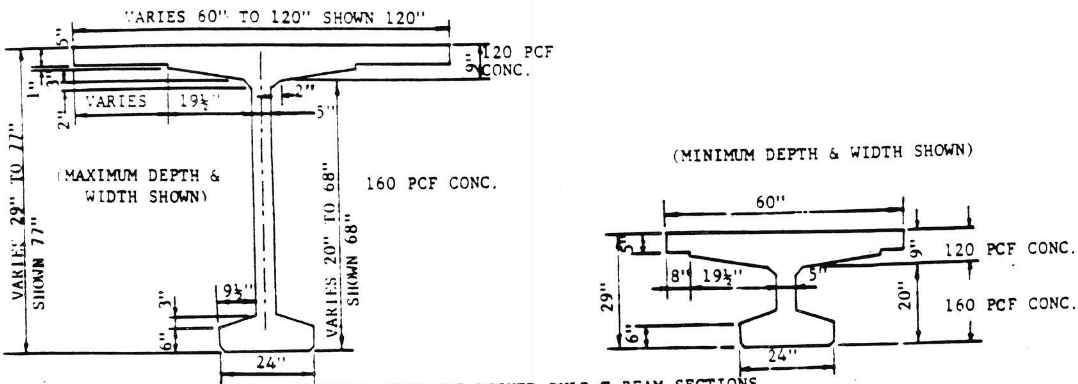


Fig. 1.2 Box Beam Section Bridge (2)



(b) LIGHTWEIGHT CONCRETE DECKED BULB-T BEAM SECTIONS

Fig. 1.3 T Sections (2)

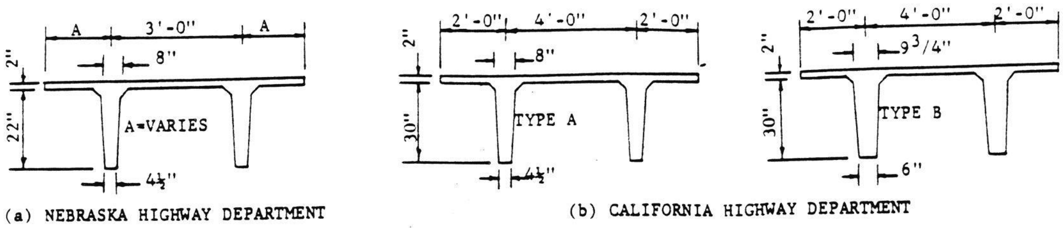


Fig. 1.4 Double T Sections (2)

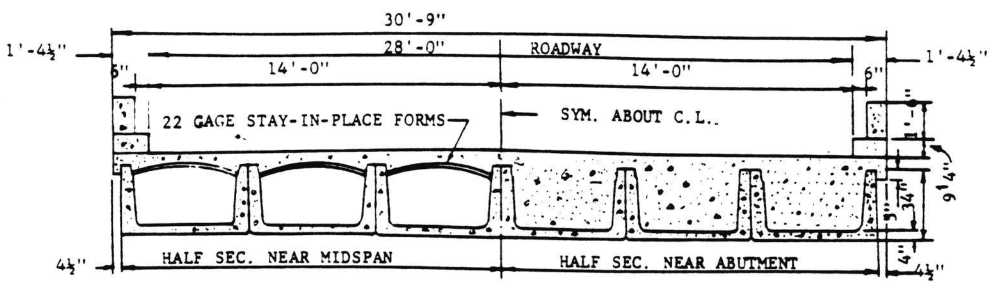


Fig. 1.5 U Section Bridge (2)

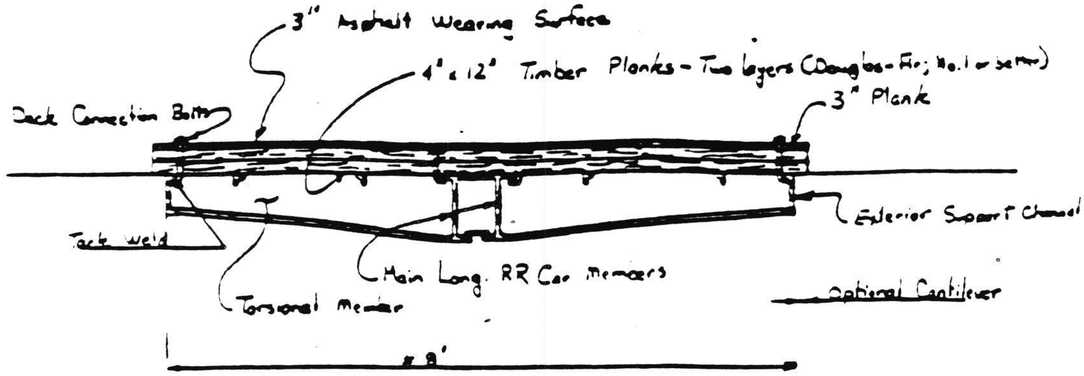


Fig. 1.6 Timber Deck Flat Car Bridge (4)

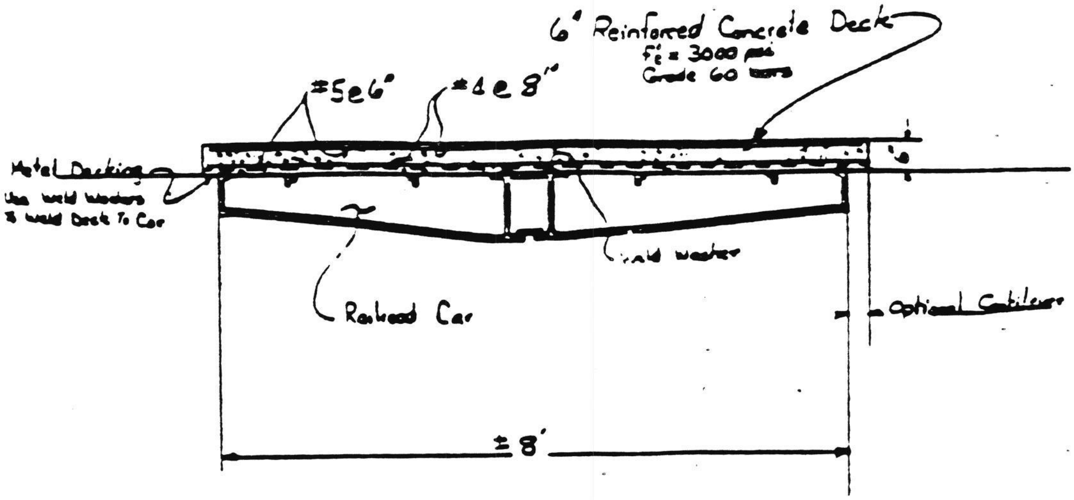


Fig. 1.7 Concrete Deck Flat Car Bridge (4)

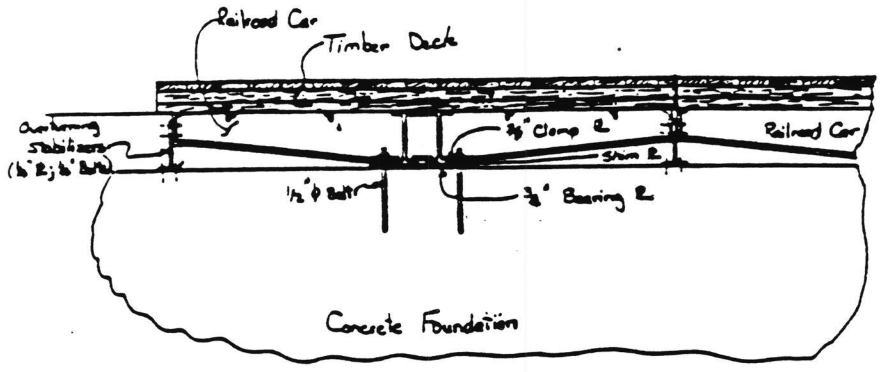


Fig. 1.8 Abutment Connection Details (4)

condition of bent, twisted or cracked members. This information would yield section properties and it can serve as a reference for future bridge inspections.

Strength of the members could be determined by the Hardness Test and stress-strain curves developed from samples. The most common material characteristic found in the cars was that similar to A36 steel. If riveted connections are found, the steel may be A7, which is not weldable and has a strength of 23,000 psi. When purchasing a car, the following tests are suggested:

1. Test the main members for cracks by using a dye penetrant.
2. Support the car on timbers and drive over it with a D8 tractor.
3. Support the car on timbers, load it and measure deflections, then compare calculated deflection vs. actual stiffness.

1.4.7 Railroad Cars

There are approximately 12 companies which manufacture railroad cars. These companies do not independently design and manufacture a car for the purpose of selling them to the railroad. Instead, the railroad specifies type (flat bed, box, tank, etc.), length, width and load capacity for a series of cars, then bids are taken on the series. As a result, each series of railroad cars has a separate set of design specifications and drawings.

Criteria for scrapping a car is based on economic reasons. Once the repair costs exceed the depreciated value of the car, it is scrapped. Repair costs include repair of running gear, car seals, replacement of decking, corrosion damage, fatigue cracking and damage due to derailment. The running gear seems to be the deciding factor in most cases. Age is also a replacement factor. If the car is 40 to 50 years old, it can be used only for in-line service. If it is 50 years or older, a special permit is required. Scrap value of a car 30 to 50 years old is about $300-$500 and cars less than 20 years old have a value of approximately $3000.

CHAPTER 2

STATE SURVEY

2.1 Introduction

A survey document was developed and sent to the county judges and city governments in Arkansas. A follow-up survey form was sent to the county judges who did not respond to the first mailing. Telephone interviews were conducted with the county judges who did not respond to the second mailing. No follow-up action was taken with the city governments because no respondent used a railroad car bridge and only a few were interested in their use. A copy of the survey form is found in Appendix A.

2.2 Survey Objectives

The objectives of the survey was to determine the following:

1. Number of officials interested in using railroad car bridges.
2. Number of officials who have used railroad cars for bridges.
3. Number of railroad car bridges in place.
4. Number of single, double or triple span bridges, span lengths, width of the bridges and abutment conditions.
5. Types of railroad cars used (box, flat bed, etc.)
6. Interest in a short course on the selection and installation of railroad car bridges.

2.3 County Judge Survey Results

Results of the county judge survey is given in Appendix A. Thirty-six of the 75 judges reported that railroad car bridges are being used in their counties. The judges reported that there were 167 railroad car bridges in the state in the fall of 1988.

2.3.1 Response to Questions

1. Have you considered using railroad cars as short span bridges or are you using these bridges?

   Seventy five percent of the judges reported that they had considered using railroad car bridges. Of this 75 percent, 36 (64%) have used railroad car bridges.

2. How were you informed about the use of railroad cars as short span bridges?

   Fifty six judges reported that they considered using railroad cars as short span bridges. Fourteen percent learned about the bridges from a friend, 29 percent from a supplier, 20 percent saw one in place, 4 percent from an article, 9 percent by other means, and 24 percent did not respond to the question.

3. Number of Spans.

   Of the 167 bridges reported in the state during the fall 1988, 77 percent (128) were single span, 19 percent (31) were double span, and 1 percent (2) had three or more spans.

4. Width of the Bridges.

Bridge width was reported for 163 of the 167 bridges. Seventeen percent (28) were one car wide, 71 percent (115) were two cars and 12 percent (20) were two cars plus a spacer.

5. Span Lengths of the Bridges

Bridge span length was reported for 165 of the 167 bridges. The results are shown in Table 2.1.

Table 2.1 Bridge Span Lengths

Span Length (ft)	Number of Bridges	Percent
0 - 20	3	1.8
21 - 25	8	4.8
26 - 30	17	10.3
31 - 35	4	2.4
36 - 40	10	6.1
41 - 45	3	1.8
46 - 50	42	25.6
51 - 55	21	12.7
56+	57	34.5

6. Type of Railroad Car Used

Types of railroad cars used in construction were reported for 150 of the 167 bridges in use. Seventy three percent (110) were flat cars and 24 percent (40) were box cars with the sides removed.

7. Expansion Joints

Twenty seven of the judges responded to the use of expansion joints. Three reported considering their use while none gave information on the type of joints used.

8. Abutments

Method of attaching the railroad car to the abutment was reported for 125 of the 167 bridges. The car was placed on top of the abutment in 68 bridges (54%), main beams were notched in order to help maintain the road grade for 28 bridges (29%), cast into the abutment for 15 bridges (12%), and 6 bridges (5%) used other methods.

9. Desire a Short Course

The judges were polled to determine if they were interested in a short course on the selection and installation of railroad car bridges. Sixty-nine of the 75 judges responded, and 56 percent (42) were interested in the course.

2.4 City Government Survey

The survey form was sent to all city governments in Arkansas, a total of 485, and thirty four percent (166) responded. None reported the use of railroad car bridges, however, some were interested in their use.

2.4.1 City Response

Thirty of the 166 cities (18%) responded that they had considered using railroad car bridges. Twenty-one of the 30 were interested in a short course. Thirty stated they had not considered using the railroad cars but that they would be interested in the course. Overall, 51 (31 percent) of the city governments are interested in the short course.

2.4.2 Distribution of Responses

Thirty four percent (166) of the cities responded. The respondents are located in 68 of the 75 counties in Arkansas, and the number of respondents per county is shown in Fig. 2.1.

2.5 Summary of Comments

Selected samples of the comments concerning bridges constructed from railroad cars are:

1. I'm very pleased with them.
2. Stronger than wooden bridges
   Less expensive than concrete bridges
   Less overall maintenance
3. I find railroad flat cars fast and cheap for less traveled roads.
4. You can build a 90 ft. bridge in two weeks. It's fast and much cheaper.
5. I believe there is a place for them on county roads. The economy of this is the determining factor.
6. We would be interested in methods of construction and removal of of existing bridges.
7. We try to meet state highway standards. Since counties must post deficient bridges, they must be constructed to pass inspection. Coordination with AHTD would be necessary to ensure railroad car bridges are acceptable.
8. This is a new concept to me. I would need to be educated as to procedure.

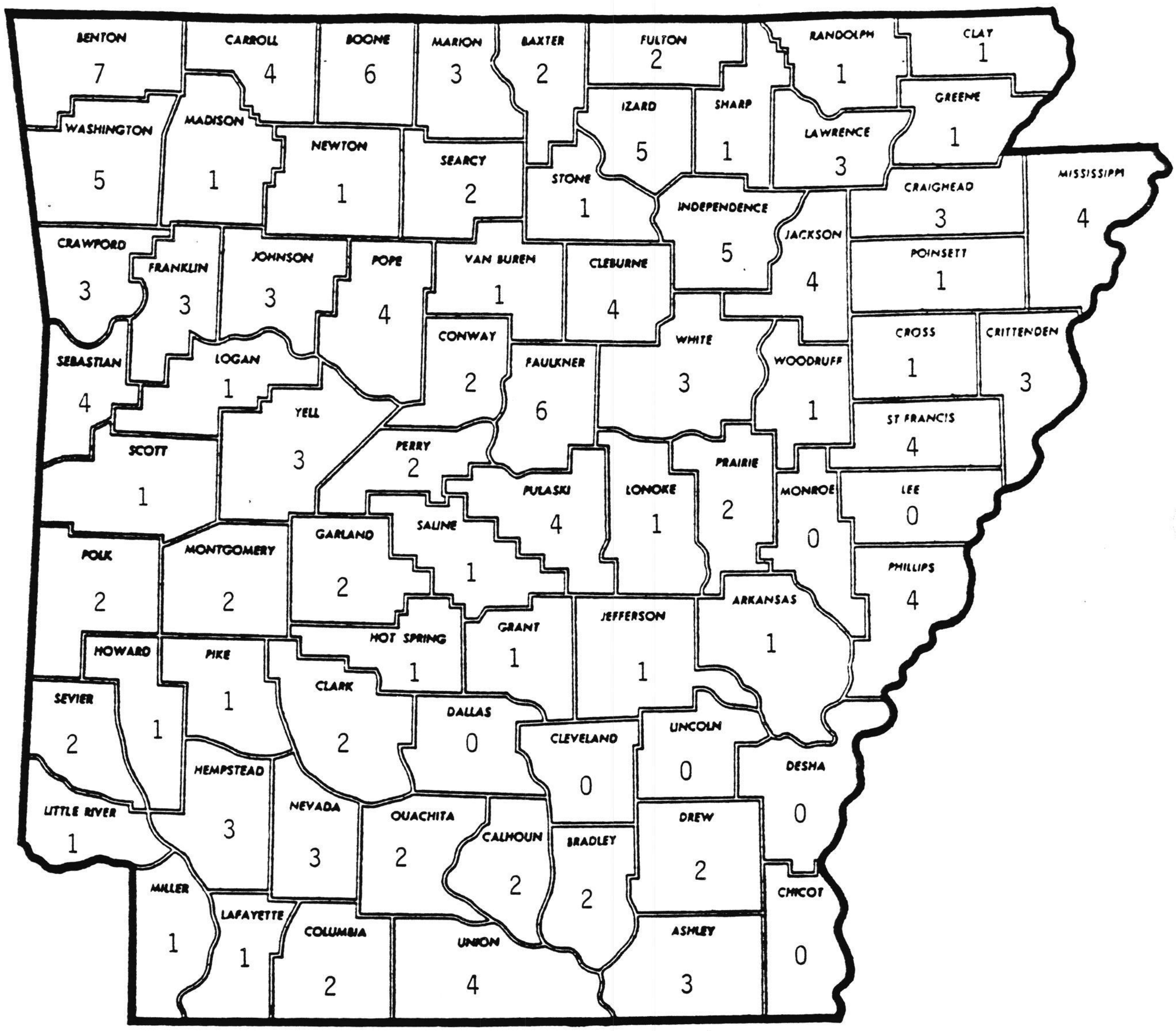


Fig. 2.1 Respondents per County

2.6 Suppliers

The judges reported that 11 suppliers were providing cars. Arkansas Reclamation Co. was referred to 17 times. Other sources mentioned were:

a. Camden, AR
b. R&S Steel
c. North Little Rock
d. Rock Island R.R.
e. Lafevers
f. Texarkana
g. Gray Supply Co. - North Little Rock
h. Jack Sipes (salvage)
i. North Side Steel - Jonesboro
j. Weyerhauser

CHAPTER 3

FIELD VISITS

3.1 Introduction

Railroad car bridges in Fulton, Izard, Independence, Lee, Cleveland and Hot Springs counties were visited. Survey results indicate that 43 percent of the railroad car bridges are located in these counties. Fulton, Izard and Independence counties are in the North Central region of the state, or the Ozark Mountains. Lee County is in the Delta or flat region along the Mississippi River. Hot Springs and Cleveland Counties are in the Southern Central region where terrain is a mixture of low hills and flatlands. Field visits revealed that each county has its own method of bridge construction which varied widely from county to county. Field visits were limited to the bridge locations inspected by AHTD in 1986.

3.2 Ozark Region

A total of seven bridges were visited in the Ozark Region. This represented 41 percent of total bridges reported in this region.

3.2.1 Fulton County

The railroad car bridge in Fulton County was a single box car cast in concrete abutments (Fig. 3.1 and 3.2). The car's steel floor was used as the bridge deck. The major structural damage noted was that one of the exterior sills or stringers was buckled.

3.2.2 Izard County

Five bridges were inspected in Izard County. Four of them were single span and one had two spans. Four bridges were two cars wide, and

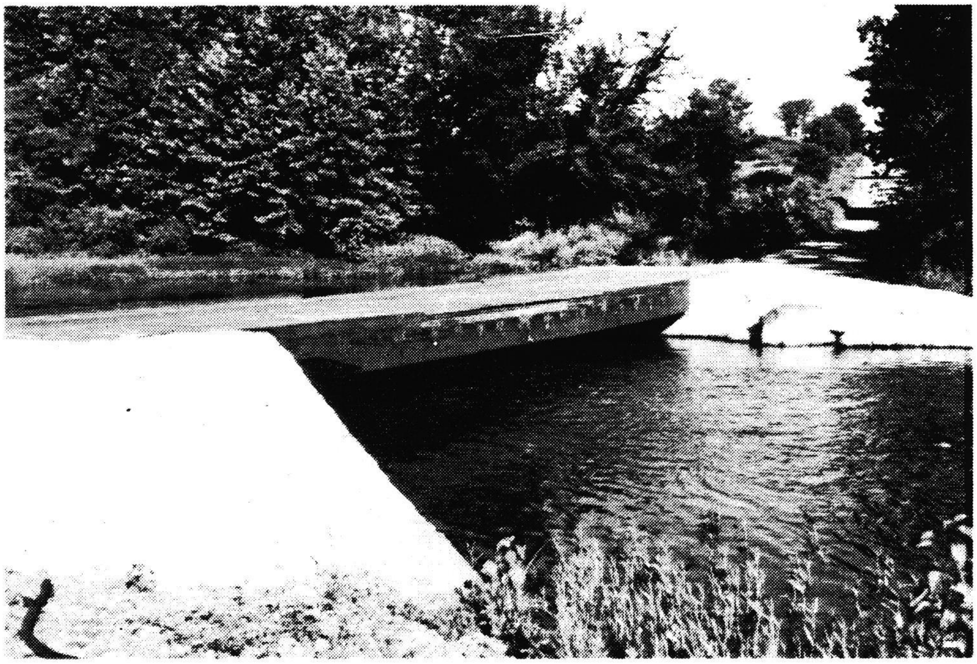


Fig. 3.1 Railroad Box Car Bridge

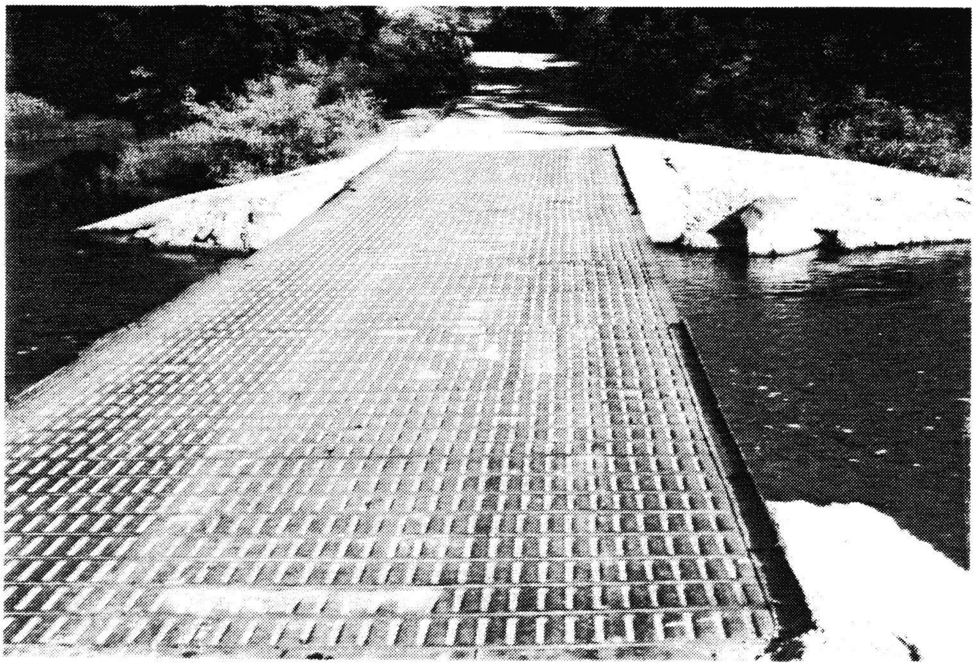


Fig. 3.2 Steel Bridge Deck

the other was one car wide; all were placed on top of concrete abutments. One abutment was damaged, therefore, it had been reinforced by placing steel beams at the abutment to support the cars (Fig. 3.3).

The railroad cars had steel floors which were used as the bridge decks. An examination of the decks revealed little or no problems with supporting the vehicle loads nor breaks in the welds between the deck and the car frame. In all cases the bridges were constructed from box cars.

One bridge was a replacement for a low water crossing (Fig. 3.4)., which resulted in a two span bridge. The central and exterior sills were notched at the abutment (Fig. 3.5). A close observation revealed that the sills shear strength was greatly reduced, but the stringers between the sills were resting on the abutment.

Most of the structural damage noted was limited to the exterior sills. In many cases they were buckled (Fig. 3.6).

3.2.3 Independence County

One bridge was visited in Independence County. It was two cars wide and constructed from box cars, with a spacer between the cars (Fig. 3.7). Again, the exterior sills were buckled. Abutments were designed to support the bolster where the trucks were attached to cars (Fig. 3.8). This design resulted in the maximum shear transfer at the abutment and prevented the car from sliding off the abutment. The bridge deck consisted of a concrete slab being placed over the car's steel floor.

3.3 Lee County

The County Judge reported that 27 railroad car bridges were in place in Lee county. Field visits were made to 12 (44%) of the bridges. Eight

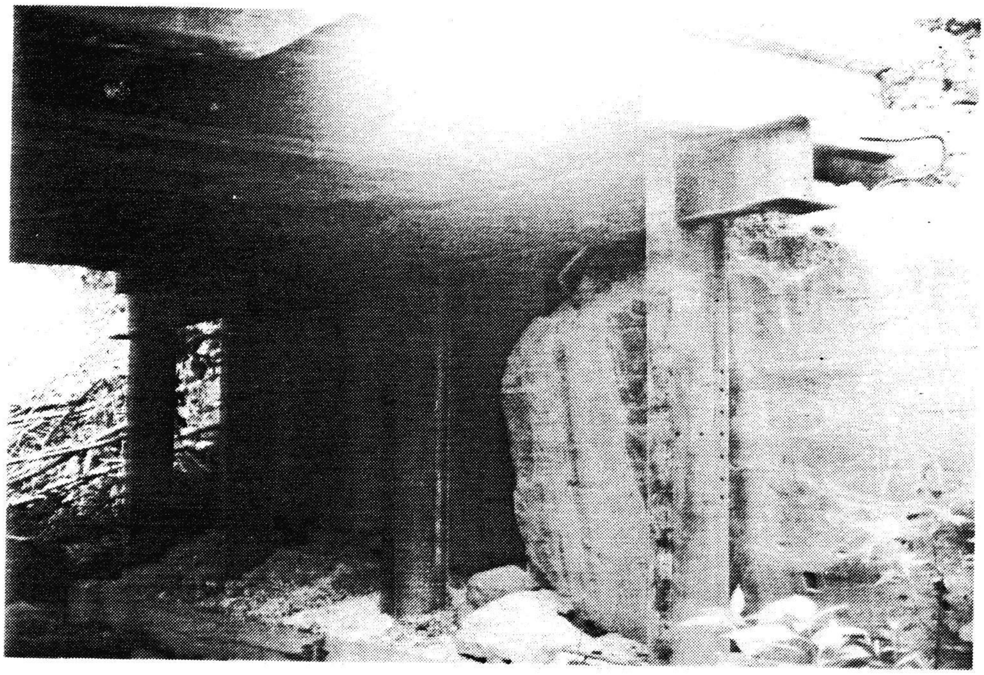


Fig. 3.3 Reinforced Abutment

Fig. 3.4 Two Span Bridge

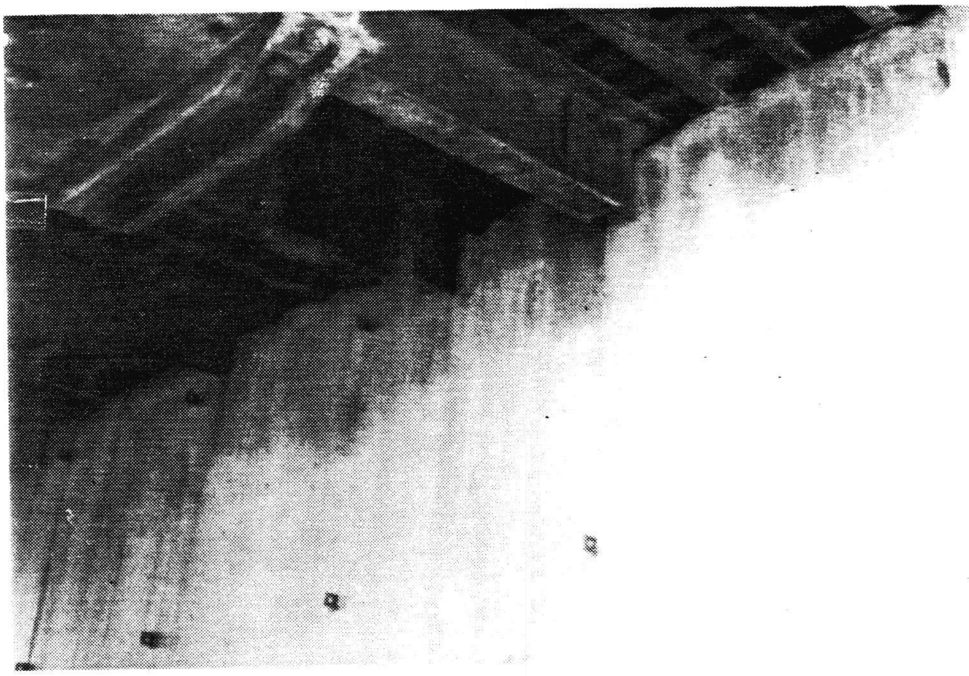


Fig. 3.5 Notched Sills

Fig. 3.6 Buckeled Side Sills

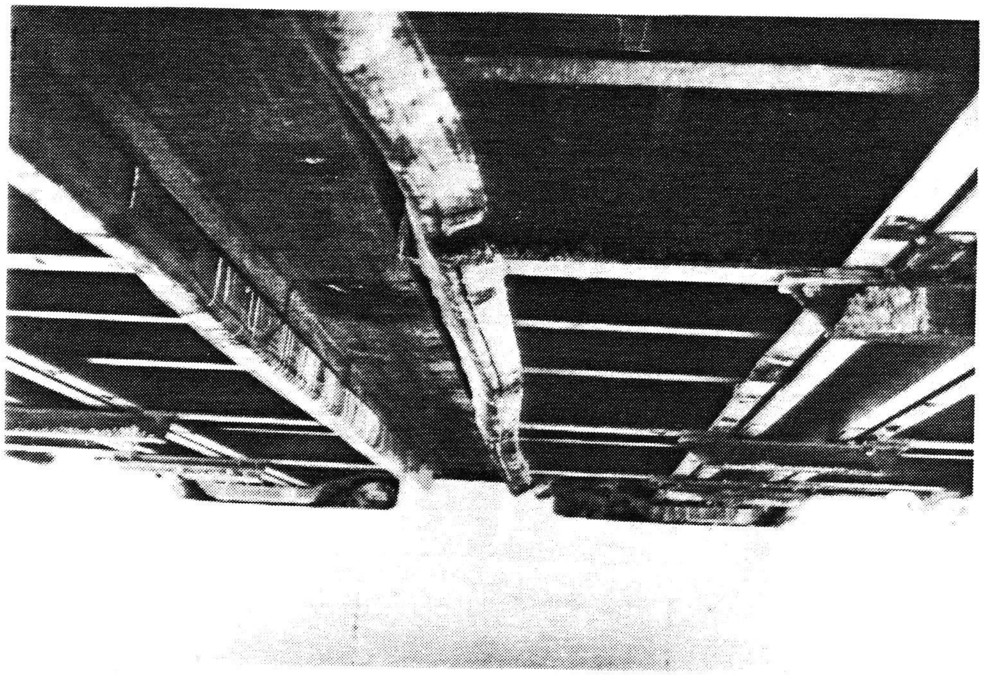


Fig. 3.7 Center Spacer

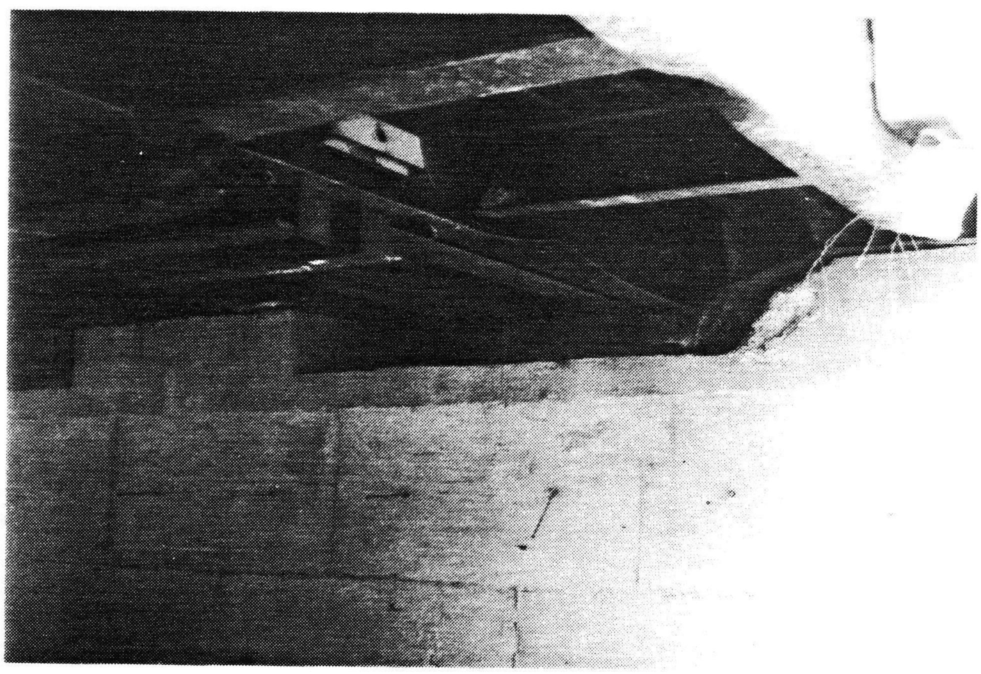


Fig. 3.8 Bolster Supported by Abutment

of the twelve were constructed from box cars (Fig. 3.9). In each case, the car's steel floor was used as the roadway. It was noted, however, that in a few cases some of the welds between the flat car deck and the frame had broken.

All 12 bridges were two cars wide. A problem was noted when two flat cars were placed side by side (Fig. 3.10). Due to manner of construction of some flat cars, a gap was left in the bridge deck.

The abutments ranged from heavy concrete beams (Fig. 3.11) to the car being placed directly on the ground (Fig. 3.12). When the cars were not supported by an abutment, a problem in maintaining a level bridge deck was noted (Fig. 3.13).

3.4 South Central Region

Eight bridges were visited in Cleveland and Hot Springs Counties, representing 29 percent of the bridges reported by judges in these counties.

3.4.1 Cleveland County

Four bridges were inspected in Cleveland County. Two were constructed from box cars and two from gondola cars. In each case, the car's floor was covered with a minimum of four inches of gravel. With the deck covered by gravel, it was difficult to detect when the bridge was being crossed. Both timber and earth abutments were in use. The cars were generally supported by an earth abutment three feet long.

3.4.2 Hot Springs County

Four bridges were inspected in Hot Springs County. All were well

Fig. 3.9 Flat Car Bridge

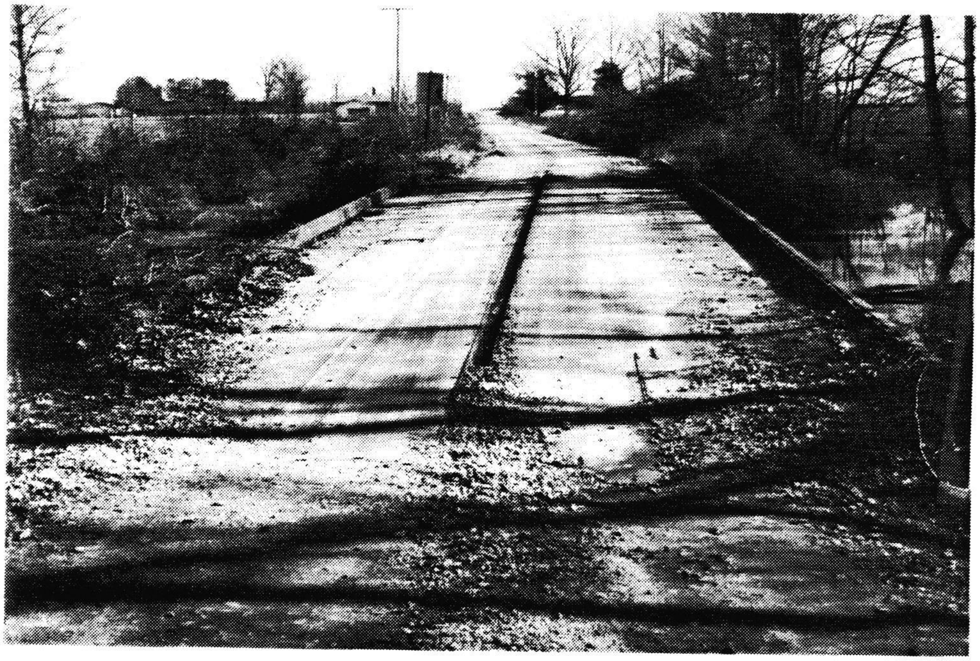


Fig. 3.10 Flat Car Bridge Deck

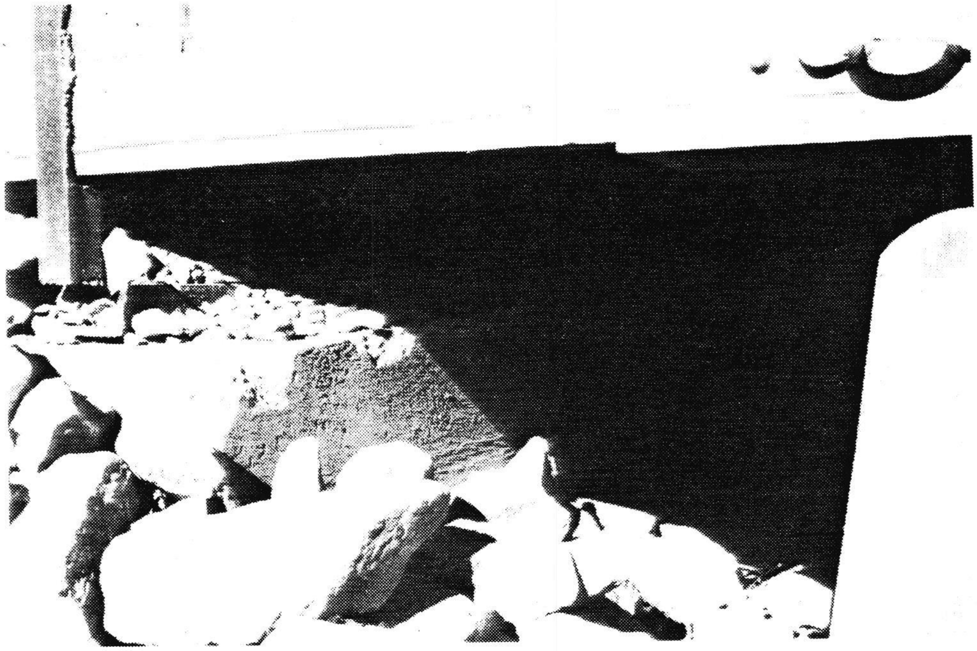


Fig. 3.11 Concrete Beam Abutment

Fig. 3.12 Earth Abutment

constructed, from box cars - two cars wide, and had concrete abutments. Bridge decks consisted of asphalt pavement over the steel floor. Support columns had been placed between the top of the abutment and the car to help transmit the load to the abutment. In one case, a bridge was constructed by placing two cars side by side, and it was reinforced with two interior steel beam piers underneath the bridge. This resulted in a three span bridge constructed from continuous beams.

Fig. 3.13 Settlement at Abutment

3.5 Car Numbers

A total of 27 bridges were visited during the field trips. This represented 16 percent of all the railroad car bridges in the state. The 27 bridges were constructed from 52 railroad cars. Of these, 41 were box cars, eight flat cars, and three gondola cars. Car numbers were found on all of the flat cars, on nine of the 41 box cars, and on none of the gondola cars. A listing of the car numbers is presented in Table 3.1.

Table 3.1 Car Numbers

Box Cars	Flat Cars
MP 119252	TTX 600346
MP 253717	TTX 755125
MP 388047	
	NIFX 1330
NP 2158	NIFX 1325
	NIFX 1074
CB&Q 47474	
CB&Q 49412	NAFX 703
	NAFX 711
Southern 556075	NAFX 220
Southern 550581	
C&EI 67079	

3.6 Age of Cars

In a few cases the date of manufacture was printed on the railroad car. The following dates were observed during the field visits: 6-57, 1959, 3-65, 4-67, 4-74 and 7-19-79.

CHAPTER 4

AMERICAN ASSOCIATION OF RAILROADS

STANDARDS AND RECOMMENDED PRACTICES

4.1 Introduction

The American Association of Railroads (AAR) developed the Specifications for Design, Fabrication and Construction of Freight Cars on September 1, 1964. Prior to 1964 each railroad had its own standard for design. The standards specify design loads, draft and compression axial loads on the cars, loading conditions, recommended stress, analysis procedures and allowable material stresses.

4.2 Design Loads and Stresses

The AAR Manual of Standards states that "Each member in the car structure shall be investigated for its most critical loading condition. Such critical loading conditions may result from loads applied singly or in combination provided such combination can rationally occur" (5).

The loads considered are vertical live load or load induced by the goods which the car is transporting, dead load or weight of the selected car members, draft load or tension load induced on car when train is accelerating, compressive end load or load induced when the train is decelerating, and fork lift truck load or wheel weights of a loaded fork lift truck.

The combination of loads to be considered in the design is as follows:

"For all conditions of vertical live load, dead load and draft load applied singly or in combination, the load factor for each shall be

1.8 and the allowable design stress shall be the yield or 80% of ultimate, whichever is lower, or the critical buckling stress.

For all critical conditions resulting from vertical live and dead loads in combination with fork lift truck, tractor for loading trailers or compressive end loads, for roof loads, jacking loads and vertical loads on the coupler, the load factors applied to each load shall be 1.0 and the allowable design stress shall be the yield or 80% of ultimate, whichever is lower, or the critical buckling stress.

For all critical conditions resulting from vertical live and dead loads in combination with impact loads, the load factor for the vertical load or forces resulting from vertical acceleration induced by horizontal impact force and the load factor applied to the impact load shall be 1.0 and such loading may develop the ultimate load carrying capacity of the member being investigated" (5).

4.2.1 Design Loads

The value of draft and compressive end loads are given in Table 4.1.

Table 4.1 Draft and Compressive End Loads

	1964	1987
Draft Load (lb)	300,000	350,000
Compressive End Load (lb)	800,000	1,000,000

The vertical live load is a function of the car's design capacity expressed in tons. The common design capacities and dimensions for the various cars is given in Table 4.2.

Table 4.2 Design Capacity and Dimensions

Car Type	Weight Class	Design Weight	Length	Vintage
Box	50 Tons	144,000 lb.*	40 ft.	1945-1960
	70 Tons	204,000 lb.	50 ft.	1960-Present
	100 Tons	242,000 lb.	50 ft.	1970-Present
	50-100 Tons	-	50 & 60 ft.	-
	50-100 Tons	Auto Parts**	60 ft.	Late 70's
	50-100 Tons	Auto Parts	86 ft.	Late 70's
Gondola	50-100 Tons	-	52 or 65 ft.	-
Flat	50-100 Tons	-	85 ft.	1957-1961
	50-100 Tons	-	89 ft.	1962-Present

*Design load of car minus weight of truck or live load plus dead weight
**Design for light duty

4.2.2 Design Stress

The design stresses or allowable stresses for various grades of steel is presented in Appendix B. The AAR Manual of Standards and Recommended Practice specifies the various grades of steel for different parts of the cars. They are as follows:

Carbon Steel Plates, Shapes And Bars

Structural Steel, Plates, Shapes and bars, ASTM A36
Structural Steel, Shapes and Bars for Locomotives and Cars, ASTM A283, Grades B and D
Structural Steel Plates, ASTM A283, Grades A, B, C and D
Hot Rolled Carbon Steel Bars, Merchant Quality, ASTM A575
Hot Rolled Carbon Steel Bars, Special Quality, ASTM A576
Shapes, Plates and Bars, composition of which corresponds to the AISI standard grades of carbon steel.

From conversations with engineers associated with the design and construction of freight cars, the following information was learned about the grade of steel used in the car frames.

<u>Box Car</u> - Center Sill - Standard Construction

Prior to 1960	- ASTM A7	- Grade 33
Post 1960	- A36	- Grade 36
Rolled Shapes	- A36	
Z Shape	- A572	- Grade 42

<u>Box Car</u> - Center Sill - Sliding Sill Construction

A441 Grade 50
A572 Grade 50

<u>Flat Car</u> - Center Sill

A441 Plate

4.2.3 Fork Lift Truck Loads

The floor of the box car was designed to hold a fully loaded fork lift truck. The fork lift specifications are:

> "General Service cars shall be designed for front axle loads of 25,000 pounds, or a wheel load of 12,500 pounds. The treads of the truck wheels shall be assumed to be on 36 inch centers and the tire print to be 10-1/2 x 8.72 inch width of tire.
>
> Heavy duty service cars shall be designed for front axle loads of 50,000 pounds, or a wheel load of 25,000 pounds. The treads of the truck shall be assumed to be on 32 inch centers and the tire print to be 13-1/2 x 5.325 inches with 16 inch width of tire" (5).

4.3 Load Distributions

Design procedures recommended by AAR describe several live load loading conditions for box and flat cars (6). These loading conditions will produce the highest bending and shear stresses in the frame and are presented in Appendix C.

The fork lift truck loading conditions generally result in the bending and shear stresses which are used to design the car floor, stringers, crossties and crossbearers. The locations of these members are presented in Fig. 4.1. Recommended location of the truck loadings is presented in Appendix C.

Flooring for gondola cars is designed for a uniformly distributed load equal to 87 percent of the live load distribution over the full width of the car and over a length of 18 ft. at the center of the car.

4.4 Design of Specific Members

The following loadings and support conditions are recommended by AAR for the design of components of the frame. Location of the components in plan view is presented in Fig. 4.2.

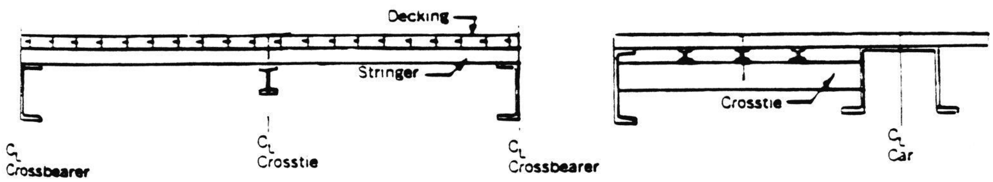


Fig. 4.1 Frame Members

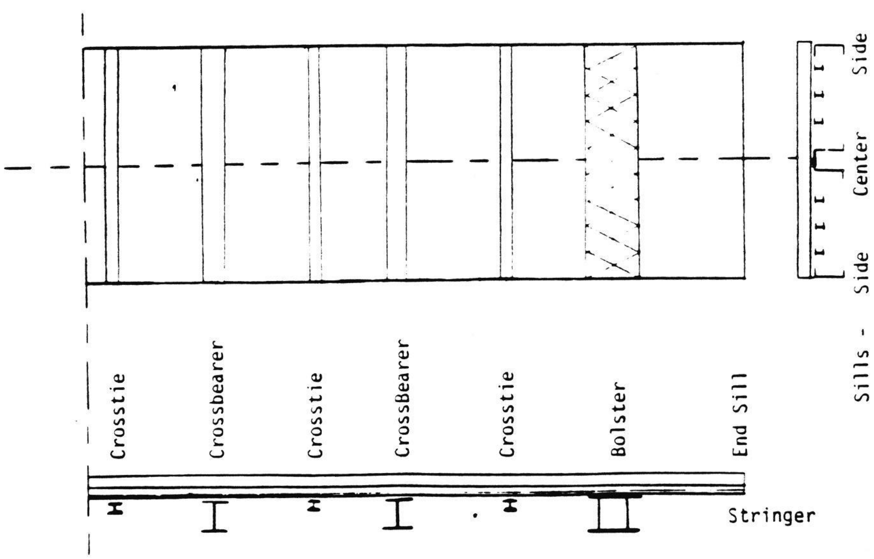


Fig. 4.2 Plan View of railroad Car Frame

4.4.1 Floor Stringers

When floor stringers are continuous between bolsters they are considered to be uniformly loaded. For concentrated loads, the critically loaded span may be considered as 50 percent restrained at the ends of the loaded span. When stringers are applied in sections between cross members they are considered to be simple-supported beams unless the construction is such as to provide continuity over two or more spans.

Box car floor stringers are designed for dead load combined with lift truck wheel loads which are located to obtain critical loadings. Stringers are also designed for dead load and a uniformly distributed live load combined with the critical end load.

General service flat cars floor stringers are designed for dead load combined with lift truck wheel loads. Additional loads considered for design are a uniformly distributed live load, dead load and the critical end load.

Gondola cars floor stringers are designed for dead load and a uniformly distributed live load. Also, the stringers are also designed for the dead load, uniformly distributed live load and critical end load.

4.4.2 Crossties

Crossties are considered as beams simple-supported at the center and side sills. Box and flat cars crossties are designed for the dead load combined with the lift truck loads. Also, they are designed for dead load and critical live load combined with vertical acceleration forces induced by the horizontal impact load.

Gondola cars are generally designed with or without stringers between the sills. For cars with stringers between the center sill and side sills, the crosstie loads are considered as concentrated loads from the stringer reactions from the dead load and live loads. For cars without stringers between the center sill and side sills, the crosstie load shall be considered as a uniformly distributed load and may be computed by the panel area method from the dead load and the live load distribution.

4.4.3 Crossbearers

Crossbearers for box and gondola cars are designed as simple beams supported at side sills. Crossbearers for flat cars are designed on the basis of equal deflection of the longitudinal load-carrying members (center sill and side sills) of the car (ie; the amount of load carried by each being proportional to their respective moments of inertia.) The crossbearer for flat cars may be considered as a simple beam or a cantilever beam as specified for the particular loading indicated.

Loads considered for the design of crossbearers for box cars are the reactions obtained from the center sill and floor stringers from the dead load and the critical uniformly distributed live load conditions. Also, reactions from the center sill and floor stringers from the dead load combined with the applicable lift truck wheel loads should be considered. The centerline of the lift truck axles should be on centerline of crossbearer as to obtain critical loading.

In design, the crossbearer is considered as a beam or truss simply supported at side sills with a concentrated load at center equal to 75 percent of load limit multiplied by the percentage of load carried by both side sills. Also, the crossbearer is considered as a cantilever beam or truss fixed at the center sill and loaded with a concentrated load on each side sill equal to 75 percent of the load limit multiplied by one-half the percentage of the load carried by the center sill.

The crossbearer is considered as a cantilever beam or truss fixed at the center sill and loaded with a concentrated load on each side sill equal to 75 percent of the load limit multiplied by 1/2 the percentage of the load carried by the center sill.

The crossbearer for flat cars in trailer or auto rack service are designed for the trailer transport car load described in Appendix B. The standards also provide container loads for container flat cars.

The crossbearer for the gondola car is designed for the dead load and the reactions from a load applied on bearing piece across full width of car which is equal to 75 percent of the load limit. Also, the crossbearer is designed for the loading produced by the critical lateral force produced by the bulk material. Stresses induced by these loadings are to be combined with stresses induced by the vertical loads. Lastly, the crossbearer is designed for the above loads combined with vertical acceleration forces induced by the horizontal impact load.

4.4.4 Center Sill - Conventional Underframe

In box and gondola car design, the center sill is considered as a continuous beam supported at ends of car, bolsters and crossbearers. They are designed for 1) dead load and critical live load combined with the draft load, and 2) dead load and critical live load combined with critical end load.

After the bending moments have been determined, the combined unit tensile and compressive stresses at any section of the center is determined by:

$$\sigma = P/A \pm M/S$$

where:

P = Maximum end load

A = Area of section

M = Combined bending moments

S = Section modulus

In flat car design, the center sill and side sills are designed for the load requirements described in Section 4.2 and may be considered as beams with overhanging ends supported at the bolsters. Bending moments induced by vertical loads may be distributed to the center sill and side sills on the basis of equal deflection. Between the bolsters the bending moments induced by the eccentric application of end load to the center sill may be distributed to the center sill and side sills on the basis of equal deflection. In front of bolster the bending moment induced by the eccentric application of the end load may be considered as being resisted by the center sill only.

The following formula is used for the determination of stresses induced in center and side sills by the compressive end load.

$$\sigma = P/A_c \pm Pe/S \quad \text{(center sill in front of bolster)}$$

$$\sigma = P/A \pm Pe/S\ (I_m/I_t)$$

Where:

P = Compressive end load

A = Combined area of center and side sills in portion between bolsters.

A_c = Area of center sill in front of bolsters.

S = Section modulus of member under consideration.

e = Eccentricity of P with respect to center of gravity of center sill.

I_m = Moment of inertia of member under consideration.

I_t = Sum of moments of inertia of center and side sills in portion between bolsters.

The total combined tensile and compressive stresses are computed by combining these with the stresses induced by vertical loads.

4.4.5 Sliding Center Sill - Cushion Under Car Frame

The sliding center sill is designed for the entire compressive and load applied at the rear draft lugs at each end of car. The restraints must be adequate to prevent buckling in any direction.

In box and gondola car design the fixed center sill is considered as continuous beams supported at ends of car, bolsters and crossbearers, and are designed for the following loads:

Dead load and critical live load

Increment of the impact load plus dead load and critical live load

CHAPTER 5

LIMITED RAILROAD CAR ARCHIVE

5.1 Introduction

A limited railroad car archive was developed from the information obtained from the railroads. The Union Pacific Railroad, Burlington Northern Railroad, Norfolk Southern Railroad, Trailer Train and General Electric Railcar Service Corporation were contacted in order to obtain structural information related to the railroad cars identified during the field visits. As a result of the contacts, drawings for six box cars were obtained; two each from the Norfolk Southern Railroad, Burlington Northern Railroad and Union Pacific Railroad. This information was used to develop the limited archive.

5.2 Archive Format

The information provided by the railroads was reviewed and organized into a limited archive. A summary of the information obtained is presented in Appendix D. The drawings were reviewed for structural information such as member spacings, and dimensions on stringers, crossties, crossbearers, side sills and center sills.

The information was organized into the following format: (1) Identification Page - Identifies the railroad, car number, bridge number and county where the bridge is located. (2) Layout Page - A quarter section of the frame, showing crosstie, crossbearer, bolster and stringer spacings, is presented. Also, car length over end sills, truck spacing and width of car over side sills is presented. (3) A page presenting drawings of the crossbearer and crosstie as obtained from the railroad drawings. (4) An illustration of stringer sizes, side sill and center sill drawings and dimensions is presented as obtained from railroad car drawings.

5.3 Information Detail

Information provided by Burlington Northern and Norfolk Southern Railroads were complete enough to perform a structural analysis of the frame. The only exception was the crossbearer information provided by the Norfolk Southern. However, no detail information was obtained on the decking. The Norfolk Southern Railroad did provide a set of structural specifications. A summary of the structural specifications is included in Appendix D.

Information provided by Union Pacific was incomplete. Spacing of members could be obtained along with shapes of the various structural members. Very limited dimensions were obtained from the drawings provide for the crossties, crossbearers, side sills and center sills. Size of one stringer was provided. However, a set of specifications was provided for Car Number #253717 which did describe the structural members. A summary of specifications is included in Appendix D.

5.4 Comparison to AHTD Data

The railroad drawings were compared to the bridge inspection forms provided by Arkansas State Highway and Transportation Department Bridge Division to determine similarities or differences between the data sets. Comparisons were conducted for four bridges.

5.4.1 Bridge Number 19912, Izard County

Stringer spacings varied within one inch of those reported on tl two sets of drawings. Spacing of crossties and crossbearers were reported to be 4'-10 1/2" on the railroad drawings and 3'- 9" from field measurements. Overall, there was a good comparison between the two sets of drawings.

5.4.2. Bridge Number 19908, Izard County

Stringer spacing was not similar on the two drawings, for there were over two inches difference in the reported spacings. Crosstie and crossbearer spacing differed by one foot. It appears that the drawing provided by the railroad does not agree with the field inspection.

5.4.3 Bridge Number 19910, Izard County

Stringer spacings were similar on the two drawings. They agreed within one inch. Crossbearer and crosstie spacing also agreed within one inch. Overall there was a good comparison between the two sets of drawings.

5.4.4 Bridge Number 20428, Lee County

Stringer spacings could not be compared due to the quality of the field drawings. Crossbearer and crosstie spacings were off by four inches. However, the distance between crossbearers were the same, and dimensions of the side sills were close. There was a reasonable comparison between the drawings except for crosstie and crossbearer spacings.

It should be noted that there were two Norfolk Southern railroad cars which made up the bridge. The field drawing provided did agree closely with one car but not the other.

CHAPTER 6

LOAD RATING PROGRAM

6.1 Introduction

A load rating program was developed which would predict the load rating for individual railroad cars. The load rating scheme consists of performing a finite element analysis of the railroad car frame loaded with unit inventory vehicles, operating vehicles, and car dead loads. The scheme would determine the load rating for each type of vehicle by 1) calculating the factored moment capacity of each structural member in the bridge, 2) subtracting the factored dead load moment, and 3) dividing by the factored unit live load moment produced by each class of vehicle. The unit live load moment was achieved by modeling a 2,000 pound unit vehicle representing each class of inventory and operating vehicles.

The load rating program generated the finite element files needed to perform the analysis. This was achieved by writing software which generated the required files with minimum input. The input consisted of the number, spacing and type of cross beams, and number and spacing of stringers along with the sectional dimensions for each structural member. The program calculates the node indices based on the standard geometry of the railroad car, the sectional properties, position of the unit vehicles and corresponding node point loads and writes the required finite element file. It can handle box car frames with stationary and sliding center sills and flat car frames with constant cross section or trussed floor beams.

Another part of the software reads the results of the finite element analysis, or the output files, for each unit vehicle and dead load and calculates the load rating. It first computes the maximum factored moment each structural member could resist, subtracts the corresponding factored dead load moments and calculates the load rating by dividing by the moments produced by the factored unit vehicle. Thus, a load rating is produced for each structural member in the car.

In order to make modifications to existing finite element files, special software was developed. This software would calculate the new sectional properties of deteriorated members, apply these new properties to specified elements in the finite element file, and add supports. This permits the modeling of deteriorated members and changes in the conditions of member over time.

6.2 Flat Car Program

The flat car program was developed around the standard geometry of the flat car. Its general geometry consists of a central box beam or center sill which has a reduction in height at the ends of the car where the running gear is attached. The geometry also consists of cross beams running between the box beam and side sills (beams along the outside edge of the car). The cross beams are either 1) a constant cross-section beam, 2) a tapering cross-section beam, or 3) a truss or constant cross-section beam reinforced by a diagonal running from the end of the cross beam to the base of the central box beam. There are three forms of cross beams alternating along the length of the frame. The first is the bolster. It is a light box section located only where the trucks are attached to the car frame. The second and third types are the floor beam and cross tie.

The floor beam is the stronger of the two and has one of the following shapes: 1) constant cross section, 2) a tapered cross section, or 3) a trussed shape. The cross tie is the lightest cross beam. It generally has a constant cross section. The last structural member is the stringer. It runs parallel between the side and center sills and the frame usually consists of one to three of these beams per side.

6.2.1 Flat Car Finite Element Configurations

The finite element configuration for the flat car frame consists of the following format. The center sill, side sills, and stringers are each divided into equal number of elements. The element length is defined as the distance between the points of intersection of two consecutive cross-beams. Therefore, the number of elements that form these structural members is equal to one less than the number of cross beams including the two end beams. The cross beams elements are defined by the intersection points of the cross beam with the center sill, stringers, or side sill. Therefore, if there were two stringers on each side of the car, the cross beam will be divided into three elements per side. In order to maintain the width of the car, the center sill was modeled as two beams connected together at the floor beams. The distance between the beams is defined as the width of the center sill box section. The sectional properties of each beam is defined as one-half of the sectional properties of the center sill box sections. Supports are added at each end of the model, and consist of a ten-inch heavy steel beam attached to the side and center sills. At one end of the car, the supports are fixed with respect to the three axis and at the other end the model is free to move along the long axis. There are no moment restraints.

The worst case was assumed, so the stiffness of the deck on the car frame was neglected. It was felt that over time the deck could separate at enough locations so that the stiffening effect would be greatly reduced.

6.3 Box Car Program

The box car program is based on the standard geometry of the box car frame, stationary center sill and sliding center sill. The stationary center sill frame geometry consists of a hat shaped center sill and side sills constructed from channels or Z shapes, with stringers of usually I or Z shapes. Generally the frame consists of one to three stringers per side. The cross beams consist of either a floor beam, cross tie, or bolster. The arrangement of cross beams is symmetric with respect to the center of the frame.

The sliding center sill frame has a geometry similar to the stationary center sill frame with the following exception. The hat shaped center sill slides freely with respect to the length of the frame between two heavy channels which are connected to the cross beams. The channels are usually connected together at the floor beams by an angle section. This section is located under and perpendicular to the sliding sill. The effect of the sliding center sill acting as a beam in bending was neglected in the analysis. The channels are considered as the center sill.

6.3.1 Box Car Finite Element Configuration

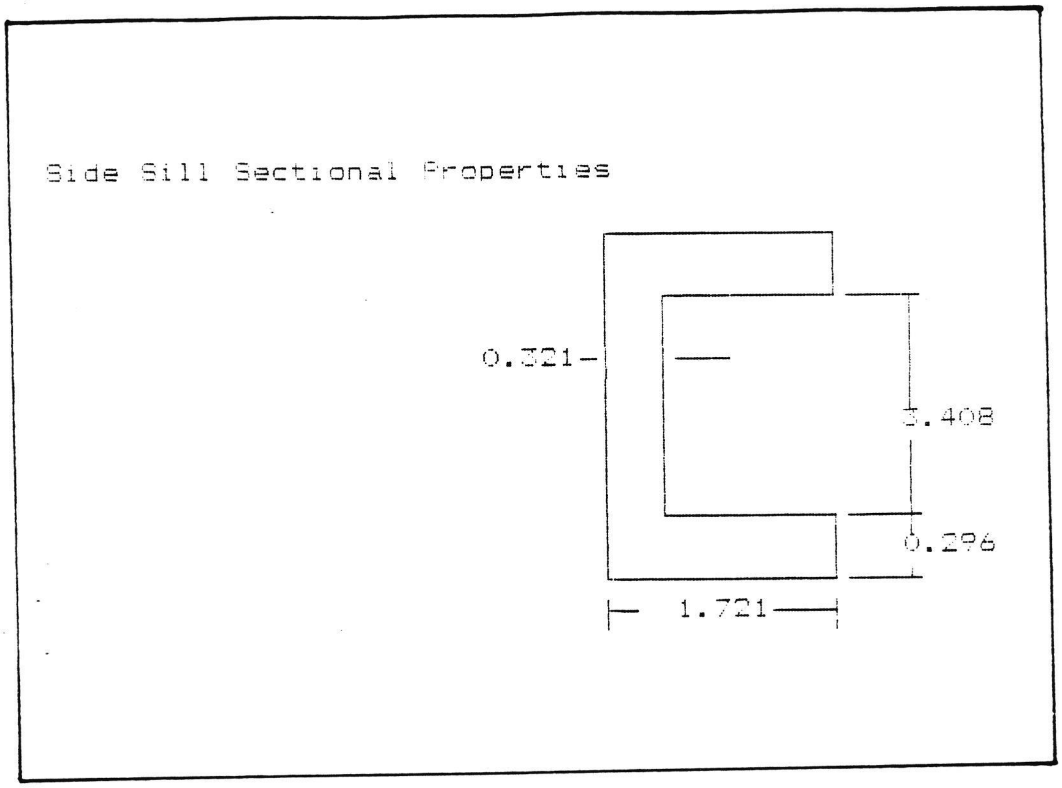
The finite element configuration consists of the following format. The center sill, side sills, and stringers are each divided into equal numbers of elements. The elements length is defined as one-half of the distance between points of the intersection of two consecutive cross beams. Therefore, two elements of equal length define these beams between the cross beams. The cross beam elements are defined by the points of intersection of the cross beam with the center sill, stringers, or side sills. Again, the stiffening effect of the deck was neglected as in the flat car case and the support conditions are the same as prescribed for the flat car.

