

Experimental and Analysis Of Cold Formed Steel Channel Section

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ABSTRACT

The comparison of cold formed steel section and hot rolled steel section of equal cross sectional area is done in this project. Sections were experimentally tested under axial, biaxial and eccentric compression in universal testing machine. Simultaneously, ultimate compressive strength of cold formed members and hot rolled members has been investigated. Also, different properties of the sections are obtained experimentally. The validation of results is done by preparing finite element model in “ABAQUS 6.11” SOFTWARE under point loading with fixed end condition.

Key word: cold formed steel, axial, biaxial, finite element model, under point loading and fixed end condition.

1. INTRODUCTION

1.1 GENERAL

Light gauge steel evolved as a building material in the 1930’s and reached large scale usage only after the Second World War. In comparison with conventional steel construction, where standard hot-rolled shapes are used, the cold-formed Light gauge steel structures are relatively new development.

Light gauge steel sections are cold-formed in rolls by rolling the material in cold condition or by bending the steel sheets or strips in press brakes, cold rolling being used for mass production while press brakes are used for economical production of small quantities of special shapes. These are used widely in structures subjected to light or moderate loads or for the members of short span length. For such structures the use of hot- rolled shapes is often uneconomical

and the stresses developed in the smallest available shape may be very low. Earlier, use of light gauge steel was limited to building construction only but now it finds application in trucks and trailer bodies, rail coaches, etc., Light gauge members are connected by spot welds or by screws, rivets, bolts, etc.

Shapes which can be cold –formed are many and varied. Generally, the shape varies with its application. Engineers have learned to adopt this versatility to advantage in design of compression members, studs, joists, beams, roof, panels and other industrial structural members .In the design of structural sections for framing members the main aim is to develop shapes which combine economy of material with versatility ,ease of mass production, and provision for effective and simple connection to other structural members or to non-structural materials or both of them.

The usual shapes of framing members are channels, zees, hat sections, tees, I sections and tubular sections as in fig. These sections 50 to 300 mm in depth can carry substantial loads and are used as primary framing members in residential, commercial and industrial buildings up to two stories in height and roof trusses up to 15 m span.

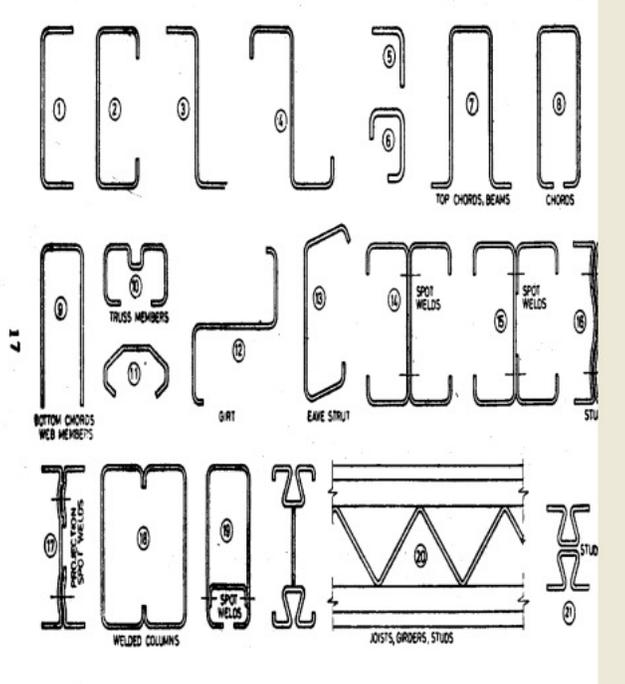


Figure 1. Light gauge shapes for structural framing

1.2 Hot rolled Vs cold formed members

Cold – formed steel members can be easily shaped and sized to meet any particular design requirements.

Cold- formed steel members are lighter compared to hot rolled members.

Cold- formed steel beams are more economical compared to hot rolled steel beams for low rise buildings when the beam spans are not long and to any shapes compared to light gauge members.

Cold formed light gauge steel members can be manufactured for light loads and short spans

1.3 APPLICATIONS OF COLD FORM MEMBERS

Agriculture

- Mining
- Aircraft Industry
- Nuclear Industries
- Railway
- Bridges
- Storage Racks
- Car bodies

1.4 ADVANTAGES OF COLD-FORMED STEEL

Cold forming has the effect of increasing the yield strength of steel, the increase being the consequence of cold working in to strain hardening range. These increases are predominant in zones where the metal is bent by folding .The effect of cold working is thus to enhance the main yield stress by 15%-30%. For purpose of design, the yield stress may be regarded as having been enhanced by a minimum of 15%. Generally, cold formed steel sections have several advantages over hot rolled sections and timber trusses .The main advantages are listed as follows.

a) Consistency and accuracy of profile

The nature of manufacturing process of cold rolling includes includes the ability of desired profile to be maintained and repeated for as long as required with minimum tolerances. Cross sectional shapes are formed to close tolerances and these can be consistently repeated for as long as required. The consistency and accuracy of profile can be achieved by the use of computer control system. The quality of the section can be efficiently controlled in the factory, and does not depend on environmental factor as in the case of timber.

b) Versatility of profile shape

Cold rolling can be employed to produce almost any desired shape to any desired length. Almost any desired section such as T-section, Z-section, hat section, the size, length, shape, and thickness can be produced by cold rolling.

c) Corrosion Resistance by Pre-galvanisation or Pre-coating

The steel material may be pre-galvanized or pre-coated with materials such as zinc hi-ten to enhance its corrosion resistance and attractive surface finish. This coating gives the truss an attractive silver finish and avoids the messy requirement of painting on frames on site.

d) Variety of connection and jointing methods

All conventional methods of connecting components such as riveting, bolting, welding, screwing, and adhesives materials are suitable for cold formed section. A pointed long screw about 10 mm long and 5 mm in diameter was used in the study since it is the fastest and easiest way available in the local market.

