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Wei-Wen Yu Center for Cold-Formed Steel Structures

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Abstracts of Conference Papers for 17th International Specialty Conference on Cold-Formed Steel Structures 2004

On November 4th and 5th, 2004 the 17th International Specialty Conference on Cold-Formed Steel Structures will be held in Orlando, Florida. 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@umr.edu). This Technical Bulletin provides a brief summary of the papers that are scheduled to be presented and will appear in the conference proceedings.

"Introduction to the Theory and Finite Element Implementation of (Steel) Plasticity," H. Hofmeyer
This paper presents the application of finite element to plasticity theory by presenting fundamental theory and some very practical examples. For a two-dimensional plain stress state, a Hubert-Henky yield criterion is derived. The flow rule is discussed, including an explanatory numerical example. The yield criterion and flow rule are theoretically applied in a four node finite element. This element is used to show all the conditions and limitations of a plastic calculation in the finite element method. Finally, some real finite element calculations are made for illustrating the theory derived when applied to thin-walled steel structures.

"Cold-Formed Steel Examples to the Theory and Finite Element Implementation of Plasticity," H. Hofmeyer
This paper presents two examples to the theory and finite element implementation of plasticity. The first example is on the cross-sectional behavior of trapezoidal sheeting subjected to a concentrated load. It is shown that the number of elements (and thus the number of integration points) along the corner radius are important for the correct modeling of this static problem. The second example is on the failure of first-generation sheeting subjected to a concentrated load and a bending moment.

"Effects of Hail Damage on the Carrying Capacity of Standing Seam Profiles," A. Hubner, and H. Saal
Industrially prefabricated standing seam systems are used in the construction of facades and roofs. The standing seam profiles can be quickly assembled with special zipping machines to form roof systems. The load carrying capacity of standing seam profiles has been established by experiments according to a standardized procedure for thin-walled trapezoidal sheeting. During a thunderstorm the roof of a book warehouse constructed from standing seam profiles was heavily damaged by the impact of hailstones. This problem is discussed in the present paper. The research deals with the effect of hail dents on the carrying capacity of the profiles. The results of the experimental load carrying capacity of the damaged panels are compared to analytical results for damaged and undamaged panels. The influence of the dents is analyzed and possible solutions for better prediction of likely damages are presented.

"New Ultra Long-Spanning, Combined Steel Formwork and Reinforcement Hybrid Decking System Using Cold-Formed Components," M. Glaesle, M. Patrick, and R. Grey
A revolutionary ultra-lightweight, combined steel formwork and reinforcement system designed to span in the vicinity of 7 to 8 meters without shoring has been under development for nearly a decade in Australia. The steel deck comprises a number of innovative features that make it adaptable for almost any type of building construction ranging from conventional shallow one-way composite slabs in steel-frame buildings to deep two-way post-tensioned slabs in concrete-frame buildings. The primary element is a closed cellular section that is pre-cambered to control deflection under wet concrete conditions. Comprehensive sets of tests, some quite innovative, have been performed to thoroughly investigate the behavior of the system in both the formwork and composite states.

"Influence of Profile Distortion on the Shear Flexibility of Profiled Steel Sheeting Diaphragms," M. Duerr and H. Saal

The shear flexibility of diaphragms consisting of profiled steel sheeting can be calculated by means of the ECCS-Recommendations TC7 TWG 7.5. The main component of the total shear flexibility accounts for sheet deformation, which consists of profile distortion c1,1 and shear strain c1,2. The dominant part c1,1 is proportional to Ki. The factor Ki = K1 applies with fasteners in every trough and Ki = K2 applies with fasteners in alternate troughs. Both K1 and K2 depend on the ratios l/d and h/d of the cross section dimensions d = pitch of the corrugations, h = height of the sheeting profile and l =width of the top flange. For vertical webs K1 is larger than K2. This means that larger profile distortion is predicted with fastening in every trough rather then with fastening in alternate troughs. This is in contradiction to reality. Finite-Element calculations show that the K2-values given in ECCS-Recommendation TC7 TWG 7.5 are wrong. The correct values for K2 are given as result of the investigation.

"Strength and Stiffness of Conventional Bridging Systems for Cold-Formed Cee Studs," P.S. Green, T. Sputo, and V. Urala

An experimental testing program has been carried out on typical bridging components and connections used in North American practice to provide bracing to cold-formed lipped cee-studs, in order to determine the in-plane and out-of-plane strength and stiffness of the bridging components and connections. The stud sizes ranged from 362S-125-33 to 800S-162-97. Bridging systems tested included cold-formed bridging channels directly welded to the stud, bridging channels connected to the stud web through a welded connection to a clip angle, and bridging channels connected to the stud web through a screwed connection to a clip angle. Bridging connections were loaded axially (into the stud web) and laterally (parallel to the stud web). Load-deformation response curves were plotted for each tested connection type and stud cross-section and thickness. Analysis of the test results indicates that conventional bridging used in current North American practice has adequate stiffness and strength to brace axially loaded and curtain wall steel studs.

"Bracing Strength and Stiffness Requirements for Axially Loaded Cee Studs," P.S. Green, T. Sputo, and V. Urala

An experimental testing program has been carried out on axially loaded cold-formed lipped cee-studs to determine the required flexural and torsional bracing strength and stiffness demand of the stud. The stud sizes ranged from 362S-125-33 to 800S-162-97. Conventional bridging or nodal bracing has been simulated in the experiments using steel wires attached to the stud flanges at mid-height. A range of brace stiffness from less than 30 lbs/in. to greater than 4000 lbs/in. was simulated in the testing frame by using various diameters and lengths of wire. The axial load, individual brace forces, axial shortening, and in-plane (weak-axis) and out-of-plane (strong-axis) lateral displacements were measured in each test. The required bracing stiffness was experimentally determined by varying the brace stiffness for a given stud size and was based on the ability of the stud to develop it's nominal axial compressive capacity as predicted by the 1996 AISI Cold-Formed Steel Specification (including 1999 addendum). The experimental results were compared to existing nodal bracing models, analytical prediction models, and the current column bracing provisions that are part of the 1999 AISC-LRFD Specification for Structural Steel Buildings.

