

# Behaviour of Cold Formed Light Gauge Steel Angle Columns Subjected To Eccentric Loading

Busanaboyina Jagadish Chakravarti, Bhamidipati Sai Krishna



**Abstract:** Coldformed steel is an exceptional engineering material for residential and commercial applications because of its inherent structural efficiency obtained by hot and cold bending and its wide range of prefabricated geometries. A lot of research has been done to study the structural behaviour of light gauge axially loaded steel angle columns. The study of cold formed light gauge steel angle columns subjected to eccentric load is to be required to know its performance in the place of hot rolled steel columns. The load is varying from shear centre to centre of gravity of angle section. The study of such columns can be done experimentally with varying thickness and b/t ratios by taking fixed-hinged end condition and the same can be validated in the finite element model by using ABAQUS / CAE 6.14 finite element software to find the buckling behaviour of different columns

**Keywords:** Cold formed steel, Angle columns, eccentric loading, buckling behaviour, finite element analysis, ABAQUS etc.

## I. INTRODUCTION

Light gauge steel individuals are cold-framed from steel sheets or strips. The thickness for surrounding individuals, for example, shafts, studs, joists, and so on by and large changes from 1.2 to 4.0mm. for floor divider boards and, for long range rooftop deck thickness shifts from 1.2 to 2.5mm, and for standard rooftop deck and divider claddings extending from 0.8 to 1.2mm. These limits compares to typical structure practice, yet ought not be comprehended to confine the utilization of material of littler or bigger thickness. In India cold shaped steel individuals are broadly utilized in transport body development, railroad mentors, and so forth and the thickness of such individuals fluctuates from 1.0 to 3.2mm

Shaping is done in press brakes or by cool rolling. Light check individuals can be either cool framed in rolls or by press brake from level steel commonly not thicker than 12.5mm. For tedious large scale manufacturing they are framed most financially by chilly rolling while little amounts of extraordinary shapes are most monetarily delivered on press brakes. The last procedure with its incredible flexibility of shape variety makes this kind of development as versatile to uncommon prerequisites as strengthened cement is in its field use. By and by light measure individuals are created in India both by press stopping mechanism (for little amounts) and by cold-framing (for huge quantities). These individuals are fortified together for the most part by spot welds, cold riveting and by special fasteners

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The cold formed angle sections are utilized for basic surrounding in transmission line towers, Steel supports and low ascent structures.

## II. ADVANTAGES OF COLD FORMED STEEL SECTIONS

Cold forming results in an increase in the yield stress of the steel, which results from cold work in the hardening zone. These altitudes prevail in areas where the metal is bent by bending. Cold working has the effect of increasing the average yield stress from 15 to 30% for design purposes, the yield stress can then be considered increased to a minimum of 15%.

Here are some of the main advantages of cold-rolled steel sections over their hot-rolled counterparts.

- The transverse shapes are framed to close resilientances and these can be rehashed always during the fundamental time
- Cold rolling can produce almost any shape and any length
- A high strength-to-weight ratio is achieved with cold-rolled products
- All regular holding techniques, for example, riveting, screws, welds and glues might be utilized
- They are generally lightweight, facilitating easy transportation and assembly

## III. NON – LINEARITY

Non-linear auxiliary issues incorporate the variety of solidness of the structure with the adjustment in twisting and the materials stress-strain conduct. By and large all physical structures display non-straight conduct. Direct investigation is a proper methodology that is regularly appropriate for configuration purposes. It is clearly inadmissible for some, auxiliary re-enactments, including assembling forms, for example, fashioning or stepping; mishap examination; and investigation of elastic parts, for example, tires or motor mounts. When the reaction of the structure to a connected outside burden isn't straight, the heap versus avoidance bend won't be direct The force and displacement relation for a spring with non-straight solidifying reaction is demonstrated as follows

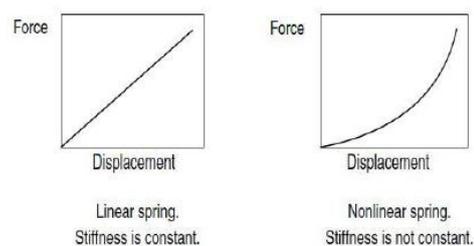


Figure 1: linear and nonlinear spring characteristics

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## A. Types of Nonlinearity:

Previously examining the numerical techniques, the wellsprings of nonlinearity have been written beneath. There are three sorts of nonlinearities.

1. Geometric Non-linearity
2. Material Non-linearity
3. Boundary Non-linearity

### i. Geometric Nonlinearity:

This kind of nonlinearity emerges when huge redirection influences the reaction of the structure.

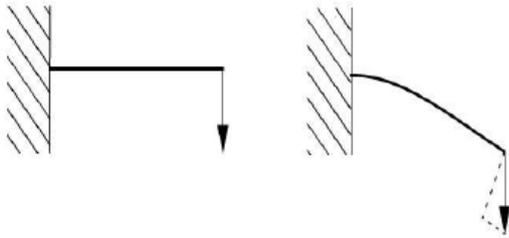


Figure 2: Large deflection of cantilever beam

Geometric nonlinearity can be three types:

- a) Huge relocation and little strain conduct: this arrangement with the diminutiveness of one of the worldwide directions of a body exposed to stack.
- b) Enormous dislodging and huge strain conduct: when changes to all the worldwide directions of the body are tantamount, the stress appropriation toward any path can't be disregarded.
- c) Linear stability analysis: on the off chance that because of outer burden the body is very nearly stable balance and any further burden will cause a flimsy harmony in the framework, the conduct of framework can be considered as a straight capacity of connected burden.

### ii. Material non-linearity:

Material non-linearity is caused because of the nonlinear connection among anxiety past as far as possible. Past this point of confinement some part of the part will begin yielding and dependent on materials, nonlinear constitutive connection begin to react in-flexibly. This causes changes in the firmness of the part which relies upon the material conduct called Elasto-plastic conduct

The present work included just Elasto-Plastic conduct. Expansion of the yield stress is alluded to as solidifying and its reduction is called softening. Ordinarily, numerous materials at first solidify and later mollify as appeared in Fig.4. A plot of a stress - strain bend characterizes material conduct.

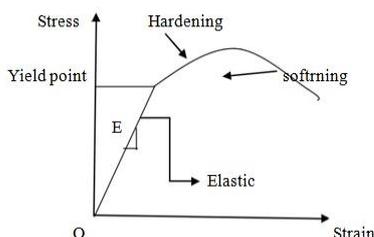


Figure 3: Strain Hardening behaviour

In view of stress-strain graph material conduct can be delegated

- a) Perfectly plastic
- b) Elasto-Plastic strain hardening
- c) Elasto-plastic strain softening

### B. Perfectly plastic

It is the property of material for which the stress, strain bend of the material ends up parallel to strain hub, for example there is a huge increment in strain for constant yield stress esteem

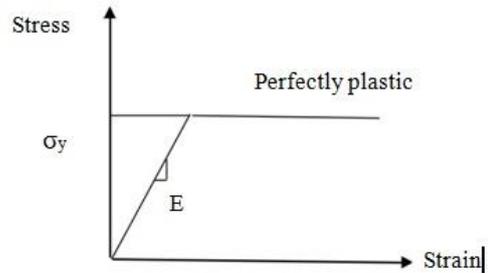


Figure 4: Perfectly plastic behaviour

### B. Elasto-plastic strain hardening:

Materials display a trademark called work or strain solidifying, which is fortifying of metal by plastic twisting. The yield surface for such materials will when all is said in done increment in size with further straining. It can likewise be ordered into two kinds.

