Wei-Wen Yu Center for Cold-Formed Steel Structures

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Abstracts of Conference Papers for 19th International Specialty Conference on Cold-Formed Steel Structures 2008

On October 14th and 15th, 2008 the 19th International Specialty Conference on Cold-Formed Steel Structures will be held in St. Louis, Missouri. For further information regarding the conference, contact the Wei-Wen Yu Center for Cold-Formed Steel Structures (Telephone: 573-341-4471, Fax: 573-341-4476, e-mail: ccfss@mst.edu), or visit our website at http://ccfssonline.org for a pdf copy of the brochure and program as well as online registration. This Technical Bulletin provides a brief summary of the papers that are scheduled to be presented and will appear in the conference proceedings.

"Floor System Design for Distortional Buckling Including Sheathing Restraint," Schafer, B.W., Sangree, R.H., Guan, Y.

The objective of this paper is to describe how to include the beneficial rotational restraint, provided by sheathing to the compression flange of a cold-formed steel floor joist, to partially or fully retard the formation of distortional buckling. The design method for checking distortional buckling adopted in the 2007 AISI Specification (AISI-S100-07) provides a means to include a rotational restraint term, k?, to account for sheathing restraint. A series of cantilever tests were conducted to determine the rotational stiffness, k?, between a joist and attached sheathing. Tests were conducted for different joist thicknesses, depths, and flange widths, two fastener types, and plywood, oriented strand board, and gypsum board sheathing. The testing lead to (a) the development of a proposed design method, and (b) improvements to the AISI test standard for cantilever tests; both of which are presented herein. The focus of the design method and the improvements to the test standard are the separation of the rotational stiffness, k?, into contributions from the sheathing and from the local fastener (connector) deformations. It is shown that the sheathing stiffness is well correlated with tabled bending rigidity values, and the connector stiffness is primarily derived from the thickness of the flange. The developed recommendations have been proposed for the next edition of AISI standards and are presented in an Appendix.

"Simplified Methods for Predicting Elastic Buckling of Cold-Formed Steel Structural Members with Holes," Cristopher D. Moen , B.W. Schafer

Simplified methods for approximating the local, distortional, and global critical elastic buckling loads of cold-formed steel columns and beams with holes are developed and summarized. These methods are central to the extension of the Direct Strength Method (DSM) to members with holes, as DSM employs elastic buckling properties to predict ultimate strength. The simplified methods are developed as a convenient alternative to shell finite element eigenbuckling analysis, which requires commercial software not always accessible to the engineering community. A variety of simplified methods are pursued including (a) hand methods founded primarily on classical plate stability approximations and (b) empirical extensions to the semi-analytical finite strip method (i.e., modifying and using the freely available, open source software, CUFSM). The proposed methods are verified with shell finite element eigenbuckling studies. The developed simplified methods are intended to be general enough to accommodate the range of hole shapes, locations, and spacings common in industry, while at the same time also defining regimes where explicit use of shell finite element analyses are still needed for adequate accuracy.

"**Generalized Beam Theory Formulation Able to Capture Load Application and Localized Web Buckling Effects," Nuno M.F. Silva, Dinar Camotim and Nuno Silvestre**

This paper presents the formulation and illustrates the application of a novel Generalized Beam Theory (GBT) formulation able to handle the influence of localized effects on the buckling behavior of prismatic thin-walled members (e.g., cold-formed steel profiles) for instance, this formulation accounts for effects stemming from (i) the position of transverse loads

(with respect to cross-section shear centers) or (ii) the occurrence of web buckling phenomena (e.g., web crippling). In order to achieve this goal, the GBT formulation traditionally employed in buckling analyses must be enhanced by including specific (i) non-linear terms and (ii) transverse extension modes. Due to its unique modal nature and computational efficiency, this GBT formulation/implementation is a very advantageous alternative to shell finite element analyses at present, the only available method to capture the above localized effects rigorously. In order to illustrate the application and capabilities of the proposed GBT formulation-implementation, one presents and discusses numerical results concerning the buckling behavior of (i) hat and I-section cantilevers acted by transverse tip point loads applied at various cross-section points, and (ii) I-section simply supported beams under top-flange distributed and point loads - one also assesses how end support transverse web stiffeners improve the beam buckling behavior. For validation, the GBT results are compared with values reported in the literature and/or yielded by ABAQUS shell finite element analyses.

“GBTUL - A Code for the Buckling Analysis of Cold-Formed Steel Members,” Rui Bebiano , Nuno Silvestre and Dinar Camotim

This paper presents GBTUL 1.0 , a code to perform buckling and vibration analyses of open-section cold-formed members that is now available online as freeware. This code, developed at the Department of Civil Engineering and Architecture of the Technical University of Lisbon (ICIST/IST - UTL), constitutes the numerical implementation of a recent Generalized Beam Theory (GBT) formulation - GBT is a thin-walled beam theory that incorporates local deformation and discretizes a member deformed configuration (e.g., a buckling or vibration mode shape) into a linear combination of cross-section deformation modes with longitudinally varying amplitudes. After presenting a very brief overview of the GBT formulation, one addresses the GBTUL 1.0 graphic user interface and describes its main commands. Finally, the paper closes with an illustrative example: the application of the code to analyze the buckling behavior of a lipped channel cantilever beam - particular attention is paid to the quality of the code graphic outputs (2D and 3D mode shape representations).

"Impact of Global Flexural Imperfections on the Cold-Formed Steel Column Curve," Schafer, B.W., Zeinoddini, V.M.