e) Speed in construction and easy to erect

Generally, steel construction has eliminated the curing time which is inevitable in concrete construction. The use of cold-formed steel section has a better advantage than hot rolled steel since they can be cut easily and erected with very light machine and need less workers

f) Increase in Yield strength Due to cold forming

The cold forming process introduces local work hardening in the strip being formed in the vicinity of the formed corners. This local work hardening may result in an increment of ultimate yield strength of about 25% from its expected design strength.

g) Minimum use of material

Since the material can be very thin in comparison with the lower thickness limit of hot rolled sections, it therefore allows the usage of material for the given strength or stiffness requirement to much less than that of hot rolled sections. The material thickness, or even the cross-sectional geometrics, could be controlled to achieve the structural features with the minimum material weight.

h) Lower in production cost and higher in profit

In cold rolled process the manufacturing costs involve the purchasing of the rolling machine

and the steel strip coils. The cost of the machine can be easily recovered in the continuous mass production of the section. The cold formed steel roof truss system, which is great demand and not enough supply locally can be considered as having a good potential as construction material.

1.5 VARIETIES OF COLD-FORMED SHAPES

The built-up members are formed by connecting two or more cold-formed steel members together, such as I section Member built up by connecting two channel sections back to-back. These structural shapes can be used in buildings as eave struts, purling, grits, studs, headers, floor joists, braces and other building Components. Various shapes are also available for wall, floor, and roof diaphragms and coverings.

Open sections, closed sections and built-up sections. C, Z, double channel I sections, hat, and angle sections are open sections while box sections and pipes are closed sections .

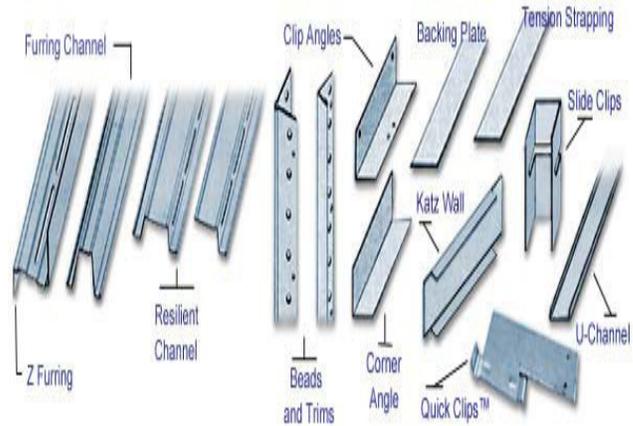


Fig 2. Varieties of Cold formed shapes

1.6 TYPES OF ELEMENTS

Cold formed steel elements are either stiffened or unstiffened.

Stiffened compression element is a flat compression element of which both edges parallel to the direction of stress are stiffened.

An unstiffened element is a flat compression element stiffened at only one edge parallel to the direction of stress.

When an element is stiffened web, or between a web and an edge, by providing intermediate stiffeners parallel to the direction of stress, then the element is considered as multiple stiffened elements.

1.7 OBJECTIVES OF THE WORK

To study the behaviour of cold-formed steel plain channel sections as short and intermediate columns under fixed end condition subjected to axial and eccentric loading.

To study the load versus axial shortening behaviour, the effect of change in flat width to thickness ratio and the slenderness ratio on the load carrying capacity, and their initial stiffness characteristics.

To develop a non-linear finite element model incorporating the geometrical imperfections for predicting the ultimate load carrying capacity.

To study the effect of eccentrically applied loads on the load carrying capacity.

To compare the experimental, analytical load carrying capacity of the short and intermediate channel columns and also their stiffness characteristics.

To study the possible modes of failure of the members under static loading by performing non-linear analysis using ABAQUS 6.11 software

To study the possible modes of failure of the members under static loading.

1.8 SCOPE

To study the behaviour of plain channel cold formed steel section under axial and eccentric loading. There is a need for brief investigation to understand their stress strain behaviour, load deflection behaviour under static loading. Four specimens with different geometric properties have

been analysed using “ABAQUS 6.11” SOFTWARE under point loading with fixed end condition.

2. NUMERICAL INVESTIGATION

2.1 GENERAL

An experimental investigation can be supplemented with a numerical method of predicting the behaviour within the acceptable accuracy limit. There are many practical engineering problems for which one cannot obtain exact solutions. This inability to obtain exact solution may be attributed to either the complex nature of governing differential equations or the difficulties that arise from dealing with the complicated boundary conditions. The Finite Element Method (FEM) is a numerical technique to obtain approximate solutions to a wide variety of engineering problems where the variables are related by means of algebraic, differential and integral equations. Finite Element Analysis converts the physical structure to a complex system of points called nodes which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. It has the capability of both linear and non-linear analysis. Linear models use simple parameters and assume that the material is not plastically deformed. Non-linear models include the stressing of the material past its elastic limits.

The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Most of the engineering problems today make it necessary to obtain approximate numerical solutions to problems rather than exact closed form solutions. The basic concept behind the finite element analysis is that structure is divided into a finite number of elements having finite dimensions and reducing the structure having infinite degrees of freedom to finite degrees of freedom. Then

original structure is assemblage of these elements connected at a finite number of joints called Nodal points (Nodes). For the finite element analysis advanced software ABAQUS 6.11 was used.

2.2 PROCEDURE OF ABAQUS

In all Finite Element Analysis, engineering problem can be solved in many steps. In the Finite Element Analysis Software ABAQUS 6.11, problems are solved in three phases such as

1. Pre processing
2. Solution
3. Post processing

2.3 Modelling

The modelling is done by using ABAQUS 6.11. The connectivity between the web and the flange is done by welding process. The dimension of the channel sections are 100mmx50mmx2mm and 90mmx50mmx2mm, each has a length of 700mm.

