

# STUDY ON THE BEHAVIOUR OF COLD FORMED STEEL FRAMES HOLLOW SECTION

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**ABSTRACT** - The aim of the project is to study the behavior of cold formed steel frames made using channel sections. From the review of literature it has been found that much work has not been done on cold formed steel hollow section frames. Therefore this study on cold formed steel channel section frames is undertaken. The study involves hollow section tests on cold-formed steel frame are two specimens of single bayed-two storeyed frames of 3mm thickness are tested along both the major and minor axis.

Cold formed steel hollow section frames connected along to major and minor axes connections are tested experimentally under concentrated loading. Stress strain curves are plotted and compared with that of hot rolled steel. It was found out that frames connected along major axis exhibit 38% higher load carrying capacity than that of the frames connected along minor axis.

**KEYWORDS:** Cold-Formed, Steel, Ductility, Major & Minor Axis.

## 1. INTRODUCTION

In recent years, cold formed steel housing (CFS) has been growing in popularity all over the world, because it represents a suitable solution to the demand for low-cost high performance houses. The CFS members, obtained by cold rolling, are produced by pressing or bending steel sheets. This construction process provide several advantages such as the lightness of systems, the high quality of end products, production in controlled environment and the flexibility due to the wide variety of shapes and section dimensions that can be obtained by the cold rolling process. Moreover the CFS systems, being dry constructions, ensure short execution time. Besides, economy in transportation and handling, the low maintenance along the life time together with the high strength to weight ratio, an essential requirement for a competitive behavior under seismic actions, represents additional benefits that CFS are able to achieve. In addition, CFS are in line with the requirements of sustainability. Indeed, the use of recyclable and light gauge

materials, the flexibility of systems, the dry construction process and the possibility to reuse the elements at the end of the life cycle, contribute to minimize the environmental impacts.



Fig. 1.1 Cold Formed Steel Section

## 1.1 COLD FORMED STEEL SECTION

Cold-formed steel (CFS) is the common term for products made by rolling or pressing thin gauges of sheet steel into goods. Cold-formed steel goods are created by the working of sheet steel using stamping, rolling, or presses to deform the sheet into a usable product. Cold worked steel products are commonly used in all areas of manufacturing of durable goods like appliances or automobiles but the phrase cold form steel is most prevalently used to describe construction materials. The use of cold-formed steel construction materials has become more and more popular since its initial introduction of codified standards in 1946. In the construction industry both structural and non-structural elements are created from thin gauges of sheet steel. These building materials encompass columns, beams, joists, studs, floor decking, built-up sections and other components. Cold-formed steel construction materials differ from other steel construction materials known as hot-rolled steel (structural steel). The manufacturing of cold-formed steel products occurs at room temperature using rolling or pressing. The strength of elements used for design is usually governed by

buckling. The construction practices are more similar to timber framing using screws to assemble stud frames.

## 1.2 PROPERTIES OF CFS

- ▲ Lightness in weight
- ▲ High strength and stiffness
- ▲ Ease of prefabrication and mass production
- ▲ Fast and easy erection and installation
- ▲ Substantial elimination of delays due to weather
- ▲ More accurate detailing
- ▲ Non shrinking and non-creeping at ambient temperatures
- ▲ No formwork needed
- ▲ Termite-proof and rot proof
- ▲ Uniform quality
- ▲ Economy in transportation and handling
- ▲ Non combustibility
- ▲ Recyclable material

## 1.3 ADVANTAGES OF COLD FORMED SECTIONS

Cold forming has the effect of increasing the yield strength of steel, the increase being the consequence of cold working well into the 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 mean yield stress by 15% - 30%. For purposes of design, the yield stress may be regarded as having been enhanced by a minimum of 15%. Some of the main advantages of cold rolled sections, as compared with their hot-rolled counterparts are as follows:

- Cross sectional shapes are formed to close tolerances and these can be consistently repeated for as long as required.
- Cold rolling can be employed to produce almost any desired shape to any desired length.
- Pre-galvanized or pre-coated metals can be formed, so that high resistance to corrosion, besides an attractive surface finish, can be achieved.
- All conventional jointing methods, (i.e. riveting, bolting, welding and adhesives) can be employed.
- High strength to weight ratio is achieved in cold-rolled products.
- They are usually light making it easy to transport and erect.