- (i) Isotropic hardening
- (ii) Kinematic hardening

### i. Isotropic hardening:

It is described by the growing yield surface of same shape with expanding stress

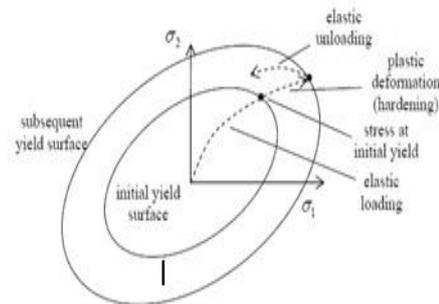


Figure 5: Isotropic hardening behaviour

### ii. Kinematic Hardening:

It is described by the yield surface of same shape and size interpreting in stress space

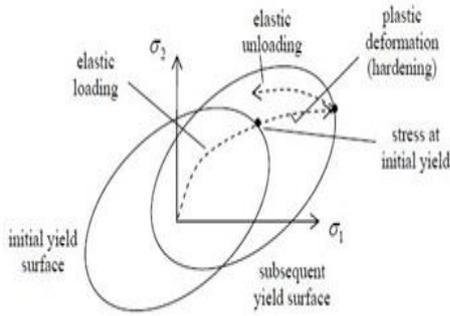


Figure 6: Kinematic hardening behaviour

IV. OBJECTIVE

The main objective of this study is to study the buckling behaviour of cold formed light gauge steel angle columns subjected to eccentric loading and validating the results in the finite element model by using the finite element software ABAQUS/CAE 6.14

V. APPLICATIONS OF COLD-FORMED STEEL IN BUILDING CONSTRUCTION

In construction, cold-formed steel products are mainly used as components, membranes and coatings for roofs, walls and floors. Several types of cold-formed steel molds are available as components, including open sections, closed sections and designed sections. The sections C, Z, double channel, plate and angle are open sections, while the sections and tubes of the boxes are closed sections. The constructed elements are formed by joining two or more cold-formed steel members into a single section I element constructed by connecting two back-to-back channel sections. This type of construction can be used in buildings such as cranes, installations, gratings, poles, collectors, floor beams and other components. Different shapes are also available for membranes and wall, floor and ceiling covering

A. Metal Building Construction

In pre-projected steel buildings, the entire structure of the building is composed of steel products and approximately 40 to 60% of the total steel consumed is cold formed steel. A run of the mill metal structure framework comprises of rigid primary structures, secondary members, cladding and reinforcement. Primary rigid frames are generally constructed using welded plates with sizes optimized to meet design requirements. Secondary members, such as purlins and grits, support roof and wall coverings and provide lateral stability to members of the primary rigid frame. Cold formed metal roof and wall panels are often used as building coatings. They transfer loads, such as wind and snow loads for secondary members and provide the integrity of the entire building. The strips or rods are often used as supporting elements that maintain the stability of the building in the direction perpendicular to

the primary rigid structures. They are also frequently used on end walls for stability

**B. Construction of floors in floor construction, floor platforms, steel beams (tongs) and trusses are often used as floor coverings, diaphragms and floor framing, respectively**

i. Floor Deck.

Cold-formed steel platforms are widely used in the construction of commercial and institutional buildings. They are formed by forming cold formed steel sheets in corrugated profiles, which greatly increases the bending capacity of the steel sheet and results in a very high strength / weight ratio. One of the great advantages of using steel roofing in building construction is that it can function as a working platform and serve as a form of permanence in place that loads loads of construction and weight of concrete during construction and as permanent part of the building load resistance system in service. There are two types of deck made up of floor platform and deck shape. While both types are widely used in building construction, composite platforms generally provide means as inlays to interconnect the sheath to concrete so that it can achieve greater shear strength. Composite platforms generally have greater strength and are capable of reaching a greater extent. Multifunction steel platforms, such as a cellular deck, can carry electrical cables and communication cables, as well as heating and air conditioning ducts

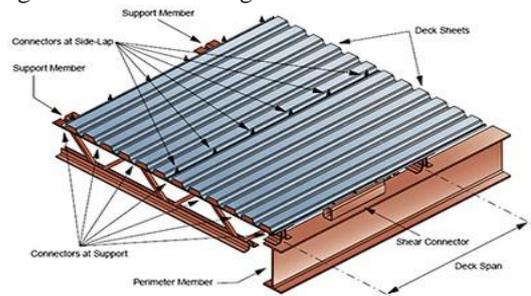


Fig 7: Floor Deck

ii. Floor Framing.

Cold formed steel can also be used in underbody structures. They generally consist of cold C-shaped beams or cold-formed steel rods spaced 40 cm apart. or 45 cm. supported in the middle and with diagonal or horizontal toes from 2.4 m to 3 m in the middle. Concrete or plywood floors can be installed on cold formed steel floor. Cold-formed steel structures are used in light commercial buildings

C.Roof construction

**i. Ceiling panels:**  
Cold formed steel roof panels function as structural components, resisting wind elevation and snow loading and maintaining the integrity of the building under side wind and seismic loads. They also meet attractive architectural requirements. The roof panels can be fixed to the purlins as in a fixed roof system or be connected to meshes with hidden sliding clips as in a permanent seam roof system. The permanent seam roof system can accommodate the movement of the roof panel due to temperature changes, which makes the permanent seam roof panels produce weather resistant products.

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Permanent mounting roof panels are not only used in new buildings, but are also widely used in the restoration and renovation of existing buildings. Cold-formed steel roof platforms can serve as part of the roof substructure, resisting the forces of the roof diaphragm and supporting roofs with insulation and waterproofing membrane. Steel roof platforms are generally 3.8 cm or 7.5 cm deep, depending on the extension requirement.

### ii. Roof Framing:

Cold-formed steel can also serve as a roof substructure in the manner of roof panels or roof trusses. In a steel building, Z-shaped and C-shaped roof panels are generally used to support roof panels and to transfer roof loads, such as wind and snow loads to the primary frames, providing the same time the lateral stability to the primary elements of the frame. Cold-formed steel trusses are used in residential and light commercial buildings. They can be made of regular screws of section C or other proprietary forms. Cold formed steel trusses provide the same extension capabilities and design flexibilities as wood trusses, but are lighter and more dimensionally stable than wood beams. Most cold formed steel roof trusses are pre-engineered and pre-fabricated with the help of computer software, allowing you to accommodate various roof configurations and designs. This design flexibility makes cold formed steel beams ideal for almost all types of buildings, including residential, commercial, institutional, educational and industrial structures.