"Software Development for Cold-Formed Steel Elements," F.J. Granados and W.G. Reyes

This paper discusses the development of a design tool which will help the engineers, architects and students work with cold-formed elements. The software will provide a fast and easy way to create analysis and budgets in a very short time. This will help companies respond to their clients needs in a very fast and accurate way. The software contains five different modules: Graphics and tables for design of C- and Z-shapes; Metaldeck (Steel deck) design; joist design for floor structures; purlin design for roof structures; and truss and rigid frame design.

"Cold-Formed Steel Slip-Track Connection," J.R. Gerloff, H. P. Huttelmaier, and P. W. Ford

The slip-track connection is one of the most commonly used connections in the design of curtain wall systems. There is little guidance for the design of this connection in the North American Specification for the Design of Cold-Formed Steel Structural Members (2001). The purpose of this research was to determine appropriate guidelines for the effective distribution width of the track. A parametric test program of slip-track connections was conducted as well as finite element modeling. Tests included specimens with stud widths of 1 5/8" and 2 ½", stud spacing of 16" and 24", and track thickness varying from 14, 16, and 18 gauge. A gap between the web of the track and the top of the stud of ½" and 1" was used in the tests. Finite element analyses of the test specimens were conducted and compared with the test results. Proposed design procedures based on the results of the project are provided.

"Behaviour of Cold-formed High Strength Stainless Steel Sections," B. Young and W. M. Lui

This paper presents the behavior of cold-formed high strength stainless steel sections. The test specimens were coldrolled from high strength flat strips of duplex and high strength austenitic stainless steel. The material properties of high strength stainless steel square and rectangular hollow sections were determined. Tensile coupons at different locations across the cross-sections were tested. Hence, the distribution of ultimate tensile strength and 0.2% proof stress measured in cold-formed high strength stainless steel sections were plotted. The material properties of the complete cross-section in the cold-worked state were obtained from stub column tests. Local buckling load of the square and rectangular hollow sections were also determined. Detailed measurements of initial local geometric imperfections of the sections were obtained. Furthermore, residual stress measurements of the high strength stainless steel sections were conducted.

"Design of Fixed-Ended Cold-Formed Steel Plain Angle Compression Members ," B. Young
Design equations for cold-formed steel plain angle columns are proposed in this paper. The proposed equations are modified from the current design equations in the American Specification and Australian/New Zealand Standard for cold-formed steel structures. A series of tests on cold-formed steel plain angle columns compressed between fixed ends is described in this paper. The test strengths are compared with the design strengths calculated using the American Specification and Australian/New Zealand Standard for cold-formed steel structures. The required additional moment as specified in the Specification and Standard was not included in calculating the design strengths for slender and non-slender angle sections. It is shown that the design strengths predicted by the Specification and Standard are generally very conservative. Whereas the proposed design equations provided much more accurate results compared with the current design rules for both slender and non-slender plain angle sections.

"Design of Cold-Formed Stainless Steel Sections with Single Web Subjected to Web Crippling," F. Zhou and B. Young
An experimental investigation of cold-formed stainless steel hollow sections subjected to web crippling is presented in this paper. Tests were conducted on square and rectangular hollow sections of austenitic stainless steel type 304. Compression coupon tests were performed to obtain the transverse compression material properties. The web crippling tests were conducted under two loading conditions for End-Two-Flange (ETF) and Interior-Two-Flange (ITF) specified in the current American specification and Australian/New Zealand standard for cold-formed stainless steel structures. The test strengths obtained from this project and the test strengths conducted by other researchers are compared with the design strengths obtained using the current American specification, Australian/New Zealand standard and European code for cold-formed stainless steel structures. In addition, the test strengths are also compared with the design strengths obtained using the North American specification for cold-formed carbon steel structural members. A new unified web crippling design equation is proposed and calibrated with the test results.

"Mechanical Properties of Cold-Formed Steel at Elevated Temperatures," J. Chen and B. Young
This paper reports the mechanical properties data for thin-walled structural materials at elevated temperatures. The deterioration of the mechanical properties of 0.2% proof stress (yield stress) and Young's modulus of elasticity are the primary properties in the design and analysis of thin-walled structures under fire. However, values of these properties at different temperatures are not well reported. Therefore, tensile coupon tests were conducted at different temperatures ranged from 22 - 1000 ºC to obtain the mechanical properties of thin-walled structural materials. This study includes the flat and corner coupons of cold-formed steel, stainless steel and aluminum materials. The plate thickness ranged from 1.0 to 3.0 mm. Stress-strain curves for different temperatures are plotted. In addition, curves of Young's modulus, 0.2% proof stress and ultimate strength verse different temperatures are also plotted and compared with the results obtained from Australian, European and British standards, as well as results predicted by other researchers. The empirical equations for material properties of cold-formed steel, stainless steel and aluminum at elevated temperatures are proposed in this paper.