Due to inherent complications in manufacturing and installation global out-of-straightness imperfections in cold-formed steel columns may sometimes be greater than L/960, which is the maximum amount assumed in North American cold-formed steel design specifications. The correction that should be applied to currently used column design curves to account for imperfections larger than L/960 is unknown. To find this correction the strength of typical cold-formed steel columns with explicit imperfections is determined using a geometric and material nonlinear beam finite element solution, and a closed-formed solution. The closed-formed solution is shown to agree well with the finite element solution and accurately recreates the current design specification column curves at the L/960 imperfection level. The closed-formed solution is used as the basis for predicting reductions in the nominal column stress for columns with imperfections that are greater than L/960. The developed solution is recommended in design for those situations in which large out-of-straightness imperfections are encountered.

"Computed Flexural Buckling Stress for Cold-Formed Stainless Steel Columns," Shin-Hua Lin , Chi-Ling Pan and Chih-Peng Yu

For the design of cold-formed stainless steel compression members, the ASCE Standard Specification can be used to determine the design axial strength. Due to the nonlinear stress strain behavior of the material, the design of stainless steel compression member is more complex than those of carbon steels. Instead of using the modulus of elasticity (Eo), the non-linear tangent modulus (Et) were used for the design of cold-formed stainless steel columns. In this case, iterative procedures are needed to calculate the column buckling stress. Consequently, a simplified approach is developed to compute the column flexural buckling stress while without iterative process. In this simplified formulation, mathematical operation was utilized for numerical approximations. It is shown that the column strengths computed by the simplified formulas had good agreement with those determined by the ASCE Standard Specification. The simplified formulas are proposed to calculate the flexural buckling stress of cold-formed stainless steel columns. This paper presents the development of the proposed formulas for the design of stainless steel columns.

“Stability of Cold-Formed Steel Simple and Lipped Angles Under Compression,” W. F. Maia , J. Munaiar Neto, and M. Malite

The structural analysis of a simple angle under axial compression appears to be an elementary and therefore well known problem. However, cold-formed angles, especially those with slender legs, present two critical modes: (i) global flexural mode, in the case of long members, and (ii) a coincident local-plate/global-torsional mode (herein dubbed L/T), which is critical for shorter members. Recent works indicate that considering the L/T mode as a global mode is too conservative,

while other works indicate the need for this approach. The present work involves an in-depth investigation of the structural response of simple and lipped angles subjected to centered and eccentric compression, by means of experimental and nonlinear numerical analysis via finite elements. An evaluation is made of the initial geometric imperfections, and of the results of the following standard procedures: (i) the classical effective width method, and (ii) the direct strength method (DSM), in which the angles are not considered pre-qualified sections. The results of the experimental analysis and the nonlinear numerical analysis with initial geometric imperfections indicate the need to consider the L/T mode as both a local mode and a global mode.

"Structural Analysis of Scaffolding with Plank and Anchor Rod During Construction," Jui-Lin Peng, Chi-Ling Pan, Kuan-Hung Chen, and Siu-Lai Chan

This study focuses on the critical loads of scaffolding with the anchor rods, plank and inner knee brace under concentric and eccentric loads during construction. The steel rebar is used in place of the patent anchor rod in this research. This study shows that the critical load of the scaffolding increases by 1.5 times when the anchor rods of length of 30 cm are used on two sides of every story of scaffolding. The critical load increases by 4 times when the scaffolding has both anchor rods and plank. The critical load of scaffolding with the anchor rods placed on each story is twice as large as the load with anchor rod added every two stories. In addition; the failure mode of the structure is also transformed from the in-plane direction to the out-of-plane direction. The 30 cm long anchor rod, a steel bar of grade 3, provides a good lateral restraint to the scaffolding. The setup plank can significantly increase the critical load of the scaffolding. The critical load increases by 1.5 times under the concentric load, and increases up to 2.2 times under the TL/4 eccentric load defined as the load applied a quarter distances from the end. The anchor rods and the planks are suggested to install in a scaffolding to improve stability, especially under eccentric loads during construction.

"What's New in the 2007 Edition of the North American Cold-Formed Steel Specification?," Roger Brockenbrough, Reinhold Schuster, Roger LaBoube, Helen Chen

The 2007 edition of the North American Specification for the Design of Cold-Formed Steel Structural Members (Specification) was published recently by AISI (2007a). As the name indicates, the Specification is intended for use throughout Canada, Mexico and the United States. The Specification has been approved in the United States by the American National Standards Institute as the American National Standard, in Canada by the Canadian Standards Association, and has been endorsed in Mexico by Camara Nacional de la Inductria del Hirrro y del Acero (CANACERO). In the 2007 edition, many new design provisions were adopted and significant editorial and technical changes were made. This paper provides an overview of the major changes and additions.

"An Update on AISI Standards for Cold-Formed Steel Framing," Jay W. Larson

The Committee on Framing Standards of the American Iron and Steel Institute (AISI) continues its mission to eliminate regulatory barriers and increase the reliability and cost competitiveness of cold-formed steel framing through improved design and installation standards. Its suite of eight ANSI-approved, building code adopted standards and its Code of Standard Practice for Cold-Formed Steel Structural Framing build upon AISI S100, the North American Specification for the Design of Cold-Formed Steel Structural Members. This paper provides an overview of the significant documents that have been produced by the AISI Committee on Framing Standards and describes the ongoing work of the committee.

