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Current Research on Cold-formed Steel Structures

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CURRENT RESEARCH ON COLD-FORMED STEEL STRUCTURES

George E. Blandford[1]

ABSTRACT

A survey of current research on cold-formed steel structures by the Subcommittee on Current Research and Future Needs of the Committee on Cold-Formed Members, Structural Division, American Society of Civil Engineers is reported. Survey results provide information on research currently being conducted worldwide as related to cold-formed steel structures. Research projects which have been initiated since the last survey conducted in 1987 are included in the present survey.

INTRODUCTION

A survey of current research on cold-formed steel structures has been conducted by the Department of Civil Engineering, University of Kentucky for 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 July, 1989 with a follow up mailing in January, 1990. The principal purposes of the survey are: (1)to assist the Subcommittee in preparing a report on the current research work being conducted in the cold-formed members area, (2) in planning future research needs, (3) maintaining or initiating contact with the investigators working in the field of cold-formed steel research, and (4) provide 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, Europe, India, Japan, People's Republic of China, Republic of China, Singapore, South Africa, South America and the United States. Completed question aires for 56 research projects in Australia, Belgium, Canada, England, France, India, Netherlands, Peoples Republic of China, Republic of China, Singapore, South Africa, Switzerland, United Kingdom and 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 are not reported.

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. 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.

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This is followed by a block of information which includes the name(s) of the principal investigator(s), 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 COLD WORK IN COLD FORMED STEEL AND ITS UTILIZATION
J.C.-Cheng, 20 Qinging Aingbin Road, Heilongjiang Institute of Low Temperature Construction Science, Harbin, CHINA
Sponsor: Planning Committee, People's Republic of China

The investigation focuses on the analytical development of two formulas to predict corner yield strength. Both equations are in very good agreement with test data and exhibit good universality and reliability. In order to apply the equations in design, simplified full section yield strength and design strength with the effects of cold work have been developed for Chinese Standard GBJ18-87. The equations are succinct and have sufficient accuracy, universality and reliability for engineering purposes. The equations are applicable to thin and thick wall shapes, to different a/t ratio corners and different forming techniques.

1.2 RESIDUAL STRESSES IN COLD-ROLLED PROFILES (22)
Jacques Rondal, Civil Engineering Institute, University of Liege, Quai Banning, 6, B-4000, Liege, BELGIUM
Sponsor: Belgian National Foundation for Scientific Research

The two objectives of the research are:
(1) Experimental determination of the residual stresses due to cold-rolling by means of a method which uses an air-abrasive hole drilling technique combined with an electro-chemical layer erosion. This method leads to the knowledge of the residual stresses through the thickness of the profiles.
(2) Preparation of a theoretical method for the prediction of the residual stresses based on the history of cold-rolled forming.

1.3 STRUCTURAL PERFORMANCE AND APPLICATIONS OF STAINLESS STEEL (5)
G.J. van den Berg, Department of Civil Engineering and P. van der Merwe, College of Engineering, P.O. Box 524, Johannesburg, f2000, SOUTH AFRICA
Sponsor: Chromium Centre

In co-operation with the University of Missouri-Rolla, research is being conducted on the structural performance and application of thin-walled cold-formed stainless steel structural members. The structural behavior of columns and beams including local and shear buckling is being investigated. The effect of cold work of forming and residual stresses on the structural behavior of structural members, which might differ from carbon steel, are also being investigated. Tests were carried out on welded and bolted connections.

II. STRENGTH OF THIN ELEMENTS

2.1 CAPACITY OF C- AND Z-SECTION PURLINS

Benjamin Wallace, Department of Civil Engineering, Fear Structural Engineering Laboratory, University of Oklahoma, Norman, OK 73019

Sponsor: Vulcraft, A Division of NUCOR Corporation, Grapeland, TX

The gravity load capacity of single and three span C- and Z-section purlins were experimentally determined and compared to capacities predicted using the 1986 AISI code. Supplementary tests include the shear strength of wall and roof panel assemblies and connection restraint measurements for standing seam clips.

2.2 OPTIMIZATION OF COLD-FORMED STEEL MEMBER EDGE STIFFENERS

C.C. Weng, Department of Civil Engineering, National Chiao-Tung University, Hsinchu, Taiwan, Republic of China

Sponsor: National Science Council of the Republic of China

To study the effect of edge stiffeners on the local buckling strength of thin-walled sections. The Finite Strip Method (FSM) is used to obtain an optimum length and angle of the edge stiffener design.

2.3 A REVIEW OF THE METHODS FOR PREDICTING YIELD STRENGTH OF COLD FORMED STEEL

J.C.-Cheng, 20 Qinging Aingbin Road, Heilongjiang Institute of Low Temperature Construction Science, Harbin, CHINA

Sponsor: Planning Committee, People's Republic of China

The AISI and CSA equations used to predict the yield strength of cold formed steel is compared with an equation developed by the investigator. Comparing test data with the generated equations leads to the conclusion the a modified AISI equation agrees with the test data for large a/t ratio corners and thick cold formed steel. Other situations also show good agreement with the developed modified AISI equation.

