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Wei-Wen Yu Center for Cold-Formed Steel Structures

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Abstracts of Conference Papers for 22nd International Specialty Conference on Cold-Formed Steel Structures 2014

On November 5th and 6th, 2014 the 22nd International Specialty Conference on Cold-Formed Steel Structures will be held in St. Louis, Missouri, USA. For further information regarding the conference, contact the Wei-Wen Yu Center for Cold-Formed Steel Structures (e-mail: ccfss@mst.edu , Telephone: 573-341-4471, Fax: 573-341-4476,), or visit the Center's website at http://ccfssonline.org. This Technical Bulletin provides a brief summary of the papers that are scheduled to be presented and will appear in the conference proceedings.

Bond-Slip Characteristics between Cold-Formed Metal and Concrete, Y. Majdi, C. T. Hsu, and S. Punurai
Composite action in systems consisting of steel and concrete depends on an effective shear-transfer mechanism between the two materials. Such mechanism for smooth steel surfaces inside concrete will be limited to the bond-slip behavior at the steel/concrete interfaces. This research investigates the bond-slip behavior of galvanized cold-formed (light gauge) steel profiles embedded in concrete. A new innovative pull-out test is presented and global bond-slip curves for different values of concrete strength are obtained from such tests. Next, through an innovative procedure, mathematical equations and a few points from the experimental global bond-slip curves are used to develop a bi-linear local bond-slip model which represents the local bond-slip behavior. Then by curve fitting, empirical equations are proposed to determine the suggested model's parameters based on concrete compressive strength. Finally, validity of the proposed model is explored by two methods: 1) by comparing its resulting global bond-slip graphs from analytical equations with test results. 2) by comparing its resulting global bond-slip graphs from finite element modeling with test results.

Finite Element Modeling of New Composite Floors Having Cold-Formed Steel and Concrete Slab, Y. Majdi, C.T. Hsu, and M. Zarei
In this research, the structural behavior of a new type of U.S. patented composite floor system is explored through finite element modeling. The new composite floor incorporates cold-formed (light-gauge) steel profiles as the joist on bottom, a corrugated steel deck as the formwork for concrete, a hat channel (furring channel) as the continuous shear connector and finally a concrete slab on top. All steel parts in the system are cold-formed and connected together by self-drilling fasteners. In this study, a comprehensive three-dimensional finite element modeling is performed for the composite floor system. A local bond-slip model is applied to simulate the slip of the shear connector inside the concrete slab. A nonlinear analysis is performed on the composite floor considering all different types of structural nonlinearities and the behavior of the system is monitored from beginning of loading all the way to failure. Results of finite element analysis are compared with experimental results. Further, during the course of this study, several parametric studies are conducted to determine the effect of bond-slip behavior on reducing ultimate strength and initial stiffness of such a floor system.

Steel Deck Institute Design Manuals for Floor and Roof Deck, T. Sputo
The Steel Deck Institute (SDI) has developed new design manuals to assist in the use of their consensus floor and roof deck standards The SDI Floor Deck Design Manual, 1st Edition (FDDM) is based on the requirements of the ANSI/SDI NC-2010 Standard for Non-composite Steel Floor Deck and the ANSI/SDI C-2011 Standard for Composite Steel Floor Deck-Slabs. The SDI Roof Deck Design Manual, 1st Edition (RDDM) is based on the requirements of the ANSI/SDI RD-2010 Standard for Steel Roof Deck. Both manuals contain information on available deck profiles and finishes, and design and installation information. Additionally, both manuals contain extensive tables for design and design examples. This paper will illustrate the key features of both manuals.

Cold-formed Steel Channel Sections with Web Stiffeners subjected to Local and Distortional Buckling — Part I: Tests and Finite Element Analysis, L. Wang and B. Young
An experimental investigation of simply supported beams with two different stiffened channel sections has been conducted under both four-point bending and three-point bending about the major axis of the sections. Stiffeners were employed to the web of plain channel and lipped channel sections to improve the flexural strength of cold-formed steel sections that are prone to local buckling and distor-

tural steel sheets with nominal 0.2% proof stresses of 500 and 550 MPa, respectively. The high strength stiffened channel sections had the thicknesses of 0.48, 1.0 and 1.2 mm. Material properties were obtained from the tensile coupon tests. The moment capacities and observed failure modes at ultimate loads in the beam tests were reported. A nonlinear finite element model (FEM) was developed and verified against the test results in terms of strengths, failure modes and moment-curvature curves. It is shown that the FEM well predicted the moment capacities and failure modes of the test beams.

Cold-formed Steel Channel Sections with Web Stiffeners subjected to Local and Distortional Buckling — Part II: Parametric Study and Design Rule, L. Wang and B. Young
A parametric study of cold-formed steel channel sections with web stiffeners subjected to bending was performed using finite element analysis (FEA). An accurate finite element model was used for the parametric study. The parametric study included 75 beams of plain and lipped channel sections with web stiffeners. The beams were simply supported and subjected to four-point bending. The strengths and failure modes of specimens obtained from experimental and FEA results were compared with design strengths predicted using the direct strength method (DSM) specified in the North American Specification for cold-formed steel structures. The comparison shows that the design strengths predicted by the current DSM are conservative for both local buckling and distortional buckling in this study. Hence, the DSM is modified to cover the new stiffened channel sections investigated in this study. A reliability analysis was also performed to assess the current and modified DSM.

Pull-through Failure Tests of Thin Steel Roof Battens under Wind Uplift Loads, M. Sivapathasundaram and M. Mahendran
Thin profiled steel roof sheeting and battens are increasingly used in the construction of roofing systems of residential, commercial, industrial and farm buildings in Australia. The critical load combination of external wind suction and internal wind pressures that occur during high wind events such as thunderstorms and tropical cyclones often dislocate the roofing systems partially or even completely due to premature roof connection failures. Past wind damage investigations have shown that roof sheeting failures occurred at their screw connections to battens. In most of these cases, the screw fastener head pulled through the thin roof sheeting whilst the screw fasteners also pulled out from the battens. Research studies undertaken on the roof sheeting to batten connection failures have improved this situation. However, the batten to rafter or truss connections have not been investigated adequately. Failure of these connections can cause the failure of the entire roof structure as observed during recent high wind events. Therefore a detailed experimental study consisting of both small scale and full scale tests has been undertaken to investigate the steel roof batten pull-through failures in relation to many critical parameters such as steel batten geometry, thickness and grade, screw fastener head sizes and screw tightening. This paper presents the details of this experimental study and the pull-through failure load results obtained from them. Finally it discusses the development of suitable design rules that can be used to determine the pull-through connection capacities of thin steel roof battens under wind uplift loads.

Numerical Studies of Rivet-Fastened Rectangular Hollow Flange Channel Beams, R. Siahaan, P. Keerthan and M. Mahendran
The rivet-fastened rectangular hollow flange channel beam (RHFCB) is a new cold-formed hollow section proposed as an alternative to welded hollow flange beams. It is a monosymmetric channel section made by rivet-fastening two torsionally rigid rectangular hollow flanges to a web plate. This method will allow the designers to develop optimum sections, with affordable rivet connection between their web and flange elements. In addition to this unique geometry, the rivet-fastened RHFCBs also have unique characteristics relating to their stress-strain characteristics, residual stresses, initial geometric imperfections and hollow flanges that are not encountered in conventional hot-rolled and cold-formed steel channel sections. Therefore detailed experimental and numerical studies were conducted to study the section moment capacities of rivet-fastened RHFCBs. This paper presents the details of the numerical study of rivet-fastened RHFCBs and the results. Finite element models of rivet-fastened RHFCBs were developed by including all the significant effects that influence their ultimate section moment capacities, including material inelasticity, and geometric imperfections. The results from finite element analyses were then compared with corresponding experimental results and the predictions from the current design rules. Test results showed that the developed finite element models were able to predict the behaviour and section moment capacities of RHFCBs. The validated model was then used in a detailed parametric study that produced additional section moment capacity data of the rivet-fastened RHFCBs.