"Overview of the Standard for Seismic Design of Cold-Formed Steel Structural Systems - Special Bolted Moment Frames," Helen Chen, Chia-Ming Uang, Reidar Bjorhovde and Bonnie Manley

Cold-formed steel has been widely used for components and main force resisting systems in commercial, industrial, and residential buildings. Cold-formed steel structural members are designed using AISI S100, North American Specification for the Design of Cold-Formed structures Members [AISI, 2007]. For applications in high seismic regions, additional requirements may be needed. In fact, cold-formed steel design standards have been developed for applications in high seismic regions for both rack structures [RMI, 2004] and cold-formed steel light frame construction [AISI, 2007a]. In 2003, the American Iron and Steel Institute (AISI) established a seismic design committee. Composed of suppliers, manufacturers, engineers, researchers and professors, the committee is responsible for developing design standards applicable to cold-formed steel structural systems located in seismic regions. The first edition of the Standard for Seismic Design of Cold-Formed Steel Structural Systems - Special Bolted Moment Frames (hereinafter referred as the Standard) was finished in 2007. The Standard has also been approved by ANSI and an American National Standard. As the title indicates, this edition of the Standard focuses on the design of the seismic force resisting system for special bolted moment frames, which consist of tubular columns, cold-formed channel beams and bolted moment connections. A typical connection of a cold-formed steel special bolted moment frame (CFS-SBMF) is illustrated in Figure 1. This type of special bolted moment frame is widely used in industrial platform mezzanines such as the one shown in Figure 2. The 2007 edition of

the Standard is based on the 2005 edition of the ANSI/AISC 341, Seismic Provisions for Structural Steel Buildings, [AISC, 2007] and research work [Sato and Uang, 2007] on cold-formed steel special bolted moment frame systems as a seismic force resisting system. This paper will briefly review the design provisions included in the Standard.

"Buckling Studies of Thin-Walled Channel Sections under Combined Bending and Shear," Cao Hung Pham and Gregory J. Hancock

Thin-walled section members can be subjected to axial force, bending and shear. In the cases of cantilever beams and continuous lapped purlins, where combined bending and shear occur at the purlin section just outside the end of the lap, thin-walled sections may buckle at a lower stress than if only one action was present without the other. The computational modelling of the thin-walled steel sections is implemented by means of a spline finite strip analysis to determine the elastic buckling stresses of channel sections subject to bending and shear alone and interaction relations under combined bending and shear. Both unlipped and lipped channels are studied where the main variables are the flange width, different boundary conditions and shear flow distribution. Comparisons between cases, and with classical solutions are included in this report.

"Experimental Study on Web Crippling of Lapped Cold-Formed Steel Channels Subjected To InteriorTwo-Flange Loading," Q. Rahman; K. Sennah; and S. Fox

This investigation focused on the effects of lapped channels on the web crippling capacity of cold-formed steel members. The current design recommendations in North America Specifications specifies expressions for web crippling strength of different joist geometries in case of exterior end and concentrated load locations. However, it does not permit an increase in web crippling capacity when lapped cold-formed steel channels are subjected to interior two-flange loading. This may be attributed to the lack of experimental data on web crippling strength at interior support locations. Thus, the objective of the current research is to generate experimental data for CFS channels where both flanges of channel members are lapped at the interior support location and being loaded simultaneously. This paper summarizes the results of investigation. Test specimens were loaded to failure and load history and the failure pattern were recorded. Recommendations for further testing were drawn to establish design equations for web crippling strength of lapped CFS channels at interior support location when subjected to two flange loading. The test specimen used for the investigation is single web C-section.

"Simplified Models for Cross-Section Stress Demands on C-Section Purlins in Uplift," L.C.M. Vieira Jr., M. Malite and B.W. Schafer

The objective of this paper is to provide and verify simplified models that predict the longitudinal stresses that develop in C-section purlins in uplift The paper covers the simple case of flexural stress, where the force has to be applied at the shear center or the section braced in both flanges, up through the more complex problem of bending where movement of the tension flange alone is restricted, as commonly found in purlin-sheeting systems. Winter's model for predicting the normal stresses developed due to direct torsion is reviewed, verified, and then extended to cover the case of a bending member with tension flange restraint alone. The impact of considering the combined longitudinal stresses, in determining the elastic stability behavior is highlighted. Strength predictions of typical C-section purlins are provided for existing AISI methods and a newly proposed extension to the Direct Strength Method.

"Flexural Resistance of Cold-formed Steel Built-Up Box Sections Subjected to Eccentric Loading," L. Xu and P. Sultana

In cold-formed steel building construction, there are several applications where built-up box sections made of a C-shape nested with a track section, with screw fastenings, are used to resist loads induced in a structural member; when a single section is not sufficient to carry the design load. The cold-formed steel box section may be subjected to eccentric loading when the web of one of the sections receives the load and transfers it through the connection to another section. There may be an unequal distribution of load in cold-formed steel built-up box assemblies loaded from one side. In the current North American Specification for the Design of Cold-Formed Steel Structural Members (CSA, 2002), there is no guideline or design equation to calculate the flexural capacity of this type of section. Cold-formed Steel Framing Design Guide (AISI, 2002) has recommended that the moment resistance and moment of inertia of the built-up sections can be taken as the sum of the two components; based on deflection compatibility of the components. However, this design approximation has yet to be justified by experimental or numerical study especially for the case of eccentric loading. Therefore, a research project involving finite element analysis was undertaken to investigate the flexural behaviour of built-up box sections assembled from cold-formed steel C-shape and track sections when subjected to eccentric loading. The proposed finite element model of the built-up box sections was validated with the tests carried out by Beshara and Lawson (2002). The ultimate moment capacities obtained from the finite element analysis were then compared with the predictions from the current design method; in order to asses its suitability. Parametric studies were carried out to identi-

fy the factors affecting the flexural capacity of built up cold-formed steel box sections.

