

1958

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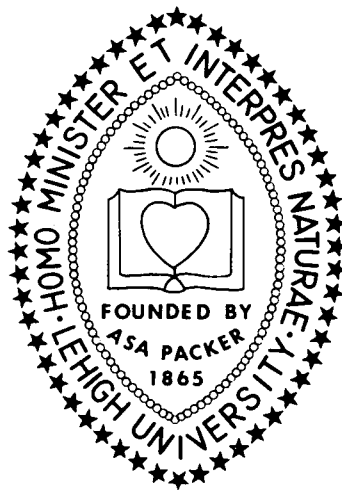
Fritz Lab, "Structural steel research, Fritz Engineering Laboratory, 1958" (1958). *Fritz Laboratory Reports*. Paper 1600.  
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# STRUCTURAL STEEL RESEARCH

FRITZ ENGINEERING LABORATORY

Lehigh  
University



PROJECTS OF THE STRUCTURAL METALS DIVISION

PROJECT NO.	TITLE	RESEARCH PERSONNEL
205	WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS (PLASTIC DESIGN)	L.S. Beedle B. Thurlimann G.C. Driscoll
205A	COLUMNS IN CONTINUOUS FRAMES	T.V. Galambos G.C. Lee
205C	CORNER CONNECTIONS	G.C. Driscoll G.C. Lee
205D	INDUSTRIAL FRAMES	G.C. Driscoll L.W. Lu
205E	INELASTIC INSTABILITY	B. Thurlimann
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THE FRITZ ENGINEERING LABORATORY  
AND  
STRUCTURAL STEEL RESEARCH

Since its founding in 1909 Fritz Engineering Laboratory has served industry through its research programs and its industrial testing facilities. Modernization in 1954-55 enabled the University to continue to provide the finest facilities for research in the fields of structures, materials, hydraulics, and structural model analysis. In addition, modern laboratories in soils and sanitation are provided. Professor Wm. J. Eney is director of the laboratory and head of the Department of Civil Engineering of which it is a part.

The laboratory facilities are housed in two large structures directly connected with one another, to which heavy equipment may be delivered by truck. Testing machines and other facilities provide the means whereby the largest structures may be tested statically or dynamically. A research library is maintained where current reports from laboratories throughout the world are available for study.

Through its Institute of Research, Lenigh University contracts with research councils, industrial corporations, companies, or associations to undertake cooperative research. The sponsor pays all costs plus a reasonable percentage for overhead. At least a one-year duration is expected on such projects, and publication of results in technical magazines is normally anticipated.

Except for interruption due to World War II, continuous metals research programs have been underway since 1931, predominantly in structural steel.

Among the sponsors of these fundamental investigations have been Welding Research Council, American Institute of Steel Construction, American Iron and Steel Institute, Column Research Council, Association of Iron and Steel Engineers, Research Corporation, Association of American Railroads, consulting engineers and various state and federal governmental agencies.

Investigations have ranged from studies of material properties and characteristics up to tests of full-size structures for buildings and bridges. Structural steel research programs have improved design procedures by this approach. Specifications of the AISE, AISC and AREA have been revised as a direct result of research projects.

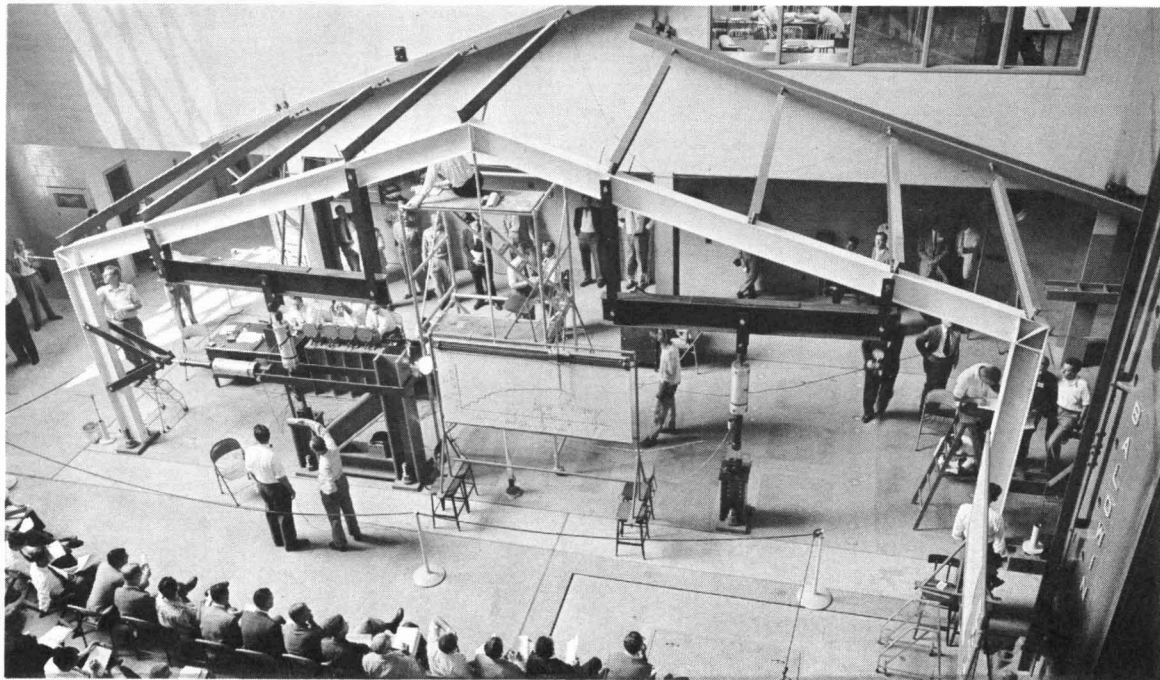
In the following pages are described current research projects and a few of those which have recently been completed. Not only are they providing a better understanding of structural behavior, but they are supplying the engineer with simpler design techniques and the consumer with more economical steel structures.

Project 205: WELDED CONTINUOUS FRAMES AND  
THEIR COMPONENTS (PLASTIC DESIGN)

Sponsors: American Institute of Steel Construction  
American Iron and Steel Institute  
Navy Department (Bureau of Ships, Bureau of Yards  
and Docks, Office of Naval Research)  
Welding Research Council

The general objectives of this research are to develop methods for predicting the ultimate load-carrying capacity of continuous steel structures and to develop practical design procedures for utilizing the reserve plastic strength. Such procedures must take into account such additional factors as fatigue, deflections, brittle fracture, local buckling, lateral buckling, etc., and this is being done on the project.

Results to date have shown that the plastic theory may be applied to the design of continuous beams and single-story industrial frames. Manuals and commentaries have been prepared to assist the designer of these structures. Research has also shown that the plastic theory shows promise for application to the design of other classes of structures, such as multi-story buildings and component parts of ships. Other aspects of this comprehensive program are explained in the following descriptions.



