

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF NEW COLD-FORMED STEEL BUILT-UP COLUMN

Submitted in partial fulfillment of the requirements for the award of

Master of Engineering degree in Structural Engineering

by

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**DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **V. A. VEERA VIGNAESH (40380003)** who carried out the project entitled **"EXPERIMENTAL AND NUMERICAL INVESTIGATION OF NEW COLD-FORMED STEEL BUILT-UP COLUMN"** under our supervision from November 2021 to May 2022.

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DECLARATION

I **V. A. VEERA VIGNAESH** hereby declare that the Project Report entitled **“EXPERIMENTAL AND NUMERICAL INVESTIGATION OF NEW COLD-FORMED STEEL BUILT-UP COLUMN”** done by me under the guidance of **Dr. C. Manoj Kumar** at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** is submitted in partial fulfillment of the requirements for the award of Master of Engineering degree in Structural Engineering.

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ABSTRACT

Cold-formed steel (CFS) columns are broadly used in the construction industry for low-rise buildings because of their lightweight, easy installation, and erection. Back-to-back built-up CFS lipped channel sections and box sections are applied in CFS structures. In this study, a new built-up column consisting of a total of 4-individual CFS channels, in which 2 are individual CFS lipped channels, which are put back-to-back and connected with the help of 2 screw fasteners at the web at specified spacing along the length of the column, while another 2-individual unlipped channels are placed around the boundary of the back-to-back channel and connected with the help of 2 screw fasteners where flanges of both the channels intersect at specified spacing along the length of the column. Finite element (FE) models are created, and buckling analysis is performed through Abaqus 6.14 software by varying the height of the column while the thickness of the section is constant. Four heights such as 300mm, 500mm, 1000mm and 1500mm of the built-up column are fabricated and an experimental investigation was carried out. Analytical results and experimental results are compared.

Keywords: Cold-formed steel, back-to-back, box section, built-up column, and Abaqus 6.14.

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LIST OF ABBREVIATIONS

CFS	COLD FORMED STEEL
FE	FINITE ELEMENT
FEA	FINITE ELEMENT ANALYSIS
CTM	COMPRESSION TESTING MACHINE
UTM	UNIVERSAL TESTING MACHINE
CR	COLD ROLLED
DSM	DIRECT STRENGTH METHOD
EWM	EFFECTIVE WIDTH METHOD

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

Cold-formed steel (CFS) sections are broadly employed in both commercial and residential structures. The application of CFS has increased as a result of its high strength-to-weight ratio. Cold-formed steel (CFS) or light gauge members are thin sheets of steel that are pressed and rolled at room temperature. Columns, beams, joists, studs, floor decking, built-up sections, and other components are included in this category. Compression and tension members are made up of CFS built-up sections. Channel, angle, Z-section, hat section, and box section are some of the different types of sections accessible. Lightweight, high strength and stiffness, quick and easy erection, uniform quality, more precise details, and cost-effective shipping and handling are all advantages of CFS. When a single cold-formed steel section is insufficient to withstand loads and spans over longer spans, built-up CFS sections are typically utilized as columns. CFS members can lead to a more economical design for low-rise buildings than hot-rolled steel sections. They're also employed when the shape necessitates the avoidance of hot-rolled steel parts. Furthermore, they can be manufactured in tiny machine shops and can be fashioned into a wider range of pieces.

The buckling of slender columns is a common occurrence. Increases in the load on such a part only result in axial shortening as long as the load is relatively minor. When the critical load is achieved, however, the member bows out sideways. This bending causes massive deformations, which leads to the member collapsing. The buckling load is thus used as a design criterion for compression members. Cold-formed steel members are prone to different buckling modes, including local, distortional, and global modes, according to previous research, and their ultimate strength behavior is dictated by these buckling modes. It's critical to understand the various buckling modes while designing cold-formed steel compression members. According to a previous study, the following buckling modes have been observed:

1.2 Local buckling:

Local buckling is a mode characterized by plate-like deformations or a state of geometric instability that occurs before the material yields. Cold-formed section plate elements are typically thin, having a higher plate slenderness ratio, and so

locally buckles before yield stress is attained. A thin-walled member's local buckling mode is determined by its

- Shape and dimensions i.e., cross-section
- Support conditions

The failure of thin elements due to elastic local buckling does not occur quickly. Prior to the failure, the elements can carry a surcharge load in the post-buckling strength. The force that induces local buckling may be several times the post-buckling strength of parts with a wide flat width to thickness ratio. As a result, post-buckling strength is taken into account in all cold-formed design parameters.

