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George E. Blandford

Asadul H. Chowdhury

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CURRENT RESEARCH ON COLD-FORMED STEEL STRUCTURES

George E. Blandford¹ and Asadul H. Chowdhury²

INTRODUCTION

A survey of current research on cold-formed steel structures has been conducted at the Departments of Civil Engineering, University of Kentucky, Lexington and North Dakota State University, Fargo by the Subcommittee on Current Research and Future Needs of the Committee on Cold-Formed Members, Structural Division, American Society of Civil Engineers. This survey was initiated in March, 1987 with a followup mailing in January, 1988. The principal purpose of the survey is to assist the Subcommittee in preparing a report on the current research work being conducted in the cold-formed members area, in planning future research needs, and maintaining or initiating contact with the investigators working in the field of cold-formed steel research. Another benefit of the survey is that it provides individual research investigators a list of potential contact people who are working in the same or related areas of research.

More than 100 questionnaires were sent to universities, research institutions, and industries in Australia, Canada, China, Europe, India, Japan, South America and the United States. Completed questionnaires for 38 research projects in Argentina, Australia, Canada, China, England, India, the United Kingdom and the United States have been received. This paper provides a brief description of each research project received through the survey.

As in previous surveys, this survey is not a complete summary of the current research being conducted on cold-formed steel. It merely reports the survey responses received. The Subcommittee recognizes that there are other current research projects ongoing which did not make the survey.

The research projects have been classified into nineteen major areas which are consistent with those used for the Subcommittee on Literature Survey. Individual research projects are listed under the appropriate research area. The arrangement of the material within a particular area is alphabetical according to the title of the project. A number is assigned to each research project.

¹ Associate Professor, Department of Civil Engineering, University of Kentucky, Lexington, KY 40506-0046

² Scientist, Structures and Computational Mechanics Group, 133 First Avenue North, EWA, Inc., Minneapolis, MN 55401; formerly Assistant Professor, Department of Civil Engineering, North Dakota State University, Fargo, ND

The first line of each research project includes its number, title and the reference number(s) in parentheses of the most significant or current reference if available. This is followed by a block of information which includes the names of the principal investigators, location of the research work and the name of the sponsor. Subsequent paragraphs provide an abstract or description of the project which is essentially the same as that furnished by the principal investigator(s).

I. MECHANICAL BEHAVIOR AND COLD-FORMING EFFECTS

1.1 YIELD STRENGTH OF COLD FORMED STEEL

Jin Chang-Cheng; Heilongjiang Provincial Low Temperature Construction Science Research Institute; Harbin, CHINA
China Planning Committee

The stress field solution for a strain hardening plate bent into a cylindrical shape by a moment and a radial pressure on the inside surface has been solved using plasticity theory. Two theoretical formulae have been analytically derived to predict the corner yield strength. One formula is based on a power model of strain hardening whereas the second formula utilizes a linear strain hardening model. A simplified formula has also been derived to predict the full section yield strength of cold formed steel. Test comparisons show that the derived formulae are in very good agreement with the observed behavior. The shortcomings of the AISI method and theoretical causes of failure for large a/t ratio corners have been analyzed resulting in a proposed modified code method.

II. STRENGTH OF THIN ELEMENTS

2.1 LOCAL BUCKLING BEHAVIOR OF PLATE ELEMENTS

T. Pekoz; Department of Structural Engineering; Cornell University; Ithaca, NY 14853-3501
American Iron and Steel Institute

Local buckling and post-buckling behavior of component plate elements of sections has been studied in this investigation. Topics covered included stiffened, unstiffened and edge stiffened elements subjected to stress gradients, sloping edge stiffeners and the interaction of plate elements. These topics are pertinent to the design of slender webs, flanges and stiffeners. Special considerations for corners with large bend radii have also been included in the research.