"Local-Plate and Distortional Post-Buckling Behavior of Cold-Formed Steel Lipped Channel Columns with Intermediate Stiffeners," N. Silvestre and D. Camotim
The objective of this paper is to present and discuss the results of an investigation concerning the local-plate and distortional post-buckling behaviours of cold-formed steel lipped channel members with intermediate (web and/or flange) stiffeners and pinned or fixed end sections. These results are obtained by means of a geometrically non linear Generalized Beam Theory (GBT), which (i) was very recently developed and implemented by the authors, (ii) is computationally very efficient and, due to its unique modal character, (ii) provides the tools for an in-depth interpretation of all the relevant behavioral aspects involved. In particular, the paper (i) includes the outcome of a parametric study concerning the influence of the intermediate stiffeners on the characteristics of the member post-buckling equilibrium paths, (ii) sheds new light on the distortional post-buckling asymmetries recently unveiled by Prola & Camotim (lipped channel

columns and beams) and Yang & Hancock (lipped channel columns with intermediate stiffeners) and (iii) addresses issues related to the occurrence of local-plate/distortional buckling mode interaction phenomena.

"Experimental Capacity Assessment of Cold-Formed Boxed Stud Wall Systems used in Australian Residential Construction," M. Pham, J.E Mills, and Y. Zhuge
Residential construction using cold-formed steel stud wall systems is steadily gaining popularity over recent years in the Australian market. The standard structural system for residential construction in Australia is brick veneer where the stud wall (whether timber or cold-formed steel) is the load-bearing element and an external skin of brickwork is used for weatherproofing, insulation and aesthetic reasons. Hence the stud frame is lined on only one side with plasterboard material. This differs from the standard practice used in North America where both sides of the stud frame are usually lined, one with internal plasterboard material and the other with insulated external cladding material and a brick skin is not used. This paper will summarize the experimental procedures and capacity assessment of single-plasterboard-lined panels under axial load, bending, and combined axial and bending. The analysis of the test results lead to numerous interesting conclusions about the behavior of single-plasterboard-lined panels within brick veneer wall system.

"Report on the Development of a Cold-Formed Steel Design Course at Kansas State University," V.J. Kircher and S.F. Stephens
Construction using cold-formed steel as the main framing system or partial framing systems continues to increase in the United States and abroad. As more and more structures are designed using cold-formed steel, it would naturally be assumed that opportunities for higher education in cold-formed steel design would be in demand. This paper presents documentation on the development and implementation of a two credit hour course in the design of cold-formed steel members in the Department of Architectural Engineering and Construction Science at Kansas State University. A description of the course goals, content and how the course was developed are addressed. An informal survey of structural engineers practicing mainly in the Kansas and Missouri area on the need for a university level design course for engineering students planning to graduate with an emphasis in structural engineering was conducted and results are presented. An assessment of the course by those students who took it is also included. Based on these results, recommendations for the continued development of the course are proposed.

"Self-drilling Screwed Knee-Joints for Cold-Formed Steel Portal Frames in Cyclonic Regions," J. Carr, A. Mansour and J. Mills
Current knee joint design practices for cold-formed steel portal frames traditionally mirror techniques used in hot-rolled steel joint design. Previous investigations conducted at the University of South Australia have shown the inadequacy of these joint designs and led to the development of a self-drilling screw joint alternative that is capable of carrying significantly higher moments than conventional designs. This study aimed to investigate the suitability of the self-drilling screwed knee joint in cyclonic regions, as well as conducting a preliminary assessment of the suitability of other joints currently used for such sheds in cyclonic regions. In addition, a new test method was developed that was more economic than past testing and more easily adaptable to test a range of section sizes and joint configurations. Test results both validated the new test method through comparison with previous testing, and showed the suitability of the self-drilling screwed joint for the higher moments required in frames subjected to cyclonic conditions.

"Performance of Ridge and Eaves Joints in Cold-Formed Steel Portal Frames," D. Dubina, A. Stratan, A. Ciutina, L. Fulop, and Z. Nagy
The paper summarizes the results of an experimental program carried out at the Politechnica University of Timisoara in order to evaluate the performance of ridge (apex) and eaves knee joints of pitched roof cold-formed steel portal frames under monotonic and cyclic loading. The behavior and failure mechanisms of joints were observed in order to evaluate their rigidity, strength, and ductility.

"Design of Distance Profiles in Walls," N. Albrecht, H. Saal, and R. Podleschny
A study of the behavior Z-profiles having trapezoidal sheeting connected such to provide space for intermediate insulation is presented. The design of the Z-profiles and their connections is for the transfer of the wind suction on the sheeting to the substructure. Finite-Element-analyses and experimental investigations showed that for the Z-profiles this design is governed by the limitation of local deformations and not by their load carrying capacity. A parametric investigation by Finite-Element-analyses gives the spacing of the fasteners required by the deflection limits and load carrying capacity of the fasteners depending on the type of Z-profile and its arrangement, the size of the wind load and the dead load (including insulation) of the sheeting.

"Shear Rigidity of Sheathed Walls with Pneumatically Driven Pin Connections"
S.W. Baur and W. Suaris
An experimental study was conducted to examine shear resistance of framed walls strength of pneumatically driven pin connections used in cold-formed steel construction. This study included the key parameters that influence the connection strength: steel thickness (16-, 18- and 20-gauge steel), sheathing thickness (1/2" (152-mm) Unipan and 1/2" (152-mm) Dens-Glass Gold). The shear design values given in the AISI design specifications for screw connections are compared with those obtained from a series of static load tests and good agreement is obtained. Additionally, observations as to the types of connection failures observed were noted with the intent of future provisions may allow for further study.