1.3 Distortional buckling:

The lip stiffener is insufficient to prevent the compression flange and associated web from becoming unstable, resulting in distortional buckling. The cross-section is distorted in distortional buckling.

1.4 Flexural buckling (bending about the principal axis):

Compression buckles out weaker principal axes in this mode, and collapses occur at a rapid rate as a result of excess buckling deformation and no twisting. Generally, long columns are prone to flexural buckling along half wavelengths.

1.5 Flexural torsional buckling:

Torsion buckling is the turning or twisting of the entire cross-section around its shear center.

1.6 ADVANTAGES OF CFS

- The durability of CFS, particularly its corrosion resistance, mold, and vermin.
- CFS contains a minimum of 25% recycled steel and satisfies the requirements of mostly all green building standards and rating systems.
- Because cold-formed steel is lightweight, it's simple to ship, easy to handle, and assemble.
- CFS is about 20% stronger than hot rolled steel. Much of the strength of CFS comes from the strain hardening that occurs as the rollers compress.

CHAPTER-2

LITERATURE REVIEW

2.1 INTRODUCTION

Several researchers had studied CFS built-up sections which are of walls, beams, and columns. For columns, an in-depth study on buckling and failure pattern has been carried out based on parameters such as screw spacing, screw pattern, hybrid section, etc. Sections are also studied on loading characteristics such as axial and eccentric loading.

2.2 LITERATURE REVIEW

G. Beulah Gnana Ananthi and B. Ashvini (2018) conducted a study on “Experimental theoretical and numerical studies on cold-formed steel stub channel columns with stiffeners” on stub columns of height 300mm of both plain and lipped sections. Stiffeners are provided in lip, flange or web portions and the end condition is kept fixed. The failure pattern of the columns is studied, which consists of either back-to-back or box configuration. The results of load against deflection, axial shortening and strain behavior are studied as well as the effect of stiffeners at different places in the load-carrying capacity are concluded. The screw connected section failed by buckling of the plate at the middle of the column and flexural buckling was witnessed at the middle or top or bottom of the column in welded section. The application of stiffeners where the flange and web intersects does not increase the load carrying capacity whereas stiffeners introduced in the web has positive results.

M.S. Deepak et al. (2021) conducted a study on “Local buckling behavior and capacities of Cold-Formed Steel Double-I-Box stub and short column sections” of 2 I box sections of both homogeneous and hybrid under axial compression. The factors considered are hybrid ratio, width to depth ratio and column height. Their overall slenderness ratio of the column studied is below 0.2 and the slenderness of the flange plate is below 1.85. the columns failed by local, yielding or by both modes of buckling. Local buckling of the bottom zone occurs at all the columns and looks like an elephant foot shape. This is due to formation of a constrain because of the poisson’s ratio and results in localized buckling of the column at bottom zone owing

to local imperfection when the load is applied. It is concluded that the axial load carrying capacity of the columns which fail by local buckling can be determined.

G. Beulah Gnana Ananthi (2016) conducted a study on “Behaviour of Cold-Formed Steel Box and Built-Up I-Section Under Compression”, and validated the investigation using finite element analysis. The experimental research findings also match with the FEA results. A reliability analysis is also done to detect the load-carrying capacity of the stub columns. Support conditions were considered as a fixed end. The values from the experimental, FEA and direct strength methods are almost similar.