2.2 ULTIMATE STRENGTH AND STABILITY OF COLD-FORMED STEEL MEMBERS (21)

Shiji Wang, Pusheng Shen, and Hanquan Luo; Department of Civil Engineering; Hunan University; Changsha, CHINA
China Technical Committee for Standards of Steel Structures

Studies on the ultimate strength and stability of cold-formed steel members include:

- a. Post-buckling behavior and effective width of plate elements (stiffened, unstiffened and edge-stiffened) under uniform or

nonuniform compression.

- b. Lateral torsional buckling of thin-walled beam-columns under axial thrust and unequal terminal moments and/or transverse loads.
- c. Ultimate strength of composite cold-formed steel-concrete members.

III. FLEXURAL MEMBERS

3.1 EXPERIMENTAL AND ANALYTICAL STUDIES OF A PROPOSED METAL BUILDING SYSTEM

Thomas M. Murray; Department of Civil Engineering; Virginia Polytechnic Institute and State University; Blacksburg, VA 24061
NUCOR Building Products

The purpose of this project is to experimentally verify the strength of cold-formed Z- and C-purlins whose shape was optimized using the provisions of the 1986 AISI "Specification for the Design of Cold-Formed Steel Members".

3.2 RE-ASSESSMENT OF EXISTING COLD-FORMED BUILDING PRODUCTS PERFORMANCES TO THE NEW BRITISH STANDARD BS 5950 PART 5.

Victor French and Paul Hunter; Ayrshire Metal Products (Daventry) Ltd.; Royal Oak Way; Daventry, Northamptonshire NN11 5NR, ENGLAND
Ayrshire Metal Products plc

Re-assessment of performance of existing purlin range to the new British Standard on the design of cold formed sections - BS 5950 Part 5. Investigation into the effect of using higher yield steels on the performance of purlin products. Study into the possibility of designing cold formed purlin sections using plastic analysis. Investigation into laterally unrestrained modified Zee section purlins.

IV. COMPRESSION MEMBERS

4.1 COLD-FORMED STEEL COLUMNS

T. Pekoz; Department of Structural Engineering; Cornell University; Ithaca, NY 14853-3501
American Iron and Steel Institute

The inelastic flexural buckling behavior of cold-formed steel columns of lipped channel shape has been studied in this project. One of the principal parameters considered was the residual stresses. Residual stresses were measured and their effects on overall column buckling behavior were studied. Residual stresses influence column buckling both directly and indirectly through their influence on local stability which influences the overall column behavior. Design approaches accounting for various parameters have been formulated on the basis of analytical studies and an extensive column testing procedure.

4.2 PERFORATED COLD-FORMED STEEL COLUMNS

T. Pekoz; Department of Structural Engineering; Cornell University;
Ithaca, NY 14853-3501
Rack Manufacturers Institute

Design approaches for the types of perforated columns and beam-columns used in industrial storage racks are being developed. On the basis of analytical and experimental studies, the provisions of the Rack Manufacturers Institute Specifications will be revised.

4.3 BEHAVIOR AND DESIGN OF THIN-WALLED COLUMNS (18)

Srinivasan Sridharan; Department of Civil Engineering; Washington University; St. Louis, MO 63130
National Science Foundation

Features of the phenomenon of interactive buckling of thin-walled columns are briefly reviewed. The theoretical results are compared with recent test results from the University of Sydney and earlier test results from Cornell University. Very good agreement between the theoretical and experimental results is demonstrated. The role of imperfections in producing scatter in the prediction of the ultimate capacity of the columns is illustrated. Design procedures, recommended by the new American Iron and Steel Institute Code, are examined in the light of the new results. In order to account for the interaction of plate elements, it is suggested that exact local critical stress be used in the effective width formula. To obtain a reliable and safe estimate of the column strength, it is proposed that the collapse load given by the design methods be multiplied by an appropriate factor. This factor must be a function of the key parameters governing the problem. A statistically derived expression for this factor is also suggested.