**Fig 8: Roof trusses**

## VI. EXPERIMENTAL STUDY

The experimental study was performed considering the cold-formed steel angle columns of  $30 \times 30 \times 1.6$  mm,  $50 \times 50 \times 1.6$  mm and  $50 \times 50 \times 2$  mm. IS 801-1975 specifies the distance between the shear and the center of gravity of the respective angular sections. In order to determine the buckling behavior of inclined columns exposed to an eccentric load, the load shall be applied at the center of the shear and with an eccentricity of the center of shear at the center of gravity, the length of the column being 1.5 m. The details of columns and load positions are shown in the table

**Table1: Column test program**

COLUMN NO	B/T RATIO	COLUMN DIMENSIONS	LOAD POSITION
1	18.75	50x50x1.6mm	At shear centre
2			At 5mm from S C
3			At centre of gravity
4	25.0	50x50x2.0mm	At shear centre
5			At 10mm from S C

6			At centre of gravity
7	31.25	50x50x1.6mm	At shear centre
8			At 10mm from S C
9			At centre of gravity

### A. Column setup:

The point sections with one end fixed i.e., base end fixed and opposite end pivoted i.e., top end is pivoted. is taken and compacted by applying the offbeat stacking at top of the segment. So as to move the heap to edge segment a M.S plate of 4mm thick is welded to the point section both at top and base to move the heap. Though it is eccentric loading a rod of 12mm diameter and 30mm length is welded on the top of the plate where we want to apply the load. the top plate with groove is welded on the top of the angle columns to attain the hinge action. On the top of the groove another ms plate of 4mm thick and dimensions as similar to the plate below 12mm rod is welded on the top of the groove. In order to place the loading cell properly as shown in fig

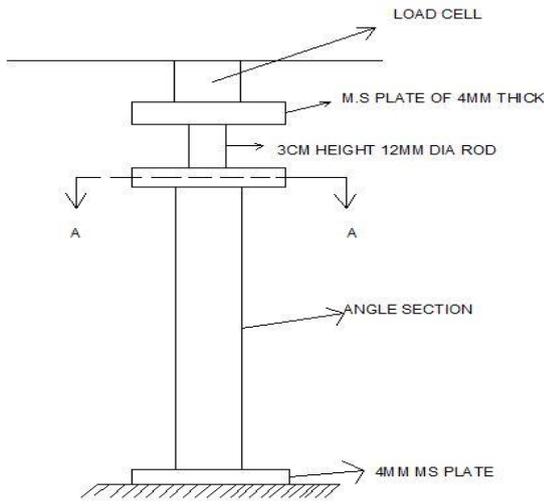


**Fig 9: COLUMN SETUP**

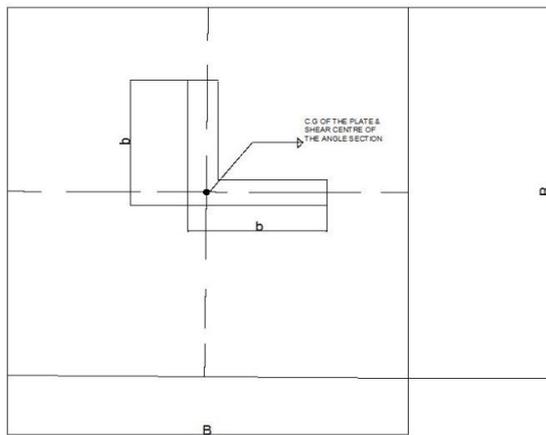
The centre of the rod should be coinciding with the middle of the top plate. The groove shall be located at the point where we want to apply the load the clear section is shown in fig. The bottom of the angle section is also connected to the MS plate of 4mm thick by providing groove to the plate in that groove the angle section is placed and welded. it will restrain the rotation when the load is applied i.e. to attain fixed condition. The bottom plate is connected to the base plate through welding as shown in fig

### B. TEST SET UP:

The linear variable displacement transducer (LVDT) is positioned at the middle height of the column in the horizontal direction the corresponding displacement is measured through the LVDT. The LVDT setup is shown in the fig:

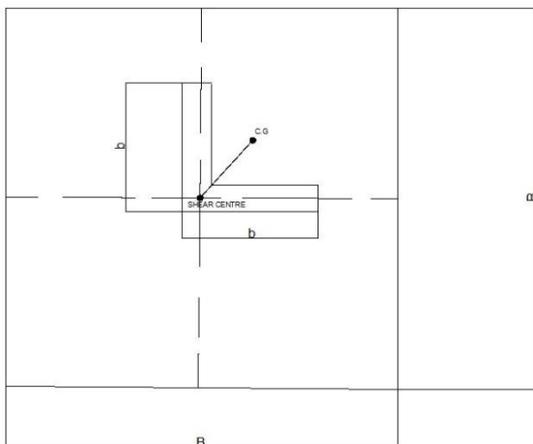


**Fig 10: ELEVATION**



**Fig 11: SECTION A-A**

The heap is connected between shear focus and focuses of gravity of point area. The situation of focus of gravity and shear focal point of edge area is appeared beneath:



**Fig 12: Shear centre and Centre of gravity of Angle section**

Cold-shaped point segment of 1.5m stature put in the stacking casing of 50 tons limit, with LVDT are associated

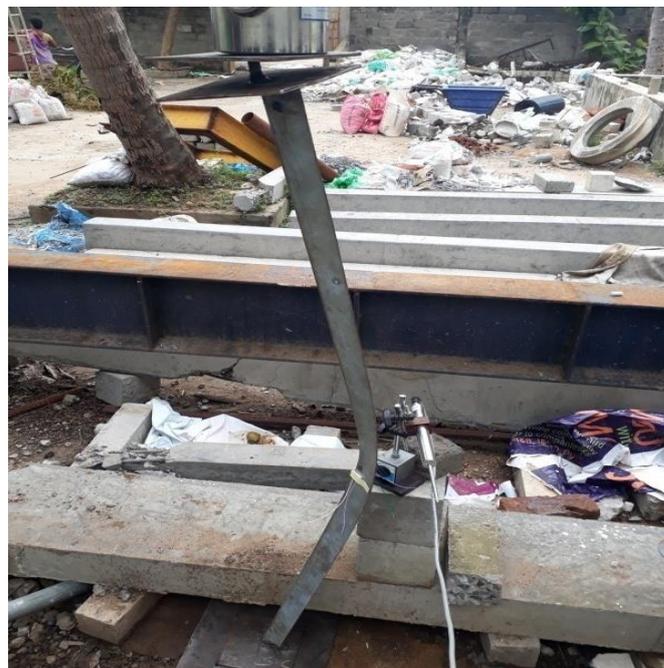
with the information procurement framework appeared in the Experimental arrangement as underneath



