Second Specialty Conference on
Cold-Formed Steel Structures

CURRENT RESEARCH AND DESIGN TRENDS

Held in St. Louis, Missouri
October 22-24, 1973

Edited by

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In Cooperation with
ASCE Task Committee on Cold-Formed Members
Column Research Council Task Group on
Thin-Walled Metal Construction

General Advisor
George Winter, The Class of 1912 Professor of Engineering, Cornell University

Representatives of Supporting Organizations

Charles Babendreir - National Science Foundation

Sam J. Errera - Column Research Council Task Group on Thin-Walled Metal Construction

Albert L. Johnson - American Iron and Steel Institute

Don S. Wolford - American Society of Civil Engineers Task Committee on Cold-Formed Members

Conference Directors

Wei-Wen Yu, Professor of Civil Engineering, University of Missouri - Rolla

Joseph H. Senne, Chairman and Professor of Civil Engineering, University of Missouri - Rolla

PREFACE

In August, 1971, the First Specialty Conference on Cold-Formed Steel Structures was successfully conducted at the University of Missouri - Rolla. More than 100 leading scientists, researchers, engineers, and educators participated in the Conference. Technical papers presented at the Conference have been published in a special issue of Proceedings for distribution to all participants and other interested individuals and organizations throughout the world.

During the past two years, significant progress has been made in various studies of cold-formed steel structures in the United States and abroad. The Second Specialty Conference on Cold-Formed Steel Structures was held in St. Louis, Missouri, on October 22-24, 1973, to review recent research findings and design methods developed during the period of 1971 to 1973.

The Second Specialty Conference was sponsored by the American Iron and Steel Institute (AISI), National Science Foundation (NSF), and the University of Missouri - Rolla in cooperation with the American Society of Civil Engineers (ASCE) Task Committee on Cold-Formed Members and the Column Research Council (CRC) Task Group on Thin-Walled Metal Construction.

This publication contains 33 papers presented at the Conference and also includes the program. The papers not only present the results of recent research but also report on the technical developments such as building systems and special structures using cold-formed steel sections.

As the Director of the Conference, I am grateful to all the sponsors for their financial and technical support and to all authors for their technical developments in the field of cold-formed steel structures. Appreciation is due to Dr. J. H. Senne, Conference Co-Director; Dr. George Winter, General Adviso ; and representatives of the supporting organizations for their advice and cooperation in preparation of the Conference. The cooperation of Mr. T. J. Jones, Project Supervisor, who represents the AISI Joint Engineering Subcommittee of the Sheet Committees is also acknowledged.

Thanks are due to Chancellor Merl Baker of the University of Missouri - Rolla for his welcoming remarks; Mr. P.F. Connor of Inland Steel Company for the banquet speech; Dr. A.L. Johnson (AISI), Dr. Charles Babendreir (NSF), Mr. D.S. Wolford (ASCE) and Dr. T.V. Galambos (CRC) for their reports on the activities of supporting organizations. Appreciation should also be expressed to all chairmen of the technical sessions, Dr. W.A. Andrews, Mr. R.D. Bay, Mr. P.T. Conroy, Dr. S.J. Errera, Professor J.W. Hubler, Dr. A.L. Johnson, Mr. K.H. Klippstein, Mr. R.B. Matlock, Mr. A.J. Oudheusden, Professor K.C. Rockey, Dr. J.H. Senne, and Mr. D.S. Wolford.

I wish also to thank the many faculty and staff members of the University of Missouri - Rolla, Dean J.S. Johnson, Dean G.E. Lorey, Dean Bill L. Atchley, Dean J.K. Roberts, Dean S.A. Douglas, Professor J.B. Heagler, Mr. Walter Ries, Mrs. N.R. Fleming, Mrs. M.A. Bolin, and many others. Their advice, encouragement and contributions have been of great value to the Conference.

Rolla, Missouri

Wei-Wen Yu

PROGRAM

SUNDAY, OCTOBER 21

3:00 p.m. - 8:00 p.m. Registration, Center Ballroom

MONDAY, OCTOBER 22

7:30 a.m. - 5:00 p.m. Registration, Center Ballroom

OPENING SESSION, 8:30 a.m.

Presiding: J.H. Senne, Chairman and Professor of Civil Engineering, University of Missouri - Rolla.

"Welcoming Remarks", Merl Baker, Chancellor of the University of Missouri - Rolla.