"Distortional Buckling Tests on Cold-Formed Steel Beams," C. Yu and B. W. Schafer
Laterally braced cold-formed steel beams generally fail due to local or distortional buckling. When the compression flange is not restrained by attachment to sheathing or paneling, such as in negative bending of continuous members (joist, purlins, etc.), members are prone to distortional failures. However, distortional buckling remains largely an unaddressed problem in the main body of the North American Specification (AISI 2002). With only limited experimental data on unrestricted distortional buckling in bending available, a new series of distortional buckling tests was completed. The test details are selected specifically to insure that the distortional buckling is free to form, but lateral buckling is restricted. Several design methods including those of the U.S., Canada, Australia, and Europe as well as the Direct Strength method were compared with the test results. Combined with our previously conducted local buckling tests (Yu and Schafer 2003), we can now provide experimental bounds for the capacity of laterally braced cold-formed steel beams in common use in North America. The experimental results have been investigated and extended through to use of nonlinear finite element analysis (FEA) with ABAQUS. The experimental data and our validated finite element model are being used to help develop new design procedures for cold-formed steel beams with and without panels attached to the compression flange - and to form the basis for more advanced design methods that account for situations partial restraint of the flange. This paper covers the detailed setup of the distortional buckling tests, test results, finite element analysis and discussion and comparison with design methods.

"Design Criteria for Seam and Sheeting-to-Framing Connections of Cold-formed Steel Shear Panels," L. Fulop and D. Dubina
A large full-scale experimental program on different typologies of wall-stud shear walls was carried out. Both monotonic and cyclic tests have been performed. The failure mode of panels was generally governed by damage of seam and sheeting-to-framing connections, which have been identified as the weakest component of the system. An additional testing program to characterize the behavior of these connections was carried out. An important aspect of the study was the influence of strain rate. This problem is of high importance for the case of seismic actions. Based on test results a three level performance criteria system was proposed for design of shear walls. The control parameter is the deformation/damage size of fasteners.

"Stress Gradient Effect on the Buckling of Thin Plates," C. Yu, B.W. Schafer
Thin-walled cold-formed steel beams suffer predominantly from one of three instabilities: local, distortional, or lateral-torsional. The last of these three, lateral-torsional, is considered in design for all steel beams and is strongly affected by the moment gradient that exists on the beam, with a uniform moment demand being the most critical case. Our development and understanding of the other two modes: local, and distortional, has ignored the influence of moment gradient. For local buckling, this has been justified by the relatively short nature of the buckling wave and subsequently the small change that occurs in the moment demand across such distances. For distortional buckling, ignoring the influence of moment gradient potentially ignores a source of significant reserve. In practice, one of the most common cases with a danger for distortional buckling includes high moment gradients: the negative bending region near the supports (columns) for a continuous beam. This paper presents a numerical approach to calculate the buckling load of cold-formed steel beams with unstiffened flanges under varying moment gradient. A classical flat plate model is employed with simple supports on three sides and one of the longitudinal edges free and the other longitudinal edge rotationally restrained with a finite stiffness. The moment gradient is then simplified as the stress gradient acting on the plate in the loading direction. The approach is applied to sections with unstiffened flanges. Finite element analysis by ABAQUS is employed to validate the numerical approach. A hand solution of the buckling load, based on this approach, is presented.

"Distortional Buckling of Cold-Formed Steel Members," G.M.B. Chodraui, M. Malite, R.M. Gonçalves, and J. M. Neto
Cold-formed steel design codes already present procedures to evaluate member's resistance due to distortional buckling, as the simplified method in the Australian code, AS/NZS 4600:1996, proposed by Hancock et al., which was adopted by the new Brazilian code NBR 14762:2001, the Direct Strength Method, recently adopted by the AISI Specification,

and the GBT (Generalized Beam Theory). This paper analyses cold-formed steel members under compression and bending, comparing results obtained by the method given in the Brazilian code, by Finite Strip Method elastic analysis - FSM, and by Finite Element Method analysis - FEM, on members with and without initial imperfections. It is also presented a comparison between Brazilian code and the Direct Strength Method.

"The Structural Behavior of Connections of Cold-Formed Steel Portal Frames," Y.B. Kwon, H.S. Cheung, and G. D. Kim
A series of connection tests of portal frames which were composed of cold-formed steel studs and rafters was carried out to study the moment-rotation relation, the rotational rigidity, and the yield and ultimate moment capacity of the connections. The connection test specimens were composed of column-base, column-rafter and rafter-rafter connections, and the closed cold-formed sections were used for the column and rafter members. The main factors of the test were the thickness and the shape of mild steel connecting members. The connection test results were compared with those obtained by using advanced analysis procedures. The secant stiffness of the connections which was estimated from the moment-rotation curves was proposed as the rotational rigidity of semi-rigid connections considered in the frame analysis. Simple formulas for the ultimate shear strength of the screw fastener connections based on the test results and AISI specifications were also proposed.

"Ultimate Strength of a Continuous Decking of Cold-Drawn, Low-Ductility High Strength Steel," A. M. Akhand and W.H.W Badaruzzaman
The profiled decking of cold-drawn high-strength low-ductility steel is relatively new product in building construction industry. This type of decking shows high sensitivity to distortional as well as local buckling. Prediction of ultimate strengths of such decking in continuous configuration is not adequately covered in any of the analytical methods of modern day codes, e.g., AISI Specifications. Instead, due to inadequate knowledge, various design codes apply additional restrictions on their design and use. The support moment-rotation and ultimate moment of resistance of such decking are the two most important parameters in designing such decking as a continuous structure for the construction stage of a composite floor. The current practices require the full-scale testing of such decking to determine these parameters, which is costly. Finite element analyses are rarely used to derive these parameters. The present paper focuses on the ultimate moment resistance of such decking in a continuous span configuration. The results of both the laboratory experiments and nonlinear finite element analyses are presented. It is demonstrated that a nonlinear finite element analysis can give a superior estimate of ultimate strength of such a decking compared to any of the analytical codes.