6.4 Data Entry

Data entry is based on the information that would be obtained from the field inspection of the bridge. It consists of the spacing of the cross beams and stringers and the physical dimensions of the center sills, side sills, stringers, floor beams, bolsters, and cross ties. The program permits spacing to be entered in feet or feet and inches.

The data required is as follows:

1. Number of cross beams including end beams.
2. Number of stringers per side of car
3. Distance between cross beams and type of cross beam, that is, either a bolster, floor beam, or cross tie.
4. Distance between the side sill and stringer.
5. Distance between stringers.
6. Distance between stringer and center sill.
7. Distance between center sills.
8. The physical dimensions are entered for the various shapes of the beams. That is, the beams could be formed from angle iron, box section, channel, hat shape, or I section. The dimensions required are illustrated in Figures 6.1 to 6.3.



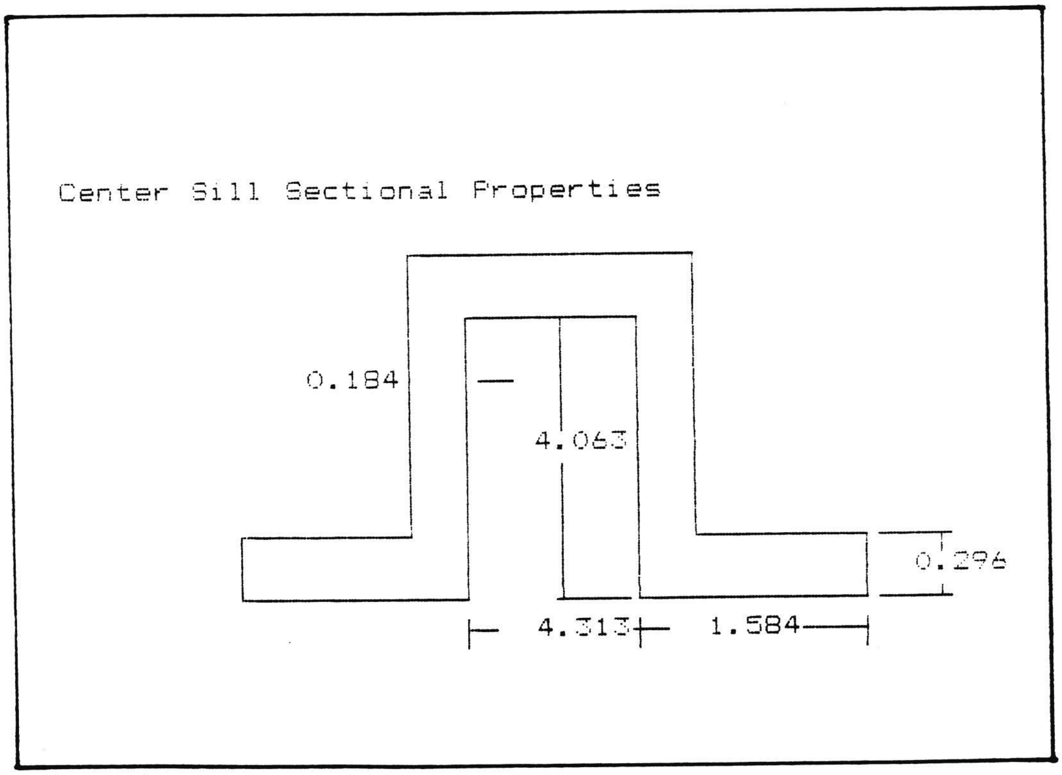
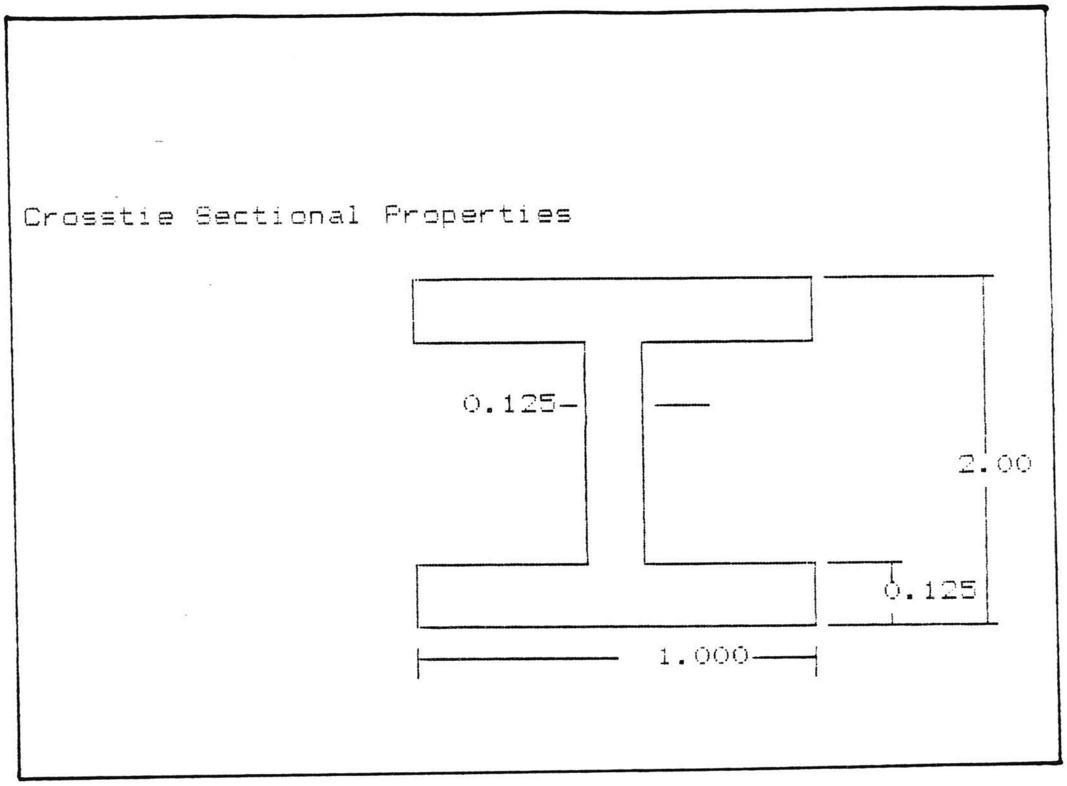


Fig. 6.1 Center and Side Sill Data Entry



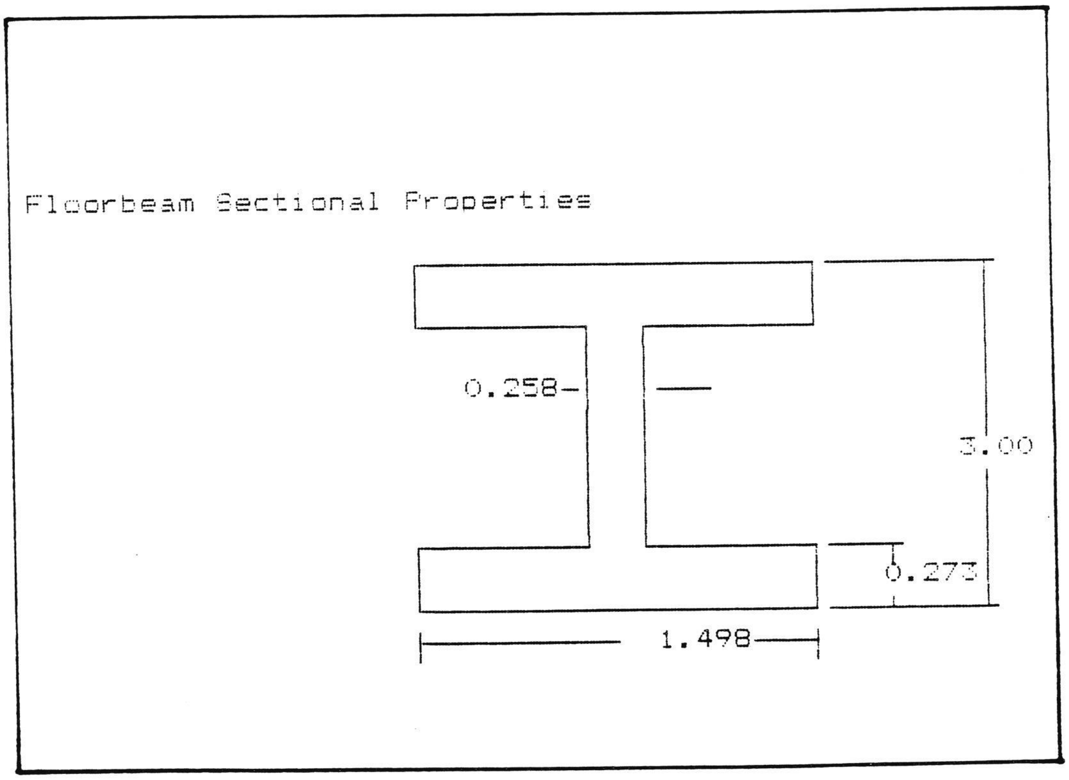


Fig. 6.2 Crosstie and Floor Beam Data Entry

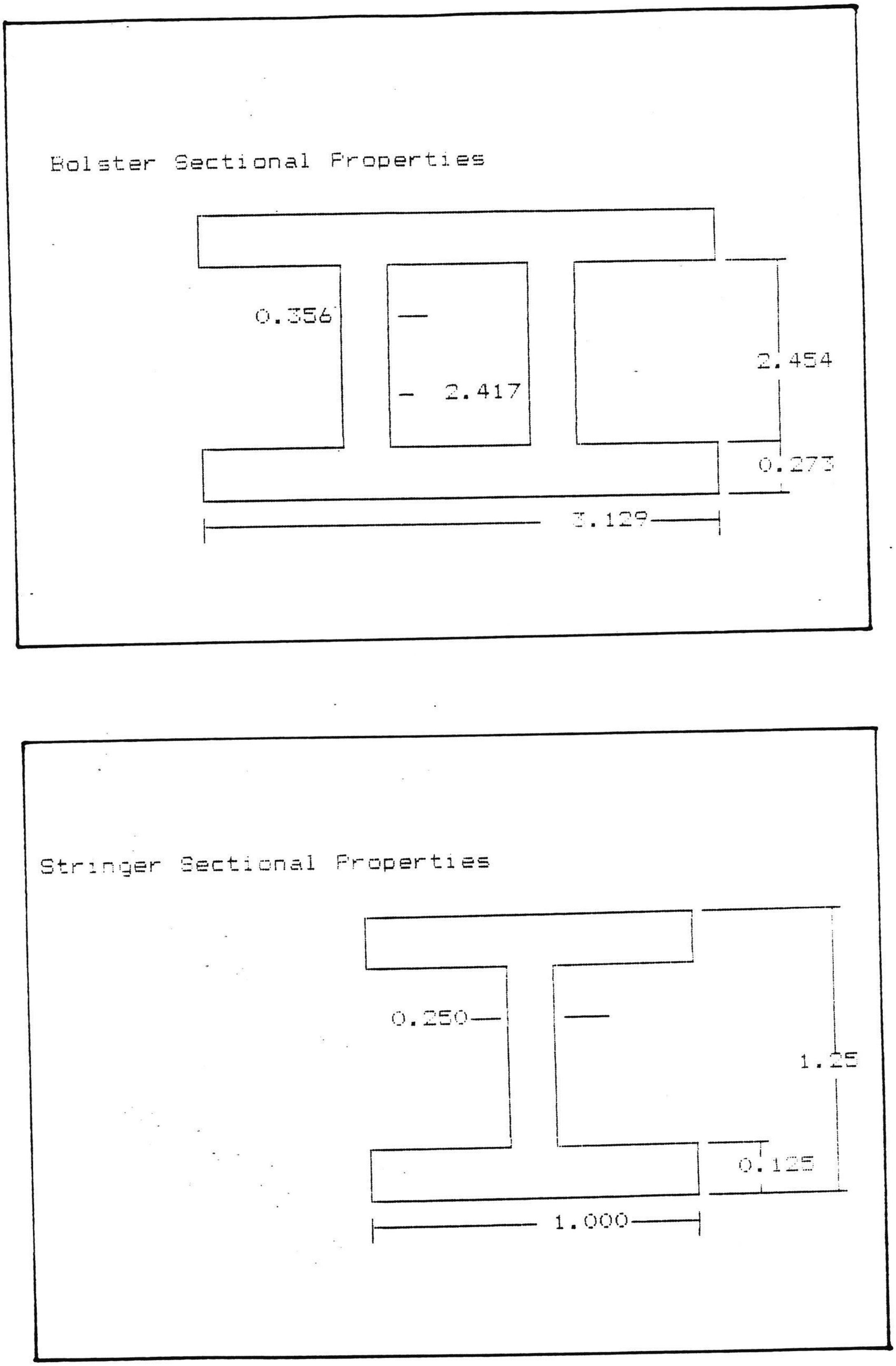


Fig. 6.3 Stringer and Bolster Data Entry

9. The dead load intensity of the decking and any covering in pounds per square foot.

6.5 Box Car and Flat Car Program Outputs

The programs were designed with a series of optional printed outputs that would permit easy checking of the data entry. The output included:

1. Cross beam type and spacing in inches.
2. Side beam, stringer and center beam spacings.
3. Node coordinates
4. Sectional properties of the structural member which includes cross section area, shear areas, moment of inertia, and distance to extreme fibers.
5. A diagram which shows a plan view of the element numbers. This would permit the programmer to locate which element properties need to be modified due to deterioration.

The program generates six finite element data files. The files are generated in the format used in M-TAb by Structural Analysis, Inc. of Austin, Texas. M-Tab is used to convert the files to the formats used in SAP, MSC/NASTRAN, MSC/PAL, STARDYNE, or ANSYS.

A separate file is generated for each type of loading imposed on the bridge. The first type is the dead load of the structural members with the dead load of the deck and coverings. Next, a file is generated for each unit inventory and operating vehicles for which the bridge is to be rated. See Figure 6.4 for a description of these trucks. The vehicles are positioned on the structure so the center of gravity of the vehicle is over the center of the span.

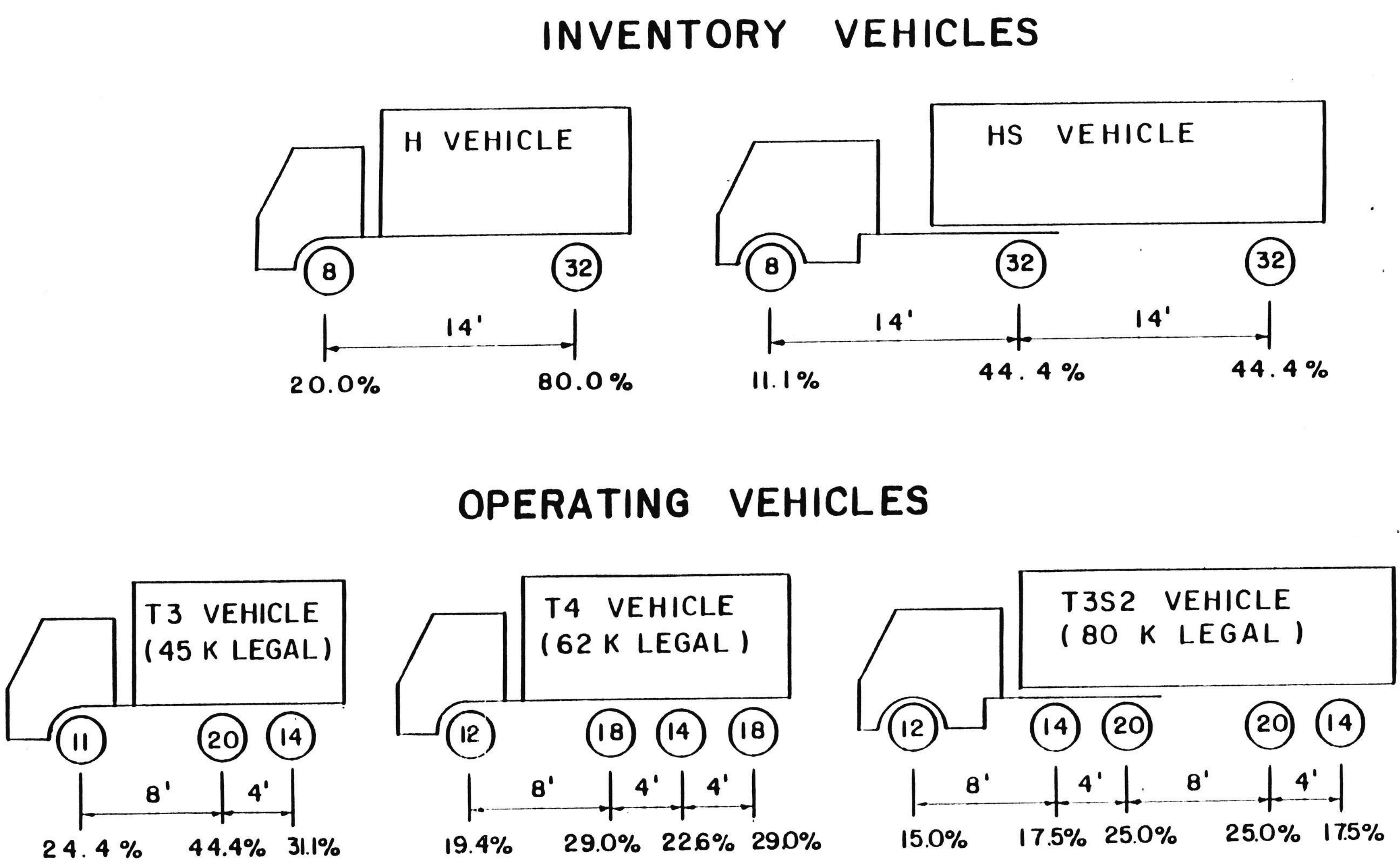


Fig. 6.4 Inventory and Operating Vehicles

6.6 Modification Program

A modification program was written so that modifications could easily be made to the files generated by the flat and box car programs. The modifications include the addition of supports and changes to specific elements in the structure. New supports can be added at any node in the finite element model. That is, if there are internal supports in the bridge, this program is used to place it in the finite element model. The supports are added by giving the number of supports and the corresponding node location of the supports.

The element properties can be changed in two ways, individual element entry or entry by a range of elements. The element properties occasionally need to be modified due to deterioration of the members or removal of side sill flanges during installation of the bridge. Once the element number is entered, the element's present properties are displayed. The new properties could be determined by:

1. Entering new values for selected element properties,
2. Entering a reduction factor as a percentage of the present values,
3. Selecting the option of re-entering the dimensions for one of the basic structural element shapes.

The new values of the element properties are displayed and the finite element files are rewritten using the modified values. The program also gives the option of printing out the node positions, element data and element properties.

6.7 Load Rating Program

The load rating program calculates the number of tons per type of vehicle. This is achieved in the following manner.

1. The program would read the output generated from the execution of the SAP86 finite element programs. The files generated by the box or flat car programs must be converted to the SAP86 format and executed. This generates the required SAP 86 output files.
2. The load rating program requests the load factors for the dead load and live loads along with the maximum permissible stress.
3. The program reads in the element properties and calculates the maximum permissible moment each structural member can support. The moment is obtained by the following equation.

$$M = (\text{Max. Stress}) * I/C \qquad \text{Equ. 6.1}$$

Where I is the member moment of Inertia and C is the distance from neutral axis to extreme fibers.

4. An array is set up which would store the maximum permissible moment for each element. The program next reads the dead load results and subtract the dead load moment times the dead load factor from each permissible moment on an element by element basis.

5. The load rating program next reads the output file generated from the execution of one of the unit vehicles. On an element by element basis, the program would read the moment values for each element, multiply by the live load factor and divide into the corresponding moments generated in step 4. For each structural member, the program would search for the smallest load rating or number of tons the bridge could support. The program then prints the type of vehicle, structural member and corresponding load limit.

6. The procedure outlined in step 5 is repeated for each type vehicle.

CHAPTER 7

INSTRUMENTATION

7.1 Introduction

A one-third scale model was constructed of a box car frame. In order to study the behavior of the model, it was instrumented with strain gauges (Micro Measurements - CEA-06-250UW-350). Therefore, instrumentation was developed which would complete the strain gauge bridge and send a noise free signal to the data acquisition system.

The instrumentation was designed to be portable so it could be used in the outdoors for the field testing part of the study. The instrumentation was developed and tested in the laboratory under simulated field conditions.

A Keithley System 570 Data Acquisition System was used to monitor the strain gauge readings. Special software was designed that efficient: monitored 30 strain-gauge signals.

7.2 System Hardware

The computer system consisted of a standard XT-type computer with an 8088 microprocessor, a math co-processor, and two hard-disk drives. The second disk drive was primarily for data storage.

The data acquisition system used was a Keithley System 570, which has a 12-bit D/A converter and 16 differential inputs or 32 single-ended inputs. The System 570 was set up for 32 single-ended inputs with a 250 ohm, 1% precision resistor as a load for each channel (a more specific explanation of the use of these resistors will be with the strain measurement boxes.)

7.3 Strain Gauge Software

The software was written in Keithley Basic, which was required to run the System 570. The software was written in several sections:

1. Zero Strain Calibration

   This section provided continuous monitoring of all strain gauges measurements, while displaying the calculated strain on the computer screen. This allowed all the strain boxes to be initially set at the same no-load zero setting.

2. Data Measurement and Retrieval Loop

   The data measurement consisted of reading the DC voltage in a channel (gauge #1) 750 times, storing the readings in an array, calculating the mean of the values from array positions 351 to 450, and storing that value into another array. The program then looped back and read gauge #2 and repeated the process until all the guages were read. Multi-dimensional arrays were used so all gauge values could be stored in the same array.

3. Data Storage and Print

   Once the primary array (the array with the mean values) was formed, the program converted the DC voltages to calculated strains. As each value was converted, the results were placed into a multi-dimensional array which was then saved with added comment lines, date and time.

   The user had the option to print the data; if not, the program ended; if yes, the data is printed in the same form as it is saved with comment lines, date and time, and the associated file name under which it was saved.

7.4 Strain Gauge Boxes

The strain measurement boxes were designed and constructed. The strain boxes were designed with three objectives in mind: 1) read the voltage across the strain gauge bridge accurately, 2) amplify the reading for strains as small as one micro-in./in., and 3) convert the resulting amplified voltage to a current loop, which would be used to send the readings through 100 ft. of cable with no voltage loss or noise interference.

1. The strain gauge was read through a standard wheatstone bridge setup, with two high-precision resistors, and one temperature-compensating gauge mounted on a small metal block, and lead wires to the active gauge. A stable voltage of 10 VDC was applied across the bridge, and the output was sent to an instrumentation amplifier.
2. The instrumentation amplifier was a Burr-Brown INA101AM, which is a high precision variable gain amplifier. The gain was set up to amplify the input by a factor of 843. An offset adjustment was also included with the amplifier which provided a means to adjust each strain box to a zero strain setting.
3. The output of the amplifier was then sent into a voltage-to-current converter, which provided a standard 4-20 ma signal to be read across the 1%, 250 ohm resistor at the data acquisition system. The converter consisted of a Texas Instruments LM358P dual op-amp and several 1% resistors.

The PC board was laid out with the aid of a CAD PCB layout package. The layout drawing was made into a photo-negative, and then used to etch the 3x4 inch board. The boards were then drilled and stuffed with the appropriate parts and a small metal box was designe to house the board so that the circuit components were protected from the weather. The boxes had metal flaps on each side with a magnetic strip so quick and convenient placement was possible.

The strain gauge wheatstone bridge had a stable voltage reference. A single, 30.00VDC power supply was made to deliver up to 5 amps load with less than 10 mv variation in output voltage. This was accomplished with the aid of the Burr Brown OPA541AP power op-amp and the Burr Brown REF102 precision voltage reference. The REF102 has a 10.00V ±0.0025V output which was sent to the op-amp, which with a gain of 3, put out a 30.00 VDC output ±0.0075V under full load. The current consumed by 30 of our strain boxes was approximately 3.5 amps.

7.5 Calibration

The strain gauge boxes were calibrated by the following procedure:

1. A strain gauge was mounted at the center of a 8x1x1/8 inch steel bar.
2. The bar was simply supported and loaded until approximately 50, 150, 300, 450, 600, 700, and 1,000 micro in./in. strains were obtained.
3. For each load, the strain was first measured using a LBH strain indicator unit. Next, the gauge was switched to an active strain gauge box. The corresponding voltage was read to the nearest ten-thousand of a volt. The voltage ranged from 4.0000 to 8.000 volts for tension and 4.0000 to 0.7000 for compression.
4. This procedure was repeated for each of the 30 strain gauge boxes.
5. It was determined that the following equation could be used to convert the voltage read from the strain gauge box to strain.

$$\text{Strain} = \text{voltage} * 222.2 - 888.8 \qquad \text{Equ. 7.1}$$

Equation 7.1 could be used for each of the 30 boxes constructed with a maximum error of one micro in./in. of strain or well within the accuracy of the LBH strain indicator.

The procedure outlined in steps 3 through 5 was repeated three times to verify the accuracy of the strain gauge boxes.

7.6 Noise

Due to the low voltages involved in the instrumentation, the strain gauge box was checked for the amount of interference from outside noise. This was done by monitoring the response of the strain gauge boxes over a period of seven seconds. This procedure was repeated in the field as well as in the laboratory. The variation of strain observed from the boxes was plotted. It was found that the variation in strain observed was equal to one count on the A/D converter in the data acquisition system.

CHAPTER 8

SCALE MODEL TESTING

8.1 Introduction

In order to obtain a thorough understanding of the behavior of a railroad car bridge, a one-third scale model of a typical box car frame was constructed and tested in the laboratory. The model was instrumented with strain gauges at various locations and subjected to several types of loadings. The laboratory results were compared to the results obtained from a finite element analysis so adjustments in the analysis could be made.

8.2. One-Third Scale Model

The box car drawings obtained from the railroads were received and a typical box car frame was selected. The scale model was based on the stationary center sill frame drawings obtained from the Norfolk and Southern Railroad. A comparison of the strong axis moments of inertia for the different structural members reviewed are presented in Table 8.1.

Table 8.1. Box Car Frame Structural Properties

Structural Member	Railroad and Car Number		
	Southern 556075 I_{xx}	Southern 550581 I_{xx}	CB&Q 47574 I_{xx}
Side Sill	315	315	554
Center Sill	687	2 at 239	650
Crosstie	16.4	16.4	68.9
Floor Beam	138	92	260
Bolster	310	314	-
Stringer	6.1	6.1	2.5

A one-third scale model of the stationary center sill car frame was constructed. The model was 202.1 inches long and 38.34 inches wide. The structural members spacing is presented in Fig. 8.1 and the properties of the corresponding structural members are listed in Table 8.2.

Table 8.2. Model Structural Members

Structural Member	I_{xx} (in.^{4}) Used	Required	Structural Shape
Side Sill	4.59	3.89	C 4 x 7.25
Center Sill	10.22	8.48	2-C 4 x 5.4 with 1/8"x 6" plate
Crosstie	.28	.21	C 2 x 1 x 1/8
Floor Beam	1.84	1.70	C 3 x 5.0
Bolster	4.12	3.83	2 C 3 x 6.0
Stringer	0.10	.08	2 C 1.25 x 1/2 x 1/8

All connections in the model were welded and the steel decking was not considered. The model was not an exact copy of the railroad car frame considered, but is a reasonable representation of a typical frame. The main longitudinal beams, center and side sills, are stiffer than in the box car frame considered. However, the intent of the model was 1) to verify the accuracy of the finite element program for different loading configurations, and 2) to study the effect of member deterioration on the model and how to model it in finite element code.

8.3 Model Instrumentation

The model was instrumented with strain gauges at several locations and in two stages. The first stage consisted of placing 15 Micro

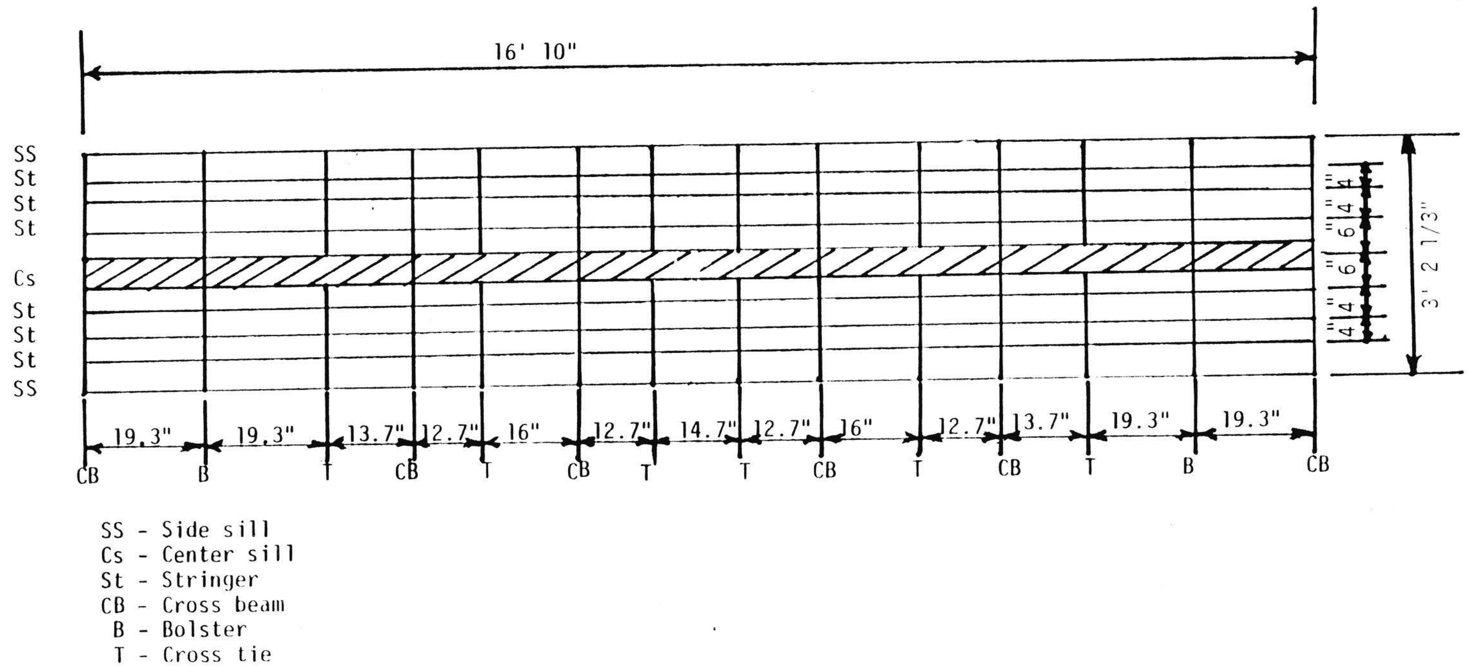


Fig. 8.1 Structural Member Spacings

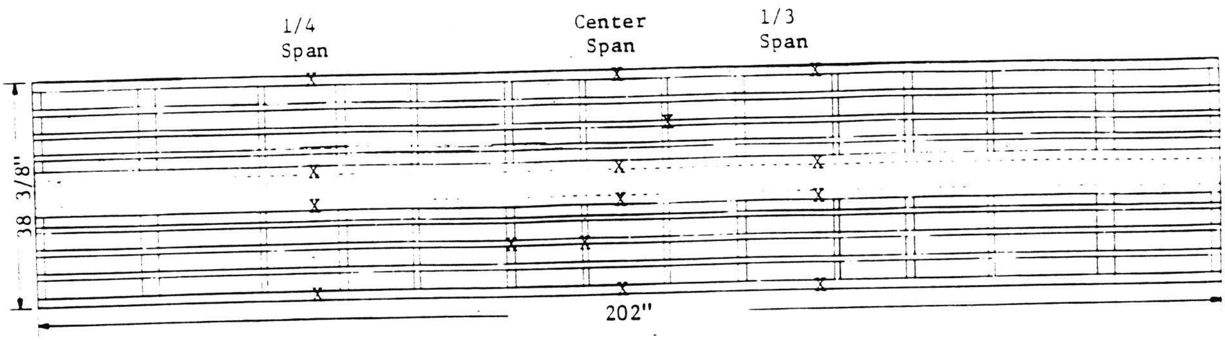
Measurements CEA-06-250UW-350 strain gauges at the one-quarter, center-line and one-third points along the length of the model. See Figure 8.2. The gauges were placed on the bottom side of the model and measured the tensile strain in the side and center sills. One gauge was placed on the cross beam and very low strain readings were obtained from this gauge. The second stage of strain gauge application included the placement of additional strain gauges on the center sill and side sills. The side sill was instrumented with gauges on the top and bottom flanges at the one-third, center line, and one-quarter points. The center sill gauges were placed on both bottom flanges and three gauges on the top section; one near each edge and one centered. See Figure 8.3 and 8.4 for gauge locations.

8.4. Model Load Points

The model was subjected to three types of load; single axle, tandem axle, and point loads. The loads were applied up to nine locations, which are listed in Table 8.3.

Table 8.3. Load Locations

Load type	Location	
	Along Length	Along Width
Single Axle	1/4, Center line, 1/3	Centered
	1/4, Center line, 1/3	Off to East side
	1/4, Center line, 1/3	Off to West side
Tandem Axle	1/4, Center line, 1/3	Centered
	1/4, Center line, 1/3	Off to East side
	1/4, Center line, 1/3	Off to West side
Point	1/4, Center line, 1/3	Along East edge
	1/4, Center line, 1/3	Centered
	1/4, Center line, 1/3	Along West edge

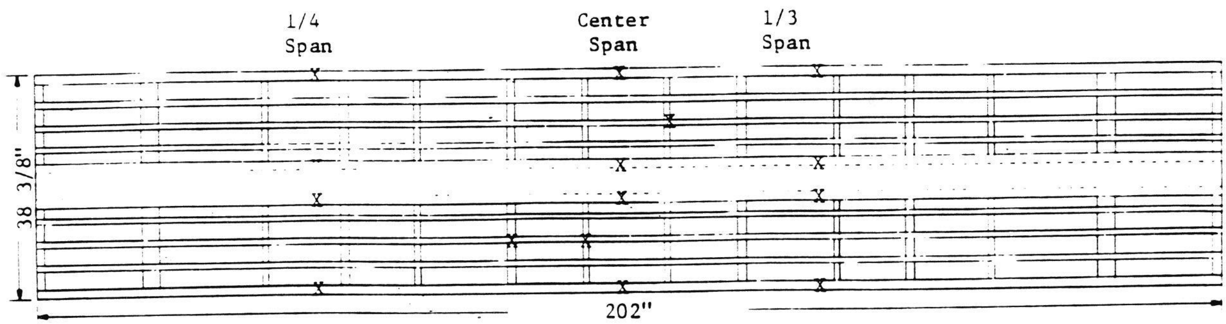


Plan View

West Side Sill	4	9	15
Center Sill	3	8	14
	2	7	13
East Side Sill	1	6	12

Corresponding Tension Gauge Numbers

Fig. 8.2 First Stage Gauge Numbers and Location



Plan View

West Side Sill	7	19	30
Center Sill	3	17	28
		13	25
East Side Sill	1	12	23

Corresponding Tension Gauge Numbers

Fig. 8.3 Second Stage Gauge Numbers and Location

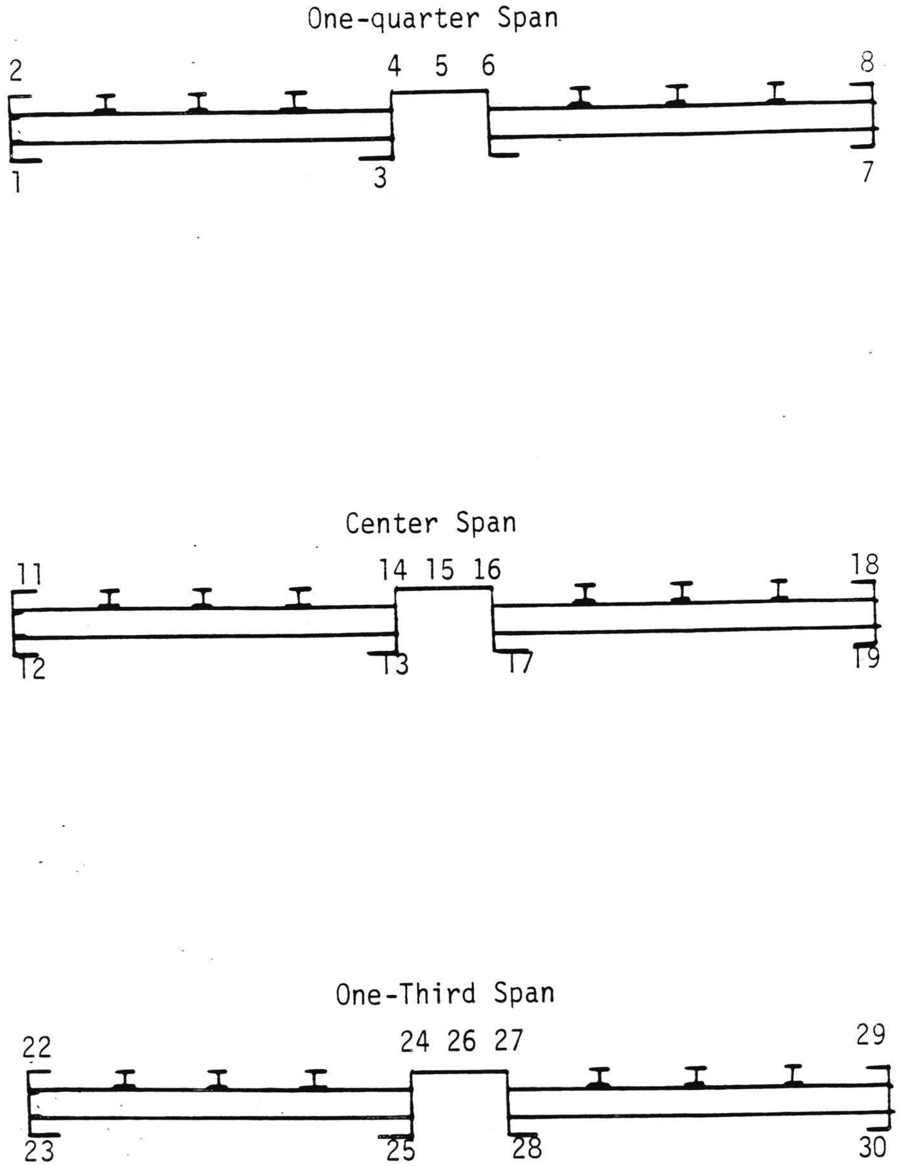


Fig. 8.4 Strain Gauge Locations and Numbers

8.5 Model Tests

The model was subjected to three different sets of tests. The first test was the placement of a single and tandem axle at the locations listed in Table 8.3. This test was used to calibrate the finite element analysis. The second test was to study the effect of the single axle positioned centered and along one edge of the model. This test was used to determine the worst possible axle loading condition. The third test cycle was the application of a point load on the model at nine locations with additional side sills connected to the model. This studied the effect of two railroad cars being bolted together in the field.

8.6 Model Calibration

The model calibration consisted of loading the model with four point loads representing a single truck axle with dual tires. The load spacing was modeled from AASHTO standard wheel spacing for bridge design. The axle load points are listed in Table 8.3. The tests were repeated for the tandem axle set. A 2400 pound load was placed on the single axle and a 3800 pound load on the tandem axle.

The results of the axle tests were compared to the predictions made by the finite element analysis. The finite element analysis was calibrated by varying the modulus of elasticity from 29×10^6 to 32×10^6 psi. The results are presented in Appendix E. For the tandem axle case, there was up to ten percent difference between the measured strain and the calculated strain using Equation 8.1.

$$\text{Strain} = (\text{Moment})(C)/[(I_x)(\text{Elastic Modulus})] \qquad \text{Equ. 8.1}$$

For the side sill, C was set equal to one-half the side sill depth and C for the center sill was calculated based on its shape. Similar correlations were noted for the single axle study. It was determined that the best modulus of elasticity to use was 32×10^6 psi.

To verify the selection of the modulus of elasticity, a deflection study was performed on the model. Deflections were measured at mid-span and centered and on the west edge with respect to the width. The single axle was positioned at mid and one-third span positions and with it centered and along the west edge with respect to the width. Measured deflections versus load are presented in Figure 8.5 along with the calculated deflection from the finite element analysis for several modulus of elasticity. A complete set of graphs for all load cases considered is given in Appendix E. Again, modulus of elasticity of 32×10^6 produced the best correlation.

The elastic behavior of the model was checked by incrementing the loading from 0 to 5000^+ pounds and noting the deflections and strains in several strain gauges. A plot of the strains is presented in Figure 8.6. The deflections are presented in Figure 8.5 and Appendix E. As noted in the figures, linear or near linear graphs were obtained which indicate an elastic behavior in the model up to 5000 pounds for a single axle load.

8.7 Single Axle Tests

The objective of the single axle test was to determine the worst possible loading case for the load rating program. That is, should the truck be centered on the car or positioned along the edge of the car? In this test the single axle was positioned at the center and along the edge with respect to the width of the car for the one-quarter span, Section A,

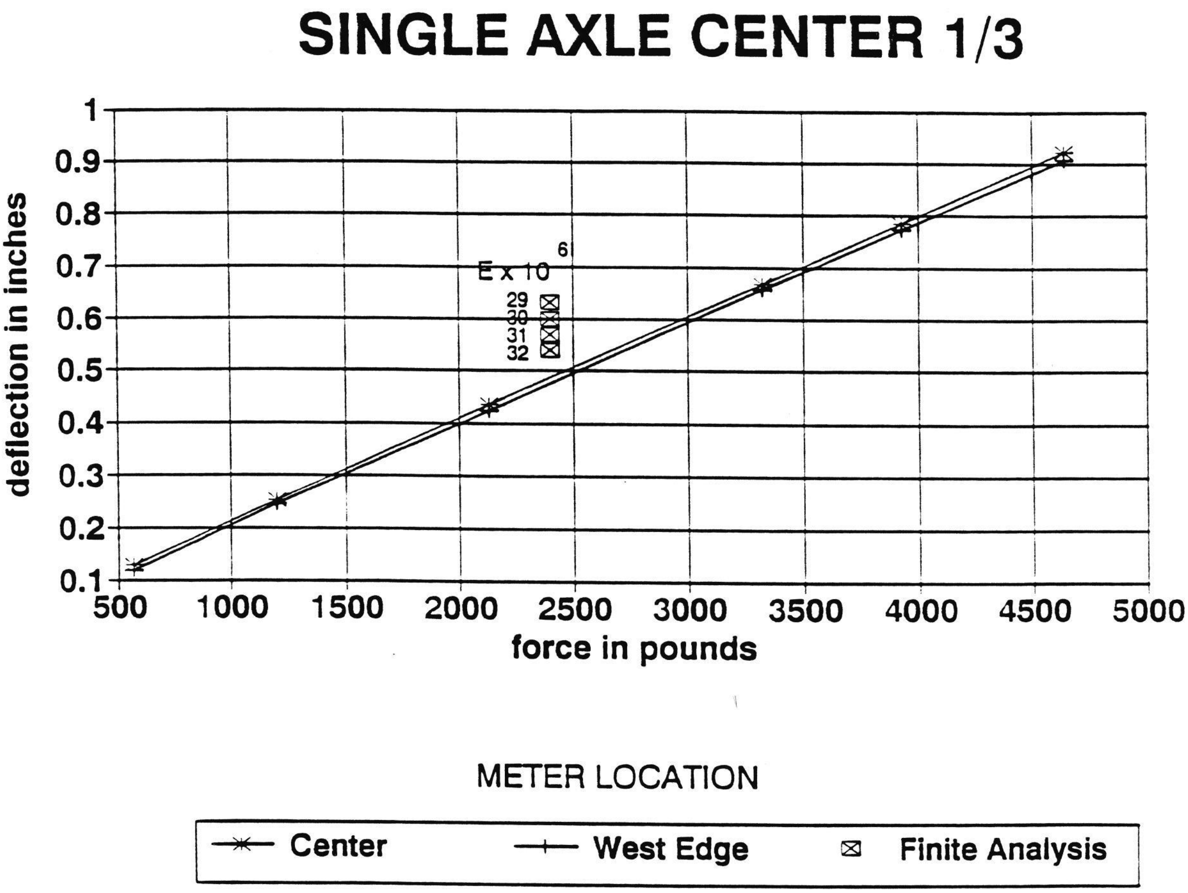


Fig. 8.5 Model Deflection Versus Load

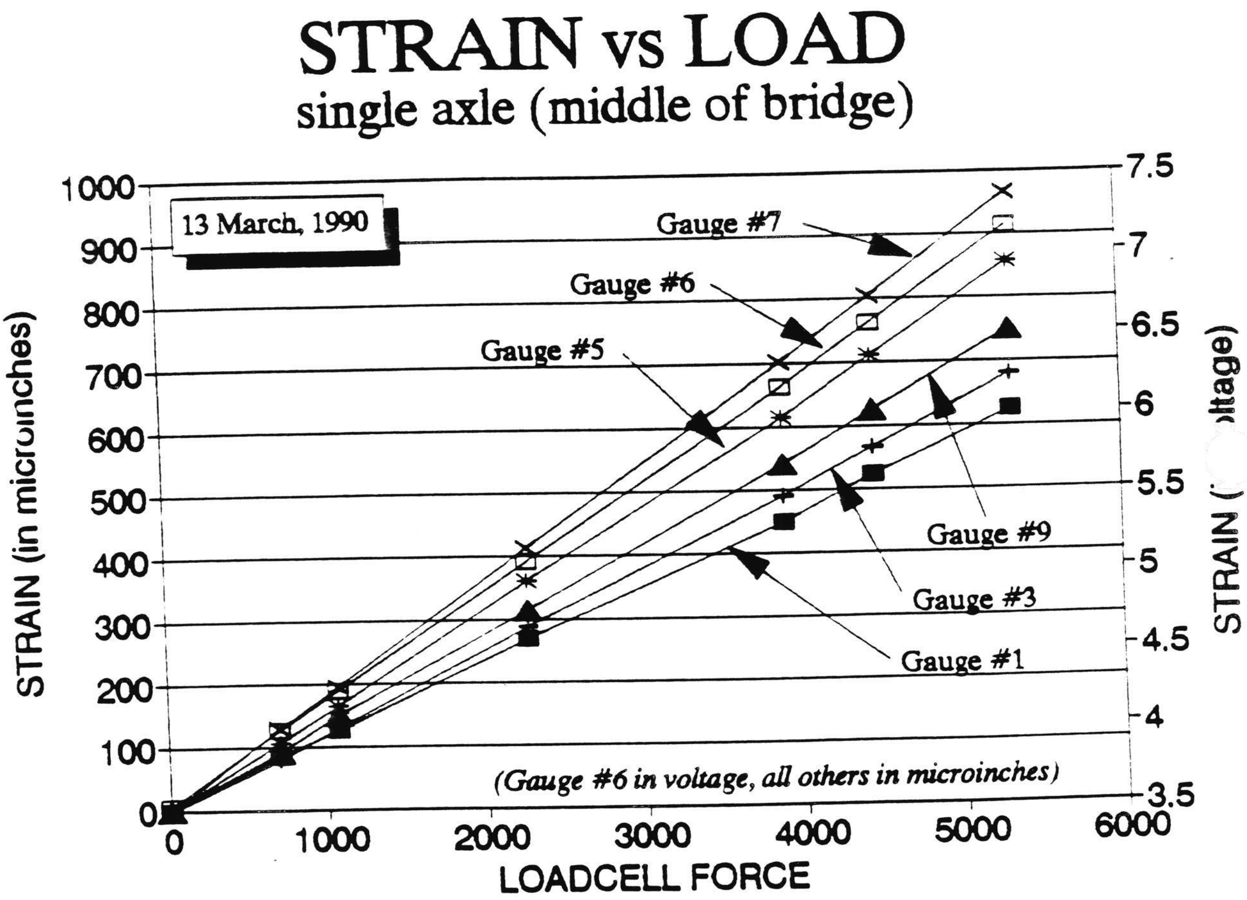


Fig. 8.6 Model Strain Versus Load

center of span, Section B, and one-third span, Section C locations. A sample of the results are presented in Table 8.4 and the full set of results is presented in Appendix E. The tests revealed that the worst loading case or maximum strains were obtained when the single axle was positioned at mid span and along the edge of the car. This was true for both the center sill and side sill.

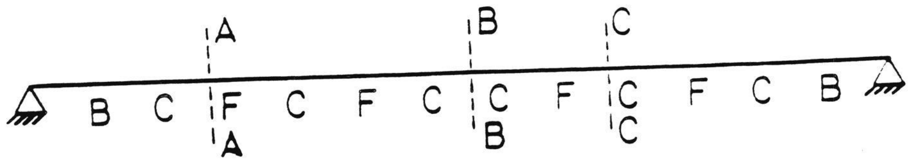
The laboratory strains were compared to the predicted strains using the finite element analysis for all load cases. The comparisons are presented in Table 8.4 and Appendix E. The strains were generally within ten percent of each other. The maximum error occurred at the strain gauge locations farthest away from the point of application of load. In all cases, the strains were within ten percent at the point of application of load or where the maximum strains occurred.

8.8. Multi-Side Sills

The objective of this series of tests on the model was to study the effect of two railroad cars being tied together by a series of bolts between the side sills. This was accomplished by bolting a second channel of same dimensions to a side sill. The channel was positioned so that webs were next to each other. One set of tests was performed with the channel bolted to the east side sill. A second set of tests was conducted with channels bolted to both side sills. The loading consisted of simulating dual tires positioned at Sections A (quarter span), B (mid-span), and C (third span), and at both edges and centered with respect to the width at each section.

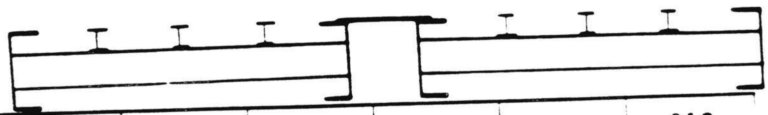
The testing was performed in two stages. The first was the testing of the model with the point load along the east edge of the model, then re-

Table 8-4
Single Axle Load Test



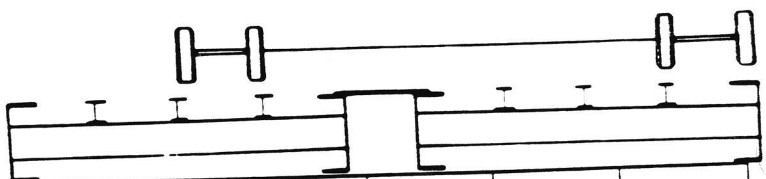
Measured Strains 10^{-6}

Section A-A



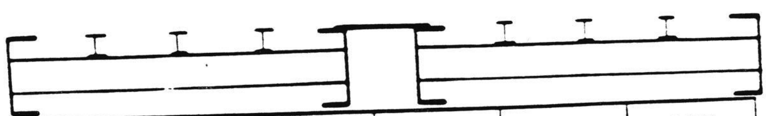
Analysis	179		216			210
Measured	173		237			191
% Difference	3.5		-8.9			9.9

Section B-B



Analysis	289		402	402		481
Measured	312		434	419		436
% Difference	-7.4		-7.4	-4.1		10.3

Section C-C



Analysis	233		287	287		287
Measured	227		293	332		297
% Difference	2.6		-2	-14		-3.4

testing the model with an additional channel bolted to the side sill. The channel was bolted at the midpoint between every second cross beam. A 5/16 inch bolt was used with a nut as a spacer between the channels. The nuts were only finger tightened.

The test results were compared to the finite elements analysis and are presented in Appendix E. The following was observed with the point load at section A and positioned on a single channel, then on the double channels.

1) At section A, for the single channel case, the finite element analysis under predicted the strain at the point of load by 22 percent and over predicted the strain at the other side sill by 200 percent.

2) At section B for the single channel case, the finite element analysis under predicted the strain on the loaded side of the car by 40 percent and over predicted the strain at the other side sill by 158 percent.

3) At section C for the single channel case, the finite element analysis under predicted the strain on the loaded side of the car by 43 percent and under predicted the strain at the other side sill by 12 percent.

4) At section A for the double channel case, the finite element analysis over predicted the strain at the loaded side of the model by 52 percent and under predicted the strain at the other side sill by 49 percent.

5. At section B for the double channel case, the finite element analysis over predicted the strain by seven percent and under predicted the strain at the other side sill by 20 percent.

6. At section C for the double channel case, the finite element analysis under predicted the strain by 27 percent and under predicted the strain at the other side sill by 40 percent.

For the single channel case, similar behaviors were noted for the point load at sections B and C and the following observations for the double channel case.

1. With the load at section B or mid span, the finite element analysis under predicted the strain at the loaded side of the model and over predicted at the other side sill.
2. With the load at section C or one-third span, the finite element analysis was under and over predicted the strain at the load side of the model and under predicted the strain at the other side sill.

As observed, the finite element analysis was not accurate when the model was subjected to torsional behavior. This behavior was introduced by the point load being positioned on a side sill. It was observed that the analysis appeared not to be torsional stiff enough in the single channel case since it under predicted the strain at the load side of the model and over predicted the strain at the other side sill. Therefore, too much moment was being transmitted to the non-loaded side of the frame. However, in the double channel case, it appeared that the analysis was too torsionally stiff since it over predicted at the loaded side and under predicted on the non-loaded side of the model. The only change in the analysis was that the strong axis moment of inertia was doubled in the elements which composed the side sill with the double channel. It was felt that this was a proper alteration since there was only a shear connection between the two channels at the center of the web.

The second stage of testing consisted of 1) moving the point load to the center of the model with respect to its width, and 2) moving the load to the other side sill and testing with one and two double side sill or channels. The results are presented in Appendix E. The following trends were observed.

1. Point load at the center of the model with respect to the width:
   (a) With one double side sill, the strain at the double side sill ranged from 69 to 72 percent of the strain at the opposite side sill in the model where there was only one side sill. The average difference was 77 percent.
   (b) With two double side sills, the strain was approximately equal at the two sides of the model.
2. Point load at the edge of the model over the single side sill.
   (a) The strain at the load ranged from 11.3 to 14.0 times the strain at the non-loaded side when there was one double side sill.
   (b) The strain at the other cross sections on the loaded side of the model ranged from 1.3 to 6.9 times the strain at the non-loaded side when there was one double side sill.
3. Point load at the edge with two double sills.
   (a) The strain at the load ranged from 11.4 to 13.8 times the strain at the non-loaded side.

(b) The strain at the other cross sections on the loaded side of the model ranged from 1.4 to 6.2 times the strain at the non-loaded side.

It could be observed when the load was at the center of the model with respect to its width, the strain at the double side sill was more than expected. One would expect the strain to be little over half of the strain at the opposite side sill. If the moment of inertia doubles, the strain should decrease by two. However, the stiffer side should carry more moment, but in some cases, the two strains were almost equal. Second, it was observed that with the point load at the edge of the model, the difference in strains between one and two double side sill remained approximately the same.

CHAPTER 9

DESTRUCTIVE TESTING

9.1 Objective

The objective of the destructive testing of the model was to determine the accuracy of the finite element analysis in predicting the behavior of the model when it had been damaged. The damage consisted of removal of some pieces of flange in the side sills and simulating cracks in the side sills and center sill. The damage to the model would simulate the corrosion of flanges and cracked members in the field bridges. The destructive testing simulated extreme measures such as main structural members almost severed.

9.2 Destructive Tests

A series of eight destructive tests were carried out on the model. The tests were designed so that six independent damage series could be conducted. That is, the model was damaged and then repaired back to the original state. To verify the model was back to the original state, a series of load tests were conducted before any further damage was done. It was found that in all cases, the model exhibited the same behavior after the repair as it did before any damage had occurred.

The set of destructive tests consisted of four basic steps. The first step was to test the model before any damage was done. The second was to cut through or remove the bottom flange. The third was to cut to about half the depth of the web. The last step was to cut the web to the point of intersection with the top flange.

Eight sets of tests were performed on the model. A description of the cuts sequence for each set of tests is presented in Table 9.1. The location of the tests are presented in Figure 9.1. For each set of tests, the model was loaded with the single axle centered with respect to the width at one-quarter of the span and at mid-span. Strain gauge readings were recorded at approximately 1000 and 2000 pound loads on the axle. A sample of the test results are presented in Table 9.2 and the full set of results are given in Appendix F.

9.3 Finite Element Analysis

For each damage series, a finite element analysis was performed. The analysis was achieved by modifying the beam element data at the corresponding location where the damage was done. The element stiffness data was modified by re-calculating the strong axis moment of inertia. This was achieved by only taking into account the remaining steel or all uncut cross sectional area. The results of the analysis are presented in Appendix F. Only the tensile strain gauge results are presented. The results are expressed as a percentage of the strain gauge readings and a positive number means the percent over prediction and the negative number means percent under prediction by the analysis.

9.4 Findings

The series of destructive tests revealed that there was good agreement between the strains measured in the model and the strain predicted by the finite element analysis when there was limited damage. That is, when the flange was cut or removed. However, when half of the depth of the web was cut, in some cases the predicted strains were up to

Table 9.1
Damage Details

Test	Member Type	Depth of Cut from Bottom of Flange A	B	C
D1	East Side Sill	0.25	1.39	3.36
	Remove 7 3/8" of flange			
Repair to Original				
D2	East Side Sill	0.25	1.39	3.50
Repair to Original				
D3	East Side Sill	0.26	1.39	3.42
Then Cut				
D4	West Side Sill	0.28	1.37	3.53
Repair to Original				
D5	East Side Sill	0.30	2.04	3.49
Repair to Original				
D6	East Side of Center Sill	0.42	1.83	3.40
Then Cut				
D7	West Side of Center Sill	2.03	3.10	
Repair to Original				
D8	East Side Sill	0.25		
	Remove 16" of Flange			

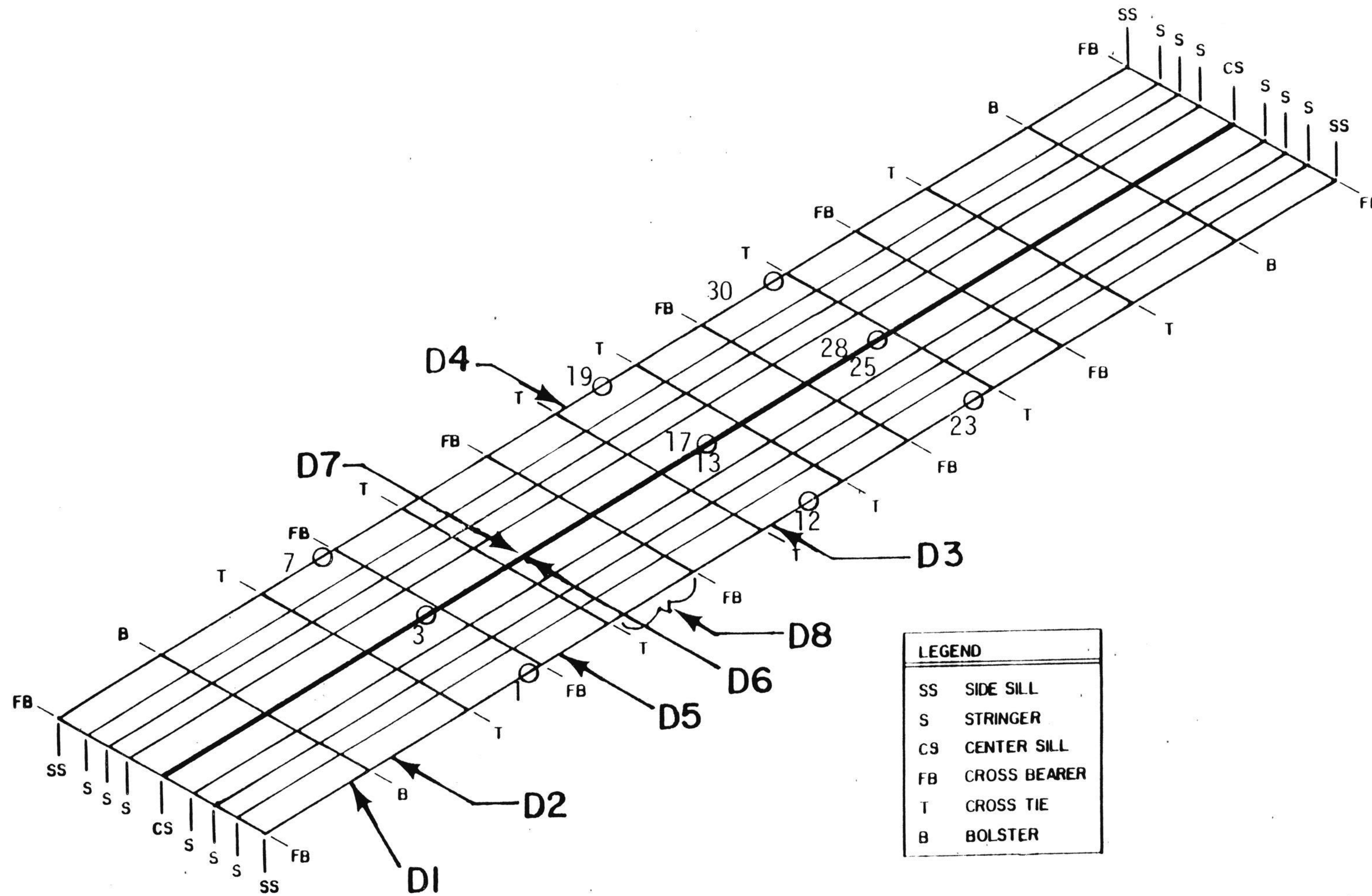
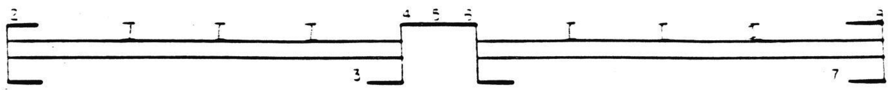


Fig. 9.1 Destructive Test and Strain Gauge Locations

Table 9-2
Damage Test D3 Test Results

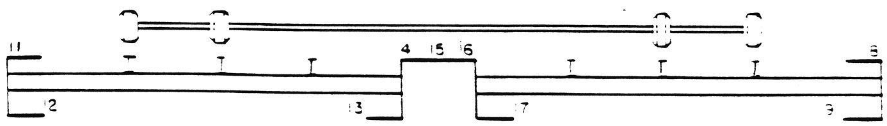
LOADED AT CENTER OF SPAN

Gauge No.	DNO		D3A		D3B		D3C	
1/4 Point	1011 lb	2005 lb	1005 lb	2035 lb	1011 lb	1994 lb	989 lb	1994 lb



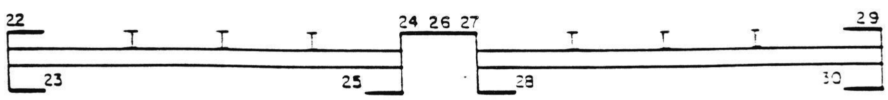
1	76	151	74	148	67	134	30	66
2	-53	-106	-53	-105	-48	-94	-23	-49
3	91	184	92	188	90	179	82	167
4	-45	-90	-45	-91	-45	-90	-47	-97
5	-43	-86	-44	-88	-43	-87	-48	-96
6	-49	-96	-48	-98	-50	-99	-59	-114
7	75	151	76	156	76	153	93	186
8	-52	-106	-53	-110	-56	-111	-73	-145

Centerline



11	-113	-225	-124	-249	-116	-231	-48	-102
12	153	308	143	288	122	243	26	63
13	173	343	172	351	177	351	231	460
14	-95	-188	-97	-196	-100	-198	-118	-236
15	-130	-254	-131	-268	-134	-268	-170	-340
16	-87	-168	-85	-172	-87	-173	-122	-242
17	177	345	188	371	182	361	213	428
18	-124	-241	-123	-251	-123	-243	-111	-224
19	165	321	161	335	161	324	155	299

1/3 Point



22	-78	-151	-76	-155	-70	-140	-41	-81
23	106	206	101	209	94	180	47	98
24	-62	-120	-60	-125	-61	-116	-62	-123
25	124	242	123	258	128	241	155	291
26	-58	-114	-58	-121	-60	-113	-68	-130
27	-58	-112	-58	-121	-59	-113	-70	-133
28	126	244	124	258	128	241	144	275
29	-79	-153	-79	-162	-80	-152	-89	-170
30	110	214	109	226	110	209	120	230

25 percent over or under the true strains. The difference between the true or predicted strain widen even more when the web was cut to the intersection of the top flange.