G. Beulah Gnana Ananthi (2017) conducted a study on “Cold-Formed Steel Compound Angle Section Subjected to Axial Compression” and examined the compressive strength of the built-up box column consisting of double angles. In this investigation, four distinct types of cross-sections of two variable thicknesses were adopted. All the stub and short columns are examined for their ultimate load-carrying capacity. Two similar lipped angle sections are positioned facing each other and fastened with screws via the lips in a specific spacing throughout the whole length of the built-up box angle sections. A numerical FE model is made up in the Abaqus software to check the outcomes of experiments on the actions of built-up box columns. The geometric and material nonlinearities are held in the FE Model. A parameter investigation is carried out after the verification of FE models for various slenderness ratios such as 20 to 120. The quantitative results were found to be in good acceptance with the experimental outcomes. The outcomes of both the investigation are compared against each other with the help of results from the DSM strength. DSM is also employed.

G. Beulah Gnana Ananthi (2017) conducted a study on “Cold-Formed Steel Battened Box Columns Under Axial Compression”. In this paper the experimental, numerical, and theoretical analyses of pin-ended CFS battened box columns subjected to axial compression are studied and Abaqus software is used for creating the finite element model. The outcomes shown good acceptance with the experimental outcomes. Prequalified portions of single-lipped channel sections are chosen for the study based on the AISI S100-2007 limitations. Two different cross-sections of CFS lipped channel sections comprising of various batten widths aligned to construct a box section. Parametric research was conducted that included changing the slenderness ratio from 20 to 120, width of the batten is varied, and

changing the number of battens. The DSM is used in the theoretical analysis, and the findings are compared to those of FEA. Based on the findings, DSM is given a design guideline for prediction of the ultimate capacity of box battened columns.

Krishanu Roy et al. (2019) performed a study on “Finite element modeling of back-to-back built-up cold-formed stainless-steel lipped channels under axial compression”. In this work, the impact of spacing of screws on the axial strength of these built-up columns was studied. The columns categorized as short and intermediate failed due to local-global or local-distortional buckling interactions, but in the columns categorized as long failure, global buckling failure occurred. Local buckling caused the failure of all other stub columns. The behaviour of the present design recommendations by AISI and AS/NZS was then evaluated by comprehensive parametric research that covered a various span of slenderness and varied geometries of the cross-section. According to the results of the parametric analysis, the AISI and AS/NZS are conservative by roughly 10% to 20% for lipped channels that failed due to overall buckling. Furthermore, for all other columns that failed due to local buckling, the AISI and AS/NZS can be 6 percent conservative.

Krishanu Roy et al. (2019) performed a study on “Experimental and numerical study of an innovative 4- channels cold-formed steel built-up column under axial compression”. Evaluations on the buckling and behaviour of collapse of an innovative built-up CFS column are described. Two CFS-lipped channels were put back-to-back at the web and 2 fasteners are used to connect at given spacing along the length of the column, while the other 2 channels were put flange-to-flange and are connected with the help of one fastener at the prescribed spacing along the length of the column. All specimens had their initial geometric flaws and material attributes determined. For various lengths and spacing of the screws, the effect of spacing of the screw, load against axial shortening, and modes of the buckling were explored. Nonlinear finite element (FE) models with material nonlinearities and starting geometric flaws were also constructed. In terms of modes of failure and axial capacity, the FE model were evaluated against experimental results. In addition, parametric research was undertaken Furthermore, from the experiment and numerical results, the axial load carrying capacity, the AISI and AS/NZS can be 6 percent conservative.

Krishanu Roy et al. (2019) conducted a study on “Experimental and numerical investigations on axial strength of back-to-back built-up cold-formed steel angle columns”. According to this work, the axial compression is tested for the proposed design of CFS built-up column using angle sections. A FE model is developed for nonlinear analysis and the geometry properties and fasteners are generated. The FE model was evaluated using the results of the experimental study. The influence of spacing of the fastener on axial strength was studied. The parametric analysis looked at four distinct cross-sections and two different thicknesses, also the slenderness ratio spanning from 20 to 120. The efficiency of the present design standards as per the DSM was evaluated using axial strengths acquired from experimental and numerical analysis; the results revealed that the DSM is 13% conservative. As a result, better design criteria for the DSM have been provided, and their accuracy has been verified using both experimental and FE results of the designed column.