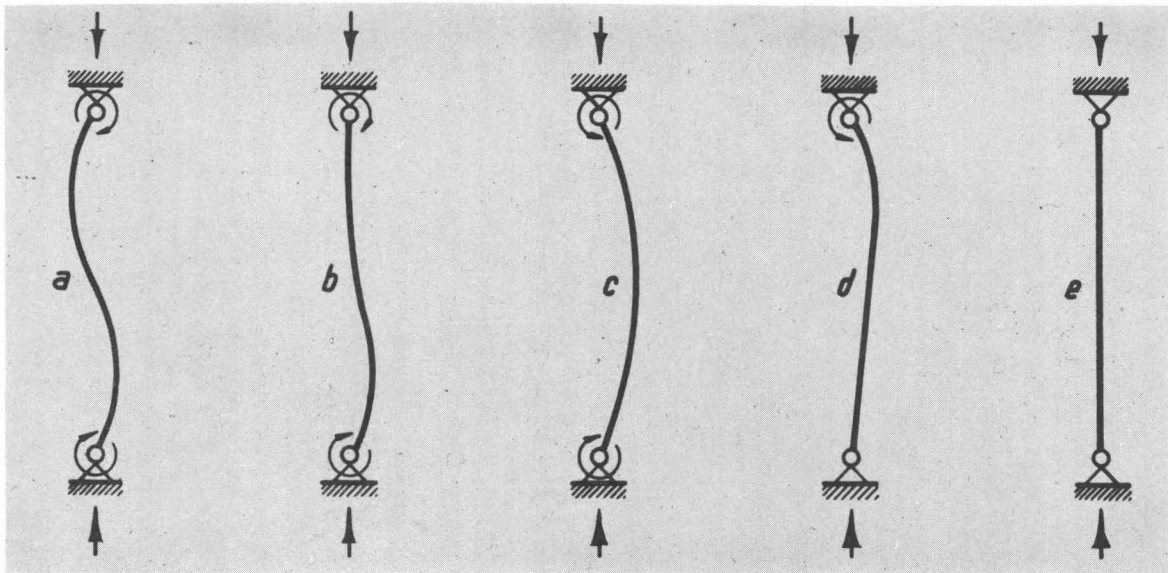
Test of full-size frame verifies plastic design theory

Project 205A: COLUMNS IN CONTINUOUS FRAMES

Sponsors: See 205

In the plastic design of steel rigid frames it is intended to utilize each member to its maximum carrying capacity. The primary purpose of the particular project on columns is to determine the maximum strength of those members in a rigid frame which are subjected to a combination of axial force and end-bending moments. The work requires an evaluation of the effect of residual stresses and the various possible combinations of end-bending moments. In addition, the influence of lateral-torsional buckling must be evaluated and the rotation capacity at column ends is being investigated.

Solutions are being obtained by analytical and experimental means. The findings are intended to provide specification writers with aid in writing rational design rules, some parts already having been incorporated in the AISC Manual on plastic design.



CONDITION OF TEST

Project 205C: CORNER CONNECTIONS

Sponsors: See 205

Connections transmit forces from one member to the next, enabling the members to share in supporting the loads placed upon the structure. Studies have been made to obtain information on how to proportion corner connections for portal frames in order that they may meet the requirements imposed by their use in plastically designed structures. Tests of square, tapered and curved corner connections have verified that they can be designed to have the proper strength, stiffness, and rotation capacity to serve their purpose.

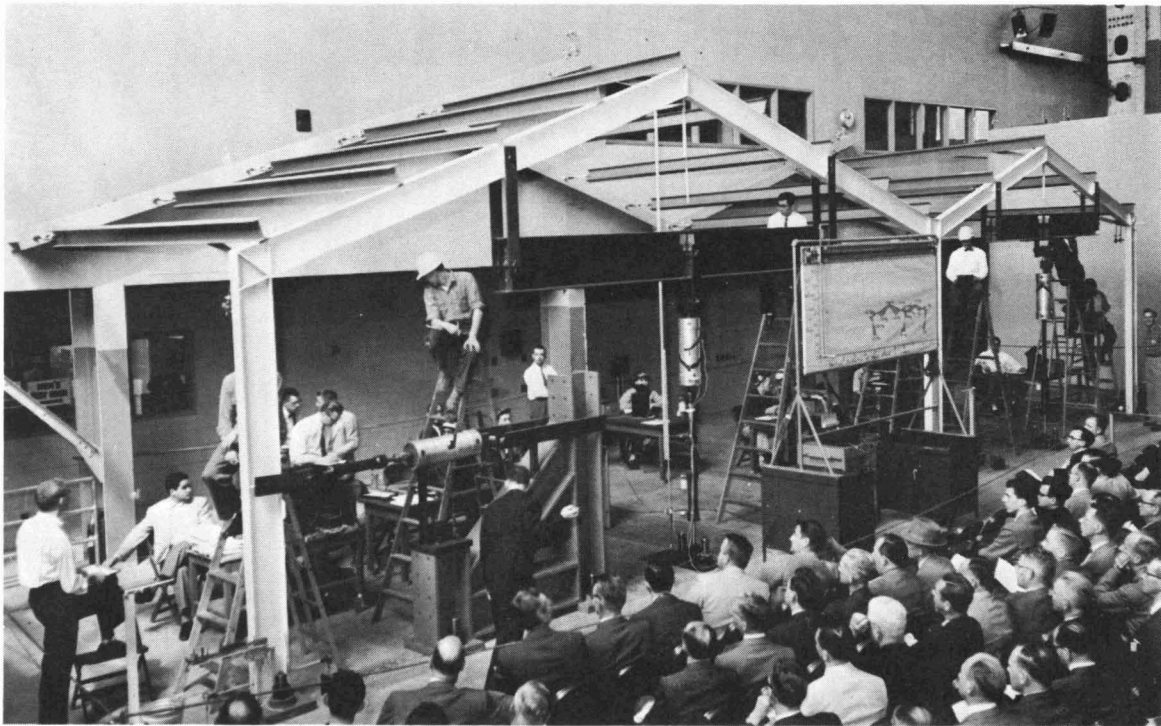


Test of a corner connection joining 30WF108 beam and column

Project 205D: INDUSTRIAL FRAMES

Sponsors: See 205

The single or multi-span portal frame is the basic structural unit of many industrial buildings. Research has shown that the strength and behavior of welded steel frames designed by plastic theory may be predicted and controlled within the necessary limits to assure their safety in everyday use. Therefore, the improvements in design methods and the economies effected by plastic design are already being put to use in the building industry.



Two-span rigid frame being tested to failure

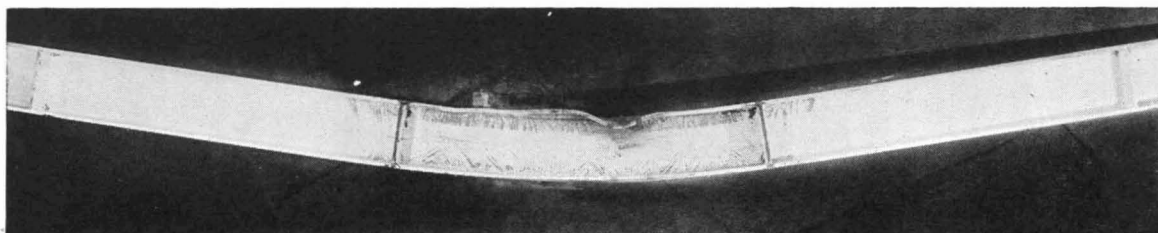
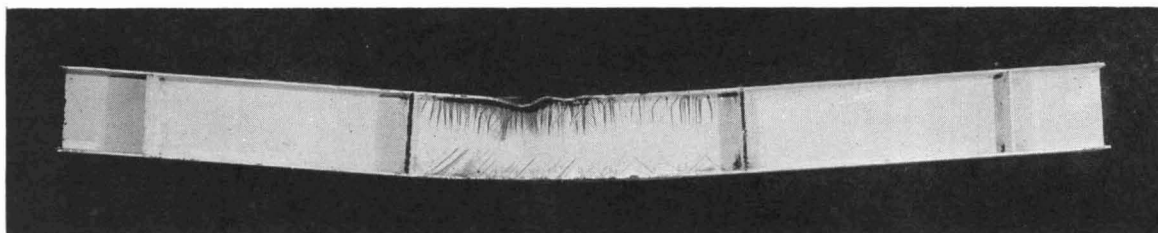
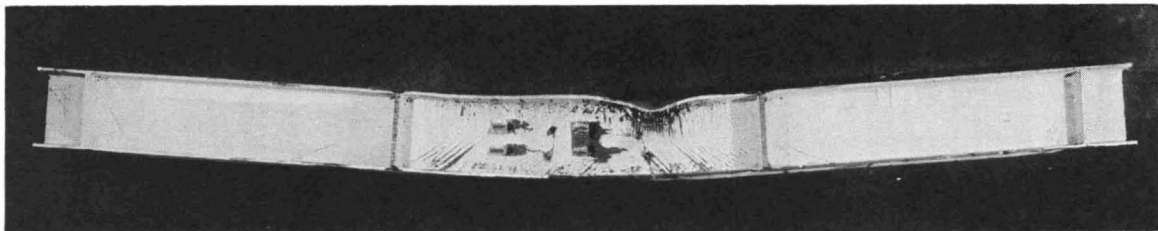