"Design of Cold-Formed Web Members with Non-Uniform Cross Sections," S. Parent, J. J. Pote, and K.W. Neale
In this paper, design algorithms are proposed for the design of cold-formed webs used in joists and girders built with conventional hot-rolled chords. Two types of web members with non-uniform cross section are investigated: single channels periodically closed and back-to-back channels with batten plates. The design method for periodically closed sections is based on the representation of the cross sectional properties using Fourier series introduced in an energy balance for the determination of the buckling loads about each of the three member axes. The back-to-back channels case is solved by the adaptation of the classical Engesser solution and by the critical shear ratio approach. In all cases, the proposed algorithms are integrated in the actual frame of the AISI 96 standard design curves with appropriate effective lengths coefficients.

"An Experimental Study of the Compressive Performance of Structural Panels with Cold-Formed Thin-Walled Perforated Steel Channels," B. Salhab and Y.C. Wang
This paper presents the results of an experimental investigation of the structural performance of full-scale panels tested under compression and at ambient and elevated temperatures. These tests are now taking place in the fire-testing laboratory of the University of Manchester. The panels are 2m high and use 100×54×15×1.2mm lipped cold-formed steel channels with perforations along the entire web length. ISO 1000 mineral wool manufactured by British Gypsum Limited is used as internal insulation. FireLine gypsum boards with a thickness of 12.5 mm (also manufactured by British Gypsum Limited) are attached to both sides of the perforated channels by bolts. One specimen will be tested at ambient temperature and one exposed to the standard fire condition. The results of these tests will be compared against previous tests of the research group where solid section channels were used. As part of the study to predict thermal stud structural performance in fire, some 3-D thermal analyses have been performed to obtain temperatures in the test specimens. This paper will present the simulation results.

"An Update on Cold-Formed Steel Framing Standards Development in the U.S.," J.W. Larson
The American Iron and Steel Institute helps turn state-of-the research into industry practice by serving as an ANSI-accredited standards development organization. Its Committee on Framing Standards (COFS) has as its mission to elim-

inate regulatory barriers and increase the reliability and cost competitiveness of cold-formed steel framing through improved design and installation standards. This relatively new organization published four new standards in 2001, addressing General Provisions, Truss Design, Header Design, and a Prescriptive Method for One and Two Family Dwellings. In 2004, the COFS updated each of these existing standards and completed two new standards addressing Lateral Design and Wall Stud Design. The COFS also helped facilitate the development of a Code of Standard Practice for the Cold-Formed Steel Structural Framing Industry. This paper provides an overview of these significant documents and describes the ongoing work of the committee.

"Shear Stiffness of Pallet Rack Upright Frames," S. S. Rao, R.G. Beale, and M.H.R Godley
Pallet racks, often fabricated using cold-formed steel members, improve the storage of goods by the efficient use of the cubic space available for storage. Uprights (columns) of these racks are braced in cross-aisle direction forming a frame, which behaves like a built-up column. Evaluation of the shear stiffness of this frame is needed to determine the elastic buckling load. Currently there are two approaches prevailing in rack industry to consider the effect of shear. The Rack Manufacturers Institute (RMI) code recommends the use of a theoretical formula based on Timoshenko's theory. The Federation Europeenne de la Manutention (FEM) code requires that the shear stiffness per unit length of the frame be determined by testing. There is a considerable difference in the shear stiffness values determined by these two approaches. The present paper describes experimental and numerical studies to evaluate shear stiffness of upright frames. The paper also explains the effect of various factors such as the flexibility of uprights, eccentric loading on bracing members, the aspect ratio of frame panels and bolt bending on the difference in two approaches. The study is limited to upright frames with bolted lacings or battens, which are common in Europe.

"Seismic Performance of Sheathed Cold-Formed Shear Walls," R. Landolfo, L. Fiorino, G. Della Corte
Recent research developments in seismic design of reinforced concrete and steel structures highlight the need to overcome some limitations of current codified force-based and prescriptive design rules and to implement a probabilistic performance-based approach. The latter methodology is mature to be applied in the design and analysis of classic reinforced concrete and steel structures, but its application cold-formed steel framed structures is largely unexplored. The research activities presented in this paper are focused on the **"**stick-built construction**"**. These are systems that certainly represent the most used structural solution. In the stick-built structures seismic loads are generally absorbed by horizontal (floors) and vertical (walls) diaphragms that are obtained by assembling cold-formed profiles braced by wood-based or gypsum-based sheathings. Therefore, the seismic performance of stick-built structures may be evaluated by means of the analysis of behaviour of the stud shear walls under cyclic loading.

"Structural Behavior of High-Strength, Cold-Formed Steel Z-Purlins with Overlaps," K.F. Chung and H.C. Ho
This paper presents a comprehensive study on the structural behavior of bolted moment connections in lapped cold-formed steel Z sections through experimental investigations. Four different configurations with various degree of ease of installation were examined, and a total of 36 tests on lapped connections between Z sections with various section sizes and lap lengths were carried out. Both the strength and the deformation characteristics of these lapped connections were examined in detail in order to understand the structural performance of multi-span purlins over internal supports. The research work aims to provide detailed understanding to the structural performance of lapped connections between cold-formed steel Z sections, and hence, to develop a set of rational design rules for multi-span purlin systems with overlaps.

"Behavior of Complex Hat Shapes Used as Truss Chord Members," N. Nuttayasakul and W. S. Easterling
The cold-formed steel roof truss system that uses complex hat shape members for both top and bottom chord elements is a growing trend in the North America steel framing industry. When designing cold-formed steel sections, a structural engineer typically tries to improve the local buckling behavior of the cold-formed steel elements. The complex hat shape has proved to limit the negative influence of local buckling, however, the distortional buckling mode can be the control mode of failure in the design for the chord member with an intermediate un-braced length. The chord member may be subjected to both bending and compressive load because of the continuity of the top and bottom chord members. Numerical analyses using finite strip and finite element procedures was developed to compare with experimental results. A parametric study was also conducted to investigate the factors that affect the ultimate strength behavior of a particular complex hat shape. The results of these analyses will be presented in the paper.

