

MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

LOAD-DEFLECTION TESTS ON CORRUGATED
MULTI-PLATE SECTIONS

By

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An Investigation by the Michigan State Highway
Department in cooperation with the Bureau of
Public Roads; the Armco Drainage and Metal Products
Co., Inc.; the Republic Steel Corporation, and
United Steel Fabricators, Inc.

Prepared for Presentation to Bridge Committee
At the A.A.S.H.O. Meeting in San Antonio, Texas
October 8-9, 1949

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Research Project 49 F-19
Progress Report No. 1

Research Laboratory
Testing and Research Division
Report No. 136
November 1, 1949

FOREWORD

Hundreds of corrugated metal pipe and arch installations throughout the United States have proved, on the whole, highly satisfactory. Occasionally, however, failures have occurred. These structures are generally designed by highly empirical methods based on past experience but the variables are so numerous that engineers find it difficult to apply the data from one successful installation to another. Height of fill, character and water content of soil, both above and below the pipe, method of back filling, gage and diameter of pipe and whether or not it is installed in a trench - all these factors vitally affect the safety of the design. Recently, two new variables have been introduced which render somewhat questionable the use of existing installations as the criteria of design. The manufacturers are now using 1-3/4 and 2 inch depth of corrugation in place of the 1-1/2 inches formerly prevailing and second, an entirely new shape of corrugation known as the "box type" has been designed and put in competition with the standard type.

Realizing these conditions, the A.A.S.H.O. Bridge Committee in 1948 established the need for a comprehensive investigation on the subject which would include: (1) laboratory load tests on various sizes, shapes, and gages of corrugated plate sections now in current production and possibly (2) field tests on multi-plate structures under different loading conditions.

In order to expedite the work, Raymond Archibald, Chairman of the Bridge Committee, organized a meeting in Washington, D.C. of the following group for the purpose of correlating and establishing ways and means of carrying out the necessary testing program.

Eric L. Erickson, Chairman	- Chief Bridge Division Bureau of Public Roads
Dudley P. Babcock	Highway Bridge Engineer Bureau of Public Roads
Earl F. Kelley	Chief Division of Physical Research Bureau of Public Roads
Raymond Archibald	Chairman, A.A.S.H.O. Bridge Committee
George M. Foster	Bridge Engineer Michigan State Highway Department
Tage Beck	United Steel Fabricators, Inc.
C. R. Clauer	United Steel Fabricators, Inc.
David Henderson	Armco Drainage and Metal Products Co.
George E. Shaefer	Armco Drainage and Metal Products Co.
T. F. de Capiteau	Republic Steel Corporation
W. R. Fraser	Republic Steel Corporation

At this meeting, the Michigan State Highway Department, represented by George M. Foster, Bridge Engineer, agreed to provide laboratory facilities and perform the laboratory tests. The three steel plate fabricators - Armco Drainage and Metal Products Company, Republic Steel Corporation and United Steel Fabricators, Inc., agreed to furnish the necessary test specimens and cooperate in the investigation.

The above committee in turn decided it would be best to place the responsibility for working out the details of the tests in the hands of a subcommittee to consist of the following members:

Eric L. Erickson, Chairman
George M. Foster
C. R. Clauer
T. F. de Capiteau
George E. Shaefer

At a meeting of this subcommittee in Lansing on February 25, 1949 tentative plans and procedures were established for doing the laboratory testing work. It was agreed that the testing work would be done by the Research Laboratory of the Michigan State Highway Department and that it would consist of simple load-deflection tests on parallel specimens of corrugated plate sections in current production by the three participating fabricators.

At a subsequent meeting on August 23, 1949 at East Lansing, members of the subcommittee inspected the laboratory work and after formal discussion approved the work program described in the following text.

LOAD-DEFLECTION TESTS ON CORRUGATED MULTI-PLATE SECTIONS

This report describes the program of laboratory testing of various corrugated multi-plate sections in parallel to determine their relative stability under different static load conditions. It contains the objectives and scope of the project, testing procedure, progress of the work, and examples of results being obtained. It is expected that the laboratory tests will throw light on a few of the uncertainties which are now obvious in the field of multi-plate construction and definite answers to the following:

1. Can designs for pipes and arches be made on the basis of section modulus, irrespective of depth or type of corrugation as at present manufactured?
2. Do the present methods of making the seams fully develop the metal, both in bending and direct stress or any combination of stress?

Scope of Study

The laboratory study will consist essentially of a series of column and beam tests on plain and bolted corrugated plate sections of current design including straight and curved shapes in several gage thicknesses. A few samples of old style plates will be tested for comparative purposes. Specimens for study of joint performance are also included in the testing program.

The primary factors to be considered in the Laboratory study are:

- (1) size and type of corrugations, (2) radius of curvature of bent plate, (3) gage of metal, (4) method of jointing (butt or lap), (5) tensile stresses in bolts, (6) torque resistance of bolts, (7) influence of initial bolt tightness on joint performance, (8) single versus double bolted joints, (9) physical and chemical properties of the metal in bolts and plate.

Test Specimens: With the exception of the old style plate, all test specimens will be representative samples selected by the manufacturer from current stock plate and formed to meet test conditions. The test program includes from each manufacturer three plates each of No. 1, 7, and 12 gage metal in the following shapes and sizes. Each plate has covering width of 21-1/2 inches.

<u>Shape</u>	<u>Radius</u>	<u>Length Parallel to Corrugation</u>	<u>Condition</u>
Straight	0	52-3/4 inches	Plain
Straight	0	24 inches	Bolted
Curved	30 inches	52-3/4 inches	Plain & Bolted
Curved	50 inches	52-3/4 inches	Plain & Bolted
Curved	150 inches	52-3/4 inches	Plain & Bolted

The old style number 10 gage plates are of the following shapes and sizes:

Straight	0	24 inches	Bolted
Curved	50 inches	52-3/4 inches	Plain & Bolted
Curved	150 inches	52-3/4 inches	Plain & Bolted

The corrugations of the plate specimens include two shapes, the circular arch type and the so-called "box type". The pitch of corrugations in all cases is six inches. The depth of corrugations of the circular arch types are 1-1/2 - 1-3/4 and 2 inches, and 2 inches for the "box type".