Project 205E: INELASTIC INSTABILITY

Sponsors: See 205

The problem of the local buckling of rolled wide-flange shapes in the plastic region has been solved insofar as the requirements of plastic design are concerned. Based on this work, design procedures have been set up to control the geometry of cross-section so that local failure does not prevent the formation of plastic hinges.

The lateral stability of beams subjected to given moments and deformations and having a given lateral bracing has been studied both theoretically and experimentally. Although the work is not yet completed, the results show that the required spacing of lateral bracing supports will be within practicable limits.



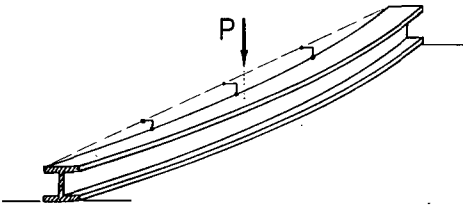
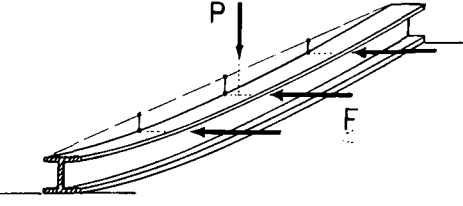
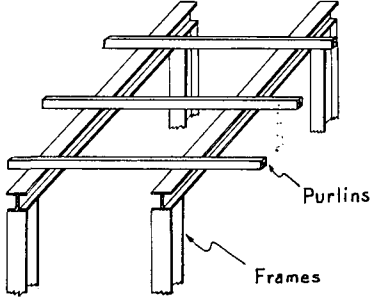
Local buckling pattern of plastically bent wide-flange beams

Project 205H: LATERAL BRACING REQUIREMENTS

Sponsors: See 205

In a plastically designed structure, a member must undergo large inelastic rotations within the region of a "plastic hinge" so that the moments may be redistributed to develop the full strength of the structure. To achieve these large rotations, provision must be made to prevent the member from failing prematurely due to lateral-torsional buckling.

The purpose of this project is to determine practical means for bracing a member so that it can fully develop its ultimate strength. It is desired to establish necessary design criteria for various types of lateral bracing under various conditions.

	<p>When the load <math>P</math> is increased to a certain amount the beam will deflect not only vertically but also will twist and start to move laterally in a direction perpendicular to that of the load.</p> <p>When the twisting angle and lateral movement become sufficiently large, the beam will not be able to carry more load. (Lateral-torsional buckling failure)</p>
	<p>How big are the lateral forces, <math>F</math>, required to hold the beam from twisting and deflecting laterally until the maximum strength of the beam can be fully utilized. (Plastic design)</p>
	<p>In building frames the problem is to select adequate purlins to provide enough restraint to the frame such that the maximum strength of the frame can be achieved.</p>

Project 248: BUILT-UP MEMBERS IN PLASTIC DESIGN

Sponsor: Navy Department (Bureau of Ships)

Built-up members are very often used in practice, especially in ship structures. Typical examples are deck girders with openings in the corners and through the webs. A Vierendeel girder presents a further typical example. The application of plastic design to such members offers some new problems. One of these is the influence of lateral pressure on the stability of stiffened panels.

Although there are considerable experimental data available on the inelastic stability of stiffened plates under axial compression, none is available when lateral pressure is also present. It is the purpose of this program to conduct an experimental investigation to show the effect of lateral pressure. The results will be analyzed and recommendations will be made for the design of ship bottom plating based on ultimate strength.

Project 268: ROTATION CAPACITY REQUIREMENTS

Sponsors: See 205

Plastic analysis of steel structures depends on the ability of the members to form "plastic hinges" and to redistribute moments. In order for redistribution of moment to take place, certain plastic hinges must sustain their plastic moment through a certain angle of rotation. The amount of rotation required may affect the geometry of the structural shapes selected and the spacing of lateral bracing.

This project consists of theoretical studies predicting how much rotation capacity is required of plastic hinges in structures. Comparison of the theoretical requirements with the experimentally determined values assures that the required rotation can take place for the structures that have been studied up to the present time.

Project 273: MULTI-STORY FRAMES

Sponsors: See 205

In applying plastic theory to the design of multi-story building frames, the basic principles involved are the same as for single-story frames. However, certain factors such as frame stability and column behavior take on additional importance in multi-story frames. Also design techniques and procedures tend to become more complicated and should be simplified.

The general objective of this project is to obtain practical methods for the analysis and design of multi-story frames.

Project 276: FRAME STABILITY

Sponsors: See 205

For simple frames, the load to cause formation of a mechanism is easily predicted by simple plastic theory. However, it is not yet known how to calculate theoretically whether or not "frame instability" will prevent a given frame from reaching the predicted maximum load. By frame instability is meant that phenomenon in which a frame unrestrained against sidesway, will buckle as a unit. The columns which buckle in this form of failure are subjected to restraints at their connections and bases and these restraints have not previously been evaluated.

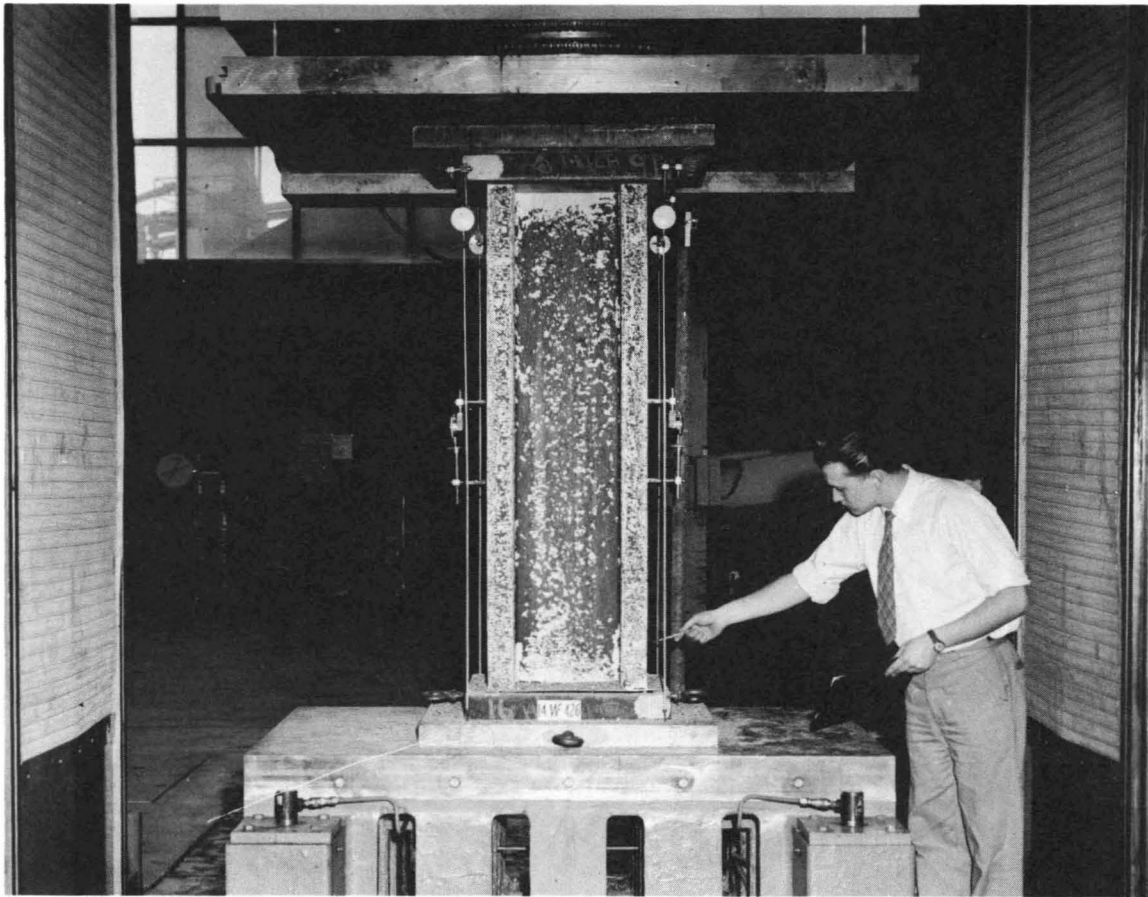
This project will attempt to determine the loading and geometry of structural frames that will resist failure by frame instability. It will also suggest methods for modifying a design to assure the needed stability.