2.4 STRENGTH OF C- AND Z- PURLIN SUPPORTED STANDING SEAM ROOF SYSTEMS SUBJECTED TO GRAVITY LOADING

Thomas M. Murray, Department of Civil Engineering, Virginia Tech, Blacksburg, VA 24061

Sponsor: Metal Building Manufacturers Association and American Iron and Steel Institute

This project is concerned with determining the strength of C- and Z-purlin supported standing seam roof systems. Because of the wide variety of standing seam components, the study is experimental. A "base test method", where the results of a single span test are used to predict the strength of a multi-span system, is being verified. Results from eleven sets of tests show that the method is reliable.

2.5 STRENGTH OF STRUT PURLINS

Thomas M. Murray and W. Samuel Easterling, Department of Civil Engineering, Virginia Tech, Blacksburg, VA 24061

Sponsor: Metal Building Manufacturers Association and American Iron and Steel Institute

This study includes analytical and experimental investigations of strut purlins. These purlins are subjected to both uplift and axial loading. An AISI interaction equation is being used to predict the purlin strength. Full-scale tests are being conducted to verify the analytical results.

III. FLEXURAL MEMBERS

3.1 EXPERIMENTAL INVESTIGATION INTO THE BEHAVIOR OF THIN-WALLED BEAMS WITH DIFFERENT BOUNDARY CONDITIONS (8)

David B. Moore and D.M. Currie, Building Research Establishment, Garston, Watford WD2 7JR, UNITED KINGDOM

Sponsor: Construction Industry Directorate (Building Regulations)

A preliminary experimental investigation into the behavior of thin-walled steel beams with different boundary conditions, in particular different degrees of warping restraint, is being conducted at the Building Research Station. A test rig has been developed which enables the degree of warping restraint applied to the test beam at the supports to be varied by a system of restraint diaphragms.

3.2 STABILITY OF BUILT-UP BEAMS AND COLUMNS WITH THIN-WALLED MEMBERS

Jacques Rondal, Civil Engineering Institute, University of Liege, Quai Banning, 6, B-4000, Liege, BELGIUM

Sponsor: Metal Working Industry Scientific and Technical Research Centre

The aim of the research is to study the behaviour of beams and columns composed of two C thin-walled profiles connected by means of battened plates or by C stitches. In the experimental part of the research, 54 specimens have been tested.

IV. COMPRESSION MEMBERS

4.1 BUCKLING BEHAVIOR OF COLD-FORMED LIPPED CHANNELS WITH PERFORATED WEB

Bao-Kang He, Department of Civil Engineering, Xian Institute of Metallurgy and Construction Engineering, Xian, Shaanxi, PEOPLES REPUBLIC OF CHINA

Sponsor: China Technical Committee for Standards of Steel Structures

Finite element analysis is being used to investigate the buckling behavior of lipped channels with perforated compression webs. The buckling coefficient K, related to diameter of aperture and width of adjoining plate of perforated web, is given. Twenty-one cold-formed stub columns with lipped channels were tested. A method for determining the buckling load of perforated plates is suggested. The nonuniform stress distribution before and after buckling and the failure mechanism of the perforated plates were discussed. A proposed effective width formula for determining the ultimate car-

rying capacity of a perforated plate has been developed.

4.2 INFLUENCE OF LIPS ON THE STABILITY OF ANGLES AND FLANGES
Cedric Marsh, Centre for Building Studies, Concordia University, 1455 de Maisonneuve W., Montreal, CANADA H3G 1M8
Sponsor: National Science and Engineering Research Council, Canada

While the addition of lips to the ends of the flanges in I and C sections will increase the local buckling stress, in the case of angle section struts they reduce the critical stress for torsional buckling (there is no local buckling in angle struts). In I and C sections it is, in general, impossible to provide a lip that will fully support the edge of the flange without the lip itself becoming unstable. A rational design procedure has been developed. Experiments are being conducted.

4.3 INTERACTION OF BENDING AND WEB CRIPPLING IN RECTANGULAR HOLLOW SECTIONS
Gregory J. Hancock and Zhao Xiaoling, School of Civil and Mining Engineering, University of Sydney, Sydney, AUSTRALIA
Sponsor: Tubemakers (Australia) LTD

Tests on rectangular hollow sections subjected to combined bending and lateral force to produce web crippling have been performed. The lateral force has been applied by a branch member welded to the rectangular hollow sections. The branch member, which is itself a square hollow section, has a ratio of width to that of the section under test ranging from 0.5 to 1.0.