"Cold-Formed Steel Frame Shear Wall Applications with Structural Adhesives," R. Serrette, I. Lam, H. Q., H. Hernandez, and A. Toback
This paper presents the results from a series of shear wall tests that were conducted to evaluate the performances of sheet steel, metal lath and wood structural panels (rated sheathing) attached to cold-formed steel framing with a struc-

tural adhesive and screws or steel pins. The metal lath and sheet steel walls were 8 ft high by 4 ft. wide and the wood panel walls were 8 ft. high by 2 ft. wide. Each wall was tested under reversed cyclic loading similar to the procedures currently used for seismic evaluation of cold-formed steel systems. The overall performance of the walls was similar to that of wall configurations permitted in current building codes (even for the walls with sheathing attached using steel pins). The notable difference in performance of these walls compared to walls without adhesive was an increased lateral stiffness. The narrow shear walls exceed expected capacities and failures were confined to the wood structural panel. Based on this research, it appears that structural adhesives can provide significant added benefits in shear wall applications.

"Performance of Deep Leg L-Headers," R. Serrette, K. Chau, D. Peyton, and B. Waters
The L-header assembly as an alternative to back-to-back and boxed header assemblies is an efficient means of supporting openings in cold-formed steel frame construction. The design of L-headers is currently governed by the AISI Header Standard and the North American Specification for the Design of Cold-Formed Steel Structural Members. The research effort described in this paper involved an evaluation of a modified L-header configuration aimed at developing higher strength than the conventional L-header. Specifically, a series of modified 13-¼ in. (51.18 mm) deep 33 ksi (227.5 MPa) single- and double-sided modified L-header configurations were tested under monotonic gravity and uplift loads. The basic modification involved an extension and attachment of the long leg of the L-header to the head track of the spanned opening. The results showed that higher strengths can indeed be obtained with the extended leg and an appropriate fastener schedule. Further, it was found that single-sided L-headers can be designed to develop the same capacity as a double-sided L-header of the same dimensions and thickness by a nominal change in the number of fasteners used. In the uplift load tests, capacities similar to those obtained under gravity load were measured. These test results suggest that additional research should be undertaken to provide a broader evaluation of the modified L-header and provide data for a possible expansion of the Header Standard.

"Stainless Steel Stub Columns Subject to Combined Bending and Axial Loading," M. Macdonald and J. Rhodes
Stainless steel exhibits highly non-linear behaviour, and in the case of short column structural members, this can lead to substantial conservatism in the prediction of load capacity by design codes due to their use of the 0.2% proof stress as an upper limit of capacity. This paper examines the behaviour of short stainless steel stub columns in which the material follows a Ramberg-Osgood type of stress-strain law. The column length is varied to examine the effects on the load capacity when the column is subjected to varying magnitudes of combined bending and axial compression loading. The loading is applied as eccentric axial loading, with the eccentricity being positive at one end and negative at the other to produce varying moments along the column under load. Two different methods of analysis are employed, (1) the ASCE design code using a Ramberg-Osgood stress-strain law combined with a full section moment capacity within the interaction formula with nominal levels of loading eccentricity, and (2), the same approach, but using the true eccentricity with reference to the unsupported length of the columns. The results are compared with those obtained from a series of compression tests performed on cold formed stainless steel Type 304 stub columns of lipped channel cross-section for the same conditions.

"Design of Cold-Formed Steel Compression Members Subject to Distortional Buckling at Elevated Temperatures," T. Ranawaka and M. Mahendran
Cold-formed steel sections are being used extensively in residential, industrial and commercial buildings as primary load bearing structural components. However, these members are susceptible to various buckling modes including local and distortional buckling and their ultimate strength behavior is governed by these buckling modes. Fire safety design of building structures has received greater attention in recent times due to continuing losses of properties and lives in fires. Hence there is a need to assess the performance of cold-formed steel structures under fire conditions. Past research has focused heavily on heavier, hot-rolled steel members. The buckling behavior of cold-formed steel members under fire conditions is not well understood. The buckling effects associated with thin steels are significant and have to be taken into account in fire safety design. Therefore a research project involving both experimental and numerical studies was undertaken to investigate the distortional buckling behavior of cold-formed steel structures under axial compression. Numerical studies were used to investigate the distortional buckling behavior of a series of compression members with five different cross-sections and various thicknesses: 0.6, 0.8, 1.0 and 1.2 mm. The sections were made of both lower and higher grade steels (G300, G500 and G550 steels). Numerical studies included elastic buckling analyses using finite strip program Thin-wall and nonlinear analyses using ABAQUS. The distortional buckling and ultimate strength results were then compared with available experimental results and predictions from currently available design methods in order to assess the suitability of these design methods under fire conditions. Degradation of mechanical properties with temperature was included in the numerical studies and design procedure evaluation. This paper presents the details of this investigation and the results.

"Local Connection Failures in Composite Sandwich Panel Systems," A. Smith, B. Kershaw, M. Mahendran, and S. Wanniarachchi
Although the past research in Europe and the United States has made significant advances to the structural behavior and design of sandwich panels, there is a lack of knowledge and design information on the pull-through failure of connections in sandwich. This research project was therefore undertaken to gain an understanding of the pull-through failure of sandwich panel connections using experimental studies. It was found that a number of other parameters including foam core characteristics influenced the pull-through strength in addition to the primary parameters of washer diameter, fact thickness and strength. An interim design equation was developed. This paper presents the details of this research project.