Project 220A: RESIDUAL STRESS AND  
THE COMPRESSIVE PROPERTIES OF STEEL

Sponsors: Bureau of Public Roads  
Column Research Council  
National Science Foundation  
Pennsylvania Department of Highways

This program of research is aimed at answering fundamental questions about the behavior of steel columns. These are problems that have been of concern to designers and to specification-writing bodies ever since the advent of rolled and welded steel sections. When the research is completed, the design of steel columns will be based on a much more complete knowledge of their behavior, assuring safety with maximum possible economy.

The results have already been used in the writing of the Column Research Council Specification Guide. Thus, they will become available to every designer of bridges, buildings and other structures.



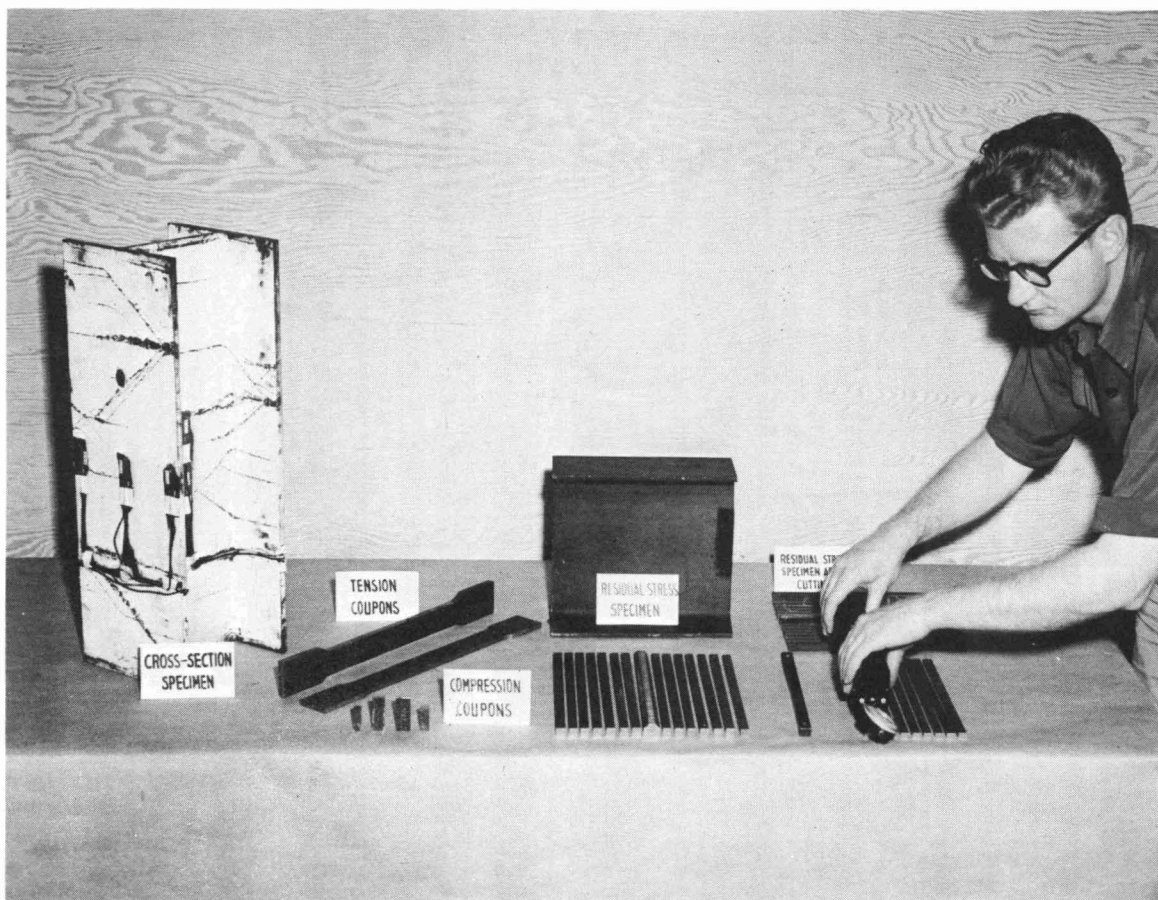
Stub column test of heaviest rolled section manufactured (14WF426)

Project 249: WELDED BUILT-UP COLUMNS

Sponsors: See 220A

When columns are built up from separate plates by welding, they will not necessarily have the same strength as a similar rolled column. After a plate is welded, and allowed to cool, there will remain in the plate residual stresses which are due to the uneven cooling. Because of these stresses, certain portions of the cross section of a column have a decreased capacity for load, whereas other portions have an increased capacity. The residual stresses and their distribution in the cross section play a very important part in the strength of the column.

The position of the weld relative to the plates can either increase or decrease the effect of the residual stresses. It is the purpose of this project to show how plates should be welded together to produce a column with the maximum possible strength.



