PERFORMANCE OF THIN-WALLED LIPPED CHANNEL SECTIONS UNDER AXIAL COMPRESSION

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ABSTRACT

Usage of thin-walled members for construction of residential and industrial structures is on the rise. As the thin-walled members are susceptible to different buckling modes, utilization of full capacity of the cross-sections is impossible. Towards maximize the utilization, these members are used in composite with other materials and structures. However, understanding the fundamental performance of the individual members is base line for further studies. Hence, the objective of this paper is to investigate the buckling behavior of thin-walled steel lipped channel column with the influence of imperfections. The Finite Element model is incorporated with material and geometric non-linearities. Further, it is also incorporate with geometrical imperfections through linear buckling analysis. The respective mode shapes corresponding to the local buckling and overall buckling has been incorporated with the scale factor. This is followed by non-linear buckling analysis which works based on the Riks algorithm was done to get correct and more realistic information of post-buckling response. The results obtained from the Finite Element analysis is compared with that of the experiments.

Keywords: influences of imperfections, linear buckling, nonlinear buckling, elasto-plastic material behaviour, post buckling.

I INTRODUCTION

Thin walled steel sections have been extensively used in residential, industrial and commercial buildings as primary load bearing structural components. The rising popularity of these sections are due to the high strength to weight ratio, economy of transportation and handling, ease of fabrication, accurate detailing, quick installation and simple erection. The thin-walled steel structural members such as the „C", „Z" or tubular sections are commonly used in floor and roofing frame due to their mono-symmetric cross section. Web crippling, flexural buckling, torsional buckling, local buckling are some of the failure modes of thin walled sections. These thin steel sections can be produced to any shape according to the requirements by the following three methods.

i) cold roll forming.

ii) press brake operation.

iii) bending break operation.

Thin-walled lipped intermediate columns are vulnerable to local or distortional buckling or both, because of the high width-to-thickness ratios of the web or flange. Local buckling occurs when the line junction of both corners does not change, with the adjoining lip, flange and web elements failing by plate flexure alone. Distortional buckling occurs in thin-walled lipped channel sections when the lip-stiffened flange of the section rotates about the flange-web junction. This usually occurs if the lip stiffener does not have enough stiffness to prevent the flange from rotating. The rotation can cause the flange to either move outward or inward depending on the nature of the load, supporting system or imperfections. At ultimate failure, both rotations can be accompanied by the bending of the web. The wave length of this mode of failure is in most cases between that of local and overall member buckling, which makes it a practical member length.

The most common failure mode in thin-walled sections is Local buckling mode which depends, on its cross section geometry and end support conditions. In this mode, compression buckles out weaker principle axis and collapses occur at rate following excessive buckling deformation. Normally, long columns undergo flexural buckling along half wavelengths. Due to smaller thickness of light gauge channel section, they have low torsional stiffness and Centre of Gravity (CG) does not coincide with Shear Center (SC), section will undergo flexural – torsional buckling.

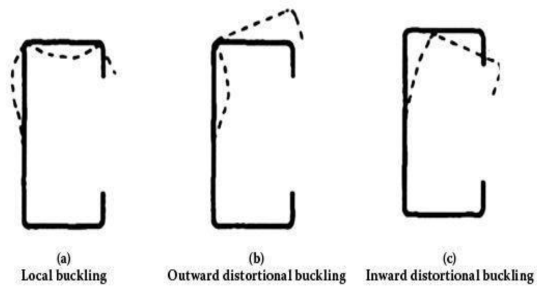

Fig 1 Local and half-wave length distortional buckling modes

II LITERATURE REVIEW

Ben Young et al (2002) presented a design and numerical investigations into the strengths and behavior of cold-formed lipped channel columns under fixed end condition by using FEA. A nonlinear FE model was developed and verified against fixed-ended channel column tests. Geometric and material nonlinearities were included in the FE model. It was demonstrated that the FE model closely predicted the experimental ultimate loads and the behaviour of the cold-formed channel columns. The column strengths obtained from the FEA are compared with the design column strengths calculated by using the American, Australian/New Zealand, and European specifications for CFS structures. It was shown that the design column strengths calculated from the three specifications are generally conservative for lipped channels having a maximum plate thickness of 6.0 mm.