"Web Crippling Behaviour of Thin-Walled Lipped Channel Beams Subjected to EOF and ETF Loading," Martin Macdonald, Manoj A. Heiyantuduwa and Jim Rhodes
This paper presents the results of an investigation conducted to study web crippling behaviour of cold-formed thin-walled steel lipped channel beams subjected to End-One-Flange (EOF) and End-Two-Flange (ETF) loading conditions as defined by the American Iron and Steel Institute (AISI). An experimental program was designed to obtain the load-deformation characteristics of beam members with varying cross-sectional and loading parameters under the two web crippling loading conditions. The results of the experiments mainly comprised of the ultimate web crippling strength values of thirty-six specimens tested. Nonlinear finite element models were developed to simulate web crippling failure of the two loading conditions considered in the experimental program. The comparison of experimental and finite element results revealed that the nonlinear finite element models were capable of closely simulating the web crippling failure behaviour observed in the experiments. Web crippling strength predicted from the AISI Specification was also compared with the experimental results and the comparisons indicated considerable underestimations for the range of specimens under EOF and ETF loading conditions.

"Simplified Consideration of Down-Aisle Stability in Pallet Racking," J Rhodes and M. Macdonald
The sway buckling loads predicted by the approximate equations given in European pallet racking codes are compared with those predicted by frame finite element analysis. It is found that the load capacities predicted by the approximate equations are accurate and conservative in comparison to the finite element predictions if the uprights are pin-ended and the spacing between all beam levels is constant. If the uprights have base rotational restraint, and/or the height of the first storey is less than that of the higher storeys then inaccuracy and non-conservatism can arise using the approximate equations, and the non-conservatism increases as the number of storeys increases. An attempt is made to improve the accuracy by modifying the approximate equations. The modified equations give, in general, more accurate predictions of sway buckling loads and in particular reduce the non-conservatism. The modifications also tend to ensure that for racks with properties outside the range examined in this paper the buckling loads predicted would err on the safe side.

"Response of Metal Roofs to Uniform Static and True Hurricane Wind Loads," R. Ralph Sinno
The state of the art of laboratory simulating of high velocity wind loading presents an extremely complex problem. Field instrumentations of roofs have established that the data for applied wind loads are highly dependent on multitude of variables. Test results from boundary layer wind tunnel testing on small scale models are the only reliable data that is available to date. It is well accepted now by all structural engineers that the intensity of wind loading in time and space is unsteady and non-uniform. The simulation of wind tunnel loading data applied to full-scale roofs for wind velocities up to 160 mph is presented. Evaluations and measurements of the anchoring reactions of the roofs subjected to uniform static loading and simulated wind tunnel loading are also presented. The test results are compared. Uniform static loading followed the ASTM E-1592-01 testing procedures. The primary objective of this work is two fold: (1) Development of a test method that simulates the non-uniform unsteady wind loading conditions in time and space on a roof of a low rise building. This is done using electromagnetic controlled uplift pressures, suction, on metal roofs. (2) To establish a comparative correlation between the current uniform static loading used for design, ASCE-7, and the dynamic uplift testing. This is the first time ever that the wind tunnel data for the footprint of true hurricane wind loading is duplicated and applied successfully to full-scale roofs in the laboratory. The test results confirmed that the maximum anchoring reactions are almost proportional to the square of the wind speed under static and simulated true wind loading. These reactions are considerably lower under true wind loading than those from the ASCE-7-05 for uniform static loading. Failure modes of the tested roofs are found to differ as they reflect the seriousness of the high intensity of wind loading at and around the roof corners. Deflections and deformations of end panels of the roof are noted to be excessively higher under true wind loading than those under uniform static loading. These approaches, test results, and findings presented here are applicable to any type of roof system and materials used to construct and build the roof in real life.

"State of the art report on Thin-Walled Cold-Formed Profiled Steel Decking," N.A.Hedaoo, L.M. Gupta, G.N. Ronghe, S.K.Parikh
Thin-walled cold-formed profiled steel decking is used extensively in the composite concrete slabs construction of modern buildings. Extensive research on cold-formed profiled steel decks has been carried out using experimental, analytical and numerical methods. In this paper, a review of the research carried out on cold-formed profiled steel decking is given with emphasis on experimental and analytical work. Experimental data has been collected and compiled in a comprehensive format listing parameters involved in the study. The review also includes research work that has been carried out to date accounting for the effects of different buckling modes and its behaviour, intermediate stiffeners, web crippling

strength, embossments, ultimate moment capacity and load carrying capacity of the profiled decks.

"Vibration Performance of Lightweight Floor Systems Supported by Cold-formed Steel Joists," B.W. Davis, R. Parnell and L. Xu
A study investigating dynamic characteristics of full-scale floor systems was performed for several laboratory-constructed and in situ floors. Floors were constructed with cold-formed steel joists and designed for residential mid-rise applications. Typical construction details including span, subfloor, topping, strongback and framing condition were varied, and their influence on fundamental frequency, damping ratio and deflection at mid-span compared. Changes in construction details which significantly increased floor mass, regardless of added stiffness, were found to lower the fundamental frequency. Adding a strongback with restrained ends provided a significant increase in fundamental frequency, stiffness and damping ratio. Laboratory tested floor systems were generally found to be the worst-case scenario for natural frequency and damping ratio.