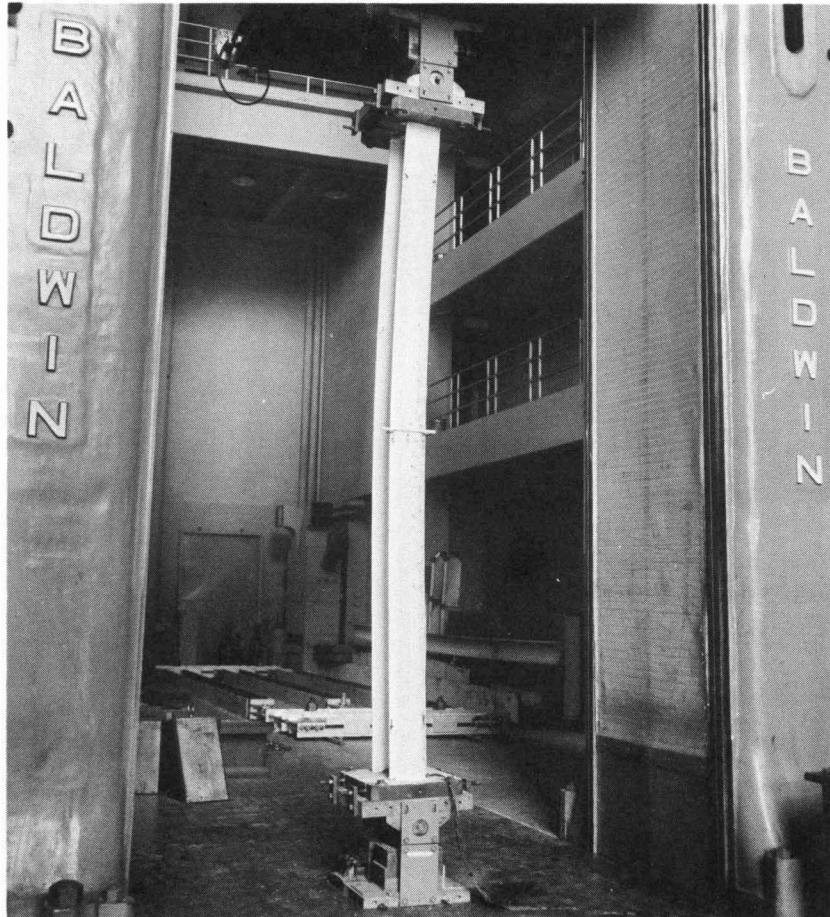
Sequence of tests for measurement of residual stresses and material properties

Project 269: COMPRESSIVE PROPERTIES  
OF LOW-ALLOY STEELS

Sponsors: See 220A

In the drive for economy, the strength of structural members should be exploited to the highest possible degree. This means that all of the influencing factors must be well known in order to assure the needed safety. One factor which only recently has come into the picture is the influence of stresses present in the unloaded member. These "locked-in" or residual stresses originate from temperature differences during the cooling process after rolling. They have been shown to influence the carrying capacity of mild steel columns. Theory predicts that in the low-alloy steels (yield point about 55 ksi) the residual stresses have relatively less influence than in ordinary structural steel (yield 33 ksi).

This project is intended to check these predictions. The positive results obtained so far suggest this additional advantage of using high-strength steel.



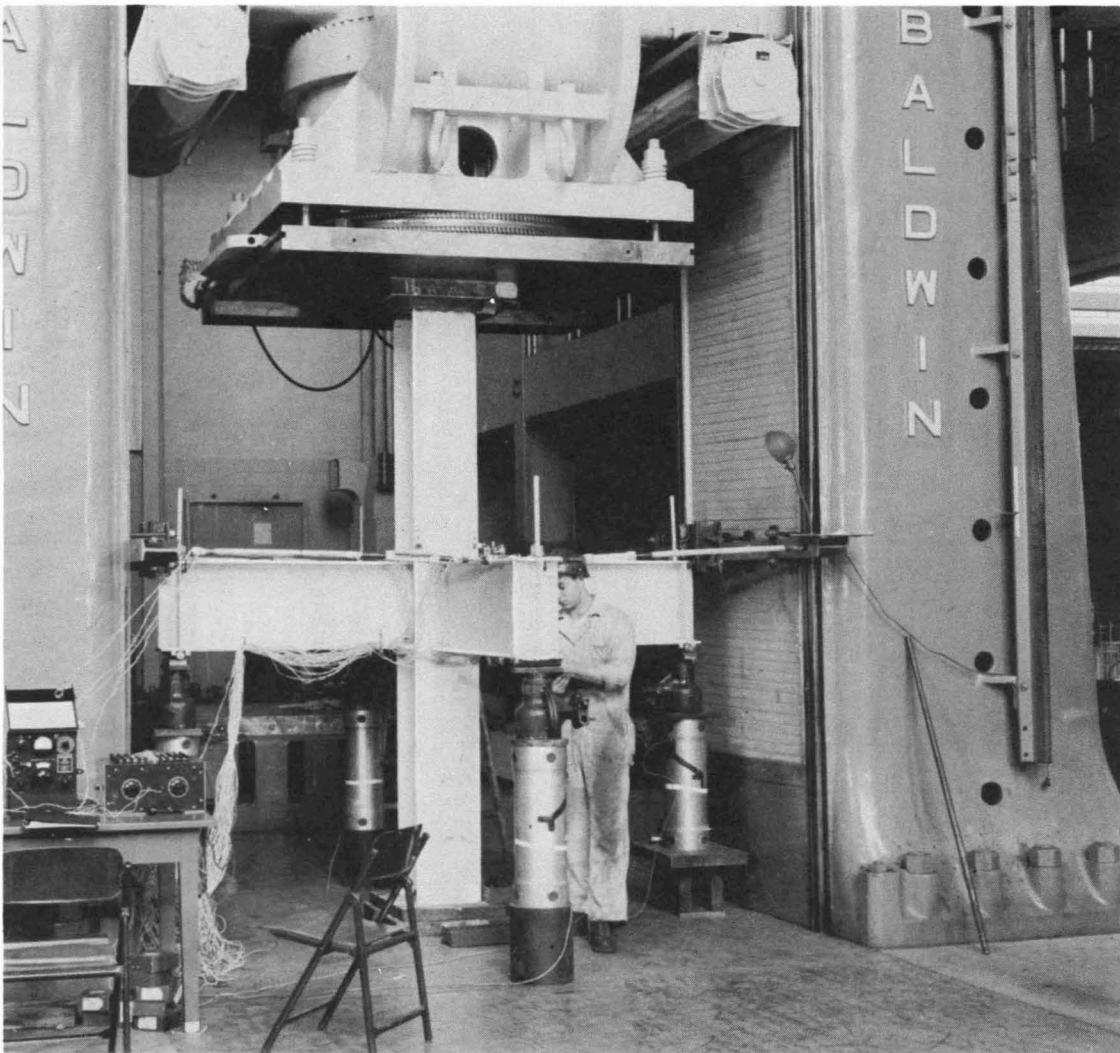
Low-alloy steel column after test

Project 233: WELDED INTERIOR BEAM COLUMN CONNECTIONS

Sponsor: American Institute of Steel Construction

This program of research is aimed at determining the stiffening requirements of columns at the beam connection in tier buildings. For relatively large columns, no stiffening is needed, and for other sizes, the project is furnishing information that will tell the designer the dimensions and locations of any needed stiffening. Further, the project is supplying means for evaluating the degree of restraint and reserve strength of the designed assembly.

The purpose of this project is to investigate these items with a view to making connection design more uniform and economical.