2.3.1 Material Properties

The value of Young's modulus as $1.86 \times 10^5 \text{ N/mm}^2$, Poisson's ratio is 0.3. The Yield stress is 186 N/mm^2 .

2.3.2 Element type

If the section thickness is less than one tenth of an elemental dimensions, then the section is modeled as shell elements. Since the cross-section considered for the study had thickness much less than the least dimension in any direction, a shell element was chosen for analysis. The software chosen for numerical investigation was ABAQUS. ABAQUS shell element library provides numerous types of shell elements that allow modeling of curved surface, intersection of shells and non-linear material response. These shell elements are divided into three categories consisting of general-purpose, thin, and thick shell elements. The modeling pattern for the shell S4R is shown in fig 3.1.

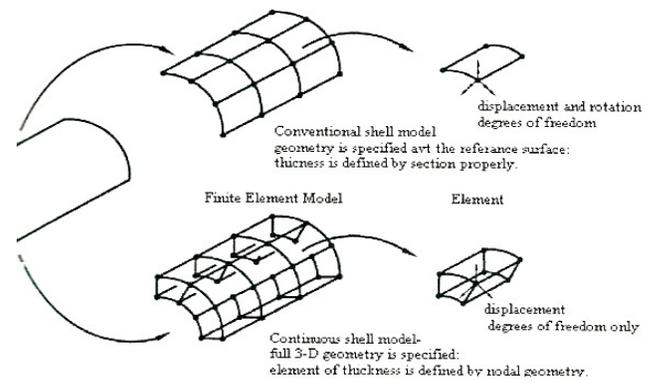


Fig 3. Modeling pattern of shell C4R

For performing static analysis, general-purpose shell elements were appropriate and 4-noded shell elements were adopted for most of FE models. S4R a 4-noded doubly curved general-purpose shell, element with reduced integration hourglass control and with finite membrane strains was used.

Higher resolution of the transverse shear was obtained by stacking continuum shell elements. C3D8R, a solid element was used to model the end plates which were used to transfer the load to the load to the channel column section. This element was defined by an 8-noded linear brick, with reduced integration and hourglass control. Figure 3.2 shows the element characteristics of SOLID C3D8R.

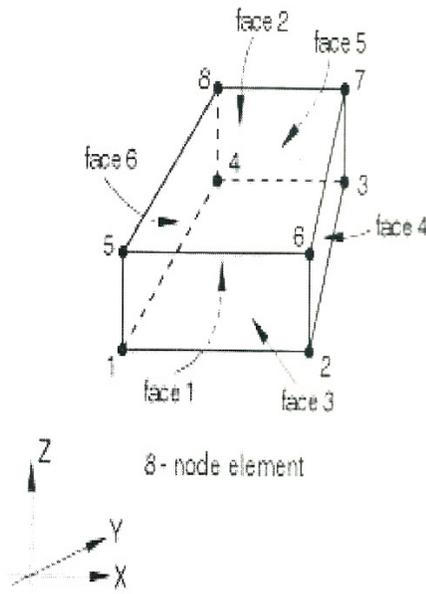


Fig 4. Element characteristic of solid C3D8R element

A detailed parametric study was conducted taking into account two different webs of depth 100 and 90 mm respectively and plate thickness of 2 mm each with flange width of 40 mm for all variations.

2.3.3 Meshing

Element aspect ratios were 1-2 range as it was found to give better results based on the results obtained by earlier researchers. Analysis with a high mesh density usually increases the accuracy of the results obtained at the expense of computational time, while analysis using low mesh density though takes less time can lead to serious errors. Therefore the element meshes are usually refined until an acceptable converged solution is obtained. The refined finite element mesh chosen was arrived at after conducting a series of studies to satisfy the convergence criteria. Element meshes were refined until the acceptable converged solution was obtained.

2.3.4 Displacement constraints

Both the ends of the specimen were assigned to be fixed ends using Displacement/Rotation option

in which the loaded end is given as ($u_1=u_2=ur_1=ur_2=ur_3=0$) and the other end ($u_1=u_2=u_3=ur_1=ur_2=ur_3=0$).

2.3.5 Load Application

Loads can be applied to the finite element model in various forms such as applying loads to the key points, lines, areas, elements and at the nodes. For our problem the analysis is carried out for a concentrated loading on the column at axial and eccentricity.

2.3.6 Geometric imperfection

While obtaining buckling deformation during nonlinear analysis, the column was assumed to have initial geometric imperfections. This was achieved by modeling the structure with an initial out-of plane deflection. Precise data of the distribution of geometric imperfections was obtained for all the experimental specimens. The scaled value of linear buckling mode shape was used to create an initial imperfection for the nonlinear post buckling analysis. The degree of imperfection was assumed as the maximum amplitude of the buckling mode shape and considered as a percentage of element thickness. Geometric imperfections were considered as a maximum local imperfection in the stiffened element and maximum deviation from straightness in unstiffened element. Pekoz and Schafer (1996) suggested expression for average degree of imperfection for the cold-formed steel members was between $0.14t$ and $0.66t$, where t is the thickness of sheet steel. Hence, in this study, the results based on the expression suggested by Pekoz were used. The local buckling imperfection amplitude of $0.2t$ to $0.5t$ and the overall imperfection amplitude of $L/200$ to $L/1000$ were used for eccentrically loaded and for the axially loaded and for the axially loaded channels respectively.

2.3.7 Solution

In this stage problem is subjected to static linear analysis. The errors and warnings are

identified at this stage. After nullifying those errors the solution process gets completed.

2.3.8 Post processing

Post processor helps us to view the results obtained from the analysis. The results obtained as nodal solution may be viewed in the of tables form or contour plots. These plots are very much useful for us to identify the results such as displacements stresses and strains and also their maximum and minimum values.

3. ANALYSIS

Analysis in ABAQUS is done by 3 stages.