Krishanu Roy et al. (2017) conducted a study on the “Effect of screw spacing on behavior of axially loaded back-to-back cold-formed steel built-up channel sections”. In these columns, individual channel portions do not buckle independently because of intermediate fasteners at distinct positions along the column length. The AISI and AS/NZS for built-up sections, recommend using a modified slenderness technique to accommodate for screw spacing. However, only a few experimental experiments or finite element calculations for such sections are described in the study to conclude the influence of the spacing of the screw. This problem is discussed in this research. A FE model was cultivated and agrees well with the experimental test outcomes. While the modified slenderness technique is generally conservative, it is found to be unconservative by roughly 10% for stub columns.

Hieng Ho Lau et al. (2019) conducted a study on “Nonlinear behavior of axially loaded back-to-back built-up cold-formed steel un-lipped channel sections”, in which intermediate fasteners were used to resist the buckling of individual channel sections. Very few literatures are available on the influence of spacing of the screw under axial capacity of the unlipped column. Finite element models are created and analysis is done ranging from stub to slender column. Parametric investigation is carried out based on the result of spacing of the screw on the axial strength. When the results are, we discovered that the axial strength of unlipped sections is 31% lower than lipped channels. The AISI and AS/NZS are likewise found to be over-

conservative by about 15% for columns that failed due to overall buckling, but unconservative by about 8% for columns that failed due to local buckling.

Hieng Ho Lau et al. (2019) conducted a study on “Experiments and finite element modelling of screw pattern of self-drilling screw connections for high strength cold-formed steel”. Very less research on the influence of patterns of the screws on the connection, where individual screws might fail in a variety of ways, such as shear failure, bearing, pull-out, and tilting, especially for CFS plates of grade 550. This problem is evaluated using both the experimental and numerical technique. The experimental study looks into the effect of patterns of the screws, numbers, and spacing of the screws with respect to connection strength; 12 and 14 gauge screws are used in the tests. The steel sheets were then subjected to a fracture criterion by creating a FE model and a nonlinear analysis was performed. Both the FE model and experimental outcomes are compared and found to be quite accurate in terms of strength of connection and modes of failure, such as shear failure, bearing, pull-out, and tilting.

Shao-Feng Nie et al. (2020) conducted a study on “Compressive behavior of built-up closed box section columns consisting of two cold-formed steel channels”. The proposed design of the built-up column was tested for both concentric and eccentric axial loading by varying the cross-section, length, and thickness. From the failure modes the load against displacement graph is obtained. Under concentric axial loading the columns of long and medium, flexural buckling occurred at weak axis and short columns failed due to excessive local buckling. Whereas for eccentric loading the columns failed due to flexural and flexural-torsional buckling about the weak and strong axes respectively. Models based on finite elements (FE) were created. For a wide range of factors, parametric studies were done to assess the code equations’ accuracy. The concentric axial load carrying capacity is contrarily proportional to the slenderness ratio or the web to thickness ratio; the column's stability is directly proportional to the flange width and strength; and the column's eccentric axial compression strength declined faster around the weak axis than it did around the strong axis, according to the FE analysis results. Ultimately, the potency of the design methods used to predict the strength of the column, is similarly to the resistance factor design in AISI, load, EWM, DSM, and effective width to thickness ratio method in the Chinese code.

M. Anbarasu (2019) conducted a study on “Behaviour of cold-formed steel built-up battened columns composed of four lipped angles: Tests and numerical validation”. The main focus of this paper is on the strength and structural behaviour of a built-up box column with lipped angles and batten, under axial loading. 10 specimens with two varied cross-section dimensions and 5 varied geometric column lengths were built and evaluated under pin end support with warping-restrained end conditions. Coupon tests are performed to find the material property for which 3 specimens are tested. The initial geometric flaws were measured in total. The effects of the slenderness of the plate, slenderness of the member, the slenderness of the chord, and slenderness of the batten plate on the compression behaviour of battened box columns were studied. The compressive capacity of the columns was shown to be strongly affected by chord slenderness. The test findings were provided, including resistances of compression, load against displacement values, and deformation forms. The outcomes of the tests were compared to the expected design outcomes utilizing the AISI and EN code, and El Aghoury et al design's equations. These two design standards predicted design strengths that were not conservative, with El Aghoury et al standard's performance was better. FE model results and the experimental results are compared against each other.