"Experimental Investigation of Distortional Buckling of Cold-Formed Stainless Steel Sections," M. Lecce and K. Rasmussen
Distortional buckling is a stability phenomenon which has been extensively researched at the University of Sydney and elsewhere on structural "carbon" steel and design guidelines are in place for carbon steel structures. However, until recently there has been limited experimental research on distortional buckling of stainless steel open sections and current design guidelines are not well founded. Stainless steel alloys have non-linear stress-strain relationships with a markedly low proportionality stress. Furthermore, stainless steel alloys are anisotropic and have different properties in tension and compression. The behavior of stainless steel is also complicated by the fact that each alloy has a different stress-strain response which can be described by unique Ramberg-Osgood parameters. These material properties need to be considered in the distortional buckling design procedures for stainless steel sections. Simple lipped channels and lipped channels with intermediate stiffeners were brake-pressed from annealed stainless steel alloys including Austenitic 304, Ferritic 430 and Ferritic 3cr12. Column profiles and lengths were based on elastic finite strip buckling analyses to isolate the distortional buckling mode, thereby eliminating influence from local and overall modes. The paper details stub column tests as well as distortional buckling tests of columns of lengths 500mm to 1200mm loaded under fixed-ended conditions. Imperfections and enhanced corner properties of the brake-pressed sections as well as stress-strain non-linearity and anisotropy material characteristics have been determined experimentally. The paper also describes a numerical investigation of the distortional buckling strength of a wide range of sections based on the Finite Element program, ABAQUS.

"Design of Stainless Steel Sections Against Distortional Buckling," M. Lecce and K. Rasmussen
Stainless steel roof sheeting has proven to be both functional and aesthetically pleasing and the best option for buildings which require protection against environmental elements. The design procedures for stainless steel roof sections, such as those available in ASCE 2003, Eurocode3: Part 1.4, and the Australian Standard AS/NZS 4673, refers to the codes available for cold-formed carbon steel, thus making little, if any, distinction between the design of stainless and carbon steel. However, stainless steel alloys have non-linear stress -strain relationships with a markedly low proportionality stress. Furthermore, stainless steel alloys are anisotropic and have different properties in tension and compression. The behavior of stainless steel is also complicated by the fact that each alloy has a different stress-strain response which can be described by unique Ramberg-Osgood parameters. These material properties need to be considered in the distortional buckling design procedures for stainless steel sections. Until recently, experimental research investigating stainless steel characteristics and their influence on the distortional buckling behavior under bending has been lacking. Experimental tests on two different profiles of common roof sheeting with intermediate stiffeners made from Ferritic 445 stainless steel have been carried out to investigate the distortional buckling behavior. The test rig was designed to create pure bending conditions in the roof section thereby eliminating any influence from shear or axial loading. Correlation of experimental results is made with finite element analysis, which was used to generate additional data for the distortional buckling failure mode. Experimental procedures and results of Ferritic stainless steel roof sections in pure bending along with finite element results are presented in this paper.

"The 2002 AISI Cold-Formed Steel Design Manual," R. Kaehler and H. Chen
AISI recently published the 2001 edition of the Cold-Formed Steel Design Manual. The new edition incorporates the provisions of the 2001 North American Specification for the Design of Cold-Formed Structural Steel Members. Cross sections used in tables and example problems have been updated to either be identical to or more closely representative of widely produced components. New design aids have been added. Example problems have been added and existing problems have been expanded to better illustrate new and old Specification provisions. Equal treatment is given to LRFD and ASD.

"Tests of Storage Rack Channel Columns with Rear Flanges," N. Abdel-Rahman, A. Fadel, M. El-Sadaawy, and S. Mourad
Pallet racking is one of the most widely used light steel rack systems. The racking consists of thin walled compression members and beams with hook-on connectors. Columns of individual steel storage racks are generally made of cold-formed steel lipped channels. The columns are braced into upright frames by connecting inclined bracing between the channel lips of opposing channels using either welded or bolted connections. If bolting is used, additional elements, called **"**Rear Flanges**"**, parallel to the channel flanges are located at the ends of the flange stiffening lips to permit the braces to be bolted to the channel column. An experimental study was performed at the Housing and Building Research Center (HBRC) in Giza, Egypt, to investigate the ultimate strength and modes of failure of axially loaded channel rack columns with rear flanges. The effects of column slenderness ratio, thickness, perforation, and end conditions on the column ultimate strength and mode of failure were studied. The test failure loads were compared to the ultimate load predictions of the 2001 North American Specification. The comparison showed a consistent un-conservative nature of the Specification's load predictions. These un-conservative predictions suggest that the proportioning of the cross-sectional dimensions of the lipped channel sections with rear flanges may have a direct effect on the weakening of the columns.

"Computer Modeling of Sloped Z-Purlin Supported Roof Systems to Predict Lateral Restraint Force Requirements," M.W. Seek and T.M. Murray
Lateral restraint or anchorage forces in Z-purlin supported through-fastened and standing seam (concealed clip) roof systems have been studied using the finite element method. Results from bending and axial element models as well as full plate models are presented and compared to experimental results. Single and three span continuous systems with five restraint configurations were examined at roof slopes varying from zero to 18 degrees from the horizontal. Recommendations for modification of existing anchorage force prediction equations are made.

"Web Crippling of Cold Formed Steel Multi-Web Deck Sections Subjected to End One Flange loading," J.W. Wallace and R.M. Schuster
Investigated in this study was the web crippling capacity of multi-web deck sections subjected to End One-Flange loading (EOF). There was limited data available in the published literature to support the EOF loading web crippling coefficients for multi-web deck sections contained in the current North American Specification for the Design of Cold-Formed Steel Structural Members. Consequently, this research was initiated to establish the appropriate web crippling coefficients for multi-web deck sections subjected to EOF loading. A total of 148 tests were carried out on a range of deck profiles, bearing widths, and fastening conditions. In addition, test data from previous web crippling studies of multi-web deck sections were also considered. New coefficients were established using the data from this study and any appropriate data from previous published research. New resistance factors and factors of safety were also developed based on the appropriate calibrations.