All plate sections with seams are furnished single bolted. A complete summary of test specimens will be found in Table I.

Testing Program: The test program on the plates consists of testing two of each type of specimen from each manufacturer under identical conditions and reserving the third specimen for supplementary tests and for the double bolted joint study. Test values from two similar specimens will be averaged for final presentation of test data. The test program is outlined as follows:

A. Tested as Columns:

Test # 1 - 52-3/4 inch plain straight sections
Test # 3 - 150 inch radius curved sections (plain and bolted)
Test # 4 - 30 inch radius curved sections (plain and bolted)

B. Tested as Beams:

Test # 5 - 150 inch radius curved sections (plain and bolted)
Test # 6 - 50 inch radius curved sections (plain and bolted)

C. Tested for Joint Performance:

Test # 2 - 24 inch straight single and double bolted sections

The testing of straight sections as beams was not included in the program because it was the general opinion of the subcommittee that nothing of value would be gained by such tests since straight plates are not used in the field.

In the performance of the load deflection tests, each test will be carried sufficiently beyond point of ultimate failure so as to exaggerate the deformation and failure characteristics in the plate and at the joints. In general, the load will be applied continuously in definite load increments until failure of the plate. In a few cases it is planned to restore the load to zero between each load increment.

The bolts in all jointed specimens will be tightened to a torque of 200 foot pounds. This value was agreed upon by the committee in light of laboratory tests and field experiences. However, it is planned to include a series of column tests on short jointed sections with bolts tightened to higher torque values.

Double Bolted Joint Tests: Double bolted sections will be included in all of the three phases of testing as outlined above. The double bolted section will be provided by drilling additional holes in the extra test specimens and inserting the necessary bolts.

Bolt Tests: Incidental tests on bolts will include a series of torque tests (ultimate resistance to twisting with a torque wrench) for each type of bolt furnished. Further, tension tests with S-R strain gages on the bolts will be attempted during the bending or beam test on certain specimens.

Material Tests: Chemical and physical properties of the metal in the bolts and plates will be determined.

Testing Equipment and Procedures

Considerable improvisation in the developing of test equipment has been necessary in order to handle all phases of the test program in a satisfactory manner. Tests conducted to date and equipment employed will be described in the following text:

Joint Tests: A 150,000 pound Olsen Universal Testing Machine was available to test the 24 inch bolted specimens (Test No. 2) in the lighter gages. A 480,000 pound machine now under construction will be available for testing the heavier gage specimens. The specimens are installed in the Olsen machine, as shown in Figure 1, and load applied in 5,000 pound increments through a specially designed loading head which insures uniform pressure at top edge of specimen without lateral restraint. Four .001 Federal dials are attached to the specimen in manner shown in Figure 1 to measure the relative movement of the two plates at the joint. The dials are read at the end of each load increment. The average of the four dial readings is used in plotting the load-deflection curve. The specimens are tested to failure, which may be either buckling of the plate above or below the joint or plastic deformation of the metal around the bolts, and the ultimate load recorded. After completion of each test, pictures are taken and notations made relative to characteristics of the failure.

Beam Tests: The equipment used in making the beam tests is shown in Figure 2. It consists essentially of a modified 50 ton Dake hydraulic press which has sufficient capacity to handle all of the beam specimens. The beam plate specimens are tested with the concave side down. Each end of the plate rests in a 2-1/2 inch by 2-1/2 inch by 1/4 inch channel to which is attached a 1 inch round bar that rests in a groove in a flat bearing plate. The grooved bearing plates at each end of the specimens are supported by three 1 inch rollers which in turn rest on smooth flat plates. These latter plates are supported at proper testing height by concrete block columns. This method of end support allows complete freedom of rotation and longitudinal movement of the ends of the curved beam specimens during test.

The load is applied to the specimen through a dynamometer ring which controls and measures the load intensity and a specially constructed loading head. A wooden bearing block is custom fitted to the corrugations on each type of specimen. A rubber insert between wooden bearing head and specimen is provided to insure uniform distribution of the load. A rigid steel loading head is placed between the dynamometer ring and wood bearing block to distribute the load on the wood block.

Two .001 dial indicators are attached to machine frame on either side of hydraulic work head to measure vertical deflections. Horizontal movement of the specimen ends is measured directly to 1/64 inches by a steel rule.

Loads are applied in increments of 1000 pounds. At each increment of load the deflections and span are measured.

Column Tests: The loading equipment to be used for the Long column tests (No. 1, 3, and 4) is now under construction. Therefore, the test

procedure cannot be described at this time.

Progress of the Investigation

At the present writing, load-deflection tests on all of the beam specimens, plain and with single bolted joints, have been completed. Also load-deflection tests have been completed on the 24 inch jointed specimens in the 7, 10, and 12 gage sections only. Tests on the one gage 24 inch jointed specimens must wait until equipment with greater load capacity is available.

Work is in progress on the construction of more adequate testing equipment to complete the laboratory testing work. Data from the tests completed remain to be plotted and analyzed. Tentatively it appears that all laboratory work can be completed by January 1, 1950. There are presented in Figures 3 through 16, inclusively, typical examples of how these specimens appear at failure.

General Remarks

Results of tests to date have revealed several significant things which may be mentioned at this time.