The stages are as follows:

Static linear Analysis

Buckling Analysis

Non-Linear Analysis

The results obtained from the ABAQUS analysis of I section and C section beam models are presented. Comparisons were made between the ABAQUS and experimental results. Discussions were carried out with respect to the comparisons of load capacities and the mode of failure occurred.

3.1 PROCEDURE OF ANALYSIS

The material type used to model is shell type and element type is S4R.

The model is being developed.

The properties are now assigned to the model.

Now meshing of the instance is done

The end condition of fixed-fixed is applied with some displacement constraints.

The load is being applied to the model and the analysis is done.

Give the incremental steps as 10

Note down the displacement and deflected mode shape of the model.

3.1.1 Static linear Analysis

The procedure for Static linear analysis is to create a Step in which the increment can be suggested as 10. Go to step→ General→ Static, General.

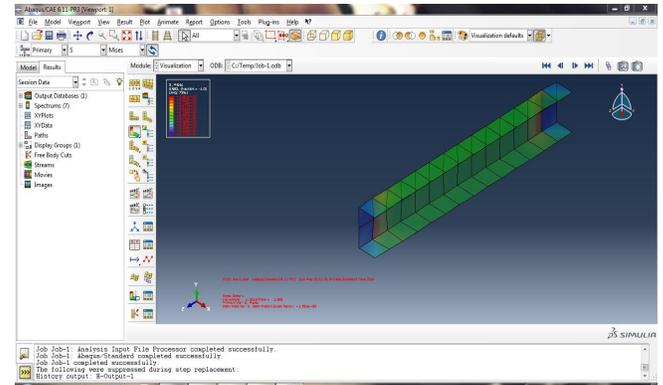


Fig 5. Linear analysis

3.1.2 Buckling Analysis

The buckling analyses were carried out to predict the buckling loads and the corresponding buckling shapes. These were used as a parameter in determining the post-buckling strength and had additional application for incorporating the input values of the geometric imperfection by using first few buckling mode shape values. The buckling analysis was carried out for the eigen values of 50 using LANCZOS eigen solver by applying an initial displacement of 1 mm at the point of application of load. Then, the displacement corresponding to local and overall buckling was added to get the total displacement.

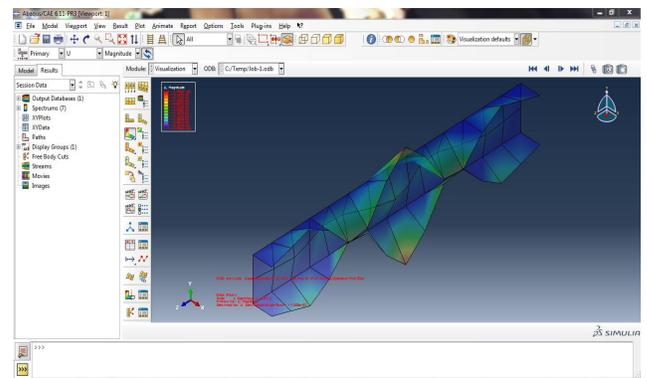


Fig 6. Buckling Analysis

3.1.3 Non Linear Analysis

For the nonlinear post buckling analysis, the model was developed by incorporating the geometric imperfections to simulate the exact specimen details.

The geometric dimensions were measured at ten different locations at equal intervals along the length of the specimen. The section geometric imperfections included the thickness of the section, the width of the stiffened, unstiffened plate elements.

The basic approach to non-linear solutions was to break the load into a series of load increments. The load step Riks method was used for the displacement increment method. It consisted of load increments applied either over several load steps or over several sub steps. Material and geometrical nonlinearities were incorporated to predict the experimental strength and behaviour. Only the displacement increment method used in model validation but for the parametric study, the section was loaded axially at the movable end by prescribing suitable increments of axial displacements.

For each incremental step of end-shortening the total load or reaction at the fixed end was obtained. Post buckling analysis was required to study the load-deflection behaviour of cold-formed steel members. There are several methods available namely Newton-Raphson method, Modified Newton-Raphson method, Incremental method, and Quasi-Newton method. Among them Modified Riks method is efficient and quite accurate which is used for the cases where the load magnitude is governed by a single scalar parameter. Thus Modified Riks method (Arc length based) was tried by considering both geometric nonlinearity and material non-linearity, but this method did not predict accurately for problems involving strong local instability and redistribution. The analysis was terminated when calculation was lost to the peak load due to convergence problems. The sections were axially (or) eccentrically loaded at the top by prescribing suitable increments of displacements. The load carrying capacity of section was traced for every increment of displacement. The results from a non-linear post-buckling analysis of ABAQUS consisted mainly of displacements, stresses, strains and reaction forces. The general post processor in ABAQUS provided

plotting and listing capabilities of these results over the entire model. The visualization feature was used to review results at specific points in the model over all time steps.

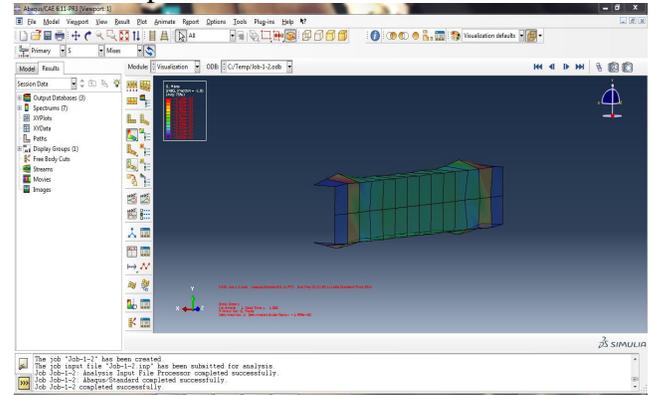


Fig 7. Non-Linear Analysis

Graph obtained

After the non-linear analysis is done the graph between load and displacement is obtained from the software where the x axis is displacement and y axis is load

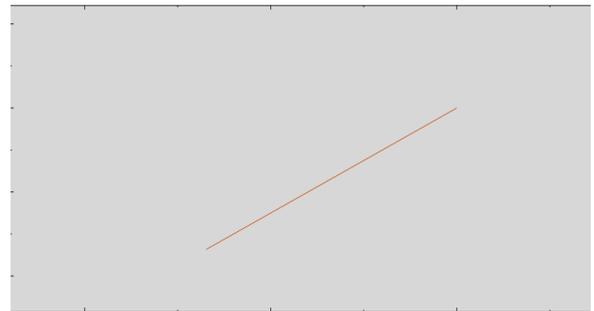


Fig 8. Load vs displacement curve.