Section Moment Capacity Tests of Rivet-Fastened Rectangular Hollow Flange Channel Beams, R. Siahaan, P. Keerthan and M.Mahendran
The rivet-fastened rectangular hollow flange channel beam (RHFCB) is a new cold-formed hollow section proposed as an alternative to welded hollow flange steel beams. It is a mono-symmetric channel section made by rivet fastening two torsionally rigid rectangular hollow flanges to a web plate. This method will allow the designers to develop optimum sections, with affordable rivet connection between the web and flange elements. The new rivet-fastened RHFCB has unique characteristics that are not encountered in conventional hot-rolled and cold-formed steel channel sections. Therefore an experimental study consisting of 15 section moment capacity tests was conducted with different rivet spacings to investigate the flexural behaviour and strength of rivet-fastened RHFCB members. The ultimate moment capacities from the tests were compared with the capacities predicted by the current design rules for steel structures, and their suitability to predict the section moment capacities of RHFCBs was investigated. The applicability of the Direct Strength Method based design rules was also investigated. This paper presents the details of this experimental study and the results.

Finite Element analysis of cold-formed dimpled steel columns, V.B. Nguyen, M.A. English and M.A. Castellucci
Dimpled steel products are produced from the combination of an innovative dimpling process and a traditional forming process such as cold-roll forming or press-braking. The wider use of cold-formed dimpled steel members has promoted considerable interest in the

local instability and strength of these members. Of particular interest is their buckling behaviour and ultimate strength capacity. However, the dimpling process produces cold-formed sections with a complex 'dimpled' surface topography and the 'dimpled' material is non-uniformly work hardened through the entire thickness. Owing to these complex issues, there are no existing methods to calculate the buckling strength of the dimpled products and validate against physical measurements. This paper presents a Finite Element analysis of the compressive behaviour of cold-formed dimpled steel columns. True stress-strain data obtained from physical tests were incorporated into nonlinear simulations of dimpled steel columns. The simulation results were compared with compression test results on dimpled channel and lipped channel columns and good agreements in both buckling and ultimate strength were obtained. It is demonstrated that the Finite Element analysis can therefore be used to analyse and design cold-formed dimpled steel columns.

Acoustic performance of different cold-formed studs in double-leaf walls by Finite Element analysis and experiment, V.B. Nguyen, T. Morgan, M.A. English and M.A. Castellucci
Cold-formed steel studs are often used in lightweight partition walls to provide structural stability but in the same time they change the acoustic performance of the whole system. The overall design of such lightweight structures for acoustic sound insulation becomes very complicated as the sound passing through stud needs to be quantified. One of the greatest challenges is to characterise the stud's geometric effects on the sound transmission of the partition walls. This paper presents a Finite Element modelling approach and results into the acoustic performance of cold-formed studs in double-leaf walls which are placed in between a source room and a receiving room. The acoustic medium was modelled using fluid elements and the structure was modelled with conventional stress elements. The interaction between the acoustic medium and the structure was modelled in a coupled structural-acoustic analysis. An FE modelling setup which includes appropriate model parameters to be used in the structural-acoustic analysis was presented. The FE sound transmission loss of double-leaf walls using two different stud profiles was then calculated. Experimental tests complying with BS EN Standards 717 and 140 were also carried out to evaluate the FE results. It has shown that the FE results have similar trends are in fair agreement with the experimental results; and the stud's shape have significant effects on the sound transmission of the double-leaf walls. The FE analysis is a powerful tool and can be used as a complementary and alternative method to the laboratory tests for acoustic performance of double-leaf walls with steel studs.

Structural Strength of Lapped Cold-Formed Steel Z-shaped Purlin Connections with Vertical Slotted Holes, J. Liu, L. Xu and S. Fox
Abstract: Lapped joints of cold-formed steel (CFS) Z-shaped purlins are extensively used in metal building roof systems. The research that has been carried out so far for these lapped connections is primarily focused on connections with round holes. However, the lapped connections with vertical slotted holes are extensively used in current construction practice to simplify the erection of continuous Z-shaped roof purlins. There are no design guidelines or recommendations available for CFS Z-purlin lapped connections with vertical slotted holes.

Presented in this paper are the results of an experimental study on the structural strength behaviour of lapped CFS Z-shaped purlin connections with vertical slotted holes. A total of 42 flexural tests were performed on lapped CFS Z-shaped purlins with vertical slotted holes in different lap lengths, purlin depths, thicknesses and spans. The flexural strength and deflection of each specimen were measured. The characteristics of moment resistance were computed. The test results indicate that the characteristics of moment resistance in the slotted connections are dependent on the ratio of lap length to purlin depth and ratio of purlin depth to purlin thickness. Based on the results, design recommendations for evaluating the moment resistance of lapped slotted connections are proposed.

Simplified Seismic Design of Cold-Formed Steel Hybrid Building Structures, X.L. Yuan and L. Xu
Presented in this paper is a practical approach for the seismic design of cold-formed steel hybrid building structures. In current design practice the presence of vertical irregularities on both mass and stiffness inherited in such hybrid building structures creates a challenge for the seismic design. Currently, a two stage lateral force procedure prescribed in ASCE 7 is prescribed for evaluating the seismic load if the lateral stiffness of the lower structure of the building is considerably more rigid than the upper one. In the proposed approach the requirement associated with the two stage analysis procedure on the lateral stiffness ratio between the lower and upper structures prescribed in ASCE 7 is abandoned. The seismic design can be obtained based on the required stiffness ratio determined by the proposed approach. Two examples are presented to demonstrate the efficiency of the proposed approach. The results obtained from proposed approach are justified by the verification of the dynamic analysis. Also found in this study is that in some cases over increasing the rigidity of lower structure of the hybrid structure so that the two stage analysis procedure can be applied may lead to a design that is not only uneconomic but also unsafe.

The Effects of End Conditions on the Load Capacity of Cold-Formed Steel Column Members of Lipped Channel Cross-Section with Perforations Subjected to Compression Loading, M. Macdonald and M. P. Kulatunga
The effects of end boundary conditions on the compressive load carrying capacity of cold-formed lipped channel sections with perforations are investigated and discussed. Most structural cold-formed steel members are typically manufactured with perforations. These perforations are pre-cut to accommodate electrical, plumbing, and heating services and so on. Due to the size, shape, and position of perforations and end conditions, ultimate strength and elastic stiffness of a structural member can be varied. This paper describes the ultimate strength results obtained from numerical, experimental, and theoretical investigations for two types of end conditions namely, flat-end and fixed-fixed. The numerical results given have been obtained using the ANSYS FEA software package. An experimental study of the buckling behaviour of lipped channel columns of same cross-section, but with different perforation shapes and end conditions is reported and the findings from this are used to validate numerical results; good correlation was obtained both with ultimate

strength and failure modes. Further, the study showed that there are similar ultimate load values for corresponding compression members under flat-end and fixed-fixed end conditions, and in general, more conservative estimates of design rule predictions: AISI Specification, British Standard - BS 5950 Part 5, and Eurocode 3.

Shape optimisation of cold-formed steel profiles with manufacturing constraints - Part I: Algorithm, B. Wang, B. P. Gilbert, A. M. Molinier, H. Guan, L. H. Teh
This paper presents a Genetic Algorithm optimisation method with manufacturing constraints for shape optimisation of cold-formed steel (CFS) profiles. Previous studies on unconstrained shape optimisation of CFS cross-sections, where the sole aim was to optimise the weight-to-capacity ratio of the profiles, yielded cross-sections that cannot be manufactured. Current cold-forming processes, such as roll-forming and brake-pressing, have limited ability to form continuously curved surfaces without discrete bends. This paper defines simple manufacturing rules and introduces them into the evolutionary algorithm. Augmented Lagrangian constraint-handling technique, with equality and inequality constrained violations, is used to avoid ill-conditioned problems. The ability and accuracy of the algorithm to handle the defined manufacturing constraints are verified by implementing it to optimise the section capacity of bisymmetric closed thin-walled profiles, for which an analytical solution is known.