**Fig 13: TEST SETUP**

The load cell, LVDT, strain gauges were connected to the system consisting of prosaf software through the channel slots present in the system. After the load cell, LVDT, strain gauges were connected we have enable the channel slots and the auto balancing is to be done. After auto balancing the system the load is applied gradually by the manually operated hydraulic loading machine the load is applied until the failure of column takes place the corresponding values are saved in the data acquisition system. The corresponding buckling modes are shown below





**Fig 14: Failure of columns**

## VII. FINITE ELEMENT ANALYSIS

Finite Element Nonlinear Analysis of Cold-formed Steel Angular Columns are done by the Static Risk procedure available in the finite element package ABAQUS/CAE 6.14 which is followed by Eigen value buckling analysis done by linear perturbation step available in ABAQUS. From Eigen value buckling analysis buckling modes and loads are obtained

### A. ABAQUS Modeling and analysis

In ABAQUS displaying and examination incorporate after three stages:

1. Pre-processing
2. Simulation
3. Post processing

#### i. Pre-processing

It is the fundamental development to analyze the physical issue. In this movement model of the physical issue is

portrayed and an ABAQUS info record (job.inp) in delivered. Basic key centers like material properties, part type, limit condition, load, contact, work is described here

#### ii. Simulation

Simulation is usually done as a basic method. This ABAQUS information document created previously deals with the numerical problem characterized in the model. For example, print inspection performance contains the problem of displacement and stress sensitivity and is stored in parallel records in the simulation to be used for post-processing. The output file is created as a job

During the simulation, ABAQUS uses Newton Raphson's technique to tackle the non-linear sort issues. In contrast to linear investigation, load application to the framework is gradual in non-linear case. ABAQUS breaks the simulation arrange into number of burden increases and toward the finish of each heap increase it finds a rough harmony setup. At times ABAQUS takes various emphases to locate a satisfactory arrangement relies upon resilience indicated, for a specific burden increase. At last the aggregate summation of all heap gradual reactions is the inexact answer for that non-linear issue. Thusly ABAQUS utilizes both steady and iterative techniques to take care of non-linear issues.

There are three stages in simulation

- Analysis step
- Load increase
- Iteration

Analysis step which for the most part comprises of stacking alternative, yield demand. Yield solicitation portrays the estimations of required parameters like uprooting, stress, strain, response power, bowing minute and so on.

In Load Increase step, first weight expansion is to be described by the customer and the resulting growths will be picked by ABAQUS normally

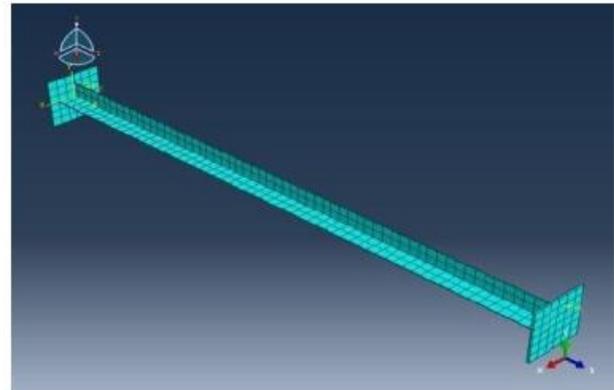
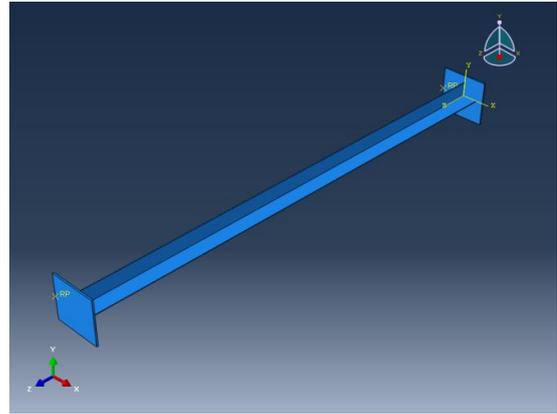
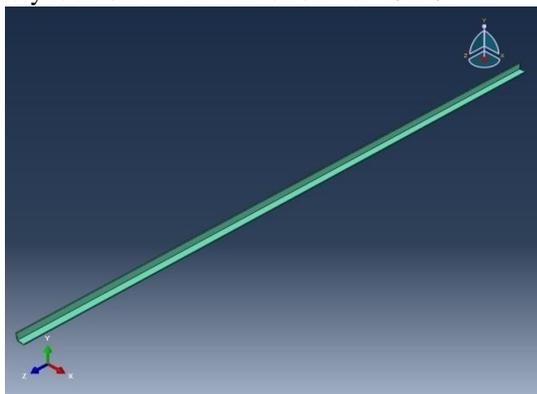
Iteration proceeds till ABAQUS enhance the remaining powers to the given resilience esteem. Henceforth, after each heap increase the structure fulfills the harmony conditions and relating yield solicitation esteems are to be kept in touch with the yield database record.

**iii. Post processing**

Once the simulation is complete, the calculated quantities such as stresses, displacements, deformations, reaction forces, etc. can be displayed via the ABAQUS visualization module. The visualization engine includes various options for displaying results, such as: Animation, color contour plots, distorted shapes, and X-Y traces

**B. Finite Element Modelling and Assembly:**

The angle column is modelled as a solid element by using solid extrusion option in ABAQUS and the plates connecting angle column are modelled as a rigid element to transfer the load to the column. The properties of cold shaped steel are assigned to the angle section modulus of elasticity  $E=203.4\text{Gpa}$ , poissons ratio  $\nu=0.3$ . The angle column section is assembled with the rigid plates at top and base of the column in such a way that centroid of the plate will coincide with the shear centre of the angle section. The assembly is meshed with a mesh size of  $10 \times 10$ .



**C. Boundary conditions and load:** The cold shaped steel angle columns were compressed under fixed bonding conditions. The lower end of the column is fixed and the upper end can rotate. The point charge concentration is applied to the angle column between the shear and the centre of gravity.

**D. Validation of model:** The model was approved by utilizing the trial results on the fixed-pivoted finishes equivalent plain edge section examples, exposed to offbeat burdens. Limited component displaying was finished utilizing the ABAQUS programming and the information parameters were likewise given.