3.2 For +ve eccentricity and -ve eccentricity of 30mm in y-axis

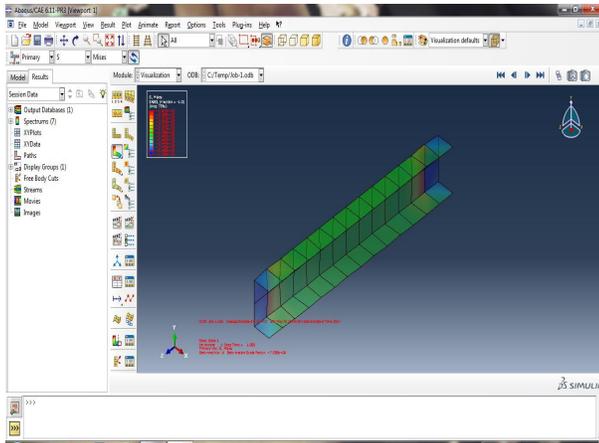


Fig 9. Linear Analysis

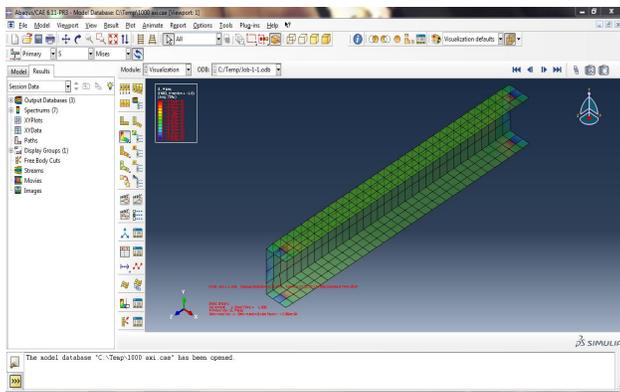


Fig 10. Buckling Analysis

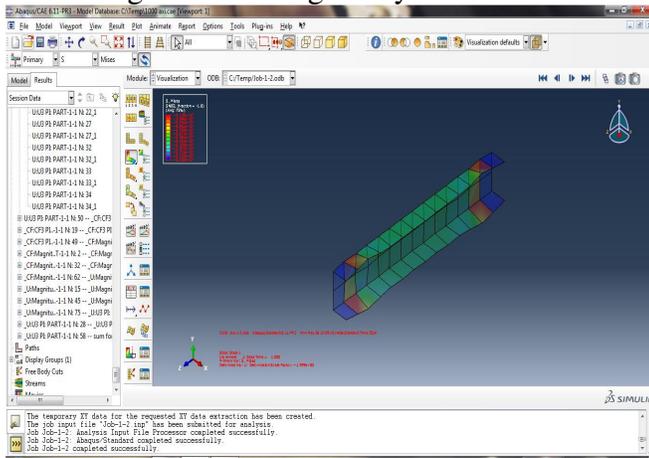


Fig 11. Non –Linear Analysis

4. EXPERIMENTAL INVESTIGATION

4.1 INTRODUCTION

Experimental study is carried out on the channel section in universal testing machine. The Light gauge steel members can be cast into different shapes and dimensions easily. This chapter deals with the specimen dimensions and the arrangements of the specimens and instruments of the cold-formed steel column

4.2 TENSION TEST ON STEEL SHEET

IS 1663 – 1960 part I prescribes the method of conducting tensile test on steel sheet strip less than 3 mm and not less than 0.5 mm thick.

The test piece has a width ‘b’ of 20mm and a gauge length L_0 of 80mm. However if the nominal thickness of ‘a’ is not greater than 2mm, the test piece may have a width of 12.5mm and a gauge length ‘ L_0 ’ of 50mm.

The test piece generally has enlarged ends, in which case there is a transition radius of not less than 20 mm between the gripped ends and the parallel lengths. The width of the enlarged ends is not less than 20 mm and not more than 40 mm.

The ends of the test piece metal held in suitable grips in the testing machine in such a way that the centre line of pull coincides with the longitudinal axis of the test piece. The parallel length is kept between $L_0 + b/2$ & $L_0 + 2b$.

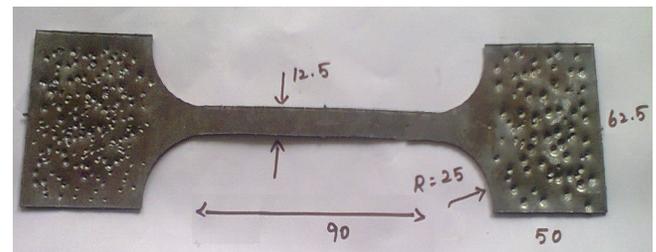


Fig 12. Tensile test-Steel sheet specimen

4.3 TEST PROCEDURE:

Totally six specimens were fabricated for the above mentioned dimensions. Tensile test was usually conducted in universal tensile machine.

Two flange portion of the test piece were fixed at the bottom and top clamp in universal testing machine and also an extensometer with gauge length of 2 inch was fixed at the web portion of the test piece. Test setup of tensile test is shown in the figure. After fixation, tensile force was applied upto breaking of test piece. Manually deflection and load are noted and then graphs were plotted. From the graph the young’s modulus and the yield stress were calculated.