Innovative Cold-Formed Steel Framed Shear Wall Sheathed with Corrugated Steel Sheets: Experiments and Dynamic Analysis, C. Yu, G. Yu, J. Wang
Cold-formed steel framed shear wall sheathed with corrugated steel sheets is a promising shear wall system for low- and mid-rise constructions in high wind and seismic zones due to its advantages of non-combustibility, high shear strength, and high stiffness. However recent research projects showed that the corrugated steel sheathing demonstrated low ductility. This paper presents an experimental study aimed at improving the ductility of cold-formed steel shear walls sheathed with corrugated steel sheathing. A method of using opening in the sheathing is employed to improve the shear wall's ductility meanwhile controlling the damage locations and failure mechanism. A total of 11 sheathing configurations were investigated and 19 monotonic and cyclic full-scale shear wall tests were conducted in this project. The research discovered that with proper opening in the sheathing, the corrugated sheet shear wall can yield significantly improved ductility while maintaining high-level shear strength. Additionally, nonlinear dynamic analyses were also carried on to verify the building's seismic performance when the innovative shear wall was installed. The dynamic analyses show that the new shear wall system can greatly reduce the seismic effects and decrease the building's collapse probability.

Fragility curves for thin-walled Cold-formed steel wall frames affected by ground settlements due to land subsidence, L. A. Hernández-Castillo, J. A. Ortiz-Lozano, M. Hernández-Marín, J. Pacheco-Martínez, M. E. Zermeño-deLeón, J. J. Soto-Bernal, J. Ramos-RuizFlores, M. A. Soto-Zamora
Land subsidence phenomenon due to ground water withdrawal is a current problem in many places around the world, particularly in the shallows of Mexico. This causes ground differential settlements that affect structures, mainly dwellings and buildings based on reinforced concrete and masonry. Eventually, these structural materials do not exhibit an adequate performance beyond a certain level of angular distortion. This work presents the results about a study regarding the performance of thin-walled cold-formed steel wall frames with different sheathing systems affected by angular distortions simulating ground differential settlements due to land subsidence. The wall frames are composed by vertical (studs) and horizontal elements (tracks), with different sheathing systems: polystyrene, OSB, gypsum and calcium silicate. By means of experimental testing of wall frames subjected to monotonic lateral loads, the rotational stiffness was obtained for the wall frames with polystyrene. Likewise the rotational stiffness of the other wall frame systems was calculated based on the data provided by other author's publications. On the other hand, by means of numerical simulation, all the wall frame systems were modeled in structural analysis software, calibrating them based on the rotational stiffness. Also, the moment-rotation curves were calculated for the studs and tracks based on the direct strength method. A non-linear static pull down analysis was performed producing several degrees of angular distortion simulating ground settlements for all the wall frames sheathing systems. With the data acquired fragility curves were calculated according three levels of damage for the wall frames with different sheathing system.

Design Equations for Tensile Rupture Resistance of Bolted Connections in Cold-Formed Steel Members, L. H. Teh and B. P. Gilbert
This paper summarises and re-examines the authors' previous research results concerning the tensile rupture resistance of cold-formed steel bolted connections in a flat sheet, in a channel's web, and in one leg of an angle section. Staggered bolted connections are also included. The fundamental shortcomings of the design equations given in the 2012 North American Specification for the Design of Cold-formed Steel Structural Members are described, and the alternative design equations proposed by the authors are shown. The alternative equations are checked against laboratory test results obtained by the authors and other researchers where the bolts had not been snug-tightened and the failure modes were correctly identified. The reliability analyses previously carried out by the authors are repeated using additional test data and the statistical data provided in the current North American specification. A uniform resistance factor of 0.70 is recommended for all the proposed equations for determining the tensile rupture resistance of bolted connections in cold-formed steel members.

Study on the Flexural Capacity of Cold-Formed Steel Joists-OSB Composite Floors, X.H. Zhou, Y.Shi, R.C.Wang, Y.J. Liu
Two full scale specimens were tested to study the flexural capacity of cold-formed steel joists and OSB(Oriented strand board) composite floors. Test results indicated the composite floors had high bearing capacity and small deformation, and the screws spacing significantly affected the load-carrying capacity. The main failure modes were bending-torsion buckling of floor joist, and the relatively buckling of compression flange, web and crimping. The wave length of bucking was the adjacent screws spacing. Then the speci-

mens were analyzed by ANSYS software and the nonlinear FEM calculation results agreed well with the test results. Furthermore, details including the screws spacing and the length-width ratio were varied to observe their influence on the flexural capacity of the composite floors. FEM analysis results indicated that the reasonable screws spacing is 150mm on-center at OSB edges and 150~300mm on-center at intermediate supports, and the load-carrying capacity of the composite floors linearly increased as the number of joists increases. Finally, simplified calculation model and method were proposed on the basis of experimental study and FEM analysis.

Strain and Stress Distributions in Composite Deck Slabs: A Numerical Study, V. V. Degtyarev
This paper describes results of a study on strain and stress distributions in compact and slender composite deck slabs using nonlinear three-dimensional finite element models. The slabs were modeled as flexural members made of steel deck units and structural concrete fillings interconnected at the interface with nonlinear springs representing bond between two materials. The models are capable of accounting for partial interaction between the deck and the concrete, discrete concrete cracking in the slab tension zone, and nonlinear behavior of the materials and the interface. They were validated against published test data and have proved to be effective in predicting load-deflection responses of composite deck slabs. The study showed that the strain and stress distributions are greatly affected by concrete cracking and slip between the deck and the concrete. The study provides information that may be useful in understanding composite slab behavior and in developing analytical models for predicting slab strength and stiffness.

Fire resistance prediction of load bearing cold-formed steel walls lined with gypsum composite panels, W. Chen, J. Ye
An innovative load-bearing cold-formed steel (CFS) wall lined with gypsum composite panels was developed with the goal of improving the construction efficiency and fire performance of these walls for applications in mid/high-rise buildings. The gypsum composite panel was formed by sandwiching insulation and plasterboard strips between two layers of gypsum plasterboards. The CFS wall lined with gypsum composite panels had the advantages of easy construction and elimination of the unfavorable influence of opening of the board joints on the temperature profiles of the steel studs when the wall experiences a fire. Subsequently, the predicted fire resistance of these CFS walls was predicted based on our previously developed and experimentally validated modeling method. The thermal response of CFS walls was simulated by a heat transfer analysis using an implicit finite-difference model. The time-dependent lateral deflection of CFS walls in fire was simplified to a second-order analysis of the flexural deflection for a simple supported steel stud under the comprehensive action of lateral restraints provided by the composite panels, with a constant axial load and non-uniform temperature distribution. The fire resistance time of CFS wall was estimated based on the yielding of the cold flange at the mid-height instead of global and local buckling of the studs. The degenerated material properties of the cold-formed steel and thermal physical property of the gypsum plasterboard and aluminum silicate wool were obtained from our pervious experimental investigations and used as the basic input parameters in the present fire resistance modeling. The results showed that the fire performance of the CFS walls lined with gypsum composite panels improved greatly. The configuration details and corresponding design load levels were also determined for the CFS walls with a fire resistant rating of 120 and 150 min.

Lateral Loading Response of CFS Framed Shear Walls Sheathed with Cement Board Panels, N. Baldassino, M. Accorti, R. Zandonini, F. Scavazza, C.A. Rogers
The University of Trento has recently been involved in a research project focusing on the development of an innovative industrialised housing system composed of cold-formed steel profiles. This paper describes the laboratory testing phase of the research project comprising the development of lateral design information for cold-formed steel framed walls that are sheathed with cement board panels. A summary is provided of the shear wall test program, as well as the ancillary characterization tests on the sheathing and the sheathing connections, in addition to the results of the application of existing hand calculation methods to determine shear wall resistance to lateral loads and lateral stiffness.