4.4 INTERACTIVE BUCKLING OF COLD FORMED SECTIONS (14)
P. Leach, Department of Civil Engineering, University of Salford, Salford M5 4WT, ENGLAND
Sponsor: Department of Civil Engineering, University of Salford

A method of analysis is presented in (14) which allows both rigid body movement and cross section distortion (including local buckling). Using finite difference techniques, this method can be used to solve second order elastic critical buckling problems, including the interaction of local buckling, overall buckling and cross section distortion.

4.5 LATERALLY UNSUPPORTED COMPRESSION FLANGES
Teoman Pekoz, School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853
Sponsor: American Iron and Steel Institute

Local buckling and post-buckling behavior of laterally unsupported flanges of sections are being studied. In this project, standing seam and other types of panes are being investigated as well.

4.6 STUB COLUMN TESTS
K.H. Klippstein and L.R. Daudet, Department of Civil Engineering, University of Pittsburg, Pittsburg, PA 15261
Sponsor: Dietrich Industries

Investigations on 70 stub columns with (a) solid webs, (b) round

plus oval holes, and (c) different end conditions. Work is aimed at developing effective areas for studs with holes loaded in compression and simplifying test procedures.

V. BEAM-COLUMNS

5.1 BEHAVIOUR OF THIN-WALLED STEEL BOX COLUMNS SUBJECTED TO BIAXIAL LOADING (21, 23)
S. L. Lee and N. E. Shanmugam, Department of Civil Engineering, National University of Singapore, Kent Ridge, SINGAPORE 0511
Sponsor: National University of Singapore

The object of the project is to investigate the strength and behavior of pin ended steel box columns built-up of thin plates and subjected to biaxial loading. Effect of local buckling of component plates, overall column buckling and interaction of local and overall buckling on the strength of these columns is studied. Comprehensive effective width formulae have been proposed to predict the sub-ultimate and ultimate strength of simply supported plates subjected to uniform compression and bending. They are used to study the behavior of thin-walled box columns under biaxial loading. Extensive test programs are in progress in which box-column models are tested to failure. The columns are subjected to compressive loading applied with biaxial eccentricity. The failure loads are used to establish the accuracy of the proposed method. Simplified design formulae are being proposed for these columns and the formulae will account for the effect of residual stresses and local buckling of component plates on the ultimate column strength.

5.2 INTERACTION OF LOCAL AND DISTORTIONAL BUCKLING IN COLD-FORMED SECTIONS (13)
Gregory J. Hancock and Y.B. Kwon, School of Civil and Mining Engineering, University of Sydney, Sydney, AUSTRALIA
Sponsor: Australian Research Council

A finite strip nonlinear elastic analysis has been developed to study the interaction of local and distortional buckling in cold-formed sections. Sections are currently being studied both experimentally and analytically.

5.3 INTERACTIVE STABILITY ANALYSIS OF THIN-WALLED OPEN SECTIONS BY p-VERSION OF FINITE ELEMENT METHOD (1)
P.K. Basu, Department of Civil Engineering, Vanderbilt University, P.O. Box 15-B, Nashville, TN 37235
Sponsor: National Science Foundation and Vanderbilt University

Local, overall, and interactive buckling as well as general and local collapse are important considerations in the design of thin-walled members for applications related to aerospace, ship building, manufacturing and construction industries. The p-version of the FEM has been found to be the most reliable and efficient modeling scheme for these phenomena on a digital computer. As a part of this effort, a finite element code has been developed so that the aforementioned behaviors could be modeled accurately. The effect of residual stresses was included. Prismatic and tapered members

with open and closed sections, and subjected to axial compression and flexural loads were modeled with just as many finite elements as there were component plates. A series of parametric studies were undertaken for a wide range of cross-sectional shapes which led to deeper insight into the instability characteristics of such members. All possible buckling modes could be realized with the same model. As a result of these studies a series of charts were developed that may prove to be useful for design purposes.

5.4 PERFORATED COLD-FORMED STEEL COLUMNS
Teoman Pekoz, School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853
Sponsor: Rack Manufacturers Institute

Design approaches for the types of perforated columns and beam-columns used in industrial storage racks are being developed.

5.5 ULTIMATE STRENGTH OF COLD-FORMED STEEL COLUMNS
C.C. Weng, Department of Civil Engineering, National Chiao-Tung University, Hsinchu, Taiwan, REPUBLIC OF CHINA
Sponsor: National Science Council of the Republic of China

To develop a computer program which accounts for the effects of residual stress and initial out-of-straightness on the column strength. The program is based on Jezek's approximation of beam-column theory.

VI. CYLINDRICAL TUBULAR MEMBERS

6.1 COLD-FORMED STAINLESS STEEL TUBULAR COLUMNS
Gregory J. Hancock and Kim J.R. Rasmussen, School of Civil and Mining Engineering, University of Sydney, Sydney, AUSTRALIA
Sponsor: BHP Coated Products Division - Stainless

Tubular columns of both circular and rectangular hollow section are being tested between pinned ends to determine appropriate column design procedures. In particular, the effect of cold-work in the manufacturing process on both the yield stress and the Young's modulus is being accounted for in the design procedure.