4.4 DISTORTIONAL BUCKLING OF CHANNEL COLUMNS (10)

Gregory Hancock; School of Civil and Mining Engineering; University of Sydney; Sydney, N.S.W., AUSTRALIA 2006
University of Sydney and Colby Engineering

The object of the project is to produce design formulae to predict the distortional buckling mode in cold-formed channel section columns. The method must account for yielding and geometric imperfections as well as buckling. Currently, a series of tests on a range of section profiles is being calibrated against buckling formulae to produce design formulae.

V. BEAM-COLUMNS

5.1 FINITE ELEMENT MODELING TO STUDY LOCAL-OVERALL INTERACTION BUCKLING OF COLD-FORMED SECTIONS BASED ON THE P-VERSION (2)

P.K. Basu; Department of Civil and Environmental Engineering; Vanderbilt University; Nashville, TN 37235
Vanderbilt University Research Council

A general analysis capability for studying the buckling characteristics of thin walled members under flexure and compression by the perversion of the finite element method is being developed. An investigation of prismatic and non-prismatic members with arbitrary end conditions and various discontinuities is being conducted.

5.2 INTERACTIVE BUCKLING IN THIN-WALLED BEAM-COLUMNS (1,17)

Srinivasan Sridharan; Department of Civil Engineering; Washington University; St. Louis, MO 63130
National Science Foundation

A new formulation has been developed to study the interactive buckling of thin-walled columns having arbitrary cross-sections. However, the emphasis is on columns with a single axis of symmetry. The formulation is designed to take into account the simultaneous interaction of the purely flexural and flexural-torsional overall modes of buckling with local buckling. The local buckling deformations are described in terms of a primary local mode together with two secondary local modes of the same wavelength. The latter are triggered by the interaction of bending in two perpendicular planes with the primary local mode. The three eigenmodes and the six second-order in-plane displacement fields are all computed using a finite strip technique. The modulation of the amplitudes of the local modes and the overall displacements are described in terms of a one-dimensional finite element model. Thus a new beam element which has embedded in it the local buckling information is developed. It appears that the present analytical model is very versatile being applicable to members of arbitrary cross-section and end conditions. For columns with a single axis of symmetry, it is seen that there exists a non-linear coupling between the purely flexural and the flexural-torsional modes of buckling via local buckling deformation. Typical examples of channel column sections are presented. It is shown that the section columns of commonly used proportions are highly imperfection sensitive in the context of combined interaction of the enumerated modes of buckling. This sensitivity remains even for columns with well separated overall and local critical stresses; a feature which is in stark contrast with the behavior of the Tvergaard panel.

5.3 LOCAL AND POSTBUCKLING BEHAVIOR OF NON-UNIFORMITY COMPRESSED UNSTIFFENED ELEMENTS

P. Jayabalan and V. Kalyanaraman; Structural Engineering Laboratory; Indian Institute of Technology; Madras - 600036, INDIA
Indian Institute of Technology, Madras

The local and postbuckling behavior of non-uniformly compressed unstiffened elements has been studied. An analytical investigation of the local buckling and postbuckling behavior of unstiffened elements with an elastic rotational restraint has been carried out. Galerkin's method of analysis is used. The analytical results are presented in the form of non-dimensional graphs and empirical equations. Results of experiments on beams and beam-columns to study the behavior of non-uniformly compressed unstiffened elements are presented and compared with the analytical solution.

An effective width equation for the postbuckling range of non-uniformly compressed unstiffened elements is presented. On the basis of the derived expression a method for calculating the strength of cold formed steel beams and beam-columns with locally buckled unstiffened elements subject to non-uniform compression is described. The theoretical and experimental results are compared.

5.4 NONLINEAR BIAXIAL BENDING BEHAVIOR OF THIN WALLED MEMBERS

A.C.R. Djugash; Structural Engineering Research Centre; CSIR Complex; Taramani, Madras-600113, INDIA and V. Kalyanaraman; Structural Engineering Laboratory; Indian Institute of Technology; Madras-600036, INDIA
Structural Engineering Research Centre

Warping deformations are very important in thin walled members, especially for members having unsymmetrical sections such as Zed beams with unequal flanges. The warping of such members should be taken into account while analyzing the behavior of beams subjected to biaxial bending and torsion as a result of the applied load not along any one of the principal planes and not passing through the shear centre.