1. There seems to be a point in gage thickness which may decide whether or not a structure should be single or double bolted to develop the full strength of the plate.
2. Tightness of the bolts, especially in case of heavy gage plates will influence to a considerable extent the friction factor in joint performance. (See Figure 17)
3. Single bolted specimens in beam tests do not develop the strength of unbolted specimens. (See Figure 18)
4. All other factors equal, the shape and depth of the corrugations have a decided influence upon the ultimate strength of the

specimens. (See Figure 19)

5. Relationships between gage of plate and ultimate strength will be obtained for design purposes. (See Figure 20)

TABLE I.
SUMMARY OF TEST SPECIMENS
IN MULTI-PLATE INVESTIGATION

Fabricator	Speci.	12 GAGE												7 GAGE													
		#1 Column		#2 Column		#3 Column		#4 Column		#5 Beam		#6 Beam		#1 Column		#2 Column		#3 Column		#4 Column		#5 Beam		#6 Beam			
		52 ³ / ₄ "str. unbolting	24"str. bolted	52 ³ / ₄ "-150"rad. bolted	52 ³ / ₄ "-150"rad. unbolting	52 ³ / ₄ "-30"rad. bolted	52 ³ / ₄ "-30"rad. unbolting	52 ³ / ₄ "-150"rad. bolted	52 ³ / ₄ "-150"rad. unbolting	52 ³ / ₄ "-50"rad. bolted	52 ³ / ₄ "-50"rad. unbolting	52 ³ / ₄ "str. unbolting	24"str. bolted	52 ³ / ₄ "-150"rad. bolted	52 ³ / ₄ "-150"rad. unbolting	52 ³ / ₄ "-30"rad. bolted	52 ³ / ₄ "-30"rad. unbolting	52 ³ / ₄ "-150"rad. bolted	52 ³ / ₄ "-150"rad. unbolting	52 ³ / ₄ "-50"rad. bolted	52 ³ / ₄ "-50"rad. unbolting						
		P	S	S	P	S	P	S	P	S	P	S	P			S	P	S	P	S	P	S	P				
Republic Steel R	X	R1X12P	R2X12S	R3X12S	R3X12P	R4X12S	R4X12P	R5X12S	R5X12P	R6X12S	R6X12P	R1X7P	R2X7S	R3X7S	R3X7P	R4X7S	R4X7P	R5X7S	R5X7P	R6X7S	R6X7P						
	Y	R1Y12P	R2Y12S	R3Y12S	R3Y12P	R4Y12S	R4Y12P	R5Y12S	R5Y12P	R6Y12S	R6Y12P	R1Y7P	R2Y7S	R3Y7S	R3Y7P	R4Y7S	R4Y7P	R5Y7S	R5Y7P	R6Y7S	R6Y7P						
	Z	R1Z12P	R2Z12S	R3Z12S	R3Z12P	R4Z12S	R4Z12P	R5Z12S	R5Z12P	R6Z12S	R6Z12P	R1Z7P	R2Z7S	R3Z7S	R3Z7P	R4Z7S	R4Z7P	R5Z7S	R5Z7P	R6Z7S	R6Z7P						
Armco Steel A	X	A1X12P	A2X12S	A3X12S	A3X12P	A4X12S	A4X12P	A5X12S	A5X12P	A6X12S	A6X12P	A1X7P	A2X7S	A3X7S	A3X7P	A5X7S	A4X7P	A5X7S	A5X7P	A6X7S	A6X7P						
	Y	A1Y12P	A2Y12S	A3Y12S	A3Y12P	A4Y12S	A4Y12P	A5Y12S	A5Y12P	A6Y12S	A6Y12P	A1Y7P	A2Y7S	A3Y7S	A3Y7P	A5Y7S	A4Y7P	A5Y7S	A5Y7P	A6Y7S	A6Y7P						
	Z	A1Z12P	A2Z12S	A3Z12S	A3Z12P	A4Z12S	A4Z12P	A5Z12S	A5Z12P	A6Z12S	A6Z12P	A1Z7P	A2Z7S	A3Z7S	A3Z7P	A5Z7S	A4Z7P	A5Z7S	A5Z7P	A6Z7S	A6Z7P						
United Steel U	X	U1X12P	U2X12S	U3X12S	U3X12P	U4X12S	U4X12P	U5X12S	U5X12P	U6X12S	U6X12P	U1X7P	U2X7S	U3X7S	U3X7P	U4X7S	U4X7P	U5X7S	U5X7P	U6X7S	U6X7P						
	Y	U1Y12P	U2Y12S	U3Y12S	U3Y12P	U4Y12S	U4Y12P	U5Y12S	U5Y12P	U6Y12S	U6Y12P	U1Y7P	U2Y7S	U3Y7S	U3Y7P	U4Y7S	U4Y7P	U5Y7S	U5Y7P	U6Y7S	U6Y7P						
	Z	U1Z12P	U2Z12S	U3Z12S	U3Z12P	U4Z12S	U4Z12P	U5Z12S	U5Z12P	U6Z12S	U6Z12P	U1Z7P	U2Z7S	U3Z7S	U3Z7P	U4Z7S	U4Z7P	U5Z7S	U5Z7P	U6Z7S	U6Z7P						
Republic				1 GAGE																							
	X	R1X1P	R2X1S	R3X1S	R3X1P	R4X1S	R4X1P	R5X1S	R5X1P	R6X1S	R6X1P		R2X10S								R5X10P						
	Y	R1Y1P	R2Y1S	R3Y1S	R3Y1P	R4Y1S	R4Y1P	R5Y1S	R5Y1P	R6Y1S	R6Y1P		R2Y10S								R5Y10P						
Armco	X	A1X1P	A2X1S	A3X1S	A3X1P	A4X1S	A4X1P	A5X1S	A5X1P	A6X1S	A6X1P										A5X10S	A5X10P	A6X10S	A6X10P			
	Y	A1Y1P	A2Y1S	A3Y1S	A3Y1P	A4Y1S	A4Y1P	A5Y1S	A5Y1P	A6Y1S	A6Y1P											A5Y10S	A5Y10P	A6Y10S	A6Y10P		
	Z	A1Z1P	A2Z1S	A3Z1S	A3Z1P	A4Z1S	A4Z1P	A5Z1S	A5Z1P	A6Z1S	A6Z1P											A5Z10S	A5Z10P	A6Z10S	A6Z10P		
United	X	U1X1P	U2X1S	U3X1S	U3X1P	U4X1S	U4X1P	U5X1S	U5X1P	U6X1S	U6X1P											U5X10S	U5X10P	U6X10S	U6X10P		
	Y	U1Y1P	U2Y1S	U3Y1S	U3Y1P	U4Y1S	U4Y1P	U5Y1S	U5Y1P	U6Y1S	U6Y1P												U5Y10S	U5Y10P	U6Y10S	U6Y10P	
	Z	U1Z1P	U2Z1S	U3Z1S	U3Z1P	U4Z1S	U4Z1P	U5Z1S	U5Z1P	U6Z1S	U6Z1P												U5Z10S	U5Z10P	U6Z10S	U6Z10P	
Republic				1 GAGE																							
	X	R1X1P	R2X1S	R3X1S	R3X1P	R4X1S	R4X1P	R5X1S	R5X1P	R6X1S	R6X1P		R2X10S									R5X10P					
	Y	R1Y1P	R2Y1S	R3Y1S	R3Y1P	R4Y1S	R4Y1P	R5Y1S	R5Y1P	R6Y1S	R6Y1P		R2Y10S									R5Y10P					
Armco	X	A1X1P	A2X1S	A3X1S	A3X1P	A4X1S	A4X1P	A5X1S	A5X1P	A6X1S	A6X1P											A5X10S	A5X10P	A6X10S	A6X10P		
	Y	A1Y1P	A2Y1S	A3Y1S	A3Y1P	A4Y1S	A4Y1P	A5Y1S	A5Y1P	A6Y1S	A6Y1P												A5Y10S	A5Y10P	A6Y10S	A6Y10P	
	Z	A1Z1P	A2Z1S	A3Z1S	A3Z1P	A4Z1S	A4Z1P	A5Z1S	A5Z1P	A6Z1S	A6Z1P												A5Z10S	A5Z10P	A6Z10S	A6Z10P	
United	X	U1X1P	U2X1S	U3X1S	U3X1P	U4X1S	U4X1P	U5X1S	U5X1P	U6X1S	U6X1P												U5X10S	U5X10P	U6X10S	U6X10P	
	Y	U1Y1P	U2Y1S	U3Y1S	U3Y1P	U4Y1S	U4Y1P	U5Y1S	U5Y1P	U6Y1S	U6Y1P													U5Y10S	U5Y10P	U6Y10S	U6Y10P
	Z	U1Z1P	U2Z1S	U3Z1S	U3Z1P	U4Z1S	U4Z1P	U5Z1S	U5Z1P	U6Z1S	U6Z1P													U5Z10S	U5Z10P	U6Z10S	U6Z10P