VII. CONNECTIONS

7.1 EXPERIMENTAL INVESTIGATION INTO THE BEHAVIOR OF PURLIN CONNECTIONS
David B. Moore, Building Research Establishment, Garston, Watford WD2 7JR, UNITED KINGDOM
Sponsor: Construction Industry Directorate (Building Regulations)

An experimental investigation into the behavior of sheared and unsheared zed, zeta and sigma purlin connections has been undertaken at the Building Research Establishment. The aim of this investigation is the formulate design rules for predicting the moment-rotation characteristics of purlin connections. The results of this work will be presented at the Tenth International Specialty Conference on Cold-Formed Steel Structures in October 1990.

7.2 JOINT BEHAVIOUR IN COLD ROLLED STEEL SECTIONS (6)
E. R. Bryan and P. Leach, Department of Civil Engineering, University of Salford, Salford M5 4WT, ENGLAND
Sponsor: Science and Engineering Research Council (UK)

To carry out a theoretical and experimental investigation into the load/slip and moment/rotation characteristics of bolted joints in cold rolled steel assemblies and structures, and to draw up design rules. To consider the effect of such semi-rigid joints on the elastic behavior of structures and, depending on the rotation capacity of the joints, to consider whether limited plastic design is feasible.

7.3 INFLUENCE OF THE SEAM FASTENERS ON THE STRENGTH AND STIFFNESS OF STRESSED SKIN DIAPHRAGMS
Jacques Rondal, Civil Engineering Institute, University of Liege, Quai Banning, 6, B-4000, Liege, BELGIUM
Sponsor: Metal Working Industry Scientific and Technical Research Centre

The aim of the research is to study the influence of the number of seam fasteners on the strength and stiffness of stressed skin diaphragms utilizing trapezoidally profiled steel sheets. Twenty-four tests have been performed on complete shear panels, They have shown that a decrease of the number of seam fasteners does not significantly influence the strength of the diaphragm but can lead to a fragile like failure.

7.4 THERMAL PERFORMANCE OF LONG SPAN ROOFS
R.M. Lawson, Steel Construction Institute, Silwood Park, Buckhurst Road, Ascot, Berks SL5 7QN, GREAT BRITAIN
Sponsor: British Steel (Strip Products Group)

There is some evidence of tearing of fasteners in industrial buildings where long sheets are used (up to 20 meters or 65 feet. Finite element analyses of typical long span roofs have been carried out using 'spring' stiffeners associated with the fasteners and purlin-rafter connections. An interim (confidential) report on the problem has been prepared.

7.5 UPLIFT STRENGTH OF WELDED CONNECTIONS
Wei-Wen Yu and Roger A. LaBoube, Department of Civil Engineering, University of Missouri-Rolla, Rolla, MO 65401
Sponsor: American Iron and Steel Institute

The objective of this research project is to experimentally study the tensile strength of arc spot welds and arc seam welds for connecting roof decks to support beams. General design provisions will be developed from the available test results.

VIII. SHEAR DIAPHRAGMS

NONE REPORTED

IX. CORRUGATED SHEETS AND FORMED PANELS

9.1 AUTOMOTIVE STRUCTURAL COMPONENTS USING HIGH STRENGTH SHEET STEELS (19)
Wei-Wen Yu, Department of Civil Engineering, Department of Civil Engineering, University of Missouri-Rolla, Rolla, MO 65401
Sponsor: 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, (4) effect of strain rate on mechanical properties, (5) strength of automotive components under dynamic loads, and (6) development of new design criteria.

9.2 DESIGN OF STRUCTURAL SANDWICH PANELS (10)
J.M. Davies, J.B. McNicholas and M.R. Hakmi, Department of Civil Engineering, University of Salford, Salford M5 4WT, ENGLAND
Sponsor: Marinetech North West

Structural sandwich panels are frequently manufactured with thin metal faces, which may be flat or profiled, and a lightweight core. The core is generally a foamed plastic (polyurethane, polystyrene, etc.) though a wide variety of materials are technically possible. Other layers of non-combustible material may also be incorporated in order to improve the fire resistance. The scope of this research covers a wide variety of topics including fire resistance and the development of new materials and material combinations. In the context of this survey, a primary subject area is the local buckling of thin metal elements supported by foam core material.

9.3 LATERAL RESTRAINT TO PURLINS WITH THICK OVER-PURLIN INSULATION
R.M. Lawson, Steel Construction Institute, Silwood Park, Buckhurst Road, Ascot, Berks SL5 7QN, GREAT BRITAIN
Sponsor: British Steel (Strip Products Group)

As standards of thermal insulation in industrial buildings increase, it is necessary to consider how the secondary members such as purlins are restrained by the sheeting where the insulation passes over the purlins. The study has so far been analytical in terms of predicting the critical buckling moment of the purlins. It is intended (the subject of a further proposal) to experimentally verify the analytical results for large scale tests on purlin-roof assemblies.