The finite element method of analysis using beam elements having seven degrees of freedom at each node has been adopted in the numerical analysis of such beams. The nonlinear analysis portion of the program includes the evaluation of the large displacements and effect of geometric nonlinearity. For studying the lateral buckling, biaxial bending and large displacement behavior of cold formed steel beams experimentally, a special loading device was developed to apply two point loads in different orientation with respect to member axis and different eccentricities with respect to shear centre. Experimental and analytical results have been compared. Design equations for use in code specifications have been developed for the lateral buckling and biaxial bending of cold formed steel members.

VI. CYLINDRICAL TUBULAR MEMBERS

NONE REPORTED.

VII. CONNECTIONS

7.1 BEHAVIOR/ANALYSIS OF FLEXIBLY CONNECTED THIN-WALLED PLANE FRAMES (6)

George E. Blandford; Department of Civil Engineering; University of Kentucky; Lexington, KY 40506-0046
University of Kentucky

The static analysis and behavior of plane frames including nonlinear semi-rigid connection behavior, post-local-buckling strength of thin-walled steel members and first-order geometric nonlinearity is being investigated. Semi-rigid connection behavior is being modeled using an exponential approximation of the connection flexibility - moment relationship. Post-local-buckling behavior is approximated using an effective width concept. Both axial and bending stresses are inclu-

ded. Discretization of the nonlinear equilibrium equations is based on an exact elastic stiffness matrix formulation coupled with a finite element representation of first-order geometric nonlinearity. Solution of the resulting nonlinear algebraic equations is obtained using an iterative predictor-corrector strategy along with a constant spherical arc-length constraint algorithm for the automatic selection of the load step increments. The secondary moments caused by beam-column and P-delta effects have been determined to be a significant influence on the response of flexibly connected plane frames. Inelastic connection response is currently being investigated.

7.2 BEHAVIOR OF FLEXIBLY CONNECTED SPACE FRAMES (5,6)

G. E. Blandford and S. T. Wang; Department of Civil Engineering; University of Kentucky; Lexington, KY 40506-0046
AISC and NSF EPSCoR Computational Sciences Project

A space frame program for the analysis of thin-walled structures with flexible (semi-rigid) connections has been developed. Warping effects and geometric nonlinearity are considered. The flexible connections are modeled as separate elements. Both linear and nonlinear joint elements have been implemented. A parametric study is being conducted. Interesting results have been obtained regarding the effects of rigidity of the flexible connections on the behavior of space framework. A study on stability problems of space frames with flexible connections is also being carried out.

VIII. SHEAR DIAPHRAGMS

8.1 REINFORCED SHEAR DIAPHRAGMS WITH END CLOSURES (20)

Larry D. Luttrell; Department of Civil Engineering; West Virginia University; P.O. Box 6101; Morgantown, WV 26506-6101
Steel Deck Institute

In certain deeper roof panels, longer spans are possible due to bending properties associated with the section shape and depth. Unfortunately, fewer opportunities for attaching the panels to the structure are available. The decreased fastener opportunity directly affects diaphragm shear response. This study is to address, through full-scale testing, the effects of increasing fastener opportunities through use of closure devices at panel ends.

8.2 SHEAR DIAPHRAGM BEHAVIOR OF DIAPHRAGM-BRACED MEMBERS (23)

Yaochun Zhang; Department of Building Structures; Harbin Architectural and Civil Engineering Institute; Harbin, CHINA
Harbin Architectural and Civil Engineering Institute

The increasing use of cold-formed steel structures, especially light steel cladding, in China dictates continuous study on the utilization of the diaphragm effect, so called shear diaphragms or stressed skin effect. The subject of investigation focuses on the behavior of shear diaphragms and diaphragm-braced members.