"Activities of Supporting Organizations", Albert L. Johnson, Chief Research Engineer, American Iron and Steel Institute; Charles Babendreir, National Science Foundation; Don S. Wolford, Chairman, ASCE Task Committee on Cold-Formed Members; Principal Research Associate, Armco Steel Corporation, and Theodore V. Galambos, Chairman, Column Research Council; Chairman of the Department of Civil and Environmental Engineering, Washington University.

TECHNICAL SESSION NO. 1, 9:30 a.m.

Influence of Cold Work

Presiding: J.H. Senne, Chairman and Professor of Civil Engineering, University of Missouri - Rolla.

"Strain-Aging and the Bauschinger Effect in Steel", S.P. Gupta, A.A. Johnson and S.P. Kodali, Washington State University.

"Properties of Cold Compressed Steel Tubes", W.C. Anderson, the Union Metal Manufacturing Company, Canton, Ohio.

"Structural Behavior and Design of Thick, Cold-Formed Steel Members", W.W. Yu, and V.A.S. Liu, University of Missouri - Rolla and W.M. McKinney, Southwest Research Institute.

10:30 a.m. - Break

TECHNICAL SESSION NO. 2, 10:45 a.m.

Buckling Behavior and Post-Buckling Strength of Flat Elements

Presiding: K.C. Rockey, Professor of Civil and Structural Engineering, University College, Cardiff, UNITED KINGDOM.

"Post-Local-Buckling Behavior of Thin-Walled Columns", S.T. Wang and Yei L. Tien, University of Kentucky.

"Post-Buckling Behavior of Thin Perforated Plate", J. Colville, University of Maryland and P.M. Meger, Naval Ship Research and Development Center, Bethesda, Maryland.

"The Buckling and Ultimate Strength of Shear Webs Containing Plane and Reinforced Circular Cut-Outs", K.C. Rockey and J. Coughlam, University College, Cardiff, UNITED KINGDOM.

"The Effect of Hole Spacing on the Buckling and Post-Buckling Strength of Stiffened Compression Elements", C.S. Davis, Ford Motor Company, Dearborn, Michigan.

"Experimental Techniques for Plate Buckling", W.P. Vann, Texas Tech University and J. Sehested, Brown and Root, Houston, Texas.

12:30 p.m. - Lunch

TECHNICAL SESSION NO. 3, 1:45 p.m.

Structural Behavior and Analysis of Thin-Walled Members

Presiding: A.L. Johnson, Chief Research Engineer, American Iron and Steel Institute, New York, New York.

"Nonlinear Analysis of Thin-Walled Continuous Beams", S.T. Wang, University of Kentucky.

"Approximation Analysis of Lateral Buckling for Light Gage Beams of Open Section", M. Levy, A. Glassman and Y. Tene, Yotam, Advanced Design Consultants Ltd., Haifa, ISRAEL.

"Ultimate Strength of Thin-Walled Members Under Patch Loading and Bending", M.A. El-gaaly and K.C. Rockey, University College, Cardiff, UNITED KINGDOM.

"Ultimate Load Capacity of the Webs of Thin-Walled Members", K.C. Rockey, D.M. Porter and H.R. Evans, University College, Cardiff, UNITED KINGDOM.

"Design of Edge Stiffeners for Thin Compression Elements", K.R. Venkataramaiah, University of Waterloo, CANADA.

"Dynamic Response of Thin-Walled Beams", R.L. Dreisbach, M.L. Moody and J. K. Iverson, University of Colorado at Denver.

3:45 p.m. - Break

TECHNICAL SESSION NO. 4, 4:00 p.m.

Structural Behavior and Application of Corrugated Sheets

Presiding: D.S. Wolford, Chairman, ASCE Task Committee on Cold-Formed Members; Principal Research Associate, Armco Steel Corporation, Middletown, Ohio.

"Bending Strength of Deep Corrugated Steel Panels", J.L. Jorgenson, C. Chern, North Dakota State University.

"On the Stiffness, Stresses and Buckling Analysis of Corrugated Shear Webs", C. Libove, Syracuse University.

"Shell Roofs and Grain Bins Made of Corrugated Steel Sheets", M.N. El-Atrouzy, Ain Shams University, Cairo, EGYPT and G. Abdel-Sayed, University of Windsor, CANADA.