Pandian et al. (2003) compared the strengths of channel, hat, box and I-sections subjected to compression by using LRFD as per AISI and BS by varying the yield strength and slenderness ratio. In each shape, one section was considered having an average area of the sections as listed in IS: 811-1987. The slenderness ratios were chosen from 25 to 125. BS and AISI codal provisions were reviewed with reference to the compression load carrying capacity of the sections.

Jintang Yan et al (2004) conducted numerical investigations on channel columns with complex stiffeners. Parametric studies on channel columns with complex stiffeners were performed using FEM and concluded that the design strengths obtained from the specification and standards are generally conservative for fixed-ended channel columns, for slender sections having a plate thickness of 1 mm, but unconservative for sections having a plate thickness of 2 mm.

Lam et al (2006) studied the load carrying capacities of CFS cut stub columns with lipped channel sections. Geometric imperfections caused by cutting the section can significantly reduce the ultimate strength of stub columns.

Anil Kumar et al (2010) studied the suitability of Direct Strength Method (DSM) to evaluate the compressive strength of plain channel, I section and rectangular tubular members. The comparative study with test results and Effective Width Method showed that DSM estimates the strength of these compression members within an acceptable accuracy, for practical purposes.

III MATERIAL CHARACTERISTICS

The specimens used in the present investigation are fabricated from sheets of 2mm thickness. The tension coupons were prepared and tested according to IS: 1608:1995 specifications. To study the material properties of the sheets used for fabrication of lipped channel sections, three standard tensile coupons were tested. The stress-strain behaviour of the tensile coupons is shown in Figure 1.

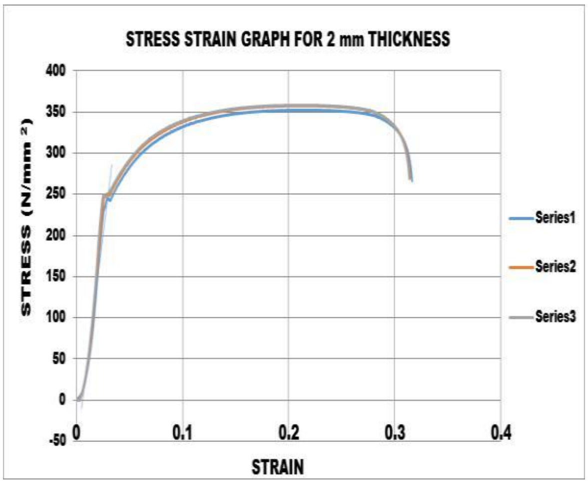

Fig 2: Stress- Strain Behaviour of Tensile Coupons of the specimen

The specimens are fabricated by Press braking method to the required shape from the steel sheets. The yield point of the steels recommended for cold-forming by the AISI ranges from 172 to 482 N/mm^2. Similarly the ultimate tensile strength of the steel specified in the AISI standards ranges from 289 to 584 N/mm^2 and the ratios of tensile strength to yield strength ranges from 1.21 to 1.8. The minimum percentage elongation recommended by the AISI ranges from 12 to 27. The average values of Modulus of Elasticity, yield stress, ultimate stress and the percentage elongation obtained from these tests are 210000 MPa, 439.32 Mpa, 610.39 Mpa, 23.3% respectively. It is observed that the yield strength, ultimate tensile strength and percentage elongation of the chosen steel falls within the ranges specified by the AISI.