IX. CORRUGATED SHEETS AND FORMED PANELS

9.1 AUTOMOTIVE STRUCTURAL COMPONENTS USING HIGH STRENGTH SHEET STEELS (13)

Wei-Wen Yu; Department of Civil Engineering; University of Missouri-Rolla; Rolla, MO
American Iron and Steel Institute

The objectives of this project include (1) determination of the characteristics of high strength automotive sheet steels which influence their performance in structural applications, (2) structural strength of members consisting of flat and curved elements, (3) web crippling strength of high strength cold-formed steel beams, and (4) development of the new design criteria.

9.2 STRUCTURAL SANDWICH PANELS (8)

J. M. Davis; Department of Civil Engineering; University of Salford; Salford M5WT, U.K.

To date the project has concentrated on structural aspects of sandwich panel design including materials, methods of analysis and design criteria. Response to temperature gradient has been a prominent factor. Emphasis is now moving on to extend the range of materials with particular reference to behavior in fire.

X. PLATE STRUCTURES

10.1 COMPOUND AND MODIFIED STRIP METHODS FOR BUCKLING ANALYSIS (14)

Ken P. Chong and Jay A. Puckett; Department of Civil Engineering; University of Wyoming; Laramie, WY 82071
University of Wyoming

Special finite strip methods are developed for (1) buckling of cold-formed columns, and (2) the analysis of linear buckling of flat plate systems that are continuous over non-rigid supports. The latter approach incorporates the effect of support elements in a direct stiffness methodology. The stiffness contribution of the support elements add directly to the plate strip stiffness matrices at the element level prior to assembly. This summation of plate and support stiffness contributions forms a substructure which is termed a compound strip. The compound strip methodology may be readily employed for the enhancement of computer programs based on traditional finite strip procedures. The validity of the compound strip method for elastic buckling analysis is demonstrated in two illustrative examples. The critical loads based on compound strip methodology compare favorably with those obtained with the finite element method.

10.2 BUCKLING BEHAVIOR AND POST-BUCKLING STRENGTH OF PERFORATED PLATES

Bao-Kang He and Qun-Ping Zhao; Department of Civil Engineering; Xian Institute of Metallurgy and Construction Engineering; Xian, CHINA
The State Capital Construction Commission of China

The finite element method of analysis is employed to determine the elastic buckling coefficient K and post-buckling strength of plates with circular or square holes. In addition to holes, the actual restraining effects of adjoining cross-sectional elements are taken into account. The theoretical analysis is verified by test results. For design purpose, a simple effective width equation is being developed to predict the post-buckling strength.

10.3 POST-BUCKLING STRENGTH OF PLATES AND STIFFENED PLATES SUBJECTED TO COMPRESSION

Guo-Liang Zhou; Department of Mechanical Engineering; Shanghai Jiao Tong University; Shanghai 200030, CHINA
Shanghai Jiao Tong University

A large deflection analysis of stiffened plates based on the principle of minimum potential energy and optimization techniques is being developed. The numerical results are quite close to previously generated results. Existence of secondary buckling after primary buckling and of the minimum stiffness ratio against the ultimate strength is indicated and the theoretical results are in good agreement with the experimental results. The developed computational process is greatly simplified by the present method resulting in an effective technique for performing large deflection analysis of stiffened plates subjected to non-uniform compression.

XI. SHELL STRUCTURES

11.1 BUCKLING AND COLLAPSE OF COLD-FORMED STEEL SILOS (16)

J. Michael Rotter; School of Civil and Mining Engineering; University of Sydney; NSW 2006, AUSTRALIA
Australian Research Grants Scheme/University of Sydney

The project aims to improve current knowledge of the loading on and strength of cold-formed steel silo structures. The work is centered on cylindrical silos formed from corrugated sheets, but other cold-formed profiles are also considered.