Further investigation revealed that the percent error between the true and predicted strain values could be correlated with the shift in the location of the neutral axes. The location of the neutral axes was calculated using the compressive and tensile strain readings at several points in the model. The findings are presented in Appendix F.

A detailed summary of the observed behaviors for each series of test are as follows:

Test D1: In test D1, it was observed that the series of cuts in the side sill had no impact on the model.

Test D2: Test D2 had an impact on the behavior of the model and the finite element analysis was able to predict this behavior. The cuts were made by the bolster on the side toward the center of the model.

Tests D3 & D4: These tests had a major impact on the model. The cuts were made in the side sills near mid-span. Tests D3A and D3B had an impact that could be predicted by the analysis program. However, tests D3C and D4(A,B,C) had results that were up to 97 percent in error. Further investigation revealed that the location of the neutral axis had shifted up to 0.78 inches in the 4 in. side sill. In the areas where the neutral axis shifted, the accuracy of the predictions decreased. This behavior was observed when the model was loaded at one-quarter span and mid-span and comparisons of these loading conditions for tests D3B and D3C are present in Appendix F.

Test D5: For this damage series, cuts were made in the side sill near the one-quarter span points. Behavior of the model was reasonably predicted in this series of tests except at strain gauge 7 in tests D5B and D5C. In each case the analysis over predicted the strains. However, the moment at this location was not critical in predicting the bridge rating.

Tests D6 & D7 These series of cuts were made in the center sill approximately at one-third of the span. The cuts were between the strain gauges located at one-quarter and center span. These cuts had a major impact on the behavior of the model. The behavior in the model for cut D6A was well predicted by the analysis program. For test D6B the analysis over-predicted the strains in the center sill on both sides of the cut by 18 and 21 percent. The worst correlation was for test D6C. However, they improved for tests D7A and D7B when the center sill was almost severed. The error reduced to less than 30 percent for test D7B.

A shift in the neutral axis was also observed in this series of tests. The neutral axis shifted approximately one-half inch in the center sill in test D6C or when the error was maximum.

Test D8: Test D8 consisted of the removal of the bottom flange in a side sill at one-third of the span between the gauges located at one-quarter and mid-span. The behavior of the model was well predicted by the analysis program.

CHAPTER 10

Field Testing

10.1 Bridge Type and Locations

Four railroad car bridges, each constructed from different design of a railroad car frame, were field tested during the summer of 1990 in the Arkansas Ozark Mountains. The first bridge had a 81.6 foot clear span and was constructed from flat cars with tapered floor beams. The bridge was located in Independence County, Arkansas; Bridge No. 20581. The second bridge, No. 19896, was also located in Independence County and was constructed from flat cars. The span was 73.7 feet and the floor beams of a truss construction. The last two bridges were located in Izard County and constructed from box car frames. Bridge 3, No. 19908, was constructed from box cars with sliding center sills. The span was 45 feet with an interior support under one side sill. The last bridge, No. 19900, wa constructed from box cars with a stationary center sill. The bridge spanned 56 feet and the side sills were stiffened near mid-span.

10.2 Instrumentation

At each location, the bridge was constructed from two railroad cars placed side by side. The field testing consisted of placing 30 to 54 Micro-Measurements CEA-06-250UW-350 strain gauges on the structural frame of one of the cars. At each gauges location, two strain gauges were placed side by side. This was done in order to detect any malfunctioning strain gauges or strain gauge boxes. The location of the strain gauges for each bridge are listed in Appendix G. At Bridge 1, 27 pairs of strain gauges were mounted on the bridge. Since the data acquisition system could only read 30 gauges at one time, two sets of load tests we performed, one for each set of strain gauges. This was also done for Bridge 2 where 20 pairs of strain gauges were mounted. Bridge 3 had 11 pairs and eight single gauges mounted and 13 pairs and 4 single gauges were mounted on Bridge 4.

10.3 Loadings

The bridges were loaded by placing AHTD trucks on the bridges. Several load points were selected on the bridge. There were points such as mid-span, quarter or one-third spans, and over floor beams or cross ties. At each load point, the truck was positioned so it was either centered with respect to the width of the railroad car, or one set of duals and a front tire was positioned over either edge of the car. It was estimated that these truck positions would produce the maximum strains in the instrumented structural members.

The dynamic response of the bridge was also obtained by driving the trucks over the bridge at normal operation speeds. The data acquisition system continuously monitored the strain gauges for over seven seconds as the truck drove across the bridge. These results are presented as graphs in Appendix G.

10.4 Bridge No. 20581

This bridge was constructed by placing two flat cars with sloping or tapering floor beams side by side with an approximate 42 inch spacer between the cars. The spacer was constructed by welding 4 in. channels on approximately four feet centers between the two inside side sills. The channels were covered with a steel plate and the bridge was covered with a thin asphalt surface. The spacing of cross beams and dimensions of the structural members are presented in Appendix G, Figures G1 to G3. The locations of the strain gauges are given in Figures G1 and G4. The position of the truck rear axle for the three loading positions is presented in Figure G1.

The truck, provided by AHTD, for Bridge 1 was an empty two axle dump truck, No. 9793, weighing 11,000 pounds. The front axle weighed 4,800 pounds and the rear axle weighted 6,200 pounds with a wheel base of 11 ft. seven in. The dual tires on the rear axle was centered on 0, 13, 72 and 85 in. with the front tires centered on 77 in.

The recorded strains in micro in./in. are presented in Appendix G, Table G1. Each set of tests were repeated so that four strain gauge readings were obtained for each strain gauge location. In several cases there were less than 5 micro in./in. difference between the readings at each location.

There was a major buckle in the center sill at strain gauge locations 3, 8, and 9. Gauges 3 and 9 were located at the start and end of the buckle and gauge 8 was at the point of maximum buckle. The buckle was 2 in. long and approximately one in. out of line. An analysis of the recorded strains, when the load was located above the buckle, revealed that there was approximately a 45 percent increase in the measured strain as compared to the estimated strain. The estimated strain was obtained by averaging the strain at the ends of the buckle. The middle strain gauge, or gauge 8, was located approximately 14 inches from strain gauge 3.

Graphs of the strains in the center sill as when the truck drove across the bridge is presented in Figure 10.1. It can be observed that the strains at mid-span were smaller than at the other strain gauges locations. This is due to an increase in the moment of inertia of the center sill. The bottom plate of the center sill was spliced at this location. In order to reinforce the splice, a 9/16" cover plate was added

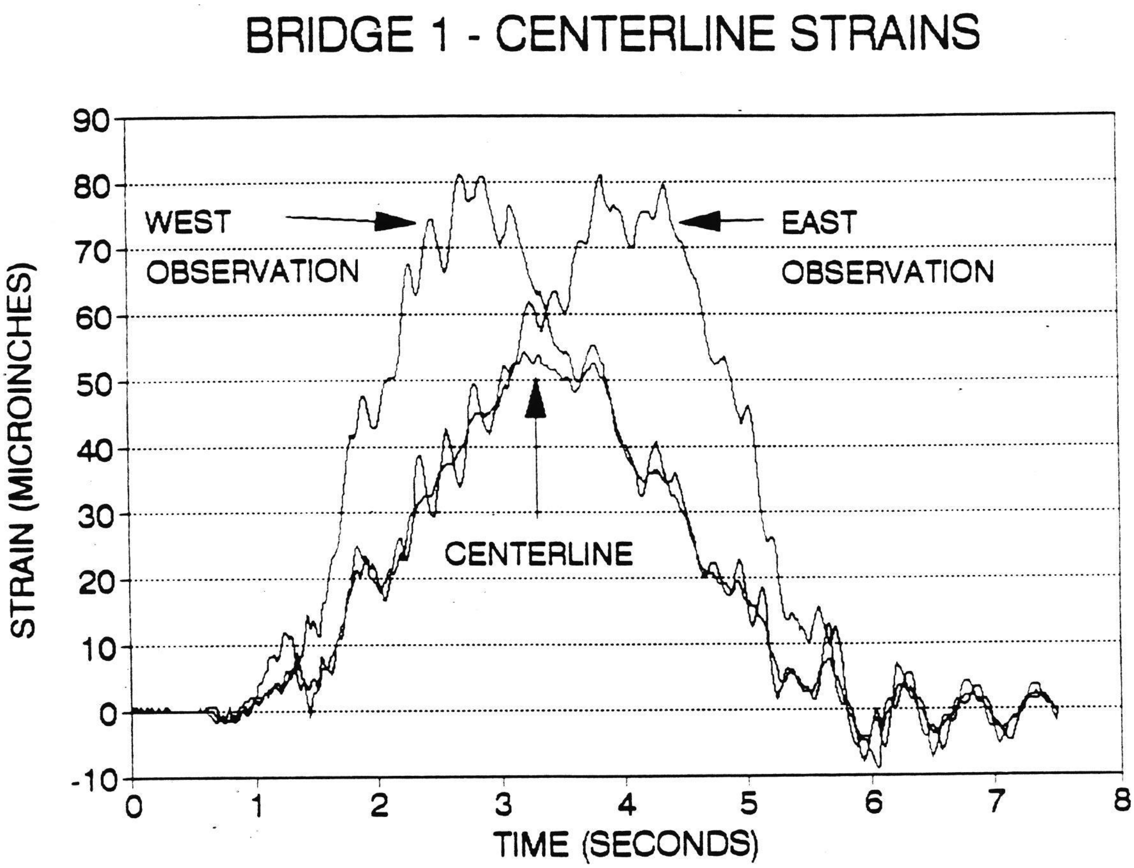


Fig. 10.1 Bridge 1 Center Sill Strains

thus increasing the moment of inertia and reducing the strains at this location. Graphs of strains at other locations are presented in Appendix G, Figures G5 through G7.

10.5 Bridge No. 19896

This bridge was constructed by placing two flat cars, with the floor beams reinforced by diagonal angle irons, side by side with a 3'10" spacer between the cars. The spacer was constructed from 7" channels welded to the side sills. The channels were covered with a steel plate and a 3" asphalt deck was placed on the existing steel deck. The spacing of the cross beams and dimensions of the structural members are presented in Appendix G, Figures G8 and G9. The location of the strain gauges are given in Figures G8 and G10 and the positions of the rear axle for the four loading positions is presented in Figure G8.

Two trucks were used to load the bridge. The first truck was No. 9793, or the truck used for the first bridge. The second truck, No. 8117, had the same dimensions and was loaded with gravel. The front axle weighed 7,700 pounds and the rear axle weighed 21,600 pounds.

The trucks were positioned, with respect to the width of the car, as either centered or with wheels positioned over the inside side sill. The strain readings in micro in./in. for the 29,300 pound truck are presented in appendix G, Tables G2 through G7, for load positions 1 to 3. The truck loading sequence was repeated twice.

It was observed from the strain gauge readings that the maximum strain reading in the center sill occurred when the rear axle was over the floor beam or Load Case 2, and center on the car with respect to the width of the car. It was also observed that the strains in the center sill at the location where it had a reduced height in cross section, section C-C, were less than the strains at other locations. Also, when the rear wheels of the truck were over this section, the strains were small. The largest strains in the inside side sill were recorded when the rear axle was over the crosstie and on the inside edge of the car. The strains measured 370 to 410 micro in./in. or approximately twice the maximum center sill strain.

The strains were also recorded when the truck drove across the bridge. Graphs of the strains are presented in Figures G11 to G17 in Appendix G. The graphs revealed that the strains in the center sill were more than the static load strains recorded for the truck when positioned at the edge of the car and less than the strains when positioned centered on the car. The strains in the inside edge side sill were approximately the same magnitude in the static and dynamic load cases. The maximum strains in the diagonal member of the floor beam were recorded for the member facing the center line of the bridge with respect to the width. This strain was about 140 micro in./in. in compression.

10.6 Bridge No. 19908

The construction of the bridge consisted of two box car frames with sliding center sills placed side by side. The steel decking of the box car served as the bridge deck. The bridge was unique in that one car had an interior support or pier. The pier also supported the inside side sill of the second box car frame of the instrumented frame. The spacing of the cross beams and dimensions of the structural members are presented in Figures G18 and G19 of Appendix G. The location of the strain gauges are presented in Figures G20 and G21. The load position are shown in Figure

G18. The load cases with respect to the width of the car included the truck center on the car and with one set of wheels over the inside side sill. The load sequence was repeated three times to check the consistency of the strain readings.

The truck used to load the bridge was a 13,300 lb. dump truck, AHTD No. 8115. The front axle weighed a 6,000 lb. and the rear weighed 7,300 lb. The front wheels were 78 in. on center and the rear wheels were 0, 12, 72, and 84 in. on centers. The trucks wheel base was 140 in.

The recorded strains in micro in./in. for the different truck loadings are presented in Table G8 through G13 in Appendix G. The maximum strains in the center sill were recorded for when the truck was center on the car with respect to the width of the car and the rear axle of the truck was at midspan. Both, the sliding and stationary center sills carried loads as indicated by the strain readings. The load ratir program was used to estimate strains and it over-predicted the strains. It should be noted that the program assumed the sliding center sill carries no load. It was observed that the sum of the stationary and sliding sill strains were close to the predicted strains. The maximum side sill strains were also recorded for this loading case. At center span, the analysis program over predicted the strains by 100 percent. At the side sill opposite the interior support, the analysis program predicted the average of the strains recorded.

The outside side sill, opposite the interior support, was damaged or buckled. In this case, the analysis program reasonably predicted the side sill strains. The beam was buckled in a manner so the moment of inertia was increased because there was more mass away from the neutral axis. However, the beam's moment of inertia was kept constant in the analysis.

Graphs of the strains as the truck drove across the bridge are presented in Figures G22 to G26. A review of the graphs revealed that the center sill dynamic strains were less than the strains for the static cases.

10.7 Bridge No. 19900

The bridge consisted of two box car frames, with a stationary center sill, placed side by side. The cars were bolted together on approximately eight ft. centers. The bolts were placed through a hole cut with a torch and not drawn tight. The car decking was used at the bridge deck. The spacing of the cross beams and dimensions of the structural members are presented in Figures G27 and G28 in Appendix G. The load positions are presented in Figure G27. The bridge was loaded with the same truck used for Bridge 19908, or the third field test. The truck was positioned center on the car with respect to the width and with the wheels over the inside side sill.

The recorded strain readings are presented in Tables G14 through G19 in Appendix G. The corresponding strain gauge locations for these readings are presented in Figures G30 and G31. The maximum strains in the center sill were obtained for the rear axle at center span. It was observed that approximately the same strain readings were obtained for the truck centered on the car or over the inside side sill. The maximum strains in the side sills occurred when the truck was in the following position: the rear axle was centered on the car with respect to the width and over the location where the side sill changed geometry. That is, the depth of the side sill changed from 10" to 18". This occurred at approximately 200" from the ends of the car. It was also observed that when the wheel loads were over the inside side sill, the strains recorded in the outside side sill or the side sill at the other end of the cross beam were equal or larger in magnitude. It should also be noted that the truck was not positioned over the outside side sill in this case. However, the maximum strains obtained were for the truck centered on the car with respect to the width.

Graphs of the strains as the truck drove across the bridge are presented in Figures G32 through G40. At center span the strains recorded in the center and side sills were approximately equal and less than the strains recorded for the static load cases except for the inside side sill. It was also observed that the strains in the side sills were less than the static load case for when the truck was centered with respect to the width of the car. This was also true when the truck was positioned over the inside side sill.

Strain gauges were also mounted at sections of the bridge where buckled beams were found. At these locations, no sharp increases in strain values were observed.

CHAPTER 11

SUMMARY AND DISCUSSION OF RESULTS

11.1 Scope of Project

The study was divided into two phases. The first phase consisted of 1) establishing the present and future usage of flat bed bridges in Arkansas and, 2) establishing a data base consisting of technical literature, member sizes, section properties and material strengths. The second phase of the project was to consist of developing a load rating program for railroad car bridges and verifying the program through laboratory and field testing.

11.2 Phase I Findings

Arkansas cities and counties were surveyed to determine the extent of use of railroad car bridges. Field visits were conducted which produced railroad car identification numbers and structural information was requested from several railroad companies.

11.2.1 Survey of Arkansas Cities and Counties

A survey instrument was sent to all cities and county judges in Arkansas, and follow-up surveys with county judges were conducted. The results indicated that the use of railroad car bridges was growing. Thirty-six of the 75 judges reported that railroad car bridges were being used in their counties, and that 167 railroad car bridges are in use in 1988, up from 74 reported in 1986. The judges report that 73 percent of the railroad cars used were flat cars and 24 percent were box cars with the sides removed.

Of the cities surveyed, none reported using railroad car bridges but 18 percent had considered using them.

Railroad car bridges in Fulton, Izard, Independence, Lee, Cleveland and Hot Springs counties were visited. Forty-three percent of the total bridges reported in the county survey were located in these counties. Twenty-seven bridges, 16 percent of the railroad car bridges in the state, were visited during the field trips. Fifty-two railroad cars were used to construct these bridges; forty-one were box cars, eight flat cars, and three gondola cars. Car numbers were found on nine box cars and eight flat cars.

The field visits revealed that 79 percent of the railroad cars were box cars and 15 percent were flat cars. These findings were surprising since the counties reported opposite numbers. Car identification numbers were found on 17 cars, or 33 percent of the cars inspected.

11.2.2 Car Manufacturers and Technical Literature

A survey of the railroads and the American Association of Railroad revealed that railroad cars are not manufactured then put up for sale. Instead, a railroad specifies a series of cars, tonnage, length, width, etc., then manufacturers bid for the sale.

11.2.3 AAR Specifications

Prior to 1964 each railroad had its own design standards. In September, 1964 the American Association of Railroads developed the Specifications for Design, Fabrication and Construction of Freight Cars. The only noted change in the specifications between 1964 and 1987 was the design loads. The draft load changed from 300,000 to 350,000 lbs and the compressive end load changed from 800,000 to 1,000,000 lbs. This would reflect the longer trains in use.

11.2.4 Technical Information Archive

Seventeen railroad car identification numbers were found during the field visits, nine on box cars and eight on flat cars. Drawings and specifications were obtained for six of the nine box cars but for none of the flat cars. Therefore, drawings were obtained for 12 percent of the cars identified during the field visits. Detailed drawings of structural members were obtained for five of the six cars. The drawings of the other car was incomplete and structural member sizes could not be determined. The drawings represent information related to four bridges out of the 167+ in Arkansas.

11.2.5 Railroad Analytical Models

All attempts to obtain the analytical models used by the railroads resulted in references to the AAR Specifications for Design,Fabrication and Construction of Freight Cars.

11.2.6 Data Archive

A limited summary of the six railroad car drawings was developed. It included structural member spacings, member dimensions and member specifications. A more comprehensive archive could not be developed due to:

1. Only a limited number of railroad cars could be identified during the field visits.
2. The location of only 74 of the 167 railroad car bridges were known at the time of the field visits. Twenty-seven bridges were visited and these bridges were constructed from 52 railroad cars.

Despite all efforts, reliable information was obtained for only five cars.

3. A review of AHTD bridge inspection forms revealed that the bridge inspection sheets produced as reliable information as the drawings provided by the railroads.

11.3 Phase 2 Findings

Software was developed which was designed to determine the load rating for a railroad car bridge. The load ratings were based on inventory and operating vehicles. The program was checked by 1) building and testing a one-third scale model of a railroad car frame, and 2) testing four bridges in the field. The results obtained from the model and field testing were compared to the predicted results obtained from the load rating program. Corrections were made as necessary.

11.3.1 Load Rating Program

The load rating program is based upon performing a finite element analysis on each railroad car used in the construction of the bridge. The software was designed so that the data from a bridge inspection would be used to produce the required finite element data files. The data consists of beam spacing, type of structural members, dimensions of the beams and the location and a description of damage to structure. The program would 1) develop the node points and element configuration, 2) determine the required beam element data, 3) load the finite element model with a unit truck, and 4) write the finite element data files. The bridge load rating is produced by a second software program which 1) calculates the structural capacity of each element, 2) subtracts the effect of the dead load, and 3) produces the load rating in terms of the number of unit trucks by dividing by the effect of a unit truck. Since the unit truck weighed one ton, the load rating is, therefore, in terms of tons. This process is repeated for each class of vehicle.

A third software program was written which permits easy modification to the finite element data files. The finite element data files are based upon there being no interior supports or damage to the structural members. To account for these conditions, the program would add supports and modify the element properties so damage could be simulated.

11.3.2 Scale Model Testing

A one-third scale model of a typical box car frame was constructed, instrumented, and tested. The objective of this task was to check the accuracy of the analysis program in predicting the behavior observed in the laboratory. The observed behavior consisted of measuring the strains at several locations in the model. This was achieved by developing instrumentation which sent noise-free signals from the strain gauge to a data acquisition system. The model testing consisted of loading the model with point loads, single axle loads, and tandem axle loads at several locations. Also, the effect of two railroad cars being bolted together was studied.

Comparisons between laboratory measured strains and calculated strains were developed. The calculated strains were determined by using the following equation:

$$\text{Strain} = M*C/(I_x*E) \qquad \text{Equ. 11.1}$$

M = results from finite element analysis

C = distance from neutral axis to the extreme fibers

I_x = moment of inertia

E = elastic modulas

It was found that an elastic modulas of 32×10^6 psi produced the best results. The calculated strains were within ten percent of the measured strains for single and tandem axle loads centered or positioned at the edge of the model (with respect to the width of the model). The worst loading case or maximum strains were obtained when the single axle was positioned at mid-span and along the edge of the frame.

The effect of two railroad cars being bolted together was obtained by adding an additional side sill to the model. This action did simulate the behavior observed in the field tests and resulted in analysis restrictions. It was found that the analysis did not accurately predict the behavior of the model when it was subjected to point loads which resulted in a torsion rotation of the model. The analysis over and under estimated the strains depending on the location of the load. However, the results were not critical for it was determined that this loading case did not produce the maximum strains. That is because the vehicle has to split its weight between the two cars to produce this loading effect and the maximum strains occurred when the vehicle was positioned at mid-span on one railroa car.

11.3.3. Damage Tests

A series of eight destructive tests were carried out on the scale model of the box car frame. These tests were carried out to determine the accuracy of the finite element analysis in predicting the behavior of the model when it had been damaged. The tests revealed that there was a good agreement between the strains measured in the model and the strains predicted by the finite element analysis when there was limited damage. The limited damage consists of the side sill bottom flange being removed or simulated cracks in main structural members to a depth of one-half the height of the web. The analysis program had limited accuracy when there was damage to a greater extent. The error in the analysis could be correlated with the shifting of the neutral axis in the region of the damage.

The tests revealed that the load rating program would produce accurate results when major structural members are buckled or the flanges are deteriorated due to severe rusting.

11.4 Field Testing.

Four railroad car bridges, each constructed from a different type of railroad car frame were field tested. The frames consisted of flat cars with tapered and trussed floor beams and box cars with stationary or sliding center sills. The bridges were constructed by placing two flat cars side-by-side with a center spacer or bolting the side sills of box cars together or just laying box cars next to each other.

The loading rating program did predict the behavior of the flat cars with reasonable accuracy. The spacer between the cars permitted the cars to act independently of each other. Thus, the load rating program should be used for each railroad car and the bridge loading based on the weakest car.

The analysis program was not as accurate when predicting the behavior of the bridges constructed from box cars. The program over estimated the strains in the bridge constructed with sliding center sill frames. It was assumed that the sliding sill would not carry load in the analysis program and the field data revealed that it did carry a significant percentage of the load. This behavior resulted in a conservative estimate of the capacity of the center sill. The other railroad car in this bridge had no effect on the analysis because the cars were not structurally tied together.

The last bridge, constructed from stationary center sill box car was unique in that the side sills were bolted together. The bolting of the sills together had a major impact on the behavior of the bridge. When trucks were positioned so that they directly loaded the inside side sill the field results showed the outside side sill across from the truck had an equal or greater strains. Therefore, the load was uniformly distributed by the composite behavior of the box car frame. However, the maximum strains were produced when the truck was centered on the car at mid-span. In order to obtain good agreement between the field data and the analysis program the moment of inertia of the inside side sill had to be doubled to account for the bolting action.

One of the loading conditions performed in the field was measuring the strains in the bridges as a truck drove under normal operating conditions across it. In all cases, the maximum static strains were greater than the observed strains. A reason for this was that the truck was carried by the two railroad cars and the static strains were obtained for the truck on one car.

CHAPTER 12

RECOMMENDATIONS AND IMPLEMENTATIONS

12.1 Software Application.

A major objective of this research project was to develop a mechanism which would result in load rating for railroad car bridges. This objective was achieved by the development of software which aided in the analysis and ratings of these bridges. It is recommended that the software be used for this purpose. The accuracy of the ratings have been checked by laboratory and field tests.

Field visits revealed that the majority of railroad car bridges consist of two railroad cars placed side by side. The normal driving lane consist of straddling both cars as one drives across the bridge. However, there exists a possibility that a vehicle may occupy one car only. Therefore, the software should be implemented for each car use to construct the bridge. The load rating should be based on the lowest obtained from either car. Also, if a spacer is used between the cars, the load capacity of the spacer should be checked and compared to the load rating obtained from the software programs, and the smaller value used.

12.2 Unanswered Questions.

All research projects have stated goals to be obtained. In the process of obtaining these goals questions are generally raised that have not been answered. These questions remain unanswered due to their limited impact on the goals of the project. These questions should be addressed as parts of future research studies along with their impact on the engineering field.

The major unanswered question in this project is the behavior of two railroad cars being bolted together. Field and laboratory tests revealed that when the wheels of the truck was over the inside side sill, the load was being transmitted throughout the railroad car frame. In many cases, strains were measured of greater magnitude in the outside sill than in the inside side sill where the load was being applied. Questions like how many cross beams are required to obtain this action? What type of connections are required? What is the impact of the decking? Can this action be used in the design of bridges so loads would be transmitted uniformly throughout the structure, thus resulting in lighter members? These are a few questions, if answered, which could have an impact on the future.

12.3 Training

Two areas of training need to be addressed. The first area is training the bridge inspector on how to log the required information needed for the implementation of the software. This should be accomplished by the development of a half-day short course describing the different types of railroad car bridges, what measurements need to be made, and how to document the observed damage to the structure so it could be accounted for in the analysis programs. This should be addressed, for the analysis program is only as good as the information fed into it.

The second area of training that needs to be addressed should be focused on the county judges who install these bridges. Some lessons were learned on how to improve the performances of these bridges in this study. The field visits revealed that the installation of many bridges could be improved. In many cases the foundations ranged from excellent to non-existing. Some bridges had guard rails and others had none. A training course or booklet should be developed which would stress the installation of these bridges so the maximum benefit toward the public safety could be obtained within the limited budgets under which these bridges are constructed. It is felt the county judges are doing the best they can with the limited engineering expertise they possess. A course or booklet could expand their knowledge and, thus, produce a safer bridge for the general public.

REFERENCES

1. "Modular Steel Deck Bridges, Data and Specifications", Booklet 2268, Bethlehem Steel Corporation, Bethlehem, PA.
2. Taly, N. B., Gangarao H. V. S., "Development of Standardized Short Span Bridges", ASCE Annual And National Environmental Engineering Convention, October 21-25, 1974, Meeting Preprint 2407.
3. "Railroad Car Bridges: Asset or Liability?", Bruce Suprenant, Montana Rural Technical Assistance Program, Montana State University, Department of Civil and Agricultural Engineering, Bozeman, Montana 59717, May 1987.
4. "Railroad Cars Offer Option for Economical Bridges," B. Suprenant, Roads and Bridges, November 1987, pp 58-61.
5. "Manual of Standards and Recommended Practices, Section C - Part II", Association of American Railroads, M-1001, Volume 1, January 1987, Washington, D.C.
6. "Manual of Standards and Recommended Practices, Section C - Part II", Association of American Railroads, M-1001, Volume 2, September 1, 1985, Washington, D.C.

Appendices

A--Survey Forms

B--Mechanical Properties

C--Loading Conditions

D--Railroad Car Data

E--Model Calibration

F--Model Damage Tests

G--Field Tests

Appendix A

Survey Forms

Name________________________________

County______________________________

City________________________________

1. Have you considered using railroad cars as short span bridges?

   Yes_______

   No________

2. Have you used railroad cars for short span bridges?

   Yes_______

   No________Go to question 12.

3. How were you informed about the use of railroad cars as short span bridges?

   From a friend_______

   From a supplier______

   From a published article_______

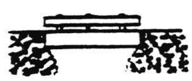
   Saw one in place_______

   Other. Explain____

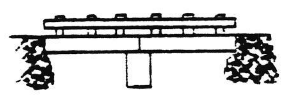
4. How many railroad car bridges do you have in place?____________

5. How many of these bridges are:

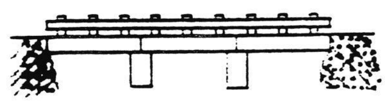
   a. Single span________



   b. 2 span________



   c. 3 or more span________



6. How many bridges are:

   a. 1 car wide_______

   b. 2 cars wide______

   c. 2 cars wide plus a spacer between cars________

7. How many bridges have span lengths (ft.):

0 - 20 _______	31 - 35 _______	46 - 50 _______
21 - 25 _______	36 - 40 _______	51 - 55 _______
26 - 30 _______	41 - 45 _______	56 or more_____

8. Did you consider thermo expansion joints in the placement of the bridges?

Yes______

No ______

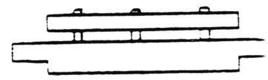
If yes what type of joint did you use?____________________________

9. How are the cars fastened to the abutment?

a. Cast into the concrete abutment________

b. Placed on top of the abutment________

c. Beams were notched in order to fit on the abutment___________



d. Other (explain)____

10. (a) From whom did you purchase the cars?

(b) Did they provide any structural information related to the cars?

Yes_______

No________

If yes, what type of information___________________________________

11. Are the cars:

Flat cars________

Box cars with tops removed__________

Other type of cars with sides removed_________

12. Would a short course discussing methods of car selection and installation be useful?

Yes_______

No________

13. Please include additional comments concerning railroad car bridges, such as type of additional information needed, reasons for using this type of bridge over other types, etc.

Survey Summary

	Arkansas	Ashley	Baxter	Benton	Boone	Bradley	Calhoun	Carroll	Chicot	Clark	Clay	Cleburne
1. Have you considered using railroad cars as short span bridges?	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	N
2. Have you used railroad cars for short span bridges?	Y	Y	N	N	-	N	-	N	N	Y	Y	-
3. How were you informed about the use of railroad cars as short span bridges?												
Friend	-	-	-	-	-	-	-	-	-	-	Y	-
Supplier	Y	-	-	-	-	-	-	-	Y	Y	-	-
Published article	-	-	-	-	-	-	-	-	-	-	-	-
Saw one in place	Y	-	-	-	-	-	-	-	-	Y	Y	-
Other	-	-	-	-	-	-	-	-	-	-	-	-
4. How many railroad car bridges do you have in place?	3	4	-	-	-	-	1	-	-	4	5	-
5. How many of these bridges are:												
Single span	3	4	-	-	-	-	-	-	-	-	5	-
Double span	-	-	-	-	-	-	-	-	-	4	-	-
Triple span	-	-	-	-	-	-	-	-	-	-	-	-
6. How many bridges are:												
1 car wide	-	-	-	-	-	-	-	-	-	4	-	-
2 cars wide	3	4	-	-	-	-	-	-	-	-	5	1
2 cars wide + spacer between cars	-	-	-	-	-	-	-	-	-	-	-	-
7. How many bridges have span lengths (ft.)												
0-20	-	-	-	-	-	-	-	-	-	-	-	-
21-25	-	1	-	-	-	-	-	-	-	-	1	-
26-30	-	-	-	-	-	-	-	-	-	-	-	-
31-35	-	-	-	-	-	-	-	-	-	-	-	-
36-40	-	-	-	-	-	-	-	-	-	-	1	-
41-45	-	-	-	-	-	-	-	-	-	-	-	-
46-50	-	-	-	-	-	-	-	-	-	-	-	-
51-55	1	3	-	-	-	-	-	-	-	2	2	1
56 or more	2	-	-	-	-	-	1	-	-	2	1	-
8. Did you consider thermo expansion joints in the placement of the bridges?	N	-	-	-	-	-	-	-	-	N	N	-
9. How are the cars fastened to the abutment?												
Cast into concrete abutment	-	2	-	-	-	-	-	-	-	-	-	-
Placed on top of abutment	3	2	-	-	-	-	-	-	-	-	?	Y
Beams notched to fit abutment	-	-	-	-	-	-	-	-	-	-	?	-
Other	-	-	-	-	-	-	-	-	-	-	-	-
10. Did vendor supply structural info?	Y	-	-	-	-	-	-	-	-	N	N	-
11. Are the cars:												
Flat cars	2	-	-	-	-	-	-	-	-	4	5	1
Box cars with tops removed	1	4	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-

Survey Summary

	Cleveland	Columbia	Conway	Craighead	Crawford	Crittenden	Cross	Dallas	Desha	Drew	Faulkner	Franklin
1. Have you considered using railroad cars as short span bridges?	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	Y
2. Have you used railroad cars for short span bridges?	Y	N	N	N	Y	Y	Y	-	N	N	Y	Y
3. How were you informed about the use of railroad cars as short span bridges?												
Friend	-	-	-	-	Y	-	-	-	-	-	-	-
Supplier	Y	Y	-	-	-	-	-	-	-	-	-	-
Published article	-	-	-	-	-	Y	-	-	-	-	-	-
Saw one in place	-	-	-	-	-	-	-	Y	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	Y	-
4. How many railroad car bridges do you have in place?	10	-	-	-	3	3	1	6	-	-	8	-
5. How many of these bridges are:												
Single span	3	-	-	-	3	3	1	-	-	-	8	-
Double span	7	-	-	-	-	-	-	6	-	-	-	-
Triple span	-	-	-	-	-	-	-	-	-	-	-	-
6. How many bridges are:												
1 car wide	3	-	-	-	-	-	-	5	-	-	-	-
2 cars wide	7	-	-	-	3	3	1	1	-	-	-	-
2 cars wide + spacer between cars	-	-	-	-	-	-	-	-	-	-	8	-
7. How many bridges have span lengths (ft.)												
0-20	-	-	-	-	-	-	-	-	-	-	-	-
21-25	-	-	-	-	-	-	-	4	-	-	-	-
26-30	6	-	-	-	-	-	-	2	-	-	-	-
31-35	1	-	-	-	1	-	-	-	-	-	-	-
36-40	-	-	-	-	-	-	-	-	-	-	-	-
41-45	-	-	-	-	-	-	-	-	-	-	-	-
46-50	3	-	-	-	-	2	-	-	-	-	-	-
51-55	-	-	-	-	2	-	-	-	-	-	5	-
56 or more	-	-	-	-	-	1	-	-	-	-	3	-
8. Did you consider thermo expansion joints in the placement of the bridges?	N	-	-	-	-	N	-	N	-	-	N	-
9. How are the cars fastened to the abutment?												
Cast into concrete abutment	-	-	-	-	-	-	-	-	-	-	-	-
Placed on top of abutment	-	-	-	-	-	3	1	-	-	-	8	-
Beams notched to fit abutment	10	-	-	-	3	-	-	6	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-
10. Did vendor supply structural info?	Y	-	-	-	N	Y	-	Y	-	-	N	-
11. Are the cars:												
Flat cars	6	-	-	-	3	2	-	-	-	-	8	-
Box cars with tops removed	4	-	-	-	-	4	-	6	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-

Survey Summary

	Fulton	Garland	Grant	Greene	Hempstead	Hot Springs	Howard	Independence	Izard	Jackson	Jefferson	Johnson
1. Have you considered using railroad cars as short span bridges?	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N
2. Have you used railroad cars for short span bridges?	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	–
3. How were you informed about the use of railroad cars as short span bridges?												
Friend	–	–	–	–	–	Y	–	–	Y	–	–	–
Supplier	–	Y	–	–	Y	–	Y	–	–	–	–	–
Published article	–	–	–	–	–	–	–	–	–	–	–	–
Saw one in place	Y	–	–	Y	Y	Y	–	–	–	–	–	–
Other	–	Y	–	–	–	–	–	–	–	–	–	–
4. How many railroad car bridges do you have in place?	2	8	–	–	8	18	2	6	9	–	1	1
5. How many of these bridges are:												
Single span	2	8	–	–	–	17	2	6	8	–	1	–
Double span	–	–	–	–	8	–	–	–	1	–	–	–
Triple span	–	–	–	–	–	1	–	–	–	–	–	–
6. How many bridges are:												
1 car wide	2	1	–	–	–	–	–	–	1	–	–	–
2 cars wide	–	2	–	–	8	18	2	6	1	–	1	–
2 cars wide + spacer between cars	–	5	–	–	–	–	–	–	7	–	–	
7. How many bridges have span lengths (ft.)												
0-20	–	–	–	–	–	–	–	–	–	–	–	–
21-25	–	–	–	–	–	–	–	–	–	–	–	–
26-30	–	1	–	–	–	4	–	–	–	–	–	–
31-35	–	2	–	–	–	–	–	–	–	–	–	–
36-40	–	2	–	–	–	4	–	–	–	–	–	–
41-45	–	–	–	–	–	3	–	–	–	–	–	–
46-50	–	–	–	–	–	5	–	–	7	–	–	–
51-55	–	–	–	–	–	–	–	–	–	–	1	–
56 or more	2	3	–	–	8	2	2	6	2	–	–	–
8. Did you consider thermo expansion joints in the placement of the bridges?	Y	N	–	–	–	N	N	–	N	–	–	–
9. How are the cars fastened to the abutment?												
Cast into concrete abutment	2	–	–	–	8	–	–	?	–	–	–	–
Placed on top of abutment	–	–	–	–	–	18	2	?	7	–	1	–
Beams notched to fit abutment	–	8	–	–	–	3	–	–	2	–	–	–
Other	–	?	–	–	–	?	–	?	–	–	–	–
10. Did vendor supply structural info?	Y	Y	–	–	Y	Y	–	Y	Y	–	Y	–
11. Are the cars:												
Flat cars	2	8	–	–	8	18	2	6	2	–	1	–
Box cars with tops removed	–	–	–	–	–	–	–	–	17	–	–	–
Other	–	–	–	–	–	–	–	–	–	–	–	–

Survey Summary

	Lafayette	Lawrence	Lee	Lincoln	Little River	Logan	Lonoke	Madison	Marion	Miller	Mississippi	Monroe
1. Have you considered using railroad cars as short span bridges?	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N
2. Have you used railroad cars for short span bridges?	Y	N	Y	Y	N	N	Y	-	N	N	Y	-
3. How were you informed about the use of railroad cars as short span bridges?												
Friend	-	-	-	-	-	-	-	-	-	-	-	-
Supplier	Y	-	-	Y	-	-	Y	-	-	-	Y	-
Published article	-	-	-	-	-	-	-	-	-	-	-	-
Saw one in place	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	Y	-	-	-	-	-	-	-	-	-
4. How many railroad car bridges do you have in place?	1	-	27	4	-	-	1	-	-	-	1	-
5. How many of these bridges are:												
Single span	1	-	27	4	-	-	1	-	-	-	1	-
Double span	-	-	-	-	-	-	-	-	-	-	-	-
Triple span	-	-	-	-	-	-	-	-	-	-	-	-
6. How many bridges are:												
1 car wide	1	-	-	-	-	-	-	-	-	-	-	-
2 cars wide	-	-	27	4	-	-	1	-	-	-	1	-
2 cars wide + spacer between cars	-	-	-	-	-	-	-	-	-	-	-	-
7. How many bridges have span lengths (ft.)												
0-20	1	-	-	-	-	-	-	-	-	-	1	-
21-25	-	-	-	-	-	-	-	-	-	-	-	-
26-30	-	-	-	4	-	-	-	-	-	-	-	-
31-35	-	-	-	-	-	-	-	-	-	-	-	-
36-40	-	-	-	-	-	-	-	-	-	-	-	-
41-45	-	-	-	-	-	-	-	-	-	-	-	-
46-50	-	-	17	-	-	-	-	-	-	-	-	-
51-55	-	-	-	-	-	-	-	-	-	-	-	-
56 or more	-	-	10	-	-	-	1	-	-	-	-	-
8. Did you consider thermo expansion joints in the placement of the bridges?	N	-	N	N	-	-	N	-	-	-	N	-
9. How are the cars fastened to the abutment?												
Cast into concrete abutment	1	-	-	-	-	-	-	-	-	-	-	-
Placed on top of abutment	-	-	?	4	-	-	1	-	-	-	1	-
Beams notched to fit abutment	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	?	-	-	-	-	-	-	-	-	-
10. Did vendor supply structural info?	Y	-	Y	Y	-	-	-	-	-	-	Y	-
11. Are the cars:												
Flat cars	1	-	?	4	-	-	1	-	-	-	-	-
Box cars with tops removed	-	-	?	-	-	-	-	-	-	-	1	-
Other	-	-	-	-	-	-	-	-	-	-	-	-

Survey Summary

	Montgomery	Nevada	Newton	Ouachita	Perry	Phillips	Pike	Poinsett	Polk	Pope	Prairie	Pulaski	Randolph
1. Have you considered using railroad cars as short span bridges?	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2. Have you used railroad cars for short span bridges?	N	Y	N	Y	Y	N	–	N	Y	N	N	N	Y
3. How were you informed about the use of railroad cars as short span bridges?													
Friend	–	–	–	Y	Y	–	–	–	Y	–	–	–	–
Supplier	–	–	–	Y	–	–	–	–	Y	–	–	–	–
Published article	–	–	–	–	–	–	–	–	Y	–	–	–	–
Saw one in place	–	–	–	–	–	–	–	–	Y	–	–	–	Y
Other	–	–	–	–	–	–	–	–	–	–	–	–	–
4. How many railroad car bridges do you have in place?	–	2	–	1	1	–	–	–	6	–	–	–	2
5. How many of these bridges are:													
Single span	–	2	–	–	1	–	–	–	6	–	–	–	2
Double span	–	–	–	–	–	–	–	–	–	–	–	–	–
Triple span	–	–	–	1	–	–	–	–	–	–	–	–	–
6. How many bridges are:													
1 car wide	–	1	–	1	1	–	–	–	2	–	–	–	2
2 cars wide	–	1	–	–	–	–	–	–	4	–	–	–	–
2 cars wide + spacer between cars	–	–	–	–	–	–	–	–	–	–	–	–	–
7. How many bridges have span lengths (ft.)													
0-20	–	–	–	–	1	–	–	–	–	–	–	–	–
21-25	–	–	–	–	–	–	–	–	–	–	–	–	2
26-30	–	–	–	–	–	–	–	–	–	–	–	–	–
31-35	–	–	–	–	–	–	–	–	–	–	–	–	–
36-40	–	–	–	–	–	–	–	–	–	–	–	–	–
41-45	–	–	–	–	–	–	–	–	–	–	–	–	–
46-50	–	1	–	–	–	–	–	–	3	–	–	–	–
51-55	–	–	–	–	–	–	–	–	–	–	–	–	–
56 or more	–	–	–	1	–	–	–	–	3	–	–	–	–
8. Did you consider thermo expansion joints in the placement of the bridges?	–	–	–	N	N	–	–	–	N	–	–	–	N
9. How are the cars fastened to the abutment?													
Cast into concrete abutment	–	–	–	–	–	–	–	–	–	–	–	–	2
Placed on top of abutment	–	–	–	–	–	–	–	–	–	–	–	–	–
Beams notched to fit abutment	–	–	–	1	1	–	–	–	–	–	–	–	–
Other	–	–	–	–	–	–	–	–	6	–	–	–	–
10. Did vendor supply structural info?	–	–	–	N	N	–	–	–	N	–	–	–	N
11. Are the cars:													
Flat cars	–	–	–	1	1	–	–	–	3	–	–	–	2
Box cars with tops removed	–	–	–	–	–	–	–	–	3	–	–	–	–
Other	–	–	–	–	–	–	–	–	–	–	–	–	–

Survey Summary

	Saline	Scott	Searcy	Sebastian	Sevier	Sharp	St. Francis	Stone	Union	Van Buren	Washington	White	Woodruff	Yell
1. Have you considered using railroad cars as short span bridges?	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	Y	*	Y
2. Have you used railroad cars for short span bridges?	N	Y	N	N	Y	N	Y	N	Y	N	N	Y	*	Y
3. How were you informed about the use of railroad cars as short span bridges?														
Friend	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Supplier	-	-	-	-	Y	-	-	-	Y	-	-	-	-	-
Published article	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saw one in place	-	-	-	-	-	-	-	-	-	-	-	-	-	Y
Other	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-
4. How many railroad car bridges do you have in place?	-	2	-	-	1	-	1	-	4	-	-	2	*	8
5. How many of these bridges are:														
Single span	-	2	-	-	-	-	1	-	4	-	-	2	*	-
Double span	-	-	-	-	1	-	-	-	-	-	-	-	-	4
Triple span	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6. How many bridges are:														
1 car wide	-	1	-	-	-	-	-	-	3	-	-	-	-	-
2 cars wide	-	1	-	-	1	-	1	-	2	-	-	2	-	4
2 cars wide + spacer between cars	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7. How many bridges have span lengths (ft.)														
0-20	-	-	-	-	-	-	-	-	-	-	-	-	*	-
21-25	-	-	-	-	-	-	-	-	-	-	-	-	*	-
26-30	-	-	-	-	-	-	-	-	-	-	-	-	*	-
31-35	-	-	-	-	-	-	-	-	-	-	-	-	*	-
36-40	-	-	-	-	-	-	-	-	3	-	-	-	*	-
41-45	-	-	-	-	-	-	-	-	-	-	-	-	*	-
46-50	-	1	-	-	-	-	1	-	2	-	-	-	*	-
51-55	-	-	-	-	-	-	-	-	-	-	-	-	*	-
56 or more	-	1	-	-	-	-	-	-	-	-	-	2	*	4
8. Did you consider thermo expansion joints in the placement of the bridges?	-	N	-	-	Y	-	N	-	N	-	-	N	-	N
9. How are the cars fastened to the abutment?														
Cast into concrete abutment	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Placed on top of abutment	-	-	-	-	1	-	1	-	5	-	-	2	-	8
Beams notched to fit abutment	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. Did vendor supply structural info?	-	N	-	-	N	-	Y	-	Y	-	-	N	-	Y
11. Are the cars:														
Flat cars	-	2	-	-	1	-	1	-	5	-	-	2	-	8
Box cars with tops removed	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix B
Mechanical Properties

CARBON STEEL PLATES, SHAPES AND BARS

Specification Designation	SPECIFIED MECHANICAL PROPERTIES							DESIGN MECHANICAL PROPERTIES					
	Grade or Class	Thickness or Diameter		Tensile Strength σ_μ	Yield Point σ_y	Elong. in 2 In.	Reduct. in Area	Yield Stress			Shear Strength $\tau_u = 0.75\sigma_\mu$	Modulus of Elasticity E	Poisson's Ratio μ
		Over	Not Over					Tension σ_y, Bending σ_b, Compr'n σ_c $= \sigma_y$	Bearing $\sigma_{br} = 1.40\sigma_y$	Shear $\tau = 0.58\sigma_y$			
		In.	In.	psi (Min)	psi (Min)	% (Min)	% (Min)	psi	psi	psi	psi	psi	
ASTM-A36	Grade A			58,000	36,000	23		36,000	50,400	20,900	43,500	29 x 10^6	0.30
ASTM-A113	Grade A			60,000	33,000	24		33,000	46,200	19,100	45,000	29 x 10^6	0.30
	Grade B			50,000	27,000	28		27,000	37,800	15,700	37,500	29 x 10^6	0.30
	Grade C			48,000	26,000	29		26,000	36,400	15,100	36,000	29 x 10^6	0.30
ASTM-A283	Grade A		2	45,000	24,000	30		24,000	33,600	13,900	33,800	29 x 10^6	0.30
	Grade B		2	50,000	27,000	28		27,000	37,800	15,700	36,500	29 x 10^6	0.30
	Grade C		2	55,000	30,000	27		30,000	42,000	17,400	41,300	29 x 10^6	0.30
	Grade D		2	60,000	33,000	24		33,000	46,200	19,100	45,000	29 x 10^6	0.30

CARBON STEEL SHEET—UNCOATED

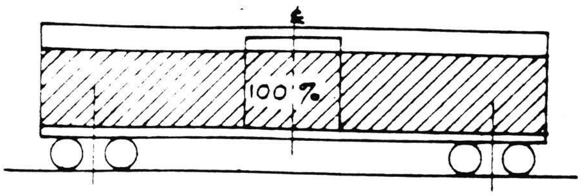
Specification Designation	Grade or Class	Over	Not Over	Tensile Strength	Yield Point	Elong. in 2 In.	Reduct. in Area	Tension, Bending, Compr'n	Bearing	Shear	Shear Strength	Modulus of Elasticity	Poisson's Ratio
ASTM-A245	Grade A	0.0972	0.2299	45,000	25,000	27		25,000	35,000	14,500	33,750	29 x 10^6	0.30
		0.0636	0.0971	45,000	25,000	25		25,000	35,000	14,500	33,750	29 x 10^6	0.30
		0.0225	0.0635	45,000	25,000	23		25,000	35,000	14,500	33,750	29 x 10^6	0.30
	Grade B	0.0972	0.2299	49,000	30,000	25		30,000	42,000	17,400	36,750	29 x 10^6	0.30
		0.0636	0.0971	49,000	30,000	24		30,000	42,000	17,400	36,750	29 x 10^6	0.30
		0.0225	0.0635	49,000	30,000	21		30,000	42,000	17,400	36,750	29 x 10^6	0.30
	Grade C	0.0972	0.2299	52,000	33,000	23		33,000	46,200	19,100	39,000	29 x 10^6	0.30
		0.0636	0.0971	52,000	33,000	22		33,000	46,200	19,100	39,000	29 x 10^6	0.30
		0.0225	0.0635	52,000	33,000	18		33,000	46,200	19,100	39,000	29 x 10^6	0.30
	Grade D	0.0972	0.2299	55,000	40,000	21		40,000	56,000	23,200	41,250	29 x 10^6	0.30
		0.0636	0.0971	55,000	40,000	20		40,000	56,000	23,200	41,250	29 x 10^6	0.30
		0.0225	0.0635	55,000	40,000	15		40,000	56,000	23,200	41,250	29 x 10^6	0.30

CAST STEEL

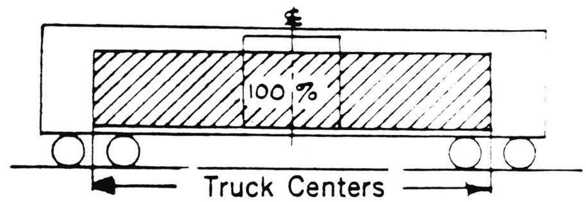
Specification Designation	Grade or Class	Thickness or Diameter: Over (In.)	Thickness or Diameter: Not Over (In.)	Tensile Strength σ_μ psi (Min)	Yield Point σ_y psi (Min)	Elong. in 2 In. % (Min)	Reduct. in Area % (Min)	Yield Stress: Tension σ_y, Bending σ_b, Compr'n σ_c $= \sigma_y$ psi	Yield Stress: Bearing $\sigma_{br} = 1.40\sigma_y$ psi	Yield Stress: Shear $\tau = 0.58\sigma_y$ psi	Shear Strength $\tau_u = 0.75\sigma_\mu$ psi	Modulus of Elasticity E psi	Poisson's Ratio μ
				SPECIFIED MECHANICAL PROPERTIES				DESIGN MECHANICAL PROPERTIES					
ASTM-A27	U60-30			60,000	30,000	22	30	30,000	42,000	17,400	45,000	29×10^6	0.30
	60-30			60,000	30,000	24	35	30,000	42,000	17,400	45,000	29×10^6	0.30
	65-35			65,000	35,000	24	35	35,000	49,000	20,300	48,800	29×10^6	0.30
	70-36			70,000	36,000	22	30	36,000	50,000	20,900	52,500	29×10^6	0.30
	70-40			70,000	40,000	22	30	40,000	56,000	23,200	52,500	29×10^6	0.30
ASTM-A148	80-40			80,000	40,000	18	30	40,000	56,000	23,200	60,000	29×10^6	0.30
	80-50			80,000	50,000	22	35	50,000	70,000	29,000	60,000	29×10^6	0.30
	90-60			90,000	60,000	20	40	60,000	84,000	34,800	67,500	29×10^6	0.30
	105-85			105,000	85,000	17	35	85,000	119,000	49,300	78,800	29×10^6	0.30
	120-95			120,000	95,000	14	30	95,000	133,000	55,100	90,000	29×10^6	0.30
	150-125			150,000	125,000	9	22	125,000	175,000	72,500	112,500	29×10^6	0.30
	175-145			175,000	145,000	6	12	145,000	203,000	84,100	131,300	29×10^6	0.30
AAR-M201	Grade A (Unannealed)			60,000	30,000	22	30	30,000	42,000	17,400	45,000	29×10^6	0.30
	Grade A (Annealed)			60,000	30,000	26	38	30,000	42,000	17,400	45,000	29×10^6	0.30
	Grade B			70,000	38,000	24	36	38,000	53,200	22,000	52,500	29×10^6	0.30
	Grade C			90,000	60,000	22	45	60,000	84,000	34,800	67,500	29×10^6	0.30
	Grade D			105,000	85,000	17	35	85,000	119,000	49,300	78,800	29×10^6	0.30
	Grade E			120,000	100,000	14	30	100,000	140,000	58,000	90,000	29×10^6	0.30

Appendix C
Loading Conditions

4.1.3.1. LIVE LOAD DISTRIBUTION — BOX CARS



a



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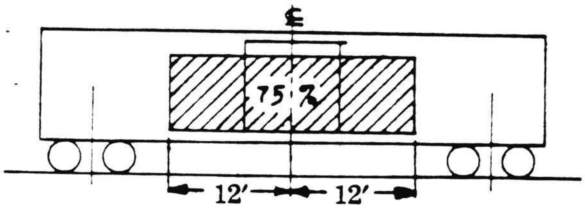

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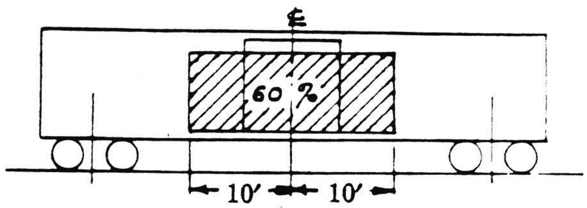

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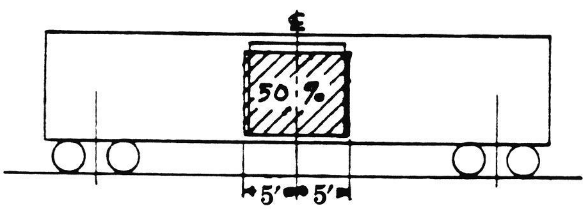

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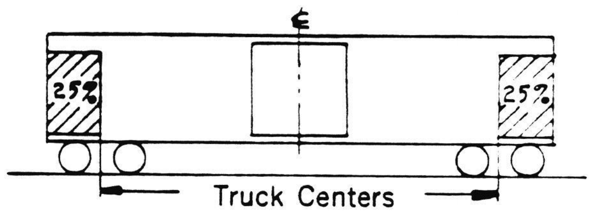
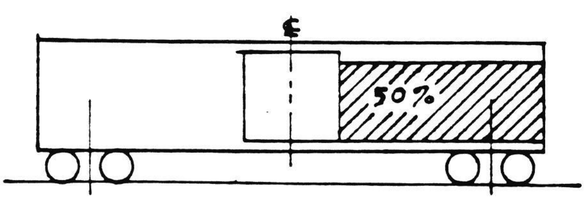
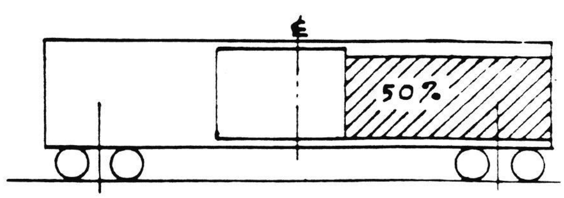


f

NOTE: The live load as indicated on diagram (e) may be placed at any location between truck centers which produces the critical loading condition on the center sill or any other member.

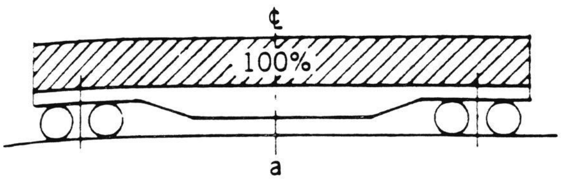


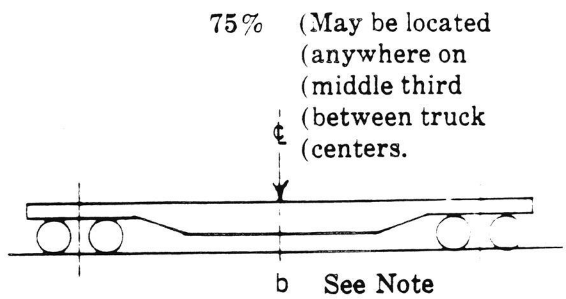
g



h

4.1.3.2. LIVE LOAD DISTRIBUTION — GENERAL SERVICE FLAT CARS AND BULKHEAD FLAT CARS

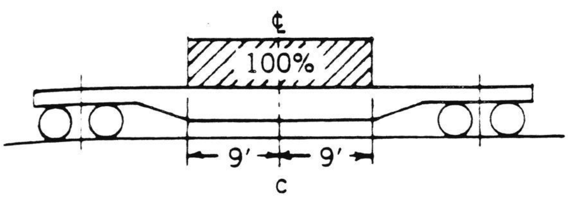


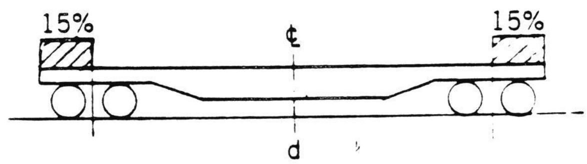


See Note

Case 1 75% applied on center sill

Case 2 37½% applied on each side sill

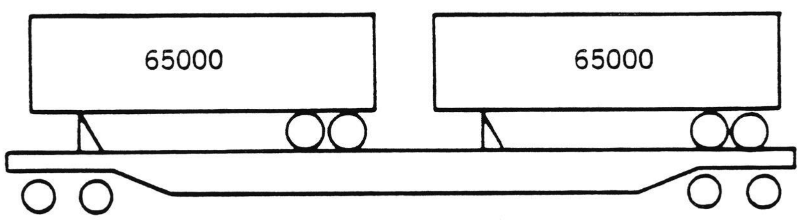


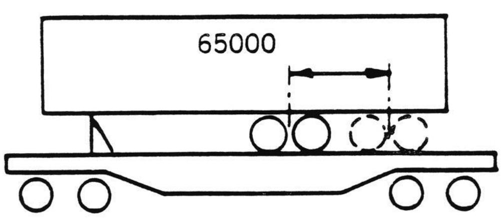


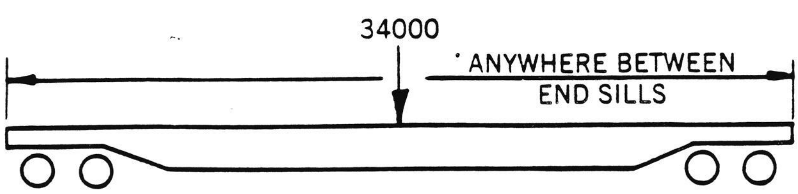
Load uniformly distributed across car

NOTE: Not applicable to Bulkhead flat cars.

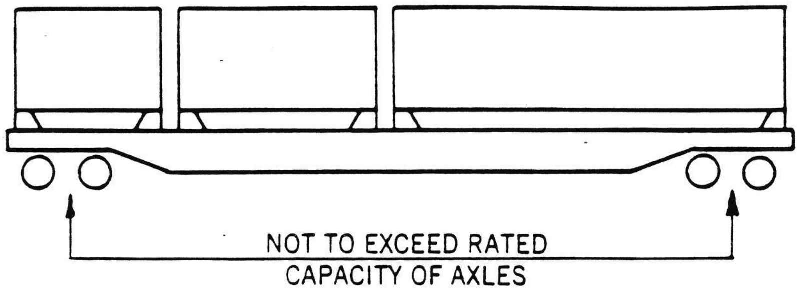
4.1.3.2.1. LIVE LOAD DISTRIBUTION TRAILER TRANSPORT CARS



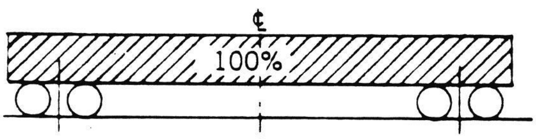




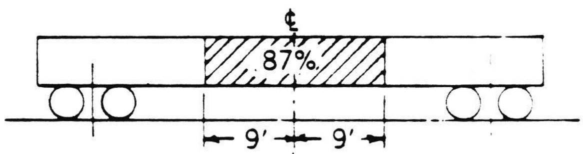
4.1.3.2.2. LIVE LOAD DISTRIBUTION CONTAINER TRANSPORT CARS



4.1.3.3. LIVE LOAD DISTRIBUTION — GONDOLA CARS

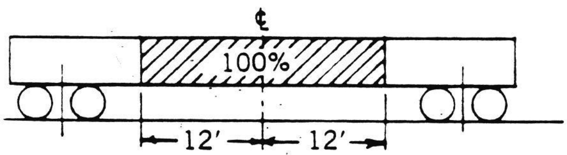


a



b

75% (May be located
(anywhere on middle
(third between
(truck center.



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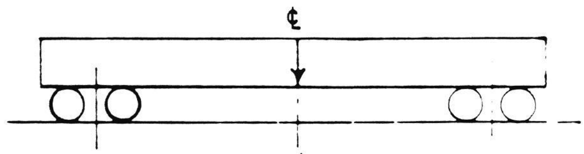
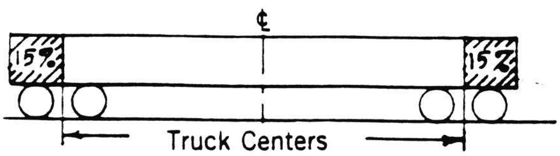


d

Load applied on bearing piece
across full width of car.



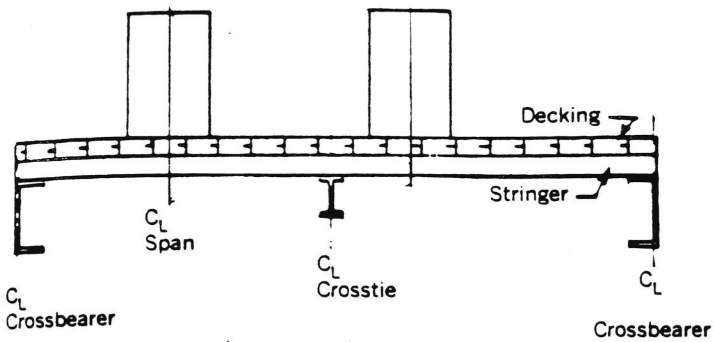
e

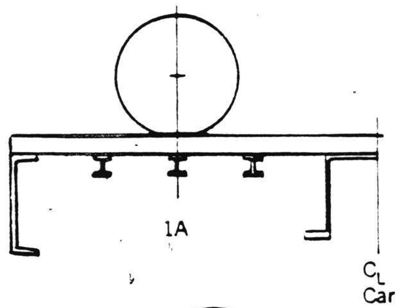
STRESS ANALYSIS
FLOOR CONSTRUCTION—BOX CAR

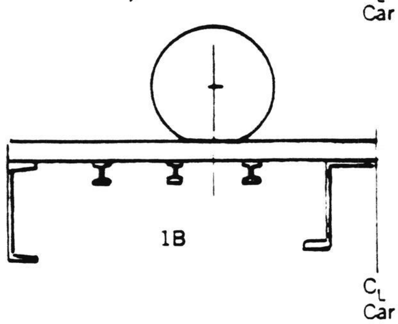
The following method of computing stress in softwood floors, stringers and crossties is considered acceptable but other rational methods of analysis are not precluded.