## 2. LITERATURE REVIEW

**2.1 ELKERSH (2010)** studied the behaviour of bolted cold formed steel frame apex connections under pure moment. The study was performed on portal frame rafter with double C cold formed sections. A total of 10 rafter sections as part of portal frames were used in the study. The study aimed to investigate the effect of different factors on both the frame capacity and connection failure mode. The effects of variable bolt pitches, thickness of gusset plates, effect of bearing or hole deformation around the bolt were investigated. A parallel theoretical study was carried out using the same boundary conditions and the results were compared with the experimental ones. The compatibility between the results was good. The flexural failure of the connected sections was always the critical. Failure modes which have been evaluated include local buckling of the gusset plate and web of the channels, lateral torsional buckling of the channels and bearing due to bolt-hole elongation. High tensile steel was used for both cold-formed section and hot rolled gusset plate to investigate both of the failure and the capacity.

**2.2 SABBAGHA ET AL (2011)** carried out analytical investigation on ductile moment-resisting frames using cold formed steel. The potential use of cold-formed steel sections (CFS sections) in moment-resisting frames (MRFs) for seismic applications were investigated. The main limitation of CFS sections were the low out-of-plane stiffness of their thin-walled elements which leads to low ductility. In earthquake resistant MRFs, the beams were designed to provide considerable ductility, whereas the other elements are mainly limited to their elastic range. The performance of a new shape of CFS beam with curved flanges were examined analytically and compared with that of conventional shapes. The proposed beam-column connections include through plates which potentially limit the out-of-plane action of the forces transferred through the connections. The behaviour of both individual CFS beam sections and CFS beam-column connections were studied by means of finite element analysis (FEA). The results of the analyses show that the new beam cross sections and connections exhibit a good ductile behaviour, something which cannot be achieved by conventional cold-formed frame elements.

**2.3 SABBAGH ET AL (2012)** carried out development of cold-formed steel elements for earthquake resistant moment frame buildings. The development of thin-walled cold-formed steel (CFS) sections as energy dissipative elements for seismic moment-resisting multi-storey frame buildings were presented through FE analysis and experimental work. At the element level, increasing the number of flange bends enhances both the elastic and inelastic behaviour, and beams with an infinite number of

bends (with curved flanges) show the highest strength, stiffness and ductility. In web bolted connections without out-of-plane stiffeners, premature web buckling results in early loss of strength. A minimum of two pairs of vertical stiffeners are identified as essential in the connection region to delay web and flange buckling and produce relatively high moment strength and ductility. This investigation is validated by beam-to-column connection tests using through plates and curved flange beams with different types of out-of-plane stiffeners in the connection region. The results show that the envelope of the hysteretic curves obtained in the tests of the CFS connections can be predicted by the FE analysis. The use of out-of-plane stiffeners can increase the seismic energy dissipation capacity by up to 90%, the moment strength by up to 35% and the ductility by up to 75% when compared with connections without stiffeners. Correspondingly the use of the two minimum pairs of the vertical stiffeners can increase the seismic energy dissipation capacity by 30%, the moment strength by 28% and the ductility by 50%. The research shows that thin-walled cold-formed steel (CFS) elements can be used as dissipative elements for moment frames in highly seismic areas.

**2.4 VOTH ET AL (2012)** carried out numerical study and design of T-type branch plate-to-circular hollow section connections. A numerical finite element parametric study were presented on the behaviour of transverse or longitudinal T-type plate-to-CHS connections loaded under branch plate tension or compression, to evaluate the suitability of current international design recommendations and the effect of boundary conditions and chord length on such connections. Finite element modelling and analysis techniques used in the parametric study were validated by comparison with previously tested experimental results. A total of 120 connections with wide-ranging values of geometric properties were modeled and analyzed using commercially available software. An analysis of the effect of chord length determined that, to exclude the influence of chord end boundary conditions, an effective chord length of at least eight times and four times the chord diameter, for thin and thick walled chords respectively, should be used for experimental and numerical studies. Evaluation of current CIDECT partial design strength functions ( $Q_u$ ) indicated general conservatism and under-utilization of branch tension-only connection capacity. Partial design strength functions, determined through regression analysis of numerical finite element results and existing international experimental data, are hence proposed with lower bound reduction (resistance) factors.