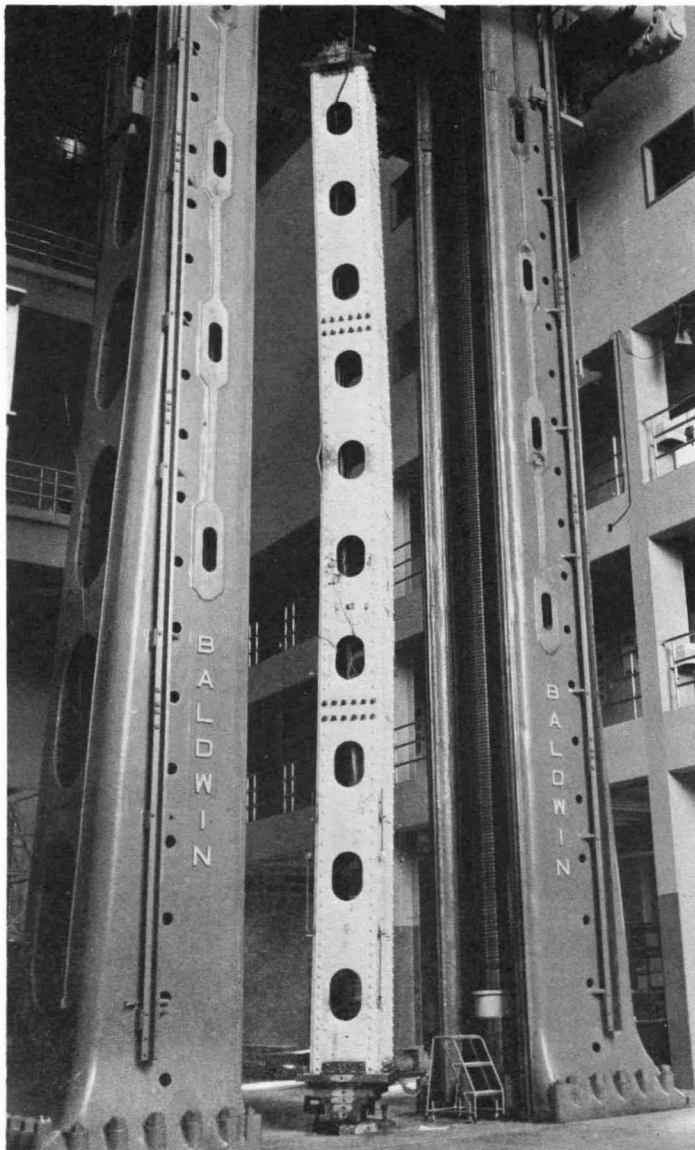
Four-way beam-column connection test in 5-million-pound machine



Project 244: COLUMNS WITH PERFORATED COVER PLATES

Sponsors: Association of American Railroads  
Mississippi River Bridge Authority  
Modjeski and Masters, Consulting Engineers

The investigation covered an analytical study of the strength of columns having perforated cover plates in place of lacing system or batten plates. Detailed recommendations for the design of such members were derived. Tests on full size columns were conducted principally:



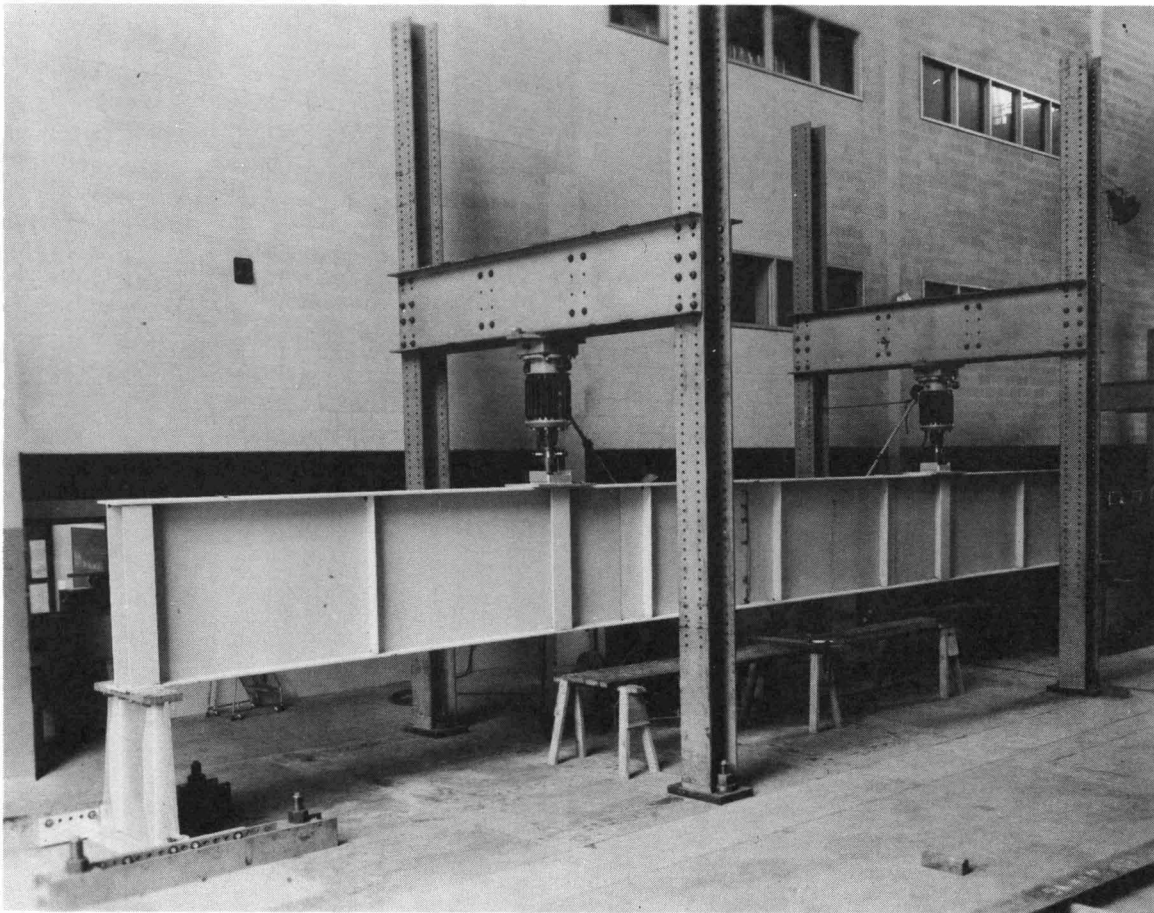
- (1) To determine and compare the ultimate carrying capacity of columns with perforated cover plates fabricated from two steels having different yield point
- (2) To substantiate experimentally present-day design practice of such members
- (3) To make an experimental check on certain features of the analytical study.

Perforated cover-plated column 38' long. Maximum load 2,808,000 lbs.

Project 251: WELDED PLATE GIRDERS

Sponsors: American Institute of Steel Construction  
American Railway Engineering Association  
Bureau of Public Roads  
Pennsylvania Department of Highways  
Welding Research Council

Present design practice for plate girders is based on a theory that is inadequate in two respects. First, actual girders do not fail by the sudden buckling as indicated by this theory. Secondly, the load-carrying capacity may be considerably higher than that predicted. It is the purpose of this experimental and theoretical investigation to study the stability and load-carrying capacity of welded plate girders under static load. The findings will be used to formulate more progressive design rules leading to more efficient and economical girders.