IV EXPERIMENTAL INVESTIGATION

The behaviour of pinned ended lipped channel column can be well ascertained economically by a conducting an experimental test. In this investigation, two experiments were carried out to study the behaviour of cold-formed steel lipped channel sections on intermediate columns and their behaviour was observed in the elastic and plastic ranges of loading. The experiments were conducted to validate the numerical results. Two specimens having constant height of 2300mm but different geometric cross-sections are loaded axially in this study to investigate its performance under compressive loading. The parameters such as web depth (h), flange width (b) and lip depth (c) are varied for the two specimens (100x40x15x2mm and 150x50x20x2mm) which are considered for the present study. In the two cases, the ends of the specimen are welded to a base plate with dimension of 300 × 200 mm and 12 mm thickness, such that the point of loading of the section coincides with the centroid of the base plate. The end base plate and the specimen ends were machine finished to obtain a perfect seating of jack. The specimens were instrumented with strain gauges at the mid-height of the columns. They were also instrumented with dial gauges at one-fourth, mid and three-fourth height from top to measure the lateral deformations in the elements. The tests were conducted in 250 Tonne MTS UTM under displacement control mode in the Structural Engineering Research Centre, CSIR Campus, Chennai. The specimen is checked for verticality using plumb bob in two perpendicular directions. Load was applied at the rate of 0.15 mm/ min, and in increments of 10% of the ultimate load. Strain gauge readings at five different locations of the specimens were taken. Nine dial gauges three at the mid height , three in the three fourth height and three in the one fourth height from the top were also recorded. The specimens were loaded to the maximum limit beyond which there was rapid increase in strain gauge and dial gauge readings with no increase in load. The failure of the specimen was noticed with a sudden drop in the load.

V FINITE ELEMENT MODELLING AND ANALYSIS

The finite element nonlinear analysis program ABAQUS is used to simulate the experimental behaviour of pinned ended cold-formed lipped channel column. The pinned ended boundary condition is modelled by restraining all the translational degrees of freedom of the nodes at both ends of the column, except for the translational degree of freedom in the axial direction at the top end. The nodes other than the two ends are free to translate and rotate in any direction. The sections are loaded axially in their centre of gravity points of the cross-section of the columns which are marked as reference points during the finite element analysis in both cases. The load transfer takes place through the multi-point constraint system which ties these reference points to the entire channel sections. Firstly, a linear perturbation buckling analysis is performed on the specimens to obtain its probable buckling mode shape (Eigen-mode) of the column in each case. The displacement control loading method is used which is identical to the loading method used in the tests. The S4R thin shell elements are used and the mesh size used in the model is investigated by varying the size of the elements.

A nonlinear buckling analysis following the Riks arc length method for equilibrium path is then carried out to analyse the post-buckling behaviour of the lipped channel columns. The eigen-mode obtained from the previous linear perturbation analysis is then scaled by a factor (scale factor) to obtain a perturbed mesh of the column for the nonlinear analysis. Element meshes are refined until the acceptable converged solution was obtained. The material nonlinearity is incorporated with the respective material curves obtained through tension coupons as per IS:1608 and the geometric imperfections were included through buckling modes with regard to local, distortional and overall modes. The main purpose of this non-linear analysis is to study the load versus axial-shortening characteristic curves and ultimate load capacity of the column sections for the accurate prediction of its strength and behaviour. For each incremental step of axial-shortening, the total reaction at the end is obtained. Thus, the performance of the specimens considered in this study are accurately predicted through this numerical study. Figure 3 shows the simulation of axially loaded columns in Finite Element Analysis performed for both the specimens.