M. Anbarasu and G. Beulah Gnana Ananthi (2014) conducted a study on “Cold-formed Steel Lipped Built-up Channel Sections Subjected to Axial Compression”. The potential of using built-up CFS columns made up of 2-lipped channels connected by a succession of batten plates is introduced in this regard. The distance between the channels was set so that the value of the moment of inertia at the minor axis is double that of the major axis. A FE model was created for performing nonlinear analysis and validated using theoretical and practical data from the literature. According to the FEA results of previous works reported, the FE model generates the behaviour of buckling, load-carrying capacity of the columns. Torsional flange buckling can reduce the ultimate capacity of axially loaded channels with stiffened flanges. The DSM is used in the theoretical analysis. Furthermore, the DSM's analytical results for the CFS built-up sections are often conservative. Variations in the slenderness ratio and number of battens were used in the parametric investigation. The FEA-derived ultimate loads have been compared.

M. Adil Dar et al. (2021) conducted a study on “Compression and stability response of short CFS battened columns with light-weight composite chords”. When compared to traditionally built built-up columns, previous works on gapped built-up columns have revealed the creation of greater axial strength and stability (especially torsional stability). The performance of gapped built-up columns is nevertheless limited by the occurrence of local buckling between the lateral connectors. Early local buckling failures have been greatly reduced because to the usage of CFS composite members, especially when a hard material like concrete is utilised. However, it undermines one of the primary benefits of adopting CFS sections, namely, light weight construction. Previous research on light-weight CFS composite members has been restricted to flexural members, despite the fact that it has been small. An experimental analysis was conducted on short fixed terminated CFS battened columns made up of composite channel sections in this study. The impact of various strengthening strategies for the web of channel sections utilising traditional stiffening and various light-weight packing materials was studied. The impact of these changes on CFS battened column axial compression capacity and stability response was investigated. The performance based on structural resistance under ultimate load, load against displacement, and modes of failure were analysed. Finally, the design strengths for CFS structures were determined using the AISI and EN code. These code standards forecasts had inconsistencies in their accuracy.

M. Anbarasu and M. Venkatesan (2019) conducted a study on “Behaviour of cold-formed steel built-up columns: tests and numerical simulation”. In this paper a test programme on CFS built-up columns made up of back-to-back two-lipped channels. 14 specimens were evaluated between pins with the warping restrained end condition in this study. Total number of initial geometric flaws is calculated. The deformed forms, compression resistance, and load-axial shortening response are all shown. FE model was generated, which included material nonlinearity, geometric nonlinearity, contact nonlinearity, and geometric imperfections. In terms of peak compression resistance, deformed forms, and load against axial shortening curves, the FEA and experimental results show good accordance. The test findings were compared to the DSM and EWM for CFS. The reliability study concludes that the design strengths anticipated by design codes provide conservative strength forecasts for the built-up columns, and these design rules are also analysed.

M. Adil Dar and M. Anbarasu (2019) conducted a study on “Axial capacity of CFS built-up columns comprising of lipped channels with spacers: Nonlinear response and design”. According to this study the axial load carrying capacity and nonlinear analysis of CFS built-up columns under concentric loads are studied. The built-up columns were made by placing the channel sections back-to-back, spacers are introduced along the web portions for connecting the channels. To join the lipped channels and spacers, screws were employed as fasteners. Finite element (FE) models were created and compared to the suitable previous works. Variations in critical factors such as slenderness of the plate for lipped channels, unbraced slenderness of the chord, and global slenderness were investigated in order to see how they affected the ultimate compression resistance of these columns. The AS/NZ Specifications and European Specifications on CFS were utilised to determine the design strengths for these built-up columns, which were then compared to the parametric research outcomes. The provisions in the present AS/NZS and European Specification for forecasting the strengths of the built-up column using spacers had flaws, according to this study. As a result, new design equations for the CFS built-up column formed of lipped channels using spacers are provided for trustworthy design strength predictions. The use of spacers reduced the local buckling half-wavelength, improving buckling resistance, especially in columns that failed due to local buckling.