**2.5 LAW AND GARDNER (2012)** analysed lateral instability of elliptical hollow section beams. Eight laterally unrestrained EHS beams, with a constant cross-sectional aspect ratio of two, were tested in three-point bending. The

test set-up, material properties, section geometry, residual stress measurements and full load-deformation responses of the test specimens are reported herein. To supplement the experimental data, numerical models were also developed and validated against the test results. Parametric studies were then performed, to assess the influence of cross-sectional aspect ratio and member slenderness on lateral stability. Based on the assembled structural performance data, lateral torsional buckling curves for elliptical hollow section beams have been developed and statistically verified. Limiting lengths below which lateral torsional buckling (LTB) need not be considered have also been proposed. It was shown that the moment capacity reduces with increasing aspect ratio owing to increased susceptibility to lateral torsional buckling.

Elastic stability of cold-formed pallet rack structures with semi-rigid connections were analysed by Sangle et al (2012). The three dimensional finite element modeling and elastic buckling analysis of single 2-D and 3-D frame (with semi-rigid connection) of conventional pallet racking system. Finite element analysis carried out on conventional pallet racks using the finite element program ANSYS with the 18 types of developed column sections. The principal aims were to find out the linear buckling load of single 2-D frames and to ascertain stability of 3-D frames of conventional pallet racking systems, made up of cold-formed sections with semi-rigid connection. Investigation into stability analysis of frames used in pallet rack structures by both experimental and finite element methods have shown that stiffening of the open upright sections using the spacer bar, channel and hat as external stiffeners will considerably increase the load carrying capacity of the frames.

## 2.6 LITERATURE SUMMARY

- ▲ The Literature review carried out for the project has been considerably beneficial in understanding,
- ▲ The buckling characteristics of cold formed steel section
- ▲ The behaviour of the welded connection under concentrated load
- ▲ The overall capacity of cold formed steel frames made out of hollow section
- ▲ The different modes of failure of joints
- ▲ Ductile behaviour of the cold formed steel in seismic regions.

## 3. THEORETICAL INVESTIGATION

### INTRODUCTION

Experimental investigations always show the real behaviour of the structure, an element or a joint. These are conducted

on models and prototypes to study the behaviour in detail. Experimental investigations are usually cumbersome, laborious, time-consuming and most of the time require skilled labour. The investigation will not be complete if the experimental behaviour is not theoretically predicted using fundamental theories. This chapter deals with the design of hollow section.

**3.1 EXPERIMENTAL INVESTIGATION**

**MATERIAL PROPERTIES**

In order to study the material properties of the sheets used for fabrication of hollow sections, tension tests are conducted on standard coupons, which are cut from the steel sheets of 3 mm thickness. Three tension test coupons are prepared and tested according to ASTM 370 standards. The specimen details as per ASTM 370 standards are shown in figure 1.1. The yield stress, the ultimate stress and the percentage elongation after failure are calculated, Young’s Modulus is calculated by finding the slope of the initial linear portion of the curve. The values of yield stress, ultimate stress, Young’s Modulus, percentage elongation and the ratio of ultimate stress to yield stress are found out.

**3.2 TEST SET-UP FOR COUPON TEST**

The experiments are conducted in the Computerized Universal Testing Machine of capacity 1000 KN (100 T) with an accuracy in load of +/- 1 % in the upper. The machine is a strain controlled machine which works on multiple level mechanisms. The machine consists of two units; that is the loading unit and control panel. The top and bottom gauge portions of the coupon specimen are firmly clamped to the top (fixed) and bottom (movable) jaws of the UTM. A typical loading frame set-up is shown in Figure 1.2.