45-ft span girder ready for testing

Project 264: INFLUENCE SURFACES FOR  
BRIDGE SLABS

Sponsor: National Science Foundation

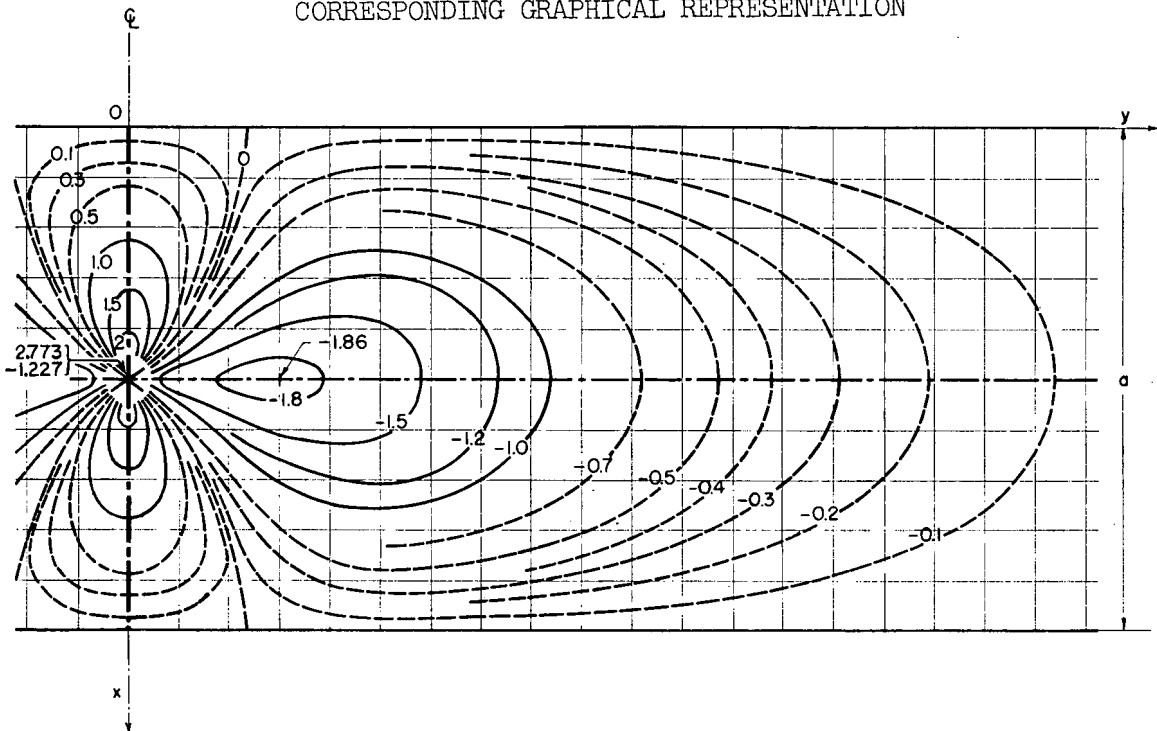
Refinements in the analysis of bridge decks have not kept pace with other and more advanced structural analysis, primarily due to the mathematical complexity of the problem. The investigation aims to derive the mathematical expressions for the analysis of such slabs and explore their solution by means of electronic computers.

Special consideration is given to the analysis of a new type of steel deck consisting of a deck plate and longitudinal and transverse stiffeners (orthotropic steel deck). Such a deck offers the double advantage of cutting the weight of the deck to about two-thirds and acting as an integral part of the bridge.

TYPICAL ANALYTICAL SOLUTION FOR CONTINUOUS PLATE

$$m_y \left( \frac{\pi}{2}, 0 \right) = \frac{1}{8\pi} \left[ (1+\nu) \left\{ [1 - (\eta - 1) e^\eta \sin \xi] \log (\cosh \eta + \sin \xi) \right. \right. \\ - [1 + (\eta - 1) e^\eta \sin \xi] \log (\cosh \eta - \sin \xi) - 2 (\eta - 1) e^\eta (\log 2 - \eta) \sin \xi \\ \left. \left. + 2 (\eta - 1) e^\eta \cos \xi \left[ \tan^{-1} \left( \frac{\cos \xi}{e^\eta - \sin \xi} \right) - \tan^{-1} \left( \frac{\cos \xi}{e^\eta + \sin \xi} \right) \right] \right\} \right. \\ \left. - 2 \eta \sinh \eta \left( \frac{1}{\cosh \eta - \sin \xi} - \frac{1}{\cosh \eta + \sin \xi} \right) \right]$$

CORRESPONDING GRAPHICAL REPRESENTATION

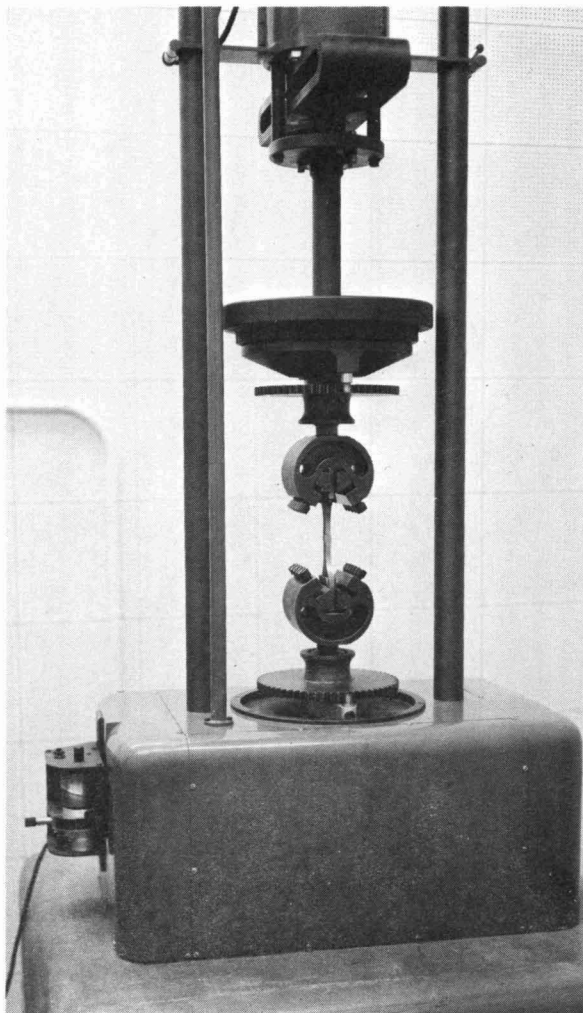


Project 265: ACCELERATED FATIGUE TESTING

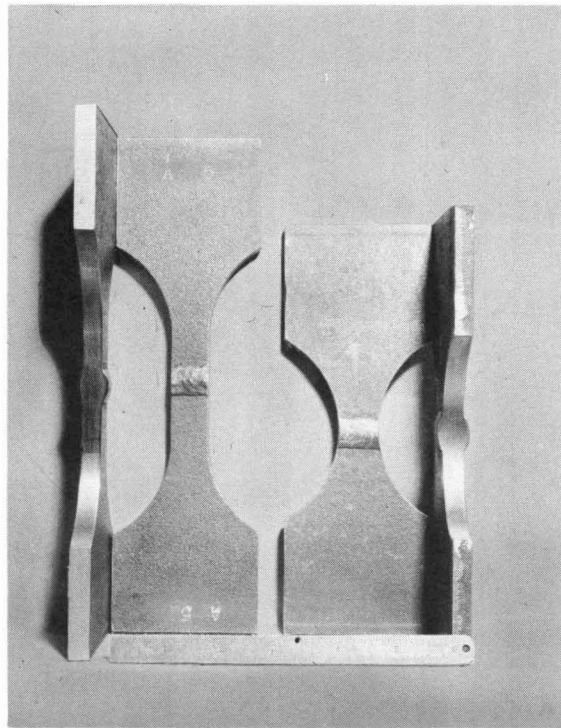
Sponsor: Welding Research Council

The experimental determination of the fatigue limit of a material or a connection is a rather time-consuming undertaking. In order to accelerate the testing, the French investigator Prot proposed to submit the specimens to linearly increasing stress cycles with time. Accepting certain assumptions, the results of such tests can be correlated to the fatigue limit.

Several investigators have successfully applied this method to plain material specimens. The present investigation should test its applicability to butt-welded specimens under tension-compression at different mean load levels.