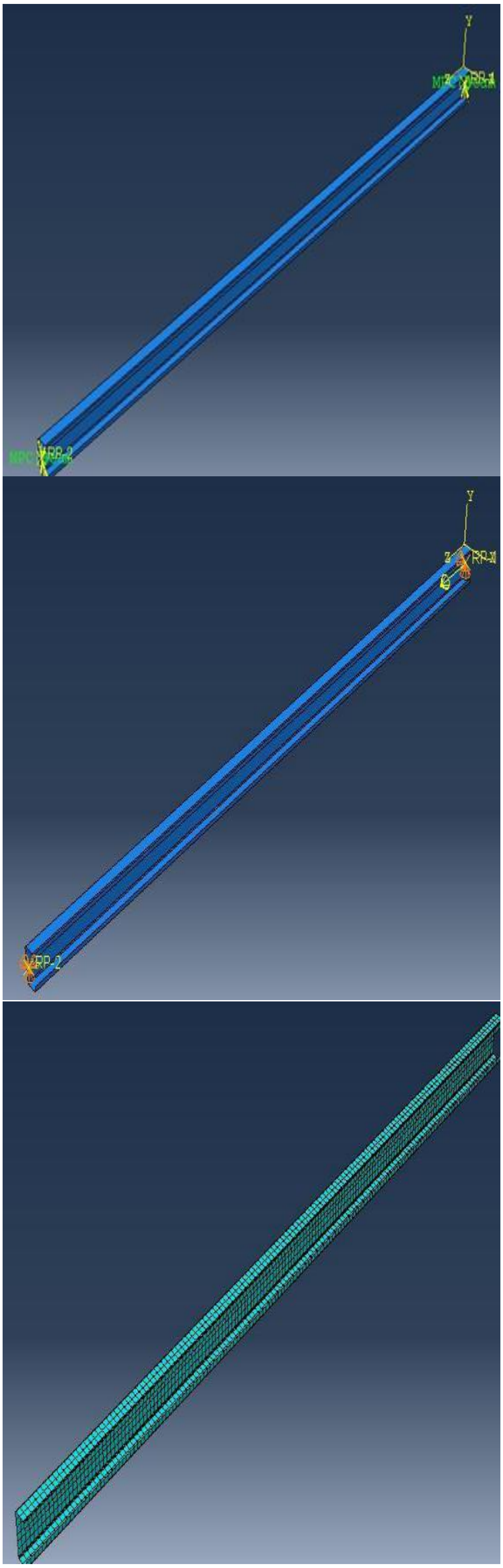

Fig 3 Simulation of axially loaded columns

VI RESULTS AND DISCUSSIONS

The behaviour of cold-formed steel lipped channel columns subjected to axial loading along the plane of symmetry was studied. The load versus axial shortening behaviour, the effect of slenderness ratio and the effect of cross section geometry was studied.

SPECIMEN ID	λ	P_{EXP}	P_{FEA}	P_{EXP} / P_{FEA}
100x40x15x2 mm	60	68.51	72.70	0.94
150x50x20x2 mm	45	95.04	97.31	0.97

The ultimate load carrying capacity of two sections obtained by Experiment and Abaqus are represented in the above table.

- **Performance of 100x40x15x2mm**

The stiff performance of this specimen was predicted due to the application of imperfections and axial load in the finite element analysis. The load versus axial shortening behaviour obtained from numerical study is linear upto 90% of the ultimate load and closely predicted the experimental ultimate loads and the behaviour of the cold-formed lipped channel columns. The non-linear buckling analysis shows that the specimen attains an ultimate load of 72.70KN for an axial displacement of approximately 3mm.It is observed that the load deformation behaviour and combined

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buckling failure mode such as overall flexural buckling about minor axis and local buckling obtained from the non-linear finite element analysis matches well with the experimental investigation results. The comparison of the results are represented in figures 4 and 5.