**Fig.1.2 Test set-up**

**3.3 TEST PROCEDURE FOR COUPON TEST**

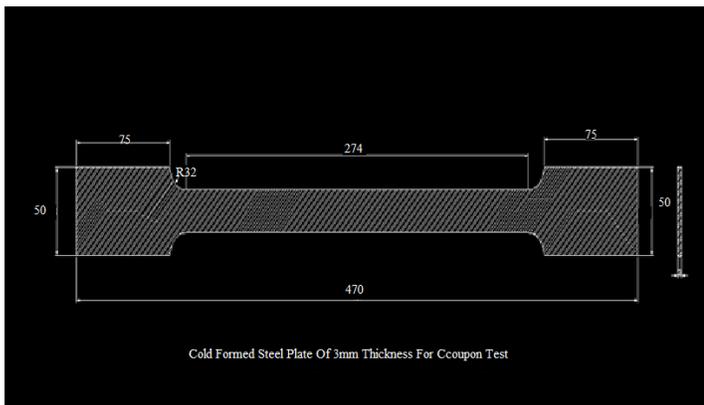
The top and bottom gauge portions of the coupon specimen are firmly clamped to the top (fixed) and bottom (movable) jaws of the UTM. The connection between the digital data acquisition system and the UTM is checked thoroughly, tare load is eliminated and the tensile load is applied at regular intervals. The coupon specimen undergoes elongation and the values of elongation of the specimen with respect to time is recorded digitally in the data acquisition system and the respective graphs were plotted. Fig1.3 shows the test setup and Fig 1.4 shows the failed specimen.



**Fig.1.3 Breakage point of coupon test specimen at ultimate load**



**Fig.1.4 Failed specimen**



**Fig.1.1 Specimen details of coupon test**

### 3.4 FABRICATION OF SINGLE BAY TWO-STORIED FRAMES

Single bay two storied frames of hollow sections with columns of size 100x50x3mm and beams of size 80x40x3 mm sections are chosen as beams such that the centre to centre distance between the columns of major axis connected frames are taken as 900 mm and columns of minor axis connected frames are taken as 950mm The vertical centre to centre distance of beams are taken as 380 mm. Two frames are fabricated such that beams are directly welded on the short sides and long sides of the columns. Figure 1.5(a) & 1.5(b) shows the details of the frames with major and minor axis connection.

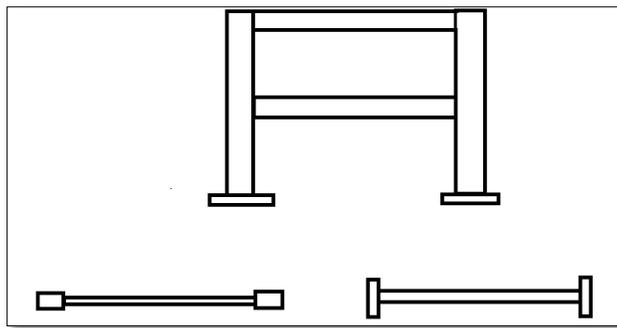


Fig.1.5 (a) Connection details



Fig.1.5 (b) Frames along major and minor axis

### 3.5 TEST SET-UP FOR SINGLE BAY TWO STORIED HOLLOW FRAMES

Testing was carried on a loading frame of 40T capacity. The frame is inserted such that the mountable head of the machine is perpendicular to the top beam. The frame is adjusted such that the load is exactly applied at the center of the top beam so that the connections are loaded equally. To avoid local effect, a small mild steel plate of 100x100x5mm was welded to the central portion in the top beam, measuring central deflection of beams. Deflections are measured at four different locations by using LVDT, one 0-10mm at the bottom central portion of the top beam and

three LVDTs of 10-50mm were used, out of which, one at the bottom central portion of the bottom beam and two at the outer top corners of each column four strain gauges(120 ohm) of 10mm were pasted on each frame. Load cell of 20T capacity is placed on the central portion of the top beam. Figure 1.6 shows the fabricated single bay two storeyed CFS hollow section frames.



Fig.1.6 Test set-up for single bay two storeyed hollow frame

### 3.6 TESTING PROCEDURE:

The frame is placed on the bending bench and the two base plates, which are welded to the bottom of the columns, are firmly clamped to the bending bench with four 20mm bolts with two bolts on either side. The loading arm of the movable head of the machine is aligned with the centre of the top beam (centre of the beam is 780 mm from the top of the base plate).the whole setup which includes LVDTs and strain gauges are connected to a digital data acquisition system. A 50,000 lbs (222.5 kN) range is chosen and set on the weighing beam with a least count of measuring 61.6N. The rate of loading As the load is increased, the frame undergoes deflection which is measured by LVDT. And strain at various points were measured using strain gauges.