X. PLATE STRUCTURES

10.1 NON-LINEAR FINITE STRIP ANALYSIS OF STIFFENED PLATES (2)
V. Kalyanaraman, Structural Engineering Laboratory, Dept. of Civil Engineering, Indian Institute of Technology, Madras-600 036, INDIA
Sponsor: Aeronautical Research and Development Board, India

Finite Strip Analysis is an effective and efficient method of analyzing prismatic plated members, since the number of degrees of

freedom in the finite strip model is usually far less than what it would be in the case of finite element model. This advantage becomes even more important, when repeated analysis is necessary as in the case of non-linear analysis. Software has been developed for the analysis of local, overall instability and interaction behaviour of plated members subjected to in plane and out of plane loading. Trigonometric functions for the deflected shape along the strips and exponential functions for across the strip deflected shape have been used. The software can also analyze orthotropic plates and hence can be used for the analysis of members made of symmetric, balanced layered fibre composite elements. Currently, the program is being enhanced to handle different boundary conditions, cross stiffeners and cut-outs in stiffened panels, which are frequently encountered in practice. Furthermore, graphic interface is being included to obtain finite strip model, deflected shapes and stress intensities.

XI. SHELL STRUCTURES

NONE REPORTED

XII. COMPOSITE CONSTRUCTION

12.1 ANALYSIS AND DESIGN OF COLD-FORMED STEEL AND COMPOSITE MEMBERS

Shiji Wang, Xuhong Zhou and Xingping Shu, Department of Civil Engineering, Hunan University, Changsha 410012, PEOPLES REPUBLIC OF CHINA

Sponsor: Foundation of the Chinese State Education Commission.

There are three sub-items included in the project:

(1) torsional-flexural buckling of open thin-walled beam-columns under unequal terminal moments and/or transverse loading;

(2) post-buckling strength and effective width of plate element subjected to combined compression and bending under various boundary conditions; and

(3) strength and design criterion of composite cold-formed steel-concrete members.

12.2 BEHAVIOR AND ULTIMATE STRENGTH OF COMPOSITE SLABS WITH COLD-FORMED STEEL DECKING (7, 9)

Michel Crisinel and Byron T. Daniels, Department of Civil Engineering, Institute for Steel Structures (ICOM), Swiss Federal Institute of Technology, Lausanne, SWITZERLAND

Sponsor: Swiss Federal Institute of Technology at Lausanne (Switzerland) and different cold-formed steel producers

Cold-formed steel sheeting and composite slabs have been a subject of active research at ICOM, steel structures institute of the Swiss Federal Institute of Technology at Lausanne, since 1972. Currently, a series of experimental and theoretical investigations are nearing completion. This research has the following goals:

1. The observation of single and multi-span composite slab behaviors. This includes anchored and non-anchored composite slabs.
2. The development of an analytical model from which a parametric analysis of composite slab behavior and ultimate strengths may

be performed.

3. The development of a simplified design method, similar in nature to design methods for other composite elements.

To meet these goals the following investigations were completed or are underway:

Single span slab tests: Two tests series were conducted. The first test series examined different rib geometries. The second test series examined the different failure modes for one decking.

Pull-out tests: A simple pull-out test was developed to investigate decking-slab interaction. The effects of force normal to the direction of slip, specimen length, decking thickness and concrete strength were investigated.

Multi-span slab tests: A series of three-span composite slab test were undertaken. Negative moment reinforcement, embossments, end anchorage and decking thickness were investigated.

Non-linear analysis with partial connection: A program was developed to analyze composite slabs. This analysis allows for non-linear material behavior due to decking and reinforcing yielding, and concrete cracking. In addition, non-linear connection behaviors are allowed.

Development of simplified design method: Comparisons between program and test results are used to determine important geometric and material properties. A simplified design method based upon partial interaction theory is being developed.

12.3 COMPOSITE BEAMS WITH PROFILED STEEL SHEETING AND NON-WELDED SHEAR CONNECTORS (18)

D.C. O'Leary, Department of Civil Engineering, University of Salford, Salford M5 4WT, ENGLAND; D.A.B. Thomas and W.S. Atkins, Consulting Engineers, Warrington, ENGLAND

Sponsor: Science and Engineering Research Council

Steel-concrete composite construction has increased greatly in recent years. A non-welded shear connector, exhibiting some advantages over a welded system, has recently been developed. Its performance and design have been evaluated through a series of full-scale beam tests at the University of Salford. A joint programme with Cardiff University involved push-out tests and 7.5m span beams using lightweight concrete. The beams were subjected to static and cyclic loading. Two types of profiled steel sheet were employed and the behavior with sheets running parallel and transverse to the underlying beam was investigated. The preliminary conclusions suggest that the system performs satisfactorily and may be designed using linear interaction theory down to 40% partial connection.