"Innovative Composite Cold Formed Steel Floor System," D.M. Fox, R.M. Schuster, and M. Strickland
Presented in this paper is a new, unique and innovative composite cold formed steel floor system developed by iSPAN Technologies, called the "iSPAN Composite Floor System". The joist sections are fabricated by fastening two cold-rolled flange chord elements with cold-driven rivets to a flat web element. This makes it possible to create a section where the flange chord elements can be of a different steel thickness with respect to the web element, resulting in a most efficient structural cross section and numerous design alternatives. The joist sections have lip-reinforced web openings spaced at 4 ft o.c. along the joist length to accommodate the usual service items. The joists are typically spaced 4 ft o.c. with a 7/8 in. corrugated steel deck spanning between the joists to support the concrete during casting. Featured in this paper are the results from push-out tests that have been carried out to establish the interlocking capacity of the concrete with the top chord of the joist section. The results of a full-scale laboratory structural test are also presented to substantiate the calculated strength and stiffness characteristics. Finally, the results of a field test during construction are presented.

"Flexural Behavior and Design of the New Built-up LiteSteel Beams," Sivapathasunderam Jeyaragan and Mahen Mahendran
A new cold-formed steel beam, known as the LiteSteel Beam (LSB), has the potential to transform the low-rise building industry. The new beam is effectively a channel section with two rectangular hollow flanges and a slender web, and is manufactured using a simultaneous cold-forming and electric resistance welding process. Built-up LSB sections are expected to improve their flexural capacity and to increase their applications. They are also likely to mitigate the detrimental effects of lateral distortional buckling observed with single LSB members of intermediate spans. However, the behaviour of built-up beams is not well understood. Currently available design rules based on longitudinal connection spacing limits and doubling the capacity of single members were found to be inadequate. Therefore a research project based on both experimental and advanced numerical studies was undertaken to investigate the flexural behaviour of back to back LSBs with various longitudinal connection spacings under a uniform moment. This paper presents the details of the experimental and numerical studies and the results.

"Experimental and Numerical Studies of the Shear Behaviour of LiteSteel Beams," P. Keerthan and M. Mahendran
This paper presents the details of experimental and numerical studies on the shear behaviour of a recently developed, cold-formed steel beam known as LiteSteel Beam (LSB). The LSB section is produced by a patented manufacturing process involving simultaneous cold-forming and electric resistance welding. It has a unique shape of a channel beam with two rectangular hollow flanges, made using a unique manufacturing process. To date, no research has been undertaken on the shear behaviour of LiteSteel beams with torsionally rigid, rectangular hollow flanges. In the present investigation, a series of numerical analyses based on three-dimensional finite element modelling and an experimental study were carried out to investigate the shear behaviour of 13 different LSB sections. It was found that the current design rules in cold-formed steel structures design codes are very conservative for the shear design of LiteSteel beams. Improvements to web shear buckling occurred due to the presence of rectangular hollow flanges while considerable post-buckling strength was also observed. Experimental and numerical analysis results are presented and compared with corresponding predictions from the current design codes in this paper.

"Inelastic Performance and Design of CFS Walls Braced with Straps having Reduced Width Fuses," K. Velchev, G. Comeau, N. Balh and C.A. Rogers
Provisions that address the seismic design of cold-formed steel frame strap braced walls are not provided in the 2005

National Building Code of Canada (NBCC) or in the Canadian Standards Association (CSA) S136 Standard for the design of cold-formed steel structures. Previous research aimed at developing appropriate seismic design provisions for these walls revealed that premature fracture of screw connected flat strap braces can lead to inadequate ductility. A subsequent research project was undertaken to evaluate the inelastic performance of screw connected single-storey braced wall configurations constructed with flat straps having a reduced width fuse. The intent of using a fuse in the brace was to reduce the extent of inelastic demand at the brace connections while confining plastic deformations to a well defined section of the brace. Test walls were specifically designed and detailed following a capacity approach. The strap braces were expected to undergo gross cross-section yielding with strain hardening along the fuse, while the other elements in the seismic force resisting system were selected to be able to carry the probable brace capacity. A summary of the test program is provided in the paper, including failure modes and ductility measures, as well as recommendations on how proper seismic detailing may be achieved. The scope of the research also included the determination of preliminary seismic force modification factors for use with the NBCC based on the measured ductility and overstrength of the test walls.

"Pilot Research on Cold-Formed Steel Framed Shear Wall Assemblies with Corrugated Sheet Steel Sheathing," Hitesh Vora, Cheng Yu

Flat steel sheet is the common steel sheathing for cold-formed steel (CFS) framed shear walls. The current American Iron and Steel Institute Standard provides nominal shear strengths for 0.018 in. and 0.027 in. sheet steel sheathed shear wall as well as CFS walls with other sheathing materials. The CFS walls with 0.018 in. or 0.027 in. sheet steel sheathing yield relatively lower shear strength compared with the walls with 7/16 in. OSB sheathing or 15/32 in. Structural 1 sheathing (4-ply). In order to develop a high strength CFS shear wall with steel sheathing, a pilot research was conducted at University of North Texas to experimentally investigate the behavior and shear strength of CFS framed wall assemblies with 0.027 in. (20 gauge) corrugated sheet steel sheathing. The parameters considered in the test program included the framing member thickness, the fastener size and spacing, and the boundary stud configurations. Both monotonic and cyclic tests were conducted. The test results indicated that with appropriate framing members and the fastener configurations, the corrugated steel sheet can form rigid sheathing for CFS shear walls. The test results indicated that the 0.027 in. corrugated sheet steel sheathing outperformed 0.027 in. think flat sheet steel sheathing as well as the 7/16 in. OSB sheathing. It can be alternative sheathing material for CFS walls.