Also investigated in this study was the web crippling capacity of partially fastened deck sections and re-entrant type deck sections subjected to EOF loading. Partially fastened decks sections are sections that are fastened to supports in a manner that does not meet common industry practice. Re-entrant deck sections are multi-web deck sections with a web inclination greater than 90º. It was found that partially-fastened deck sections, unfastened re-entrant deck sections, and fastened re-entrant deck sections all behave in a similar manner to fully-fastened multi-web deck sections and the same web crippling coefficients, resistance factors, and factors of safety can be used for design purposes.

"Channel Section Beams Under Static and Impact Loading," J. Rhodes and M. Macdonald
The elasto-plastic behavior of plain channel section beams under central point loading is investigated under static and impact loading conditions. Two different loading set-ups are considered, the first in which the load is applied to cause compression at the flange free edges and the second in which the load is applied to cause tension at the flange free edges. For each of these load set-ups static loading tests, single impact loading tests and multiple impact loading tests are carried out on a total of 86 channel beams. The energy absorption behavior of the beams tested is examined and the static and impact behavior is compared.

"Compression Behavior of Thin Gusset Plates," D. G. Lutz and R. A. LaBoube
The use of cold-formed steel members for truss applications is gaining widespread acceptance in the United States. However, there is little technical information regarding the behavior and design of thin gusset plates in compression. Thus, a study has been initiated at the University of Missouri-Rolla aimed at investigating the behavior of thin gusset plates in compression. The common connector for such applications is a self-drilling screw. Key parameters being considered for the experimental study are the thickness of the gusset plate sheet steel which ranges from 1.47 mm (0.058

in.) to 2.62 mm (0.103 in.); width and length of the gusset plates, fastener location, and fastener pattern. The paper will provide an overview of both the experimental and analytical phases of the study.

"Roof Diaphragm Strength and Stiffness," O. Avci, J. Mattingly, L.D. Luttrell, and W.S. Easterling
Five cantilever full-scale aluminum panel diaphragm tests were conducted at the Structures and Materials Research Laboratory of Virginia Polytechnic Institute and State University, Blacksburg, Virginia. The tests were sponsored by the Metal Construction Association and were conducted to evaluate the diaphragm strength and stiffness of aluminum panel assemblies over a range of panel depths and profiles. The tests were conducted in accordance with the AISI "Cantilever Test Method for Cold-Formed Steel Diaphragms." The aluminum diaphragms tested in the test program have been evaluated according to design formulas and principals contained in the Primer on Diaphragm Design, published by the MCA. The diaphragm shear stiffness development parallels that shown in the Steel Deck Institute Diaphragm Design Manual but with one modification, the introduction of a modified panel edge term, K. Most SDI diaphragms have their stiffness controlled by structural connectors along panel sidelaps with stitch fastener contribution added in through a ratio of fastener stiffness. Panel edge conditions dictate both strength and stiffness. For aluminum panel diaphragms, the general stiffness formula is modified by a term, K=2/3, which is supported by the test data. The results show remarkably narrow scatter in tested-to-theoretical strength ratios. Similarly, tested-to-theoretical stiffness ratios compare well supporting the proposed use of K = 2/3 for Eq. 6. Page 22 of the MCA Diaphragm Primer has a Case 3-Fasteners Through Aluminum Panels to Steel Supports. The listed case indicates that, the recommendations apply to aluminum panels with a maximum thickness of 0.021 inches. That recommended 0.021 in. maximum thickness represented the upper thickness limit tested during development of the MCA Primer. The current studies indicate that the aluminum thickness upper limit can be raised safely to 0.050 inches. The test data further indicate that the MCA strength and stiffness formulations work well for panels with depths through 4 inches.

"Numerical Simulations of High Strength Steel Box-Shaped Columns," D. Yang and G. J. Hancock
An experimental research project was conducted to evaluate the compression stability of high strength steel sections. To further study the structural behavior of the columns thoroughly, finite element analyses were performed using the commercial finite element package ABAQUS. This paper presents a finite element analysis of the post-buckling behavior of thin-walled compression members of high strength steel. A series of numerical simulations has been carried out to simulate compression tests performed on box-shaped stub columns and box-shaped long columns fabricated from cold-reduced high strength steel plates with nominal yield stress of 550 MPa. The paper compares the numerical simulations with the test results. The effect of the input parameters such as the degree of prescribed initial imperfection and the size of the element mesh on the convergence of the solution has been investigated and is discussed. The accurate results of the numerical simulation showed that the finite element analysis can be used to predict the ultimate loads of thin-walled members. It is demonstrated that the finite element analysis can therefore be used to design and optimize thin-walled section of high strength steel and to extrapolate beyond existing experimental data.

"Initial Geometrical Imperfections in Three-Storey Modular Steel Scaffolds," W.K. Yu, K.F. Chung and S.L. Chan
Modular steel scaffolds are commonly used as supporting scaffolds in building construction. They are highly susceptible to global and local instability, and traditionally, the load carrying capacities of these scaffolds are obtained from limited full-scale tests with little rational design. Structural failure of these scaffolds occurs from time to time due to inadequate design, poor installation and over-loads on sites. Initial geometrical imperfections are generally considered to be very important to the structural behavior of multi-storey modular steel scaffolds. This paper presents an extensive numerical investigation on three different approaches in analyzing and designing multi-storey modular steel scaffolds, namely, a) Notional Load Approach, b) Eigenmode Imperfection Approach, and c) Critical Load Approach. It should be noted that all three approaches adopt different ways to allow for the presence of initial geometrical imperfections in the scaffolds when determining their load carrying capacities. Moreover, their suitability and accuracy in predicting the structural instability of typical modular steel scaffolds are presented and discussed in details.