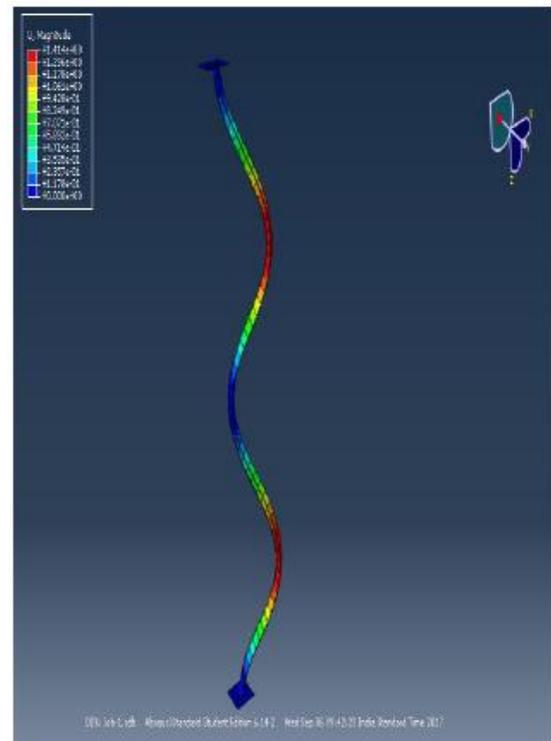
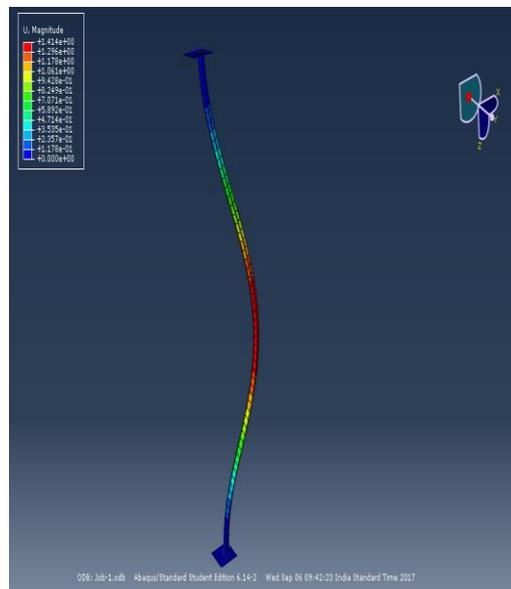
**E. Elastic Buckling Analysis:** The analysis of the elastic buckling of 9 cold formed steel columns was carried out using the "BUCKLE" option available in the ABAQUS software during a linear perturbation step, and the buckling and buckling modes were obtained from the eigenvalue buckling analysis.

The elastic buckling loads obtained from the ABAQUS software are tabulated below.

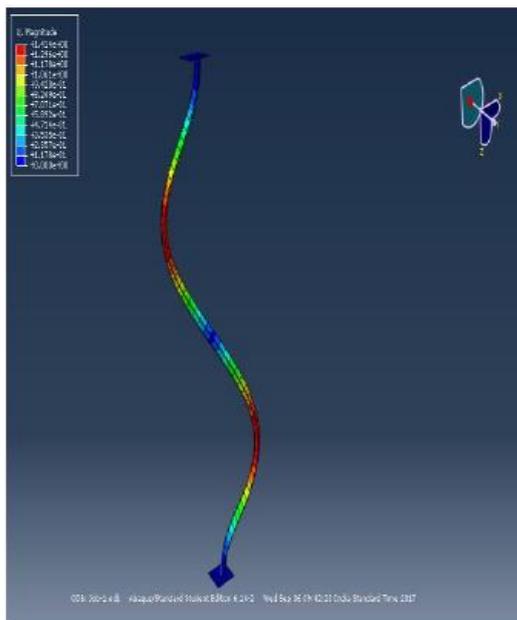
**Table 2: Elastic Buckling loads**

COLUMN NO	B/T RATIO	COLUMN DIMENSIONS	LOAD POSITION	ELASTIC BUCKLING LOADS (KN)
1	18.75	50x50x1.6mm	At shear centre	26.0
2			At 5mm from S C	25.5
3			At centre of gravity	27.0
4	25.0	50x50x2.0mm	At shear centre	30.34
5			At 10mm from S C	30.20
6			At centre of gravity	30.10
7	31.25	50x50x1.6mm	At shear centre	24.50
8			At 10mm from S C	22.80
9			At centre of gravity	24.35

**F. Buckling modes**



**Fig 15: Buckling modes**



**G. Non-linear analysis:** The Non-linear finite element analysis was done by using the static risk procedure available in ABAQUS by taking geometric non-linearity into consideration it is added by enabling the “NLGEOM” option during the step. The material non-linearity is also taken into consideration by taking elasto-plastic properties. The non-linear analysis will give the load versus displacement graph from that graph the ultimate load can be obtained

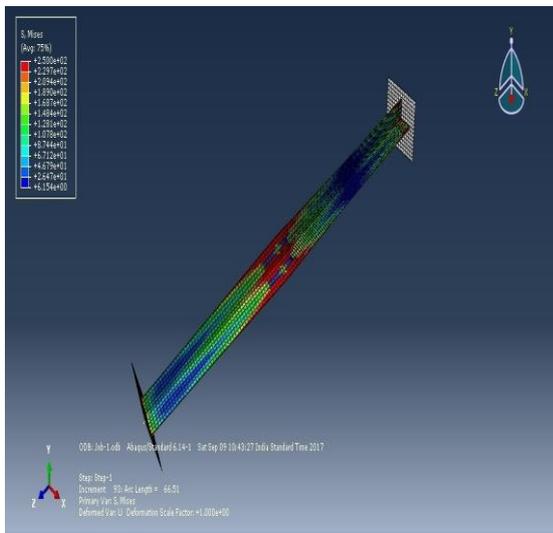
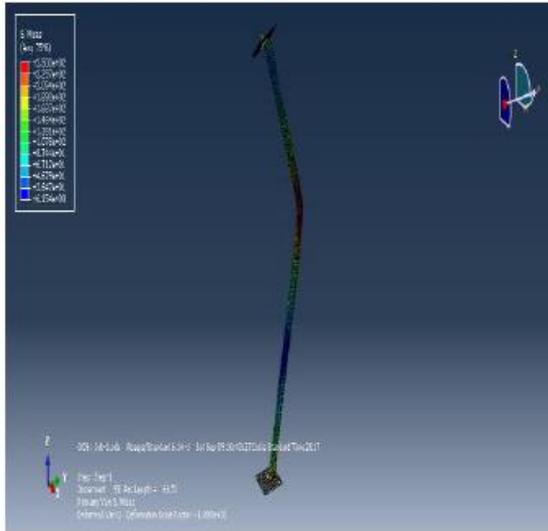
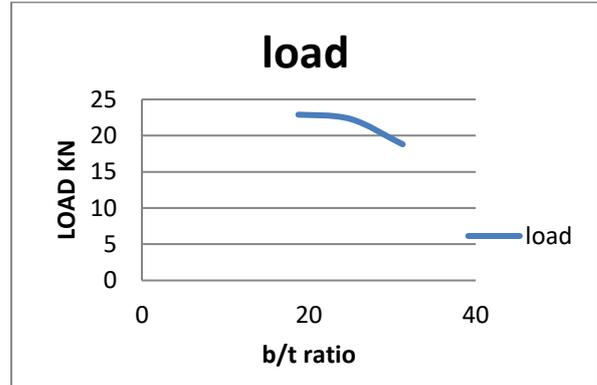
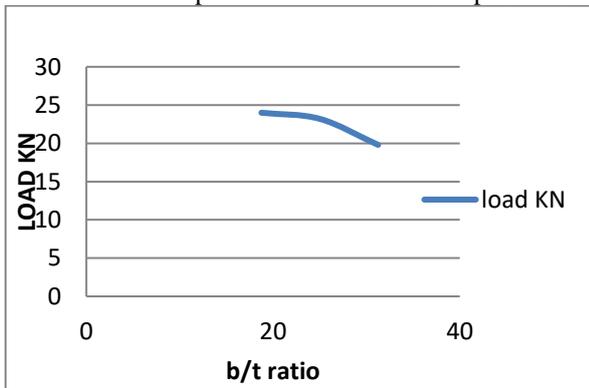