The critical lift truck position for design of decking, stringers and crossties are shown below.

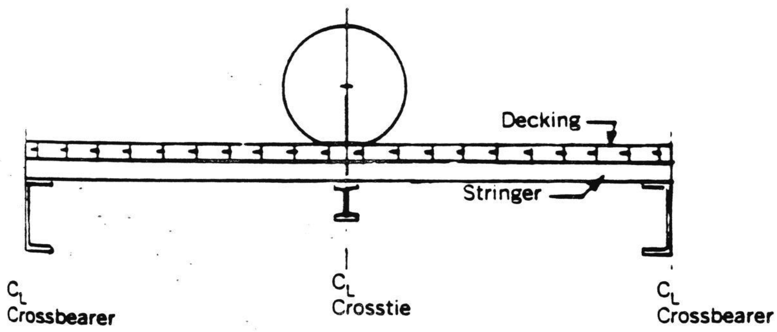
The method as illustrated applies only to a three-stringer design when the stringers are equally spaced. In the case of unequally spaced stringers or two-stringer design, additional factors and considerations must be included in the equations to correctly compute the stresses.

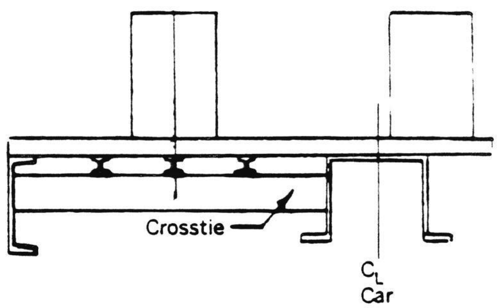






LIFT TRUCK POSITIONS NO. 1A & 1B
ENTERING DOORWAY
CRITICAL POSITIONS FOR
DECKING AND STRINGERS





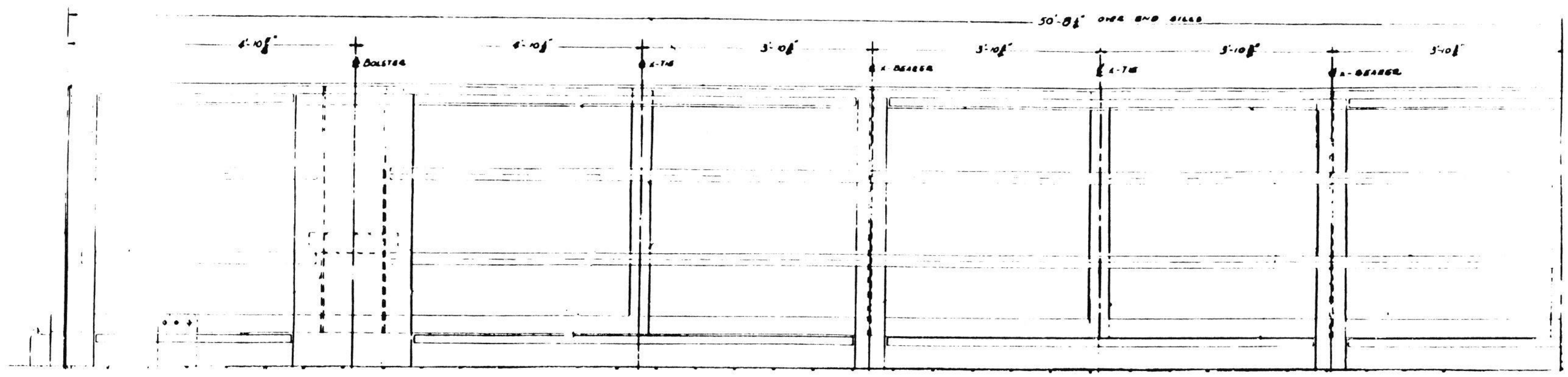
LIFT TRUCK POSITIONS NO. 1A & 1B
ENTERING DOORWAY
CRITICAL POSITIONS FOR
DECKING AND STRINGERS

LIFT TRUCK POSITION NO. 2 MOVING LENGTHWISE OF CAR
CRITICAL POSITION FOR CROSSTIE

Appendix D

Railroad Car Data

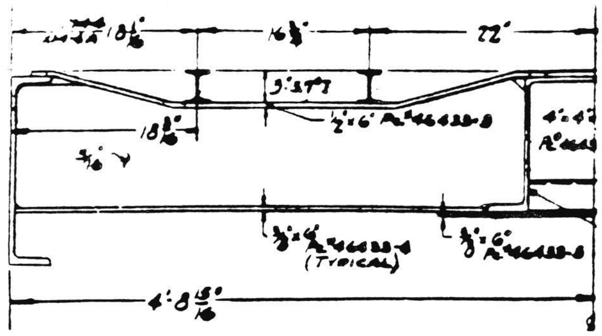
Railroad	-	Burlington Northern
Car Number	-	CB&Q 47574 CB&Q 49412
Bridge Number	-	19912
County	-	Izard



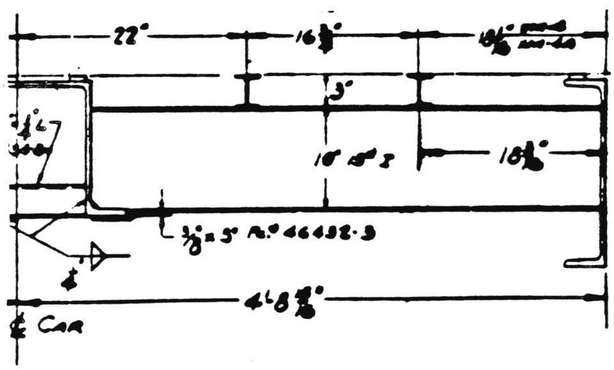
Car Length over End Sills - 50' - 8 1/4"

Car Length over Trucks - 40' - 11"

Car Width over Side Sills - 9' - 5 7/8"



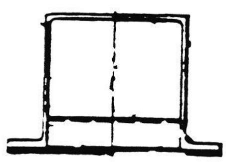
Cross Bearer



10" @ 15# I Beam
Cross Tie

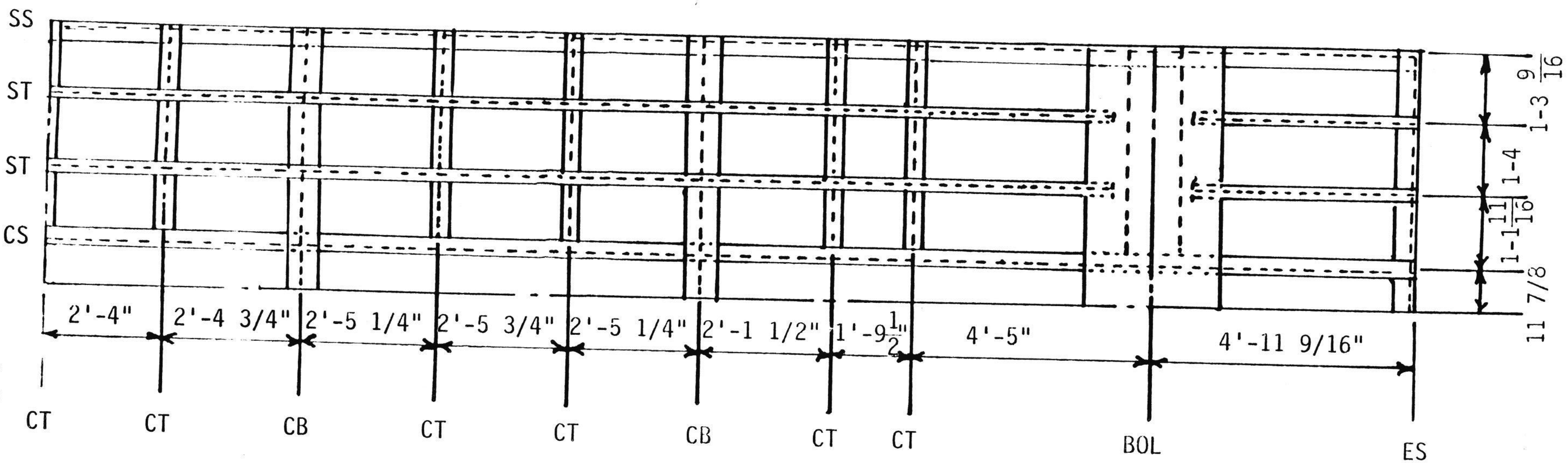
3 @ 5.7# I Beams
Stringer

18" @ 42.7 # S.B.C.
Side Sill

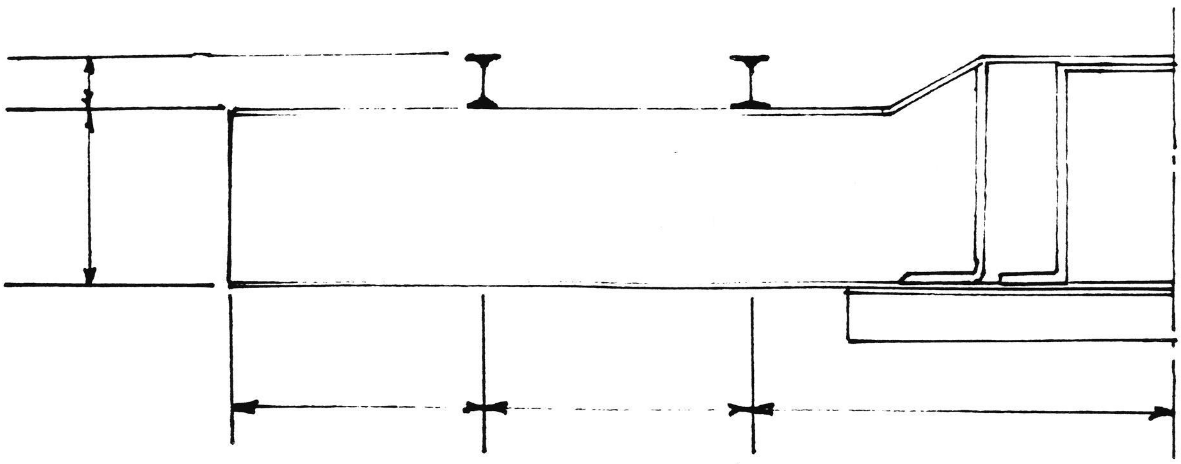


Z 26" @ 41.2# Section
Center Sill

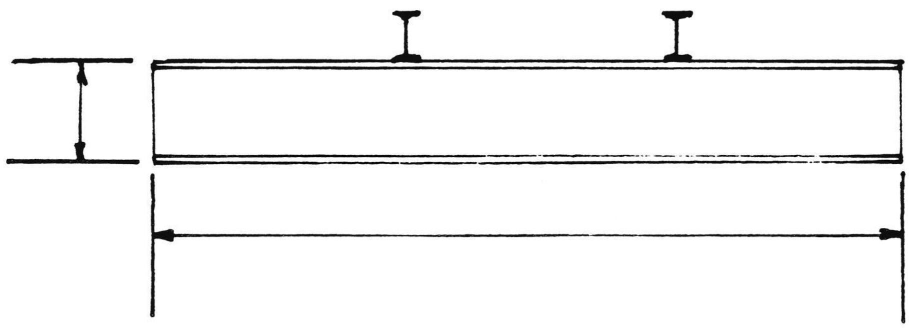
Railroad	-	Union Pacific
Car Number	-	M.P. 253717
Bridge Number	-	19908
County	-	Izard



Car Length over End Sills	50' 9 1/8"
Car Length over Trucks	40' 10"
Car Width over Side Sills	9' 6 1/4"



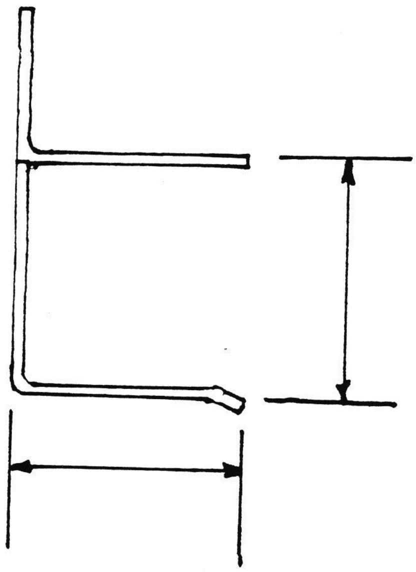
Cross Bearer



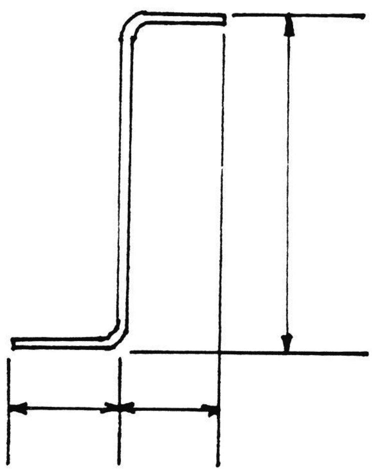
Cross Tie

3" - # I Beam

Stringer

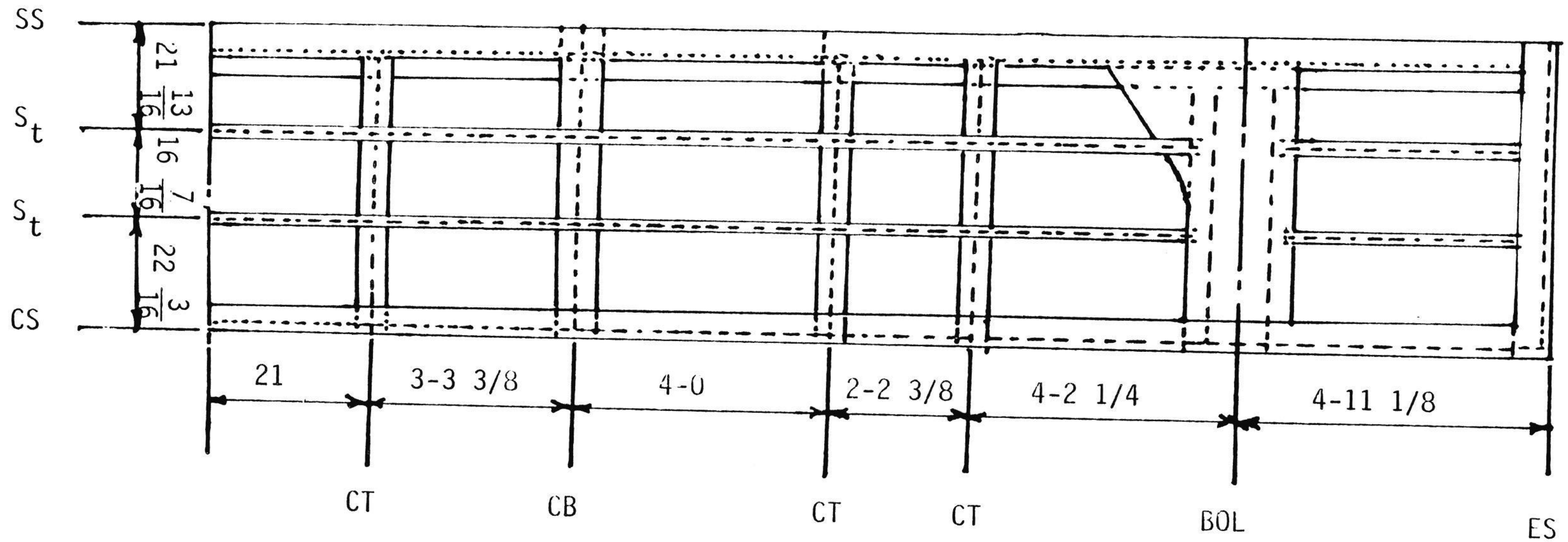


End Sill

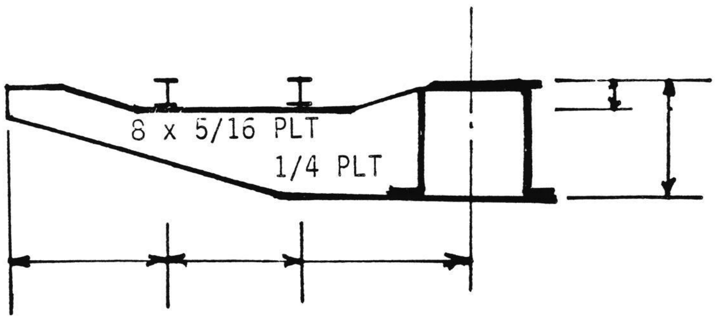


Center Sill

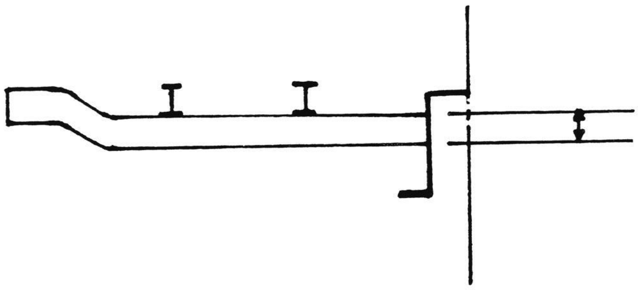
Railroad	-	Union Pacific
Car Number	-	M.P. 119252
Bridge Number	-	19910
County	-	Izard



Car Length over End Sills	40' - 8 1/4"
Car Length over Trucks	30' - 10'
Car Width over Side Sills	9' - 11 5/8"



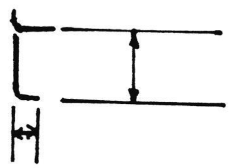
Cross Bearer



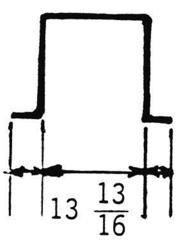
4" x 8.2 # Z Section

Cross Tie

3" x 7.5 # I Section

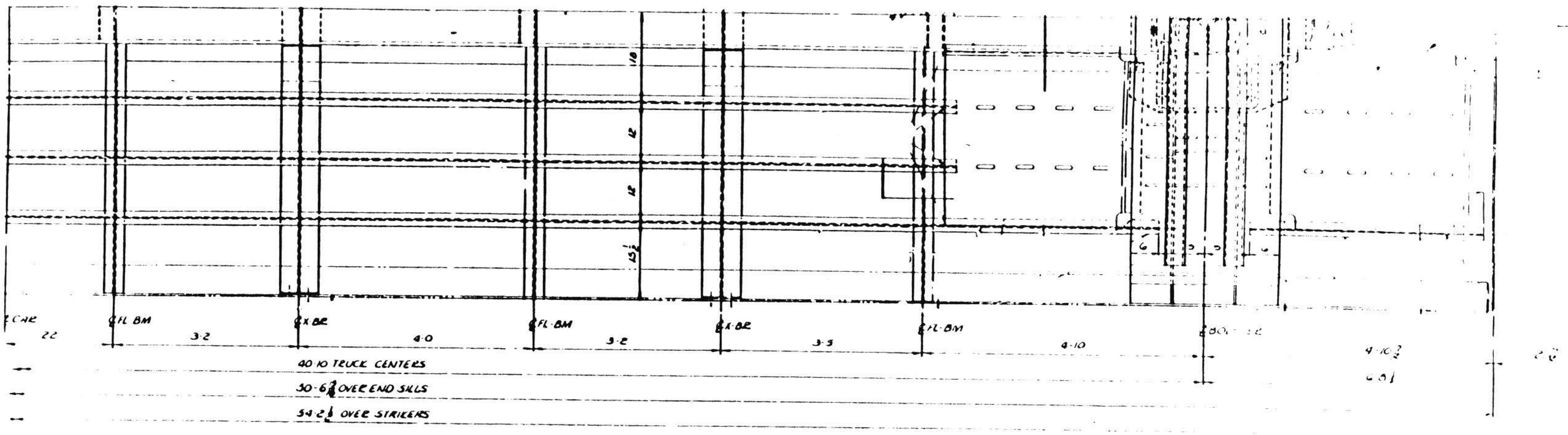


Side Sill



Center Sill

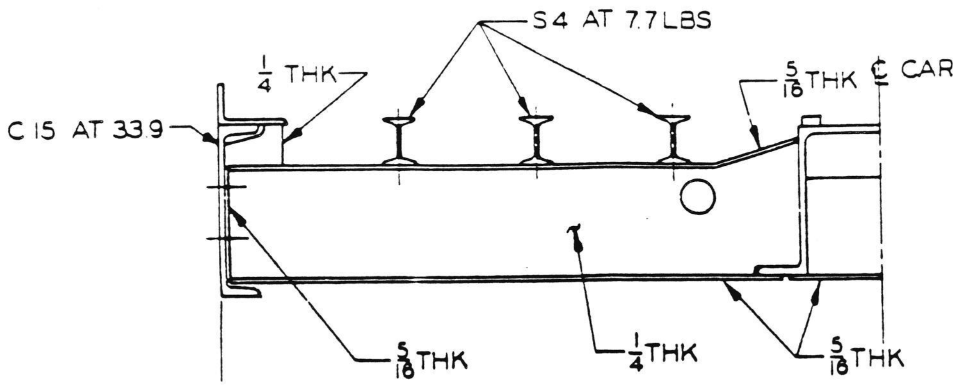
Railroad	-	Norfolk Southern
Car Number	-	Southern 556075
Bridge Number	-	20428
County	-	Lee



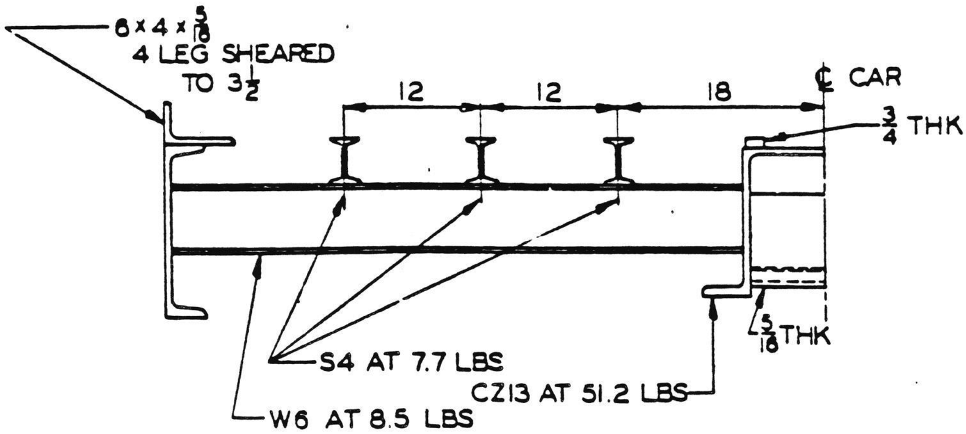
Car Length over End Sills - 50'- 6 15/16"

Car Length over Trucks - 40'- 10"

Car Width over Side Sills - 9'- 7"

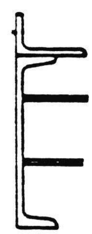


Cross Bearer

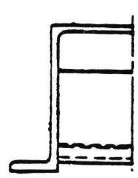


6" @ 8.5 Lbs W Section
Cross Tie

4" @ 7.7 Lbs S Beam
Stringer

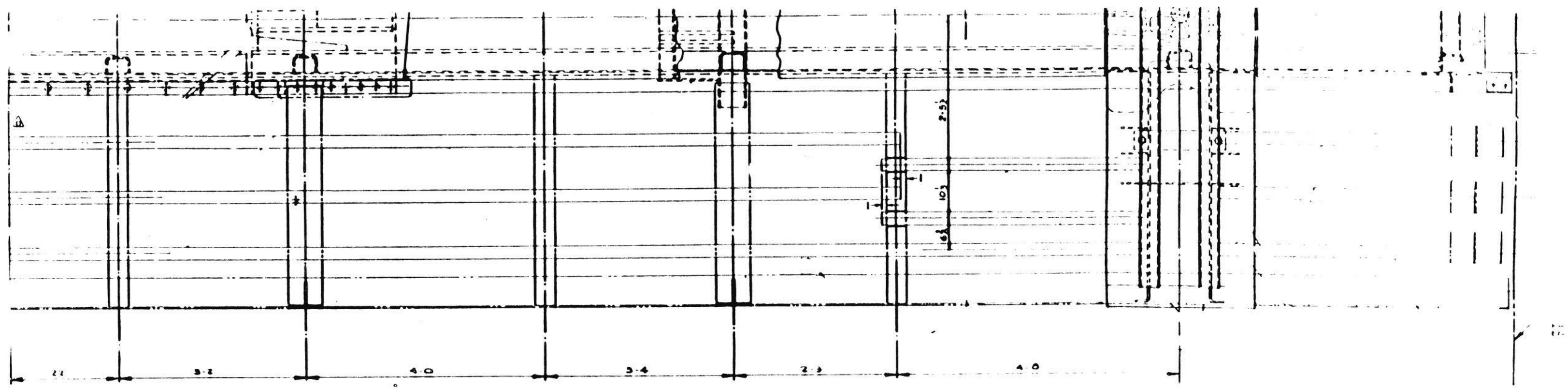


15" @ 33.9 Lbs C Section
Side Sill



13" @ 51.2 Lbs CZ Section
Center Sill

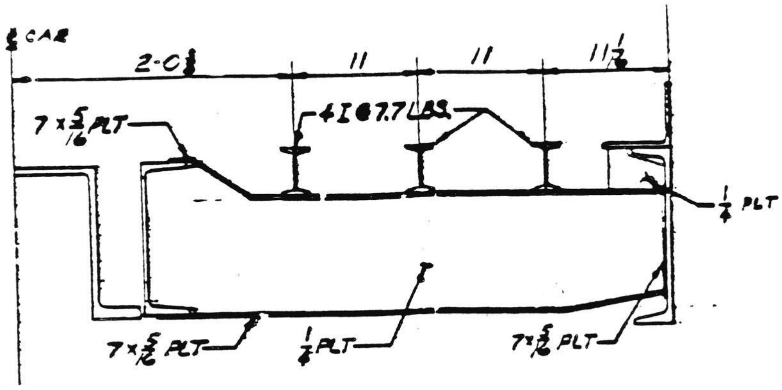
Railroad	-	Norfolk Southern
Car Number	-	Southern 550581
Bridge Number	-	20428
County	-	Lee



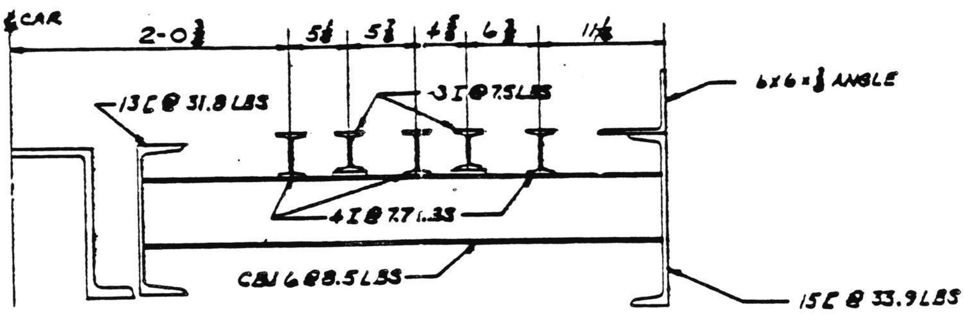
Car Length over End Sills - 50'- 6 13/16"

Car Length over Trucks - 39'- 6"

Car Width over Side Sills - 9'- 6 7/8"

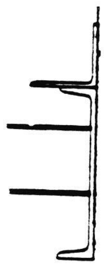


Cross Bearer

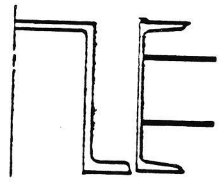


CBJ 6" @ 8-5 Lbs
Cross Tie

4" @ 7.7 Lbs I Beam
Stringer



15" @ 33.9 Lbs C Section
Side Sill



13" @ 31.8 Lbs C Section
Center Sill

STRUCTURAL MEMBER SPECIFICATIONS

Railroad - Union Pacific

Car Number - 253717

STRUCTURAL MEMBER SPECIFICATIONS

Railroad - Union Pacific

Car Number - 253717

SLIDING CENTER SILL

Two CZ13 x 41.2# HSLA, A-441 rolled steel zee sections conforming to AAR requirements. The sill extends the full length of car with the top flange edges continuously submerged arc-welded along the centerline of the car. The weld penetration shall be equal to or greater than specified in AAR Plate 525, latest revision. Total section area is 24.24 square inches. Suitable guides are welded to the sliding sill.

FIXED CENTER SILLS

Two 13-1/2" x 3/8" formed zees, ASTM A-36 located each side of the sliding center sill, extend full length of car. the top flange is depressed at bolsters and crossbearers so that bolster and crossbearer top cover plates are flush with top of fixed center sill.

BODY BOLSTER

Two per car, each consisting of four web plates, 7/16" HSLA, Gr 50, one top cover plate, 30" x 1/2" HSLA Grade 50, two bottom cover plates, 26" x 1/2" HSLA, Grade 42.

The top cover plate is reinforced with three (3) 4" @ 5.4# A-36 channels welded full length to top cover plate, with floor panels slot welded to channels.

Web plates on each side of the center sill are welded to the fixed center webs and bottom flanges and are flanged and lockbolted to the side sill reinforcement.

The top cover plates extend full width of car and are welded to the web plates, top flanges of fixed center sill, and side sills.

The bottom cover plates extend from side sill to bottom flange of fixed center sill and are welded to the web plates, fixed center sill bottom flange, and side sill reinforcement.

CROSSBEARERS

Four per car, each consisting of two (2) built-up welded I beam sections having a #4 gage (.2242") ASTM A5709 Grade "B" web plate, 7" x 3/8" ASTM A575, Grade M-1010 top cover plate and 7" x 5/16" ASTM A-36 bottom cover plate having ends bent to form connection to side sill reinforcement. Top of crossbearers are depressed to permit application of continuous floor stringers.

A 7" x 3/8" ASTM A575, Grade M-1020, top tie plate, and a bottom tie consisting of a 7" x 3/8" A572, Grade 50 bar and a MC8 x 18.7#, HSLA, Gr. 50, complete the crossbearer construction. all members are lock bolted together to form a complete unit.

The crossbearers are welded to the fixed center sill and side sill, and are secured to the side sill reinforcement with lock bolts.

CROSSTIES

Twenty-two (22) per car, eleven (11) W6 x 8.5#, HSLA Grade 50 steel on each side of the center sill are welded to the fixed center sill webs and provided with a 5/16" end plate for lock bolted attachment to the side sill reinforcement.

FLOOR STRINGERS

Four S3 x 5.7#, A-36 steel, two on each side of the center sill, each extending from bolster to bolster and from bolster to end sill.

The ends of the stringers are offset to fit under the bolster top cover plates. Stringers are secured to bolster, end sills, and all intervening crossmembers by welding.

Two additional floor stringers as described above are used for support of the bulkhead tracks, one each side and located adjacent to the side sill.

FLOORING

The flooring consists of 1-3/4" thick by 8" wide smooth surface panels of nailable steel floor, full length of car. Each panel is attached by welding one side of the panel to the side sill and floor stringers. Panels are attached together by four bridge welds across car at each joint. All panels to include #6 gage end closures.

SIDE SILL

L6 x 3-1/2 x 5/16" angle ASTM A36 running from end sill to combination side sill and side sill reinforcement at the doorway.

SIDE SILL REINFORCEMENT

14-3/4" deep 5/16" pressed angle beyond the combination side sill and side sill reinforcement at the doorway.

END SILLS

L6 x 3-1/2 x 5/16" A-36 steel angle extending full width of car with the 3-1/2" leg applied vertically.

STRUCTURAL MEMBER SPECIFICATIONS

Railroad - Norfolk Southern

Car Number - 550581

SLIDING CENTER SILL

The sliding center sill consists of two (2) A.A.R. Z-26 @ 51.2 lb. H.S.S. sections, with the top flanges seam welded the full length of the sill on the outside. The weld penetration will be 100% full length of the sill.

Travel of the sliding center sill is 30" in each direction.

The sliding center sill is protected at the outboard crossbearers, bolsters, and end sills by wear plates, for full travel of the sliding center sill. Rol-man steel welded in place.

The sliding center sill separators, four (4) per car, are 3" x 3" x 1/4" O.H.S. pressed angles, plus two (2) additional 5/8" O.H.S. flat plates, one (1) at the rear of each set of rear draft gear lugs.

STATIONARY CENTER SILL

The stationary center sill consists of two (2) 13" @ 31.8 lb., C-20, O.H.S. channels, 22-1/8" apart extending from end sill to end sill. The two (2) channels are tied together with a 25" x 1/4" H.S.S. top cover plate extending between bolsters, and from bolsters to end sills.

A stationary center sill tie assembly is provided under the sliding center sill, located outboard of the center line of the bolster, protected by wear plates.

Sliding center sill guides are welded to the stationary center sill at the bolsters, crossbearers, stationary center sill tie assembly, and floor beam each side of the latitudinal center line of the car, gauged to assure free movement of the sliding center sill.

BODY BOLSTERS

The body bolsters, two (2) per car, are built-up welded design.

The body bolster top cover is a 30" x 3/4" H.S.S. plate extending in one (1) piece over the center sill between side sills with 3/16" O.H.S. filler welded to the top flange of each stationary center sill channel.

The body bolster bottom cover is a 30" x 3/4" H.S.S. plate, without taper, extending from the bottom flange of the stationary center sill channel to the side sill reinforcement.

The body bolster webs are 3/8" H.S.S. extending between the body bolster top cover, body bolster bottom cover, stationary center sill channel web to the side sill reinforcement. The body bolster webs are flanged 90° outward of the bolster center line to rivet to the side sill reinforcement, and arc welded to the top and bottom cover plates and to the stationary center sill channel web.

The body bolster bottom cover is additionally stiffened at the tangent of the body bolster contour in the bottom cover by 3/8" H.S.S. stiffeners.

The body side bearing braces are 5/16" H.S.S. inverted "U" sections extending between body bolster webs, welded thereto and to the body bolster bottom cover.

CROSSBEARERS

The crossbearers, four (4) per car, are built-up welded construction with 1/4"

O.H.S. web plates extending between and welded to the stationary center sill web, the side connection plate, and the top and bottom cover plates.

The crossbearer top cover plates are 7" x 5/16" O.H.S. extending between and welded to the side sill and the top flange of the stationary center sill, contoured to permit the floor stringers to pass over the cover plate.

The crossbearer bottom cover plates are 7" x 5/16" O.H.S. S. extending between and welded to the side connection plate and the bottom flange of the stationary center sill.

The crossbearer side connection plates are 7" x 5/16" O.H.S. welded to the crossbearer web and bottom cover plate and riveted to the side sill reinforcement.

The crossbearer bottom cover plates are joined together, only on the crossbearers adjacent the bolsters, by a 5/16" pressed channel with a 6" x 5/16" reinforcement closure plate. The crossbearer bottom cover plates of the crossbearers adjacent the latitudinal center line of the car are joined together by the base plates of the cushion gear stops.

FLOOR BEAMS

Six (6) per car, 6" @ 8.5# CBJ-6 sections, Pullman-Standard Specification No. 526, welded to the side sill reinforcement and the stationary center sill web.

FLOOR STRINGERS

There are six (6) stringers per car, three (3) each side of the center sill consisting of the following:

The outboard stringer adjacent the side sill is a 4" @ 7.7 lb., B-16 Pullman Spec. 526 I-Beam extending from bolster to bolster.

The two (2) inboard stringers adjacent to the stationary center sill are 4" @ 7.7 lb., B-16 Pullman Spec. 526 I-Beam extending from floor beam next to bolster to floor beam next to bolster.

The two (2) inboard stringers adjacent to the stationary center sill are 3" @ 7.5 lb., B-17 H.S.S. I-Beams extending from floor beam next to bolster to bolster.

The outboard stringer adjacent the side sill is a 3" @ 7.5 lb. B-17 H.S.S. I-Beam extending from bolster to end sill.

<u>SIDE SILLS</u>

6" X 6" X 3/8" Ex-ten 60 rolled angle extending from end to end of car.

<u>SIDE SILL REINFORCEMENT</u>

The side sill is reinforced by a 15" @ 33.9# channel high strength steel welded to the underside of the horizontal flange of the side sill angle. The reinforcement extends from end sill to end sill and is fishbelly shaped.

STRUCTURAL MEMBER SPECIFICATIONS

Railroad - Norfolk Southern

Car Number -556075

CENTER SILL

The center sill consists of two (2) per car, CZ13 x 51.2 (H.S.S.) copper bearing steel,A.A.R. Z-26 center sill sections extending between strikers and welded the full length of the sill at the junction of the top horizontal flanges. The weld penetration is 100% full length of the center sills.

The center sill separators, six (6) per car, are 5/16" (PS-526) pressed "J" sections, welded to the center sill webs, located at the floor beams, plus four (4) additional 1/4" (PS-526) flat plates welded to the center sill webs, located at the crossbearers.

BODY BOLSTERS

The body bolsters, two (2) per car, are built-up welded construction.

The body bolster top cover is a 30" x 3/4" (H.S.S.) copper bearing plate extending in one (1) piece over the center sill between side sills.

The body bolster top cover plate is reinforced by two (2) pressed channels, 1/4" (H.S.S.) copper bearing, 1-9/16" high, 4" wide, one (1) located at each body bolster web, welded to the top of the cover plate.

The body bolster bottom cover is a 30" x 3/4" (H.S.S.) copper bearing plate extending from the bottom flange of the center sill to the side sill reinforcement.

The body bolster bottom cover plate is stiffened at each bend point, inboard and outboard of the body bolster webs by 3/8" (H.S.S.) copper bearing plate gussets.

The body bolster webs are 3/8" (H.S.S.) copper bearing extending between the body bolster top cover, body bolster bottom cover, and center sill web to the side sill reinforcement. The body bolster webs are welded to the side still reinforcement, and the top and bottom cover plates and the center sill web.

The 4" diameter access hole in the body bolster web is reinforced with a 4" diameter standard black pipe.

The body bolster bottom cover plates are joined together by a 7/16" (H.S.S.)copper bearing sole plate welded to the body bolster bottom cover plates.

The body side bearing braces are 1/2" (H.S.S.) copper bearing inverted "U" sections extending between body bolster webs, welded thereto and to the bod bolster bottom cover.

CROSSBEARERS

The crossbearers, four (4) per car, are built-up weldments with a 1/4" (H.S.S.) copper bearing web plate extending between and welded to the center sill web and side connection plate, and the top and bottom cover plates. The crossbearer top cover plate is reinforced by a 1/4" (H.S.S.) copper bearing gusset which is welded to the side sill reinforcement, top cover plate, and the side sill.

The crossbearer top cover plates are 8" x 5/16" (H.S.S.) copper bearing bars extending between and welded to the side connection plate and the top flange of the center sill, contoured to permit the floor stringers to pass over the cove plate.

The crossbearer bottom cover plates are 8" x 5/16" (H.S.S.) copper bearing bars extending between and welded to the side connection plate and to the bottom flange of the center sill.

The crossbearer side connection plates are 8" x 5/16" (H.S.S.) copper bearing bars, welded to the crossbearer web and bottom cover plate and riveted to the side sill reinforcement.

The crossbearer bottom cover plates are joined together by a 8" x 5/16" (H.S.S.) copper bearing plate welded to the bottom center sill flanges and the center sill separator.

FLOOR BEAMS

There are six (6) per car, 6" x 8.5# W-6 sections (H.S.S) copper bearing beams welded to the side sill reinforcement and the center sill web.

FLOOR STRINGERS

There are six (6) floor stringers per car, three (3) each side of the center sill, consisting of the following.

The outboard stringer adjacent to the side sill is an S4 x 7.7 (H.S.S.) copper bearing I-Beam extending between bolsters and an S3 x 7.5 (H.S.S.) copper bearing I-Beam from the bolsters to the end sills.

The middle stringer and the inboard stringer adjacent to the center sill are S4 x 7.7 (H.S.S.) I-Beam extending between the floor beams adjacent to the bolsters.

The stringers pass over the top of the crossbearers and floor beams and are welded to the underframe crossmembers.

In the wheel areas, the floor is supported between the center sill and the outboard stringers by 3/8" (H.S.S.) pressed plates which extend from the floor beams to the bolsters and from the bolsters to the end sills.

SIDE SILL

The side sills, two (2) per car, are 6" x 4" x 5/16" (H.S.S.) copper bearing rolled angles, end sill to end sill. The 4" vertical leg of the side sill is sheared to 3-1/2" to provide for suitable welding conditions at the side sheet and side sill lap joint.

SIDE SILL REINFORCEMENT

The side sill is continuously reinforced between end sills by a C15 x 33.9 (H.S.S.) copper bearing rolled channel with a reduced depth of 5-15/16" in the bolster area to the end of the car. The reinforcement is welded to the bottom of and flush with the side sill angle on both sides (heel and toe) through the doorway and two feet (2'-0") beyond each door post, and is attached to the crossbearers with huckbolts and welded to the floor beams and body bolsters.

The side sill reinforcement tapers in the bolster area with the appropriate amount of web removed and bottom flanges reformed and welded.

END SILLS

The end sills are 6" x 3-1/2" x 5/16" (H.S.S.) copper bearing rolled angles butt-welded to the steel end bottom sheet.

Appendix E
Model Calibration

Table E-1
Single Axle Loading Results
With $E=29x10^6$ psi

	GAUGE POSITION										
	1/4 Point			Center Line				1/3 Point			
Load Positions	1	2	3	6	7	8	9	12	13	14	15
Center line of car											
Center of car analysis	216	237	216	409	447	447	409	288	316	316	288
Measured	181	216	176	398	411	427	380	261	304	313	258
% Difference	19.3	9.7	22.7	2.8	8.8	4.7	7.6	10.3	3.9	1	11.6
1/4 point analysis	312	342	312	216	237	237	216	144	158	158	144
Measured	296	334	294	195	230	233	190	129	147	155	131
% Difference	5.4	2.4	6.1	10.8	3	1.7	13.7	11.6	7.5	1.9	9.9
1/3 point analysis	144	158	144	287	316	316	287	366	398	398	366
Measured	117	137	112	249	296	301	245	343	352	386	346
% Difference	23.1	15.3	28.6	15.3	6.8	5	17.1	6.7	13.1	3.1	5.8
Edge of Car (West)											
Analysis	197	238	232	318	444	444	531	257	317	317	316
Measured	173	237	191	312	434	419	436	227	293	332	297
% Difference	13.9	0.4	21.5	1.9	2.3	6	21.8	13.2	8.2	-4.5	6.4
1/4 point analysis	242	339	389	184	238	238	246	142	158	158	146
Measured	232	336	371	165	225	240	222	120	145	156	139
% Difference	4.3	0.9	4.9	11.5	5.8	-0.8	10.8	18.3	9	1.3	5
1/3 point analysis	141	158	147	241	317	317	333	299	396	396	443
Measured	121	150	114	212	292	314	291	271	360	390	434
% Difference	16.5	5.3	28.9	13.7	8.6	1	14.4	10.3	10	1.5	2.1
Edge of Car (East)											
Center of car analysis	232	238	197	531	444	444	318	316	317	317	257
Measured	192	195	165	471	415	448	289	293	310	294	225
% Difference	20.8	22.1	19.4	12.7	7	-0.9	10	7.8	2.3	7.8	14.2
1/4 point analysis	389	339	242	246	238	238	184	146	158	158	142
Measured	353	328	219	219	230	224	159	137	147	149	121
% Difference	10.2	3.4	10.5	12.3	3.5	6.3	15.7	6.6	7.5	6	17.4
1/3 point analysis	147	158	141	333	317	317	241	443	396	396	299
Measured	116	123	111	289	302	289	200	417	354	400	262
% Difference	26.7	28.5	27	15.2	5	9.7	20.5	6.2	11.9	-1	14.1

Table E-2
Single Axle Loading Results
With $E=30x10^6$ psi

Load Positions	1	2	3	6	7	8	9	12	13	14	15
	GAUGE POSITION										
	1/4 Point			Center Line				1/3 Point			
Center line of car											
Center of car analysis	209	229	209	395	432	432	395	278	305	305	278
Measured	181	216	176	398	411	427	380	261	304	313	258
% Difference	15.5	6	18.8	-0.8	5.1	1.2	3.9	6.5	0.3	-2.6	7.8
1/4 point analysis	302	330	302	209	229	229	209	139	153	153	139
Measured	296	334	294	195	230	233	190	129	147	155	131
% Difference	2	-1.2	2.7	7.2	-0.4	-1.7	10	7.8	4.1	-1.3	6.1
1/3 point analysis	139	153	139	278	305	305	278	354	385	385	354
Measured	117	137	112	249	296	301	245	343	352	386	346
% Difference	18.8	11.7	24.1	11.6	3	1.3	13.5	3.2	9.4	-0.3	2.3
Edge of Car (West)											
Analysis	191	230	225	308	429	429	513	248	307	307	306
Measured	173	237	191	312	434	419	436	227	293	332	297
% Difference	10.4	-3	17.8	-1.3	-1.2	2.4	17.7	9.3	4.8	-7.5	3
1/4 point analysis	234	328	376	177	230	230	238	137	153	153	141
Measured	232	336	371	165	225	240	222	120	145	156	139
% Difference	0.9	-2.4	1.3	7.3	2.2	-4.2	7.2	14.2	5.5	-1.9	1.4
1/3 point analysis	136	153	142	233	306	306	322	289	383	383	428
Measured	121	150	114	212	292	314	291	271	360	390	434
% Difference	12.4	2	24.6	9.9	4.8	-2.5	10.7	6.6	6.4	-1.8	-1.4
Edge of Car (East)											
Center of car analysis	225	230	191	513	429	429	308	306	307	307	248
Measured	192	195	165	471	415	448	289	293	310	294	225
% Difference	17.2	17.9	15.8	8.9	3.4	-4.2	6.6	4.4	-1	4.4	10.2
1/4 point analysis	376	328	234	238	230	230	177	141	153	153	137
Measured	353	328	219	219	230	224	159	137	147	149	121
% Difference	6.5	0	6.8	8.7	0	2.7	11.3	2.9	4.1	2.7	13.2
1/3 point analysis	142	153	136	322	306	306	233	428	383	383	289
Measured	116	123	111	289	302	289	200	417	354	400	262
% Difference	22.4	24.4	22.5	11.4	1.3	5.9	16.5	2.6	8.2	-4.3	10.3

Table E-3
Single Axle Loading Results
With $E=31x10^6$ psi

	GAUGE POSITION										
	1/4 Point			Center Line				1/3 Point			
Load Positions	1	2	3	6	7	8	9	12	13	14	15
Center line of car											
Center of car analysis	202	222	202	382	418	418	382	269	296	296	269
Measured	181	216	176	398	411	427	380	261	304	313	258
% Difference	11.6	2.8	14.8	-4	1.7	-2.1	0.5	3.1	-2.6	-5.4	4.3
1/4 point analysis	292	320	292	202	222	222	202	134	148	148	134
Measured	296	334	294	195	230	233	190	129	147	155	131
% Difference	-1.4	-4.2	-0.7	3.6	-3.5	-4.7	6.3	3.9	0.7	-4.5	2.3
1/3 point analysis	135	148	135	269	295	295	269	342	373	373	342
Measured	117	137	112	249	296	301	245	343	352	386	346
% Difference	15.4	8	20.5	8	-0.3	-2	9.8	-0.3	6	-3.4	-1.2
Edge of Car (West)											
Analysis	184	223	217	298	415	415	496	240	297	297	296
Measured	173	237	191	312	434	419	436	227	293	332	297
% Difference	6.4	-5.9	13.6	-4.5	-4.4	-1	13.8	5.7	1.4	-11	-0.3
1/4 point analysis	227	317	364	172	222	222	231	133	148	148	136
Measured	232	336	371	165	225	240	222	120	145	156	139
% Difference	-2.2	-5.7	-1.9	4.2	-1.3	-7.5	4.1	10.8	2.1	-5.1	-2.2
1/3 point analysis	132	148	137	226	296	296	311	280	371	371	415
Measured	121	150	114	212	292	314	291	271	360	390	434
% Difference	9.1	-1.3	20.2	6.6	1.4	-5.7	6.9	3.3	3.1	-4.9	-4.4
Edge of Car (East)											
Center of car analysis	217	223	184	496	415	415	298	296	297	297	240
Measured	192	195	165	471	415	448	289	293	310	294	225
% Difference	13	14.4	11.5	5.3	0	-7.4	3.1	1	-4.2	1	6.7
1/4 point analysis	364	317	227	231	222	222	172	136	148	148	133
Measured	353	328	219	219	230	224	159	137	147	149	121
% Difference	3.1	-3.4	3.7	5.5	-3.5	-0.9	8.2	-0.7	0.7	-0.7	9.9
1/3 point analysis	137	148	132	311	296	296	226	415	371	371	280
Measured	116	123	111	289	302	289	200	417	354	400	262
% Difference	18.1	20.3	18.9	7.6	-2	2.4	13	-0.5	4.8	-7.3	6.9

Table E-4
Single Axle Loading Results
With E=32x10^6 psi

Load Positions	GAUGE POSITION 1/4 Point 1	2	3	Center Line 6	7	8	9	1/3 Point 12	13	14	15
Center line of car											
Center of car analysis	196	215	196	370	405	405	370	261	286	286	261
Measured	181	216	176	398	411	427	380	261	304	313	258
% Difference	8.3	-0.5	11.4	-7	-1.5	-5.2	-2.6	0	-5.9	-8.6	1.2
1/4 point analysis	283	310	283	195	215	215	195	130	143	143	130
Measured	296	334	294	195	230	233	190	129	147	155	131
% Difference	-4.4	-7.2	-3.7	0	-6.5	-7.7	2.6	0.8	-2.7	-7.7	-0.8
1/3 point analysis	130	143	130	261	286	286	261	331	361	361	331
Measured	117	137	112	249	296	301	245	343	352	386	346
% Difference	11.1	4.4	16.1	4.8	-3.4	-5	6.5	-3.5	2.6	-6.5	-4.3
Edge of Car (West)											
Analysis	179	216	210	289	402	402	481	233	287	287	287
Measured	173	237	191	312	434	419	436	227	293	332	297
% Difference	3.5	-8.9	9.9	-7.4	-7.4	-4.1	10.3	2.6	-2	-14	-3.4
1/4 point analysis	220	307	352	166	215	215	223	128	143	143	132
Measured	232	336	371	165	225	240	222	120	145	156	139
% Difference	-5.2	-8.6	-5.1	0.6	-4.4	-10	0.5	6.7	-1.4	-8.3	-5
1/3 point analysis	128	143	133	219	287	287	302	271	359	359	402
Measured	121	150	114	212	292	314	291	271	360	390	434
% Difference	5.8	-4.7	16.7	3.3	-1.7	-8.6	3.8	0	-0.3	-7.9	-7.4
Edge of Car (East)											
Center of car analysis	210	216	179	481	402	402	289	287	287	287	233
Measured	192	195	165	471	415	448	289	293	310	294	225
% Difference	9.4	10.8	8.5	2.1	-3.1	-10	0	-2	-7.4	-2.4	3.6
1/4 point analysis	352	307	220	223	215	215	166	132	143	143	128
Measured	353	328	219	219	230	224	159	137	147	149	121
% Difference	-0.3	-6.4	0.5	1.8	-6.5	-4	4.4	-3.6	-2.7	-4	5.8
1/3 point analysis	133	143	128	302	287	287	219	402	359	359	271
Measured	116	123	111	289	302	289	200	417	354	400	262
% Difference	14.7	16.3	15.3	4.5	-05	-0.7	9.5	-3.6	1.4	-10	3.4

Table E-5
Tandem Axle Loading Results
With $E=29x10^6$ psi

	GAUGE POSITION										
	1/4 Point			Center Line				1/3 Point			
Load Positions	1	2	3	6	7	8	9	12	13	14	15
Center line of car											
Center of car analysis	342	375	342	631	691	691	631	456	500	500	456
Measured	295	349	290	554	655	675	590	418	488	504	422
% Difference	15.9	7.4	17.9	13.9	5.5	2.4	6.9	9.1	2.5	-0.8	8.1
1/4 point analysis	467	513	467	342	376	376	342	228	251	251	228
Measured	411	486	408	290	343	348	283	194	220	231	197
% Difference	13.6	5.6	14.5	17.9	9.6	8	20.8	17.5	14.1	8.7	15.7
1/3 point analysis	228	250	228	455	500	500	455	555	606	606	555
Measured	193	223	185	384	477	491	408	504	554	600	540
% Difference	18.1	12.1	23.2	18.5	4.8	1.8	11.5	10.1	9.4	1	2.8
Edge of Car (West)											
Analysis	311	377	369	495	687	687	781	406	502	502	502
Measured	290	383	320	467	694	661	720	370	470	534	493
% Difference	7.2	-1.6	15.3	6	-1	3.9	8.5	9.7	6.8	-6	1.8
1/4 point analysis	368	508	564	290	377	377	392	224	251	251	231
Measured	338	495	498	253	337	358	331	184	219	236	211
% Difference	8.9	2.6	13.3	14.6	11.9	5.3	18.4	21.7	14.6	6.4	9.5
1/3 point analysis	222	251	232	382	501	501	528	456	604	604	657
Measured	197	243	189	342	473	511	473	425	568	618	631
% Difference	12.7	3.3	22.8	11.7	5.9	-2	11.6	7.3	6.3	-2.3	4.1
Edge of Car (East)											
Center of car analysis	369	377	311	781	687	687	495	502	502	502	406
Measured	309	315	267	648	651	685	442	471	491	472	362
% Difference	19.4	19.7	16.5	20.5	5.5	0.3	12	6.6	2.2	6.4	12.2
1/4 point analysis	564	508	368	392	377	377	290	231	251	251	224
Measured	473	477	318	328	346	336	239	204	221	224	183
% Difference	19.2	6.5	15.7	19.5	9	12.2	21.3	13.2	13.6	12.1	22.4
1/3 point analysis	232	251	222	528	501	501	382	657	604	604	459
Measured	189	201	182	444	490	476	337	596	558	602	432
% Difference	22.8	24.9	22	18.9	2.2	5.3	13.4	10.2	8.2	0.3	6.3

Table E-6
Tandem Axle Loading Results
With E=30x10^6 psi

Load Positions	GAUGE POSITION: 1/4 Point 1	2	3	Center Line 6	7	8	9	1/3 Point 12	13	14	15
Center line of car											
Center of car analysis	330	363	330	610	668	668	610	440	484	484	440
Measured	295	349	290	554	655	675	590	418	488	504	422
% Difference	11.9	4	13.8	10.1	2	-1	3.4	5.3	-0.8	-4	4.3
1/4 point analysis	451	496	451	331	363	363	331	220	242	242	220
Measured	411	486	408	290	343	348	283	194	220	231	197
% Difference	9.7	2.1	10.5	14.1	5.8	4.3	17	13.4	10	4.8	11.7
1/3 point analysis	220	242	220	440	484	484	440	537	586	586	537
Measured	193	223	185	384	477	491	408	504	554	600	540
% Difference	14	8.5	18.9	14.6	1.5	-1.4	7.8	6.5	5.8	-2.3	-0.6
Edge of Car (West)											
Analysis	301	364	354	478	664	664	755	393	485	485	485
Measured	290	383	320	467	694	661	720	370	470	534	493
% Difference	3.8	-5	10.6	2.4	-4.3	0.5	4.9	6.2	3.2	-9.2	-1.6
1/4 point analysis	356	492	545	281	364	364	379	216	243	243	224
Measured	338	495	498	253	337	358	331	184	219	236	211
% Difference	5.3	-0.6	9.4	11.1	8	1.7	14.5	17.4	11	3	6.2
1/3 point analysis	215	242	225	369	484	484	510	444	583	583	635
Measured	197	243	189	342	473	511	473	425	568	618	631
% Difference	9.1	-0.4	19	7.9	2.3	-5.3	7.8	4.5	2.6	-5.7	0.6
Edge of Car (East)											
Center of car analysis	354	364	301	755	664	664	478	485	485	485	393
Measured	309	315	267	648	651	685	442	471	491	472	362
% Difference	14.6	15.6	12.7	16.5	2	-3.1	8.1	3	-1.2	2.8	8.6
1/4 point analysis	545	492	356	379	364	364	281	224	243	243	216
Measured	473	477	318	328	346	336	239	204	221	224	183
% Difference	15.2	3.1	11.9	15.5	5.2	8.3	17.6	9.8	10	0.4	18
1/3 point analysis	225	242	215	510	484	484	369	216	248	248	224
Measured	189	201	182	444	490	476	337	596	558	602	432
% Difference	19	20.4	18.1	14.9	-1.2	1.7	9.5	-64	-56	-59	-48

Table E-7
Tandem Axle Loading Results
With E=31x10^6 psi

Load Positions	GAUGE POSITION 1/4 Point 1	2	3	Center Line 6	7	8	9	1/3 Point 12	13	14	15
Center line of car											
Center of car analysis	320	351	320	590	647	647	590	426	468	468	426
Measured	295	349	290	554	655	675	590	418	488	504	422
% Difference	8.5	0.6	10.3	6.5	-1.2	-4.1	0	1.9	-4.1	-7.1	0.9
1/4 point analysis	436	480	436	320	352	352	320	213	234	234	213
Measured	411	486	408	290	343	348	283	194	220	231	197
% Difference	6.1	-1.2	6.9	10.3	2.6	1.1	13.1	9.8	6.4	1.3	8.1
1/3 point analysis	213	234	213	426	468	468	426	519	567	567	519
Measured	193	223	185	384	477	491	408	504	554	600	540
% Difference	10.4	4.9	15.1	10.9	-1.9	-4.7	4.4	3	2.3	-5.5	-3.9
Edge of Car (West)											
Analysis	291	353	345	463	643	643	730	380	470	470	469
Measured	290	383	320	467	694	661	720	370	470	534	493
% Difference	0.3	-7.8	7.8	-0.9	-7.3	-2.7	1.4	2.7	0	-12	-4.9
1/4 point analysis	344	476	527	271	353	353	366	210	235	235	216
Measured	338	495	498	253	337	358	331	184	219	236	211
% Difference	1.8	-3.8	5.8	7.1	4.7	-1.4	10.6	14.1	7.3	-0.4	2.4
1/3 point analysis	208	234	217	357	469	469	494	430	565	565	614
Measured	197	243	189	342	473	511	473	425	568	618	631
% Difference	5.6	-3.7	14.8	4.4	-0.8	-8.2	4.4	1.2	-0.5	-8.6	-2.7
Edge of Car (East)											
Center of car analysis	345	353	291	730	643	643	463	469	470	470	380
Measured	309	315	267	648	651	685	442	471	491	472	362
% Difference	11.7	12.1	9	12.7	-1.2	-6.1	4.8	-0.4	-4.3	-0.4	5
1/4 point analysis	527	476	344	366	353	353	271	216	235	235	210
Measured	473	477	318	328	346	336	239	204	221	224	183
% Difference	11.4	-0.2	8.2	11.6	2	5.1	13.4	5.9	6.3	4.9	14.8
1/3 point analysis	217	234	208	494	469	469	357	614	565	565	430
Measured	189	201	182	444	490	476	337	596	558	602	432
% Difference	14.8	16.4	14.3	11.3	-4.3	-1.5	5.9	3	1.3	-6.1	-0.5

Table E-8
Tandem Axle Loading Results
With $E=32x10^6$ psi

	GAUGE POSITION										
	1/4 Point			Center Line				1/3 Point			
Load Positions	1	2	3	6	7	8	9	12	13	14	15
Center line of car											
Center of car analysis	310	340	310	572	626	626	572	413	454	454	413
Measured	295	349	290	554	655	675	590	418	488	504	422
% Difference	5.1	-2.6	6.9	3.2	-4.4	-7.3	-3.1	-1.2	-7	-9.9	-2.1
1/4 point analysis	423	465	423	310	341	341	310	207	227	227	207
Measured	411	486	408	290	343	348	283	194	220	231	197
% Difference	2.9	-4.3	3.7	6.9	-0.6	-2	9.5	6.7	3.2	-1.7	5.1
1/3 point analysis	206	227	206	413	453	453	413	503	549	549	503
Measured	193	223	185	384	477	491	408	504	554	600	540
% Difference	6.7	1.8	11.4	7.6	-5	-7.7	1.2	-0.2	-0.9	-8.5	-6.9
Edge of Car (West)											
Analysis	282	342	334	448	623	623	707	368	455	455	455
Measured	290	383	320	467	694	661	720	370	470	534	493
% Difference	-2.8	-11	4.4	-4.1	-10	-5.7	-1.8	-0.5	-3.2	-15	-7.7
1/4 point analysis	333	461	511	263	342	342	355	203	227	227	210
Measured	338	495	498	253	337	358	331	184	219	236	211
% Difference	-1.5	-6.9	2.6	4	1.5	-4.5	7.3	10.3	3.7	-3.8	-0.5
1/3 point analysis	202	227	211	346	455	455	479	416	547	547	595
Measured	197	243	189	342	473	511	473	425	568	618	631
% Difference	2.5	-6.6	11.6	1.2	-3.8	-11	1.3	-2.1	-3.7	-12	-5.7
Edge of Car (East)											
Center of car analysis	334	342	282	707	623	623	448	455	455	455	368
Measured	309	315	267	648	651	685	442	471	491	472	362
% Difference	8.1	8.6	5.6	9.1	-4.3	-9.1	1.4	-3.4	-7.3	-3.6	1.7
1/4 point analysis	511	461	333	355	342	342	263	210	227	227	203
Measured	473	477	318	328	346	336	239	204	221	224	183
% Difference	8	-3.4	4.7	8.2	-1.2	1.8	10	2.9	2.7	1.3	10.9
1/3 point analysis	211	227	202	479	455	455	346	595	547	547	416
Measured	189	201	182	444	490	476	337	596	558	602	432
% Difference	11.6	12.9	11	7.9	-7.1	-4.4	2.7	-0.2	-2	-9.1	-3.7