4.3.1 RATE OF LOADING

If the yield stress is to be determined, the speed of the machine should be so regulated that the rate of increase of stress on the test piece is not more than one kilogram force per square millimeter per second, therefore rate of loading is approximately 5 kg/mm² until the yield point is reached in the specimen.



Fig 14. Tensile Test Setup



Fig 13. Specimens for Coupon test

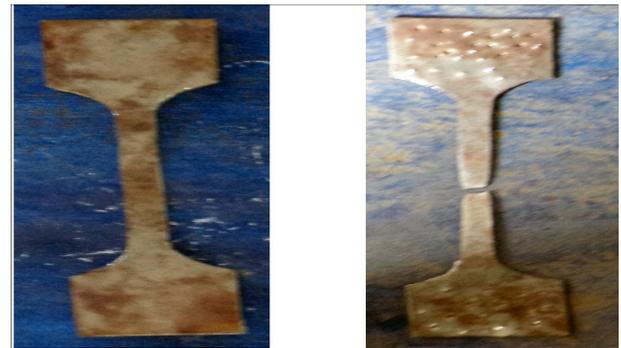


Fig15. Specimen before and after Test

From the graphs average yield stress and young’s modulus value are given in the table.1

Specimen Details	Young’s Modulus (N/mm ²)	Yield Stress (N/mm ²)	Average Young’s Modulus (N/mm ²)	Average Yield Stress (N/mm ²)
C-1	1.99 x 10 ⁵	299	2.01x 10 ⁵	301.00
C-2	1.97 x 10 ⁵	310		
C-3	2.07 x 10 ⁵	295		
C-4	2.13 x 10 ⁵	392	2.1 x 10 ⁵	397.00
C-5	1.98 x 10 ⁵	398		
C-6	2.2 x 10 ⁵	401		

Table 1. Tension test result on Steel sheet

4.3.2 Section Preparation:

CFS: Cold Formed Sheets of thickness 2mm of length 700mm are cut and bent to c-section of 100mm x 40mm using hydraulic machines.

End plates: plates are used to achieve fixed end condition

Support condition: Fixed at both ends.

Loading: concentrated loading



Fig 16. Specimens before testing

4.3.3 testing:

The section is modeled by connecting the channel section of 100mm x 40mm x 2mm with 2 plates on both the end . Length of the specimen is taken 700mm for all specimens. Six specimens were casted in each section dimension . A concentrated load is applied on the axial and eccentrical point. The eccentricity lies at 30 mm in both +ve and -ve directions. Fig 4.7 shows the experimental set up.



Fig 17. Experimental Set up

The specimen is kept on the UTM and the load is applied through the hydraulic jack and then the load ,displacement readings are noted. Load Vs Deflection curve is determined.

4.4 FAILURE MODES



Fig 18. Failure modes



Fig 19. Failure modes of 100mm x 40mm x 2mm

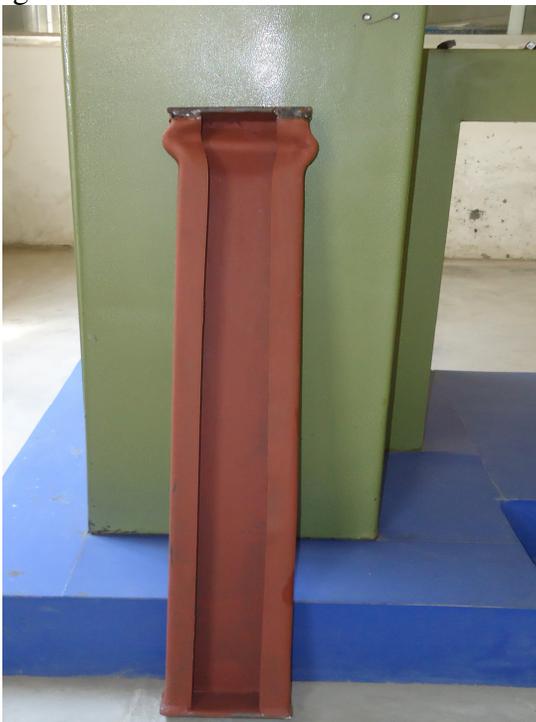


Fig 20. Failure modes of 100mm x 40mm x 2mm with lips

Specimen(mm)	Ultimate Load(kN)
40-100-2-700 (axial)	35.05
40-100-2-700(+veeccentricity)	22.65
40-100-2-700(-ve eccentricity)	27.6
40-100-2-700 (axial)	38.88
40-100-2.0-700(+ve eccentricity)	19.55
40-100-2.0-700(-ve eccentricity)	23