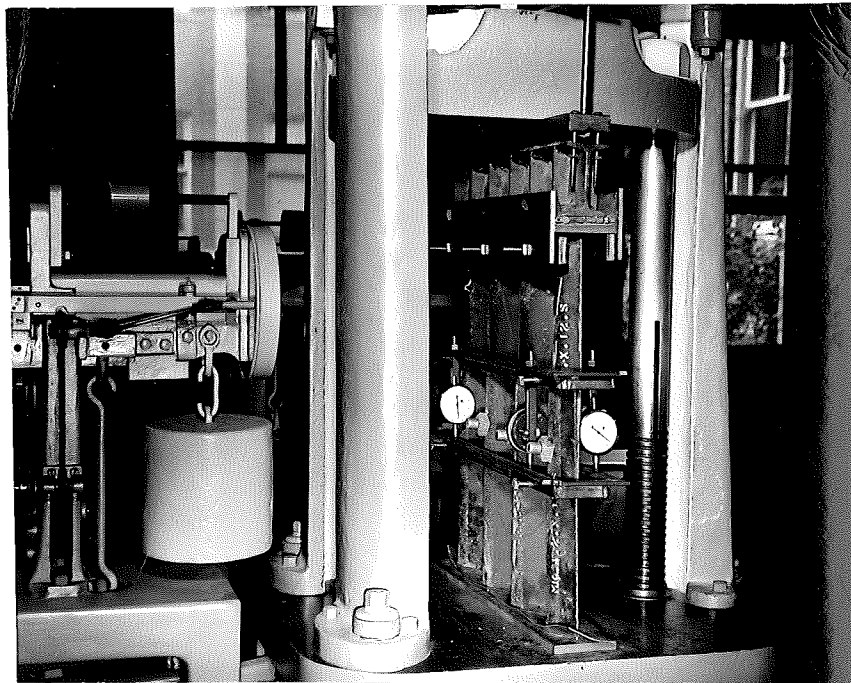


Figure 1. View of 24 inch column section mounted for test in Olsen Universal Testing Machine.