Tailoring Compression Performance of Cold-Formed Steel Columns, T. Ekmekyapar, M. T. Gogus, M. Ozacka
Since thin-walled structural analysis and design procedures are utilized for cold-formed steel columns, it is first necessary to understand thin plate behavior to employ proper cross sections which will serve under compression actions. As is well known, thin plates without any longitudinally and/or laterally stiffening elements usually are not present in structural applications. These stiffening elements significantly improve local buckling and collapse characteristics of plates, providing optimized solutions in terms of strength and cost. In cold-formed steel industry there exist some tailoring methods for columns to use the cross-section material more effectively. Designing lipped channels instead of plain ones or deploying rack sections can be shown as examples of stiffening and enhancing flange compression performance. Present study offers a novel tailoring technique which has the potential to improve collapse performance of cold-formed steel columns. Considering the manner of stiffening for thin plates, present work assesses cold-formed steel columns which are manufactured using stiffened sheets. Used stiffened sheets are called as checkered sheets which contain small stiffeners on thin plates in a shape of diamond pattern and are generally used to cover stairs and decks in outdoor environments to prevent slip. Aiming at investigating contributions of small stiffeners on compression performance of cold-formed steel columns, an experimental study was undertaken and column specimens were tested to failure. Plain channel test specimens were manufactured using press braking method and boundary conditions of specimens were designed in such a way that would represent fixed ends. Accompanying the experimental program, non-linear finite element simulation works and AISI-2007 method were employed for manufactured columns using equivalent thickness approach. Results imply that with the proper geometrical configurations, reserve of cold-formed steel columns manufactured using checkered sheets offer structural efficiency in satisfying greater compression loadings compared to that of columns manufactured using plain sheets of equivalent thickness. This stiffened sheets concept has the potential to be facilitated in cold-formed steel commercial and residential structures. More efficient sections also can be acquired for design pur-

poses by optimizing those stiffener configurations under compression loadings.

In-Plane Behavior of Cold-Formed Steel-Framed Wall Panels Sheathed with Fibre Cement Board, R. Shahi, N. Lam, E. Gad, I. Saifullah, J. Wilson and K. Watson
Shear wall panels are commonly used as lateral load resisting elements to provide stability of the cold-formed steel-framed houses in Australia against wind and earthquake actions. The effectiveness of their lateral resistance behavior is obtained usually by experimental testing although it can also be done by analytical modeling. This paper presents racking test results of steel-framed wall panels with different aspect ratios sheathed with fibre cement board subjected to monotonic and cyclic loading protocol. Performance parameters of the wall panels are obtained from the experimentally observed load-deflection curves using various existing methods and evaluation method is proposed. The evaluation method considers various performance characteristics including ductility modification factor, residual displacement recovery and load levels satisfying ultimate and serviceability limit state conditions.

Compressive Strength of Cold-formed Steel C-shape Columns with Slotted Holes, L. Xu, Y. Shi and S. Yang
Presented in this paper is an experimental investigation on the effect of web holes on the strength of cold-formed steel (CFS) C-shape columns. A total of 18 CFS C-shape stub columns were tested without and with web holes. The column length and web height of C-shape section were 490 mm (19 in) and 150 mm (6in), respectively; and the lengths of the holes investigated were 74 mm (3 in),114 mm (4.5 in) and 130 mm (5 in) whereas the width of the holes remains as 38 mm (1.5 in). It is noted that for the strength determination of uniformly compressed stiffened elements with non-circular holes AISI-S100 requires the length of the holes not to exceed 114 mm (4.5 in). The test results obtained from this investigation showed that local buckling at the column ends combining with one distortional half-wave along the column length was the predominant failure mode. Results also indicate that the presence of web holes had negligible effect on the ultimate compressive strengths for the hole dimensions considered here. A numerical investigation based on elastic buckling analysis confirmed that the elastic local buckling load is not affected by the presence of the hole while the elastic distortional buckling load decreases slightly as the increase of the length of the hole. A comparison between results of the tests and the Direct Strength Method approach (DSM) for CFS columns with holes demonstrated that the DSM design equations are valid to evaluate the strength of CFS C-shape
columns with web holes.

Understanding the global buckling behavior of thin-walled members with slotted web, B. Geleji, M. Szedlák, D. Visy, S. Ádány
In this paper flexural buckling of thin-walled members with holes are discussed. Members with few but large openings, as well as with slotted webs are studied. Large number of finite element analyses has been performed, by using a carefully constrained shell finite element model in order to exclude the distortion of the cross-section, which makes it possible to analyze flexural buckling separately from other modes. Based on the results general conclusions are drawn regarding the global behavior of members with holes. Moreover, analytical models are developed for column members with slotted webs, with neglecting or with considering the effect of shear deformations. The proposed analytical models are the adaptation of the shell-theory-based analytical models proposed by the authors earlier.

Constrained finite element method: demonstrative examples on the global modes of thin-walled members, S. Ádány
In this paper a novel method is presented for the modal decomposition of thin-walled members. The proposed method follows the logic of the constrained finite strip method (cFSM), however, polynomial longitudinal shape functions are applied together with a longitudinal discretization. Thus, strips are transformed into multiple shell finite elements. The longitudinal shape functions are selected in such a way that modal decomposition similar to cFSM can be realized, therefore, the new method can conveniently be described as constrained finite element method (cFEM), possessing all the modal features of cFSM, but with significantly more flexible applicability. The method is briefly presented and illustrated by global buckling problems.

Experimental investigation on ultimate capacity of eccentrically-compressed cold-formed beam-columns with lipped channel sections, Y. Li, Y. Li and Y. Song
This paper is mainly concerned with the in-plane behavior of eccentrically-compressed cold-formed steel beam-columns with lipped channel sections. The tested members are classified into three series by loading types including: axial compression and major axis bending (X), axial compression and minor axis bending (lips in tension, Y1), and axial compression and minor axis bending (lips in compression, Y2). A numerical model is developed and verified by the experimental results. Then the elastic local buckling loads are discussed based on test results, numerical analysis, and design methods. The comparison between test strength and nominal strength obtained by AISI specification indicates that the interaction equation can provide conservative prediction for beam-columns' strength.

Investigation on seismic performance of cold-formed steel portal frames, Y. Li, Z. Xu, Y. Li and Y. Peng
A series of monotonous loading and hysteresis loading tests on cold-formed steel portal frames were conducted in this paper. The averaged ductility factor value of tested frames is 3.15 and the strength and stiffness degradation are not obvious during the test. The failure mode of frame is local buckling at column bases followed by local buckling at the top of columns, which lead to the dropping of frame's load-carrying capacity. Then, the finite element model is developed and the analysis results match well with the test results. The research in this paper indicates that cold-formed steel portal frame has a good seismic performance.

Improved Effective Width Method Considering Distortional Buckling for Cold-formed Thin-walled Steel Members with Lipped Channel Section, X. Yao and Y. Li
The local buckling, distortional buckling, and overall buckling would occur for cold-formed thin-walled steel members with lipped channel section. The effective width method is used to considering the effect of local and distortional buckling on load-carrying capacity of member in Chinese code. Especially, a very conservative stability coefficient of partially stiffened elements used to considering the local buckling and distortional buckling of flange of lipped channel sections. In this paper, the half-wave length, the elastic buckling stress of distortional-buckling of cold-formed thin-walled steel members with lipped channel section and the corresponding stability coefficient of partially stiffened elements were developed based on the energy method. With comparison among the calculated results of elastic buckling stress and half-wave length using the improved method and the Finite Strip Method, suitability and precision of the improved method were illuminated. Then, a uniform formula for the stability coefficient of partially stiffened elements considering both local and distortional buckling effect was established based on the proposed method. Finally, with comparison on lipped channel sections in the appendix of Chinese code and existing test results conducted by many researchers and the proposed method, it is shown that the proposed uniform formula had higher precision to calculate the stability coefficient of partially stiffened elements and the ultimate load-carrying capacity of cold-formed thin-walled steel members with lipped channel section.