"Structural Testing of Corrugated Sheet Steel Shear Walls," Bozidar Stojadinovic and Steven Tipping

The objective of the research is to develop an alternative lateral bracing system comprising corrugated sheet steel shear walls for use with light-framed cold-formed steel buildings. The key element of this structural system is the corrugated sheet steel shear wall: the lateral load resistance of this structural element originates with the shear strength of the corrugated sheet steel and the shear resistance of the screws connecting the sheeting to the cold-formed steel framing. To establish a design basis, a total of 44 cyclic racking tests were conducted to establish the relation between corrugated sheet steel shear wall design parameters, such as gauge of the sheet steel, gauge of the cold-formed steel framing, size and spacing of the fasteners, and the shear strength of the wall. The results of these tests are presented. Furthermore, system-level R, Cd and o values consistent with the test results are proposed for adoption into design codes. Finally, a design table listing the nominal shear strength values for corrugated sheet steel shear walls is provided. The primary users of the system would be practicing engineers who design light-framed cold-formed steel buildings.

"Shear Resistance of Cold-Formed Steel Framed Shear Wall Assemblies with 0.027-, 0.030-, 0.033-inch Sheet Steel Sheathing," Cheng Yu

The cold-formed steel framed wall with sheet steel sheathing is a code approved structural system to resist lateral loads such as wind loads and seismic loads. The American Iron and Steel Institute Standard for Cold-Formed Steel Framing - Lateral Design 2004 Edition provides nominal shear strength for a limited range of steel sheet sheathed shear wall configurations. This paper presents a research project developed to add values for 0.030-in. and 0.033-in. steel sheet sheathed shear walls with 2:1 and 4:1 aspect ratios and 0.027-in. sheet steel shear walls with 2:1 aspect ratio. The fastener spacing taken into account in this research was 6-in., 4-in., 3-in., and 2-in. for the panel edges, and 12-in. for the panel field. The test program consisted of two series of shear wall tests. In the first series, monotonic tests were performed to determine the nominal shear strength for wind loads. In the second series, cyclic tests were conducted to obtain the nominal shear strength for seismic loads. This paper presents the details of the test program and the test results.

"Estimating the Effective Yield Strength of Cold-Formed Steel Light-Frame Shear Walls," Reynaud Serrette

Characterization of the seismic response of structural elements often requires an expression of the capability of these elements to sustain some portion of their peak strength at displacements beyond their elastic limit-a measure of ductility.

This paper presents an energy-based method for estimating elastic displacement limit/effective yield strength of cold-formed steel shear walls. The method considers the maximum usable wall displacement, the hysteretic envelope response of a wall and the expected system performance. The resulting effective yield strength limit is shown to be consistent with interpretations of yield strength in performance-based engineering design.

"Effect of Varied Imperfections on Bracing Demand of Cold-Formed Steel Stud Walls," Thomas Sputo, Kevin Beery, and Edgar Wong

The purpose of this analytical study was to determine the effect of varied out-of-straightness imperfection on the bracing strength and stiffness demand of multiple cold-formed steel stud walls. This study is an extension of previous work performed to develop relationships between the required brace strength and stiffness for bridging of multiple stud walls and the required brace strength and stiffness of a single stud. Eight-foot tall walls with three different imperfections were analyzed using critical buckling analysis. The required cross-sectional area to prevent buckling was determined and the critical brace force and stiffness were calculated for various magnitudes of imperfection. Critical brace strength was found to accumulate directly as a multiple of the number of studs, regardless of stud out-of-straightness. Critical brace stiffness is not directly related to the number of studs, but a relationship was formulated that is independent of stud out-of-straightness. The required brace strength and stiffness of a multiple stud wall with a specified initial imperfection can thus be related to the required brace strength and stiffness of a single stud for any magnitude of imperfection.

"Finite Element Analytical Investigation of Torsional Bracing Requirements for Cold-Formed Steel C-Shaped Studs," Jennifer Tovar, Todd Helwig, and Thomas Sputo

This paper provides an overview of an investigation on the torsional bracing behavior of C-shaped cold-formed steel studs. Typical bracing details for the C-shaped studs consist of a steel channel that restrains twist of the cross section. Three-dimensional finite element models were used to investigate the stiffness behavior for stability braces used to improve the torsional buckling performance of the studs. The lipped C-shaped section was modeled with pin-ended boundary conditions for the stud. Multiple models of the torsional brace were evaluated including a shell element model of a bracing channel as well as several "simpler" spring configurations. The development of these models and appropriate modeling techniques for bracing is discussed in detail. Difficulties in capturing the distortional behavior in the thin walled stud are discussed. Results from eigenvalue buckling solutions are presented. Recommendations are made for extending the use of these models to a broader range of stud sizes and analysis types to obtain recommendations for torsional bracing requirements of typical cold-formed wall studs.

"Strength of Cold-Formed Steel Jamb Stud-To-Track Connections," A.V, Lewis, S.R. Fox and R.M. Schuster

Cold-formed steel structural members are often used in building construction, with a common application being wind load-bearing steel studs. The studs frame into horizontal steel track members at the top and bottom of the wall assembly, with the stud-to-track connection typically being made with self-drilling screws. The design of the wall stud must include a check of the web crippling capacity at the end reactions, and there are design rules in place for the typical stud-to-track connection. However, at every opening in the wall assembly such as a window or door, there are jamb stud members that must also be designed for the stud-to-track connection strength. These jamb studs can occur at the termination of the bottom track or at an interior location, and can be single or multiple members. Reported in this paper are the results and analysis of a collection of end-one-flange loading tests of common jamb stud-to-track connections. Design expressions are proposed to predict the capacity of this connection for these structural members.