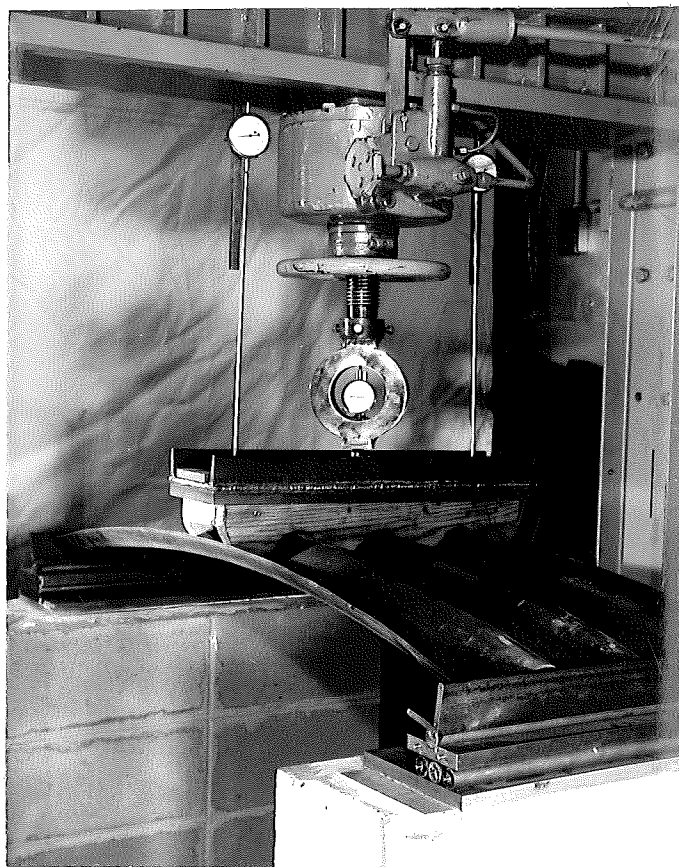


Figure 2. Method of Loading Beam Specimens

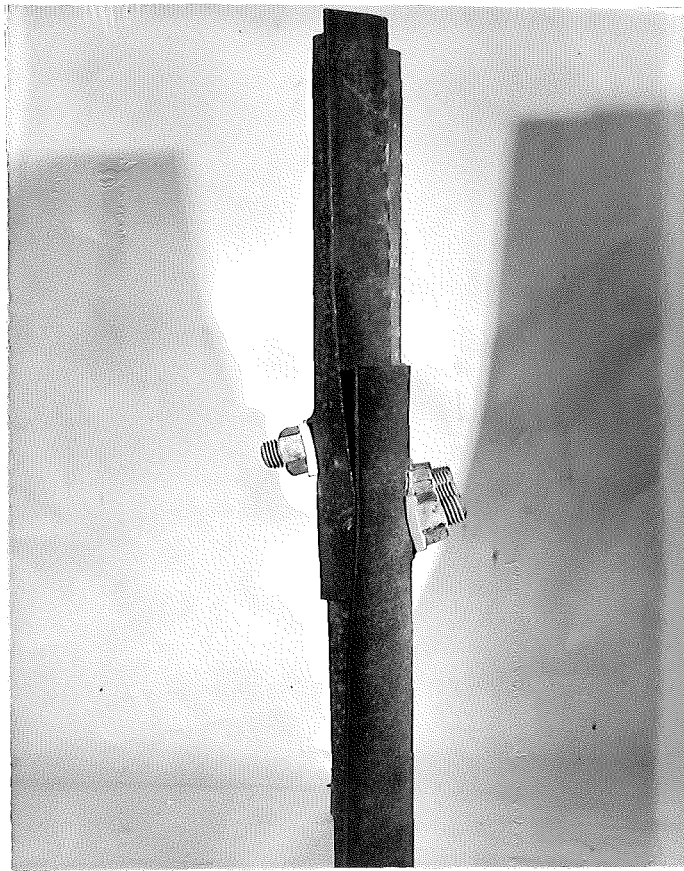


Figure 3. Typical failure of 24 inch bolted specimens.

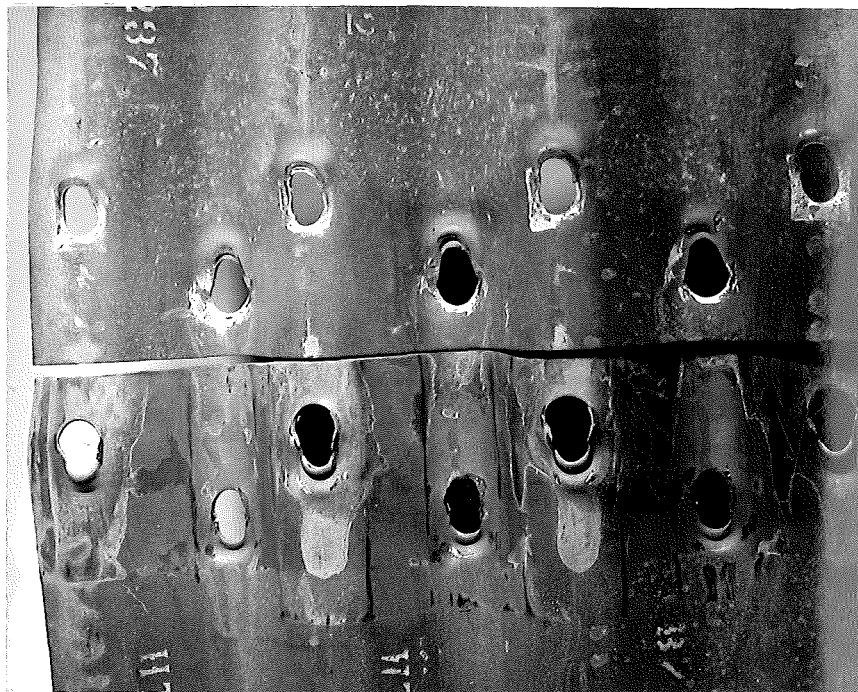


Figure 4. Typical condition of bolt holes showing failure of plate around holes, same specimen as shown in Figure 3.