12.4 COMPOSITE SLABS (15)

J.W.B. Stark and J.W.P.M. Brekelmans, Department of Steel Structures, TNO-IBBC, P.O. Box 49, 2600 AA Delft, NETHERLANDS

Sponsor: Centre for Civil Engineering Research, Codes and Specifications (CUR) and the Steel Construction Association (SG)

The aim of the project, carried out over the last five years, was to ascertain the "state of the art" for composite slabs and to prepare Dutch regulations for this type of structure. Because there were gaps, some experimental research has been carried out. For

example, a ECCS sponsored comparison of test-procedures between France, UK and the Netherlands.

12.5 COMPOSITE SLABS WITH PROFILED STEEL SHEETING (24)

D.C. O'Leary, University of Salford,Salford M5 4WT, ENGLAND; J.W.P. M. Brekelmans, Department of Steel Structures, TNO-IBBC, P.O. Box 49, 2600 AA Delft, NETHERLANDS; and C. Moun, C.T.I.C.M., Domaine de Saint Paul, F - 78470, St. Remy - Les - Chevreuses, FRANCE

Sponsor: European Economic Community, Commission DG X 111 - Telecommunications, Information Industry and Innovation

The calculation or the certification of floor systems composed of profiled metal decking and concrete (composite floor slabs) varies among many countries in Europe and is based on different procedures. The design rules (ultimate or service limit state designs), the requirements for load actions and load factors, the testing procedure which allow to asses the slip resistance between the concrete and the corrugated steel deck are different. This work was carried out:

to facilitate the exchange of information on current practice within France, United Kingdom and Netherlands;

to test existing products in different laboratories according to the National Standards of the three above-mentioned countries; and

to carry out a statistical evaluation of the test results for each product and to make comparison between the derived values and the load values used in the various countries.

12.6 COMPOSITE SPACE DECKS (12)

D.C. O'Leary, Department of Civil Engineering, University of Salford, Salford M5 4WT, ENGLAND

Sponsor: Space Decks Ltd.

The objectives of this research were to analyze and investigate the behavior of a composite space frame. The space frame is assembled from individual inverted square-base pyramids. Each pyramid consists of a steel angle section top-tray and diagonals. When the top trays are connected together, they form the top-chord members of a double-angle section connected back to back. The investigation is primarily concerned with the composite section within the space frame system which comprises the top chord members, profiled steel sheeting and a concrete slab. This composite section is also assumed to work as a system of intersecting composite T-beams. Each composite T-beam comprises a top chord member, a certain width of profiled steel sheet and a concrete slab. The composite action is ensured by a series of self-tapping screws. The investigation of the behavior of the composite T-beams with different locations and numbers of shear connectors together with the analysis of the structures comprise the main part of this work.

12.7 ECONOMIC DESIGN OF COMPOSITE DECKING

R.M. Lawson, Steel Construction Institute, Silwood Park, Buckhurst Road, Ascot, Berks SL5 7QN, GREAT BRITAIN

Sponsor: British Steel (Strip Products Group)

The design of composite decking in the construction stage is limited by the requirement for 'elastic conditions' to hold at the

ultimate limit state. This is very conservative for continuous decking and the research is aimed at developing design rules, taking account of partial 'plastification' at the supports. This may lead to the design of long-span decks (up to 4.5 m (15 ft)).

12.8 STRENGTH DETERMINATION OF MULTI-SPAN STEEL DECK REINFORCED CONCRETE FLOOR SYSTEMS

W. Samuel Easterling, Department of Civil Engineering, 200 Patton Hall, Virginia Tech, Blacksburg, VA 24061

Sponsor: Steel Deck Institute

The research project is investigating the strength of multi-span steel deck reinforced concrete floor systems. A major objective of the project is to establish the strength of test specimens that represent the field conditions more accurately than the traditional single span, single panel wide test set-up that is described in the ASCE Standard on composite slabs. Particular attention is being paid to details such as: the influence of adjacent spans and various pour stop details on preventing shear bond failures; testing the specimens in the same location in which they were cast; and testing slabs that are two panels wide instead of only one. The test results will be used to verify a simplified design procedure for SDRC floor systems.

12.9 STRENGTH OF COMPOSITE COLD-FORMED STEEL-CONCRETE FLEXURAL MEMBERS (18)

Richard P. Nguyen, Department of Civil Engineering, California State University, Long Beach, CA 90840

Sponsor: CSU Long Beach Foundation

An experimental investigation has been conducted at California State University, Long Beach to study the structural behavior of composite beams made of thin-walled cold-formed steel stiffened channel and concrete subjected to bending, shear and a combination of bending and shear. Empirical formulas have also been developed to compute the ultimate bending and shear capacities of these composite members.