Cold-Formed Steel Framing Building Test Model, Y. Li, R. Ma and Z. Shen
A nonlinear dynamic numerical simulation on seismic behavior of a two-story cold-formed steel framing building full-scale shaking table test model was carried out by the way of from components to integral structure. Firstly, refined numerical model of shear wall was established, and restoring force models of screw connections between the framing and sheathings were integrated into the numerical model of shear wall. The refined numerical model of shear wall was verified by tests. Secondly, based on refined numerical model of shear wall and modified exponential “Foschi” skeleton curve, uniform restoring force skeleton curves of two typical shear walls of the shaking table test model were obtained. Then, a simplified numerical model of shear wall was proposed. Finally, a dynamic numerical model of cold-formed steel framing building was established based on the simplified shear wall model and assumption of rigid diaphragm, and nonlinear dynamic analysis was carried out. The results of numerical simulation agreed well with the tests, which indicated that the numerical model of integral buildings can factually reflect the dynamic behavior of cold-formed steel framing building.

Design Method of Bending Load-carrying Capacity for Sandwich Panels with Different Metal Panel on Both Sides, Y. Guo, X. Yao, K. Liu
The sandwich panels, with plain and shallow grain pressed metal plate as the face sheets, and glass wools, rigid polyurethane foam, and rock wools as core materials, have excellent heat insulation and mechanical behavior, and been used as curtain walls for tall buildings in recent years in China. Since wind load and temperature action are the main actions for curtain walls, the sandwich panels are flexural members. In this paper, the design method and design formula of flexural load-carrying capacity and flexural deflection of a kind of sandwich plates with different metal panel on both sides are discussed and proposed. This proposed method considers the different load types, like uniform load, concentrated load, and temperature action, and different core materials. The FE Method can be verified by comparing on shear force distribution coefficients for different sandwich panels with same metal panels on both sides between FE results and calculated results. Then the FE Method can be used to verify the proposed method for shear force distribution coefficients of sandwich plates with different metal panel on both sides. Finally, the proposed method for bending load-carrying capacities for sandwich plates with different metal panel on both sides is verified using FE Method. These verifies show that the proposed method for shear force distribution coefficients and bending load-carrying capacities for sandwich plates with different metal panel on both sides is safe and suitable.

Numerical Studies on the Composite Action and Buckling Behavior of Built-Up Cold-Formed Steel Columns, D. C. Fratamico and B. W. Schafer
An exploratory study is performed herein on the global, local, and distortional buckling behavior of built-up cold-formed steel members constructed using industry standard lipped channel sections. The stability characteristics of these columns under concentric axial compressive loads offers insights on member assembly (e.g. fastener spacing), and on the prediction of buckling loads (e.g., section rigidities) used in design formulations. Currently, built-up column buckling is determined using a modified flexural slenderness ratio, which reduces the buckling capacity in part due to a loss of shear rigidity in the overall member’s interconnections. In this paper, a numerical study is performed to analyze the level of composite action that can be achieved with idealized standard details, and which can then be used subsequently to more accurately predict the composite member strength. A parametric study using elastic buckling analysis was conducted on a representative population of built-up structural columns in ABAQUS. Member cross-sections, fastener spacing, and fastener grouping at the column ends were varied. Notable outputs include elastic buckling loads and column critical slenderness ratios. Buckling loads from the study are compared to code-based equation predictions and show considerable composite action, which can increase a column’s buckling load by up to 85% from its non-composite lower bound, assuming discrete connections. Future work includes experimental testing, nonlinear collapse simulations, and the development of new design formulations.

Development of a new beam-column design method for cold-formed steel lipped channel members, S. Torabian, B. Zheng and B. W. Schafer
The structural strength of cold-formed steel lipped channels under combined axial force and biaxial bending moments has been predicted by geometric and material nonlinear collapse analyses performed in ABAQUS and compared to both current, and a newly proposed, beam-column design method. The ABAQUS analyses utilizes a validated modeling protocol calibrated against previous testing by the authors, and including residual stresses and strains, and geometric imperfections; as well as, appropriate cross-section dimen-

sions, member length, and boundary conditions. A total of 75 different lipped channel cross-sections have been selected and the capacity of the beam-column member has been examined under 127 combinations of actions in the P-M1-M2 space (axial load, P, and major-axis, M1, and minor-axis, M2, bending moments). The results have been used to evaluate the current beam-column design method and validate a new Direct Strength Method (DSM) approach for cold-formed steel beam-columns. The newly proposed method provides means to incorporate more realistic stability analyses of cross-sections under the applied actions, where the current design methods include only a linear prediction of the combined actions using “column strength” and “beam strength” as anchor points. Correspondingly, the reliability of both current and newly proposed methods has been evaluated. The newly proposed extensions to the Direct Strength Method show a potential to realize a sizeable strength increase in many situations, and follow the overall trends in the data (P-M1-M2 surface) well; however, additional advancement is needed to realize the complete benefits predicted in the finite element models.

Experimental seismic behavior of the CFS-NEES building: system-level performance of a full-scale two-story light steel framed building, K. D. Peterman, R. L. Madsen and B. W. Schafer
In the summer of 2013, testing of two full-scale cold-formed steel (CFS) framed buildings under seismic excitations took place at the Structural Engineering and Earthquake Simulation Lab (SEESL) at the University at Buffalo. Utilizing the twin shake tables, the two-story building specimens were subjected to ground motions from the 1994 Northridge earthquake. These experiments were conducted as a part of the CFS-NEES experimental effort in an attempt to advance cold-formed steel earthquake engineering and design. Two buildings were tested: the first, a specimen constructed with only structural components (CFS-framed gravity walls, shear walls, floor and roof diaphragms, with OSB sheathing on shear walls and diaphragms); the second began with an exact replica of the first building, but saw the addition of various non-structural systems such as gravity wall sheathing, full diaphragm sheathing, interior partition walls, and exterior weatherproofing. Prior to these experiments, little experimental data existed on full building system behavior for CFS framing. This paper presents results on full-system behavior, specifically examining: drifts, acceleration amplification, shear wall behavior, base shear, diaphragm flexibility, damping, and period of vibration. Comparison to the North American specification for CFS, and design recommendations are also provided.

Laser scanning to develop three-dimensional fields for the precise geometry of cold-formed steel members, X. Zhao and B. W. Schafer
Geometric imperfections play an important role in the performance and behavior of cold-formed steel members. The objective of this paper is to detail a newly developed imperfection measurement rig, where the full three-dimensional (3D) imperfect geometry of a cold-formed steel member can be measured and reconstructed. The measurement results in a dense three-dimensional point cloud that may be utilized to provide precise knowledge of the basic member dimensions (width, angle, radius including variation along the length), frequency content in the member (waviness, local dents, etc.), or directly as the exact geometry of the member. Practical applications of the data include basic quality control; however, the potential of the data is truly realized when applied to shell finite element models of cold-formed steel members to investigate imperfection sensitivity. The measurement rig set-up (Phase I) consists of three basic parts: a two-dimensional (2D) laser scanner with measurement range up to 304 mm [12 in.]; a linear drive system, allowing the laser to collect measurements of cross sections along the length of the target specimen; and a support beam. The raw point cloud data from the Phase I rig is input into MATLAB where custom post-processing is employed to develop the full 3D reconstruction of the target specimen. The Phase II rig adds a rotary ring, providing a rotational stage for the laser so that the cross section of the target specimen may be profiled from any direction. This paper provides several examples of full-field imperfection measurements and compares against other methods in current use. The measured imperfections contribute to the database of realized imperfections appropriate for the generation of stochastic imperfections for use in simulation. Accurate knowledge of geometric imperfections is critical to the long-term success of analysis-based design paradigms for cold-formed steel.