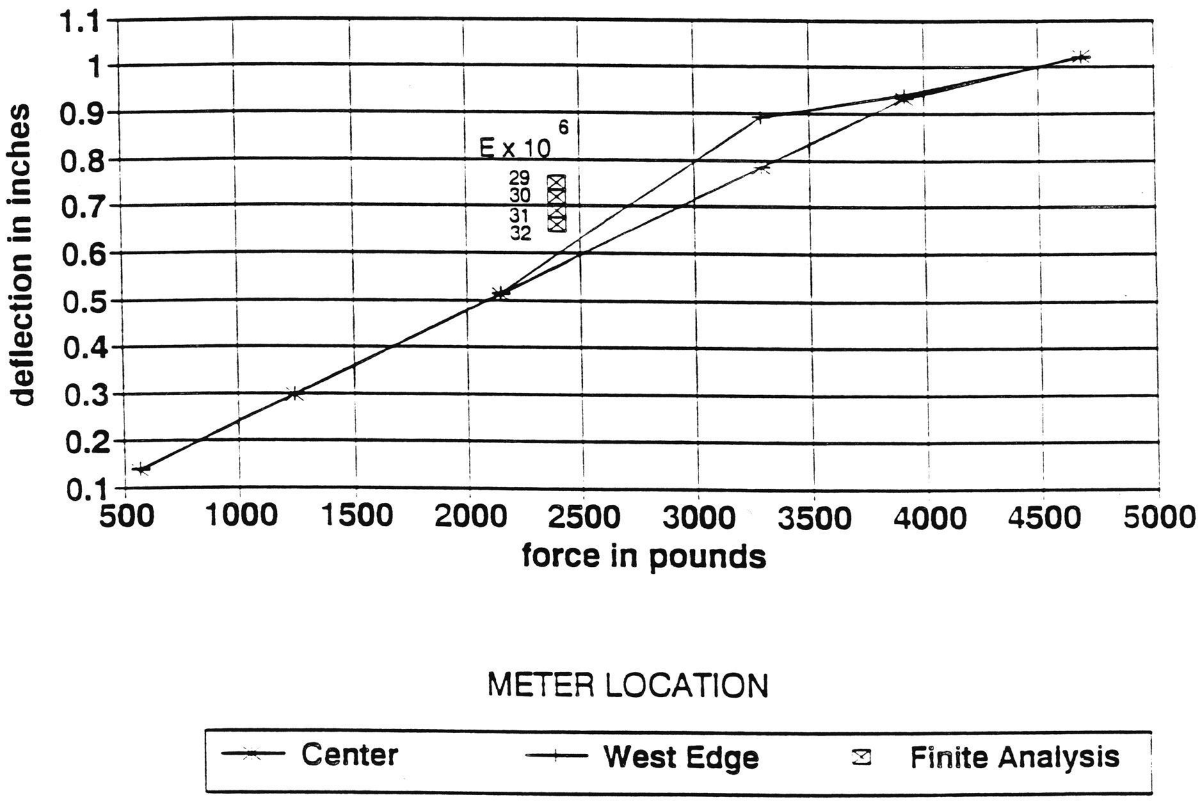


Fig. E.1 Deflections for Single Axle Centered on Model

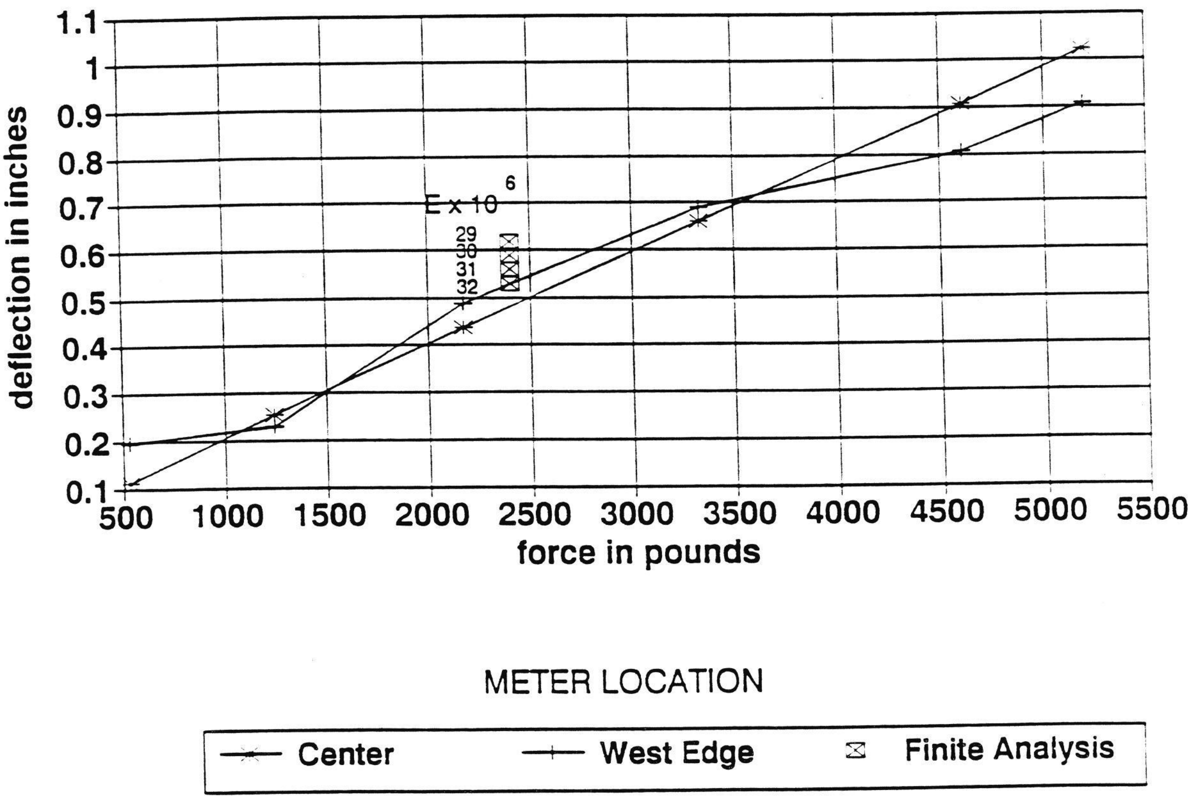


Fig. E.2 Deflections for Single Axle Along Edge at 1/3 Span

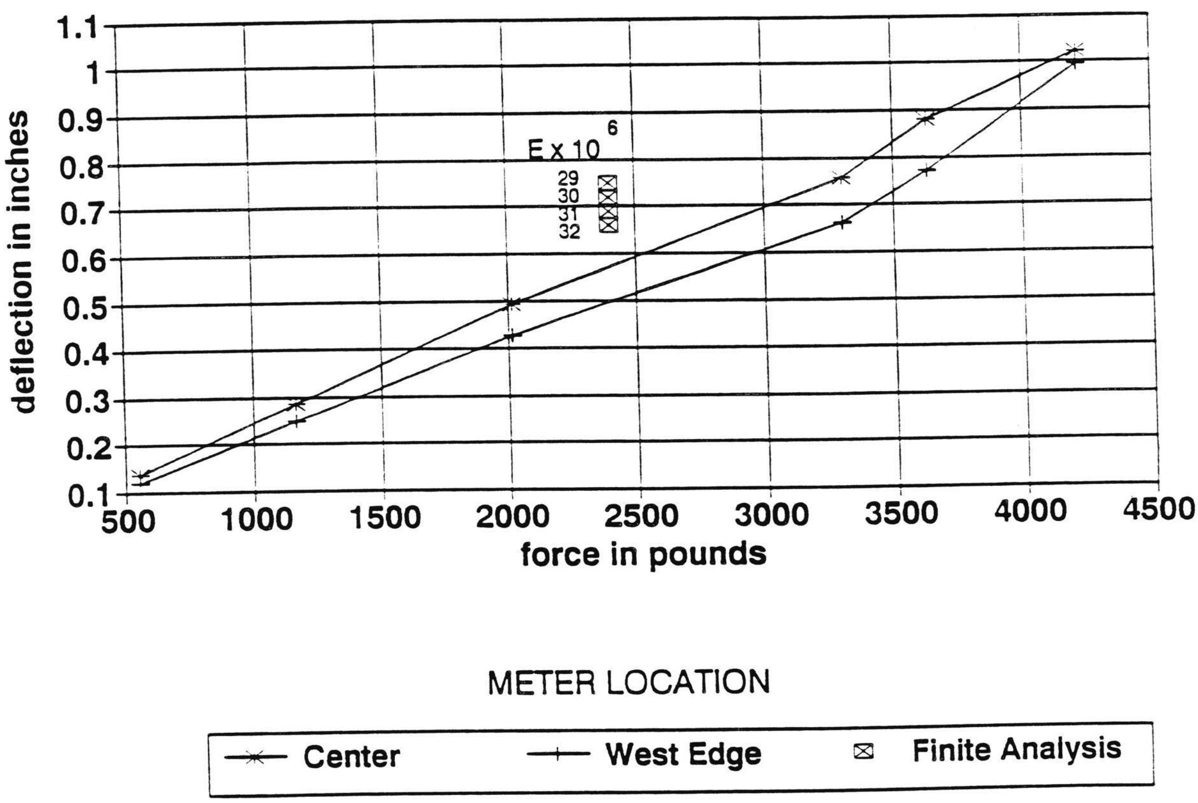
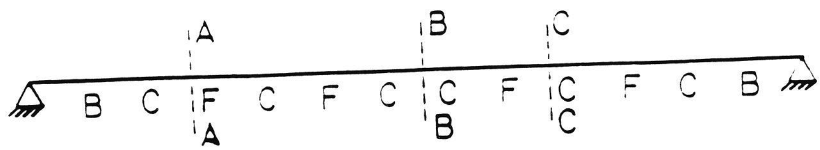


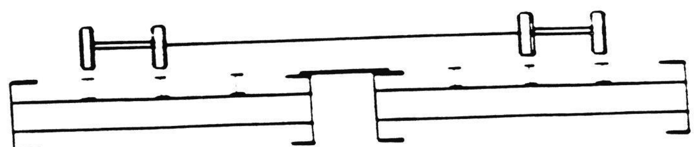
Fig. E.3 Deflections for Single Axle Along Edge at Midspan

Table E-9
Centered Single Axle
Loaded at Section A-A



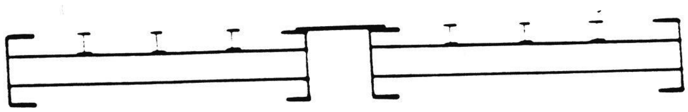
Measured Strains 10^{-6}

Section A-A



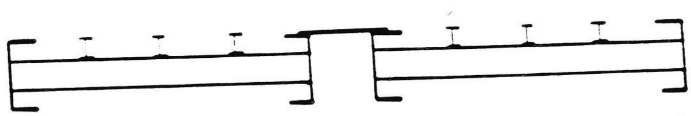
Analysis	283		310			283
Measured	296		334			294
% Difference	-4.4		-7.2			-3.7

Section B-B



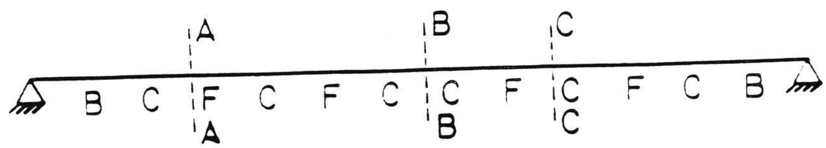
Analysis	195		215	215		195
Measured	195		230	233		190
% Difference	0		-6.5	-7.7		2.6

Section C-C



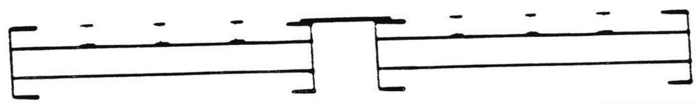
Analysis	130		143	143		130
Measured	129		147	155		131
% Difference	0.8		-2.7	-7.7		-0.8

Table E-10
Centered Single Axle
Loaded at Section B-B



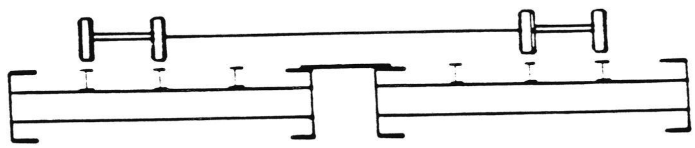
Measured Strains 10^{-6}

Section A-A



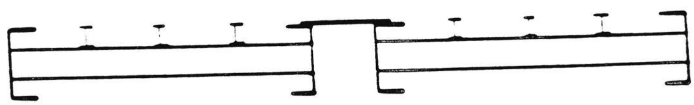
Analysis	196		215			196
Measured	181		216			176
% Difference	8.3		-0.5			11.4

Section B-B



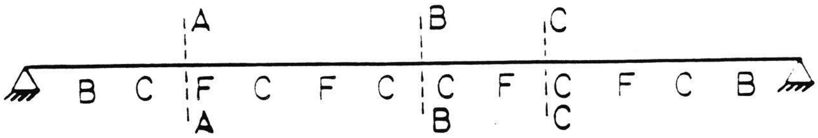
Analysis	370		405	405		370
Measured	398		411	427		380
% Difference	-7		-1.5	-5.2		-2.6

Section C-C



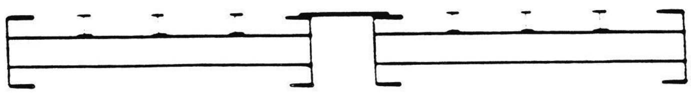
Analysis	261		286	286		261
Measured	261		304	313		258
% Difference	0		-5.9	-8.6		1.2

Table E-11
Centered Single Axle
Loaded at Section C-C



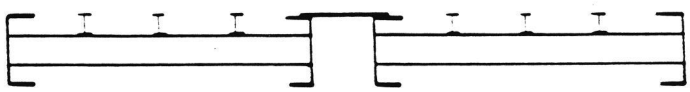
Measured Strains 10^{-6}

Section A-A



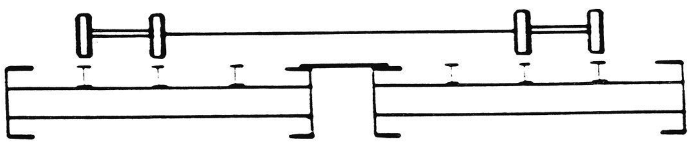
Analysis	130		143			130
Measured	117		137			112
% Difference	11.1		4.4			16.1

Section B-B



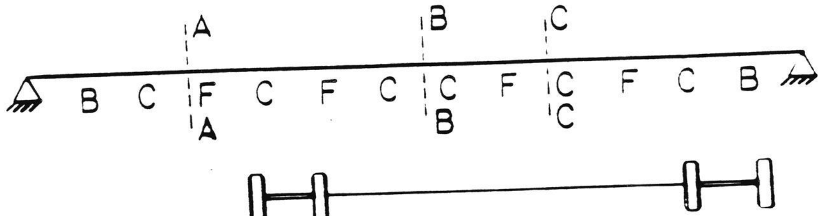
Analysis	261		286	286		261
Measured	249		296	301		245
% Difference	4.8		-3.4	-5		6.5

Section C-C



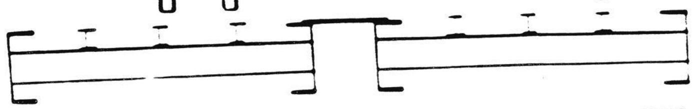
Analysis	331		361	361		331
Measured	343		352	386		346
% Difference	-3.5		2.6	-6.5		-4.3

Table E-12
Single Axle at Edge
Loaded at Section A-A



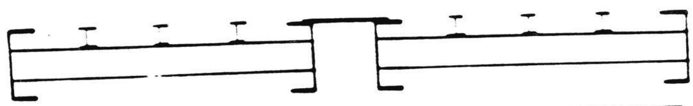
Measured Strains 10^{-6}

Section A-A



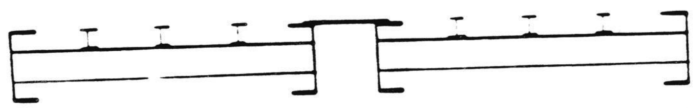
Analysis	220		307			352
Measured	232		336			371
% Difference	-5.2		-8.6			-5.1

Section B-B



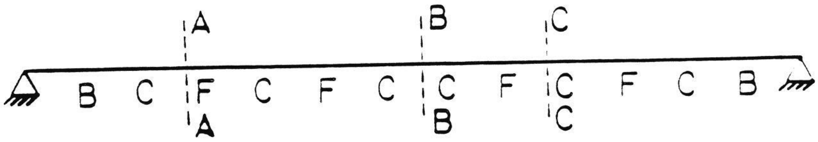
Analysis	166		215	215		223
Measured	165		225	240		222
% Difference	0.6		-4.4	-10		0.5

Section C-C



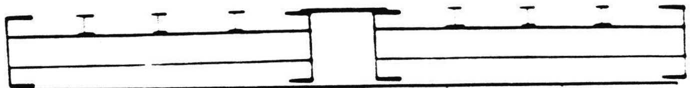
Analysis	128		143	143		132
Measured	120		145	156		139
% Difference	6.7		-1.4	-8.3		-5

Table E-13
Single Axle at Edge
Loaded at Section B-B



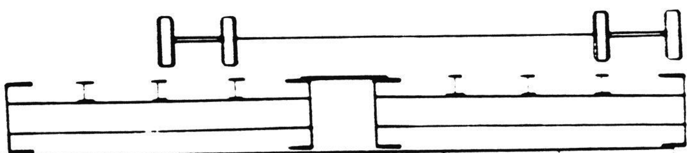
Measured Strains 10^{-6}

Section A-A



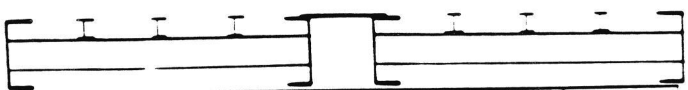
Analysis	179		216			210
Measured	173		237			191
% Difference	3.5		-8.9			9.9

Section B-B



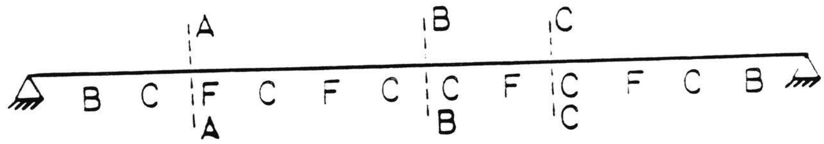
Analysis	289		402	402		481
Measured	312		434	419		436
% Difference	-7.4		-7.4	-4.1		10.3

Section C-C



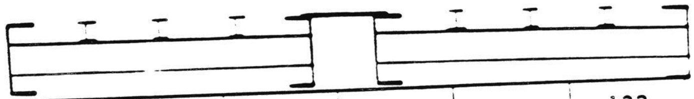
Analysis	233		287	287		287
Measured	227		293	332		297
% Difference	2.6		-2	-14		-3.4

Table E-14
Single Axle at Edge
Loaded at Section C-C



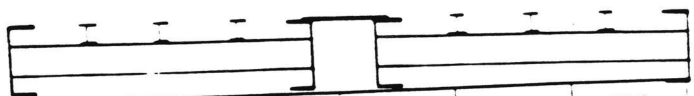
Measured Strains 10^{-6}

Section A-A



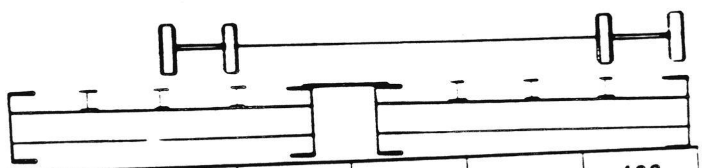
Analysis	128		143			133
Measured	121		150			114
% Difference	5.8		-4.7			16.7

Section B-B



Analysis	219		287	287		302
Measured	212		292	314		291
% Difference	3.3		-1.7	-8.6		3.8

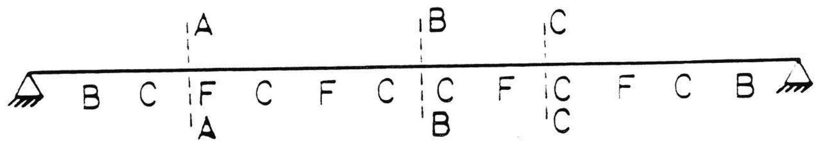
Section C-C



Analysis	271		359	359		402
Measured	271		360	390		434
% Difference	0		-0.3	-7.9		-7.4

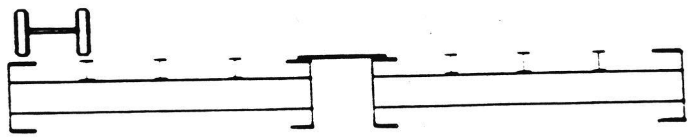
Table E-15
Point Load at Section A-A
Results at Section A-A

POINT LOAD ON SIDE SILL



Section A-A

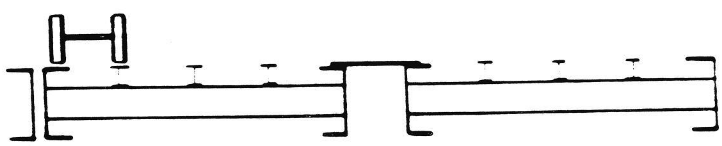
Single Side Sill



Model Strains 2000 lb load	Top	-405		-142	-117		-23
	Bottom	463		247			47
3000 lb load	Top	-603		-214	-180		-36
	Bottom	697		373			72
Analysis Strains 2000 lb load	Top	-361		-245	-245		-146
	Bottom	361		245			146
3000 lb load	Top	-541		-367	-367		-219
	Bottom	541		367	367		219

Section A-A

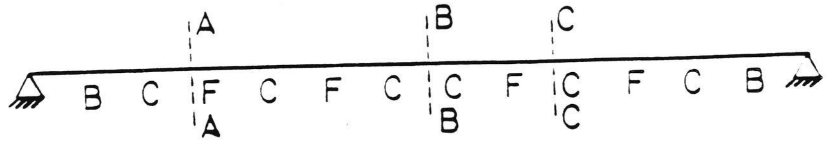
Double Side Sill



Model Strains 2000 lb load	Top	-138		-126	-134		-192
	Bottom	165		247	229		229
3000 lb load	Top	-208		-189	-206		-287
	Bottom	248		368			342
Analysis Strains 2000 lb load	Top	-251		-190	-190		-115
	Bottom	251		190			115
3000 lb load	Top	-377		-284	-284		-173
	Bottom	377		284			173

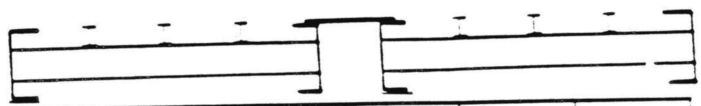
Table E-16
Point Load at Section A-A
Results at Section B-B

POINT LOAD ON SIDE SILL



Section B-B

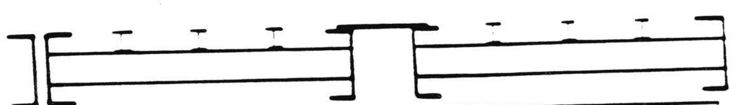
Single Side Sill



Model Strains 2000 lb load	Top	-188		-86	-89		-36
	Bottom	252		204	177		59
3000 lb load	Top	-282		-131	-135		-53
	Bottom	381		309	268		91
Analysis Strains 2000 lb load	Top	-153		-192	-192		-157
	Bottom	153		192	192		157
3000 lb load	Top	-229		-289	-289		-235
	Bottom	229		289	289		235

Section B-B

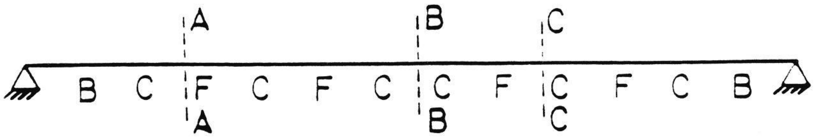
Double Side Sill



Model Strains 2000 lb load	Top	-82		-73	-70		-118
	Bottom	121		153	164		157
3000 lb load	Top	-124		-112	-105		-175
	Bottom	181		229	245		234
Analysis Strains 2000 lb load	Top	-129		-155	-155		-125
	Bottom	129		155	155		125
3000 lb load	Top	-193		-233	-233		-188
	Bottom	193		233	233		188

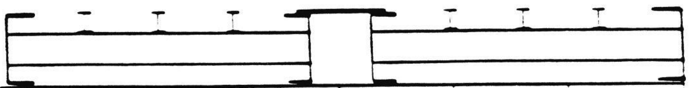
Table E-17
Point Load at Section A-A
Results at Section C-C

POINT LOAD ON SIDE SILL



Section C-C

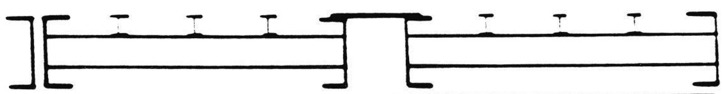
Single Side Sill



Model Strains 2000 lb load	Top	-90		-48	-52		-52
	Bottom	131		130	115		83
3000 lb load	Top	-135		-73	-78		-78
	Bottom	200		197	175		125
Analysis Strains 2000 lb load	Top	-76		-89	-89		-73
	Bottom	76		89	89		73
3000 lb load	Top	-114		-133	-133		-110
	Bottom	114		133	133		110

Section C-C

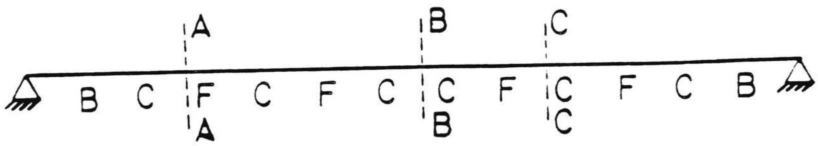
Double Side Sill



Model Strains 2000 lb load	Top	-35		-45	-41		-66
	Bottom	83		100	106		100
3000 lb load	Top	-88		-69	-62		-97
	Bottom	124		152	158		150
Analysis Strains 2000 lb load	Top	-61		-72	-72		-60
	Bottom	61		72	72		60
3000 lb load	Top	-91		-108	-108		-90
	Bottom	91		108	108		90

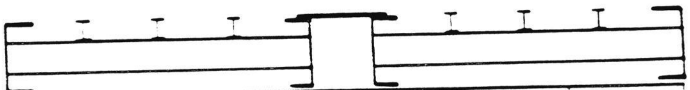
Table E-18
Point Load at Section B-B
Results at Section A-A

POINT LOAD ON SIDE SILL



Section A-A

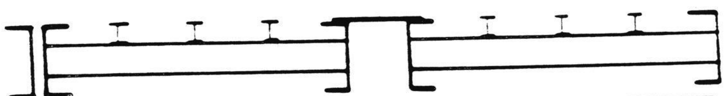
Single Side Sill



Model Strains 2000 lb load	Top	-129		-108	-74		-84
	Bottom	183		133			108
3000 lb load	Top	-194		-161	-114		-125
	Bottom	275		200			161
Analysis Strains 2000 lb load	Top	-163		-192	-192		-148
	Bottom	163		192			148
3000 lb load	Top	-244		-288	-288		-222
	Bottom	244		288			222

Section A-A

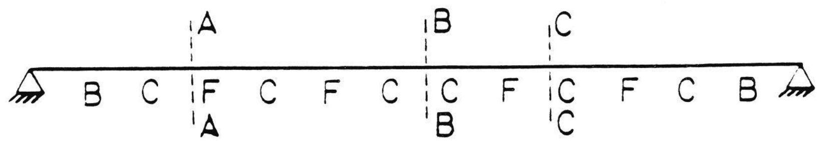
Double Side Sill



Model Strains 2000 lb load	Top	-116		-81	-55		-64
	Bottom	158		110			83
3000 lb load	Top	-176		-122	-87		-94
	Bottom	238		166			124
Analysis Strains 2000 lb load	Top	-135		-153	-153		-118
	Bottom	135		153	153		118
3000 lb load	Top	-202		-230	-230		-178
	Bottom	202		230	230		178

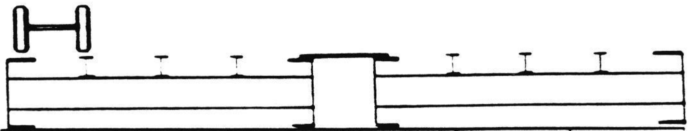
Table E-19
Point Load at Section B-B
Results at Section B-B

POINT LOAD ON SIDE SILL



Section B-B

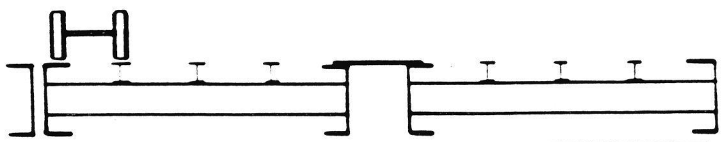
Single Side Sill



Model Strains							
2000 lb load	Top	-484		-185	-160		-23
	Bottom	651		366	293		59
3000 lb load	Top	*		-277	-239		-35
	Bottom	*		550	441		92
Analysis Strains							
2000 lb load	Top	-423		-345	-345		-240
	Bottom	423		345	345		240
3000 lb load	Top	-634		-518	-518		-360
	Bottom	634		518	518		360

Section B-B

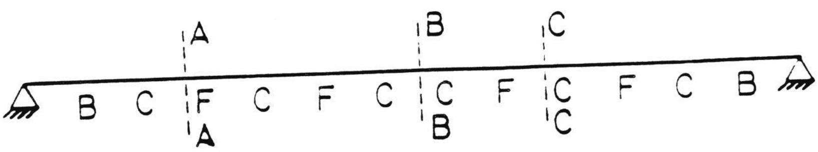
Double Side Sill



Model Strains							
2000 lb load	Top	-297		-141	-118		-27
	Bottom	424		273	222		55
3000 lb load	Top	-438		-212	-177		-44
	Bottom	629		412	334		86
Analysis Strains							
2000 lb load	Top	-308		-273	-273		-192
	Bottom	308		273	273		192
3000 lb load	Top	-462		-409	-409		-288
	Bottom	462		409	409		288

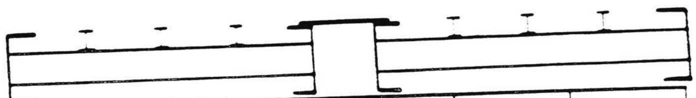
Table E-20
Point Load at Section B-B
Results at Section C-C

POINT LOAD ON SIDE SILL



Section C-C

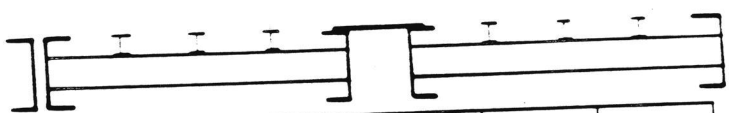
Single Side Sill



Model Strains 2000 lb load	Top	-263		-125	-130		-47
	Bottom	344		285	239		95
3000 lb load	Top	-394		-187	-195		-71
	Bottom	516		426	358		145
Analysis Strains 2000 lb load	Top	-150		-180	-180		-143
	Bottom	150		180	180		143
3000 lb load	Top	-224		-270	-270		-214
	Bottom	224		270	270		214

Section C-C

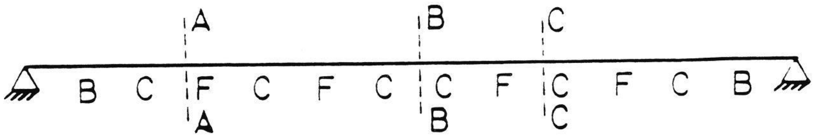
Double Side Sill



Model Strains 2000 lb load	Top	-200		-93	-96		-41
	Bottom	256		215	184		81
3000 lb load	Top	-298		-140	-145		-63
	Bottom	384		321	276		121
Analysis Strains 2000 lb load	Top	-124		-145	-145		-115
	Bottom	124		145	145		115
3000 lb load	Top	-186		-218	-218		-172
	Bottom	186		218	218		172

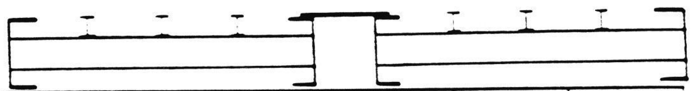
Table E-21
Point Load at Section C-C
Results at Section A-A

POINT LOAD ON SIDE SILL



Section A-A

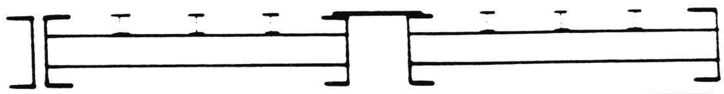
Single Side Sill



Model Strains 2000 lb load	Top	-60		-66	-38		-77
	Bottom	99		75			97
3000 lb load	Top	-90		-100	-61		-115
	Bottom	148		112			145
Analysis Strains 2000 lb load	Top	-108		-126	-126		-102
	Bottom	108		126			102
3000 lb load	Top	-163		-189	-189		-153
	Bottom	163		189	189		153

Section A-A

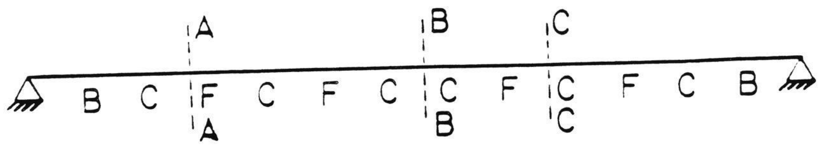
Double Side Sill



Model Strains 2000 lb load	Top	-59		-46	-44		-56
	Bottom	81		106			86
3000 lb load	Top	-89		-68	-70		-84
	Bottom	122		160			129
Analysis Strains 2000 lb load	Top	-88		-102	-102		-83
	Bottom	88		102			83
3000 lb load	Top	-132		-153	-153		-124
	Bottom	132		153			124

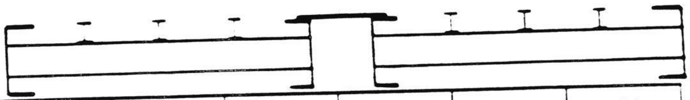
Table E-22
Point Load at Section C-C
Results at Section B-B

POINT LOAD ON SIDE SILL



Section B-B

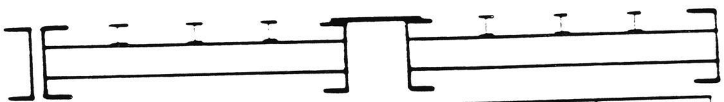
Single Side Sill



Model Strains 2000 lb load	Top	-288		-122	-126		-31
	Bottom	368		278	235		60
3000 lb load	Top	-431		-184	-189		-45
	Bottom	550		417	350		92
Analysis Strains 2000 lb load	Top	-212		-257	-257		-199
	Bottom	212		257	257		199
3000 lb load	Top	-318		-386	-386		-299
	Bottom	318		386	386		299

Section B-B

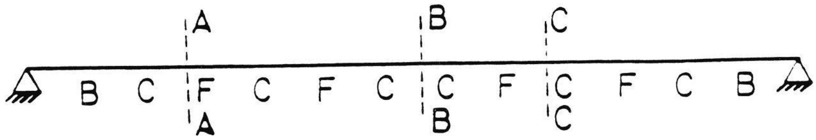
Double Side Sill



Model Strains 2000 lb load	Top	-105		-106	-105		-163
	Bottom	146		210	226		211
3000 lb load	Top	-158		-159	-157		-244
	Bottom	220		315	341		316
Analysis Strains 2000 lb load	Top	-178		-206	-206		-159
	Bottom	178		206	206		159
3000 lb load	Top	-267		-308	-308		-239
	Bottom	267		308	308		239

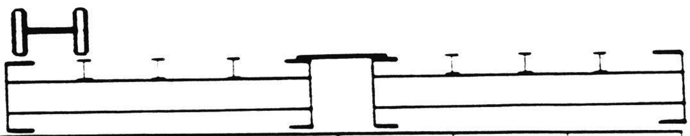
Table E-23
Point Load at Section C-C
Results at Section C-C

POINT LOAD ON SIDE SILL



Section C-C

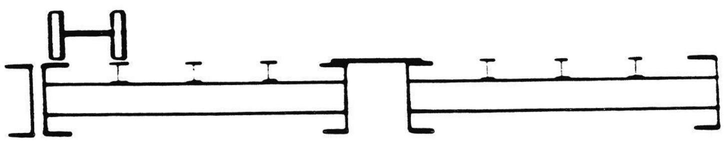
Single Side Sill



Model Strains 2000 lb load	Top	-500		-169	-150		-28
	Bottom	569		326	257		69
3000 lb load	Top	*		-253	-226		-41
	Bottom	*		489	386		104
Analysis Strains 2000 lb load	Top	-237		-236	-236		-161
	Bottom	237		236	236		161
3000 lb load	Top	-356		-354	-354		-241
	Bottom	356		354	354		241

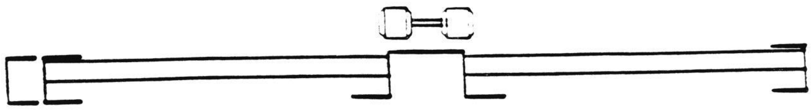
Section C-C

Double Side Sill



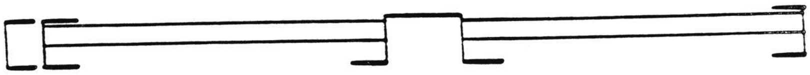
Model Strains 2000 lb load	Top	-191		-165	-142		-234
	Bottom	218		273	277		289
3000 lb load	Top	-286		-248	-214		-349
	Bottom	331		412	418		436
Analysis Strains 2000 lb load	Top	-186		-185	-185		-128
	Bottom	186		185	185		128
3000 lb load	Top	-279		-278	-278		-192
	Bottom	279		278	278		192

Table E-24
Point Load Centered at Section A-A
One Double Side Sill



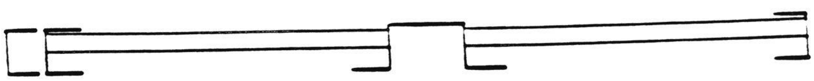
Section A-A

2000 lb Top	-112		-140	-153		-167
Bottom	146		281	---		211
3000 lb Top	-168		-211	-234		-251
Bottom	217		421	---		316



Section B-B

2000 lb Top	-82		-69	-65		-120
Bottom	121		145	158		160
3000 lb Top	-127		-106	-99		-181
Bottom	184		219	237		241

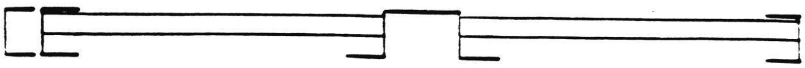


Section C-C

2000 lb Top	-58		-46	-40		-65
Bottom	85		103	104		99
3000 lb Top	-87		-68	-61		-98
Bottom	128		154	156		151

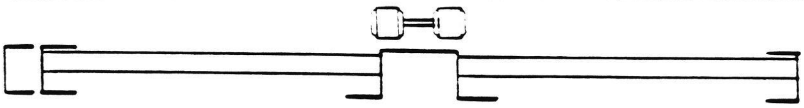
Table E-25
Point Load Centered at Section B-B
One Double Side Sill

Section A-A



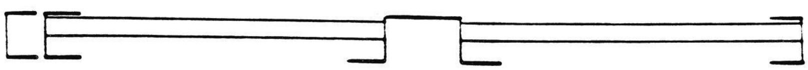
2000 lb Top	-86		-64	-65		-108
Bottom	121		147	---		152
3000 lb Top	-129		-95	-100		-163
Bottom	181		220	---		229

Section B-B



2000 lb Top	-136		-184	-204		-213
Bottom	185		376	418		257
3000 lb Top	-205		-275	-306		-322
Bottom	278		566	629		389

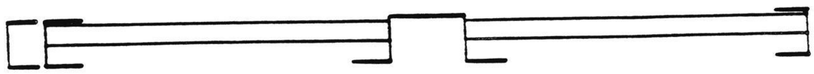
Section C-C



2000 lb Top	-119		-99	-86		-167
Bottom	162		199	205		223
3000 lb Top	-179		-149	-129		-252
Bottom	245		301	309		337

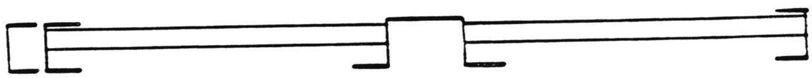
Table E-26
Point Load Centered atSection C-C
One Double Side Sill

Section A-A



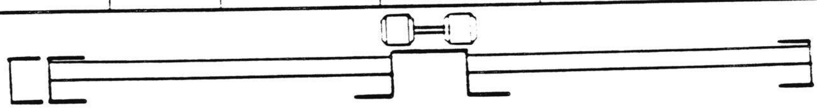
2000 lb Top	-54		-44	-40		-55
Bottom	81		100	---		89
3000 lb Top	-82		-65	-64		-84
Bottom	122		151	---		132

Section B-B



2000 lb Top	-115		-102	-96		-168
Bottom	158		205	222		212
3000 lb Top	-174		-154	-145		-254
Bottom	238		309	334		319

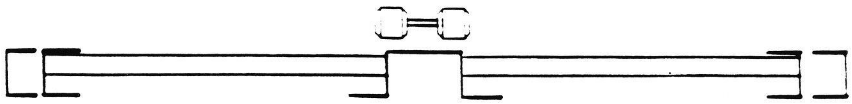
Section C-C



2000 lb Top	-131		-188	-169		-195
Bottom	176		341	355		246
3000 lb Top	-197		-281	-254		-292
Bottom	264		510	533		370

Table E-27
Point Load Centered at Section A-A
Two Double Side Sills

Section A-A



2000 lb Top	-106		-126	-143		-143
Bottom	135		249	---		175
3000 lb Top	-159		-191	-214		-214
Bottom	202		373	---		261

Section B-B

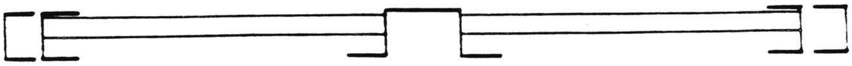
2000 lb Top	-84		-56	-54		-86
Bottom	117		120	124		111
3000 lb Top	-127		-84	-80		-128
Bottom	177		181	186		168

Section C-C

2000 lb Top	-54		-38	-33		-50
Bottom	79		82	83		82
3000 lb Top	-80		-57	-50		-76
Bottom	120		125	125		122

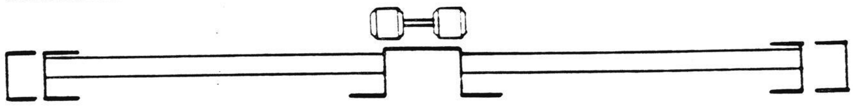
Table E-28
Point Load Centered at Section B-B
Two Double Side Sills

Section A-A



2000 lb Top	-75		-52	-47		-84
Bottom	110		113	---		116
3000 lb Top	-115		-77	-74		-126
Bottom	164		170	---		174

Section B-B



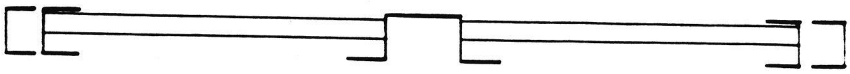
2000 lb Top	-139		-155	-202		-165
Bottom	177		354	371		197
3000 lb Top	-209		-229	-303		-250
Bottom	269		533	558		296

Section C-C

2000 lb Top	-117		-83	-71		-127
Bottom	159		172	167		176
3000 lb Top	-175		-124	-107		-194
Bottom	239		260	252		264

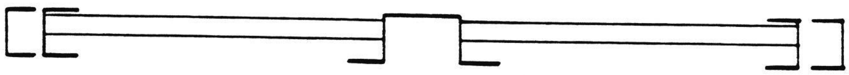
Table E-29
Point Load Centered at Section C-C
Two Double Side Sills

Section A-A



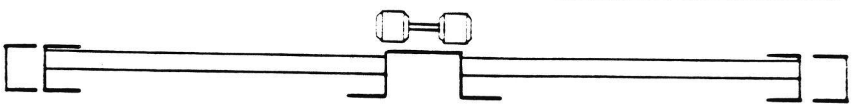
2000 lb Top	-46		-37	-30		-45
Bottom	70		81	---		70
3000 lb Top	-69		-55	-50		-67
Bottom	105		121	---		104

Section B-B



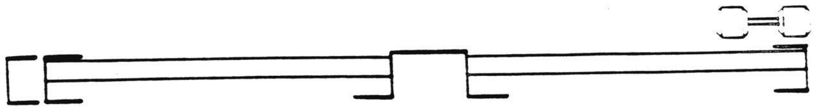
2000 lb Top	-112		-85	-83		-132
Bottom	149		177	183		163
3000 lb Top	-169		-130	-124		-198
Bottom	226		267	276		244

Section C-C



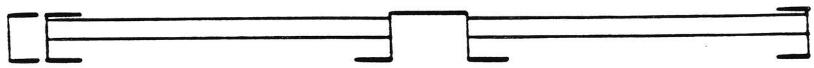
2000 lb Top	-130		-163	-154		-145
Bottom	172		291	320		189
3000 lb Top	-195		-243	-236		-220
Bottom	258		439	483		284

Table E-30
Point Load at Edge of Section A-A
One Double Side Sill



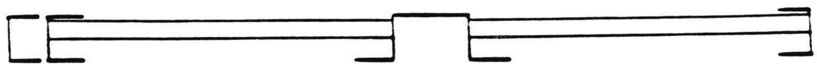
Section A-A

2000 lb Top	-12		-110	-143		-410
Bottom	39		255	---		470
3000 lb Top	-16		-164	-218		-616
Bottom	57		382	---		709



Section B-B

2000 lb Top	-19		-88	-76		-191
Bottom	49		159	199		252
3000 lb Top	-29		-134	-115		-288
Bottom	75		238	299		378

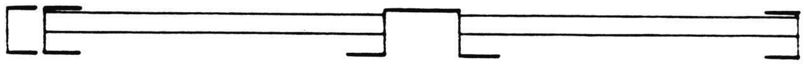


Section C-C

2000 lb Top	-37		-52	-38		-86
Bottom	55		101	121		131
3000 lb Top	-54		-78	-59		-129
Bottom	83		152	180		197

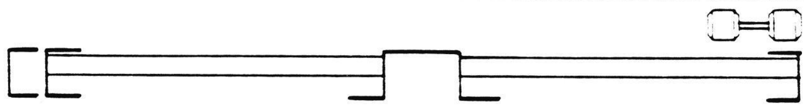
Table E-31
Point Load at Edge of Section B-B
One Double Side Sill

Section A-A



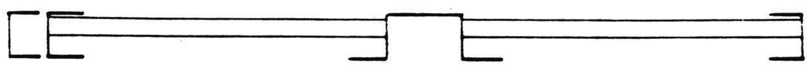
2000 lb Top	-56		-70	-99		-120
Bottom	88		226	---		185
3000 lb Top	-83		-104	-154		-179
Bottom	132		339	---		279

Section B-B



2000 lb Top	*		-159	-159		*
Bottom	50		265	357		572
3000 lb Top	*		-241	-237		*
Bottom	72		396	536		815

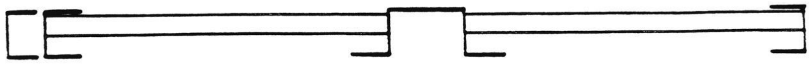
Section C-C



2000 lb Top	-26		-132	-109		-258
Bottom	56		218	271		335
3000 lb Top	-39		-198	-164		-385
Bottom	85		325	407		503

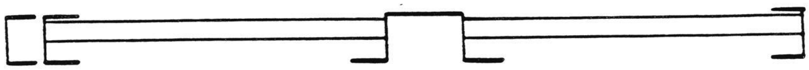
*Gauge malfunctioned.

Table E-32
Point Load at Edge of Section C-C
One Double Side Sill



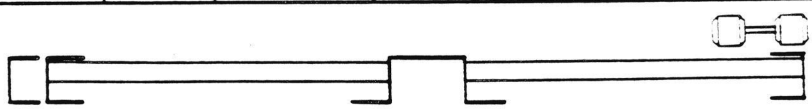
Section A-A

2000 lb Top	-53		-38	-56		-54
Bottom	74		148	---		98
3000 lb Top	-78		-55	-89		-79
Bottom	112		221	---		147



Section B-B

2000 lb Top	-19		-126	-112		-296
Bottom	54		212	274		370
3000 lb Top	-24		-188	-166		-439
Bottom	80		316	410		553

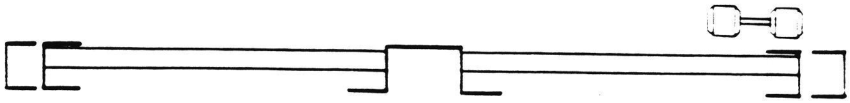


Section C-C

2000 lb Top	-13		-156	-152		-477
Bottom	38		238	331		579
3000 lb Top	-18		-234	-226		-663
Bottom	60		358	496		845

Table E-33
Point Load at Edge of Section A-A
Two Double Side Sills

Section A-A

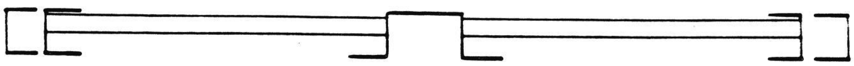


2000 lb Top	-8		-88	-112		-358
Bottom	28		195	---		399
3000 lb Top	-12		-130	-169		-527
Bottom	43		291	---		590

Section B-B

2000 lb Top	-19		-66	-56		-135
Bottom	42		118	142		169
3000 lb Top	-29		-101	-85		-210
Bottom	64		178	216		262

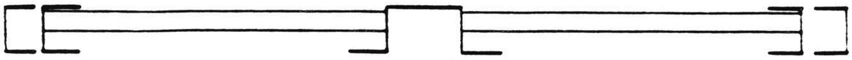
Section C-C



2000 lb Top	-30		-40	-30		-66
Bottom	44		77	87		98
3000 lb Top	-44		-60	-45		-99
Bottom	65		117	133		149

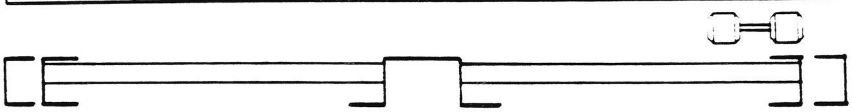
Table E-34
Point Load at Edge of Section B-B
Two Double Side Sills

Section A-A



2000 lb Top	-45		-49	-68		-76
Bottom	65		165	---		125
3000 lb Top	-66		-74	-109		-121
Bottom	99		249	---		194

Section B-B



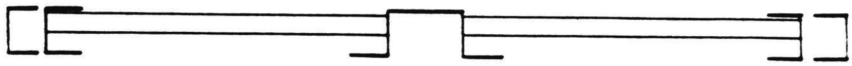
2000 lb Top	-9		-128	-127		-430
Bottom	44		205	276		479
3000 lb Top	-11		-189	-189		-636
Bottom	63		306	414		718

Section C-C

2000 lb Top	-21		-101	-88		-190
Bottom	44		171	208		249
3000 lb Top	-32		-148	-130		-271
Bottom	66		253	308		362

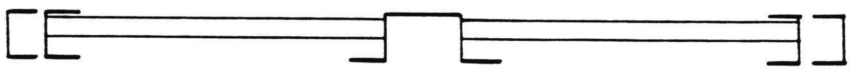
Table E-35
Point Load at Edge of Section C-C
Two Double Side Sills

Section A-A



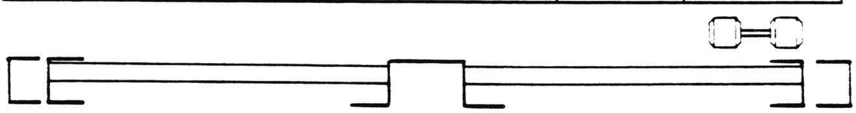
2000 lb Top	-38		-27	-41		-40
Bottom	58		111	---		77
3000 lb Top	-57		-41	-67		-64
Bottom	86		168	---		121

Section B-B



2000 lb Top	-15		-97	-86		-225
Bottom	43		102	210		271
3000 lb Top	-23		-145	-129		-333
Bottom	65		244	314		406

Section C-C

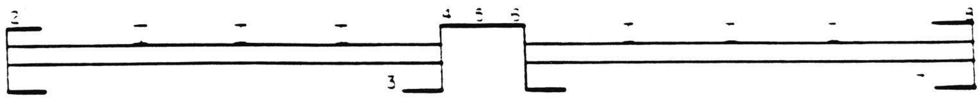


2000 lb Top	-12		-117	-118		-444
Bottom	32		186	252		464
3000 lb Top	-18		-175	-176		-661
Bottom	50		278	378		690

Appendix F
Model Damage Tests

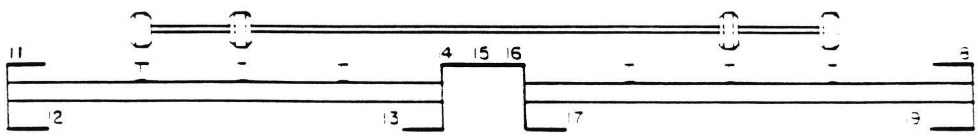
Table F-1
Damage Test D1
Loaded at Center of Span

Gauge No.	DNO		D1A		D1B		D1C	
1/4 Point	994 lb	2011 lb	1017 lb	2017 lb	1011 lb	2052 lb	1011 lb	2011 lb



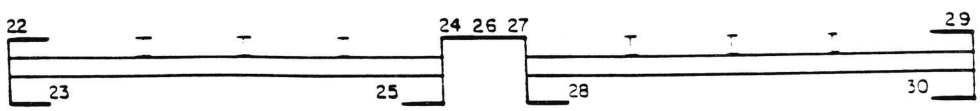
1	75	152	75	150	75	152	75	149
2	-53	-107	-53	-107	-52	-108	-51	-104
3	90	186	90	182	93	188	94	272
4	-43	-88	-45	-90	-45	-91	-45	-90
5	-42	-85	-45	-87	-43	-88	-44	-89
6	-47	-96	-48	-98	-49	-100	-50	-100
7	74	157	76	152	75	153	76	151
8	-52	-106	-54	-106	-54	-108	-52	-104

Centerline



11	-110	-225	-114	-226	-113	-227	-112	-226
12	152	308	153	307	155	309	154	310
13	171	347	175	345	174	345	174	347
14	-94	-189	-96	-191	-93	-188	-93	-186
15	-128	-261	-131	-263	-129	-263	-129	-260
16	-85	-173	-88	-174	-86	-174	-87	-174
17	177	358	180	359	174	355	178	355
18	-122	-250	-126	-249	-123	-248	-123	-248
19	163	333	167	330	162	332	163	336

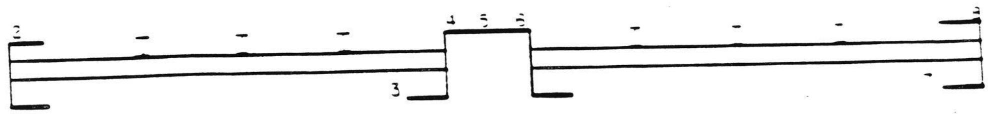
1/3 Point



22	-77	-155	-79	-156	-77	-156	-76	-155
23	104	212	106	212	105	212	104	213
24	-60	-123	-62	-124	-61	-123	-61	-124
25	124	250	124	248	123	249	124	250
26	-57	-117	-59	-118	-57	-117	-57	-117
27	-57	-116	-59	-117	-57	-116	-56	-116
28	125	253	127	252	123	251	123	251
29	-79	-159	-81	-160	-78	-158	-78	-160
30	110	223	111	222	107	219	108	221

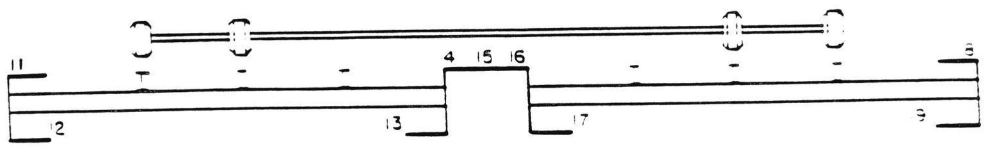
Table F-2
Damage Test D2
Loaded at Center of Span

Gauge No.	DNO		D2A		D2B		D2C	
1/4 Point	1000 lb	2023 lb	989 lb	2012 lb	994 lb	1994 lb	1006 lb	2012 lb



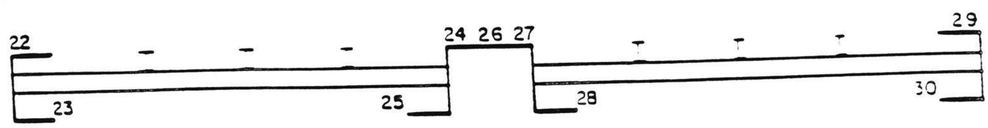
1	76	152	74	151	70	142	62	123
2	-54	-108	-53	-108	-50	-102	-46	-91
3	92	186	90	186	90	185	98	200
4	-45	-91	-45	-90	-43	-87	-42	-84
5	-43	-87	-43	-87	-43	-87	-44	-91
6	-49	-99	-48	-99	-49	-100	-54	-110
7	76	152	75	152	75	151	80	163
8	-54	-108	-53	-108	-54	-109	-58	-116

Centerline



11	-113	-229	-112	-227	-110	-223	-110	-223
12	153	311	150	308	148	300	147	299
13	174	347	171	346	168	339	171	343
14	-95	-191	-94	-191	-93	-186	-94	-186
15	-132	-267	-130	-263	-128	-258	-128	-259
16	-88	-177	-86	-176	-85	-172	-86	-172
17	177	359	175	357	174	350	176	356
18	-124	-252	-122	-250	123	-247	-128	-257
19	165	335	162	333	163	330	168	342

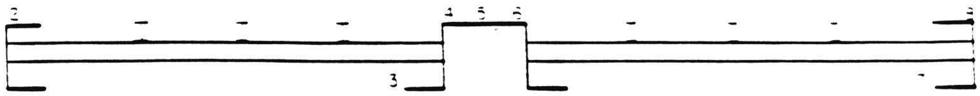
1/3 Point



22	-78	-158	-78	-157	-77	-154	-73	-154
23	107	215	105	214	101	208	97	206
24	-62	-125	-61	-124	-60	-122	-58	-123
25	123	152	122	250	121	246	116	249
26	-58	-118	-58	-118	-58	-116	-56	-117
27	-59	-118	-58	-116	-56	-114	-54	-115
28	126	255	124	252	123	248	119	253
29	-80	163	-79	-160	-79	-158	-76	-162
30	109	223	109	221	108	218	106	225

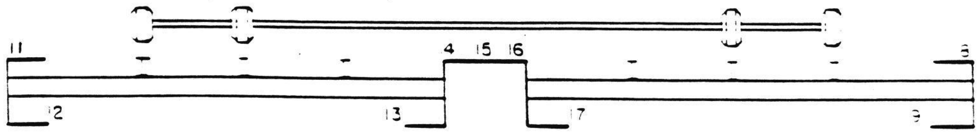
Table F-3
Damage Test D3
Loaded at Center of Span

Gauge No.	DNO		D3A		D3B		D3C	
1/4 Point	1011 lb	2005 lb	1005 lb	2035 lb	1011 lb	1994 lb	989 lb	1994 lb



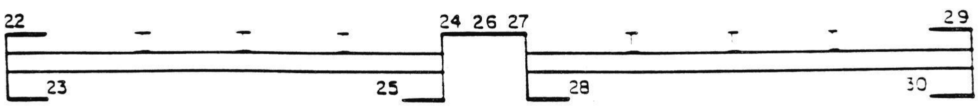
1	76	151	74	148	67	134	30	66
2	-53	-106	-53	-105	-48	-94	-23	-49
3	91	184	92	188	90	179	82	167
4	-45	-90	-45	-91	-45	-90	-47	-97
5	-43	-86	-44	-88	-43	-87	-48	-96
6	-49	-96	-48	-98	-50	-99	-59	-114
7	75	151	76	156	76	153	93	186
8	-52	-106	-53	-110	-56	-111	-73	-145

Centerline



11	-113	-225	-124	-249	-116	-231	-48	-102
12	153	308	143	288	122	243	26	63
13	173	343	172	351	177	351	231	460
14	-95	-188	-97	-196	-100	-198	-118	-236
15	-130	-254	-131	-268	-134	-268	-170	-340
16	-87	-168	-85	-172	-87	-173	-122	-242
17	177	345	188	371	182	361	213	428
18	-124	-241	-123	-251	-123	-243	-111	-224
19	165	321	161	335	161	324	155	299

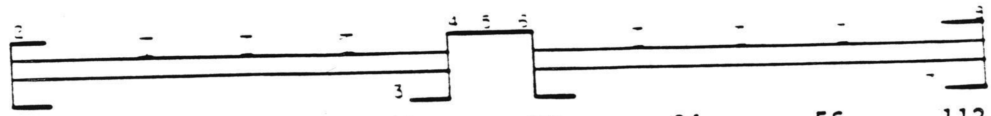
1/3 Point



22	-78	-151	-76	-155	-70	-140	-41	-81
23	106	206	101	209	94	180	47	98
24	-62	-120	-60	-125	-61	-116	-62	-123
25	124	242	123	258	128	241	155	291
26	-58	-114	-58	-121	-60	-113	-68	-130
27	-58	-112	-58	-121	-59	-113	-70	-133
28	126	244	124	258	128	241	144	275
29	-79	-153	-79	-162	-80	-152	-89	-170
30	110	214	109	226	110	209	120	230

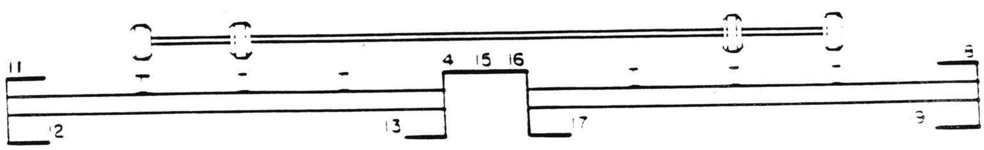
Table F-4
Damage Test D4
Loaded at Center of Span

Gauge No.	DNO		D4A		D4B		D4C	
1/4 Point	lb	lb	994 lb	2000 lb	1011 lb	2011 lb	1006 lb	1977 lb



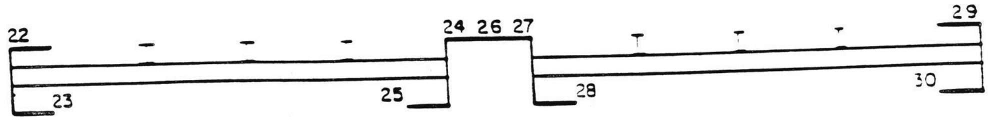
1			34	68	38	84	56	113
2			-27	-51	-28	-55	-46	-92
3			86	174	92	182	115	231
4			-49	-99	-52	-102	-61	-125
5			-48	-98	-51	-100	-54	-105
6			-58	-117	-60	-118	-62	-122
7			90	184	88	178	54	107
8			-71	-145	-69	-139	-45	-90

Centerline



11			-54	-104	-54	-102	-50	-93
12			33	62	34	63	35	66
13			232	475	244	486	267	532
14			-118	-238	-124	-245	-155	-305
15			-173	-355	-183	-266	-212	-423
16			-124	-254	-131	-259	-145	-288
17			215	439	229	451	277	549
18			-121	-243	-118	-232	-47	-91
19			99	197	81	167	33	63

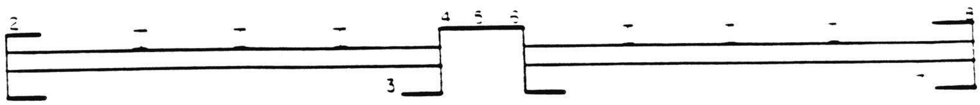
1/3 Point



22			-45	-86	-48	-93	-59	-116
23			53	103	58	109	70	138
24			-67	-130	-68	-135	-77	-153
25			154	307	163	320	174	348
26			-69	-136	-72	-140	-77	-153
27			-71	-140	-72	-142	-74	-148
28			146	289	152	300	169	334
29			-87	-172	-84	-166	-56	-112
30			116	233	113	224	66	131

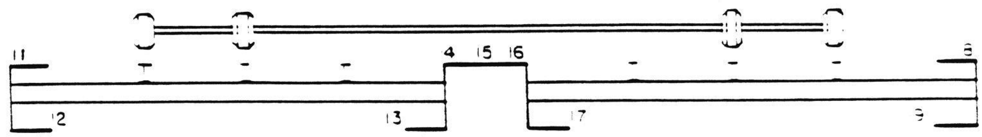
Table F-5
Damage Test D5
Loaded at Center of Span

Gauge No.	DNO		D5A		D5B		D5C	
1/4 Point	1000 lb	2005 lb	1006 lb	2023 lb	1011 lb	2017 lb	1011 lb	2047 lb



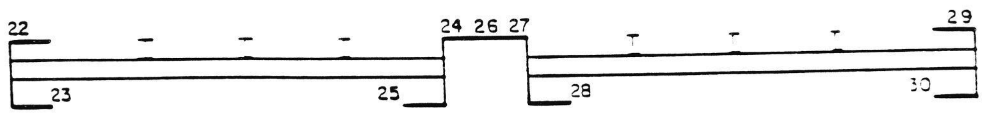
Gauge No.	DNO 1000 lb	DNO 2005 lb	D5A 1006 lb	D5A 2023 lb	D5B 1011 lb	D5B 2017 lb	D5C 1011 lb	D5C 2047 lb
1	114	229	100	218	62	121	4	21
2	-94	-189	-100	-204	-68	-135	20	35
3	137	276	131	268	149	299	203	389
4	-72	-146	-79	-162	-95	-190	-115	-229
5	-73	-147	-73	-150	-85	-170	-110	-214
6	-78	-159	-74	-155	-85	-167	-112	-213
7	117	236	116	233	108	216	94	196
8	-97	-195	-94	-192	-87	-174	-73	-152