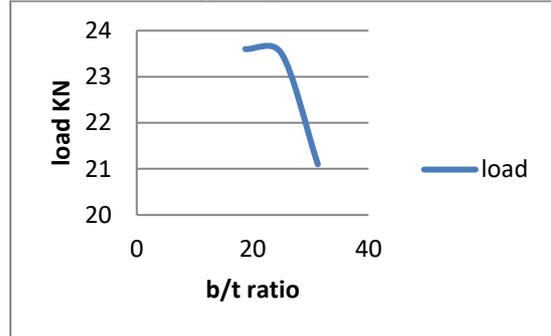
Fig 16: Failure of columns

VIII. RESULTS

The graphs are plotted between b/t ratio and ultimate load obtained from the experiment for various load positions

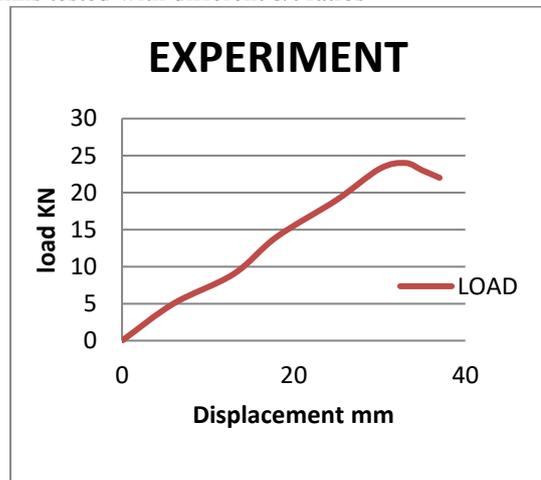


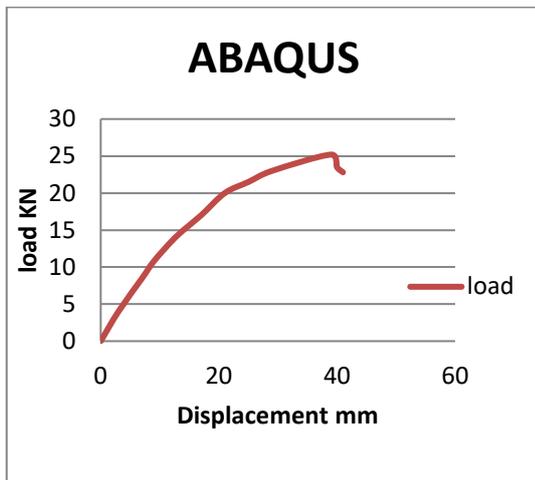
Graph 1: load vs. b/t ratio at Shear centre Graph2: load vs. b/t ratio at centre gravity



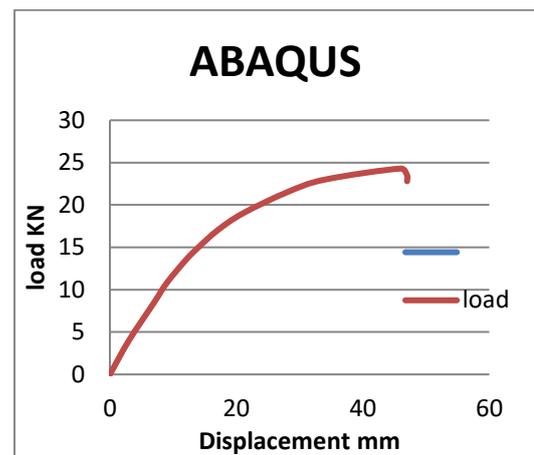
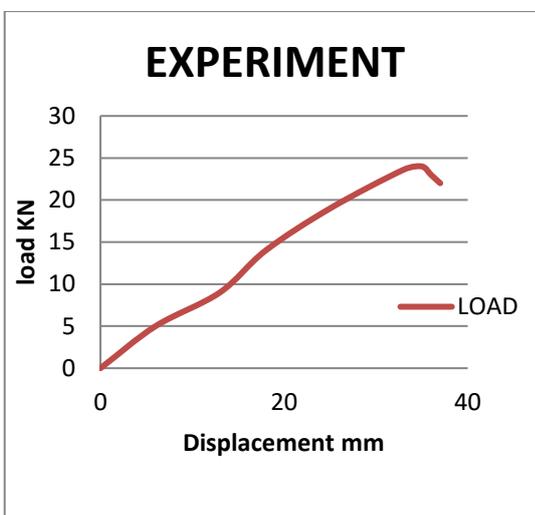
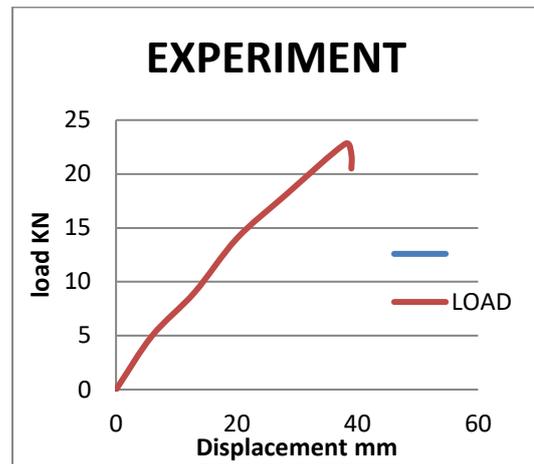
Graph 3: load vs. b/t ratio between shear centre and centre of gravity

The load versus deflection graphs are plotted for all the columns tested with different b/t ratios