5:00 p.m. - Adjourn

6:00 p.m. - Social Hour

TUESDAY, OCTOBER 23

8:30 a.m. - 5:00 p.m. Registration, Center Ballroom

TECHNICAL SESSION NO. 5, 8:30 a.m.

Shear Diaphragms

Presiding: J.W. Hubler, Macomber Inc., Canton, Ohio.

"Analysis of Light Gage Steel Shear Diaphragms", A. H. Nilson, Cornell University.

"Screw Connected Diaphragms", L. D. Luttrell, West Virginia University.

"Shear Strength of Deep Corrugated Steel Panels", C. Chern and J.L. Jorgenson, North Dakota State University.

"Behavior of Light Gage Diaphragms Coupled with X-Bracing", J. M. Fisher, University of Wisconsin-Milwaukee and D. L. Johnson, Butler Manufacturing Company, Kansas City, Missouri.

10:00 a.m. - Break

TECHNICAL SESSION NO. 6, 10:15 a.m.

Structures Braced by Diaphragms

Presiding: S.J. Errera, Chairman, CRC Task Group on Thin-Walled Metal Construction; Consulting Engineer, Bethlehem Steel Corporation, Bethlehem, Pennsylvania.

"Drift Control with Light Gage Steel Infill Panels", C. J. Miller, Case Western Reserve University.

"Cold-Formed Steel Wall Stud Design", A Simaan and T.B. Pekoz, Cornell University.

"Cold-Formed Steel Framing with Gypsum Facing", F.A. Thulin and J.L. Lutfallah, United States Gypsum Company, Des Plaines, Illinois.

"Box Beam Stiffening Using Cold Formed Decks", C.P. Heins and D. Blank, University of Maryland.

12:00 Noon - Lunch

TECHNICAL SESSION NO. 7, 1:30 p.m.

Composite Design

Presiding: A.J. Oudheusden, Consulting Engineer, Bethlehem Steel Corporation, Bethlehem, Pennsylvania.

"Tentative Criteria for Design of Composite Slabs", A.J. Oudheusden, Bethlehem Steel Corporation.

"Behavior of Concrete Slabs Reinforced With 3-inch Deep Cold-Formed Steel Decking", M.L. Porter and E.C. Ekberg, Iowa State University.

"Composite Slabs with Steel Deck Panels", L.D. Luttrell and J.H. Davison, West Virginia University.

"Tests of Composite Beams with Formed Metal Deck", J. Grant, J.W. Fisher and R.G. Slutter, Lehigh University.

3:00 p.m. - Break

TECHNICAL SESSION NO. 8, 3:15 p.m.

Rack Structures

Presiding: P.T. Conroy, Structural Engineer, Sturdi-Bilt, Material Handling Division of UNARCO Industries, Chicago, Illinois.

"Cold-Formed Steel Rack Structures", T.B. Pekoz and G. Winter, Cornell University.

"Analysis of Drive-In and Drive-Thru Storage Racks", M.A. Salmon, Sargent & Lundy Engineers, Chicago, Illinois and R.E. Welch and A. Longinow, IIT Research Institute.

"Effect of Semi-Rigid Connection to Steel Column of Cold-Formed Perforated Singly Symmetric Section", Paul H. Cheng, Interlake, Inc., Chicago, Illinois.

4:30 p.m. - Adjourn

6:00 p.m. - Social Hour

7:00 p.m. - Banquet

Presiding: J.K. Roberts, Assistant Dean of School of Engineering and Professor of Civil Engineering, University of Missouri - Rolla.

Speaker: P.F. Connor, Manager, Market Development Division, Inland Steel Company, Chicago, Illinois.

WEDNESDAY, OCTOBER 24

Lewis and Clark Room

TECHNICAL SESSION NO. 9, 8:30 a.m.

Building Systems and Other Applications

Presiding: R.B. Matlock, Director, Research and Development Division, Stran-Steel Corporation, Houston, Texas.

"Cold-Formed Steel in Light Building Construction", S. Lucas, Panelframe Systems Division of Shenango Steel Buildings, Inc., West Middlesex, Pa., and E.R. Estes, Jr., Edward R. Estes, Jr. and Associates, Youngstown, Ohio.

"Cold-Formed Steel Framing System for Low Cost Modular Housing", R.A. Dipasquale, R.A. Dipasquale & Associates, Ithaca, New York.