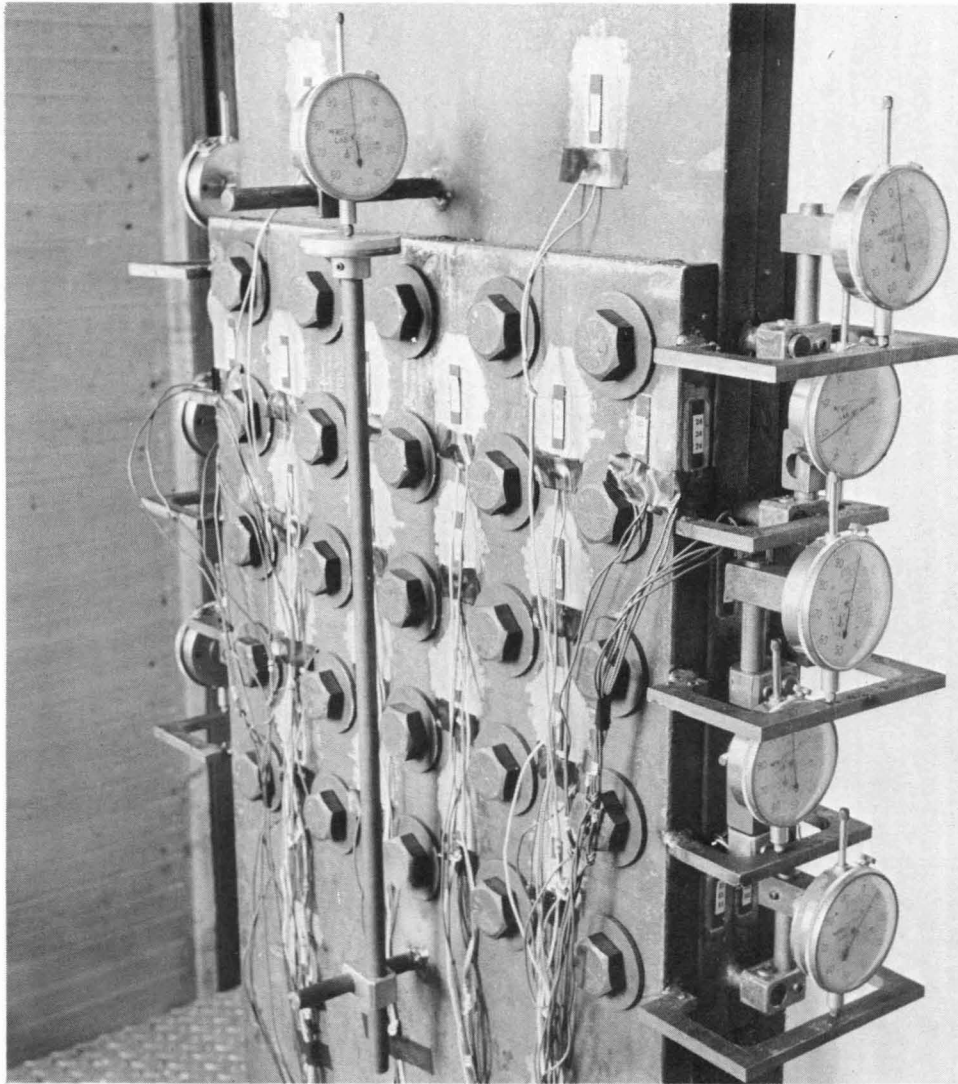
18,000 c.p.m. testing machine  
with butt-welded specimens  
(enlarged at right)



Project 271: LARGE BOLTED JOINTS

Sponsors: Bureau of Public Roads  
Pennsylvania Department of Highways  
Research Council on Riveted and Bolted  
Structural Joints

Within the last ten years the high-strength bolt has become a major method for connection of structural steel parts. Despite the higher strength of these bolts, connections are being designed currently according to "rivet" specifications in which one rivet is replaced by one bolt. The primary purpose of this research project is to determine whether fewer bolts may be used. Such a finding will produce economies in the construction of steel buildings and bridges.

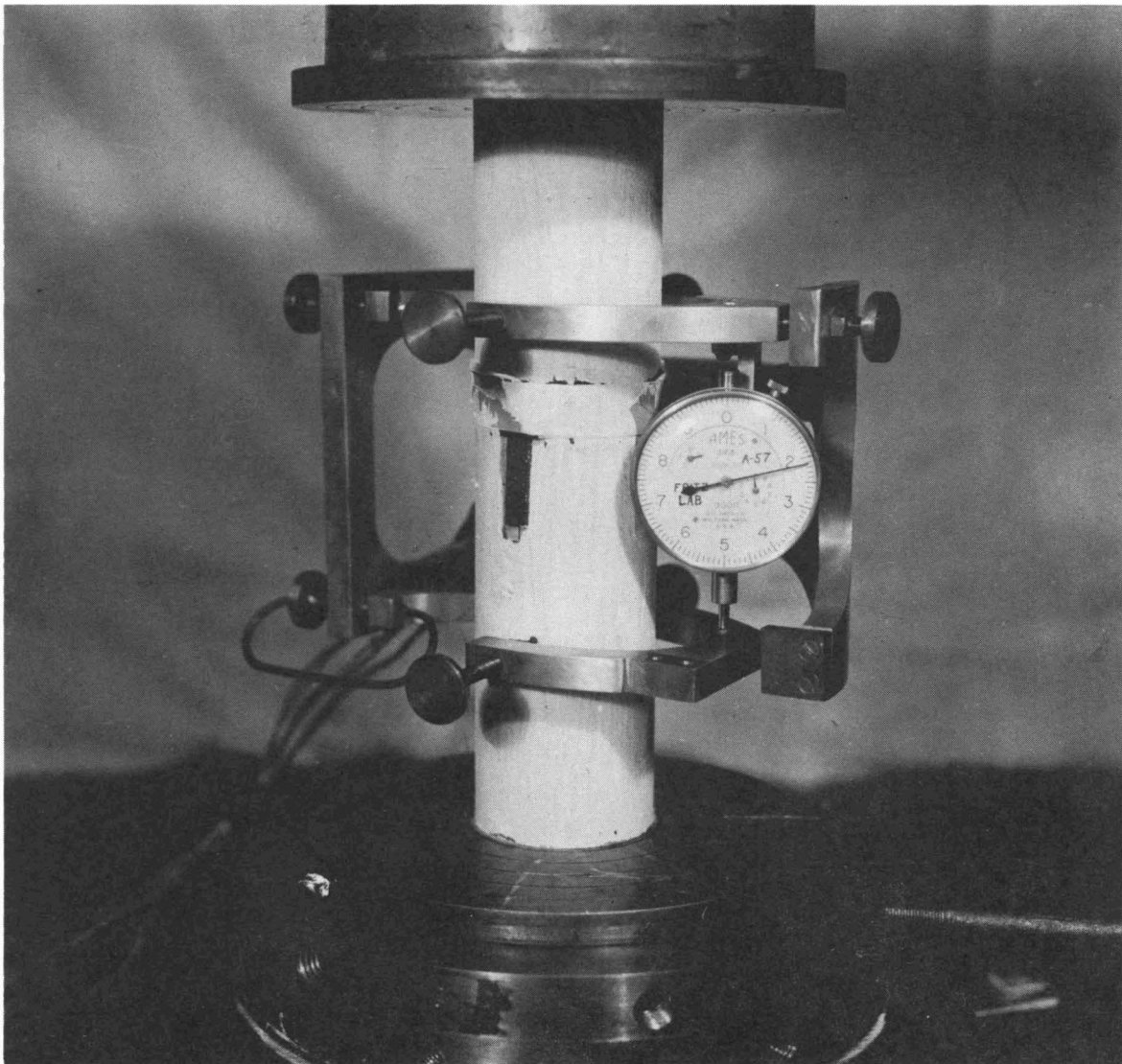


Inch-thick plates fastened with high-strength bolts

Project 272: HIGH-STRENGTH STEELS (T-1)

Sponsor: The United States Steel Corporation

The current investigation is limited to determining the influence of residual stresses on solid round sections. Their magnitude and distribution for different manufacturing processes such as quenching, tempering, air cooling, stress relieving and straightening will be determined. In addition, compression tests on short stub columns are conducted. Finally, column buckling tests are made. The results will be compared to theoretical predictions considering the influence of residual stresses.



Test of 2 3/4" round stub column