Fastener-Based Computational Models with Application to Cold-Formed Steel Shear Walls, G. Bian, S. G. Buonopane, H. H. Ngo, B. W. Schafer
The objective of this paper is to validate a tool that design engineers could employ to develop mechanics-based predictions of the lateral response of wood-sheathed cold-formed steel (CFS) framed shear walls applicable in a wide variety of situations. Wood framed shear walls enjoy a variety of tools, most notably SAPWood and its predecessor CASHEW, that provide a means to predict the complete hysteretic behavior of a shear wall based on the nail fastener schedule and board selection. The existence of these tools helps engineers in unique design situations, encourages innovation in shear wall design particularly for Type I shear walls, and provides enabling modeling details critical for seismic performance-based design. Recently, as part of the CFS-NEES effort, the cyclic performance of CFS stud-to-sheathing connections has been characterized. In addition, the cyclic performance of full CFS shear walls, utilizing the same connections, has also been characterized. This paper explores an engineering model implemented in OpenSees that directly employs the fastener-based characterization as the essential nonlinearity in a CFS framed shear wall. CFS shear wall framing is modeled with beam elements, hold downs are modeled with linear springs, sheathing is modeled as a rigid diaphragm, and the stud-to-sheathing connections as zero-length springs utilizing the Pinching04 material model in OpenSees. Production, analysis, and post-processing of the model are automated with custom Matlab scripts that form the basis for a future engineering tool. The model is validated against monotonic and cyclic shear wall tests, and is shown to have good agreement. In addition to providing a mechanical means to assess shear walls, high fidelity shell finite element models are completed in ABAQUS to shed additional light on the mechanics-based OpenSees model. The long-term goal of the modelling is to provide a reliable means to predict the lateral response of any CFS framed system that relies on connection deformations, such as gravity walls or wood-sheathed floor diaphragms in addition to shear walls.

Cold-Formed Steel Lipped Channel Columns Undergoing Local-Distortional-Global Interaction: Experimental and Numerical Investigation, E. S. Santos, P. B. Dinis, E. M. Batista and D. Camotim
Experimental and numerical results concerning the post-buckling behavior and strength of fixed-ended cold-formed steel lipped channel columns experiencing interaction involving local, distortional and global buckling (i.e., stemming from the closeness between the critical buckling stresses associated with these three buckling mode types), are reported. After briefly addressing the column specimen geometry selection, the paper presents and discusses the results of an experimental investigation carried out at COPPE, Federal University of Rio de Janeiro (UFRJ, Brazil) and involving 16 columns − its output consists of steel material properties, initial imperfection measurements, equilibrium paths and failure loads/modes. Then, some test results are compared with the values yielded by the corresponding ABAQUS shell finite element simulations. Finally, the paper closes with a brief account of the considerations prompted by the available experimental and numerical ultimate load values, concerning the Direct Strength Method (DSM) design of columns affected by triple (local distortional-global) mode interaction.

Cold-formed Lean Duplex Stainless Steel Rectangular Hollow Sections in Combined Compression and Bending, Y. Huang and B. Young
An experimental investigation of cold-formed lean duplex stainless steel members in combined compression and minor axis bending is performed. The test specimens were cold-rolled from flat strips of lean duplex stainless steel grade EN 1.4162 into two rectangular hollow sections. Different eccentricities were applied to the rectangular hollow sections, so that a beam-column interaction curve for each series of test can be obtained. Initial overall geometric imperfections of the members were measured prior to testing. The ultimate loads and the failure modes of each specimen were obtained. Failure modes include flexural buckling as well as interaction of local and flexural buckling were observed from the test specimens. The test strengths were compared with the design strengths predicted by the American, Australian/New Zealand and European specifications for stainless steel structures. It should be noted that these specifications do not cover the material of lean duplex stainless steel. Generally, the specifications are capable of predicting the beam-column strengths of the lean duplex stainless steel test specimens.

Developments in the Finite Strip Buckling Analysis of Plates and Channel Sections under Localised Loading, G. J. Hancock and C. H. Pham
Thin-walled sections under localised loading may lead to web crippling of the sections. This paper develops the Semi-Analytical Finite Strip Method (SAFSM) for thin-walled sections subject to localised loading to investigate web crippling phenomena. The method is benchmarked against analytical solutions, Finite Element Method (FEM) solutions, as well as Spline Finite Strip Method (SFSM) solutions.

Experimental Study of Longitudinally Stiffened Web Channels Subjected Predominantly to Shear, L. A. Bruneau, C. H. Pham and G. J. Hancock
The Direct Strength Method (DSM) of design of cold-formed sections has recently been extended in the North American Specification for Cold-Formed Steel Structural Members-NAS S100:2012 to include shear. The two new features of the DSM rules for shear researched are the effect of full-section shear buckling as opposed to web-only shear buckling and Tension Field Action (TFA). The prequalified sections in the rules include sections with flat webs and webs with small intermediate longitudinal stiffeners. In order to extend the range to larger intermediate stiffeners as occurs in practice, a series of fourteen shear tests have been performed at the University of Sydney for C-sections with rectangular stiffeners of varying sizes. Six different types of stiffeners were tested with an additional preferred plain section. Each type of sections was tested twice to ensure accuracy. As the web stiffener sizes increase, the shear buckling and strength of the sections are expected to improve accordingly. However, the tests show that the shear ultimate strengths only increase slightly in association with the respective increase of stiffener sizes. The test results are compared with the DSM design rules for shear and found to be lower than those predicted by the DSM curve for shear with TFA. The test failures were observed mainly due to the combined bending and shear modes. The effect of the bending is therefore significant and starts to govern when the shear capacity is significantly strengthened by adding the large longitudinal web stiffener. The test results are subsequently plotted against the DSM interaction curves between bending and shear where the interaction is found to be significant. Modifications and recommendations for prequalified sections with longitudinally stiffened web channels in shear are proposed in the paper.

The Behaviour of Cold-Formed C-Sections with Square Holes in Shear, C. H. Pham, Y. H. Chin, P. Boutros and G. J. Hancock
Cold-formed structural C-section members may be subjected to axial force, bending and shear or combinations of either two or all of these actions. Design methods for these sections are normally specified in the Australian/New Zealand Standard for Cold-Formed Steel Structures (AS/NZS 4600:2005) or the North American Specification for Cold-Formed Steel Structural Members (2012). Both Effective Width Methods (EWM) and the newly developed Direct Strength Method (DSM) can be used for the design. For shear, the NAS S100 2012 Edition has recently included DSM design rules just for the plain sections only. To date, no rules are presented in this specification for DSM in shear for sections with holes. This paper presents a testing program performed at the University of Sydney to determine the ultimate strength of high strength cold-formed C-sections with square web cut-outs. Tests were conducted on typical lipped channel sections with central square holes of varying sizes. Three different sizes of the square holes were chosen for testing. Numerical simulations using the Finite Element Method (FEM) were also performed. The simulations are compared with and calibrated against tests. The accurate results from FEM allowed extension of the test data by varying the hole sizes. The results of both the experimental tests and FEM were used and plotted on the DSM shear design curves. As required by the DSM method, the shear buckling load Vcr for the whole channel sections with holes was computed using the Spline Finite Strip Method. The proposals for an extension to the DSM in shear for channel sections with square holes are given in the paper.

Direct Strength Method for Ultimate Strength of Bolted Moment-Connections between Cold-Formed Steel Channel Members, J. B.P. Lim, G. J. Hancock, G. C. Clifton and C. H. Pham
Experimental tests have previously shown that the strength of bolted moment-connections between cold-formed steel members, where the connections are formed through an array of bolts in the web, is dependent on the length of the bolt-group. This reduced strength has been observed in tests on portal frame joints as well as over-lapped purlin joints. For a short bolt-group length, in the order of the depth of the section, this paper shows that a reasonable lower bound to this reduced strength can be predicted by using the Direct Strength Method (DSM), modified to include the effect of the bimoment at the connection. The upper bound would be the full in-plane major axis moment-capacity of the section, which can be achieved with a long bolt-group length and can also be predicted using the conventional DSM.

Effect of Stressed-Skin Action on Optimal Design of a Cold-Formed Steel Portal Framing System, D. T. Phan, A. M. Wrzesien, J. B.P. Lim and I. Hajirasouliha
Cold-formed steel portal frames can be a viable alternative to conventional hot-rolled steel portal frames. They are commonly used for low-rise commercial, light industrial and agricultural buildings. In this paper, the effect of semi-rigid joints and stressed-skin action are taken into account in the optimal design of cold-formed steel portal frames. A frame idealization is presented, the results of which are verified against full-scale. A real-coded niching genetic algorithm (RC-NGA) is then applied to search for the minimum cost for a building of span of 6 m, height-to-eaves of 3 m and length of 9 m, with a frame spacing of 3 m. It was shown that if stressed-skin action and joints effects are taken into account, that the wind load cases are no longer critical and that the serviceability limit state controls for the gravity load case with the apex deflection binding. It was also shown that frame costs are reduced by approximately 65%, when compared against a design that does not consider stressed-skin action, and 50% when compared against a design based on rigid joints.