"Developments and Application of Lightweight Steel Components in Housing", A.S. Zakrzewski, Dominion Foundries and Steel, Limited, Hamilton, Ontario, CANADA

"Production Methods for Cold-Formed Steel", T.J. Jones, R. J. Furman, and R.E. Brown, Wheeling Corrugating Company, Division of Wheeling-Pittsburgh Steel Corporation, Wheeling, West Virginia.

"Effects of Allowable Steel Thickness Variation", C.K. Brasher, Structural Engineer, Atlanta, Ga.

"Light Gage Steel and the Changing Building Codes", M.P. Walsh, Jr., City of Cincinnati, Cincinnati, Ohio.

10:30 a.m. - Break

TECHNICAL SESSION NO. 10, 10:45 a.m.

Special Design

Presiding: R.D. Bay, Director of Technical Services, Laclede Steel Company, St. Louis Missouri.

"Innovative Designs with Cold-Formed Members and Sheets", R.L. Tomasetti, Lev Zetlin Associates, New York City.

"Metal Decks Used to Form Hypar-Shell Panels", M. Biswas and J.S.B. Iffland, URS/Madigan-Praeger, Inc., New York City.

"Design Criteria for Steel Transmission Poles", E.H. Gaylord, Jr., University of Illinois at Urbana.

12:10 p.m. - Lunch

TECHNICAL SESSION NO. 11, 1:30 p.m.

Computer-Aided Design and Stainless Steel Structures

Presiding: K.H. Klippstein, Senior Research Engineer, Applied Research Laboratory, United States Steel Corporation, Monroeville, Pa.

"Automated Design of Continuous Cold-Formed Beams", K.P. Chong and D.M. Harris, Stran-Steel Corporation, Houston, Texas.

"Optimization of Long Span Truss Purlins", R.T. Douty, University of Missouri - Columbia and J.O. Crooker, Butler Manufacturing Company, Kansas City, Missouri.

"Design Trends for Stainless Steel Structural Members", D.S. Wolford, Armco Steel Corporation, Middletown, Ohio; A.L. Johnson, American Iron and Steel Institute and W.W. Yu, University of Missouri - Rolla.

2:30 p.m. - Break

TECHNICAL SESSION NO. 12, 2:45 p.m.

Connections

Presiding: William A. Andrews, Professor of Civil Engineering, University of Missouri - Rolla.

"Field Fusion Welded Connections", A.L. Johnson, American Iron and Steel Institute.

"Connection Strength in Thin Metal Roof Structures", R. W. Haussler and R.F. Pabers, R.W. Haussler, Consulting Structural Engineer, Van Nuys, California.

"European Research on Connections in Cold-Formed Steel Structures",J. Stark, IBBC-TNO, Delft, HOLLAND.

CLOSING REMARKS: Wei-Wen Yu, Professor of Civil Engineering, University of Missouri - Rolla.

4:30 p.m. - Adjourn

CONTENTS

STRAIN-AGING AND THE BAUSCHINGER EFFECT IN STEEL*

by

S. P. GUPTA, A. A. JOHNSON and S. P. KODALI**

ABSTRACT

The interaction of strain-aging and the Bauscinger effect has been studied in cylindrical mild steel specimens. Each specimen was prestrained 2% in compression at room temperature, subjected to an annealing treatment, and then strained in tension at room temperature. Isochronal annealing treatments, using an annealing time of one hour, revealed that, as the annealing temperature increased from room temperature to 150° C, the Bauschinger effect was almost completely eliminated. Isothermal studies showed that part of this effect occurred rapidly and part occurred over a period of hours. The proportion occurring rapidly increased with increasing annealing temperature.

Thus, these results show that the substantial reduction in some load bearing characteristics of a cold-formed mild steel structure caused by the Bauschinger effect can largely be removed by an annealing treatment at a moderate temperature. It has not yet been established whether this is also true for other types of steel.

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*A paper to be presented at the Conference on Cold-Formed Steel Structures to be held at St. Louis, Missouri, October 22-24, 1973.

**The authors are respectively assistant professor, chairman, and research assistant at the Department of Materials Science and Engineering, Washington State University, Pullman, Washington, 99163.