M.S. Deepak and V.M. Shanthi (2018) conducted a study on “Member distortional buckling behaviour of hybrid double-I-box beams”. The experimental and parametric studies on behaviour of the distortional buckling of the member of innovative built-up beams consisting of 2 I boxes, are presented in this research (HDIBBs). This built-up beam has a distinctive cross-section that have the shape of a box that has double I sections, made from 4-channel sections. An intermediate stiffener was added to the flange plates. There is more material in the flange regions of these built-up beams that are further away from the cross-section of their centroidal horizontal axis. As a result, the flexural stiffness of the beam increases, increasing its moment capacity under major axis bending. The geometry features a torsionally stiff closed-box web component that resists lateral buckling along minor axes. The ratio of flange yield stress to web, the ratio of section breadth to depth, and thickness of the flange plate were all variables examined. All HDIBB members failed in the experimental programme due to distortional buckling, which was determined by

buckling of the web and twisting of the flange along edges. The findings demonstrated that as the slenderness of the flange plates rises, the moment of resistance capacity decreases for the beams. ABAQUS software was used to do the numerical analysis. In comparison, the experimental and numerical results were in good agreement. Parametric experiments on ideal HDIBB models were performed using the validated finite element models. Using the EWM equations described in the Euro code standards, the experimental and parametric research findings were compared to the projected strengths. The distortional buckling resistance capacity CFS members was found to be slightly over-estimated by existing Euro code design criteria. For calculating the decrease in distortional buckling moment resistance capability, an improved design equation was developed and proposed.

M.S. Deepak and V.M. Shanthi (2018) conducted a study on “Section bending resistance of new Hybrid Double-I-Box Beams”. In this study, a fresh built-up box beam when subjected to local buckling is studied. The built-up beam section has a different cross-section that combines the benefits of both an 'I' as well a closed box section. Under four-point bending, homogeneous sections of 8 numbers and hybrid sections of 16 numbers, were evaluated. The total number of sections analysed were 24. The following variables were taken into account for the specimens' test: first, the ratio of hybrid parameter, which is the yield strength of flange to web; second, the ratio of width to overall depth; and third, the flange thickness. Because there is more material at the flanges, these built-up sections have a high moment-resisting capability. The torsional stiffness of the closed box-web part is higher. According to the test results, the performance of hybrid sections in bending resistance capability is better than homogeneous sections, implying that they have a higher strength-to-weight ratio. Both main and minor axis bending resistance increased as the B/D ratio increased. The flange plate slenderness of the intermediate flange stiffener had a considerable impact on the flange plate's local buckling resistance. ABAQUS FE analysis software was utilized to verify numerical models and conduct a parametric study. The test findings were compared to the expected design moment of resistance as determined by Eurocode design standards and the adequacy was determined.

2.3 SUMMARY

From the above-mentioned works of literature on CFS built-up sections, we can summarize that the box section carries more load than the I section, an increase in slenderness ratio decreases the load-carrying capacity, at constant vertical screw spacing of 100mm center to center it performs better in shear, increase in thickness improves the ultimate load-carrying capacity of the column and the FE model is in good relation with the experimental investigation.

CHAPTER-3

AIM AND SCOPE OF STUDY

3.1 AIM

To study and determine the buckling behavior of new cold-formed steel built-up column analytically and experimentally.

3.2 STUDY OF WORK

In this work, a new cold-formed steel built-up column cross-section is designed and studied. A total of 18 specimens were analysed using ABAQUS 4.16 software by keeping the cross-section dimension and thickness as constant and the height of the column is varied from 300mm to 2000mm by increasing at a interval of 100mm. four specimens of height 300mm, 500mm, 1000mm and 1500mm are fabricated with cold-rolled sheet of thickness of 2mm and an experimental investigation was carried out. Both the experimental and analytical results are compared.