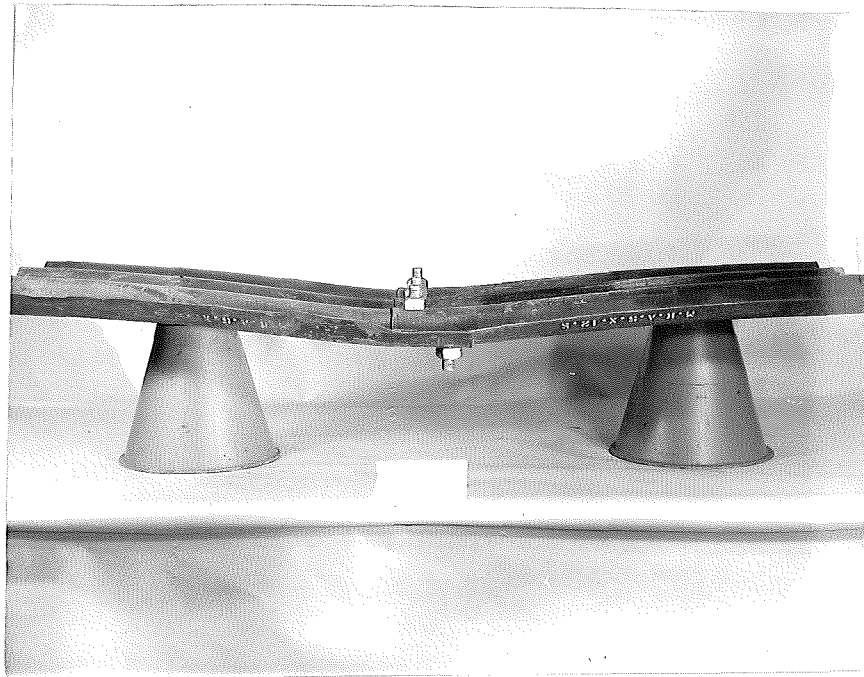


Figure 5. Typical failure of bolted beam specimens, 150 inch radius, 12 gage.



Figure 6. Showing condition of plate at bolt holes. Half of specimen illustrated in Figure 5.

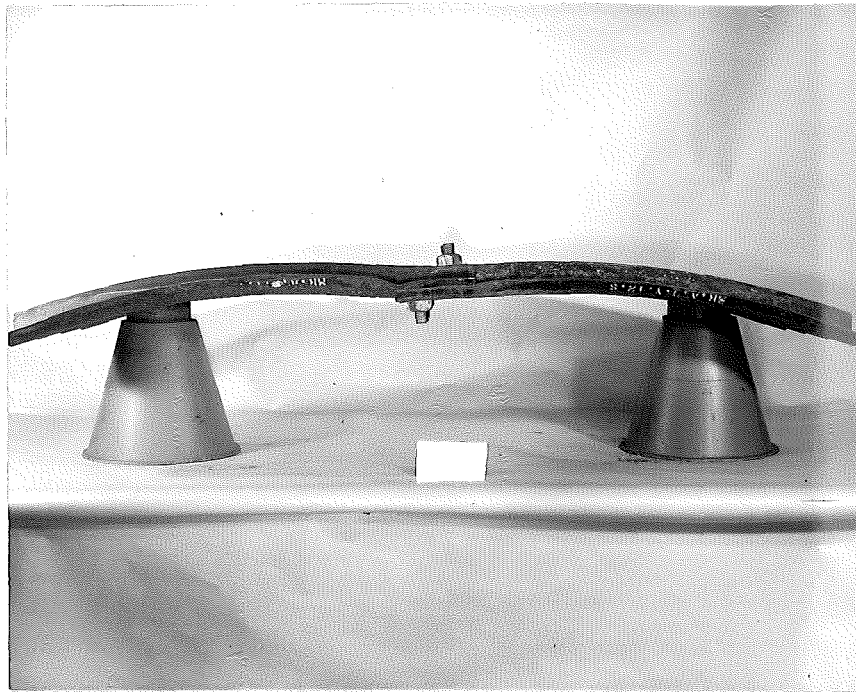


Figure 7. Typical failure bolted beam specimens, 50 inch radius, 12 gage.

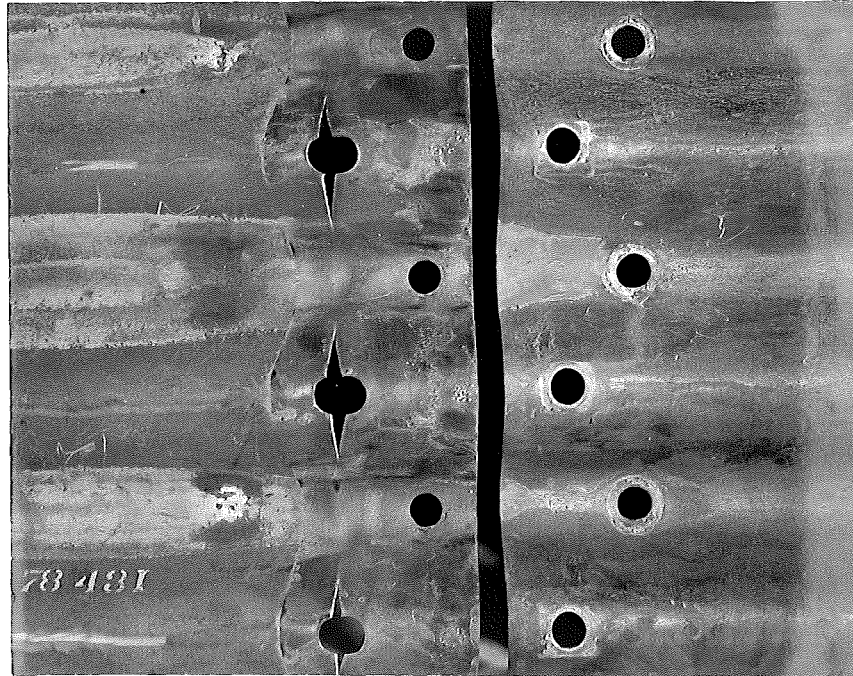


Figure 8. Same as Figure 7, note tearing of plate at bolt holes.



Figure 9. Typical failure of plain beam specimen, 150 inch radius, 7 gage.



Figure 10. Typical failure of plain beam specimen, 50 inch radius, 7 gage.