Table 2. Experimental results

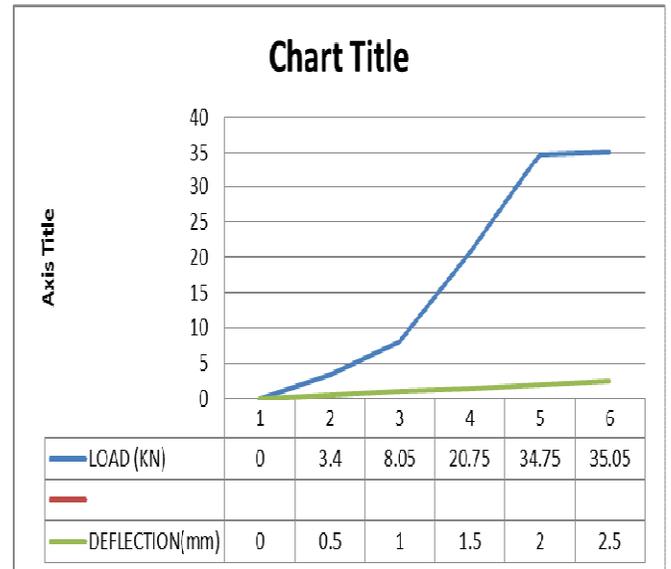


Fig 21. Load Vs Deflection for 100mm x 40mm x 2mm

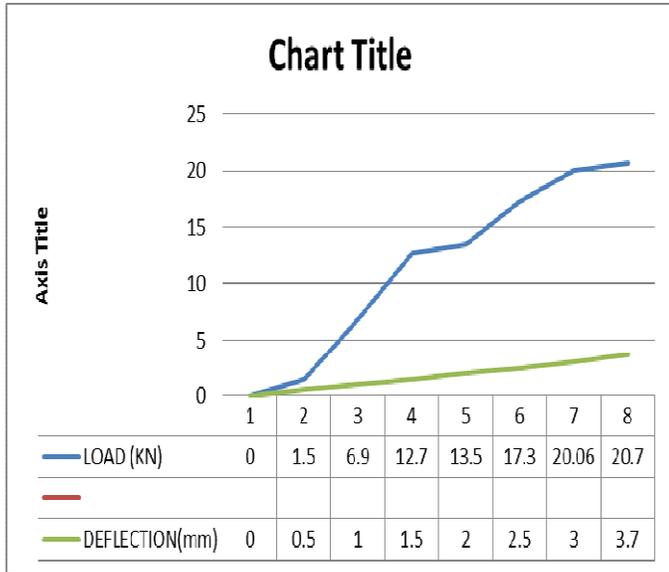


Fig 22. Load Vs Deflection for 100mm x 40mm x 2mm(+ve ecc)

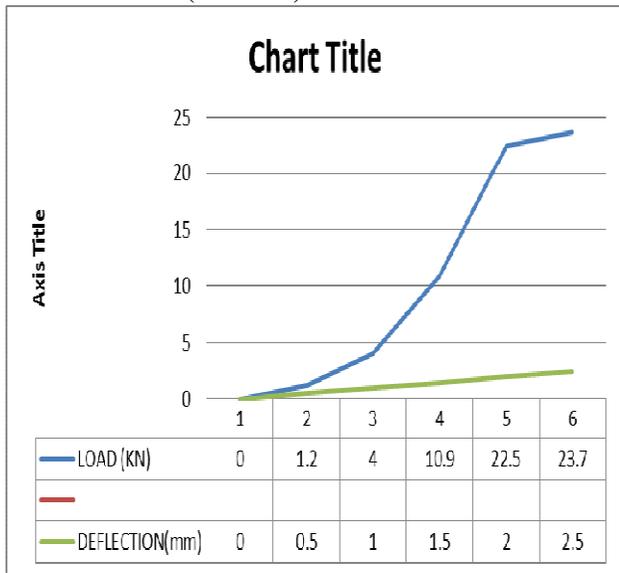


Fig 23. Load Vs Deflection for 100mm x 40mm x 2mm(-ve ecc)

CHANNEL SECTION WITH RIBS

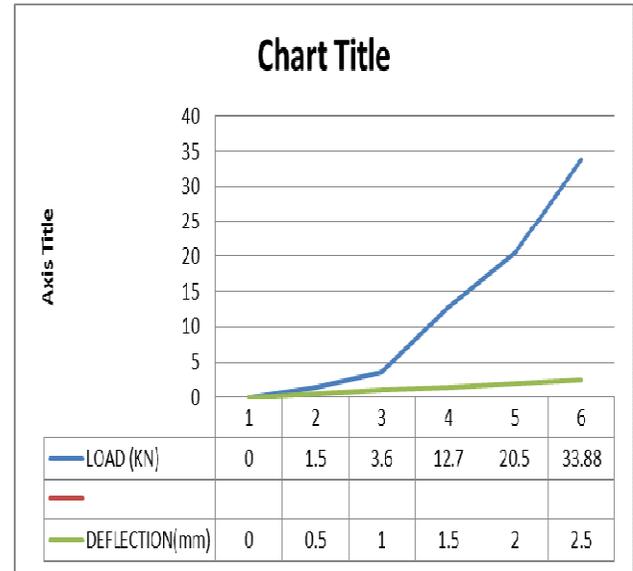


Fig 24. Load Vs Deflection for 100mm x 40mm x 2mm(axial)

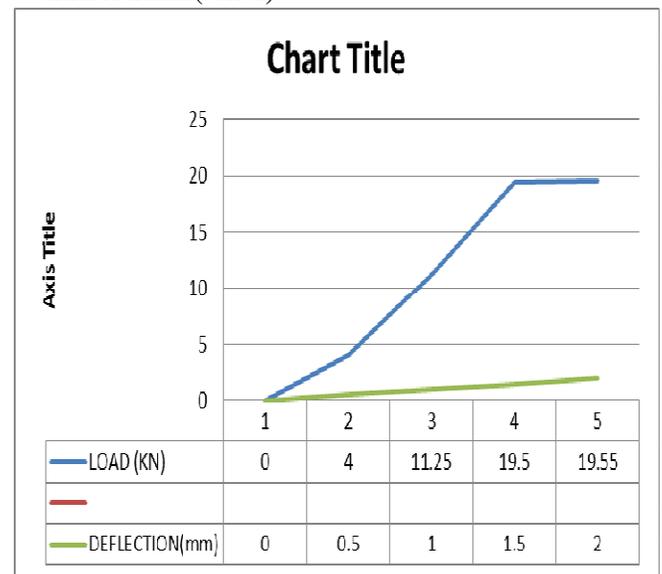


Fig 25. Load Vs Deflection for 100mm x 40mm x 2mm(+ve ecc)