XIII. STRUCTURAL SYSTEMS

13.1 CONTINUOUS PURLINS UNDER SIMULATED WIND UPLIFT - VACUUM TEST RIG

Gregory J. Hancock, School of Civil and Mining Engineering, University of Sydney, Sydney, AUSTRALIA

Sponsor: Metal Building Products Manufacturers Association of Australia

A 21.0 m x 4.0 m vacuum test rig is being used to test continuous purlins of Z-section subjected to wind uplift. The sheeting is screw fastened to the purlins in the current test series.

13.2 DESIGN OF COLD-FORMED STEEL WALL STUDS
Teoman Pekoz, School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853
Sponsor: American Iron and Steel Institute and Metal Lath Steel Framing Association

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 project is aimed at improving the current design specifications.

13.3 ECONOMICS OF STRUCTURAL LINER TRAYS IN ROOFS AND WALLS
R.M. Lawson, Steel Construction Institute, Silwood Park, Buckhurst Road, Ascot, Berks SL5 7QN, GREAT BRITAIN
Sponsor: British Steel (Strip Products Group)

In the UK, purlins, and built-up roofs are common. Alternatively, structural linear trays may be used to replace purlins and side rails by spanning directly between frames. Potentially, the structural liner tray system could be economic in cases where thick insulation is used. The study considers the design and relative economies of structural liner trays for walls and roofs. It also enhances the restraint provided to the main structural members in the frame.

13.4 STABILITY AND NONLINEAR ANALYSIS OF STEEL SPACE FRAMES WITH FLEXIBLE CONNECTIONS AND PARTIAL WARPING RIGIDITY
G.E. Blandford and S.T. Wang, Department of Civil Engineering, University of Kentucky, Lexington, KY 40506-0046
Sponsor: National Science Foundation and University of Kentucky Center for Computational Sciences

An investigation into the stability and nonlinear behavior of space frames including the effects of partially restrained connections and warping rigidity is being carried out. Nonlinear geometric effects are included via a finite element geometric stiffness matrix which includes warping deformation. A separate connection finite element is used to model flexural joint behavior. A parametric study is being conducted to investigate the effects due to connection stiffness, joint warping restraint, member orientation, loading patterns, etc. on the stability and nonlinear behavior of space frames composed of cold-form steel members.

13.5 STABILITY AND POST-BUCKLING ANALYSIS OF LOCALLY BUCKLED STEEL SPACE TRUSSES (25)
S.T. Wang and G.E. Blandford, Department of Civil Engineering, University of Kentucky, Lexington, KY 40506-0046
Sponsor: National Science Foundation and University of Kentucky Center for Computational Sciences

A methodology to perform nonlinear post-buckling analysis of steel space trusses is being investigated. Structural behavior is modeled at the element level through appropriate stress-strain relationships. Nonlinearities due to member buckling or yielding and local buckling of the member component plates are modeled using

a tangent elastic modulus in calculating the element stiffness matrix. First-order geometric effects are included using a geometric stiffness matrix. Second-order effects are included through an updated Lagrangian formulation. The developed method traces the sequence of local buckling and member buckling until eventual failure of the structure. Consequently, the developed computer code can result in a better understanding of the failure mechanism and lead to formulating design criteria for steel space truss systems.

13.6 STABILITY OF UNBRACED PALLET RACKS (26)

Y.C. Zhang, Structural Engineering Department,Harbin Architectural and Civil Engineering Institute, Harbin, PEOPLES REPUBLIC OF CHINA; and Jun Liu and Hua Yi, Designing Consultants Ltd. 14F, No. 20F The Office Building, C. Shennan Road, PEOPLES REPUBLIC OF CHINA

Sponsor: Zhongnan Building Design Institute, China

Tests show that unbraced pallet racks, because of their flexible connections and the PΔ effect, are likely to fail through instability before the uprights and beams get into the inelastic region. Therefore the determination of the ultimate capacity of unbraced pallet racks for this failure mode becomes very important. Second-order instability analysis considering the influence of inelastic behavior of the connections and experimental studies have been conducted for the single-story single-bay unbraced pallet racks in this investigation. The results of analysis and experiments are very close. Further tests and studies on multi-story, multi-bay unbraced pallet racks are needed.

XIV. COMPUTER AIDED DESIGN

NONE REPORTED

XV. DYNAMIC BEHAVIOR OF STRUCTURES

15.1 DYNAMIC ANALYSIS OF COLD FORMED STEEL STRUCTURES

P. Leach, Department of Civil Engineering, University of Salford, Salford, M5 4WT, ENGLAND

Sponsor: Department of Civil Engineering, University of Salford

Research on the dynamic behavior of cold formed section is concentrating on two areas:

(i) response of cold formed panels to blast loading; and
(ii) vibration response of lightweight panels.