Centerline



Gauge No.	DNO 1000 lb	DNO 2005 lb	D5A 1006 lb	D5A 2023 lb	D5B 1011 lb	D5B 2017 lb	D5C 1011 lb	D5C 2047 lb
11	-56	-113	-54	-111	-51	-103	-37	-90
12	80	160	78	157	70	140	50	106
13	90	182	91	185	95	190	103	205
14	-44	-89	-42	-89	-43	-86	-43	-86
15	-63	-127	-62	-128	-65	-130	-69	-138
16	-41	-83	-41	-85	-44	-88	-48	-95
17	92	188	94	190	98	194	106	210
18	-57	-116	-59	-121	-63	-127	-72	-143
19	79	159	80	162	84	169	95	187

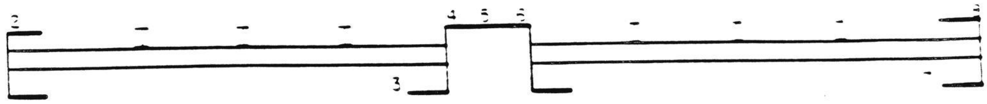
1/3 Point



Gauge No.	DNO 1000 lb	DNO 2005 lb	D5A 1006 lb	D5A 2023 lb	D5B 1011 lb	D5B 2017 lb	D5C 1011 lb	D5C 2047 lb
22	-35	-71	-35	-71	-35	-68	-31	-55
23	52	105	51	103	49	96	41	85
24	-26	-53	-26	-52	-25	-49	-22	-45
25	59	120	61	121	59	118	60	120
26	-26	-52	-26	-52	-24	-50	-24	-48
27	-25	-50	-24	-50	-23	-48	-24	-45
28	59	120	59	121	61	121	62	124
29	-34	-69	-34	-72	-39	-78	-49	-94
30	53	107	55	110	58	117	69	133

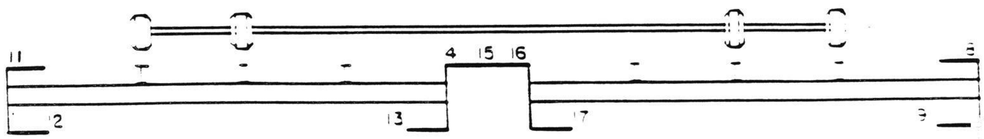
Table F-6
Damage Test D6
Loaded at Center of Span

Gauge No.	DNO		D6A		D6B		D6C	
1/4 Point	1011 lb	1994 lb	994 lb	2000 lb	988 lb	2000 lb	1000 lb	2023 lb



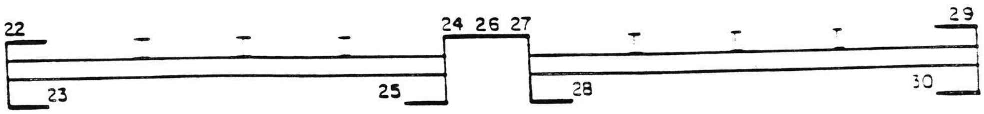
1	74	146	77	155	80	164	86	175
2	-54	-106	-57	-114	-59	-121	-64	-131
3	93	184	85	170	74	150	54	108
4	-44	-89	-43	-86	-41	-84	-41	-84
5	-43	-87	-41	-83	-38	-79	-37	-75
6	-49	-96	-45	-93	-42	-86	-37	-76
7	76	151	77	155	81	165	87	178
8	-54	-106	-55	-110	-58	-118	-63	-129

Centerline



11	-106	-217	-113	-230	-117	-237	-122	-248
12	154	304	157	314	160	326	167	341
13	174	343	161	323	149	300	129	261
14	-96	-188	-89	-179	-86	-173	-83	-167
15	-130	-259	-127	-257	-123	-252	-123	-248
16	-86	-171	-87	-174	-87	-176	-87	-175
17	178	352	178	360	181	369	190	385
18	-123	-245	-124	-251	-127	-257	-130	-264
19	166	329	166	336	169	343	174	355

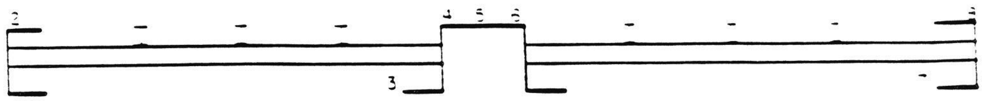
1/3 Point



22	-79	-155	-77	-154	-76	-153	-74	-151
23	106	209	104	210	104	212	105	212
24	-62	-121	-64	-128	-67	-136	-75	-150
25	124	247	123	248	122	259	122	249
26	-57	-117	-58	-117	-58	-118	-59	-120
27	-58	-116	-56	-112	-53	-108	-49	-100
28	126	249	122	249	122	248	121	247
29	-78	-155	-76	-157	-78	-158	-78	-1[illegible]
30	111	219	107	218	109	220	110	2[illegible]

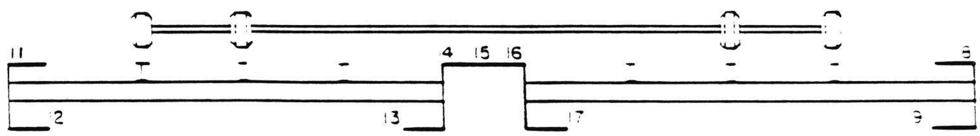
Table F-7
Damage Test D7
Loaded at Center of Span

Gauge No.	DNO lb	DNO lb	D7A 1005 lb	D7A 2005 lb	D7B 988 lb	D7B 2017 lb	D7C lb	D7C lb
1/4 Point								



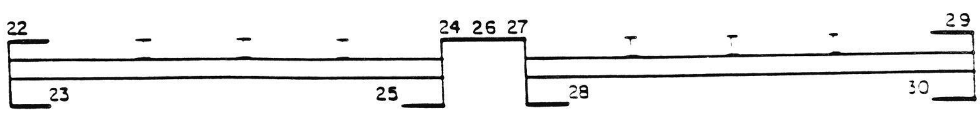
Gauge No.	DNO lb	DNO lb	D7A 1005 lb	D7A 2005 lb	D7B 988 lb	D7B 2017 lb	D7C lb	D7C lb
1			105	211	118	246		
2			-82	-164	-93	-194		
3			50	99	44	88		
4			-26	-55	-18	-36		
5			-28	-56	-22	-43		
6			-26	-51	-21	-41		
7			110	220	121	252		
8			-80	-163	-91	-190		

Centerline



Gauge No.	DNO lb	DNO lb	D7A 1005 lb	D7A 2005 lb	D7B 988 lb	D7B 2017 lb	D7C lb	D7C lb
11			-133	-271	-145	-298		
12			188	376	199	410		
13			122	244	115	233		
14			-78	-155	-73	-148		
15			-106	-214	-98	-198		
16			-72	-145	-65	-134		
17			151	303	121	244		
18			-147	-293	-157	-322		
19			200	402	215	441		

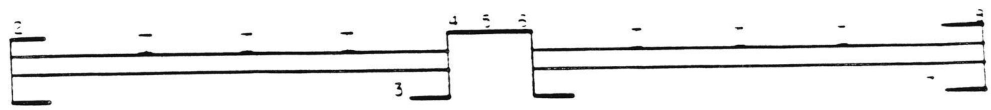
1/3 Point



Gauge No.	DNO lb	DNO lb	D7A 1005 lb	D7A 2005 lb	D7B 988 lb	D7B 2017 lb	D7C lb	D7C lb
22			-73	-147	-73	-148		
23			107	214	107	219		
24			-73	-142	-70	-142		
25			123	242	116	238		
26			-60	-123	-63	-130		
27			-58	-115	-64	-133		
28			122	244	120	245		
29			-74	-149	-71	-145		
30			111	222	111	227		

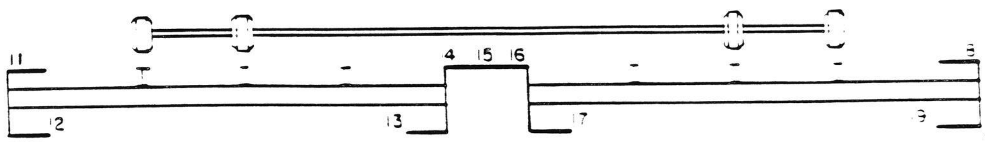
Table F-8
Damage Test D8
Loaded at Center of Span

Gauge No.	DNO		D8A		D8B		D8C	
1/4 Point	1000 lb	2011 lb	994 lb	2000 lb	lb	lb	lb	lb



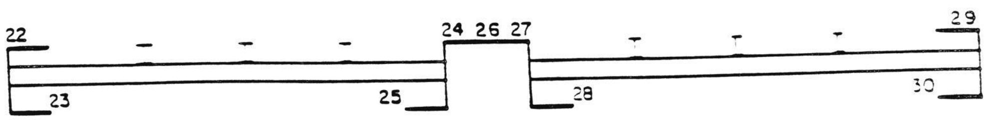
1	73	147	60	120				
2	-52	-105	-41	-82				
3	91	185	98	198				
4	-44	-90	-46	-92				
5	-43	-87	-47	-94				
6	-48	-97	-56	-113				
7.	75	151	77	154				
8	-53	-107	-55	-111				

Centerline



11	-107	-221	-100	-203				
12	151	307	140	284				
13	171	344	181	363				
14	-93	-188	-98	-195				
15	-129	-262	-135	-274				
16	-86	-173	-91	-183				
17	175	353	182	366				
18	-122	-247	-120	-242				
19	164	332	164	329				

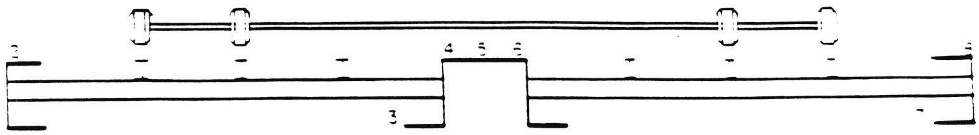
1/3 Point



22	-77	-155	-76	-150				
23	105	211	102	204				
24	-61	-123	-60	-120				
25	122	248	124	249				
26	-58	-118	-59	-118				
27	-58	-117	-57	-116				
28	124	251	125	252				
29	-77	-156	-82	-163				
30	108	218	113	227				

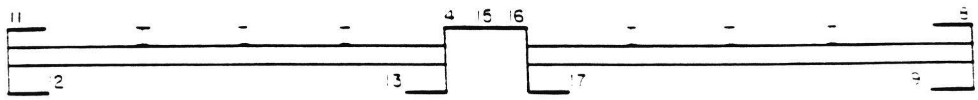
Table F-9
Damage Test D1
Loaded at 1/4 Span

Gauge No.	DNO		D1A		D1B		D1C	
1/4 Point	1006 lb	2069 lb	994 lb	2006 lb	1023 lb	1994 lb	1005 lb	2000 lb



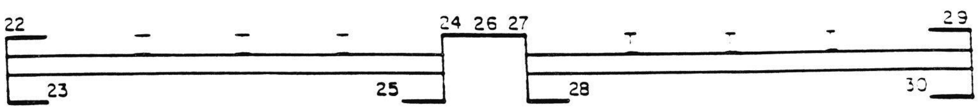
Gauge No.	DNO 1006 lb	DNO 2069 lb	D1A 994 lb	D1A 2006 lb	D1B 1023 lb	D1B 1994 lb	D1C 1005 lb	D1C 2000 lb
1	112	233	112	227	114	226	111	220
2	-93	-193	-92	-187	-94	-185	-92	-183
3	138	284	137	276	140	275	141	279
4	-71	-148	-72	-146	-75	-146	-73	-147
5	-72	-149	-72	-148	-75	-147	-75	-149
6	-79	-161	-78	-158	-81	-159	-71	-163
7	118	241	114	232	117	231	116	229
8	-98	-201	-95	-191	-97	-190	-95	-190

Centerline



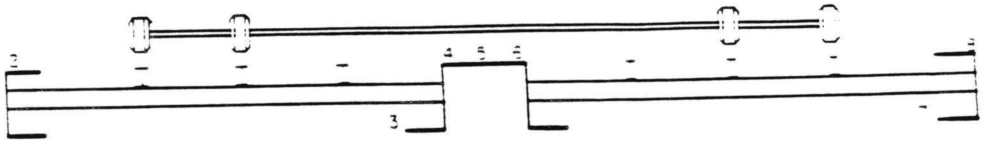
Gauge No.	DNO 1006 lb	DNO 2069 lb	D1A 994 lb	D1A 2006 lb	D1B 1023 lb	D1B 1994 lb	D1C 1005 lb	D1C 2000 lb
11	-54	-113	-56	-113	-57	-112	-56	-112
12	79	163	80	161	80	160	80	160
13	88	184	88	180	90	179	89	180
14	-44	-91	-42	-87	-45	-87	-44	-87
15	-63	-128	-60	125	-63	-125	-61	-124
16	-41	-84	-41	-82	-41	-81	-40	-82
17	92	192	91	185	93	184	93	184
18	-60	-122	-58	-117	-60	-118	-59	-118
19	79	163	78	156	81	158	79	158

1/3 Point

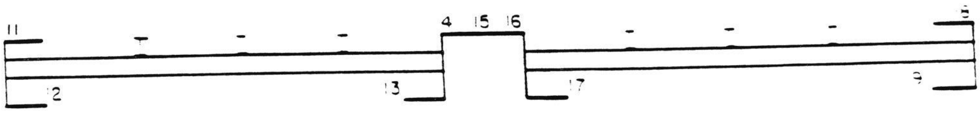


Gauge No.	DNO 1006 lb	DNO 2069 lb	D1A 994 lb	D1A 2006 lb	D1B 1023 lb	D1B 1994 lb	D1C 1005 lb	D1C 2000 lb
22	-34	-72	-35	-70	-35	-69	-35	-67
23	51	108	51	104	53	104	53	103
24	-26	-54	-25	-52	-27	-52	-26	-53
25	59	122	59	118	60	119	59	117
26	-24	-53	-24	-50	-25	-50	-25	-51
27	-24	-50	-24	-49	-24	-48	-24	-48
28	59	123	59	119	60	119	59	118
29	-34	-70	-33	-68	-34	-68	-34	-68
30	53	109	53	107	54	107	53	107

Table F-10
Damage Test D2
Loaded at 1/4 Span

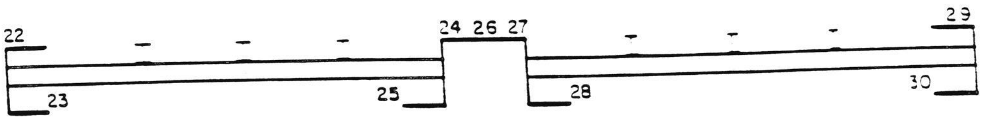


Gauge No. 1/4 Point	DNO 1017 lb	DNO 2029 lb	D2A 1006 lb	D2A 2000 lb	D2B 994 lb	D2B 2029 lb	D2C 1012 lb	D2C 2029 lb
1	114	229	112	223	118	218	98	195
2	-94	-189	-92	-186	-90	-183	-85	-171
3	139	279	138	276	140	286	147	299
4	-75	-149	-73	-146	-72	-145	-68	-139
5	-74	-148	-74	-147	-75	-151	-75	-155
6	-80	-160	-81	-160	-82	-167	-86	-176
7	116	235	116	233	117	241	123	250
8	-98	-196	-98	-195	-98	-201	-103	-209



Centerline

Gauge No. Centerline	DNO 1017 lb	DNO 2029 lb	D2A 1006 lb	D2A 2000 lb	D2B 994 lb	D2B 2029 lb	D2C 1012 lb	D2C 2029 lb
11	-55	-114	-57	-112	-56	-113	-55	-111
12	80	162	80	160	77	158	75	152
13	90	182	89	179	88	182	90	182
14	-44	-88	-44	-87	-44	-88	-42	-86
15	-63	-127	-63	-125	-62	-127	-61	-124
16	-42	-83	-41	-83	-40	-83	-41	-82
17	93	187	93	185	92	189	93	188
18	-59	-120	-60	-120	-60	-122	-64	-130
19	79	160	78	158	80	164	84	171

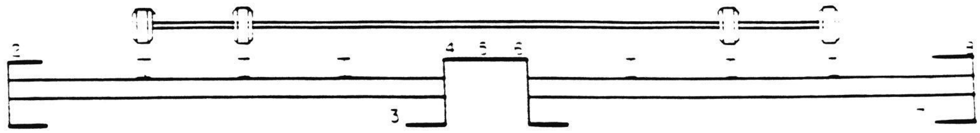


1/3 Point

Gauge No. 1/3 Point	DNO 1017 lb	DNO 2029 lb	D2A 1006 lb	D2A 2000 lb	D2B 994 lb	D2B 2029 lb	D2C 1012 lb	D2C 2029 lb
22	-36	-71	-35	-71	-36	-71	-34	
23	51	105	52	104	50	104	50	
24	-26	-53	-25	-51	-26	-53	-26	
25	60	120	60	119	59	121	60	
26	-25	-52	-25	-51	-25	-52	-25	
27	-24	-49	-24	-48	-24	-49	-24	
28	59	120	59	119	59	122	60	
29	-35	-70	-35	-70	-35	-71	-37	
30	53	108	53	106	54	110	55	

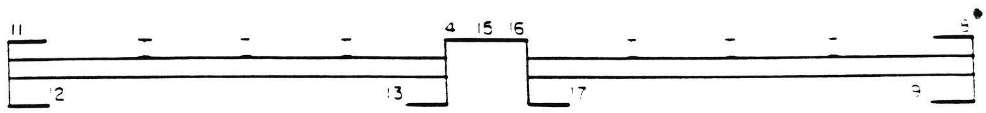
Table F-11
Damage Test D3
Loaded at 1/4 Span

Gauge No.	DNO		D3A		D3B		D3C	
1/4 Point	1000 lb	2023 lb	1006 lb	2011 lb	1005 lb	2023 lb	1005 lb	1988 lb



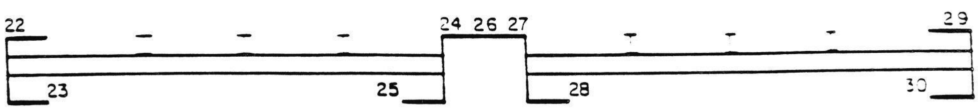
1	111	228	113	226	112	223	91	179
2	-93	-189	-92	-186	-92	-184	-78	-153
3	138	280	139	277	140	280	135	265
4	-71	-145	-71	-145	-73	-146	-75	-148
5	-73	-148	-75	-147	-74	-150	-77	-152
6	-80	-161	-80	-161	-82	-163	-85	-168
7	114	234	116	232	117	237	127	252
8	-95	-194	-95	-195	-98	200	-108	-216

Centerline



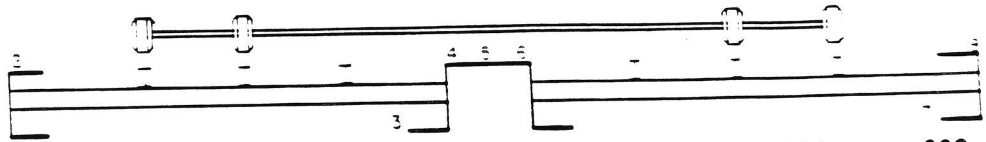
11	-56	-113	-61	-120	-62	-120	-24	-44
12	80	162	73	145	66	130	12	24
13	89	182	90	179	95	192	125	248
14	-43	-88	-45	-90	-48	-95	-58	-115
15	-61	-125	-62	-125	-65	-133	-86	-171
16	-41	-83	-41	-80	-40	-86	-62	-123
17	97	187	92	183	96	195	115	227
18	-58	-117	-58	-115	-58	-116	-53	-104
19	78	160	78	152	77	156	76	148

1/3 Point



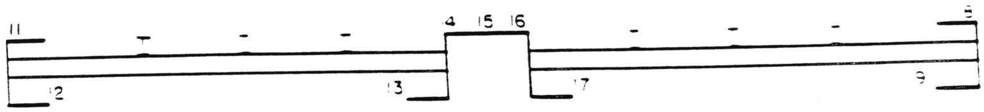
22	-34	-71	-34	-67	-32	-63	-14	-31
23	52	106	50	100	47	96	22	44
24	-25	-52	-25	-52	-26	-53	-29	-55
25	58	119	58	119	63	126	81	155
26	-25	-51	-25	-51	-26	-54	-33	-62
27	-23	-48	-24	-49	-26	-52	-34	-64
28	59	121	58	118	61	125	73	142
29	-34	-69	-35	-69	-36	-72	-42	-80
30	52	108	51	104	55	109	62	119

Table F-12
Damage Test D4
Loaded at 1/4 Span



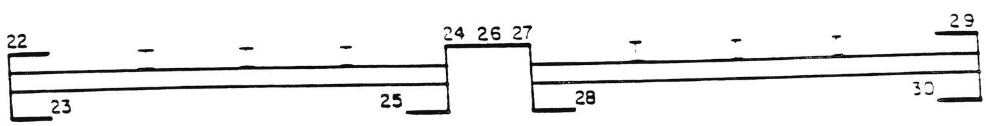
Gauge No. 1/4 Point	DNO lb	lb	D4A 1012 lb	D4A 2023 lb	D4B 994 lb	D4B 1977 lb	D4C 994 lb	D4C 2005 lb
1			92	184	91	182	104	208
2			-76	-158	-79	-158	-91	-182
3			134	271	136	270	150	301
4			-75	-151	-76	-150	-81	-162
5			-77	-153	-77	-153	-79	-159
6			-85	-171	-86	-171	-85	-174
7			125	255	123	246	103	214
8			-108	-217	-106	-210	-91	-188

Centerline



Gauge No. Centerline	DNO lb	lb	D4A 1012 lb	D4A 2023 lb	D4B 994 lb	D4B 1977 lb	D4C 994 lb	D4C 2005 lb
11			-23	-45	-23	-44	-19	-38
12			12	24	14	26	13	26
13			125	254	127	254	143	290
14			-57	-116	-60	-118	-78	-158
15			-88	-174	-90	-180	-108	-217
16			-63	-128	-65	-129	-74	-148
17			114	232	115	236	148	299
18			-58	-116	-55	-108	-12	-32
19			42	86	33	66	5	13

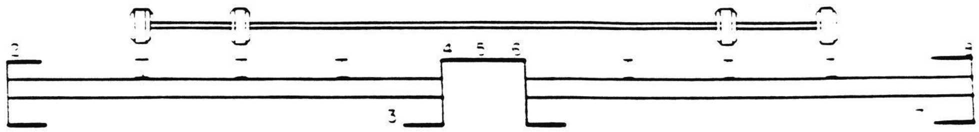
1/3 Point



Gauge No. 1/3 Point	DNO lb	lb	D4A 1012 lb	D4A 2023 lb	D4B 994 lb	D4B 1977 lb	D4C 994 lb	D4C 2005 lb
22			-16	-33	-18	-35	-24	-47
23			22	46	24	48	32	62
24			-28	-56	-30	-58	-35	-70
25			76	153	78	157	88	177
26			-30	-61	-32	-64	-36	-72
27			-31	-62	-31	-63	-33	-68
28			70	140	73	146	85	170
29			-39	-76	-36	-72	-20	-44
30			56	112	54	108	26	59

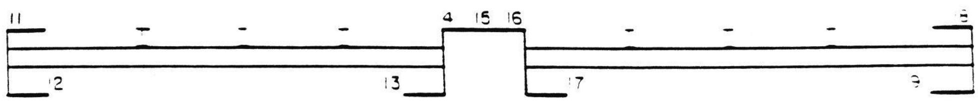
Table F-13
Damage Test D5
Loaded at 1/4 Span

Gauge No.	DNO		D5A		D5B		D5C	
1/4 Point	1000 lb	2005 lb	1006 lb	2023 lb	1011 lb	2017 lb	1011 lb	2047 lb



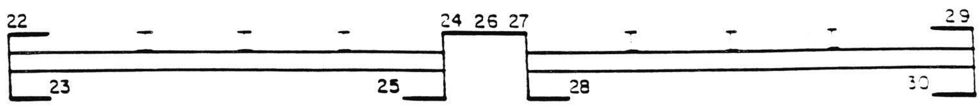
1	114	229	100	218	62	121	4	21
2	-94	-189	-100	-204	-68	-135	20	35
3	137	276	131	268	149	299	203	389
4	-72	-146	-79	-162	-95	-190	-115	-229
5	-73	-147	-73	-150	-85	-170	-110	-214
6	-78	-159	-74	-155	-85	-167	-112	-213
7	117	236	116	233	108	216	94	196
8	-97	-195	-94	-192	-87	-174	-73	-152

Centerline



11	-56	-113	-54	-111	-51	-103	-37	-90
12	80	160	78	157	70	140	50	106
13	90	182	91	185	95	190	103	205
14	-44	-89	-42	-89	-43	-86	-43	-86
15	-63	-127	-62	-128	-65	-130	-69	-138
16	-41	-83	-41	-85	-44	-88	-48	-95
17	92	188	94	190	98	194	106	210
18	-57	-116	-59	-121	-63	-127	-72	-143
19	79	159	80	162	84	169	95	187

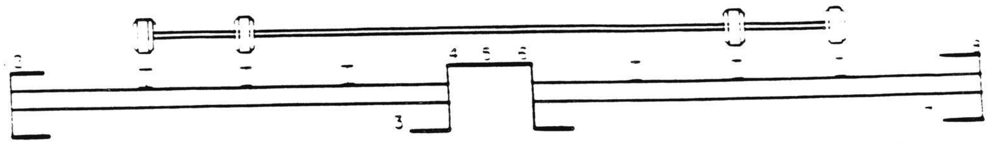
1/3 Point



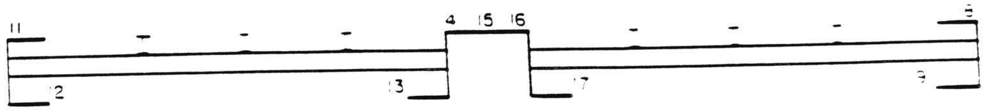
22	-35	-71	-35	-71	-35	-68	-31	-55
23	52	105	51	103	49	96	41	85
24	-26	-53	-26	-52	-25	-49	-22	-45
25	59	120	61	121	59	118	60	120
26	-26	-52	-26	-52	-24	-50	-24	-48
27	-25	-50	-24	-50	-23	-48	-24	-45
28	59	120	59	121	61	121	62	124
29	-34	-69	-34	-72	-39	-78	-49	-94
30	53	107	55	110	58	117	69	133

Table F-14
Damage Test D6
Loaded at 1/4 Span

Gauge No. 1/4 Point

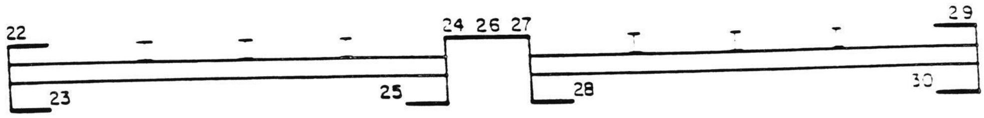


Gauge No. 1/4 Point	DNO 994 lb	DNO 2023 lb	D6A 1000 lb	D6A 2005 lb	D6B 1005 lb	D6B 1994 lb	D6C 1000 lb	D6C 2000 lb
1	111	226	115	232	119	236	123	247
2	-93	-186	-96	-192	-100	-196	-103	-206
3	137	278	130	265	123	243	104	206
4	-71	-143	-71	-143	-70	-138	-69	-138
5	-72	-147	-72	-144	-71	-140	-68	-137
6	-77	-158	-77	-154	-74	-148	-68	-139
7	116	236	117	237	123	243	128	256
8	-94	194	-98	-197	-102	-201	-105	-212



Centerline

Gauge No. Centerline	DNO 994 lb	DNO 2023 lb	D6A 1000 lb	D6A 2005 lb	D6B 1005 lb	D6B 1994 lb	D6C 1000 lb	D6C 2000 lb
11	-55	-112	-55	-114	-62	-121	-61	-127
12	79	160	82	166	88	174	94	188
13	88	180	81	162	72	142	53	106
14	-43	-87	-40	-81	-37	-76	-34	-68
15	-60	-125	-60	-122	-58	-118	-55	-112
16	-40	-82	-41	-82	-42	-84	-42	-84
17	92	187	95	192	100	197	107	213
18	-56	-115	-60	-119	-63	-123	-64	-128
19	78	158	81	163	85	168	88	176

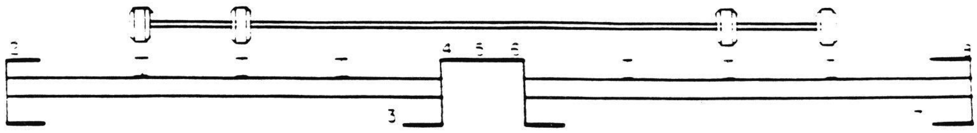


1/3 Point

Gauge No. 1/3 Point	DNO 994 lb	DNO 2023 lb	D6A 1000 lb	D6A 2005 lb	D6B 1005 lb	D6B 1994 lb	D6C 1000 lb	D6C 2000 lb
22	-34	-70	-34	-68	-34	-68	-33	-66
23	51	104	51	103	52	103	51	104
24	-26	-53	-28	-57	-32	-63	-38	-76
25	60	121	59	119	60	119	59	118
26	-25	-51	-25	-51	-26	-51	-26	-53
27	-23	-48	-23	-45	-20	-40	-17	-34
28	59	120	59	118	59	116	57	113
29	-33	-67	-34	-69	-35	-68	-34	-69
30	52	107	53	107	54	107	54	108

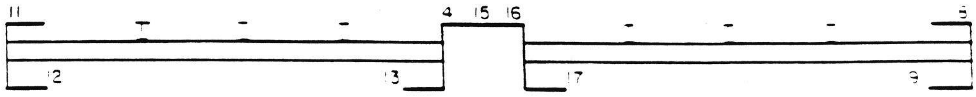
Table F-15
Damage Test D7
Loaded at 1/4 Span

Gauge No.	DNO		D7A		D7B		D7C	
1/4 Point	lb	lb	1000 lb	2005 lb	1023 lb	2017 lb	lb	lb



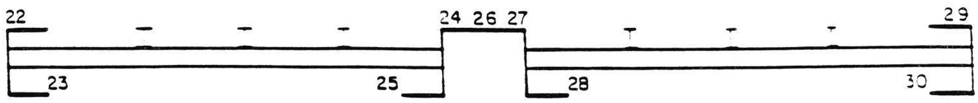
1			139	280	157	310		
2			-117	-236	-132	-260		
3			98	198	98	193		
4			-59	-117	-51	-98		
5			-60	-119	-56	-109		
6			-60	-119	-57	-111		
7			145	294	163	322		
8			-121	-244	-135	-268		

Centerline



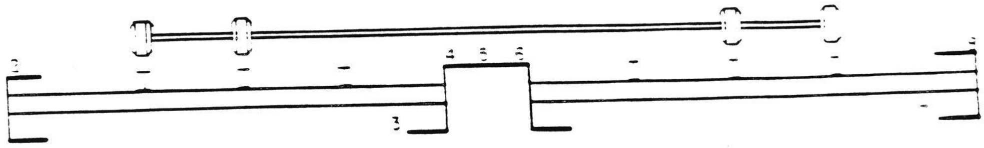
11			-75	-155	-87	-173		
12			110	222	126	247		
13			46	93	42	83		
14			-30	-60	-27	-53		
15			-43	-87	-36	-71		
16			-30	-59	-24	-49		
17			72	144	45	92		
18			-77	-154	-91	-180		
19			109	219	129	255		

1/3 Point



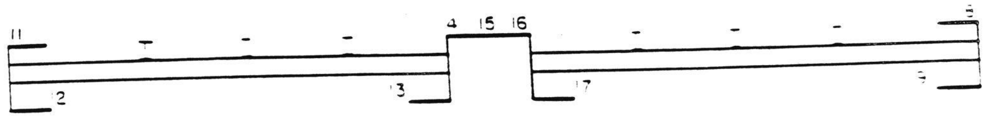
22			-32	-64	-32	-63		
23			52	107	56	110		
24			-36	-70	-35	-68		
25			56	113	55	110		
26			-28	-56	-31	-61		
27			-24	-49	-32	-64		
28			56	113	57	112		
29			-30	-62	-29	-57		
30			55	110	57	112		

Table F-16
Damage Test D8
Loaded at 1/4 Span



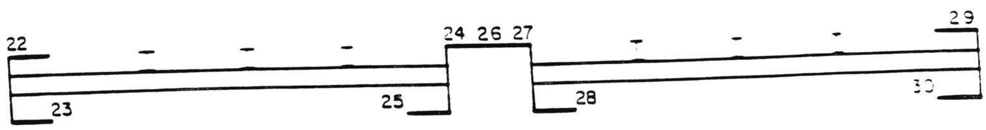
Gauge No. 1/4 Point	DNO 988 lb	DNO 1988 lb	D8A 1023 lb	D8A 2000 lb	D8B lb	D8B lb	D8C lb	D8C lb
1	110	221	103	198				
2	-92	-185	-83	-162				
3	137	273	146	287				
4	-72	-144	-76	-149				
5	-73	-147	-80	-155				
6	-78	-157	-87	-170				
7	114	230	119	234				
8	-95	-191	-99	-194				

Centerline



Centerline	DNO 988 lb	DNO 1988 lb	D8A 1023 lb	D8A 2000 lb
11	-48	-110	-51	-95
12	78	158	70	136
13	89	180	100	196
14	-44	-87	-48	-93
15	-63	-125	-69	-135
16	-41	-82	-46	-90
17	91	184	101	198
18	-57	-115	-56	-112
19	78	157	81	157

1/3 Point



1/3 Point	DNO 988 lb	DNO 1988 lb	D8A 1023 lb	D8A 2000 lb
22	-34	-70	-32	-64
23	52	104	51	97
24	-26	-52	-26	-50
25	59	117	60	118
26	-25	-51	-25	-50
27	-24	-48	-25	-48
28	59	118	61	119
29	-34	-68	-37	-74
30	52	104	58	114

Table F-17
Damage Tests D1 and D2
Comparison with Analysis

Test	Cross Section	Percentage Difference East Side Sill	Center Sill	West Side Sill
No Damage	1/4	3.4	0.9	-0.1
	Centerline	-4.2	0.2/-2.9	-11.4
	1/3	-0.2	0.5/-0.3	-5.4
D1B	1/4	1.4	0.6	2.8
	Centerline	-4.3	0.7/-2.1	-11.1
	1/3	-0.2	0.9/0.5	-3.7
D2A	1/4	1.6	1.7	3.8
	Centerline	-4.1	0.5/-2.6	-11.3
	1/3	-1.1	0.5/0.1	-4.6
D2B	1/4	2.2	4.1	5.6
	Centerline	-1.5	2.4/-0.8	-10.4
	1/3	1.8	2.1/1.7	-3.3
D2C	1/4	-25.2	8.1	3.2
	Centerline	-1.3	0.9/-2.8	-12.7
	1/3	3.0	0.7/0.4	-6.3

Table F-18
Damage Tests D3 and D4
Comparison with Analysis

Test	Cross Section	Percentage Difference: East Side Sill	Center Sill	West Side Sill
No Damage	1/4	3.4	0.9	-0.1
	Centerline	-4.2	0.2/-2.9	-11.4
	1/3	-0.2	0.5/-0.3	-5.4
D3A	1/4	4.2	0.0	2.0
	Centerline	-7.3	2.3/-3.2	-10.5
	1/3	-1.6	-2.1/-1.6	-5.3
D3B	1/4	9.9	5.6	7.4
	Centerline	-16.9	9.6/6.6	-4.1
	1/3	6.7	6.1/6.7	5.7
D3C	1/4	99.9	13.9	-4.6
	Centerline	-77.9	-0.2/7.3	14.1
	1/3	45.9	-7.5/-1.3	5.6
D4A	1/4	96.5	10.2	-6.1
	Centerline	-76.5	1.6/9.9	66.1
	1/3	38.1	-11.9/-5.7	3.3
D4B	1/4	65.6	7.2	-9.6
	Centerline	-76.2	4.8/13.0	62.6
	1/3	33.6	-14.9/-8.5	4.3
D4C	1/4	41.3	-8.1	0.7
	Centerline	-75.1	11.9/8.5	53.5
	1/3	13.1	-20.3/-16.0	62.5

Table F-19
Damage Tests D3 and D4
Neutral Axis Locations

Test	Cross Section	Location of Neutral Axis (Inches from Top Flange) East Side Sill	Center Sill	West Side Sill
No Damage	1/4	1.65	1.28	1.61
	Centerline	1.69	1.41/1.30	1.71
	1/3	1.68	1.32/1.26	1.66
D3A	1/4	1.66	1.30	1.65
	Centerline	1.85	1.43/1.27	1.71
	1/3	1.70	1.31/1.28	1.67
D3B	1/4	1.65	1.33	1.68
	Centerline	1.95	1.44/1.30	1.71
	1/3	1.75	1.30/1.28	1.68
D3C	1/4	1.70	1.47	1.75
	Centerline	2.47	1.36/1.44	1.71
	1/3	1.81	1.19/1.30	1.70
D4A	1/4	1.71	1.45	1.76
	Centerline	2.51	1.33/1.47	2.21
	1/3	1.82	1.19/1.31	1.70
D4B	1/4	1.58	1.44	1.75
	Centerline	2.47	1.34/1.46	2.33
	1/3	1.84	1.18/1.29	1.70
D4C	1/4	1.80	1.40	1.83
	Centerline	2.34	1.46/1.37	2.36
	1/3	1.83	1.22/1.23	1.84

Table F20--Load Location vs. Analysis Comparisons

Damage Test 3

Loaded at Quarter Section

Test	Cross Section	Percentage Difference: East Side Sill	Percentage Difference: Center Sill	Percentage Difference: West Side Sill
No Damage	1/4	3.4	0.9	-0.1
	Centerline	-4.2	0.2/-2.9	-11.4
	1/3	-0.2	0.5/-0.3	-5.4
D3B	1/4	0.9	-6.9	-1.2
	Centerline	-19.2	8.0/6.4	6.1
	1/3	-1.4	0.8/2.2	1.4
D3C	1/4	20.5	-1.2	-4.1
	Centerline	-78.5	0.4/8.8	22.9
	1/3	61.1	-14.1/-5.5	2.3
		Loaded at Centerline		
D3B	1/4	9.9	5.6	7.4
	Centerline	-16.9	9.6/6.6	-4.1
	1/3	6.7	6.1/6.7	5.7
D3C	1/4	99.9	13.9	-4.6
	Centerline	-77.9	-0.2/7.3	14.1
	1/3	45.9	-7.5/-1.3	5.6

Table F-21
Damage Tests D5 and D8
Comparison with Analysis

Test	Cross Section	Percentage Difference East Side Sill	Center Sill	West Side Sill
No Damage	1/4	3.4	0.9	-0.1
	Centerline	-4.2	0.2/-2.9	-11.4
	1/3	-0.2	0.5/-0.3	-5.4
D5A	1/4	2.1	9.6	8.4
	Centerline	-0.2	3.2/0.6	-7.7
	1/3	0.7	2.0/0.4	-4.0
D5B	1/4	3.0	11.9	25.5
	Centerline	2.6	3.9/1.5	-6.0
	1/3	4.8	3.0/1.8	-7.3
D5C	1/4	0.0	-6.9	49.6
	Centerline	3.4	-1.5/-3.9	-10.2
	1/3	7.0	-0.7/-2.6	-12.0
D8A	1/4	12.2	-0.7	5.7
	Centerline	1.1	-0.3/-1.1	-5.8
	1/3	2.8	0.8/0.0	-6.3

Table F-22
Damage Tests D6 and D7
Comparisons with Analysis

Loaded at Centerline

Test	Cross Section	Percentage Difference East Side Sill	Center Sill	West Side Sill
No Damage	1/4	3.4	0.9	-0.1
	Centerline	-4.2	0.2/-2.9	-11.4
	1/3	-0.2	0.5/-0.3	-5.4
D6A	1/4	4.3	7.7	4.1
	Centerline	-2.6	9.6/-1.6	-9.0
	1/3	0.6	1.3/1.3	-3.4
D6B	1/4	-0.3	20.8	-1.1
	Centerline	-6.0	17.8/-4.2	-10.6
	1/3	-0.4	-3.0/1.8	-4.3
D6C	1/4	-6.4	67.5	-8.2
	Centerline	-10.1	35.4/-8.2	-13.6
	1/3	-0.4	-0.9/2.2	-5.1
D7A	1/4	21.3	-12.9	16.0
	Centerline	-8.6	28.7/3.6	-14.2
	1/3	-2.5	5.0/4.6	-6.5
D7B	1/4	11.2	-23.9	8.2
	Centerline	-7.1	18.1/12.8	-13.2
	1/3	-4.4	6.5/3.8	-8.1

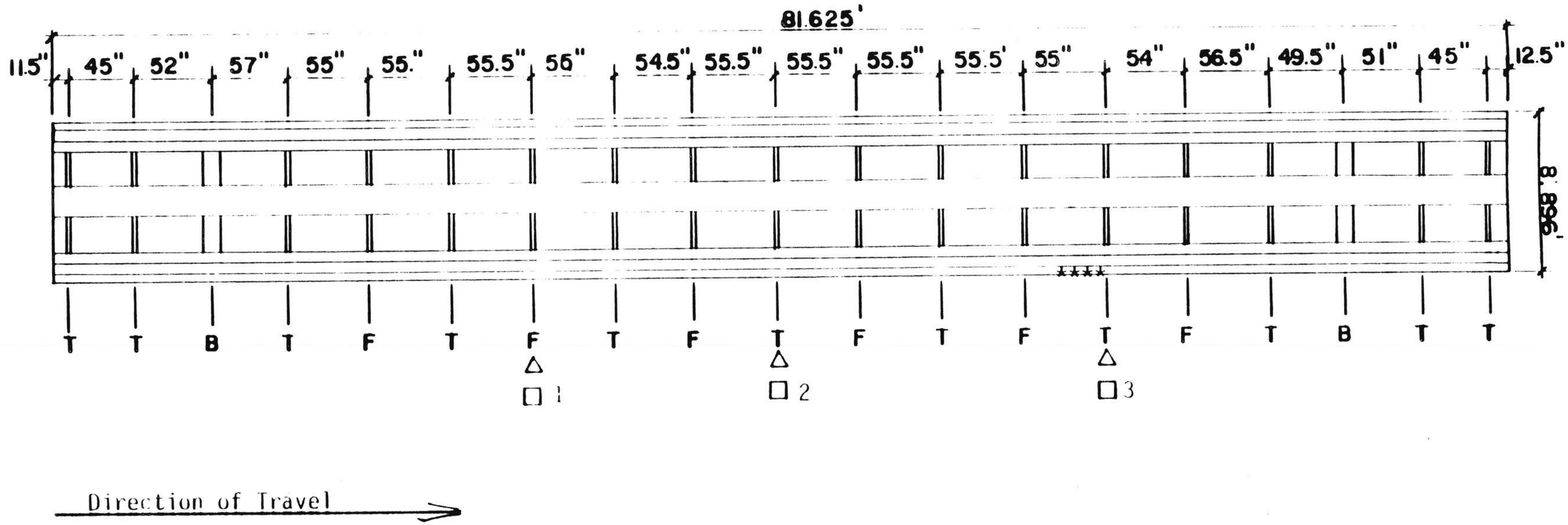
Table F-22
Damage Tests D6 and D7
Neutral Axis Locations

Test	Cross Section	Location of Neutral Axis (Inches from Top Flange) East Side Sill	Center Sill	West Side Sill
No Damage	1/4	1.65	1.28	1.61
	Centerline	1.69	1.41/1.30	1.71
	1/3	1.68	1.32/1.26	1.66
D6A	1/4	1.70	1.34	1.66
	Centerline	1.69	1.43/1.78	1.71
	1/3	1.69	1.36/1.24	1.67
D6B	1/4	1.70	1.44	1.67
	Centerline	1.68	1.46/1.29	1.71
	1/3	1.68	1.38/1.21	1.67
D6C	1/4	1.71	1.75	1.68
	Centerline	1.68	1.56/1.25	1.71
	1/3	1.66	1.50/1.15	1.68
D7A	1/4	1.75	1.43	1.70
	Centerline	1.67	1.55/1.29	1.68
	1/3	1.62	1.48/1.28	1.61
D7B	1/4	1.76	1.16	1.72
	Centerline	1.68	1.55/1.42	1.69
	1/3	1.61	1.49/1.41	1.56

Appendix G
Field Tests

Bridge 1

Field Test Data

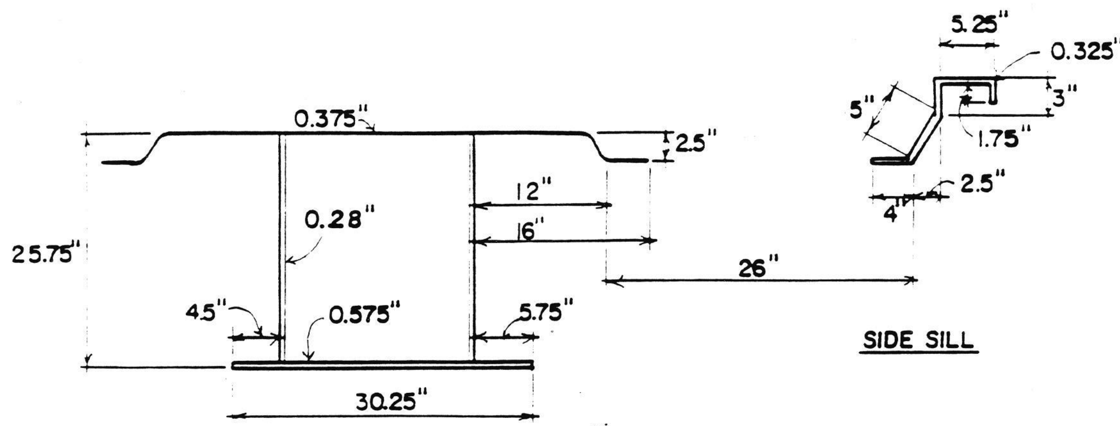


△ Gauge Location

□ Truck Stops

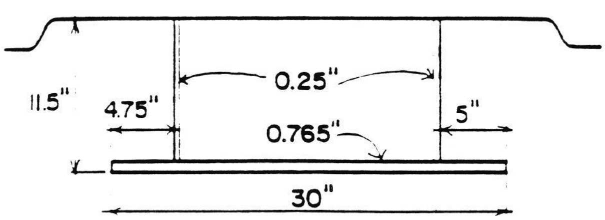
* Damage

Fig. G-1
Bridge 1--General Information

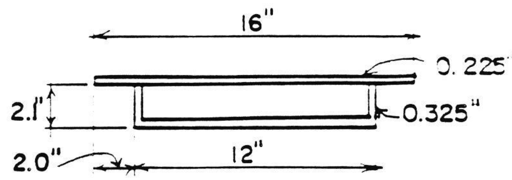


SIDE SILL

CENTER SILL
NTS

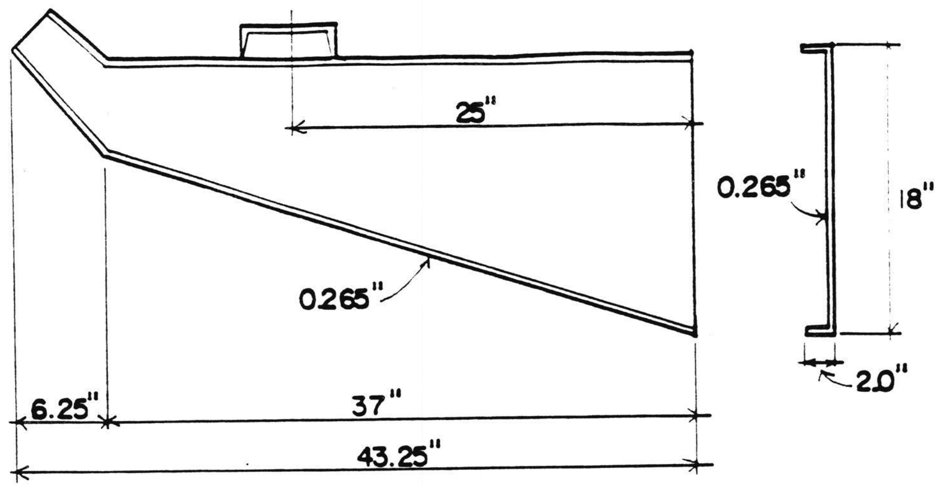


CENTER SILL AT ENDS OF CARS
NTS

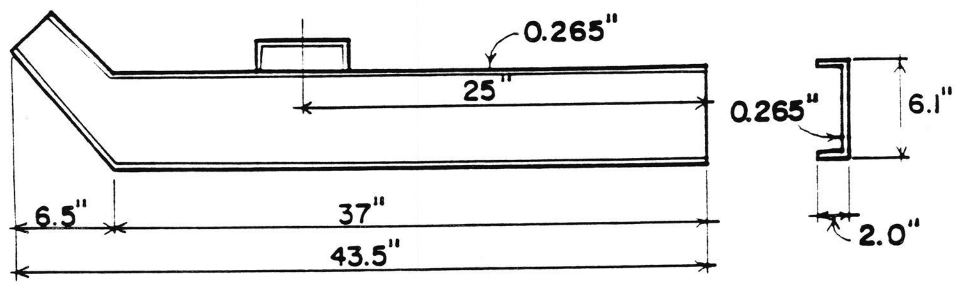


BOLSTER
NTS

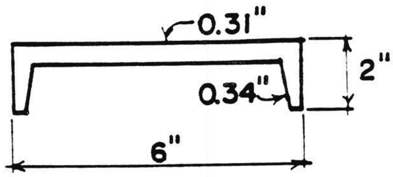
Fig. G-2
Bridge 1--Member Dimensions



FLOOR BEAM
NTS

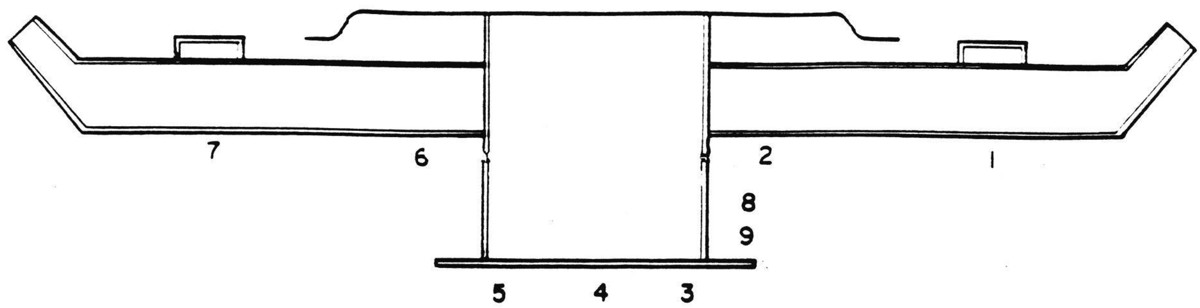


CROSS TIE
NTS

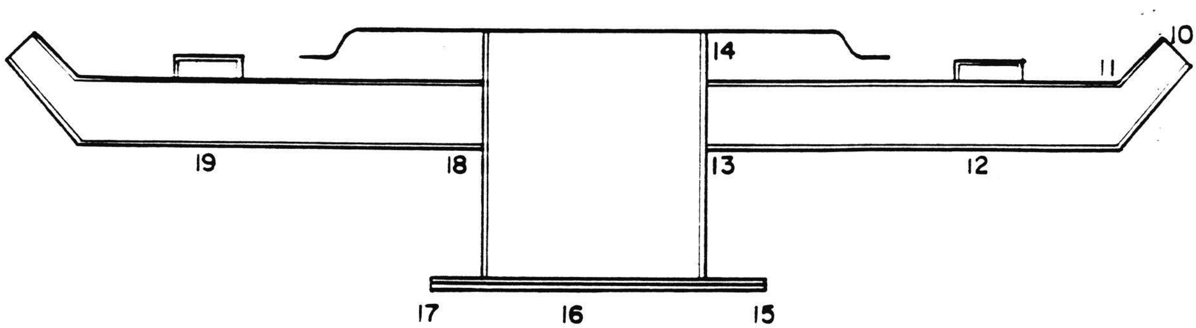


STRINGER
NTS

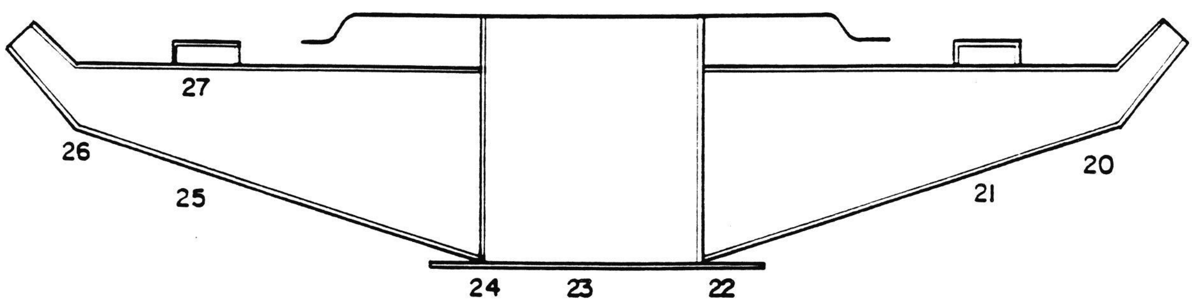
Fig. G-3
Bridge 1--Cross Beam Dimensions



REDUCED SECTION SECTION C-C
NTS



CROSS TIES SECTION B-B
NTS



FLOOR BEAM SECTION A-A
NTS

Fig. G-4
Bridge 1--Strain Gauge Locations

Table G-1
Bridge 1--Strain Measurements

Gauge Number	Loaded at Center of RR car			Loaded at Edge of RR car		
	West	Center	East	West	Center	East
Under Stringer						
7 A	1/1	-3/-3	16/20	0/1	-2/-1	-6/-3
B	0/0	-4/-3	15/16	0/1	-2/-1	0/2
19 A	9/8	14/12	1/1	2/3	-7/-8	0/0
B	-5/-5	-2/2	-1/-2	-4/-4	0/1	0/2
25 A	-22/-24	0/0	-1/0	-15/-17	-1/0	-2/-1
B	-15/-17	0/-1	-1/-1	-22/-23	-1/-2	-2/-2
Cross Beam						
2 A	3/3	-6/-5	102/105	2/2	3/3	2/2
B	1/0	-6/-19	80/106	0/0	0/0	0/0
6 A	13/14	26/26	-12/-9	2/3	7/6	3/-8
B	11/13	22/23	-32/-33	3/2	6/6	-48/-54
13 A	-3/-1	1/4	-2/-2	-2/-1	-2/-3	-1/-1
B	-/-	-/-	-/-	-/-	-/-	-/-
18 A	-18/-14	-27/-27	-2/-2	-21/-21	-24/-26	-4/-3
B	-21/-20	-57/-55	2/1	-29/-26	-64/-64	-2/-1
Buckled Section						
3 A	56/57	90/91	93/94	35/38	53/53	53/53
B	57/57	93/92	94/96	39/37	56/55	55/55
8 A	70/73	115/117	112/112	46/49	70/71	65/65
B	75/71	125/121	117/116	51/45	78/73	69/66
9 A	45/47	75/76	66/67	31/33	47/48	39/39
B	44/41	75/73	63/65	29/26	45/44	37/36
Side Sill						
Top 10 A	-31/-34	-36/-22	-35/-24	-30/-22	-41/-32	-23/-14
B	-38/-47	-95/-113	-24/-37	-39/-47	-55/-57	-41/-38
Bottom 11 A	-7/-3	-14/-11	-9/-10	-7/-7	-5/-5	-16/-16
B	-30/-28	-23/-26	-17/-17	-21/-18	-25/-23	-7/-9

Table G-1
Bridge 1--Strain Measurements (cont'd.)