1. INTRODUCTION

Consider a steel tensile specimen which is tested at room temperature to a strain, ε, and flow stress, σ_F. If it is unloaded and then retested immediately it will begin to flow again at a stress very close to σ_F. If, however, it is tested the second time in compression rather than tension it will begin to flow at a stress, σ_B, which is considerably less than σ_F. A similar reduction in flow stress is observed if the first deformation is in compression and the second in tension. This effect, usually known as the "Bauschinger effect", has been known since 1881 (Bauschinger, 1881, 1886; 1886-7).

The Bauschinger effect is quite general in that it occurs in both polycrystalline metals and in single crystals. As far as the authors are aware it has been observed in all of the metals studied from this point of view. The literature on it has been reviewed by Thompson and Wadsworth (1958), Van Beuren (1961) and others. References pertaining specifically to steels are given in a recent paper on the Bauschinger effect in a high strength steel by Jamieson and Hood (1971). A review of the literature on the Bauschinger effect reveals that very little is known about the effects of an annealing treatment interjected between the tensile and compressive deformation treatments. For this reason we are in the process of studying the effects of such annealing treatments in a variety of materials. For this conference on cold-formed steel we choose to report some of our work on a mild steel. We shall report our work in terms of engineering results without discussing the underlying physical mechanisms. These mechanisms will be dealt with in a later publication in the physical metallurgy literature.

2. SPECIMEN PREPARATION AND TESTING

The starting material for the investigation was mild steel in the form of 0.75 inch diameter rod supplied by Joseph T. Ryerson and Son Inc. According to the manufacturers, this steel contained 0.18 to 0.20 wt. % carbon, 0.6 to 0.9 wt. % manganese, 0.04 wt. % phosphorus, and 0.05 wt. % sulphur. Chemical analyses carried out for the authors at the Bridgeport Testing Laboratory gave values for the carbon, oxygen and nitrogen contents of the material of 0.22 wt. %, 0.005 to 0.028 wt. %, and 0.001 to 0.004 wt. % respectively.

Tensile specimens with threaded shoulders having gauge lengths of 2.00 inches and gauge diameters of 0.50 inch were machined from the starting material. The specimens were annealed for one hour at 1000^{o} C in a nitrogen atmosphere, furnace cooled to 600^{o} C, and then air cooled to room temperature. The nitrided surface layer was then removed with a fine grade of emergy paper. Metallographic examination revealed that the grain size was 25 to 30 μ and did not vary significantly from one specimen to another. The microstructure consisted of ferrite with colonies of coarse pearlite at the grain boundaries.

The testing was carried out on an Instron machine using a compression cell and specially designed grips appropriate for both compression and tension. All of the testing was performed at room temperature using a strain-rate of 3.33×10^{-4} sec^{-1}. In a typical experiment a specimen was compressed to a plastic strain of 2% and then immediately removed from the machine and placed in an oil bath preheated to the desired annealing temperature. After an appropriate time at this temperature it was then quenched into a mixture of ice and water, cleaned with acetone, dried, and finally tested in tension to a strain of a few percent.

3. RESULTS

One of the load-compression curves obtained in the course of precompressing all of the specimens is shown in Figure (1). It shows a sharp yield point and an irregular Luders strain preceding the work-hardening part of the curve. This type of behaviour is of course characteristic of mild steel and other body-centered cubic metals. The average lower yield stress obtained from these precompression curves was 20.55 kg. mm^{-2} with an r.m.s. deviation of $\pm$ 0.1 kg mm^{-2}. The average value of the flow stress at the end of the 2% precompression was 25.60 kg mm^{-2} with a r.m.s. deviation of $\pm$ 1.5 kg mm^{-2}.

In our first series of experiments the annealing time was held constant at one hour and the annealing temperature was varied from room temperature to 270° C. The load-elongation curves obtained by subsequent testing of these specimens at room temperature are shown in Figures (2a) and (2b). It will be seen that the yield point began to return at an annealing temperature of 100° C. If the proporational limit for those specimens that do not show a yield point and the proporational limit for those that did are plotted against annealing temperature (Figure 3) it is at once apparent that the proportional limit or yield stress increases rapidly with increasing annealing temperature. The yield stress reaches a maximum at about 150° C at a value which is higher than the yield stress of a virgin specimen but slightly lower than the flow stress reached at the end of the precompression treatment. Thus, annealing for one hour at 150° C almost completely removes the Bauschinger effect in this material.

In a second series of experiments the isothermal recovery of the Bauschinger effect was studied at 102°, 112°, 127° and 147° C (Figure 4). From these