Development of a Novel Pinned Connection for Cold-Formed Steel Trusses, C. D. Mathieson, G. C. Clifton and J. B.P. Lim
Cold-formed steel trusses are a popular form of construction for light-weight buildings, particularly portal frame structures, for which spans up to 25m are increasingly common. In these long span trusses, providing high strength connections with sufficient elastic stiffness is a current limitation to developing cost-effective solutions. A novel pin-jointed truss connection named the Howick Rivet Connector (HRC) has been tested, firstly in a T-joint arrangement, then in a truss assemblage to determine its reliable strength and stiffness. Results showed that the HRC performs similarly to a bolted connection in terms of failure modes observed and loads reached. Additionally, the process of installing the HRC creates a bearing fit, eliminating slip due to tolerances. The elastic stiffness and proportionality limit of trusses with HRCs installed was shown to be appreciably greater than similarly dimensioned conventional screwed systems. Finite element (FE) models of both T-joints and trusses tested showed good agreement with experimental results, particularly in the transition from elastic to inelastic behaviour. The peak loads predicted from the FE models were however not accurately determined. To better predict this, it is recommended that the HRC forming and installation process be modelled to capture geometric irregularities and inelastic distributions which were idealised.

Influence of diagonal bracing restraint on cold-formed steel perforated columns under axial compression, C. Ren and X. Zhao
This paper presents a numerical investigation on the influence of diagonal bracing restraint on cold-formed steel perforated columns subjected to axial compression. Finite element method (FEM) is employed to analyse the structural behaviour of perforated columns. The results obtained from the present study highlight the influence of diagonal bracing restraint on post-buckling of columns, and the distortional-flexural mode interaction is also discussed. Furthermore, the accuracy of the present model is validated by comparing the results against the available experimental data.

Improvements to the Prediction of Brace Forces in Z- Purlin Roof Systems with Support + Third Point Torsion Bracing, M. W. Seek
The Component Stiffness Method is a displacement compatibility method used to analyze C- and Z- section supported roof systems. The method provides a detailed analysis of the flexibility in the roof system and the distribution of forces as they flow out of the system. Parametric studies of the equations for typical roof systems have shown that by ignoring the flexibility of some of the components, the method can be simplified with little impact on the anchorage forces calculated. Changes have also been made to the way in which cross section deformations are incorporated into the method. This paper focuses on the changes to the supports + third point bracing configuration and compares the bracing force predicted by the revised equation to the existing equations. The prediction equations are applied to a series of purlins and sheathing systems to represent the ends of the spectrum and the results are compared.

Numerical Studies of Collapse Behaviour of Multi-span Beams With Cold Formed Sigma Sections, F. L. Wang, J. Yang and J. Lim
Multi-span cold-formed steel beams are widely used for roof purlin and cladding rails due to their high strength to weight ratio and ease of installation on site. There are a wide variety of cross-sectional shapes e.g. C, Z, top hat and sigma sections. A sigma section possesses several advantages such as high cross-sectional resistances and large torsional rigidities compared with standard Z or C sections.

Traditional design methods for cold-formed multi-span steel beams have been based on elastic theory, such as the Effective Width Method (EWM) and the Direct Strength Method (DSM). Both methods ignore the effect of redistribution of moments on the ultimate failure load. A Pseudo-Plastic Design Method (PPDM) has been recently proposed for statically indeterminate structures in order to improve the efficiency of the methods. This method is analogical to conventional plastic design theory by introducing a pseudo-plastic moment resistance (PPMR) to allow for the benefit of redistribution of moments.

The objective of this paper is to summarize the efforts in numerical validation of the PPDM method used in the continuous beams. A series of finite element models are described to examine the collapse behaviour of multi-span cold-formed beam systems. Parametric studies are carried out to investigate the influence of geometric dimensions on the collapse behaviours. Comparisons are made between different design methods and laboratory tests for determining the ultimate load, demonstrating that the PPDM method can lead to more economical result when compared with traditional design methods.

Numerical Investigation of Cold-Formed Steel Top-Hat Purlins, A. Uzzaman, A. Wrzesien, R. Hamilton, J. B.P. Lim and D. Nash
This paper considers the use of cold-formed steel top-hat sections for purlins as an alternative to conventional zed-sections. The use of such top-hat sections may be viable for use in cold-formed steel portal framing systems, where both the frame spacing and purlin span may be smaller than in conventional hot-rolled steel portal frames. Furthermore, such sections are torsionally stiffer than zed-sections, and so have a greater resistance to lateral-torsional buckling. They also do not require the installation of anti-sag rods. The paper describes non-linear elasto plastic finite element analyses conducted on top-hat sections. The results of twenty-seven tests on four different top-hat sections are presented. Good agreement between experimental and finite element results is shown. The finite element model is then used for a parametric study to investigate the effect of different thicknesses and steel grades. Design recommendations are provided in the form of charts that can be used to assist designers when deciding which geometry of top-hat section to consider for further development. The use of the finite element method in this way exploits modern computational techniques for an otherwise difficult structural design problem and reduces the need for an expensive and time consuming full laboratory study, whilst maintaining realistic and safe coverage of the important structural design issues.

Calculation for Moment Capacity of Beam-to-Upright Connections of Steel Storage Pallet Racks, T. Wang, X. Zhao and Y. Chen
Steel storage pallet rack structures are three-dimensional framed structures, which are widely used to store different kinds of goods. For the easy accessibility to stored products, pallet racks are not usually braced in the down-aisle direction. The down-aisle stability is mostly provided by the characteristics of beam-to-upright connections, and the characteristics of upright base connections. In this paper, calculation for moment capacity of beam-to-upright connections is carried out. A mechanical model is presented firstly. Based on the model, moment capacity is related to the failure capacity, directly determined by the failure mode, of the topmost tab of the beam-end-connector and the corresponding upright wall. Different methods to predict the failure capacity are derived for two types of failure modes, i.e. crack of tab and crack of upright wall. The new method has shown a satisfactory agreement with experimental results demonstrating the reliability of the model in predicting the moment capacity of beam-to-upright connections.

GBTUL 2.0 - A New/Improved Version of the GBT-Based Code for the Buckling Analysis of Cold-Formed Steel Members, R. Bebiano, D. Camotim and R. Gonçalves
This paper presents the very recent 2.0 release of software GBTUL – a computer code developed by the authors and made available as freeware at the website of the Department of Civil Engineering of the Technical University of Lisbon (Bebiano et al. 2013). The program performs linear buckling and vibration analyses of thin-walled bars based on Generalized Beam Theory (GBT), a bar theory that accounts for cross-section deformation. Its domain of application is much wider than that of the previous release (1.0b): indeed, it is now possible to analyze single or multi-span members (i) with various support conditions, including those stemming from discrete bracing systems, (ii) exhibiting open, closed or “mixed” (combining closed cells with open branches) cross-sections and (iii) acted by fairly arbitrary loadings, including concentrated and/or distributed transverse loads away from the member shear center axis. The Graphical User Interface (GUI) of the program is described and its main commands are addressed. For illustrative purposes, results concerning the buckling analysis of a two-span I-section beam subjected to mid-span concentrated loads are presented and discussed.