Gauge Number		Loaded at Center of RR car West	Center	East	Loaded at Edge of RR car West	Center	East
Center Sill							
3	A	56/57	90/91	93/94	35/38	53/53	53/53
	B	57/57	93/92	94/96	39/37	56/55	55/55
4	A	62/63	99/100	101/103	40/43	57/58	54/54
	B	62/63	98/97	101/102	43/41	59/60	55/56
5	A	60/61	95/94	91/92	36/27	50/49	43/42
	B	46/45	82/82	79/76	25/23	38/37	26/26
15	A	31/32	35/36	15/17	18/19	19/20	9/9
	B	27/25	32/31	8/8	10/9	13/10	0/-1
16	A	71/72	82/80	37/37	39/41	44/45	22/22
	B	61/57	71/69	27/25	30/28	31/32	11/10
17	A	57/60	63/65	30/33	30/33	30/33	16/19
	B	47/47	52/52	25/25	27/26	27/27	15/16
22	A	137/140	77/78	35/36	64/67	44/45	22/24
	B	123/118	68/65	21/18	54/49	31/25	5/2
23	A	138/138	88/87	40/40	74/75	50/47	26/24
	B	123/122	78/80	31/31	66/65	42/38	18/13
24	A	154/158	91/94	42/45	87/93	46/49	21/24
	B	156/154	95/95	44/42	91/88	50/47	22/20

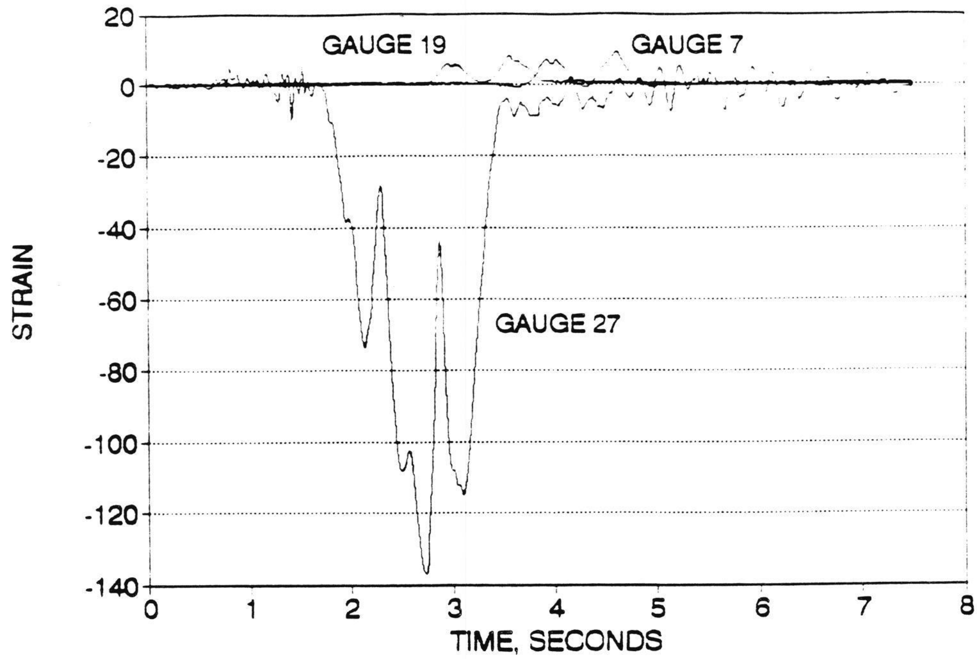


Fig. G-5
Bridge 1--Cross Beam Strains

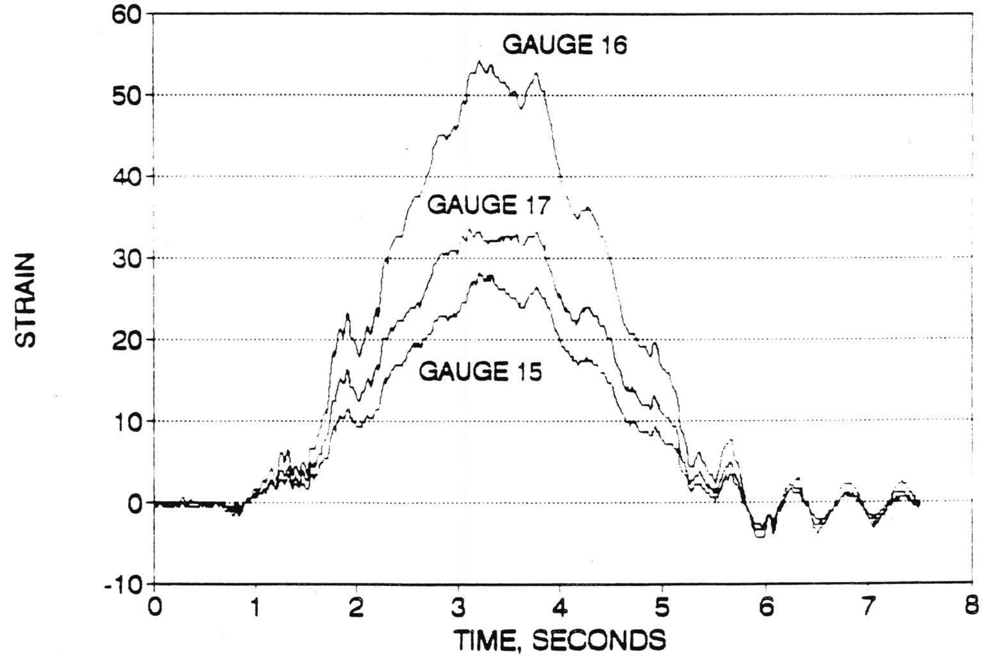


Fig. G-6
Bridge 1--Strains in Center
Sill at Center of Span

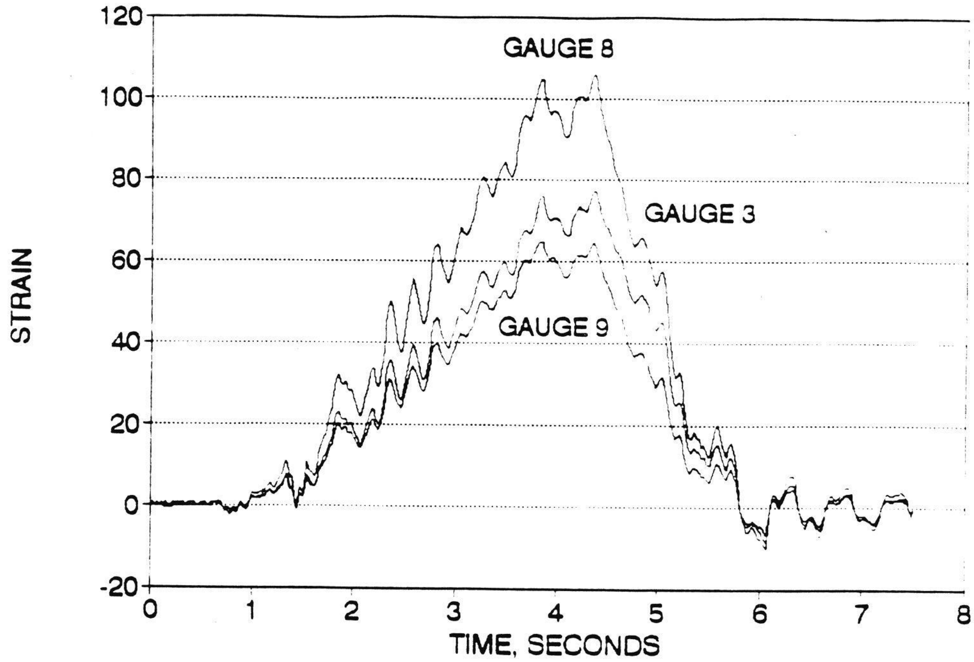


Fig. G-7
Bridge 1--Strains at Damaged Section

Bridge 2

Field Test Data

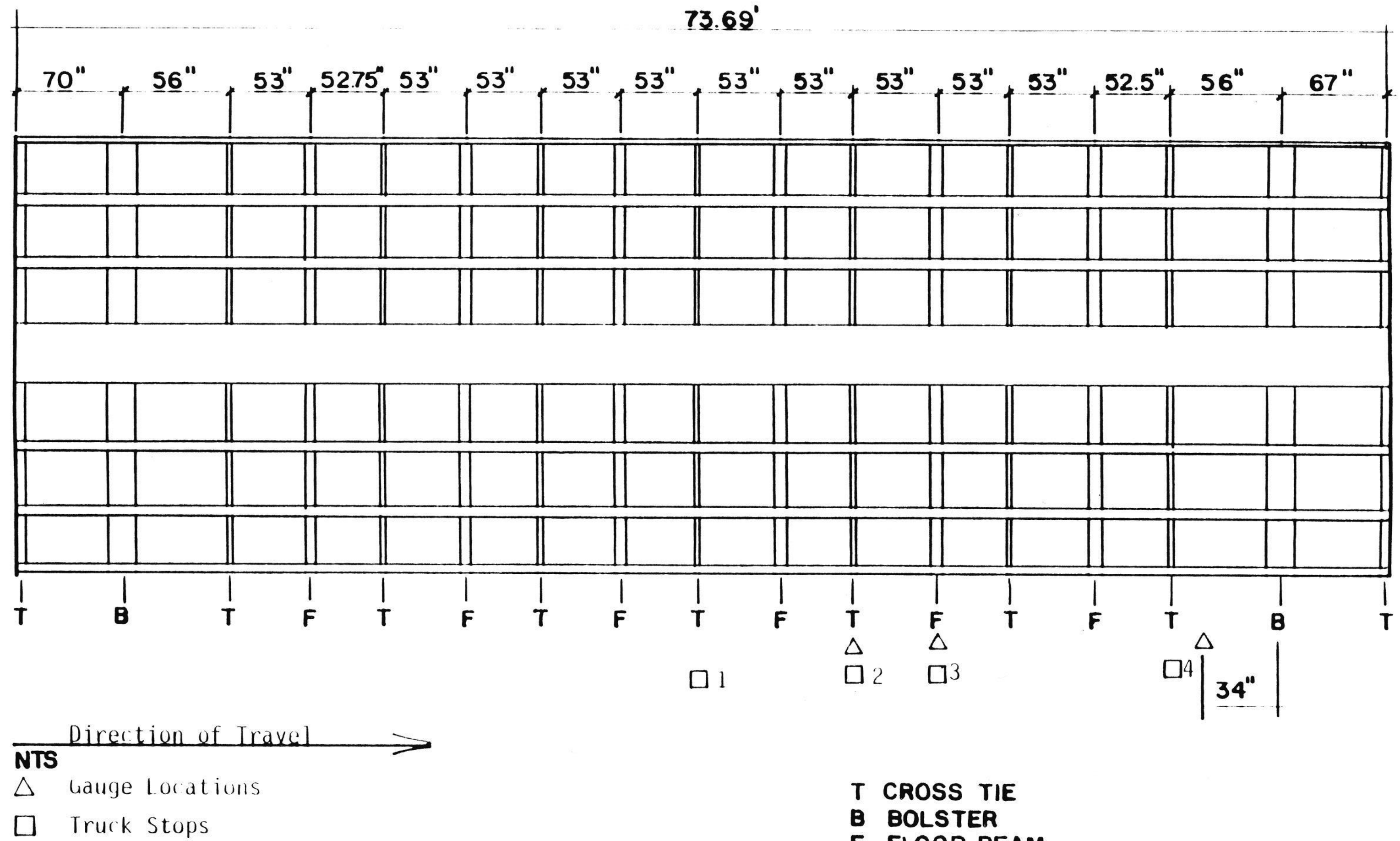


Fig. G-8
Bridge 2--General Information

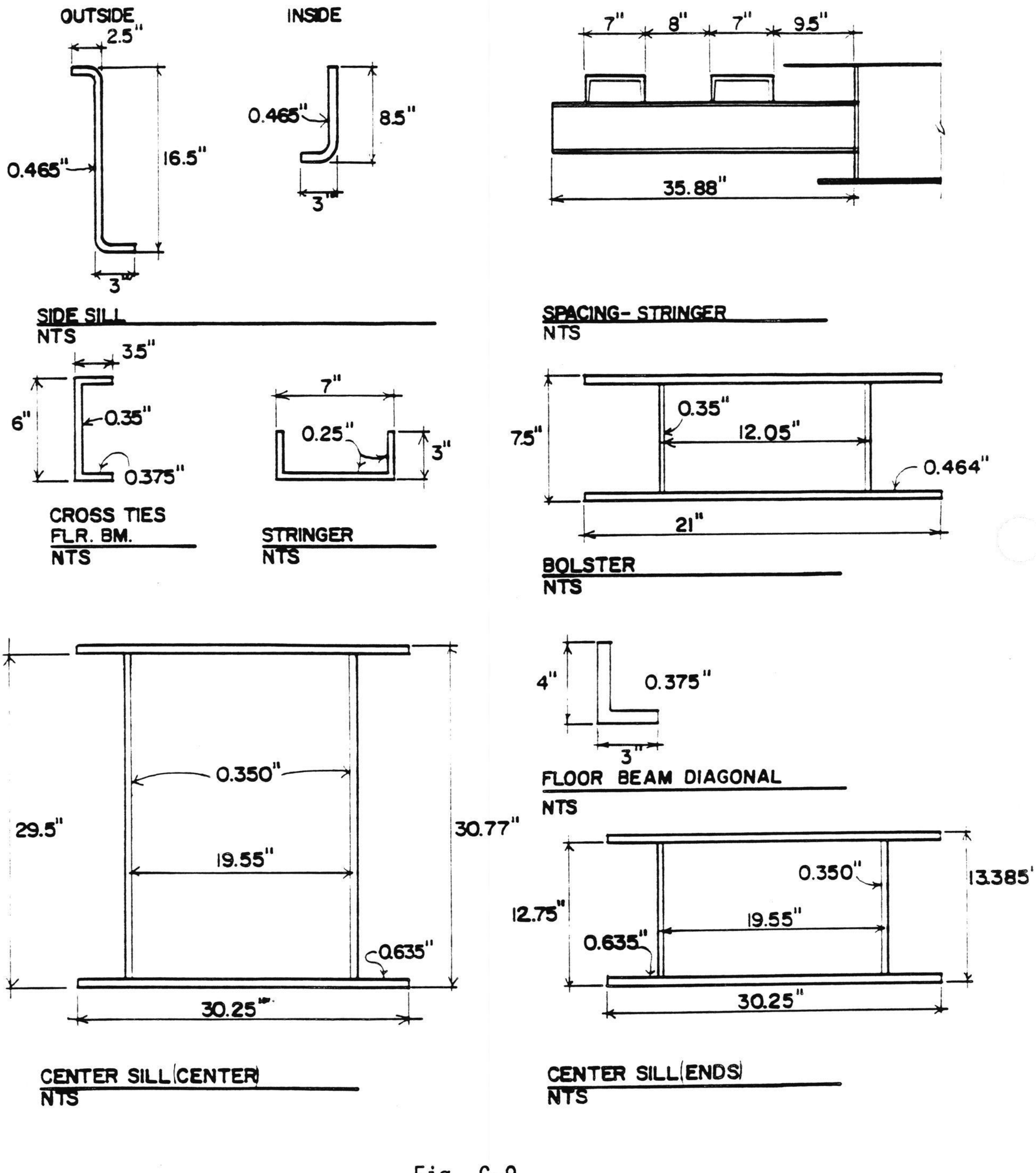
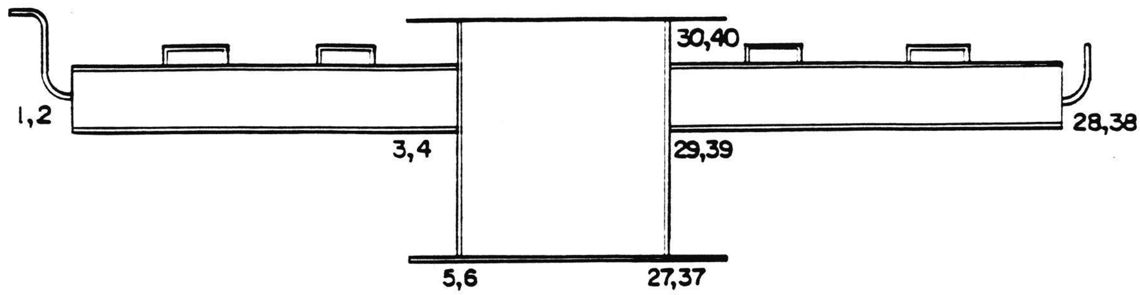
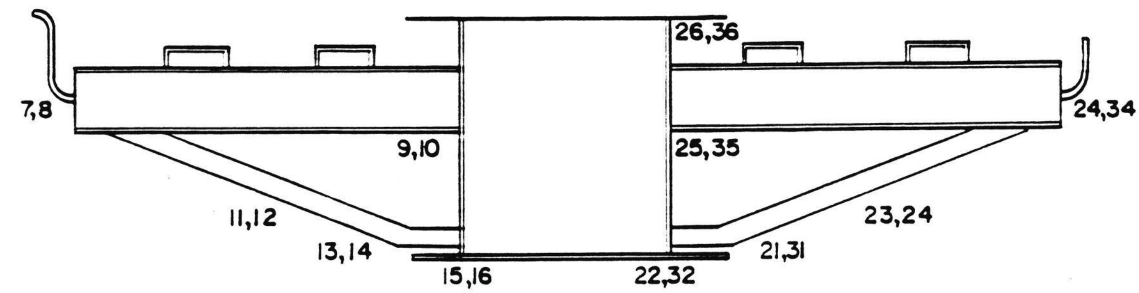


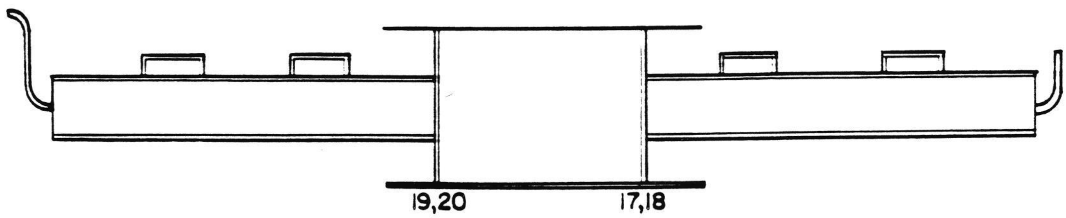
Fig. G-9
Bridge 2--Member Dimensions



CROSS TIES SECTION A-A
NTS



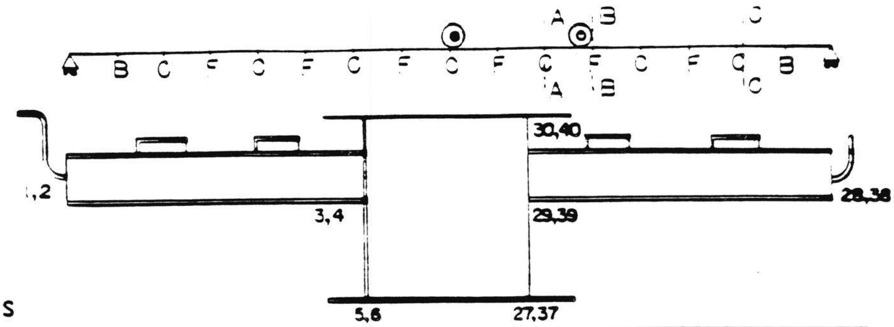
FLOOR BEAM SECTION B-B
NTS



REDUCED SECTION SECTION C-C
NTS

Fig. G-10
Bridge 2--Strain Gauge Locations

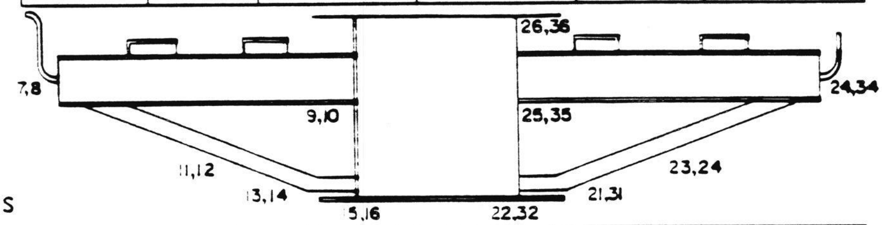
Table G-2
Bridge 2--Rear Axle at Stop 1 Centered on Car



Section A-A

Field Strains

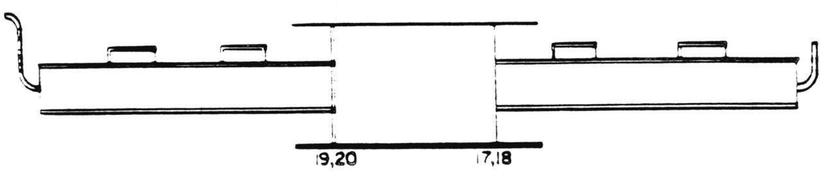
Top				-37,-36 -39,-36		
Bottom	5,1 4,1 -3,-8 -4,-8		156,163 158,165 157,163 159,164	171,213 173,215		82,100 71,92
Analysis Top	99		188	186		87*
Analysis Bottom	*97*		*189*	*187*		*45*



Section B-B

Field Strains

Top				-13,-20 -14,-20		
Bottom	20,23 24,26 19,20 20,22		178,157 159,150 156,148 158,151	140,140 142,141		251,210 238,210
Analysis Top	83		167	168		47
Analysis Bottom	*109*		*165*	*167*		*89*

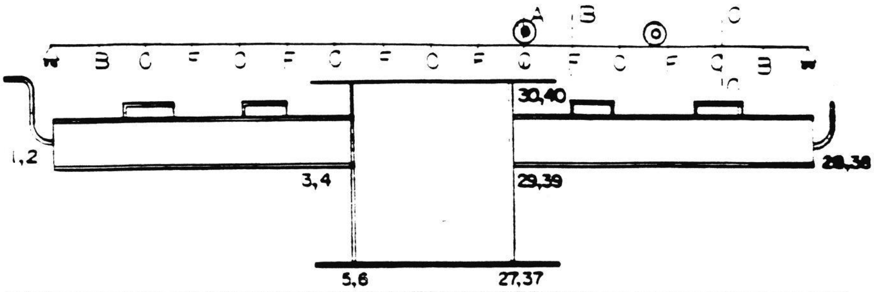


Section C-C

Field Strains	108,119 111,121 109,119 111,121	74,92 73,90 71,87 71,87
Analysis		

*No truss.

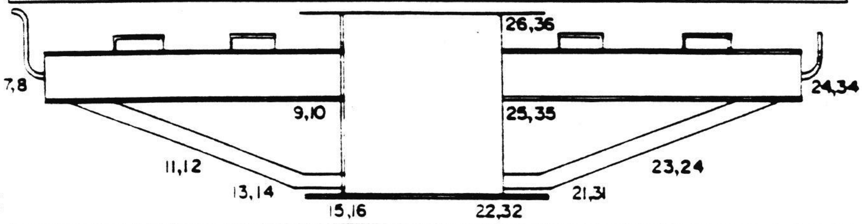
Table G-3
Bridge 2--Rear Axle at Stop 2 Centered on Car



Section A-A

Field Strains

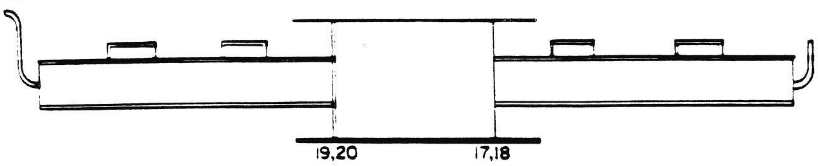
Top				-38,-38 -39,-38		
Bottom	80,76 94,44 96,92 100,97		171,179 171,179 171,178 171,176	173,160 175,161		321,356 300,341
Analysis Top	185		186	183		282*
Analysis Bottom	*190*		*186*	*183*		*236*



Section B-B

Field Strains

Top				-18,-23 -18,-24		
Bottom	-5,-1 -6,-2 -15,-12 -16,-12		178,170 180,173 173,167 176,169	159,160 161,161		173,124 164,124
Analysis Top	54		178	177		90
Analysis Bottom	*114*		*173*	*173*		*17*



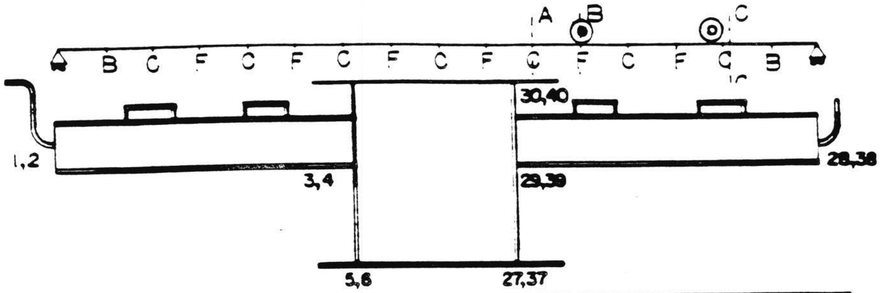
Section C-C

Field Strains	150,165 151,167 144,158 148,161	115,137 112,136 109,130 108,130
Analysis		

*No truss.

Table G-4

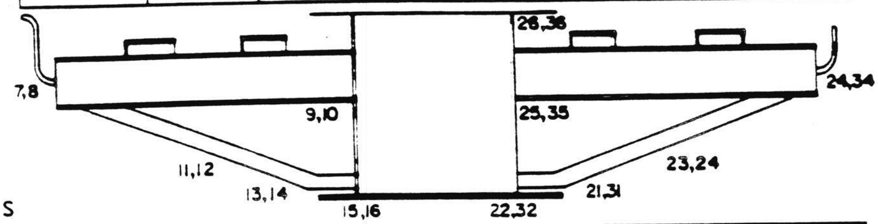
Bridge 2--Rear Axle at Stop 3 Centered on Car



Section A-A

Field Strains

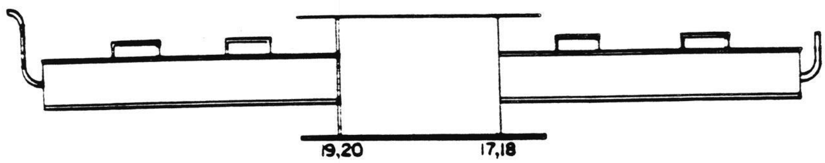
Top				-29,-26 -28,-25		
Bottom	17,14 11,10 10,8 5,4		138,144 135,140 133,140 130,135	150,149 147,147		81,97 66,85
Analysis Top	85		158	157		46
Analysis Bottom	*89*		*159*	*157*		*2**



Section B-B

Field Strains

Top				-19,-16 -21,-19		
Bottom	47,48 52,52 47,45 48,44		195,191 195,192 192,189 191,188	160,171 159,170		323,281 291,263
Analysis Top	114		173	169		73
Analysis Bottom	*197*		*164*	*163*		*225*

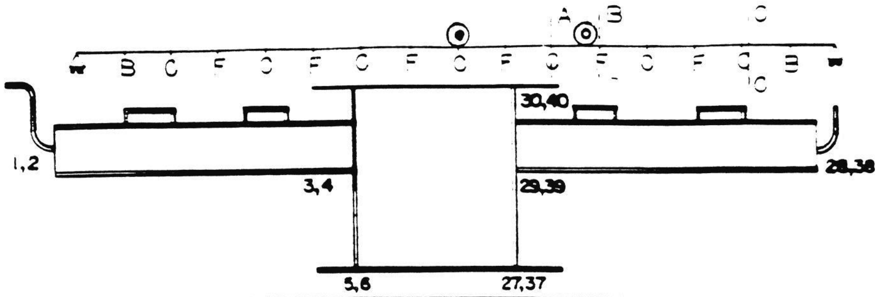


Section C-C

Field Strains	172,190 174,193 169,187 173,190	136,161 135,161 135,160 135,161
Analysis		

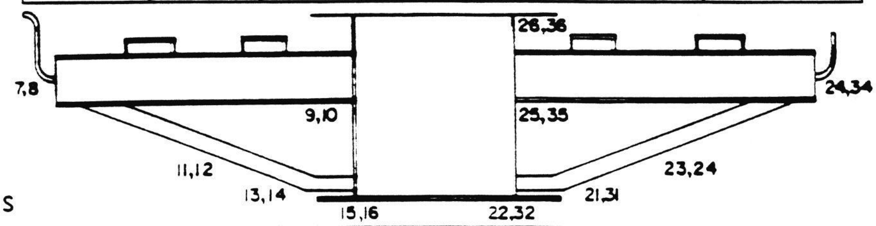
*No truss.

Table G-5
Bridge 2--Rear Axle at Stop 1 Over Inside Side Sill



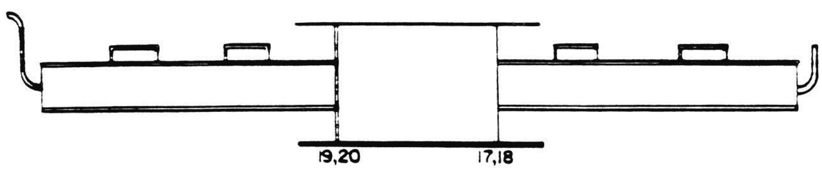
Section A-A

Field Strains						
Top				-27,-24 -28,-26		
Bottom	-4,-4 -2,-3 -5,-5 -3,-4		122,118 117,121 117,111 107,112	93,88 98,88		72,80 70,73
Analysis Top Bottom						



Section B-B

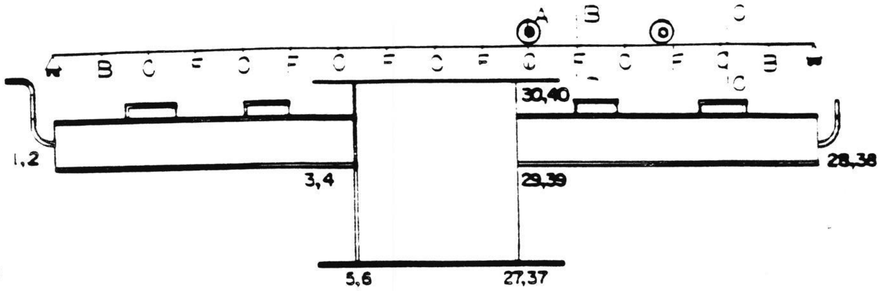
Field Strains						
Top				-12,-16 -13,-16		
Bottom	-2,-2 -2,-1 -3,-2 -3,-2		107,96 110,99 101,90 102,92	79,75 84,76		236,165 228,175
Analysis Top Bottom						



Section C-C

Field Strains	58,65 61,70 51,57 53,61	82,92 83,94 75,85 79,88
Analysis		

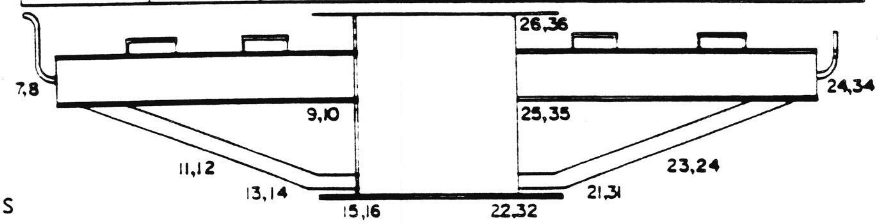
Table G-6
Bridge 2--Rear Axle at Stop 2 Over Inside Side Sill



Section A-A

Field Strains

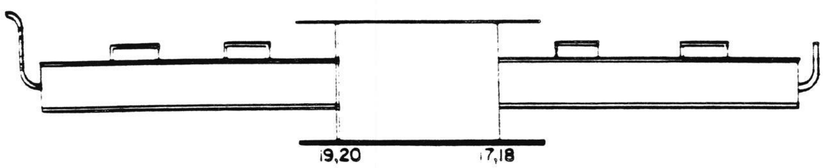
Top				-28,-26 -29,-26		
Bottom	-18,-18 -18,-17 -19,-19 -19,-19		110,116 114,118 117,111 109,114	98,93 105,97		373,413 378,390
Analysis Top Bottom						



Section B-B

Field Strains

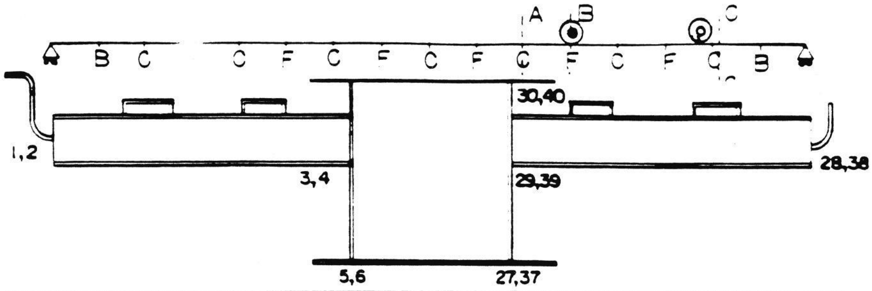
Top				-17,-22 -16,-22		
Bottom	-8,-8 -7,-7 -9,-9 -9,-9		125,116 130,119 107,111 109,114	86,94 89,98		127,68 140,94
Analysis Top Bottom						



Section C-C

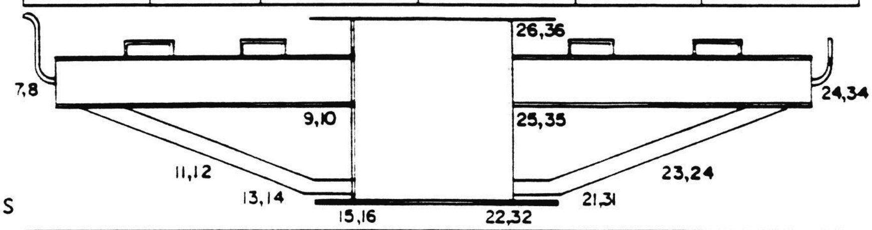
Field Strains	80,91 83,94 73,82 79,90	104,119 106,120 99,112 106,117
Analysis		

Table G-7
Bridge 2--Rear Axle at Stop 3 Over Inside Side Sill



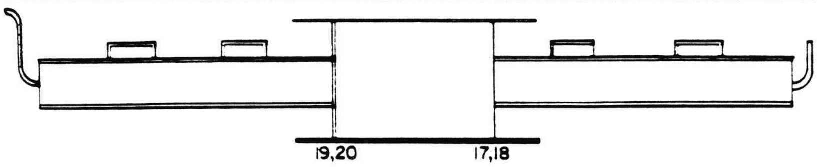
Section A-A

Field Strains Top				-24,-22 -24,-22		
Bottom	-7,-7 -5,-6 -6,-8 -6,-8		99,104 101,105 94,98 99,103	85,80 87,85		87,89 84,107
Analysis Top Bottom						



Section B-B

Field Strains Top				-18,-22 -18,-23		
Bottom	-11,-11 -10,-10 -9,-9 -9,-9		130,122 131,124 111,123 108,120	84,101 87,106		324,257 321,284
Analysis Top Bottom						



Section C-C

Field Strains	94,106 97,109 87,97 92,104	116,131 117,133 109,123 114,129
Analysis		

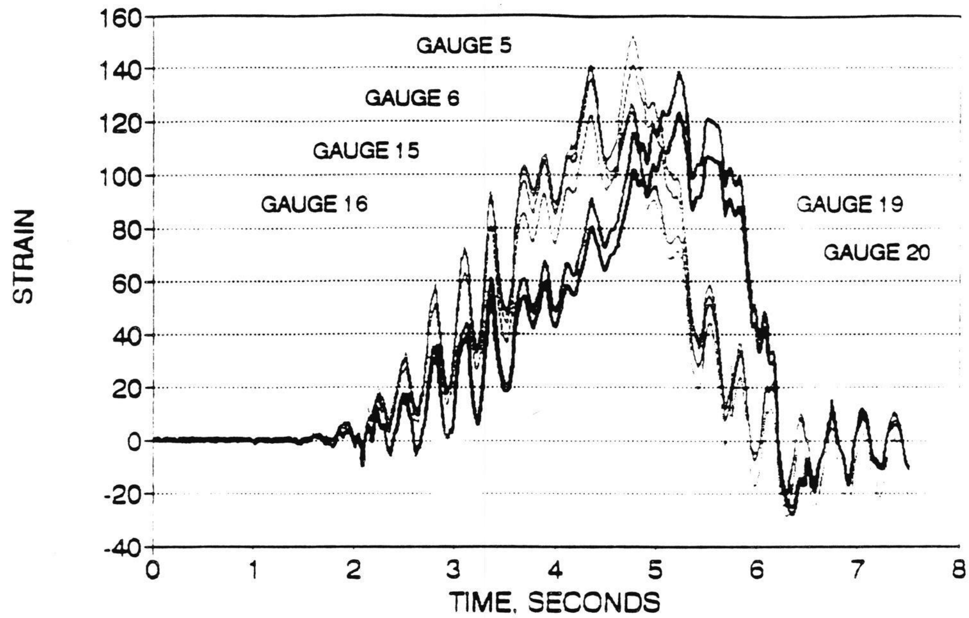


Fig. G-11
Bridge 2--Strains in Center Sill
Along Length of Car

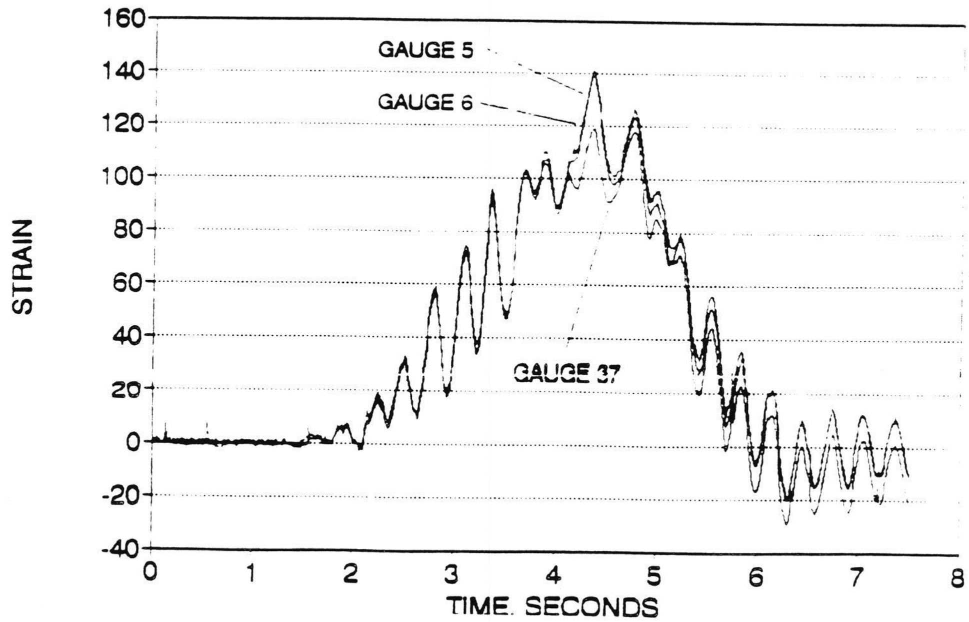


Fig. G-12
Bridge 2--Strains in Center sill at Cross Tie

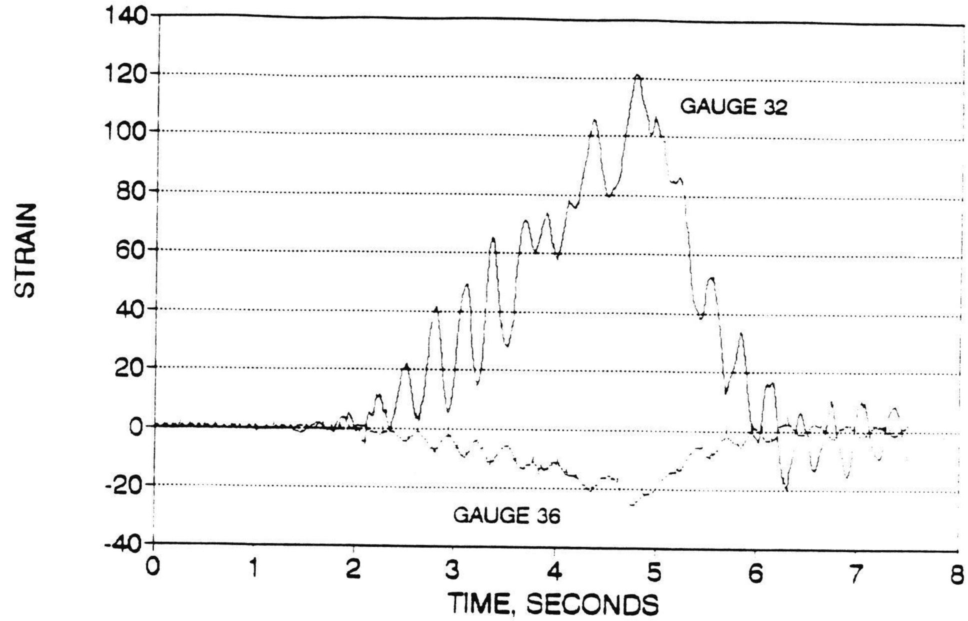


Fig. G-13
Bridge 2--Compressive and Tensile Strains in Center Sill at Floor Beam

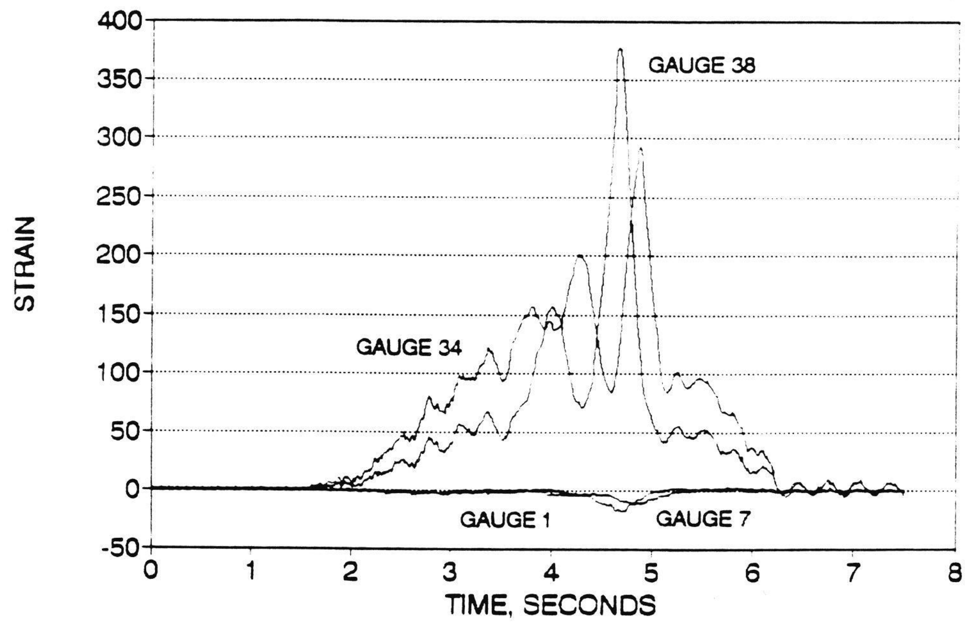


Fig. G-14
Bridge 2--Strains in Side Sill at Both Edges of Car

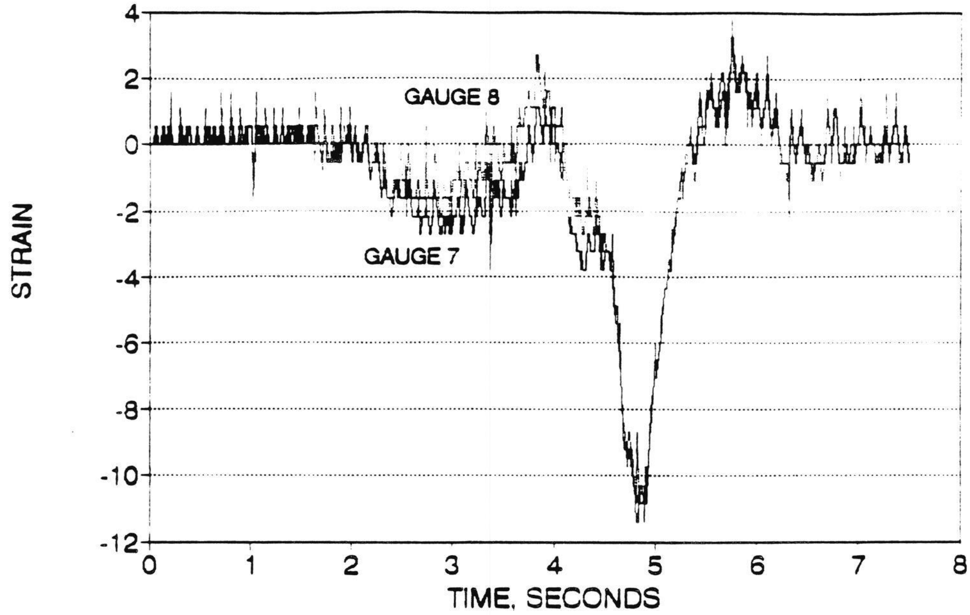


Fig. G-15
Bridge 2--Strains in Side Sill at Floor Beam at Edge of Bridge

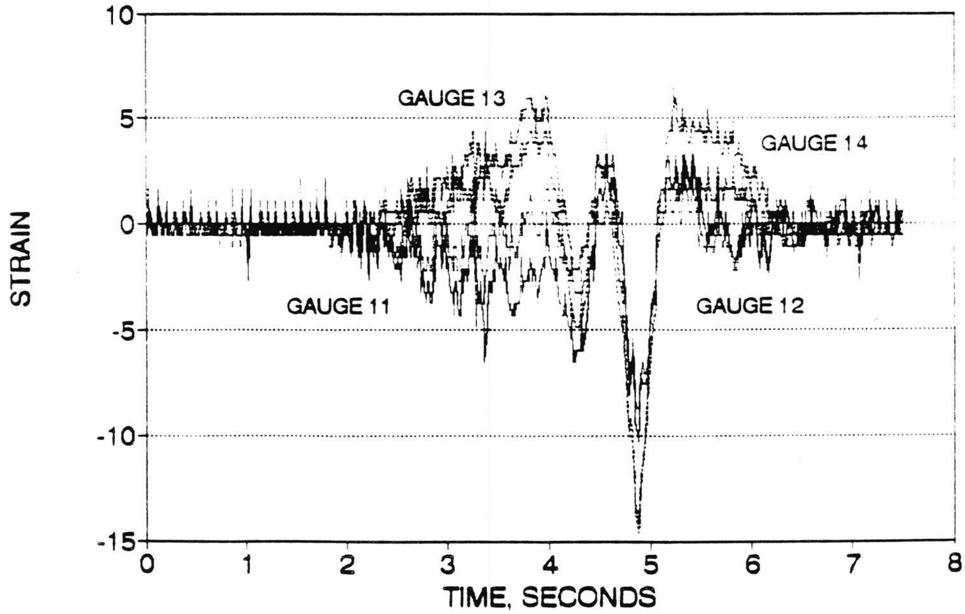


Fig. G-16
Bridge 2--Strains in Truss Member Near Edge of Bridge

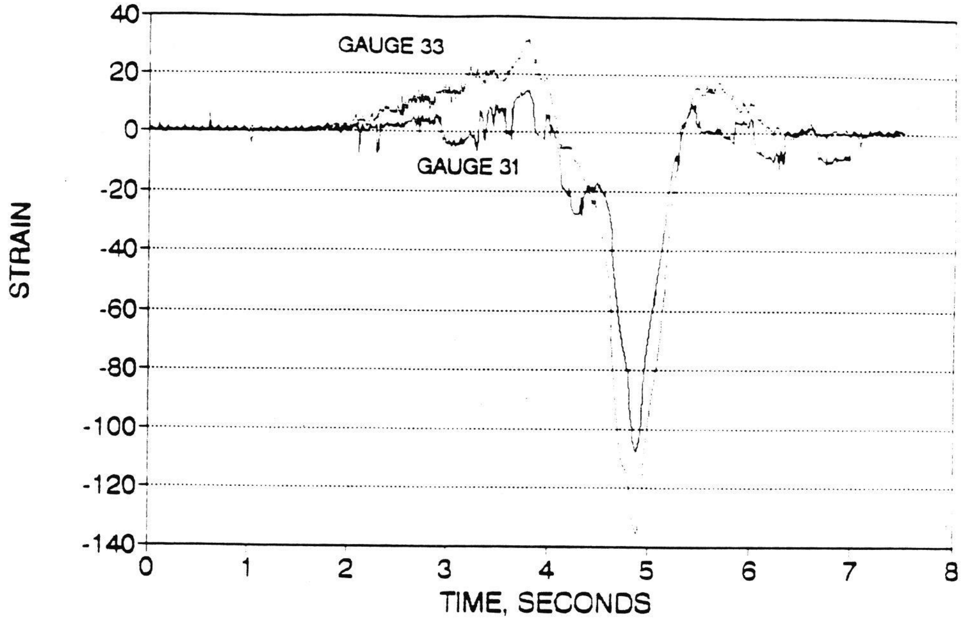


Fig. G-17
Bridge 2--Strains in Truss Member
Near Center Line of Bridge

Bridge 3

Field Test Data

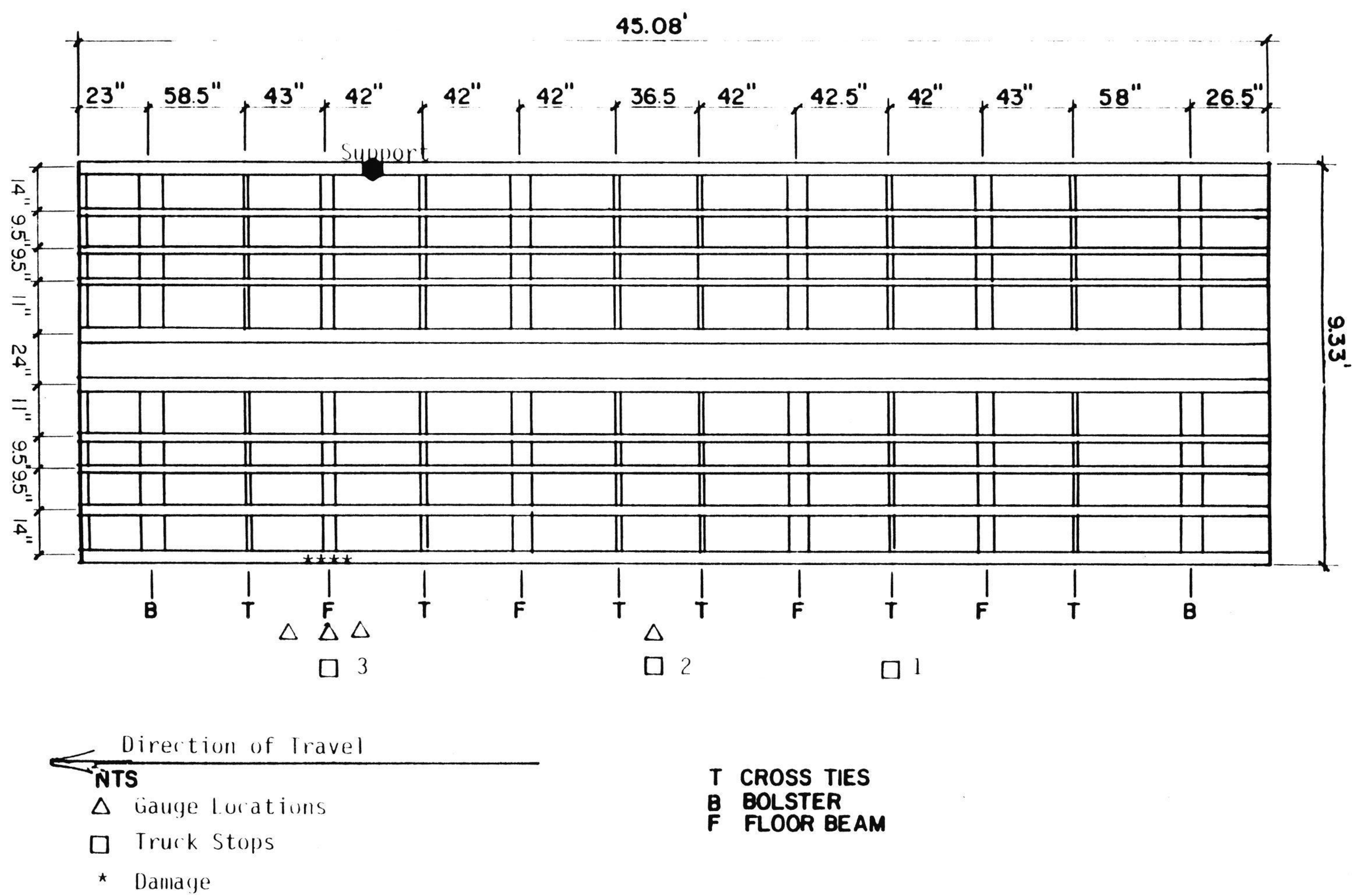


Fig. G-18
Bridge 3--General Information

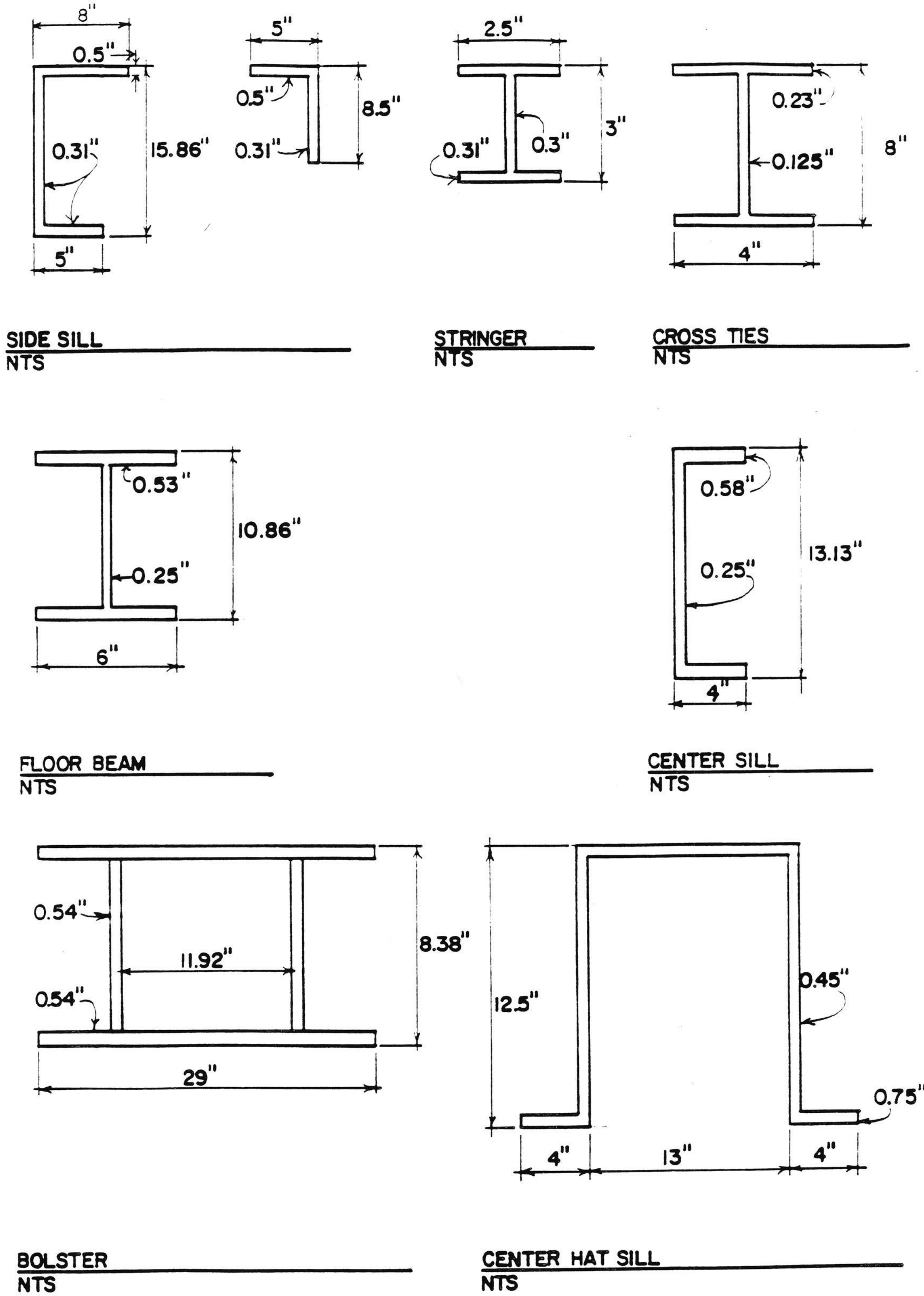


Fig. G-19
Bridge 3--Member Dimension

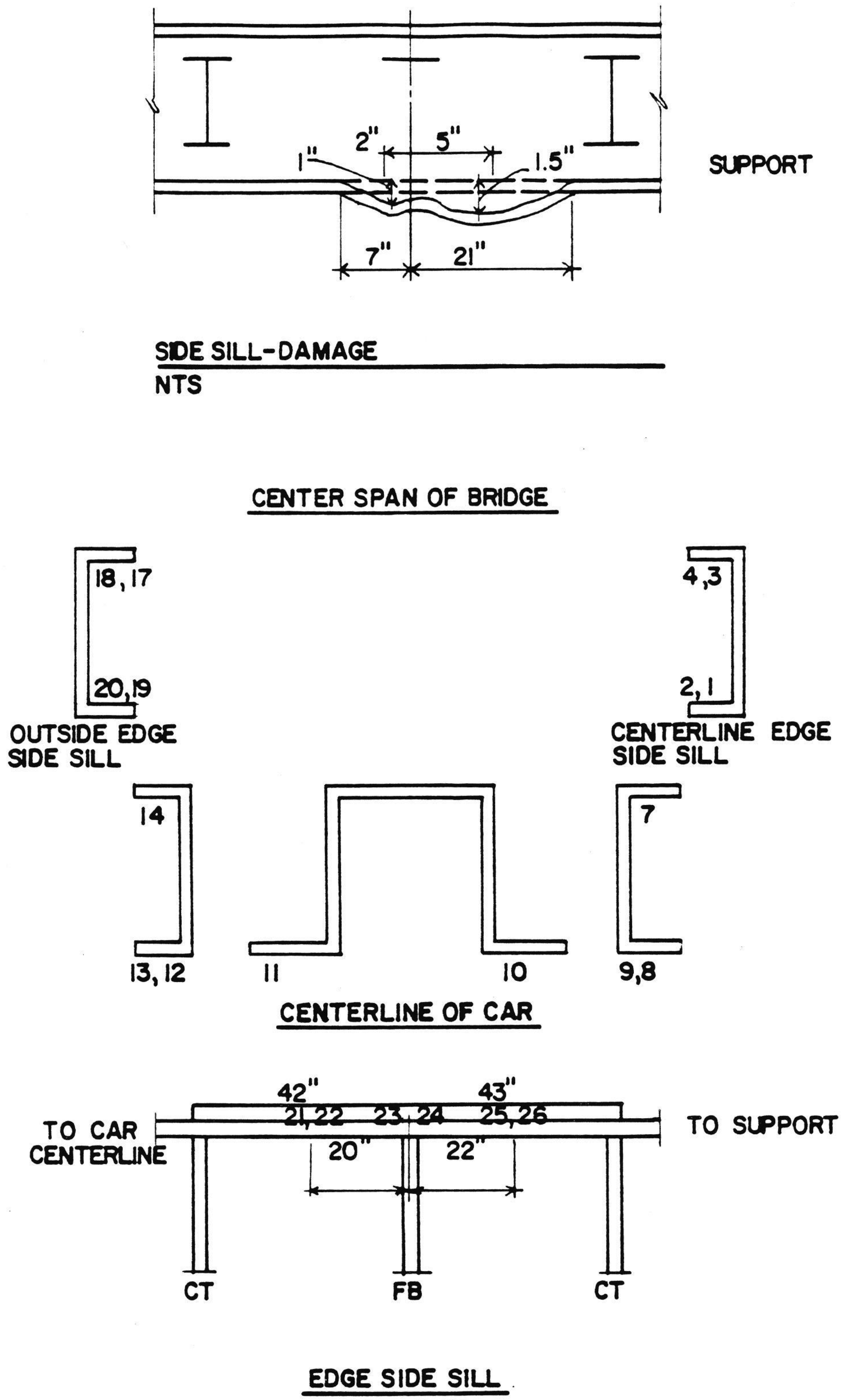
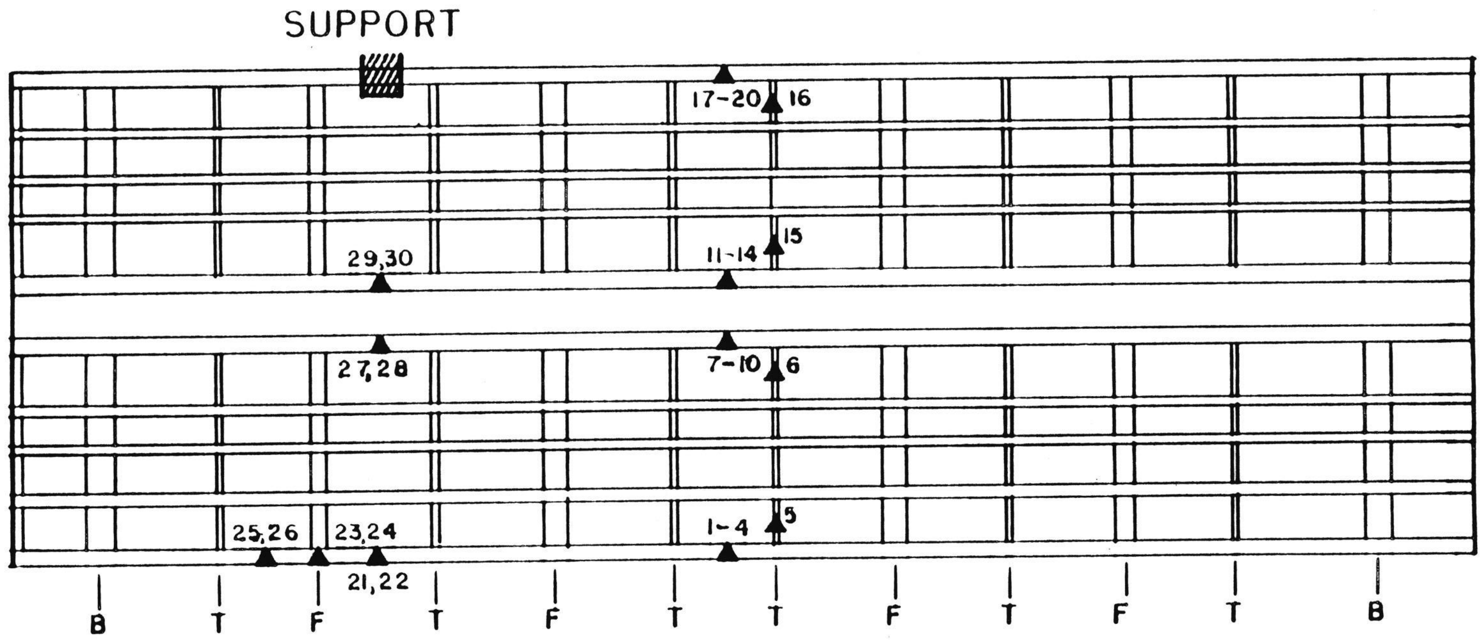


Fig. G-20
Bridge 3--Strain Gauge Numbers and Locations

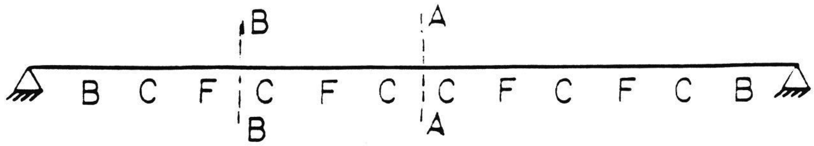


NTS

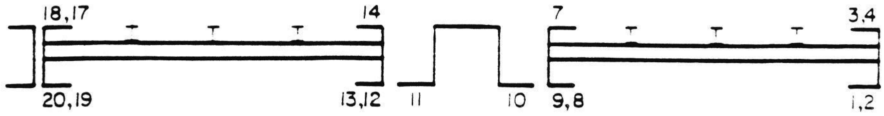
T CROSS TIES
B BOLSTER
F FLOOR BEAM

Fig. G-21
Bridge 3--Plan View of Strain Gauge Locations

Table G-8
Bridge 3--Rear Axle at Stop 1 Centered on Car

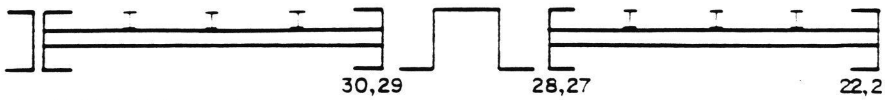


Section A-A



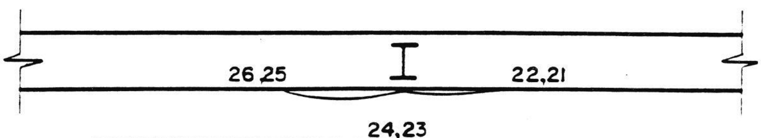
Field Strains								
Top	-18,-19 -17,-19 -19,-19		-22 -21 -21			-32 -27 -28		-64,-64 -59,-57 -59,-58
Bottom	49,48 57,55 58,56		75,76 72,72 72,72	57 54 55	62 61 60	85,56 82,57 82,55		203,212 176,182 178,185
Analysis								
Top Bottom	-63 63		-122 122			-165 165		-304 304

Section B-B



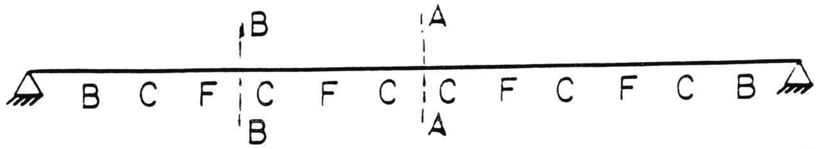
Field Strains								
Bottom			9,10 9,10 10,9			50,48 48,46 47,45		219,171 195,153 195,154
Analysis								
Bottom			12			61		186

Damaged Section

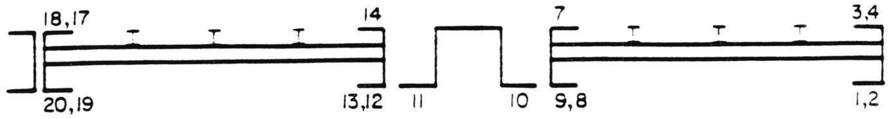


Field Strains	63,60 58,56 59,52	106,107 102,102 102,101	219,171 195,153 195,154
Analysis	101	153	186

Table G-9
Bridge 3--Rear Axle at Stop 2 Centered on Car



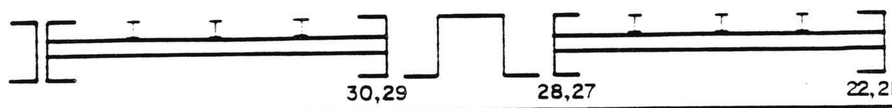
Section A-A



Field Strains

Top	-14,-12 -7,-8 -25,-16		-23 -23 -23			-40 -37 -33		-61,-59 -57,-56 -55,-55
Bottom	29,35 28,36 35,42		85,84 75,76 76,75	56 51 53	61 59 59	99,66 97,66 99,66		195,199 175,177 166,167
Analysis								
Top Bottom	-56 56		-117 117			-161 161		-304 304

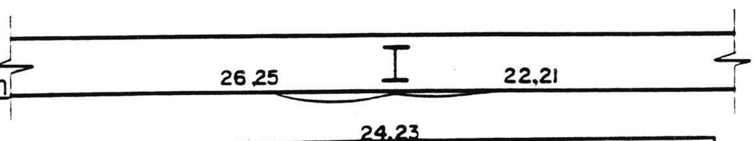
Section B-B



Field Strains

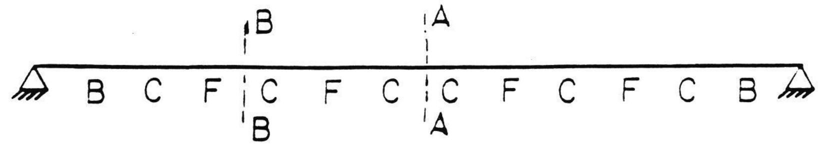
Bottom			40,42 38,40 34,35			85,84 82,81 85,83		306,246 273,218 246,198
Analysis								
Bottom			42			117		237

Damaged Section

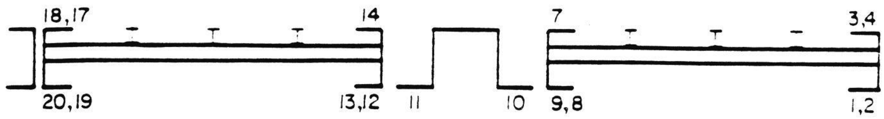


Field Strains	114,110 102,98 90,86	214,213 190,190 169,168	306,246 273,218 246,198
Analysis	148	215	237

Table G-10
Bridge 3--Rear Axle at Stop 3 Centered on Car

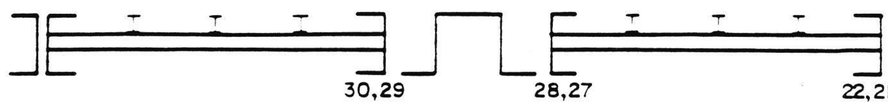


Section A-A



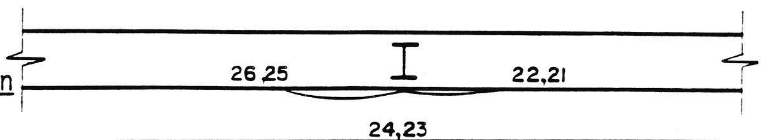
Field Strains								
Top	-4,-3 -3,-4 -4,-4		-3 -5 -4			-6 -6 -5		-19,-19 -19,-18 -17,-16
Bottom	-1,-1 -2,-2 -3,-3		21,20 20,21 18,18	20 18 15	20 19 16	28,20 26,18 22,15		68,70 64,66 57,59
Analysis								
Top	-11		-21			-39		-95
Bottom	11		21			39		95

Section B-B



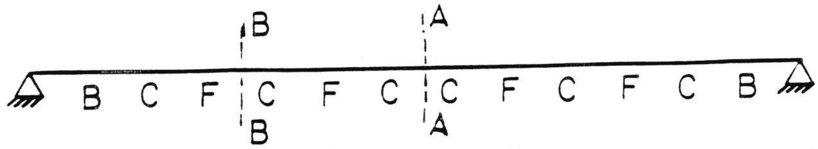
Field Strains								
Bottom			42,43 38,40 33,35			66,65 64,64 58,56		196,160 183,146 159,128
Analysis								
Bottom			46			80		129

Damaged Section

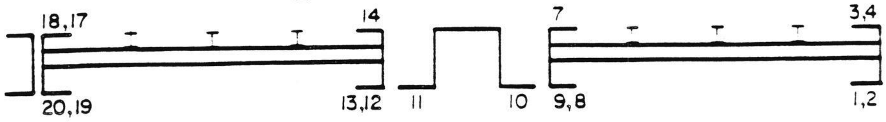


Field Strains	87,84 80,77 71,68	161,161 147,149 129,130	196,160 183,146 159,128
Analysis	94	132	129