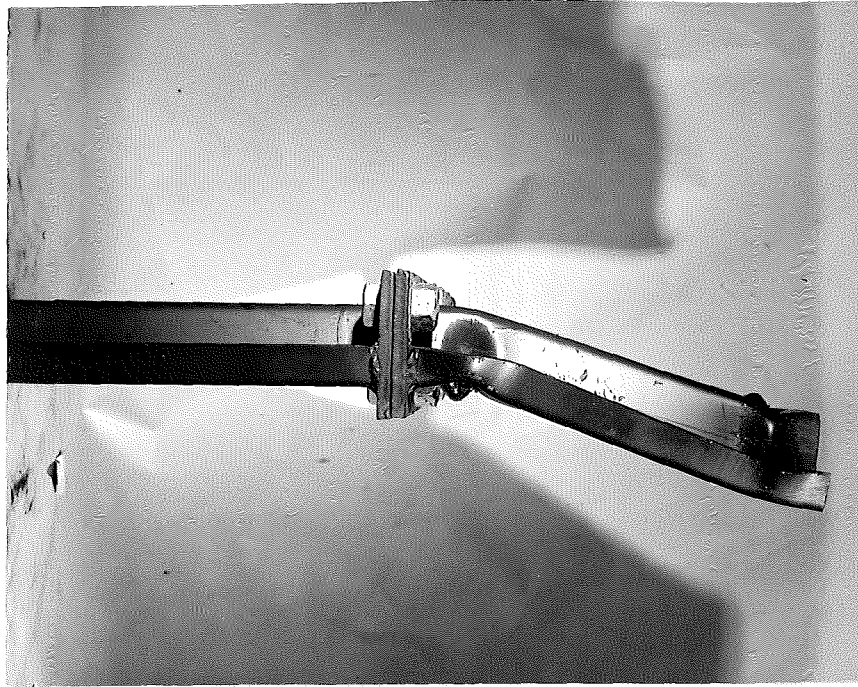


Figure 11. Typical failure of short column specimen, "box type", 12 gage.

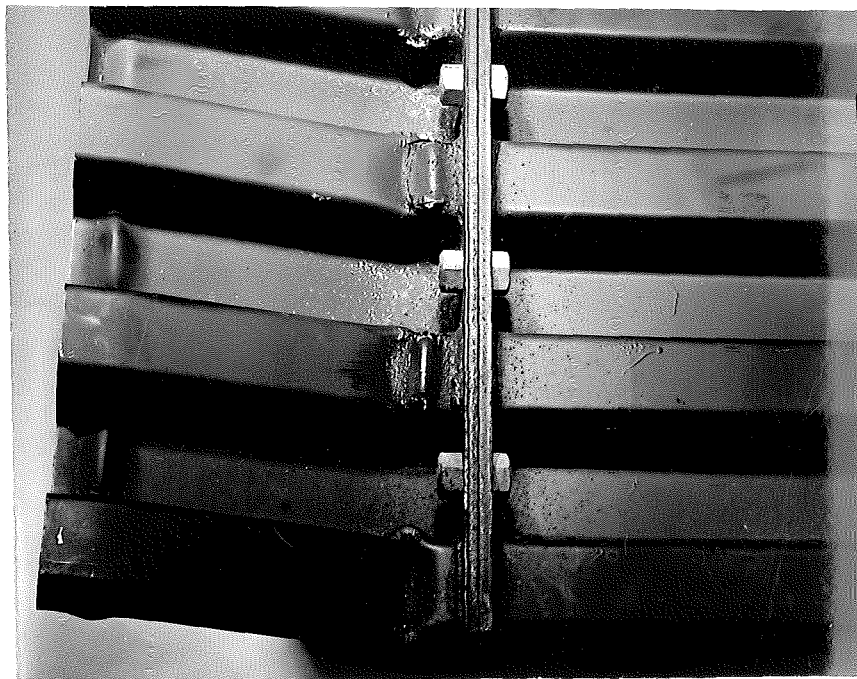


Figure 12. Front view of same specimen as in Figure 11.

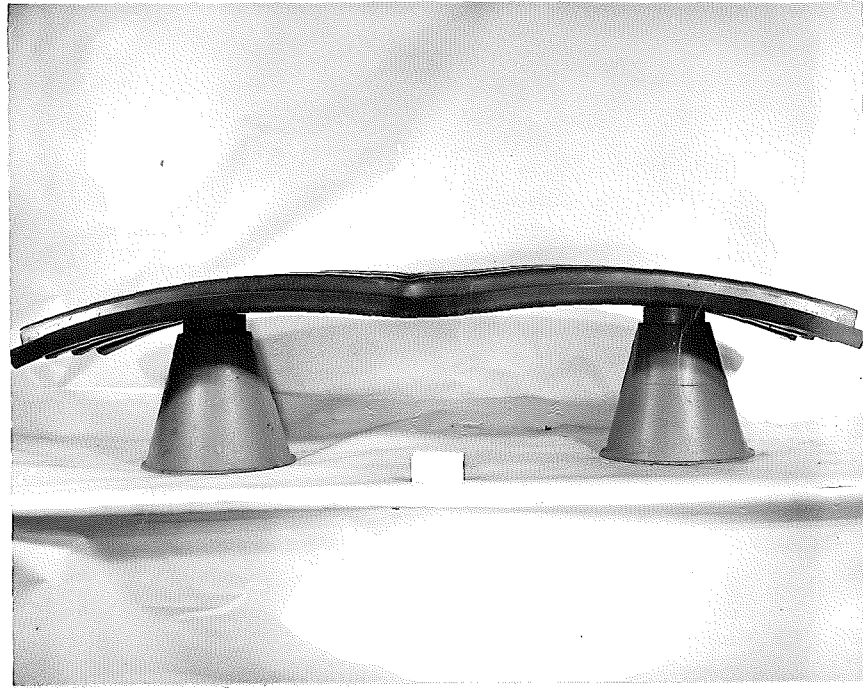


Figure 13. "Box type" specimen at failure, 7 gage, 50 inch radius.