## 4. RESULTS AND DISCUSSION

### 4.1 INTRODUCTION

This investigation presents the experimental results of the behaviour of cold formed steel hollow sectioned frames. load-deflection curves, comparison of load-deflection curves along major and minor axis connected frames, failure patterns, ductility factor, tensile strength of the specimens were presented in this chapter.

### 4.2 MATERIAL PROPERTIES FOR THE SPECIMEN

Material property of cold formed steel section deals with two main parameters

- ▲ Tensile strength
- ▲ Ductility factor

In order to find out the behaviour of a material it is important to study these factors experimentally. this is done by carrying out tensile test for CFS coupon specimens by following ASTM standards.

The curves are plotted for variation of stress-strain, stress-elongation, load-strain, load-elongation, load-time, elongation-time for various specimens as shown in respective figures. The specimen failed at a maximum load of 44.36 KN with maximum elongation 23 mm. the young's modulus of elasticity (E) of the specimen is obtained as  $2.035 \times 10^5$  N/mm<sup>2</sup>. The material starts yielding at a load of 14.08 KN and reaches its yield limit (298.2 N/mm<sup>2</sup>) at a load of 44.36 KN.

### 4.3 DUCTILITY:

Ductility is the property which allows the structure to undergo large deformation

of without losing its strength. Here, the ductility is quantified by the ductility factor. It is the ratio of ultimate strain to the yield strain. The ultimate strain and the yield strain of the specimen can be obtained from the stress versus strain curves shown in fig 1.7 of the corresponding specimen shown in fig 1.7 These values used to calculate the ductility ratio are picked from the stress-strain curves. Table 1.7 shows the yield stress and the ultimate stress of the test specimen and the elongation of the specimen.

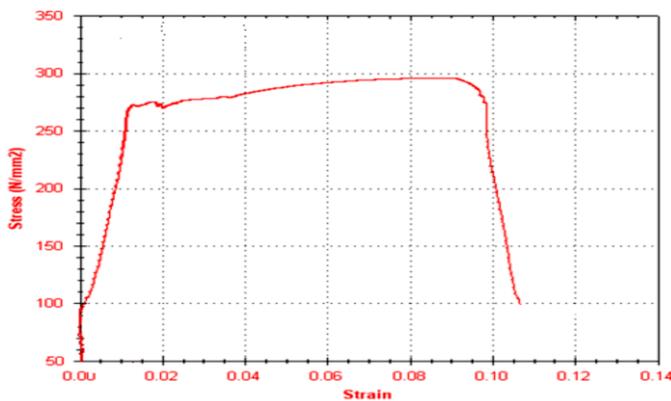


Fig.1.7 Stress-strain diagram

Results of Tension Tests Description	Thickness (mm)	E (N/mm <sup>2</sup> ) x 10 <sup>5</sup>	Fy (N/mm <sup>2</sup> )	Fu (N/mm <sup>2</sup> )	Fu/ Fy	Percentage elongation %	Ductility factor
Sheet steel	3	2.035	272.8	298.2	1.13	16.17	13.75

Tab. 1.7 Yield stress and the ultimate stress of the test specimen and the elongation of the specimen.

### 4.4 LOAD VERSUS DEFLECTION CURVE

The curves are plotted for variation of load with that of deflection for cold formed steel hollow section frames as connected along the major and minor axis shown in figure 1.8 and 1.9 respectively.

The major axis frame failed at a maximum load of 59.4KN with a maximum deflection of 12.5mm and that of minor axis connected frame failed at a maximum load of 36.1KN with a maximum deflection of 13.8mm .