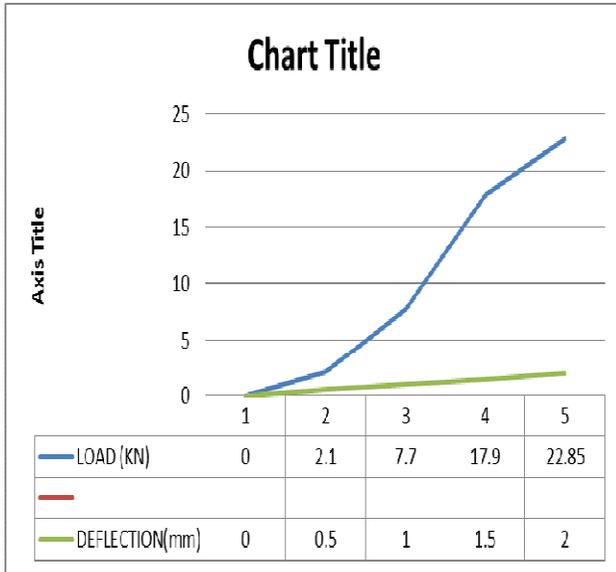


Fig 26. Load Vs Deflection for 100mm x 40mm x 2mm(-ve ecc)

5. RESULTS AND DISCUSSION

5.1 GENERAL

The load carrying capacities of specimens, estimated by using IS: 801-1985, numerical analysis and experimental, are compared. Discussions were carried out with respect to the load carrying capacities and the failure mode occurred.

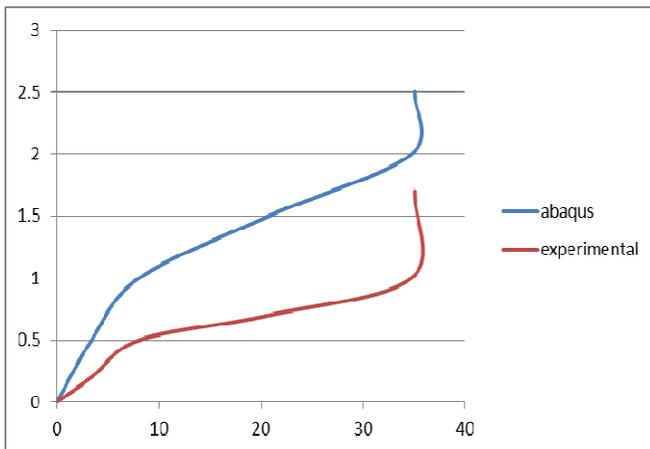


Fig 27. Comparison of Load Vs Deflection of ABAQUS and EXPERIMENTAL ANALYSIS

S.No.	Specimen (EI 40-100-2-700)	Pu (kN)
1	Results obtained from experimental analysis	33.88
2	Results obtained from ABAQUS	33.975

Table 3. Comparison of experimental results with ABAQUS results

5.2 VALIDATION OF ANALYSIS

For 100 mm x 40mm x 2mm channel section axial loading the results obtained in ABAQUS and Experimental are compared.



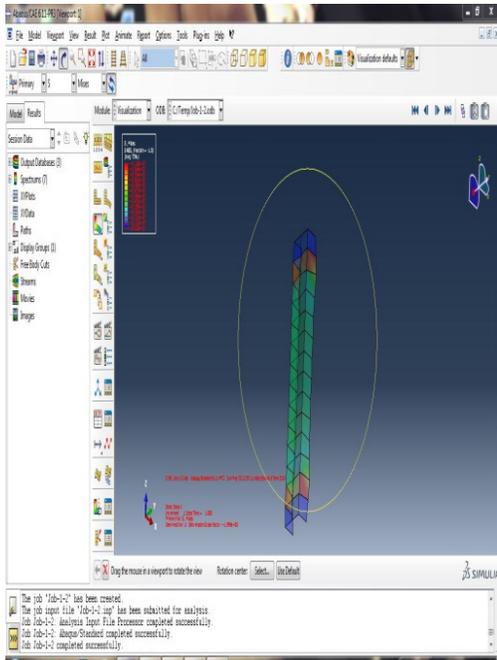


Fig 28. Comparison of experimental and analytical results

6. CONCLUSION

6.1 GENERAL

Cold-Formed Steel Channel sections of two different web depths having the same flange width of 40 mm subjected to axial and eccentric compression on both positive and negative eccentricity for a 30mm was studied. The channels were tested with fixed-fixed end condition. Experiments were also conducted on CFC 100mm x 40mm x2mm and HRS 100mm x 40mm x 2mm for applying the load concentrically and eccentrically. The load versus lateral deflection behaviour was studied for the specimen tested. Numerical Investigations were carried out on different cross sections using a finite element program ABAQUS and the experimental studies were validated for the ultimate load carrying capacity with the experimental results. The following conclusions were drawn.

6.2 EXPERIMENTAL STUDY

The ultimate load carrying capacity of axially loaded plain channels obtained from tests was

found to be twice compared to the channel loaded with 30mm positive eccentricity.

The load carrying capacity of channel loaded through 30mm negative eccentricity was 10% more than the capacity of the channel loaded through 30 mm positive eccentricity.

All the specimens exhibited compressive strains except for the specimen loaded through negative eccentricity.

6.3 NUMERICAL STUDY

Sections with lower flat width to thickness ratios of both the stiffened and unstiffened elements showed sudden increase in the load carrying capacity

6.4 COMPARISON OF RESULTS

From the analysis done with numerical study and experimental study it has been observed that for the load carrying capacity of the section its corresponding deflection will be having a slight variation within 10%. The mode shapes of the failure is about 90% similar as per the validation of the result.

6.5 SCOPE OF THE PROJECT

Similar experiments can be conducted on sections with different flange widths and the behavior can be studied.

Eccentricity along the strong axis can be chosen for different width and load can be applied through biaxial eccentricity and the behavior can be studied.

Similar studies can be conducted using other commercially available Finite Element Analysis Packages

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