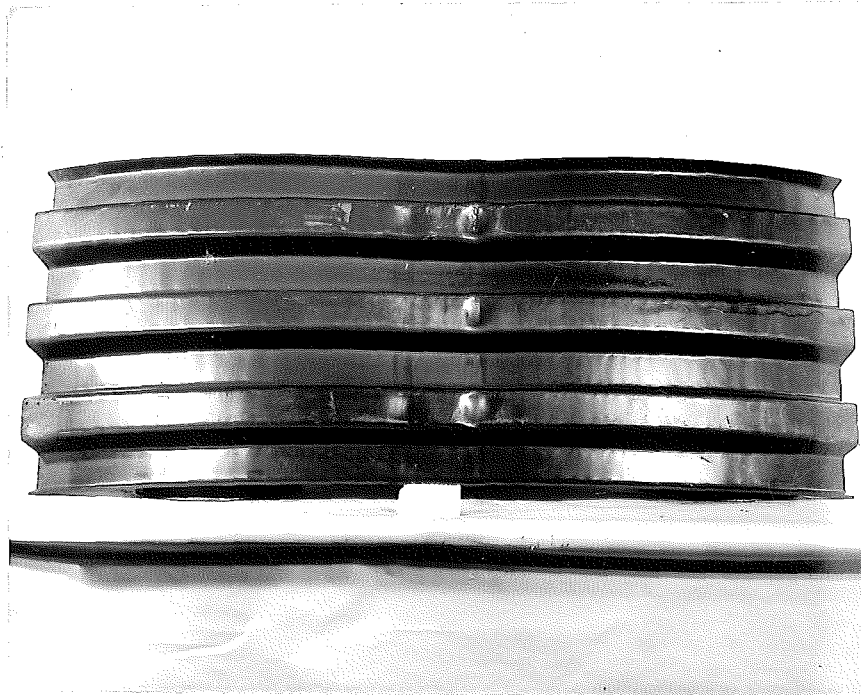


Figure 14. Top view of specimen in Figure 13 showing buckling of ribs under compression.

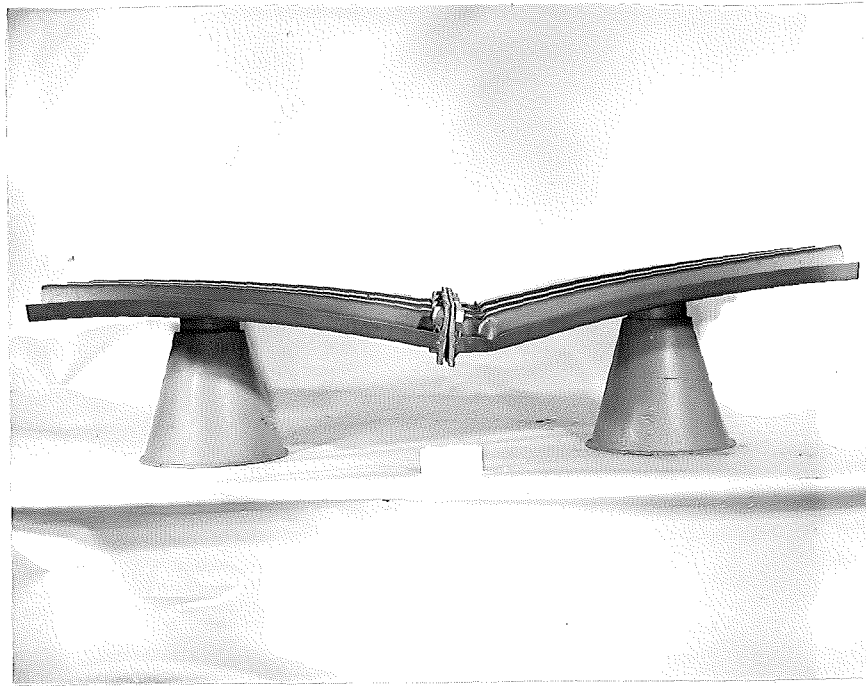


Figure 15. Bolted "box type" section in failure, 12 gage, radius 150 inches.

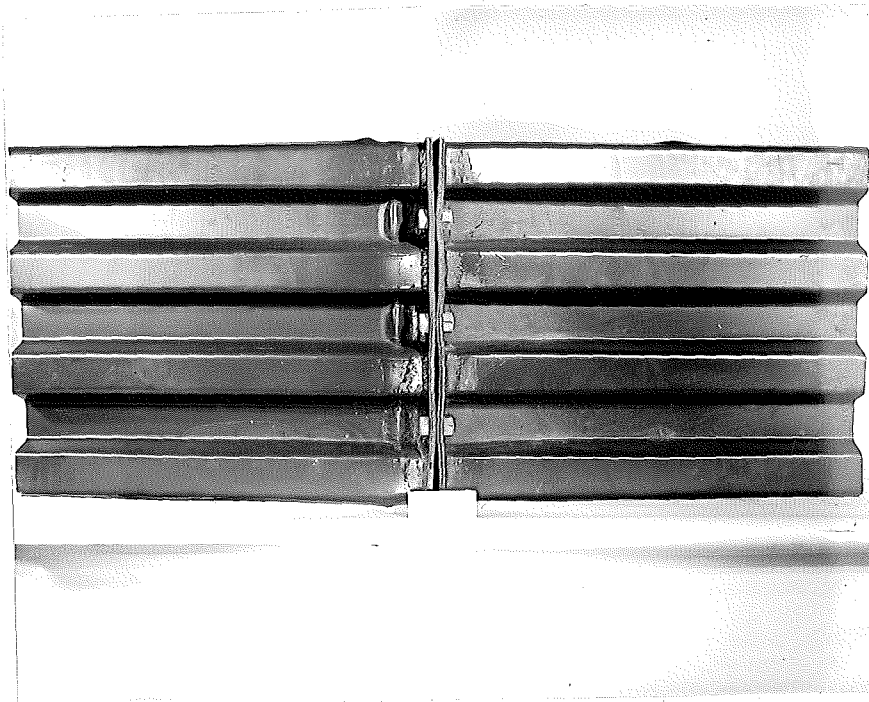


Figure 16. Bottom view of specimen in Figure 15, showing bending of joint plates between bolts.