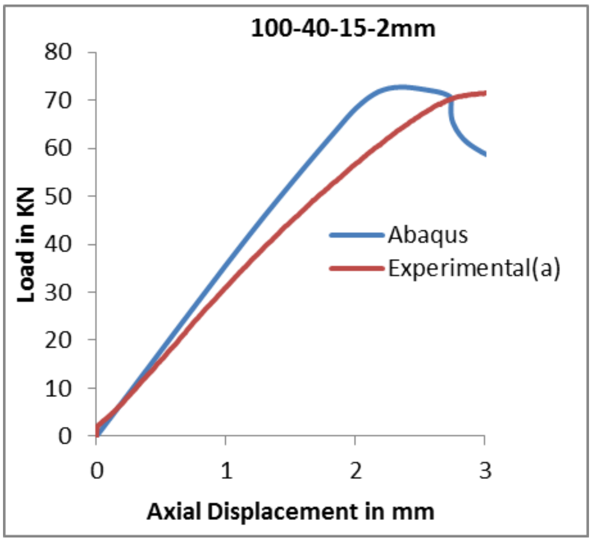

Fig.4 Load versus axial displacement curve

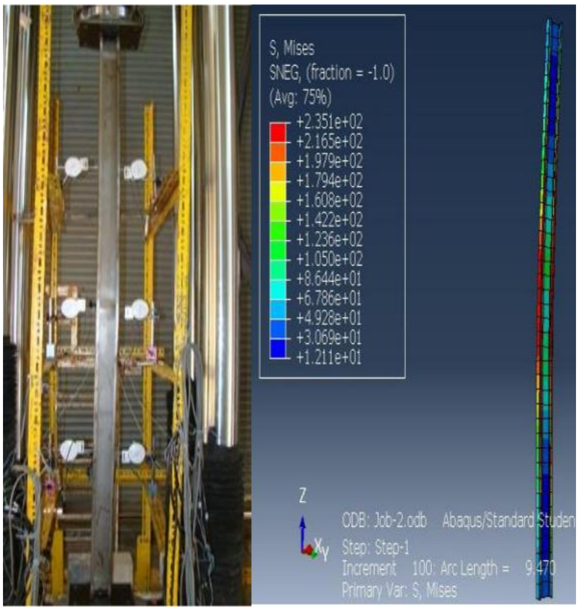

Fig.5 Overall flexural buckling about minor axis & Local buckling failure mode observed in both studies

- **Performance of 150x50x20x2mm**

The Finite Element Analysis predicts the performance of the specimen to be stiffer comparatively due to its higher cross-section geometry. The numerical investigation shows that the load versus axial deformation was linear till the local buckling occurs which was then followed by a stiffness change as it reaches its ultimate load of 97.31KN for an axial displacement of 3.79mm. The bifurcation of load deformation path took place at ultimate stage thereby leading to combined failure mode of both distortional and overall buckling in this lipped channel column. Thus, it is seen that not only the load deformation behaviour but also the combined buckling failure mode closely matches with that of the experimental behaviour. The comparison of results of both experimental and numerical studies are represented in Figures 6,7 and 8.

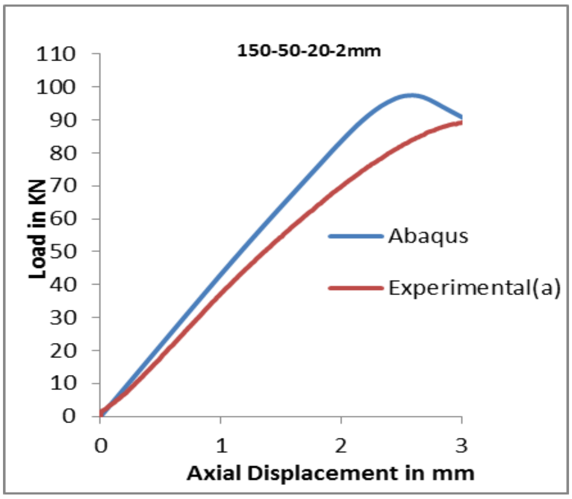

Fig 6 Load versus axial displacement curve

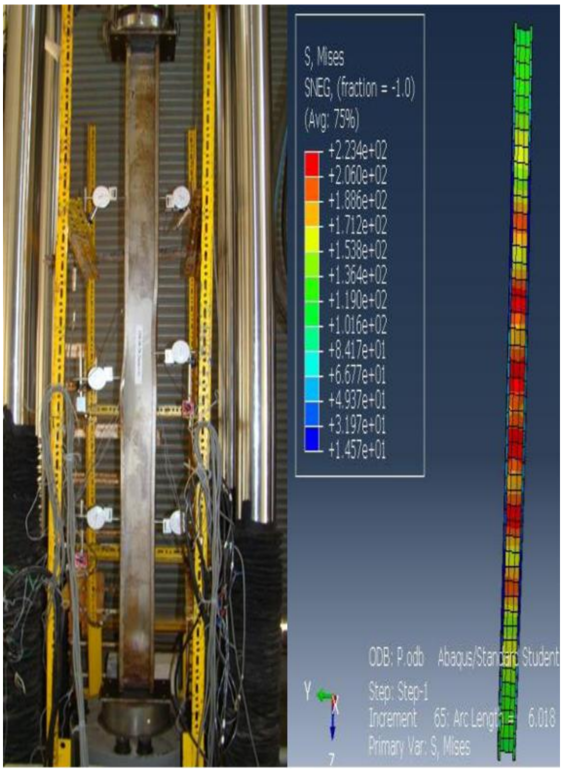

Fig.7 Distortational buckling failure mode observed in both studies.