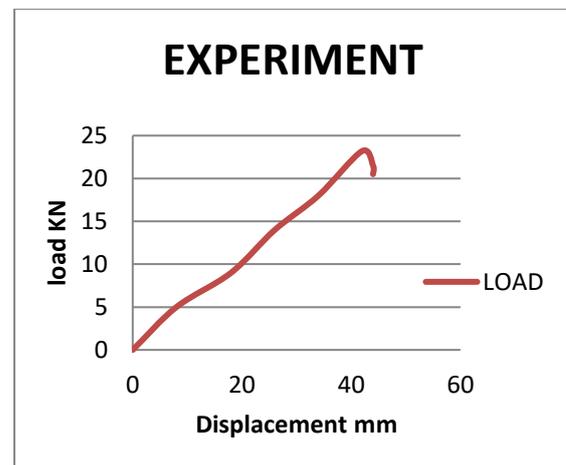
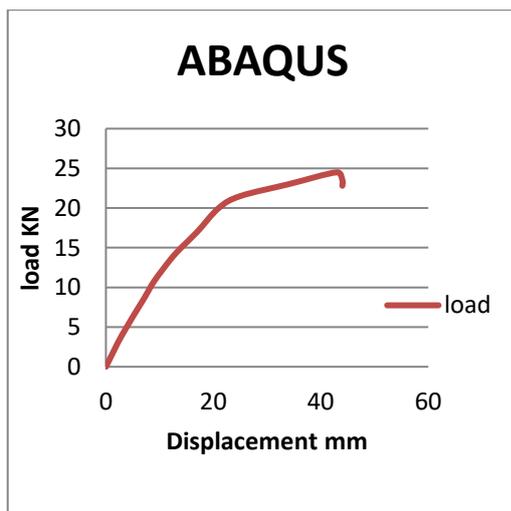




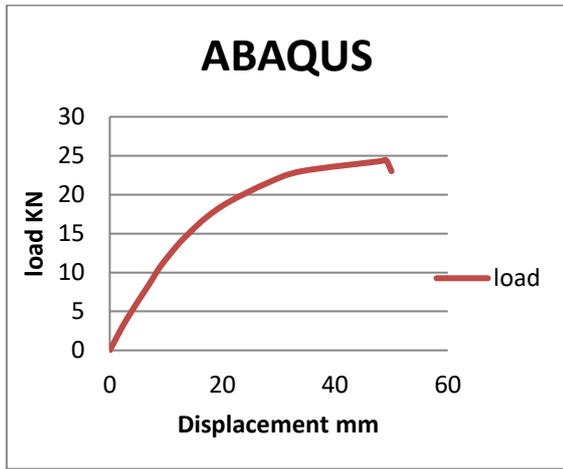
Graph 4: Load vs. Displacement for column 1



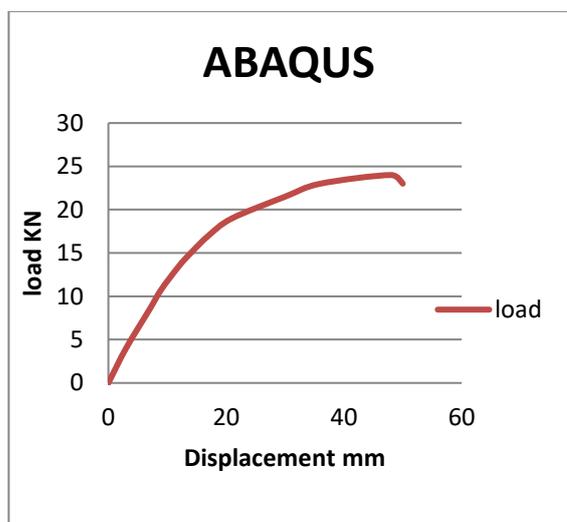
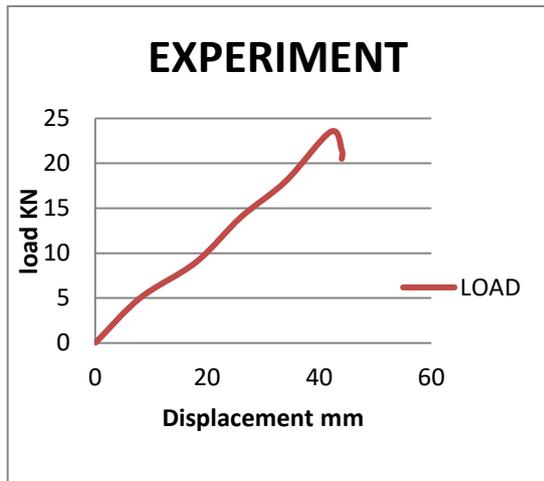
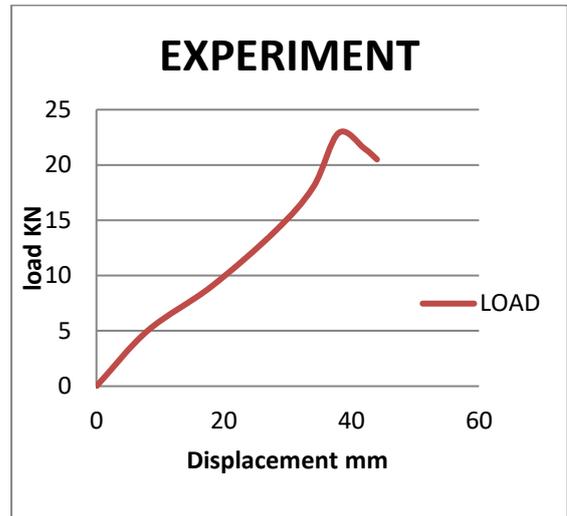
Graph 6: Load vs. Displacement for column 3



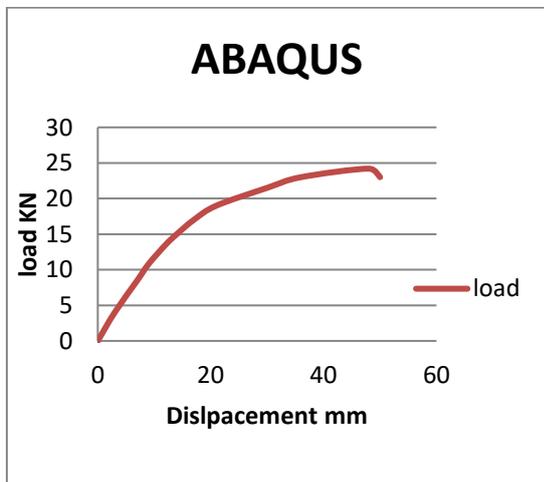
Graph 5: Load vs. Displacement for column 2



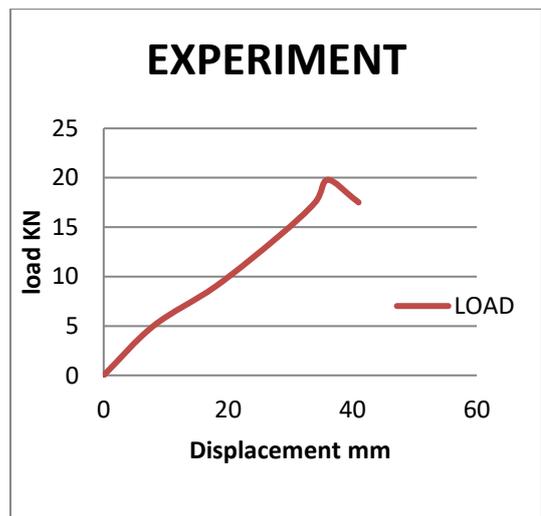
Graph 7: Load vs. Displacement for column 4