3.3 OBJECTIVE

- To detect the stress distribution of the proposed CFS built-up column.
- To detect the axial load carrying capacity and buckling actions of the CFS built-up column.
- To study the load vs deflection behavior.

3.4 SCOPE OF WORK

- The CFS built-up column will be validated by the finite element model using Abaqus 4.16 software.
- The axial load carrying capacity, deformation and stress distribution results will be obtained from the analytical analysis.
- The CFS built-up columns of required height are fabricated and experimental analysis is performed.
- Comparison of numerical and experimental results.

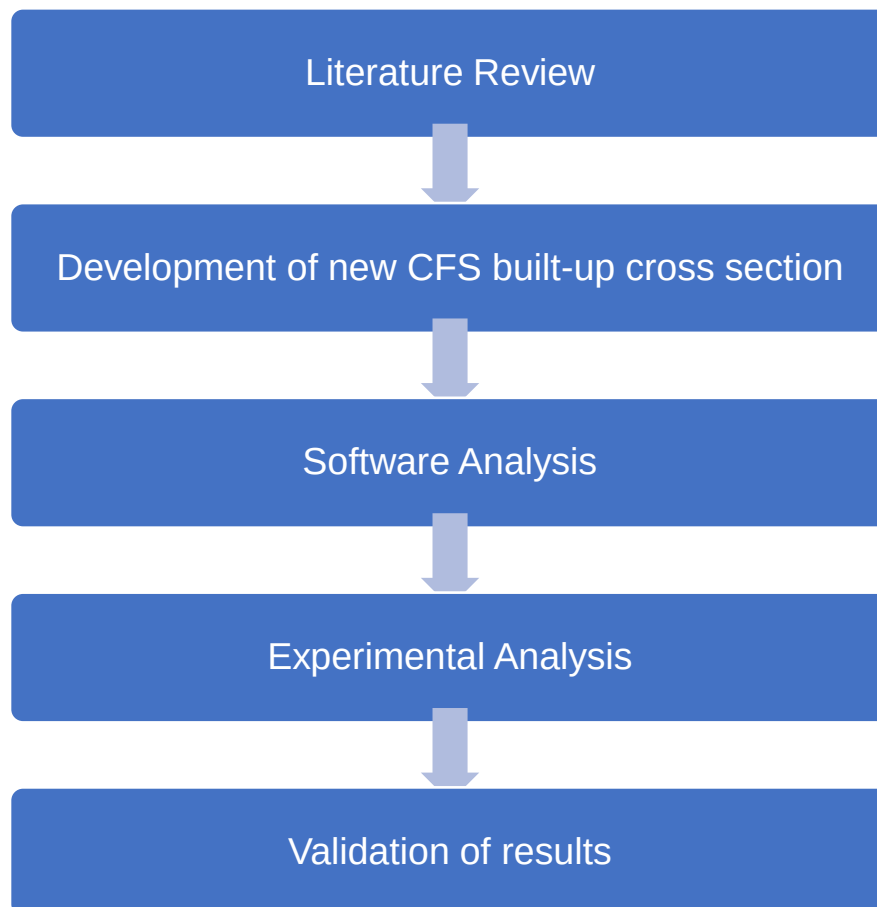
3.5 NEED FOR STUDY

- To develop a new built-up CFS column that offers more axial compression load.
- To understand the difference between software and experimental analysis.
- To promote construction of low-rise building using CFS built up column
- To be aware of the behavior of cold-formed steel built up column.
- To develop a sustainable green building.

3.6 NOVELTY OF WORK

- New innovative built-up column consisting of combination of box and I section is developed and connected using screws while the screw spacing is kept constant for all the heights of the column.