The loading on the silo wall is affected by the flexibility of the structure. This has long been recognized by the industry, but neither previous scientific study nor simple predictive techniques are known at present.

The dominant failure modes of the structure have been classified, and are described in (16). Two aspects of the strength of these silos are being investigated.

The buckling strength of cylindrical silo walls under axial compression is being studied. The effects of corrugation profile, internal pressurization, and restraint from the stored solid are all being explored. Buckling failure under eccentric discharge of the stored silos is also being investigated.

The strength of conical silo hoppers is also under study, including the behavior of and strength of the ring at the hopper/cylinder

junction.

XII. COMPOSITE CONSTRUCTION

12.1 DESIGN OF PROFILES SHEETING AS PERMANENT FORMWORK IN COMPOSITE SLABS (11)

R. M. Lawson; Steel Construction Institute; Sillwood Park, Ascot; Surrey SL5 7PY, U.K.
Construction Industry Research & Information Association

The design of composite floors is often controlled by loads applied to the profiled sheeting (decking) during concreting. The research undertaken has led to move economic design of the decking by permitting some redistribution of moment in continuous decking from the elastic design case specified in most codes of practice. The research has involved testing of decking in bending using an airbag, and examination of the post-buckling behavior in the negative moment zone (and the supports). This has been supplemented by analytical studies.

12.2 SHEAR DIAPHRAGMS WITH INSULATION (20)

Larry D. Luttrell; Department of Civil Engineering; West Virginia University; P.O. Box 6101; Morgantown, WV 26506-6101
W.R. Grace, Inc.

This project addresses the strength and stiffness changes, relative to bare deck, of shear diaphragms having cast-in-place lightweight insulating concrete fill. The project development follows the design and evaluation methods used in Part V of the Steel Deck Institute Diaphragm Design Manual, 1987 edition.

12.3 SANDWICH PANELS WITH COLD-FORMED FACINGS (7)

Ken P. Chong; Department of Civil Engineering; University of Wyoming; Laramie, WY 82071
University of Wyoming

Sandwich panels with thin-walled cold-formed facings and rigid foamed insulating core are becoming more and more popular as enclosures for system buildings. In this study, the structural behavior, including flexural stresses/deflections, axial stability, and thermal stresses, is investigated. Methods used are analytical (boundary-valued approaches), numerical (finite-strip, finite-layer, finite prism approaches) and experimental (full-scale testings). Key equations are formulated, and results by different methods are compared.

XIII. STRUCTURAL SYSTEMS

13.1 RESTRAINT REQUIREMENTS FOR Z-PURLIN SUPPORTED STANDING SEAM ROOF SYSTEMS (15)

Thomas M. Murray; Department of Civil Engineering; Virginia Polytechnic Institute and State University; Blacksburg, VA 24061
Metal Building Manufacturers Association

Restraint force (or anchorage force) requirements for Z-purlin supported, thru fastener roof systems are provided in Section D3.2.1 of the AISI Cold-Formed Steel Specification. To verify that these requirements are also applicable to Z-purlin supported standing seam roof systems, a series of two purlin, single and three-span continuous, tests were conducted. Based on a limited number of tests, results show that the current AISI specification provisions are applicable to Z-purlin standing seam roof systems.

13.2 STRENGTH OF Z-PURLIN SUPPORTED STANDING SEAM ROOF SYSTEMS

Thomas M. Murray and Siegfried M. Holzer; Department of Civil Engineering; Virginia Polytechnic Institute and State University; Blacksburg, VA 24061
Metal Building Manufacturers Association

The purpose of this project is to develop design rules for determining the strength of Z-purlin supported standing seam roof systems. Analytical studies will include the efforts of connection clip friction and panel drape. Both pan-type and rib-type panels will be considered. Analytical results will be verified with full-scale tests of roof systems.