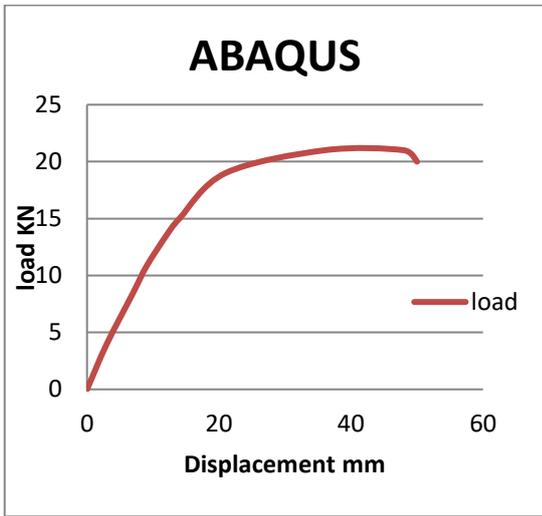


Graph 9: Load vs. Displacement for column 6

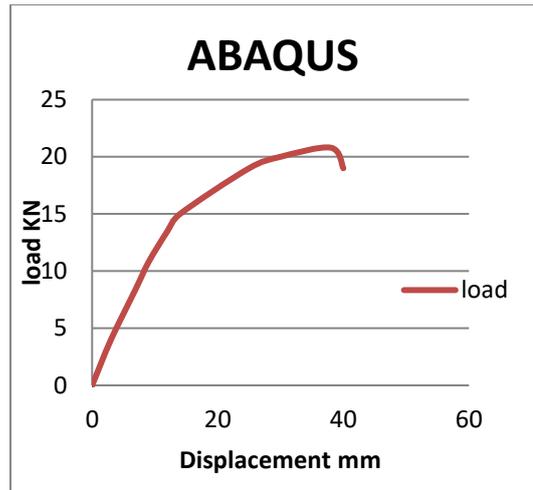
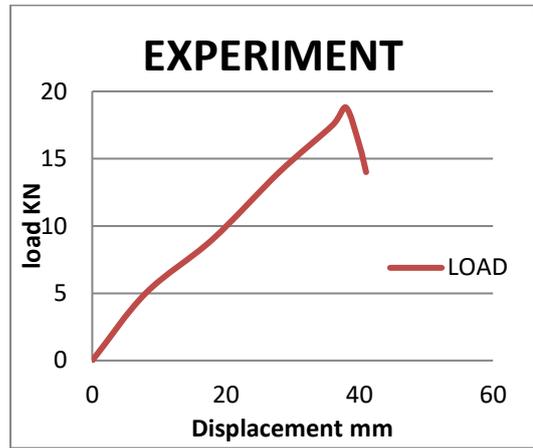


Graph 8: Load vs. Displacement for column 5

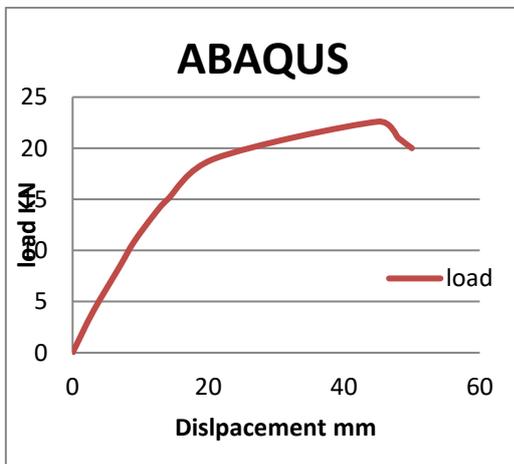
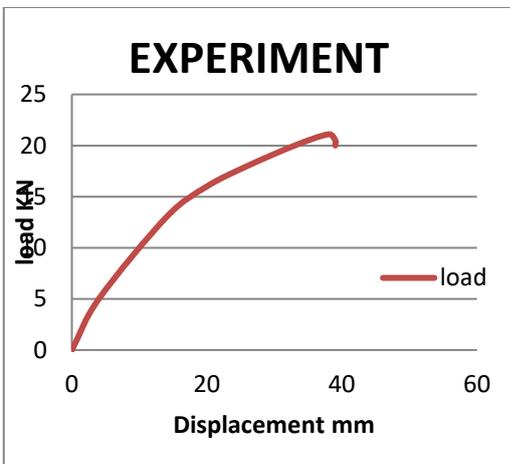




Graph 10: Load vs. Displacement for column 7



Graph 12: Load vs. Displacement for column 9



Graph 11: Load vs. Displacement for column 8

**Table 3: Experimental Results and ABAQUS Results**

Column Np	B/T RATIO	COLUMN DIMENSIONS	LOAD POSITION	EXPERIMENTAL LOAD (KN)	ABAQUS LOAD(KN)
1	18.75	30x30x1.6mm	At shear centre	24.0	25.20
2			At 5mm from S C	23.60	24.5
3			At centre of gravity	22.80	24.30
4	25.0	50x50x2.0mm	At shear centre	23.20	24.45
5			At 10mm from S C	23.50	24.20
6			At centre of gravity	22.90	24.00
7	31.25	50x50x1.6mm	At shear centre	19.80	21.0
8			At 10mm from S C	21.10	21.50
9			At centre of gravity	18.80	20.80

**IX. CONCLUSIONS:**

- The Eigen-value buckling analysis was accomplished for the prediction of elastic buckling loads and buckling modes. Analyses have been performed for fixed-hinge end conditioned specimens with different b/t ratios. It is found that with increase in b/t ratio the buckling load decreases.
- The non-linear static RIKS analysis has been completed to get the ultimate loads and load versus displacement graph. The ultimate load carrying capacity of the column decreases with increase in b/t ratio and, decrease in thickness of the column. The decrease in the load carrying ability with rise in b/t ratio is mainly due to plate buckling, predominantly due to local buckling of the member.
- Test results obtained from non-linear analysis in ABAQUS are compared with experimental results for lesser b/t ratio, the column ability predicted by ABAQUS is in good concurrence with the experimental results
- It can be seen that the local buckling starts in the sections with a larger flange width than the flange width lower than a previous time
- It is observed that the column of size 50x50x1.6mm at 10mm eccentricity from the shear centre carries maximum load.
- It is observed the columns of size 30x30x1.6mm 50x50x2.0mm at shear centre the column carries maximum load.
- The final load predicted by the ABAQUS / CAE 6.14 finite element analysis software is consistent with the experimental results. It is therefore considered as an alternative method to the experiments

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