"Thermal Performance of Plasterboard Lined Steel Stud Walls," Prakash N. Kolarkar and Mahen Mahendran

In response to the market demand for fire separations in the light industrial, commercial and residential buildings, a research project is currently under way to improve the thermal performance of cold-formed steel stud wall systems used in these buildings. Extensive fire testing of both non-load-bearing and load-bearing wall panels has been completed to date in the Fire Research Laboratory of Queensland University of Technology. This paper presents the details of this experimental study into the thermal performance of some small scale non-load-bearing walls lined with dual layers of plasterboard and insulation. The first two wall panels were built traditionally using lipped channels with two plasterboard linings on both sides and the cavity filled with and without glass fibre insulation. The third panel tested was built similarly, but with the insulation sandwiched between the plasterboards on either side of the steel wall frame instead of being placed in the cavity. Fire tests undertaken were based on the standard time-temperature curve recommended by AS 1530.4 (SA, 2005). Experimental results showed that the new stud wall system outperformed the traditional stud wall system giving a much higher fire rating.

"Testing and Evaluation of CFS L-Headers," J. Pauls, L. Xu, and S. Fox
Recently there has been an increased interest in cold-formed steel L-headers, in part due to their ease of installation and low material cost. Design guidance for L-headers is currently provided by the AISI Standard for Cold-Formed Steel Framing - Header Design in combination with the North American Specification for Design of Cold-Formed Steel Structural Members. The current AISI - Header Design provisions are, however, particularly limiting and lack certain design criteria for double and single L-header assemblies, primarily due to limited research.
Presented in this paper are the results from an extensive test program carried out at the University of Waterloo on both single and double cold-formed steel L-headers. A total of 48 single L-header assemblies and 56 double L-header assemblies were tested under gravity loading. The objective of the research was to develop improved design expressions for determining the flexural capacity and vertical deflections. A comparison between the flexural test data and the nominal flexural resistance calculated according to the current AISI Header Design standard is provided. The theory of semi-rigid connections is introduced to model the vertical deflections.

"Effects of Elevated Temperatures on Ultimate Moment Capacity of Bolted Moment-Connections between Cold-Formed Steel Members," James B.P. Lim and Ben Young
Experimental investigations at ambient temperature into the behaviour of bolted moment-connections between cold-formed steel members have previously been described. Full-scale joint tests have demonstrated that the channel-sections being connected are susceptible to premature failure, the result of web buckling caused by the concentration of load transfer from the bolts. The results of non-linear elasto-plastic finite element analyses have been shown to have good agreement. No consideration, however, has been given to the behaviour of such connections at elevated temperatures. This paper describes non-linear elasto-plastic finite element parametric studies into the effects of elevated temperatures on bolted moment-connections between cold-formed steel members; simple design rules are proposed that will enable designers to take into account the effects of elevated temperatures.

"Cold-Formed Steel Special Bolted Moment Frames: Cyclic Testing and Numerical Modeling of Moment Connections," Chia-Ming Uang, Jong-Kook Hong, Atsushi Sato and Ken Wood
Cyclic tests on nine full-scale beam-column subassemblages were carried out in support of the development of a new lateral load-resisting system recently introduced in AISI-S110: Standard for Seismic Design of Cold-Formed Steel Structural Systems?Special Bolted Moment Frames. With double channel beams and HSS columns interconnected by bearing-type high-strength bolts, all specimens showed an story drift capacity significantly larger than 0.04 radian. Typical response is characterized by a linear response, a slip range, followed by a significant hardening region due to bolt bearing. Three failure modes were identified. Confining in the connection region, inelastic action through bolt slippage and bearing is ductile and desirable. Such inelastic action always occurs first, but either column or beam may also experience buckling. Beam buckling is most undesirable due to significant post-buckling strength degradation. Extending the concept of instantaneous center of rotation of an eccentrically loaded bolt group, a model that can reliably simulate the cyclic behavior of the bolted moment connection is presented.

"Cold-Formed Steel Special Bolted Moment Frames: Capacity Design Requirements," Atsushi Sato and Chia-Ming Uang
Design provisions of the Cold-Formed Steel?Special Bolted Moment Frame (CFS?SBMF) system in the proposed AISI Seismic Standard (AISI S110) are developed such that energy dissipation in the form of bolt slippage and bearing in the bolted beam-to-column moment connections would occur during a major seismic event. Beams and columns are then designed following the capacity design principles to remain elastic. Based on the instantaneous center of rotation concept, this paper presents background information for the design provisions in the AISI standard for calculating the expected maximum seismic force in the beams and columns at the design story drift. This requires that the resistance from both the bolt slippage and bearing actions in the moment connection be computed. Design tables are provided to facilitate the design. The recommended seismic design procedure is also provided.

"Cold-Formed Steel Portal Frame Joints: a Review,"A.M. Wrzesien, J.B.P. Lim
This paper reviews research published on cold-formed steel portal joints, beginning with the laboratory tests of Baignent and Hancock (1982) and ending with those of Rhodes and Burns (2006). The moment-capacity of the cold-formed steel channel-sections being connected in the portal framing systems ranges from 3.6 kNm to 128.5 kNm, with each type of framing system employing a different joint detail. While in accordance with the Eurocode 3 joint classification system, the joints arrangements reported would be classified as semi-rigid, for the purpose of design the majority of the joints would be sufficiently rigid for the frames to be designed safely to the ultimate limit state using a rigid-joint assumption, with the joints capable of sustaining almost the full-moment capacity of the cold-formed steel channel-sections being connected.