13.3 DESIGN OF COLD-FORMED STEEL WALL-STUDS

T. Pekoz; Department of Structural Engineering; Cornell University; Ithaca, NY 14853-3501
American Iron and Steel Institute

Behavior of cold-formed steel wall-studs are being studied in a project that includes testing and analytical studies. Wall-stud assemblies with and without wall-boards and with and without intermediate braces are being studied. The effect of perforations will also be explored. The project is aimed at improving the current design specifications.

13.4 BLENDED FLOOR PANEL SYSTEMS

Larry D. Luttrell; Department of Civil Engineering; West Virginia University; P.O. Box 6101, Morgantown, WV 26506-6101
Steel Deck Institute

The use of cellular light gage steel floor panels allows for in-floor electrification and other services. Such panels are often "blended" with similar "open sections" of significantly different stiffness. This project is to address load distribution in such units and, further, to evaluate the effects of certain access holes cut into

cellular systems.

13.5 SPECIAL PURLINS FOR CLAY TILES: STRUCTURAL BEHAVIOR

Robert W. Dannemann; Malabia 2885 4-B; Buenos Aires (1425), ARGENTINA
Tejafix SRL (Private Manufacturing Company)

The structural behavior of recently designed (patent pending) roof purlins for french type clay tiles has been initiated (June 1987). Investigative topics include:

- a. Theoretical flexural capacity of the unrestrained purlin.
- b. Theoretical flexural capacity of torsionally restrained purlins.
- c. Evaluation of restraining effect of tiles.
- d. Test of a set of purlins with tiles.
- e. Comparison between theoretical and test values.

13.6 GEOMETRIC NONLINEAR ANALYSIS OF THIN-WALLED STEEL SPACE STRUCTURES

G.E. Blandford and S.T. Wang; Department of Civil Engineering;
University of Kentucky; Lexington, KY 40506-0046
NSF EPSCoR Computational Sciences Project

This investigation is an extension of the investigation being reported under the title "Behavior of Flexibly Connected Space Frames." The geometric nonlinear space frame analysis investigation includes: (1) formulation, (2) post-local-buckling behavior and (3) singly symmetric and unsymmetric members. The post-local-buckling behavior research will focus on the influence of stress gradients and torsion stresses on the strength of thin-walled members for doubly, singly and unsymmetric cross sections.

13.7 STABILITY AND LIMIT LOADS OF STEEL SPACE TRUSSES SUBJECTED TO LOCAL AND MEMBER BUCKLING (22)

S. T. Wang and G. E. Blandford; Department of Civil Engineering;
University of Kentucky; Lexington, KY 40506-0046
AISC and NSF EPSCoR Computational Sciences Project

The behavior of steel space truss structures under the interaction of local, member, and overall buckling is being investigated. Nonlinearities due to local buckling, member yielding or buckling, and geometric changes are considered. A finite element computer program based on both bifurcation and incremental solution schemes has been developed. A parametric study is being carried out. The results obtained will shed light on the effects of local buckling as well as member buckling on the global strength of space frames. This will provide better understanding of the interaction among buckling modes and the progressive failure pattern in the post-buckling domain.

XIV. COMPUTER AIDED DESIGN

NONE REPORTED.

XV. DYNAMIC BEHAVIOR OF STRUCTURES

15.1 DYNAMIC BEHAVIOR AND ANALYSIS OF THIN-WALLED PLANE FRAMES (3,4)

George E. Blandford; Department of Civil Engineering; University of Kentucky; Lexington, KY 40506-0046
University of Kentucky

The dynamic behavior and analysis of plane frames composed of thin-walled steel members is being investigated. Frame analysis includes post-local-buckling and/or first-order geometric nonlinearities. Post-local-buckling behavior is included using the effective width concept which includes both axial and bending stresses. Direct iteration is used to calculate the effective cross section properties for members which have locally buckled. An "exact" elastic stiffness matrix, finite element geometric stiffness, consistent mass and Rayleigh damping matrix formulation is used to discretize the dynamic equilibrium equations. The nonlinear dynamic equations are solved using a modified Newton-Raphson iteration strategy coupled with Newmark's time integration scheme. Dynamic wind simulations have demonstrated the importance of modeling first-order geometric nonlinearity and the inertia resistance provided by the static live loads. Additional work is underway to include inelastic flexible connection behavior and the influence of earthquake ground excitations on the response of the thin-walled frame system.