On the Influence of Local-Distortional Interaction in the Behavior and Design of Cold-Formed Steel Web-Stiffened Lipped Channel Columns, A. D. Martins, P. Borges Dinis, D. Camotim and P. Providência
This paper reports the results of a numerical (ABAQUS shell finite element analysis) investigation on the influence of local-distortional (L-D) interaction in the ultimate strength and design of cold-formed steel fixed-ended web-stiffened lipped channel columns Ḱ hereafter termed “WSLC columns”. These results concern columns with various geometries and yield stresses, ensuring a wide variety of combined ratios between (i) the distortional and local critical buckling stresses, and (ii) the yield and the higher of the above buckling stresses. The objectives of this work are two-fold: (i) to acquire in-depth understanding on the mechanics underlying the L-D interaction in the WSLC columns analyzed, all selected to ensure that local buckling is triggered by the flanges, and also (ii) to provide a first contribution towards the efficient Direct Strength Method (DSM) design of these structural elements. The results presented and discussed concern the (i) post-buckling behavior (elastic and elastic-plastic), (ii) ultimate strength and (iii) failure mechanisms of the WSLC columns previously selected to undergo L-D interaction. Special attention is paid to comparing the ultimate strength erosions, due to L-D interaction, exhibited by the WSLC columns investigated here and the “plain cross-section” (i.e., without intermediate stiffeners) columns studied earlier by the authors (Martins et al. 2014a). Finally, the paper closes with some considerations about the impact of the findings reported in this work on the design of cold-formed steel columns undergoing different levels of L-D interaction.

The 2013 AISI Cold-Formed Steel Design Manual, J. Buckholt, R. C. Kaehler and H. Chen
The 2013 edition of the AISI Cold-Formed Steel Design Manual has been published. The new edition includes updated and newly developed example problems and design aids covering new material in the 2012 edition of the AISI North American Specification for

the Design of Cold-Formed Steel Structural Members (NA Specification). Also published with the Manual are the NA Specification and the Commentary.

Shape Optimisation of Cold-Formed Steel Profiles with Manufacturing Constraints – Part II: Applications, B. Wang, B. P. Gilbert, A. M. Molinier, H. Guan and L. H. Teh
This paper uses the Genetic Algorithm (GA)-based optimisation method for cold-formed steel (CFS) profiles with manufacturing constraints, developed in the companion paper, to shape-optimise simply-supported and singly-symmetric open-section columns. Having a uniform wall thickness of 0.047 inch (1.2 mm), the columns are subjected to a compressive axial load of 16,860 lbf (75kN) and optimised for yielding and global buckling. Column lengths ranging from 3.28 ft (1,000 mm) to 9.84 ft (3,000 mm) are investigated. The algorithm is run with and without considering the manufacturing constraints. Differences between the two types of cross-sections, i.e. manufacturable and non-manufacturable, are evaluated. The influence of the number of manufacturable flat segments on the optimised cross-sectional area is also investigated. Future developments of the method for strength optimisation under combined actions and practical applications are discussed.

Towards Quantifying Beneficial System Effects In Cold-Formed Steel Wood-Sheathed Floor Diaphragms, A. Chatterjee, Y. Xiang, C. D. Moen, S. R. Arwade, B. W. Schafer
Cold-formed steel wood-sheathed floor diaphragm system behavior is analyzed from a system reliability perspective. Floor systems consisting of oriented strand board (OSB), cold-formed steel (CFS) joists, tracks and screw fasteners are modeled using shell and spring elements in ABAQUS. (Dassault-Systems ())The models consider typical seismic demand loads, with careful treatment of light steel framing diaphragm boundary conditions and OSB sheathing kinematics, i.e., two sheets pulling apart or bearing against each other at an ultimate limit state, consistent with existing experimental results. The finite element results are used to build surrogate mathematical idealizations (series, parallel-brittle and parallel-ductile) for the critical system components. System reliability and reliability sensitivity, defined as the derivative of system reliability with respect to component reliability, are studied for these idealizations. These results represent mathematical upper and lower bounds to real system behavior, and are being used in ongoing research to codify beneficial diaphragm system effects.

Local Buckling Hysteretic Nonlinear Models for Cold-Formed Steel Axial Members, D.A. Padilla-Llano, C.D. Moen, M.R. Eatherton
This paper studies the energy dissipation and damage in thin walled members that experience local buckling and presents an approach to model cold-formed steel (CFS) axial members that experience local buckling deformations. The model is implemented in OpenSees using hysteretic models for CFS axial members calibrated using experimental responses. Results from thin-shell element simulations using ABAQUS show that energy dissipation in thin plates dissipates through inelastic strains and yielding that concentrates in damaged zones that extent approximately the length of a buckled half-wave (Lcr). Generally damage accumulates in one zone but when more than one damaged zone occurred the energy dissipation increased proportionally. The results from the plate simulation and experimental results from cyclic tests on axially loaded CFS members (previously performed by the authors) support the assumptions for the modeling approach presented for CFS members governed by local buckling. Results demonstrate the capabilities of the modeling approach to efficiently and accurately simulate the response of the CFS axial members experiencing local buckling. The model presented can be used to facilitate the performance assessment of cold-formed steel lateral load resisting systems (e.g., shear walls) under different hazard/performance levels, a capability needed for the advance of performance-based earthquake engineering of cold-formed steel buildings.

AISI Newly Developed Standard AISI S310-13, North American Standard for the Design of Profiled Steel Diaphragm Panels, J. Mattingly and H. Chen
AISI S310, North American Standard for the Design of Profiled Steel Diaphragm Panels, has been approved by AISI consensus committee and approved by American National Standard Institute (ANSI) as American National Standard (ANS). This standard determines the resistance and stiffness of steel panels with or without concrete-fills, and the resistance and stiffness of connections in a diaphragm. Both analytical and test methods are provided in the standard. In this paper, a brief review of the background information and design provisions is provided.

Effect of Stressed-Skin Action on the Behaviour of Cold-Formed Steel Portal Frames, A.M. Wrzesien, J. B.P. Lim and R.M. Lawson
This paper describes six full-scale laboratory tests conducted on cold-formed steel portal frames buildings in order to investigate the effects of joint flexibility and stressed-skin diaphragm action. The frames used for the laboratory tests were of span of 6 m, height of 3 m and pitch of 10o; the frame spacing was 3 m. The laboratory test setup represented buildings of length of 9 m, having two gable frames and two internal frames. Tests were conducted on frames having two joint sizes, both with and without roof cladding. It was shown that as a result of stressed-skin diaphragm action, under horizontal load the bending moment at the eaves was reduced by approximately a factor of three, relative to the bare frame. It was also shown that as a result of stressed-skin action, the deflection of the internal frame reduced by 90%, and that the stiffness was independent of joint flexibility. On the other hand, owing to redistribution of bending moment from the eaves to the apex, the effect of joint flexibility was shown not to be significant on the overall failure load of the frame.

Evaluation of the Seismic Performance of Light Gauge Steel Walls Braced with Flat Straps, O. Iuorio, V. Macillo, M.T. Terracciano, T. Pali, L. Fiorino, R. Landolfo
The development of light weight steel structures in seismic area as Italy requires the upgrading of National Codes. To this end, in the last years a theoretical and experimental study was carried out at the University of Naples within the research project RELUIS-DPC 2010-2013. The study focused on "all steel design" solutions and investigated the seismic behaviour of strap braced stud shear walls. Three wall configurations were defined according to both elastic and dissipative design criteria for three different seismic scenarios. The lateral in-plane behavior of these systems were evaluated by 12 tests performed on full-scale CFS strap-braced stud wall specimens with dimensions 2.4 m x 2.7 m subjected to monotonic and reversed cyclic loading protocols. The experimental campaign was completed with 17 tests on materials, 8 shear tests on elementary steel connections and 28 shear tests on strap-framing connection systems. On the basis of the experimental results, and taking into account the AISI S213 provisions, behaviour factors were evaluated. This paper provides the main outcomes of the experimental tests on walls and behaviour factors evaluation.

Towards Load-Deformation Models for Screw-Fastened Cold-Formed Steel-to-Steel Shear Connections, S. Corner, C. Ding, D. A. Padilla-Llano, C. D. Moen, M. Eatherton
This paper summarizes results from an experimental program considering single-fastened cold-formed steel-to-steel shear connections. Fastener motion (displacement and tilting angle) and bearing deformation occurring on the connecting members at the fastener location were captured using an automated, optical non-contact measurement procedure. The results are used to relate cold-formed steel-to-steel shear connection load-deformation response to tilting, bearing, and tearing responses. Connection limit states, defined as the last behavior mode experiencing by the connection, are characterized considering base metal thickness and screw diameter and pitch, consistent with typical light steel framing construction details.