Work in these areas is still at an early stages

XVI. RELIABILITY ANALYSIS

16.1 RELIABILITY MODELS OF LOAD TESTING (20)

W. Brent Hall, Department of General Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801

Sponsor: National Science Foundation

Reliability methods are used to revise the estimates of structural strength or safety using information from load tests and other structural information. Applications include testing of cold-formed steel structural elements and members, among others.

XVII. FIRE RESISTANCE RATINGS

NONE REPORTED

XVIII. TEXTS, SPECIFICATIONS AND COMMENTARIES

18.1 COLD-FORMED STEEL DESIGN AIDS
Paul A. Seaburg, Department of Architectural Engineering, Penn State University, University Park, PA 16802
Sponsor: Penn State University

Subcommittee 19 of the AISI Advisory Group has initiated the development of a number of design aids covering major uses of cold-formed steel products. These aids will clearly define the proper use of the AISI Specifications and point out acceptable practices on topics not covered. The first project will cover multi-span Z purlins as typically used in metal buildings.

18.2 COMPENDIUM OF COLD FORMED SECTIONS
R.M. Lawson, Steel Construction Institute, Silwood Park, Buckhurst Road, Ascot, Berks SL5 7QN, GREAT BRITAIN
Sponsor: British Steel (Strip Products Group)

To prepare a compendium of cold formed sections marketed in the UK and to present section properties and load-span tables for members designed to BS 5950 part 5 and the European Recommendations (ECCS Technical Committee TC7). This study is intended to result in a publication by the Institute.

18.3 LOAD AND RESISTANCE FACTOR DESIGN OF COLD-FORMED STAINLESS STEEL STRUCTURAL MEMBERS (16)
Wei-Wen Yu, Department of Civil Engineering, University of Missouri-Rolla, Rolla, MO 65401 and Theodore V. Galambos, Department of Civil and Mining Engineering, University of Minnesota, Minneapolis, MN 55455
Sponsor: American Society of Civil Engineers

This research project deals with the development of the ASCE ASD and LRFD standards for the design of cold-formed stainless steel structural members and connections.

18.4 LOAD AND RESISTANCE FACTOR DESIGN OF COLD-FORMED STEEL MEMBERS (11)
Wei-Wen Yu, Department of Civil Engineering, University of Missouri-Rolla, Rolla MO 65401 and Theodore V. Galambos, Department of Civil and Mining Engineering, University of Minnesota, Minneapolis, MN 55455
Sponsor: American Iron and Steel Institute.

This research project deals with the development of the new AISI LRFD Specification for the Design of Cold-Formed Steel Structural Members and the preparation of the AISI LRFD Design Manual. The proposed LRFD Specification has been compared with the AISI ASD Specification.

18.5 MANUAL FOR THE APPLICATION OF COLD FORMED SECTIONS

A.W. Toma, Department of Steel Structures, IBBC-TNO, P.O. Box 49, 2600 AA Delft, NETHERLANDS

Sponsor: European Coal and Steel Community, European Cold Rollers Association

Drafting a survey for people who have the responsibility to decide the choice of material. Besides providing material knowledge, numerous applications of cold formed sections will be given.

18.6 SANDWICH PANEL APPLICATIONS

A.W. Toma, Department of Steel Structures, IBBC-TNO, P.O. Box 49, 2600 AA Delft, NETHERLANDS

Sponsor: Dutch Steel Industry

Drafting recommendations for the application of sandwich panels:
listing the requirements;
calculation methods for panels loaded in bending; and
testing procedures.

XIX. OTHERS

19.1 NEW HOUSING CONCEPT (3,4)

J.O. Bats and J.F.G. Janssen, University of Technology, Eindhoven, NETHERLANDS

Sponsor: University of Technology, Faculty of Architecture Building and Planning, Eindhoven, The Netherlands

This project investigates the concept of industrializing house production. The concept combines four essential points: design-independent mass production; considerable influence of occupant's wishes on lay-out and finish in combination with industrialized production; optimal use of CAD-CAM in design production; and logistic management. Use of special mass-produced elements of cold-formed steel sheets for home and low rise office buildings has been found to be advantageous.

CONCLUSIONS

Results of the 55 projects included in 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. As might be expected, the largest share of the reported research is being conducted in the United States (≈ 33%) followed by the United Kingdom (≈ 25%). Other significant contributing countries are: People's Republic of China (5 projects), Netherlands (5 projects), Australia (4 projects), and Belgium (3 projects). Most research is being conducted in the area of composite construction (9 projects) followed by the compression members, structural systems, and texts, specifications and commentaries areas with six projects each. The strength of thin elements, beam-columns and connections areas each report five ongoing projects. No project work has been reported for the shear diaphragms, shell structures, computer aided design, and fire resistance ratings areas. Only one project is reported for each of the following areas: cylindrical tubular members, plate

structures, dynamic behavior of structures and reliability analysis.

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