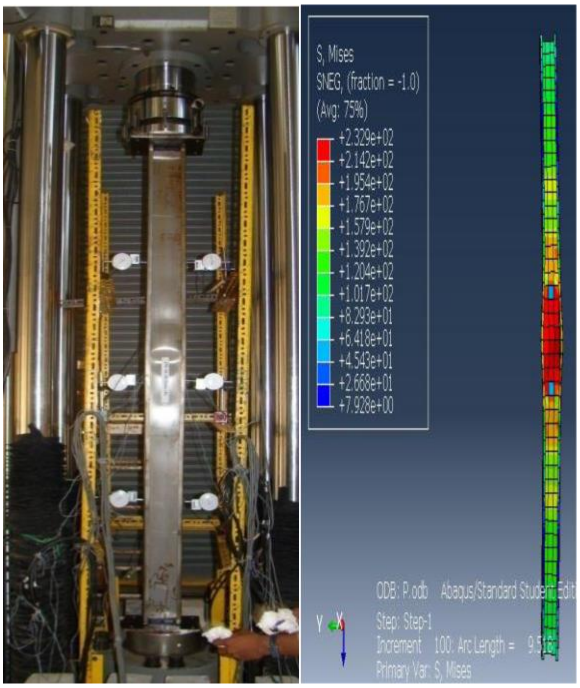

Fig.8 Local buckling failure mode observed in both studies.

VII CONCLUSIONS

From the experimental investigation and numerical analysis conducted using Finite Element Analysis software ABAQUS , the following conclusions are drawn

- For axially loaded lipped channel columns, the Finite element Analysis overestimates the experimental results in the order of 5 to 7%.
- The ultimate load carrying capacity of the specimen 150x50x20x2mm is 33% higher than that of the specimen 100x40x15x2mm due to its higher cross-section geometry.
- The Finite Element Modelling closely predicted the experimental ultimate loads as well as the behaviour of the lipped cold-formed channel columns.
- The Finite Element Analysis is useful as an alternative and complementary method to the design of cold-formed steel structures and predicts the ultimate load with reasonable accuracy.
- Hence, the performance of the lipped channel columns are compared with the experimental results in-terms of failure modes and load-displacement curves.

REFERENCES:

1. IS: 801, "Code of Practice for Use of Cold-formed Light Gauge Steel Structural Members in General Building Construction", *Bureau of Indian Standards*, 1975.

2. IS: 811, "Specification for Cold-formed Light Gauge Structural Steel Sections", *Bureau of Indian Standards*, 1987.

3. ASTM: 370-92,"Standard Test Methods and Definitions for Mechanical Testing of Steel Products", 1996.

4. BS: 5950-Part 5,"Structural use of Steelwork in Building-Code of Practice for Design of Cold-formed Sections", *British Standards Institution*, 1987.

5. NAS Manual, "Cold-formed Steel Design Manual", *American Iron and Steel Institute*, 2007.

6. Ben Young and Jintang Yan, "Finite Element Analysis and Design of Fixed-Ended Plain Channel Columns", *Journal of Finite Elements in Analysis and Design*, Vol. 38: pp. 549-566. 2002

7. Pandian, N., Arul Jayachandran, S., Seetharaman, S. and Kad Vasanti Badasaheb, "Limit State Design of Cold-formed Steel Compression Members - Codal Comparisons", *Journal of Structural Engineering, SERC*, Vol. 30, No. 3: pp.173-178, 2003.

8. Ben Young and Jintang Yan, "Numerical Investigation of Channel Columns with Complex Stiffeners- Part II: Parametric Study and Design", Thin Walled Structures, Vol. 42: pp 895–909, 2004.

9. Lam. S.S.E, Chung. K.F and Wang. X.P, "Load Carrying Capacity of Cold-Formed Steel Cut Stub Columns with Lipped C-Section", Thin Walled Structures, Vol.44:pp 1077–1083,2006.

10. Anil Kumar, M.V. and Kalyanaraman V, "Evaluation of Direct Strength method for CFS Compression Members without Stiffeners", Journal of Structural Engineering, Vol. 136, No. 7: pp. 879-885, 20