15.2 DYNAMIC INSTABILITY OF FRAMES HAVING THIN-WALLED COLUMNS (19)

Srinivasan Sridharan; Department of Civil Engineering; Washington University; St. Louis, MO 63130
National Science Foundation

Dynamic instability of single storey frames having thin-walled columns has been investigated. The lateral loads sustained by the frame are dynamic in character, while the axial loads are deemed to be quasi-statically applied. The analytical model employed has the capability of modelling the combined action of the two 'companion' local modes whose amplitudes are variable along the length of the column and any type of end conditions of the members.

For given levels of axial loads sustained by the columns, the magnitudes of lateral loads causing instability can be significantly smaller than those corresponding to static buckling, provided the dynamic load is of sufficient duration. There exists, however, a threshold value of axial force carried by the columns, below which there is no elastic instability - static or dynamic.

For columns with overall critical loads several times greater than the local critical load, there is no danger of elastic instability, but the deflections under dynamic lateral loads of less than one percent of the axial load may reach such huge values that there is a serious danger of localized plastic collapse. It is also shown that moment frames having thin-walled columns, such as those fabricated out of cold formed steel, are extremely vulnerable to moderate seismic excitation.

XVI. RELIABILITY ANALYSIS

NONE REPORTED.

XVII. FIRE RESISTANCE RATINGS**17.1 FIRE RESISTANCE OF COMPOSITE SLABS (12)**

R. M. Lawson and G. M. Newman; Steel Construction Institute; Sillwood Park, Ascot; Surry SL5 7PY, U.K.
British Steel Corporation, Fire Research Station, Construction Industry Research and Information Association

The fire resistance of composite floors has received considerable attention from designers and regulating authorities in the U.K. To resolve these concerns a series of large scale fire tests on composite floors with steel beams has been carried out. These tests showed that a fire resistance of 90 minutes could be achieved for continuous composite floors of up to 3 meters (10 ft) span with nonlinear mesh reinforcement in the concrete. Further thermal profile tests on composite slabs and composite beams are underway.

XVIII. TEXTS, SPECIFICATIONS AND COMMENTARIES**18.1 LOAD AND RESISTANCE FACTOR DESIGN OF COLD-FORMED STAINLESS STEEL STRUCTURAL MEMBERS**

Wei-Wen Yu; Department of Civil Engineering; University of Missouri-Rolla; Rolla, MO and T.V. Galambos; Department of Civil and Mining Engineering; University of Minnesota; Minneapolis, MN
American Society of Civil Engineers

This research project deals with the revision of the allowable stress design specification for cold-formed stainless steel structural members and the development of a draft standard and commentary for the design of stainless steel cold-formed steel structural sections according to load and resistance factor design methods.

18.2 LOAD AND RESISTANCE FACTOR DESIGN OF COLD-FORMED STEEL MEMBERS (9)

Wei-Wen Yu; Department of Civil Engineering; University of Missouri-Rolla; Rolla, MO and T.V. Galambos; Department of Civil and Mining Engineering; University of Minnesota; Minneapolis, MN
American Iron and Steel Institute

This research project deals with the development of the new AISI Load and Resistance Factor Design Specification for Cold-Formed Steel Structural Members. The proposed LRFD specification is compared with the allowable stress design specification.

XIX. OTHERS

NONE REPORTED.

CONCLUSIONS

Results of the survey reveal that a good mix of both applied and basic research is being performed on cold-formed steel structures. A majority of the reported research is being conducted at universities. Government, industry and universities are the primary sources of support for the research.

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