Table G-11
Bridge 3--Rear Axle at Stop 1 Over Inside Side Sill



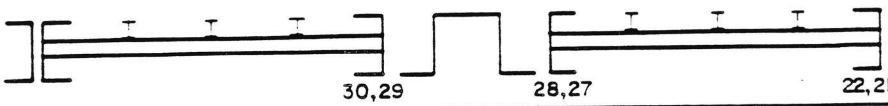
Section A-A



Field Strains

Top	15,16 18,18 17,17		-7 -8 -7			-2 -4 -4		-1,-1 -1,-2 -1,-2
Bottom	80,75 78,74 76,72		18,17 19,18 17,16	11 9 8	10 9 8	9,10 8,9 8,5		-1,-2 -2,-3 -2,-3
Analysis Top	-109		-40			-20		16
Analysis Bottom	109		40			20		-16

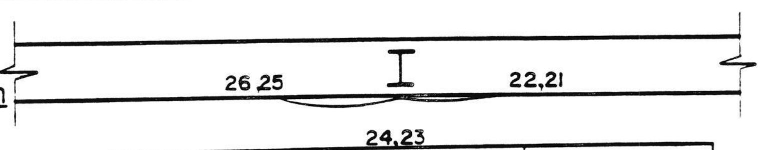
Section B-B



Field Strains

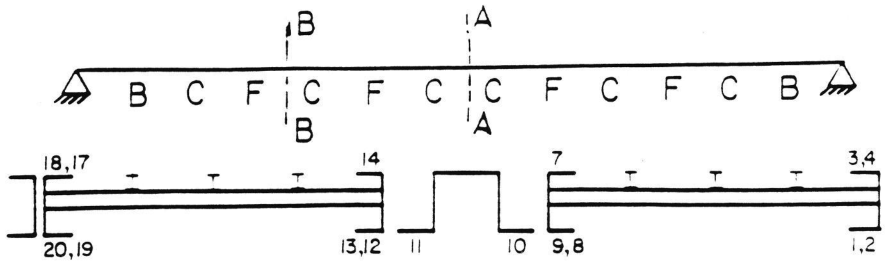
Bottom			2,0 4,1 -3,0			3,4 2,3 0,2		7,6 5,8 5,4
Analysis Bottom			-53			-23		22

Damaged Section



Field Strains	5,4 5,5 3,3	13,11 13,13 10,10	7,6 5,8 5,4
Analysis	20	29	22

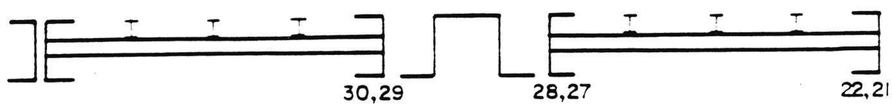
Table G-12
Bridge 3--Rear Axle at Stop 2 Over Inside Side Sill



Section A-A

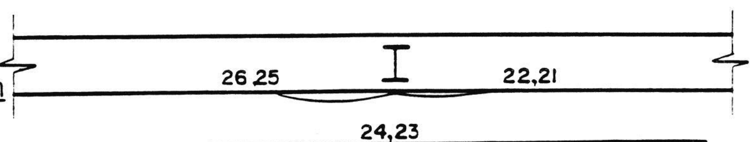
Field Strains								
Top	-2,-7 -16,-15 -15,-17		-6 -7 -5			-1 -3 -3		-2,-2 -1,-2 -1,-2
Bottom	61,64 59,61 64,66		14,12 13,13 12,11			7,10 5,3 5,3		2,2 -1,-1 -2,-1
Analysis								
Top	-133		-24			-10		10
Bottom	133		24			10		-10

Section B-B



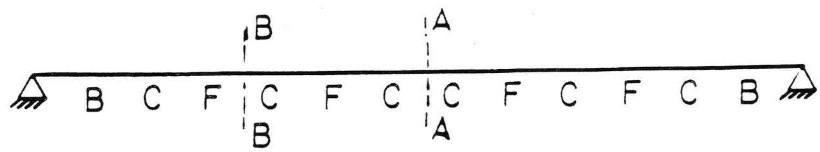
Field Strains								
Bottom			2,0 1,3 1,3			3,4 4,4 2,3		7,6 3,5 2,2
Analysis								
Bottom			-27			-11		11

Damaged Section

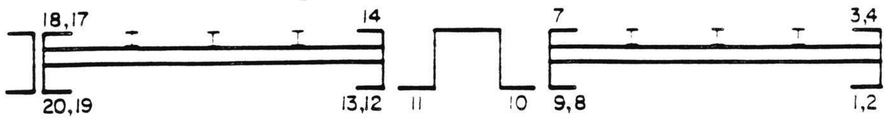


Field Strains	5,4 3,4 2,1	11,9 8,7 6,5	7,6 3,5 2,2
Analysis	11	11	11

Table G-13
Bridge 3--Rear Axle at Stop 3 Over Inside Side Sill



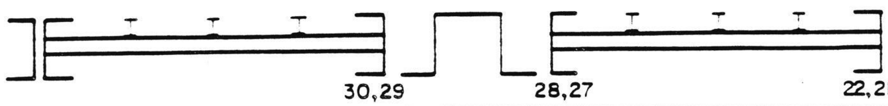
Section A-A



Field Strains

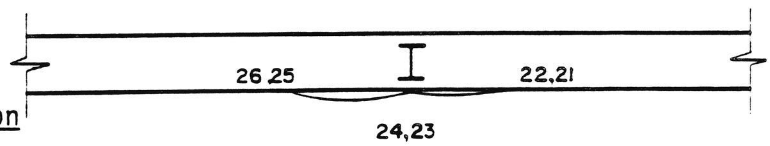
Top	1,0 -3,-3 -2,1		0 0 0			0 0 0		-1,-1 0,-1 -1,-1
Bottom	-2,-1 -1,-1 -1,0		0,0 0,0 0,0	2 0 1	-1 1 0	1,1 0,-1 1,-1		3,2 1,1 1,2
Analysis								
Top Bottom	9 -9		4 -4			1 -1		-4 4

Section B-B



Field Strains

Bottom			2,3 3,3 4,3			3,3 3,3 1,0		3,3 1,2 1,-1
Analysis								
Bottom			6			3		0



Damaged Section

Field Strains	1,1 2,1 0,0	1,1 2,2 -1,-1	3,3 1,2 1,-1
Analysis	-1	-1	0

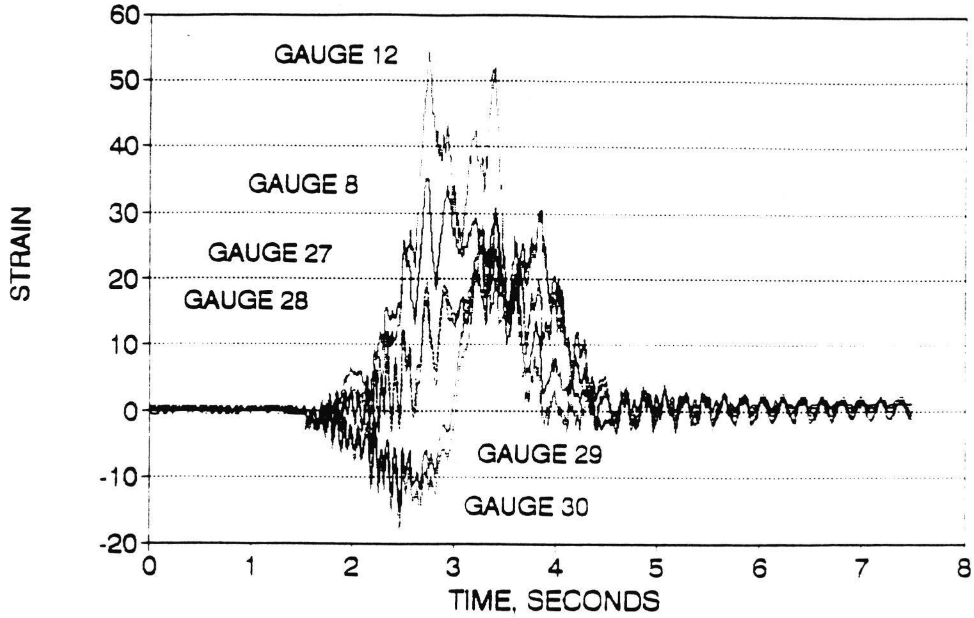


Fig. G-22
Bridge 3--Strains in Center Sill
Along Length of Car

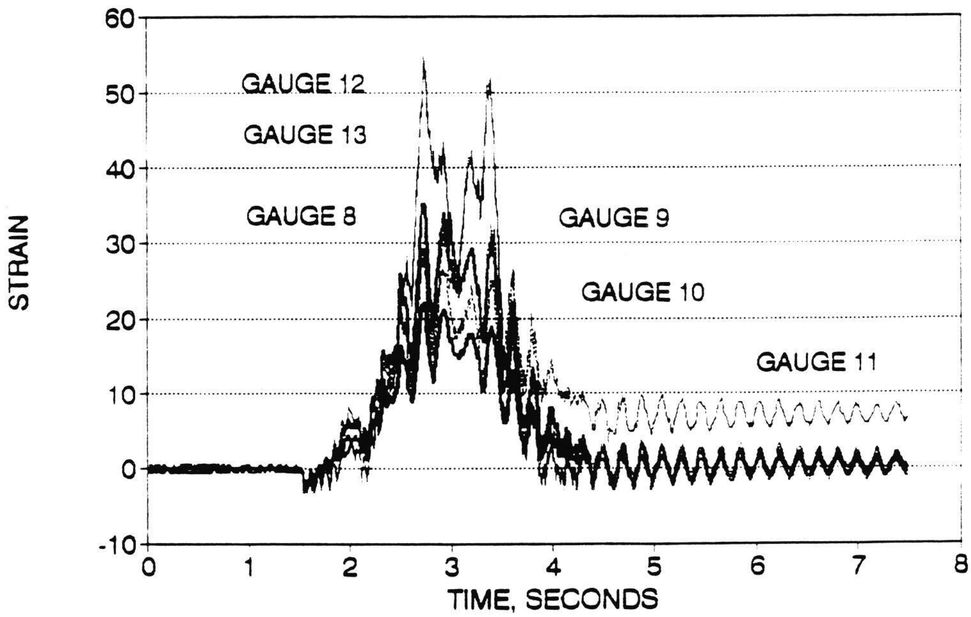


Fig. G-23
Bridge 3--Center Sill Strains at Center of Span

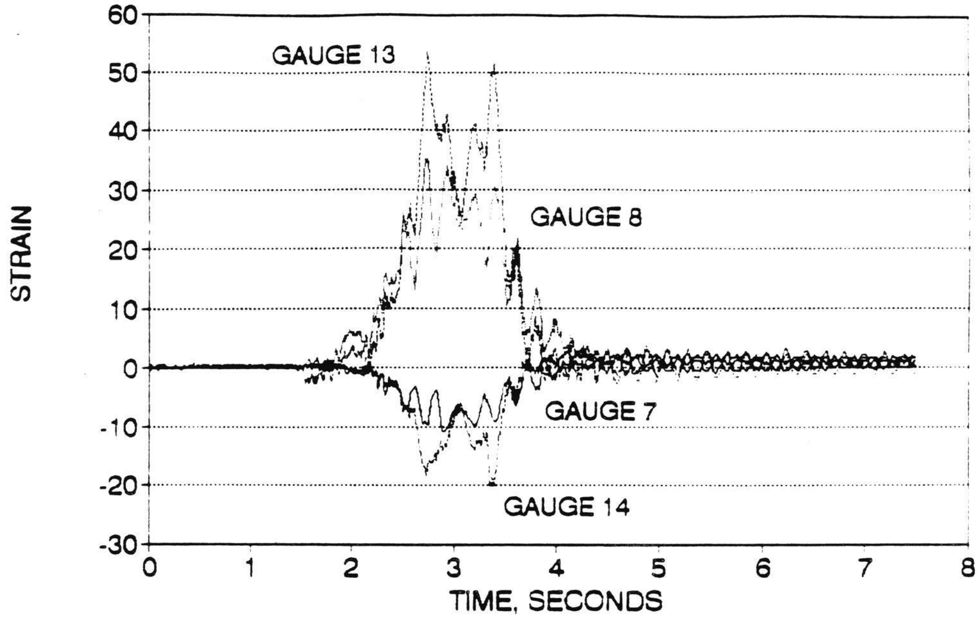


Fig. G-24
Bridge 3--Compressive and Tensile
Strains in Center Sill at Center of Span

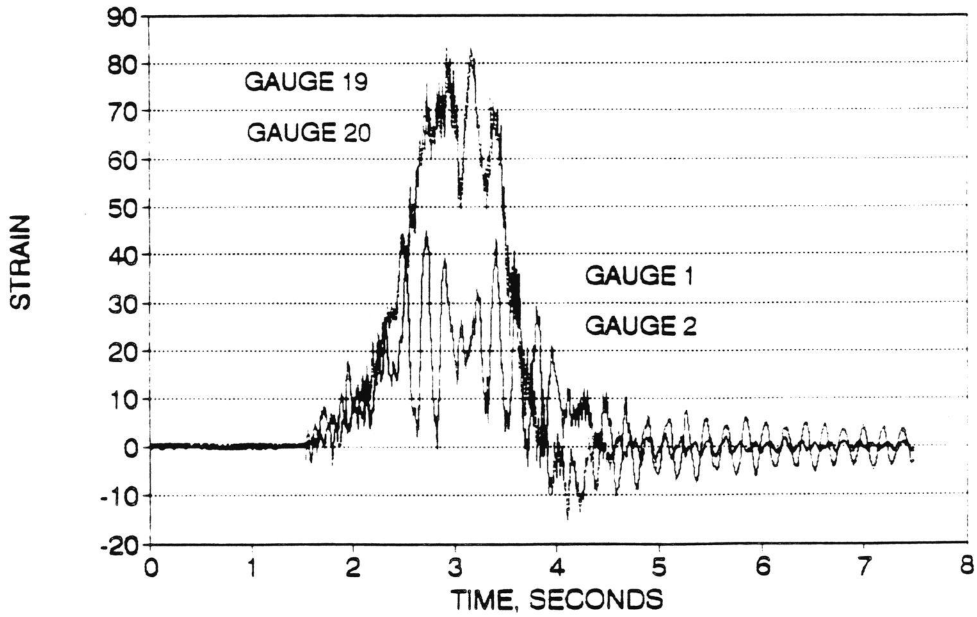


Fig. G-25
Bridge 3--Tensile Strains in Side Sills
at Center of Span

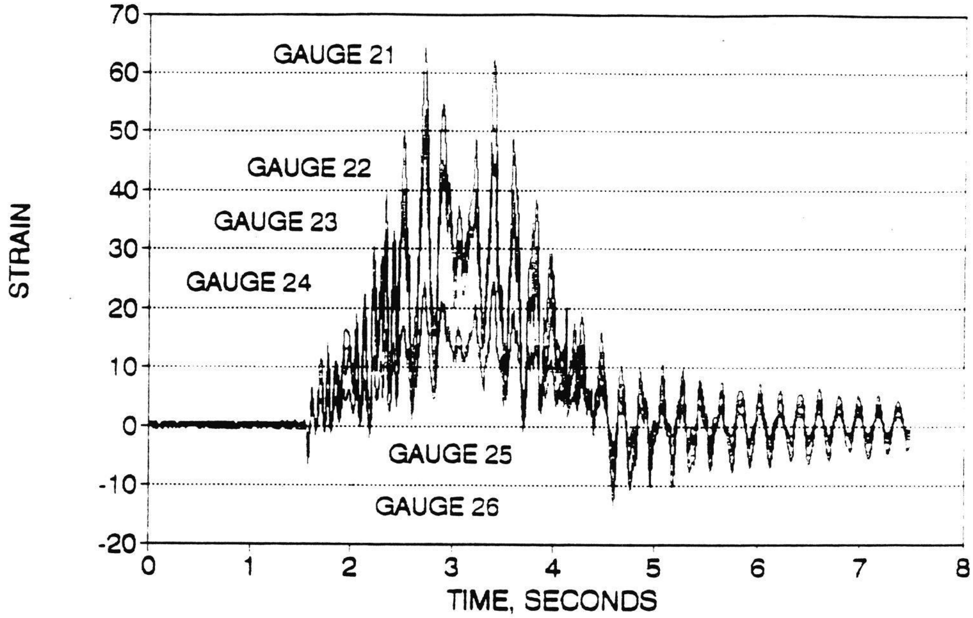


Fig. G-26
Bridge 3--Strains at Damaged Side Sill Section

Bridge 4

Field Test Data

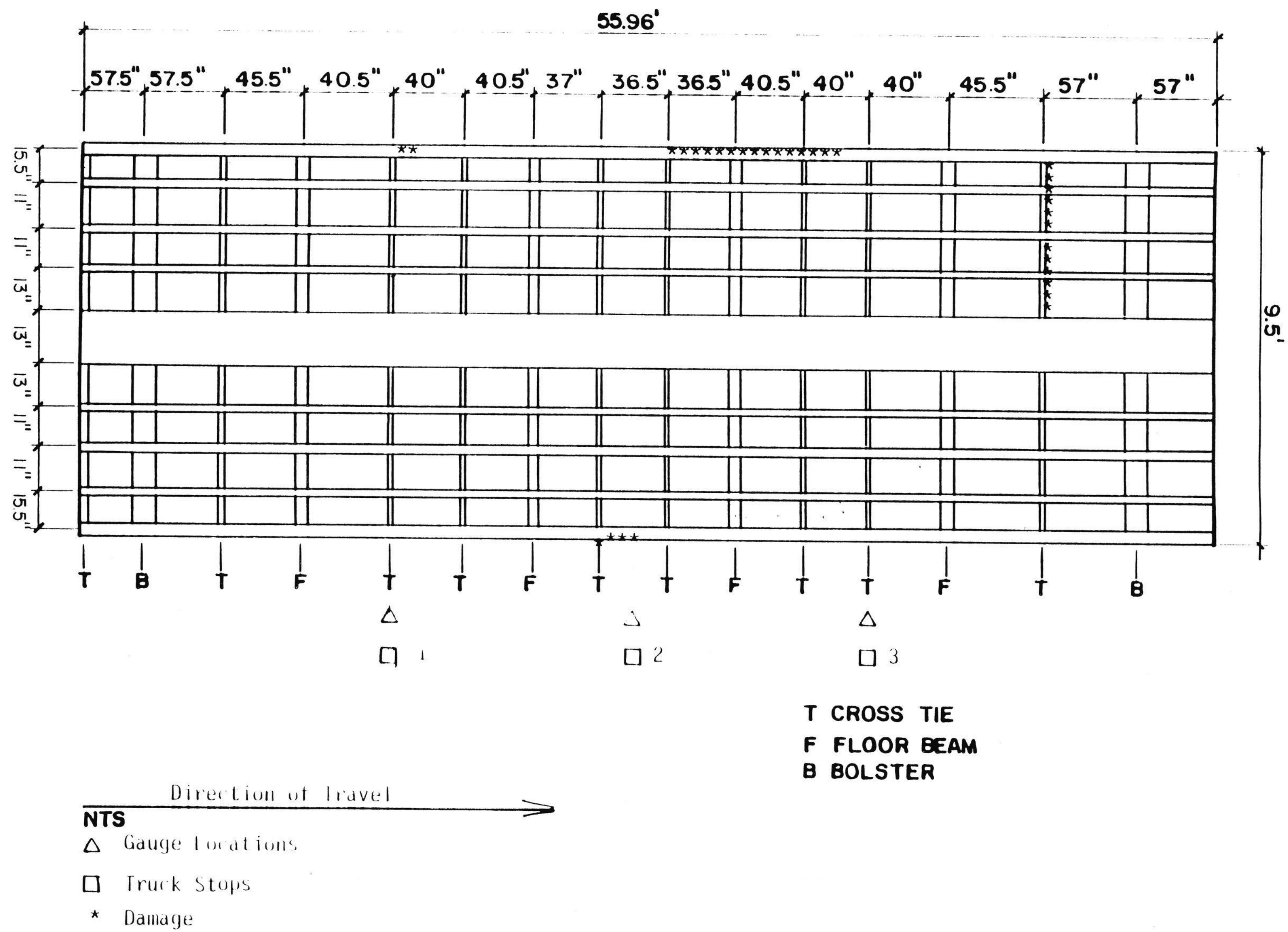


Fig. G-27
Bridge 4--General Information

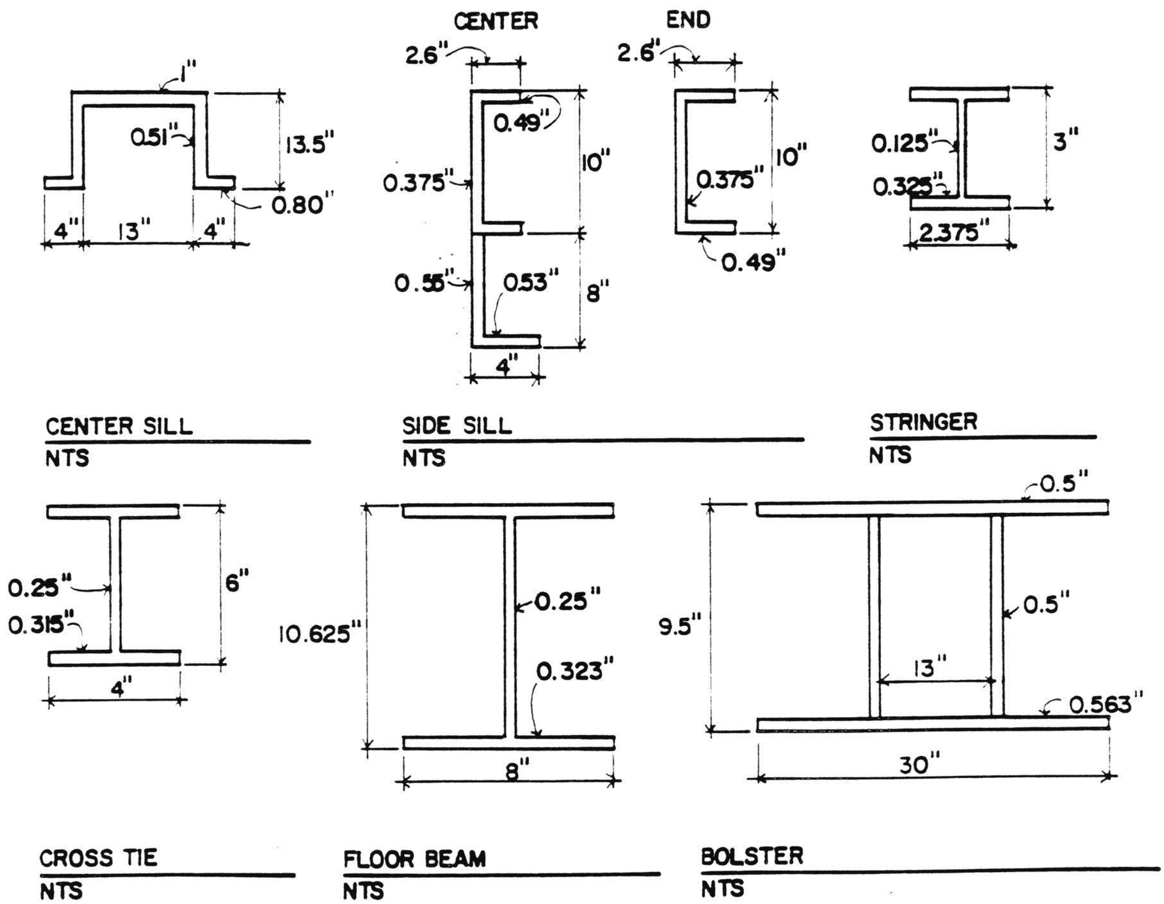


Fig. G-28
Bridge 4--Member Dimensions

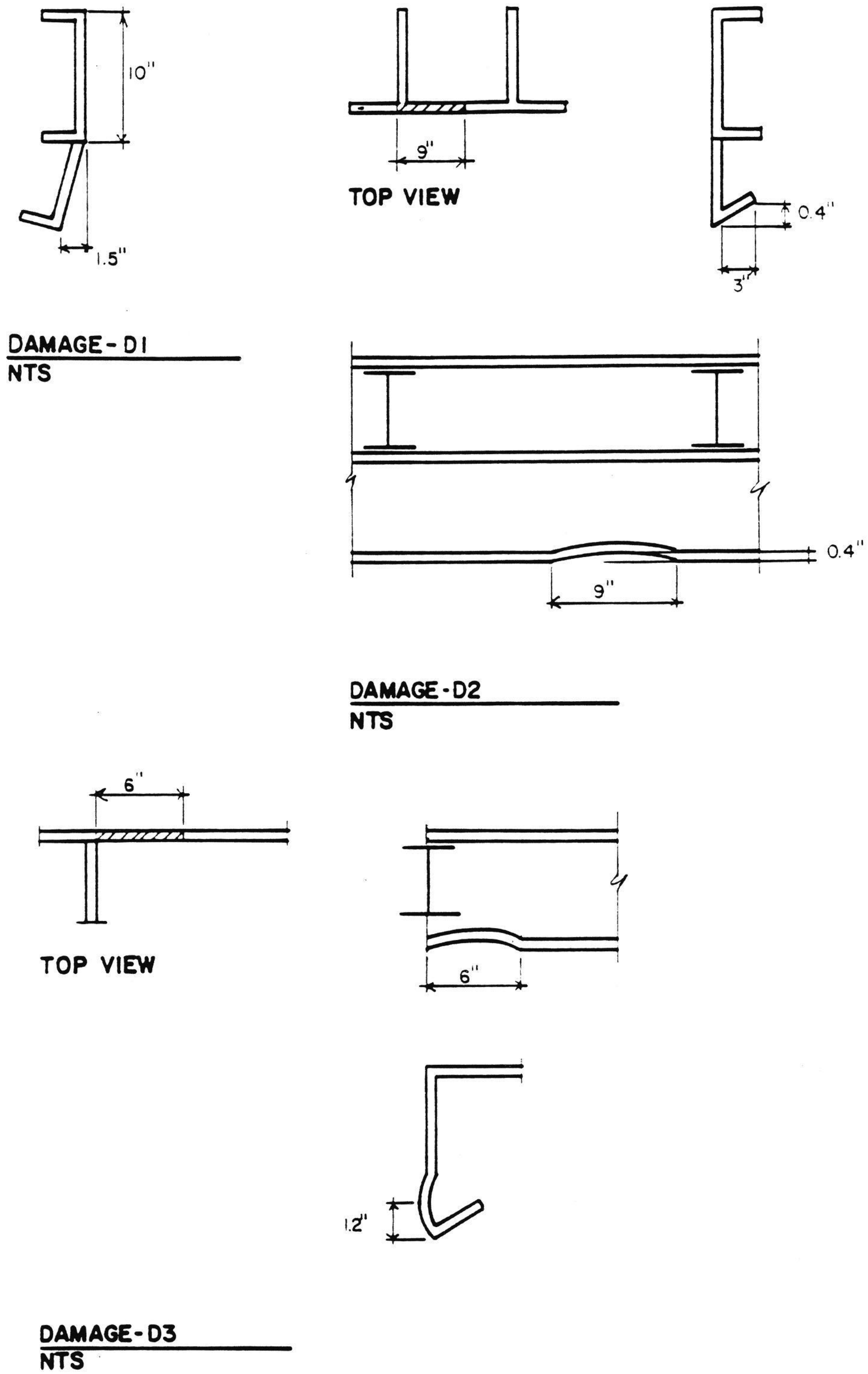


Fig. G-29
Bridge 4--Damage Sections

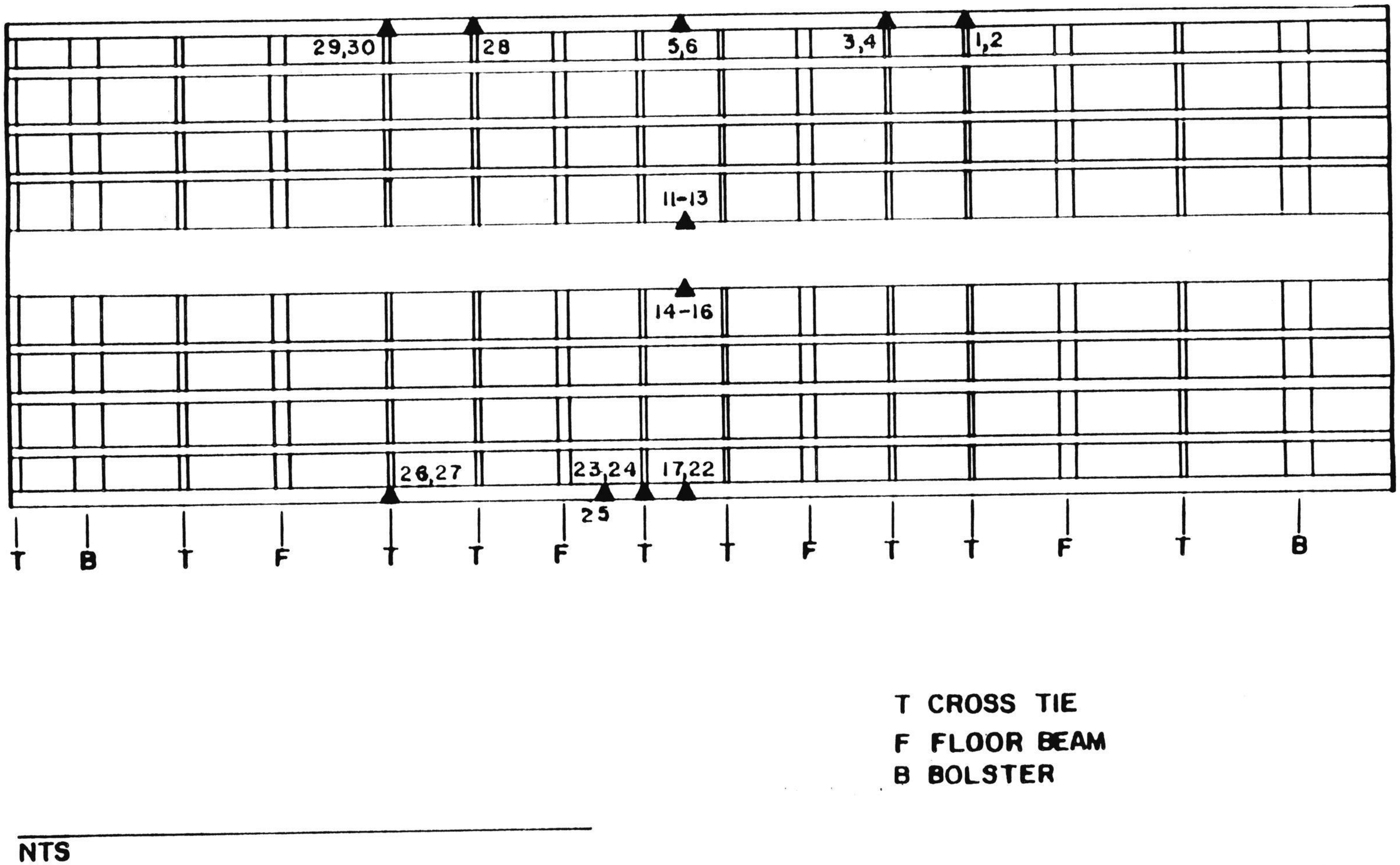
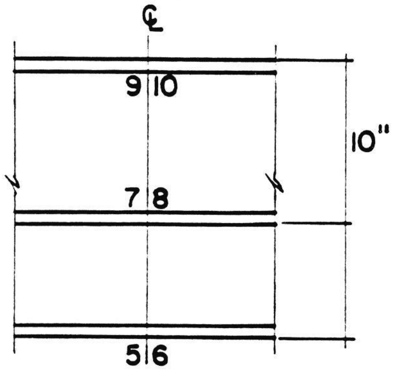
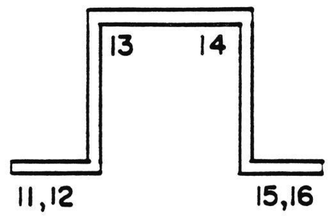


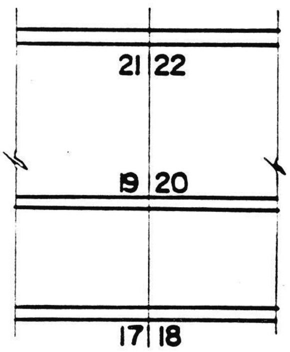
Fig. G-30
Bridge 4--Plan View of Strain Gauge Locations



SIDE SILL AT
CENTER OF BRIDGE



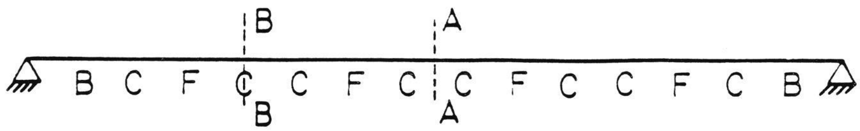
CENTER SILL



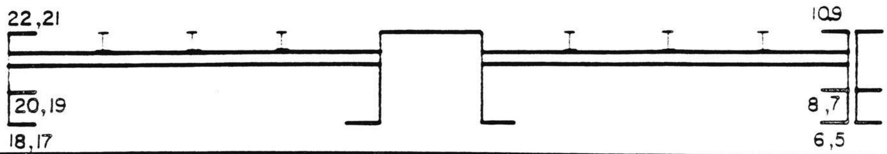
SIDE SILL AT
EDGE OF BRIDGE

Fig. G-31
Bridge 4--Strain Gauge Numbers and Locations

Table G-14
Bridge 4--Rear Axle at Stop 1 Centered on Car



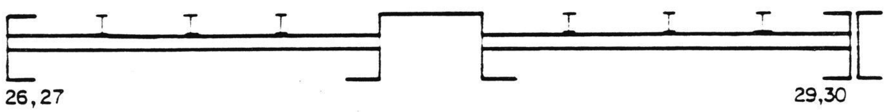
Section A-A



Field Strains

Top	-133,-131 -132,-126 -133,-127			-82 -79 -84	-76 -75 -78			-81,-68 -84,-70 -90,-75
Bottom	192,184 192,184 196,187		169,170 171,172 177,178			153,157 154,160 157,163		76,75 80,80 85,85
Analysis								
Top Bottom	-267 267		236	-236	-236	236		-267 267

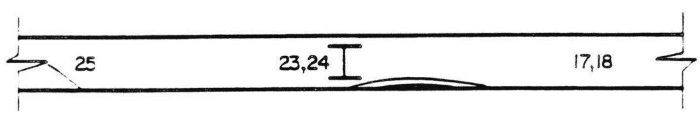
Section B-B



Field Strains

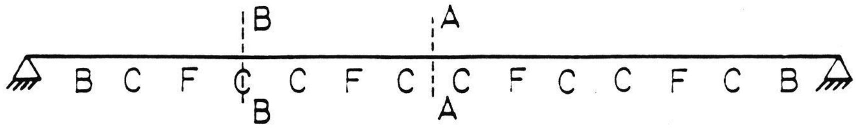
Bottom	432,426 433,427 439,433							218,212 224,217 225,218
Analysis								
Bottom	547							547

Damaged Section

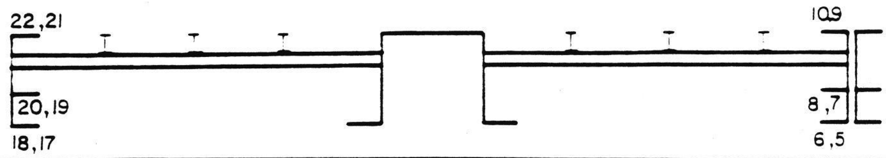


Field Strains	172 171 174	185,190 184,191 187,194	192,184 192,184 196,187
Analysis	264	272	267

Table G-15
Bridge 4--Rear Axle at Stop 2 Centered on Car

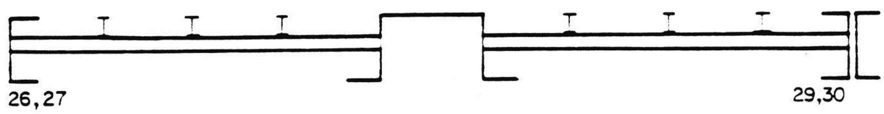


Section A-A



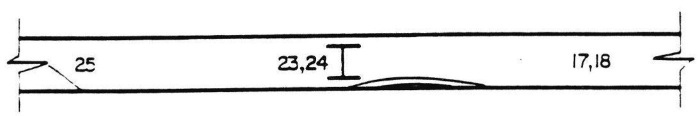
Field Strains								
Top	-137,-141 -142,-141 -144,-144			-90 -89 -90	-84 -82 -83			-87,-71 -90,-70 -94,-75
Bottom	203,194 202,193 207,198		183,184 184,185 189,190			163,166 163,168 167,172		83,83 90,90 91,92
Analysis								
Top	-277			-250	-250			-277
Bottom	277		250			250		277

Section B-B



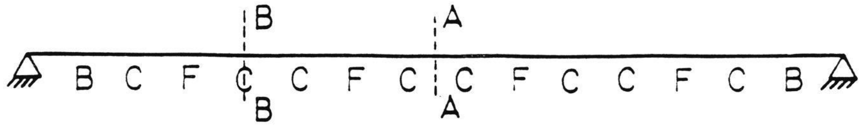
Field Strains								
Bottom	258,252 262,257 263,258							98,94 111,115 116,112
Analysis								
Bottom	383							383

Damaged Section

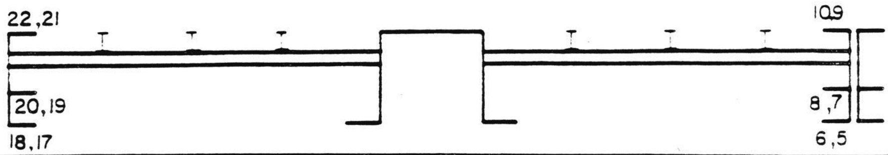


Field Strains	170 169 172	188,194 189,195 192,198	203,194 202,193 207,198
Analysis	256	273	277

Table G-16
Bridge 4--Rear Axle at Stop 3 Centered on Car

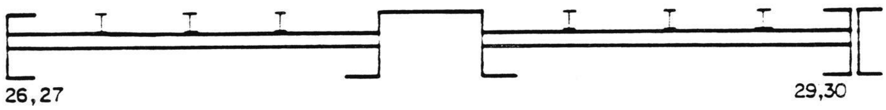


Section A-A



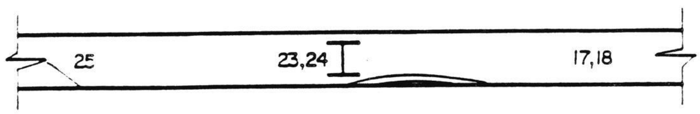
Field Strains								
Top	-64,-63 -62,-60 -64,-60			-36 -34 -37	-31 -29 -32			-33,-28 -33,-30 -36,-32
Bottom	94,89 93,87 97,92		84,84 82,82 88,88			75,76 74,75 77,79		29,28 32,32 34,34
Analysis								
Top	-142			-125	-125			-142
Bottom	142		125			125		142

Section B-B



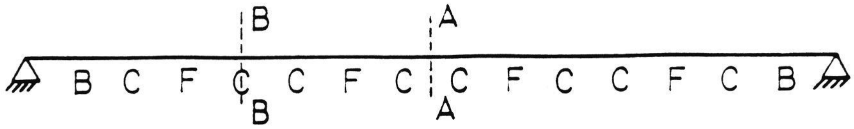
Field Strains								
Bottom	103,100 107,104 107,104							31,29 38,36 40,38
Analysis								
Bottom	191							191

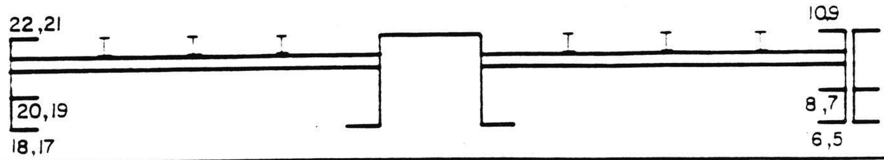
Damaged Section



Field Strains	76 73 76	83,86 82,85 84,89	94,89 93,87 97,92
Analysis	128	136	142

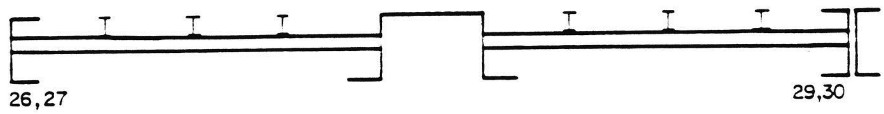
Table G-17
Bridge 4--Rear Axle at Stop 1 Over Inside Side Sill





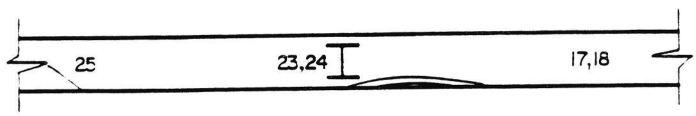
Section A-A

Field Strains								
Top	-109,-110 -109,-104 -112,-106			-77 -79 -79	-73 -73 -68			-139,-113 -123,-100 -117,-91
Bottom	158,149 161,153 164,154		163,165 162,164 164,165			144,149 146,150 145,150		110,110 104,104 102,102
Analysis								
Top	-33			-115	-115			-250
Bottom	33		115			115		250



Section B-B

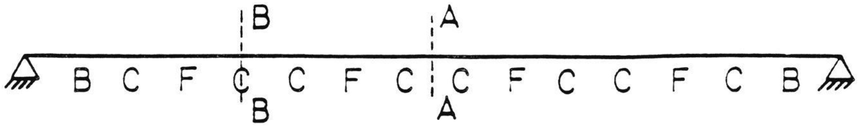
Field Strains								
Bottom	310,305 314,309 324,318							300,293 295,288 290,282
Analysis								
Bottom	0							605



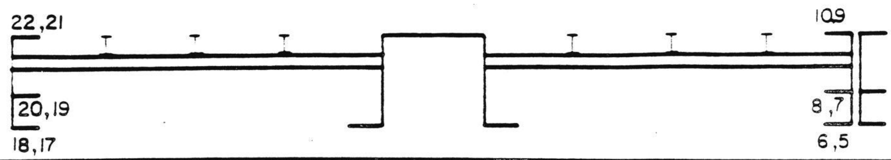
Damaged Section

Field Strains	142 145 146	150,155 154,159 157,161	158,149 161,153 164,154
Analysis	28	31	33

Table G-18
Bridge 4--Rear Axle at Stop 2 Over Inside Side Sill



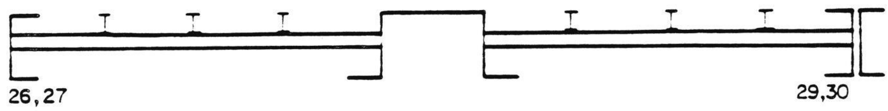
Section A-A



Field Strains

Top	-117,-110 -116,-112 -112,-107			-83 -86 -85	-79 -78 -73			-142,-105 -136,-58 -116,-51
Bottom	165,158 167,158 160,152		169,172 171,172 167,168			154,159 156,159 152,156		117,117 113,113 116,117
Analysis Top Bottom	31		118	-118	-118	118		270

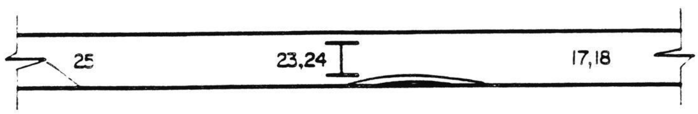
Section B-B



Field Strains

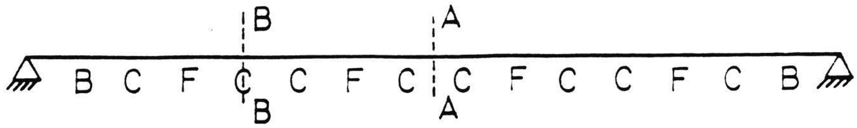
Bottom	212,208 212,208 206,202							147,144 139,138 143,141
Analysis Bottom	62							313

Damaged Section

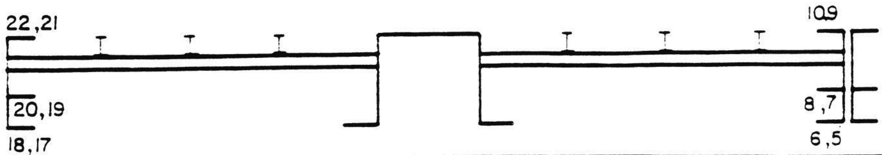


Field Strains	142 142 136	155,160 155,162 150,155	165,157 167,158 160,152
Analysis	33	32	31

Table G-19
Bridge 4--Rear Axle at Stop 3 Over Inside Side Sill

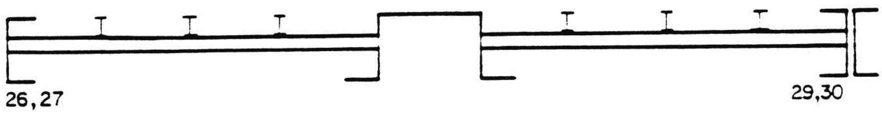


Section A-A



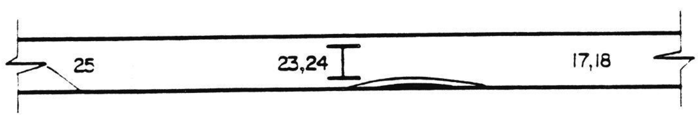
Field Strains								
Top	-60,-58 -61,-57 -63,-60			-36 -37 -37	-31 -32 -30			-34,-29 -32,-27 -33,-28
Bottom	86,80 88,83 90,85		77,78 80,80 80,80			74,76 86,77 90,78		34,33 33,32 34,34
Analysis								
Top				-66	-66			
Bottom	35		66			66		101

Section B-B



Field Strains								
Bottom	97,95 100,98 101,100							41,40 40,38 39,39
Analysis								
Bottom	71							118

Damaged Section



Field Strains	68 69 72	76,79 78,82 79,83	86,80 88,83 90,84
Analysis	37	37	35

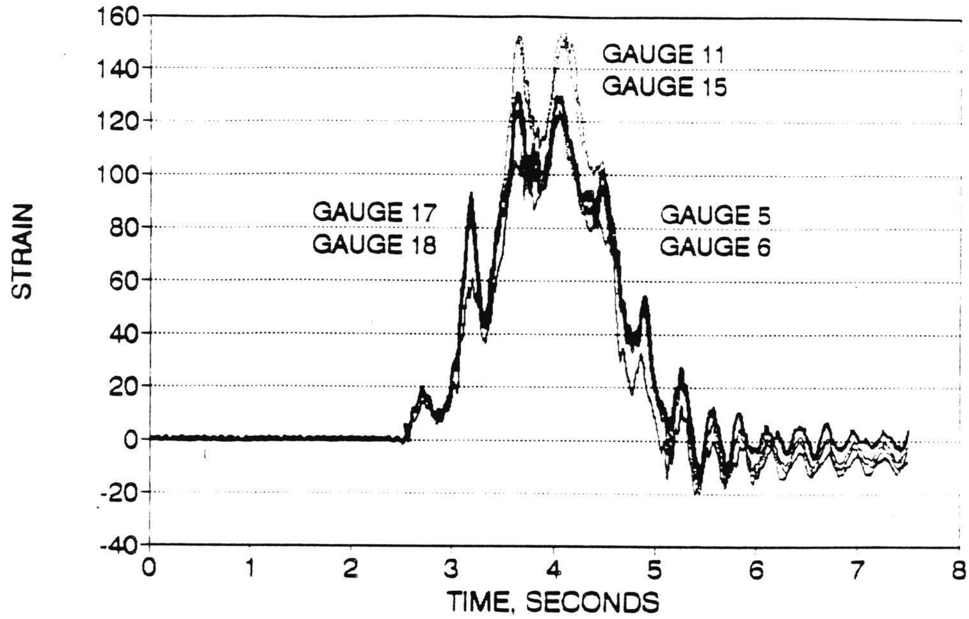


Fig. G-32
Bridge 4--Tensile Strains in Side and Center
Sills at Center of Span

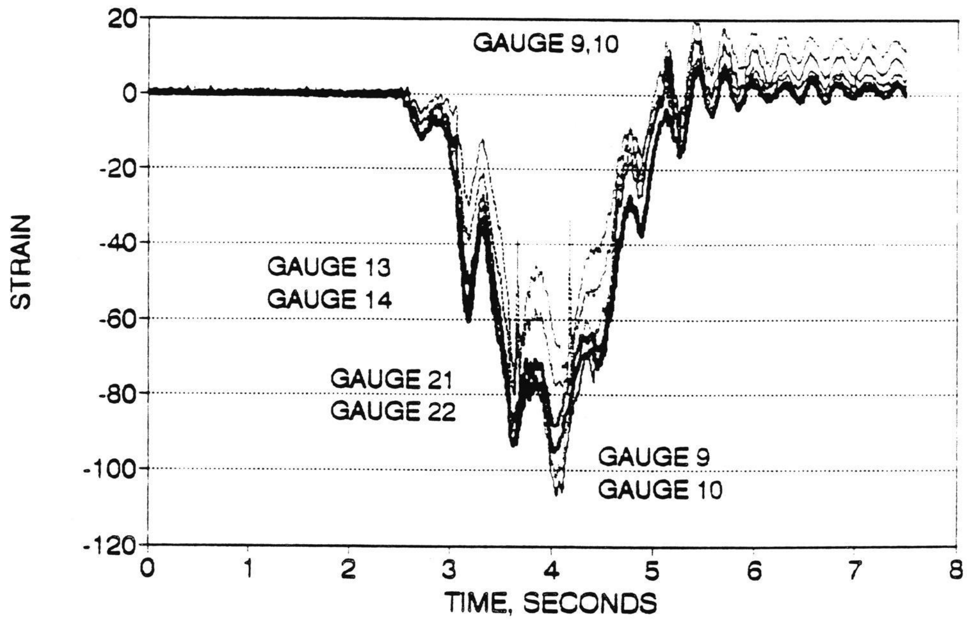


Fig. G-33
Bridge 4--Compressive Strains in Side and
Sills at Center of Span

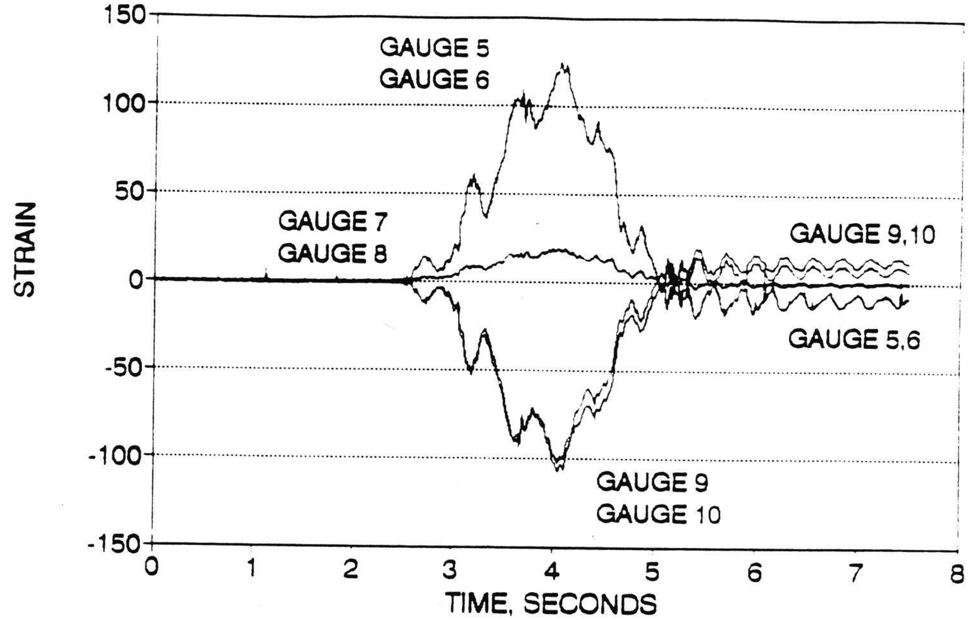


Fig. G-34
Bridge 4--Compressive and Tensile Strains in
Side Sill at Center of Span and Center Line of Bridge

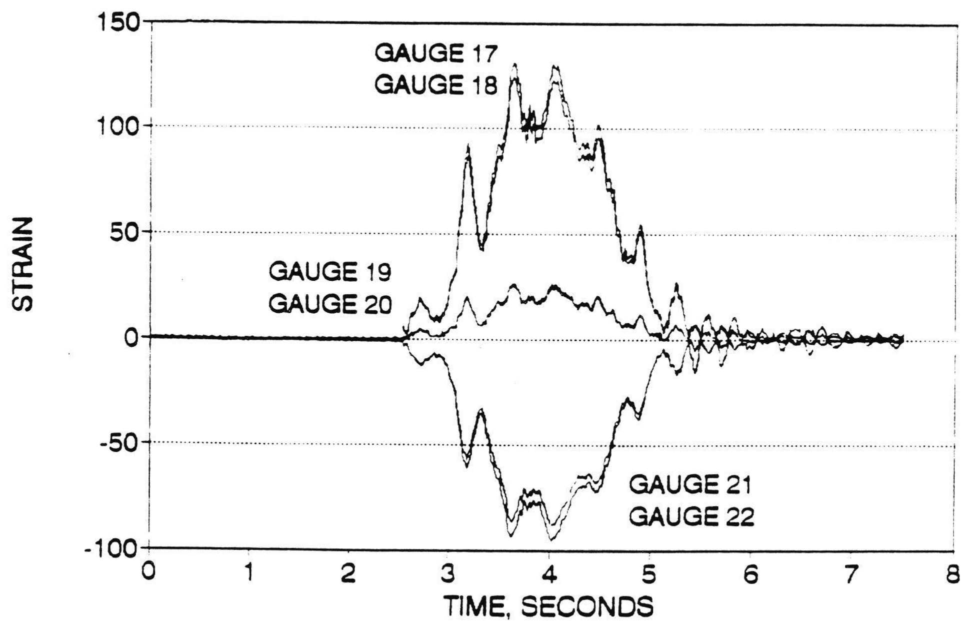


Fig. G-35
Bridge 4--Compressive and Tensile Strains in Side Sill
at Center of Span and at Edge of Bridge

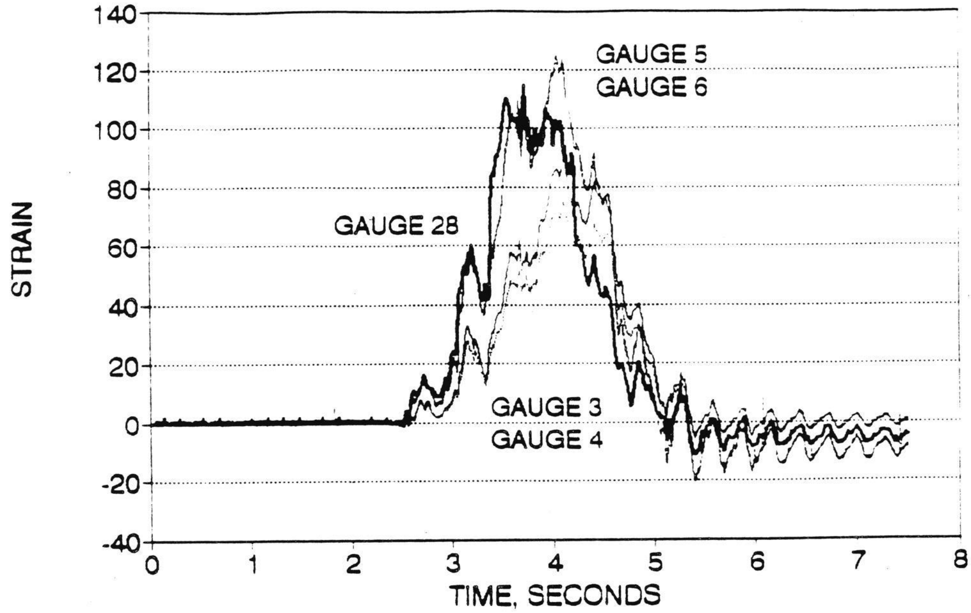


Fig. G-36
Bridge 4--Strain in Full Height Side Sill
at Center Line of Bridge

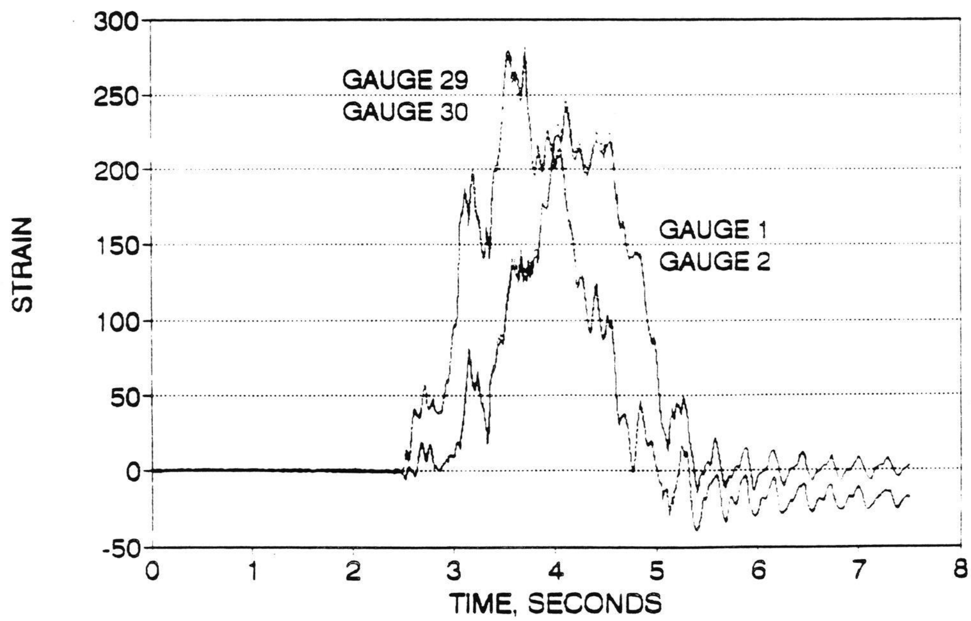


Fig. G-37
Bridge 4--Strain in Reduced Height Side Sill
at Center Line of Bridge

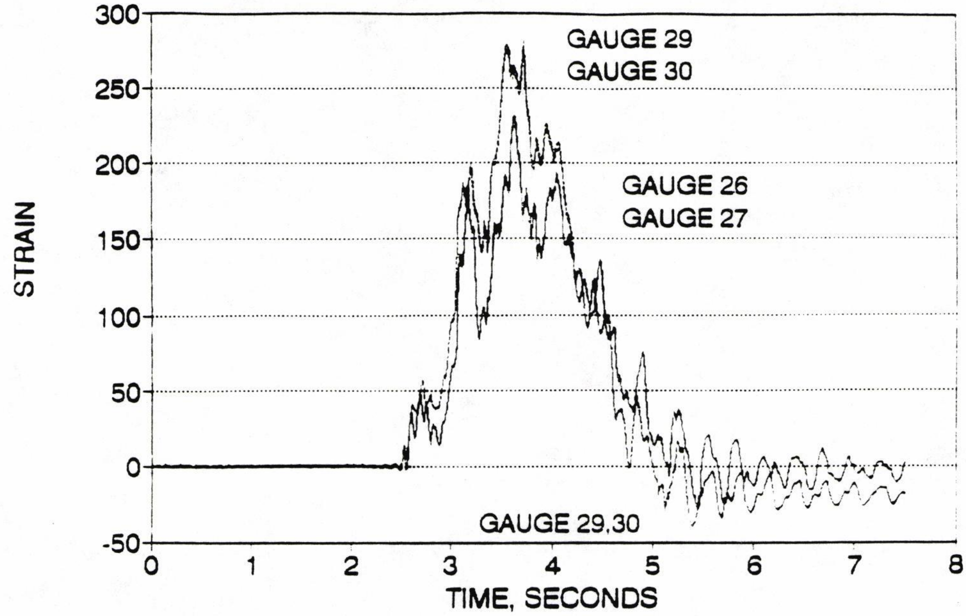


Fig. G-38
Bridge 4--Strain in Reduced Height Side Sill
at Both Sides of Bridge

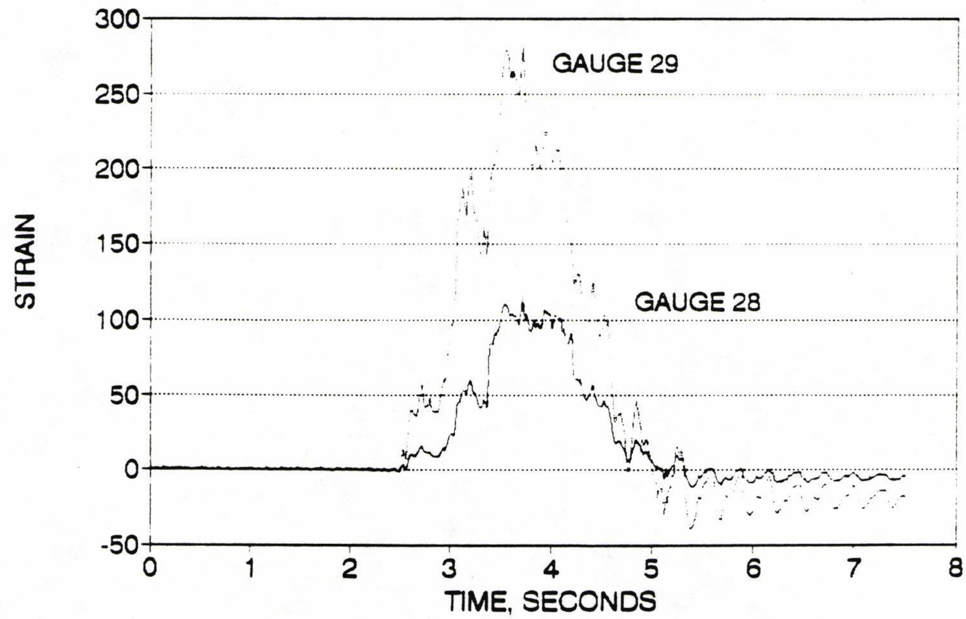


Fig. G-39
Bridge 4--Change in Strains
at Change of Side Sill Properties

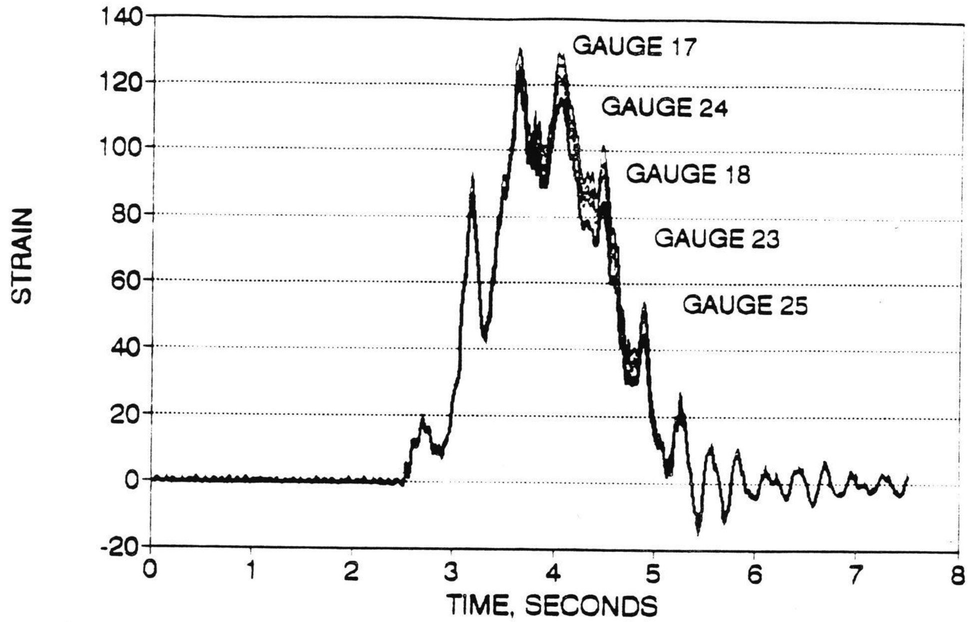


Fig. G-40
Bridge 4--Strain in Damaged Section of Side Sill
at Edge of Bridge