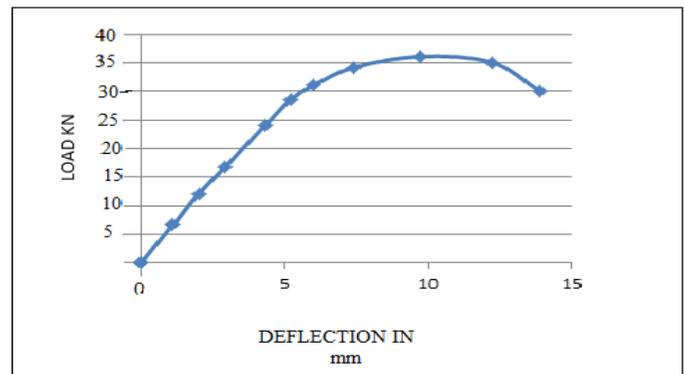


Fig.1.8 Major axis

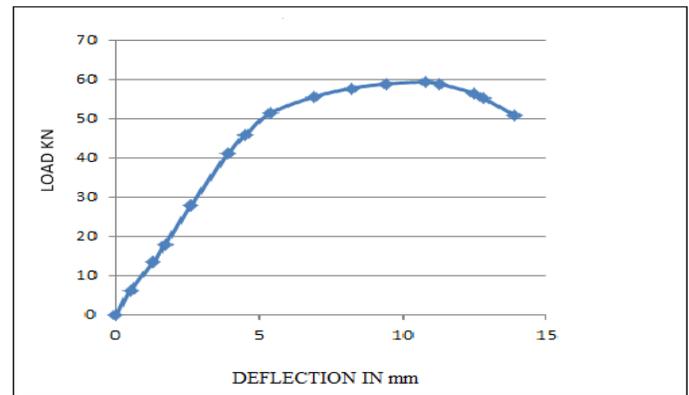


Fig.1.9 Minor Axis

### 4.5 COMPARISON OF MAJOR AND MINOR AXIS CONNECTED FRAME

The major axis connected frame carried a maximum load of 59.4KN whereas minor axis connected frame carried a maximum load of 36.1KN, The comparison of load vs deflection behaviour of cold formed steel hollow section frames connected along the major and minor axis. The major axis frame major axis connected frame showed 38% increase in load carrying capacity compared to that of minor axis frame and the minor axis connected frame showed an increased deflection of 6.06% compared to that of major axis

connected frame. Figure 1.10 shows the load-deflection for both major and minor axis connected frames.

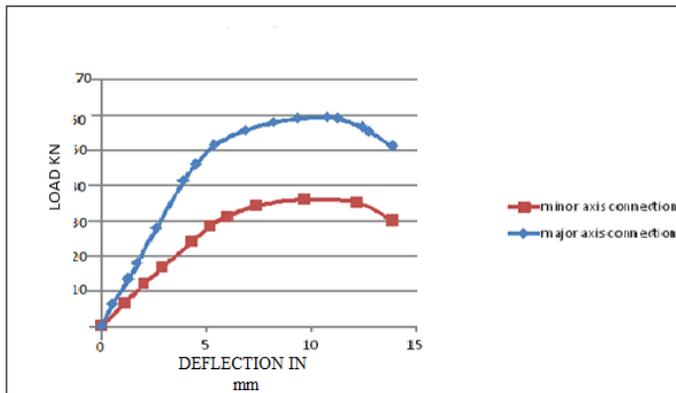


Fig.1.10 Load deflection

#### 4.6 FAILURE PATTERN

When maximum load was reached, the cold formed steel specimen on the compression zone started to fail locally as shown in figure. Local buckling prevented with the help of welded plate at the mid-section of the frame and the maximum deflection occurred at the mid span of the frame. The major failures in the frames are due to crippling and buckling action.



Fig.1.11(a) Deflection in major axis



Fig. 1.11(b) Deflection in minor axis

#### 5. CONCLUSION

The aim of the present work is to study the behavior of cold form steel frames along both the major and minor axis connection under centrally concentrated loading. The following observations and conclusions can be made on the basis of the experiments conducted on the cold formed steel frame specimens. From the experimental investigation,

- It was observed that frames connected along the major axis showed an increased load carrying capacity of 38% when compared to that of minor axis connected frames.
- The Ductility factor of frames made out of cold formed steel (13.75) was found out to be higher than that of frames made out of hot rolled steel.
- It was observed that the minor axis connected frame showed an increased deflection of 6.06% compared to that of major axis connected frame.

From this study it was found that major axis connected frames shows better performance compared to that of minor axis connected frames.

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