However, in order for the assumption of rigid joints to be valid, the number of bolts or specialist components required may, in some countries, result in the joints being uneconomical to fabricate. It is seen that of all the joints reviewed, the joint arrangement tested by Rhodes and Burns is distinctive as rigid-joints are formed inexpensively through the use of knee braces. This, however, is at the expense of losing clear height to the eaves. Using UK design practice, a parametric study of sixteen frames, having spans ranging from 8 m to 14 m, is described that compares the economy of rigid-jointed frames against that of knee-braced frames. It is shown that use of a knee-braced frame results in a 10% increase in load carrying capacity, and a 36% reduction in horizontal deflections.

"Strength of Arc Spot Welds made in Single and Multiple Steel Sheets," Gregory L. Snow and W. Samuel Easterling

The primary focus of this research was to investigate how arc spot welding is affected by arc time (flash time). Weld sizes of 3/4 in. and 5/8 in. nominal diameter were formed using three different arc times (full-time, 2/3-time and 1/3-time). Each weld was formed in a single-, double-, or quadruple-layer of sheet steel ranging from 16 gauge (0.057 in.) to 22 gauge (0.028 in.) in thickness. Test results include weld dimensions determined from weld sectioning, weld shear strengths and comparisons made with the 2001 AISI Specification.

"Cold-Formed Steel Bolted Connections without Washers on Oversized Holes: Shear and Bearing Failures in Sheets," Cheng Yu, Ibraheem Sheerah

In cold-formed steel (CFS) construction, the bolted connections without washers on oversized holes may expedite the building process and lower the cost, at the same time provides satisfied strength. The current design specifications do not stipulate provisions for such connections, and washers are required to be installed on oversized holes. In order to investigate the behavior and determine the strength of CFS bolted connections without washers on oversized holes, a test program was developed and conducted at University of North Texas. This research was focused on the shear failure and the bearing failure of the connected sheets. No washer was used for the test specimens. The studied parameters included the steel sheet thickness: from 118 mil to 33 mil; the connection type: single shear and double shear; the number of bolts: one and two; the bolt type: ASTM A307, A325; the bolt diameter: 1/4 in. and 1/2 in.; and the ductility in the sheet steel: low and high. Based on the test results, new design method for bearing strength was proposed. The paper presents the test program, test specimens, and the proposed design for CFS bolted connections without washers on oversized holes.

"Experimental Response of Connections between Cold-Formed Steel Profile and Cement-Based Panel," Luigi Fiorino, Ornella Iuorio, Raffaele Landolfo

The seismic response of sheathed cold-formed steel (CFS) structures is highly influenced by the shear behaviour of panel-to-steel framing connections. Therefore, an experimental campaign aiming at characterizing the shear behaviour of different sheathing-to-CFS profiles connections has been planed. In particular, the following objectives have been selected: to compare the response of different panel typologies (cement, wood and gypsum-based panels); to examine the effect of the loaded edge distance; to investigate the outcome of different cyclic loading protocols. This paper presents and discusses the main results of this experimental investigation carried out on cement-based sheathing-to-stud connections.

"Test Standard for Joist Hangers and Similar Devices Attached to Cold-Formed Steel Framing," G. Greenlee

This presentation will cover the newly developed standard for testing joist hanger and similar devices. It will cover the scope of the testing, test setup and required measurements. The presentation will also discuss how the results of the test shall be applied and their relevance in cold formed steel construction. Finally the presentation will review actual test results to provide insight into joist hanger performance in cold formed steel construction.

"New Test Standard for Hold-downs Attached to Cold-Formed Steel Structural Framing," Jeff Ellis

This paper discusses the new hold-down test standard entitled "Test Standard for Hold-downs Attached to Cold-Formed Steel Structural Framing" [1]developed by the AISI Committee on Framing Standards for the Design of Cold-Formed Steel Structural Members. Currently, the other AISI test standards are shown in the 2002 AISI Cold-Formed Steel Design Manual [2]. Hold-downs are defined in the AISI General Provisions standard [3], which is referenced by the 2006 International Building Code [4], and have been used successfully for many years in light-frame cold-formed steel construction. The 2006 IBC Section 1604.9 requires a continuous load path to transmit forces induced to structural members and systems to the foundation. Hold-downs are commonly used as the attachment of a structural member, such as

a post or joist, to the foundation or wall to complete the load path. Understanding their strength and displacement behavior is important to the proper design and detailing of cold-formed steel light-frame lateral force resisting systems. This test standard provides a standard methodology that may be used to determine and compare strength and displacement characteristics for the many types of devices used in the industry currently and that may be developed in the future.

"Behavior of Arc Spot Weld Connections Subjected to Combined Shear and Tension Forces," L. K. Stirnemann and R. A. LaBoube

In North America the design of arc spot weld connections is currently limited by the lack of understanding of the behavior of the welded connection when it is subject to combined shear and tension forces. An experimental investigation was conducted at the University of Missouri - Rolla to study the behavior and to develop design recommendations for the relationship (interaction) of the tension and shear forces on an arc spot weld connection. The experimental study focused on six variables that were deemed to be the key parameters that may influence the strength of the arc spot weld connection. These variables were the sheet thickness; sheet material properties to included yield strength, tensile strength and ductility of the sheet; visible diameter of the arc spot weld; and the relationship between the magnitude of the shear force and tension force. Based on an analysis of the test results, both a linear and non-linear interaction equation was developed and design recommendations were formulated based on these equations.