3.7 METHODOLOGY



4.1 CROSS-SECTION OF BUILT-UP COLUMN

15

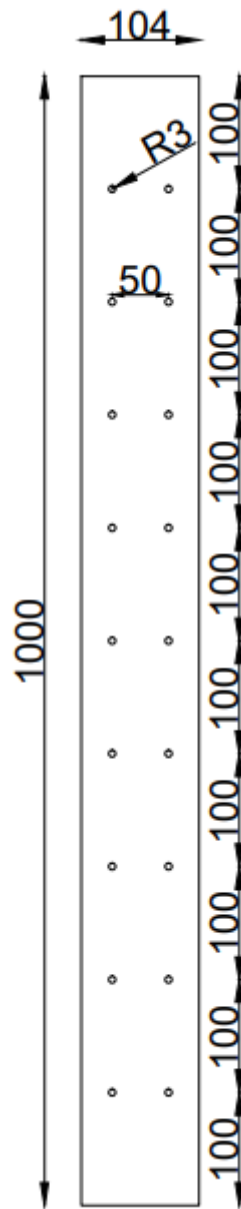


Fig 4.2 Section of Column of height 1000 mm

4.1.1 PROPERTIES OF CROSS-SECTION

Thickness, $t = 2\text{mm}$

Vertical Screw spacing, $s = 100\text{ mm}$

Slenderness ratio $= KL/r$

According to the AISI and AS/NZS, the modified slenderness ratio can be calculated as per the Equation,

Modified slenderness ratio, $(KL/r)_m = \sqrt{(KL/r)_0^2 + (S/r_i)^2}$

When, $(S/r_i) \leq 0.5 (KL/r)_0$

$(KL/r)_0$ – Overall slenderness ratio of the built up column

S- Spacing of the intermediate fasteners

r - Radius of gyration

r_i - Minimum radius of gyration of a single angle section

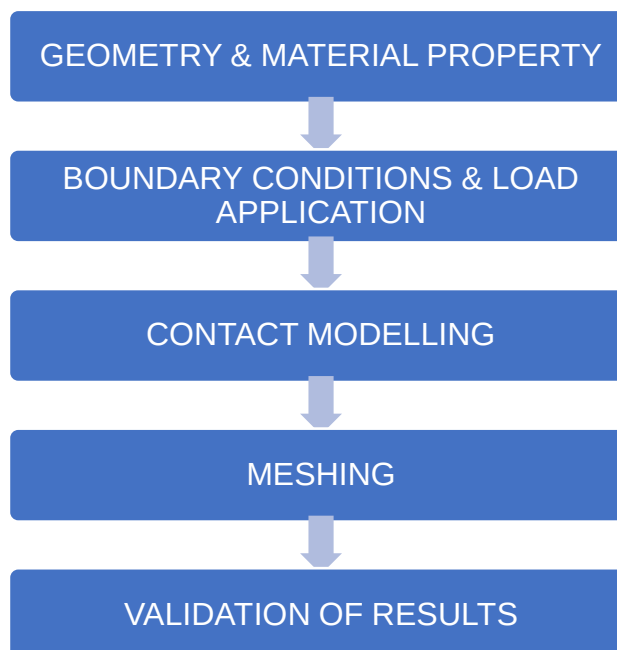
K – Factor of effective length

4.2 FINITE ELEMENT INVESTIGATION

4.2.1 GENERAL

The finite element model is created and analysed using Abaqus 4.16 software. With reference as the centre line dimensions of the cross-section, the FE model was developed. There were two types of finite element analyses carried out. First the buckling analysis is performed from which the buckling modes of the columns and the eigen values are obtained, this is a linear analysis. Then using the Riks method load against displacement is obtained which is a non-linear analysis.

4.2.2 METHODOLOGY



4.2.3 GEOMETRY & MATERIAL PROPERTY

In this study, the whole geometry of the built-up parts was modeled. To account for material non-linearities, original values of stresses and strains were applied. The investigation and validation were carried out using the ABAQUS classic metal plasticity model. The Von Mises yield criterion was used for obtaining the stress-strain curve for the CFS. Assign physical properties of the section such as young's modulus = 200000 N/mm², Yield Stress = 200 N/mm², and Poisson's Ratio = 0.3. Fig 4.3 shows the geometry and material property of the FEA model.

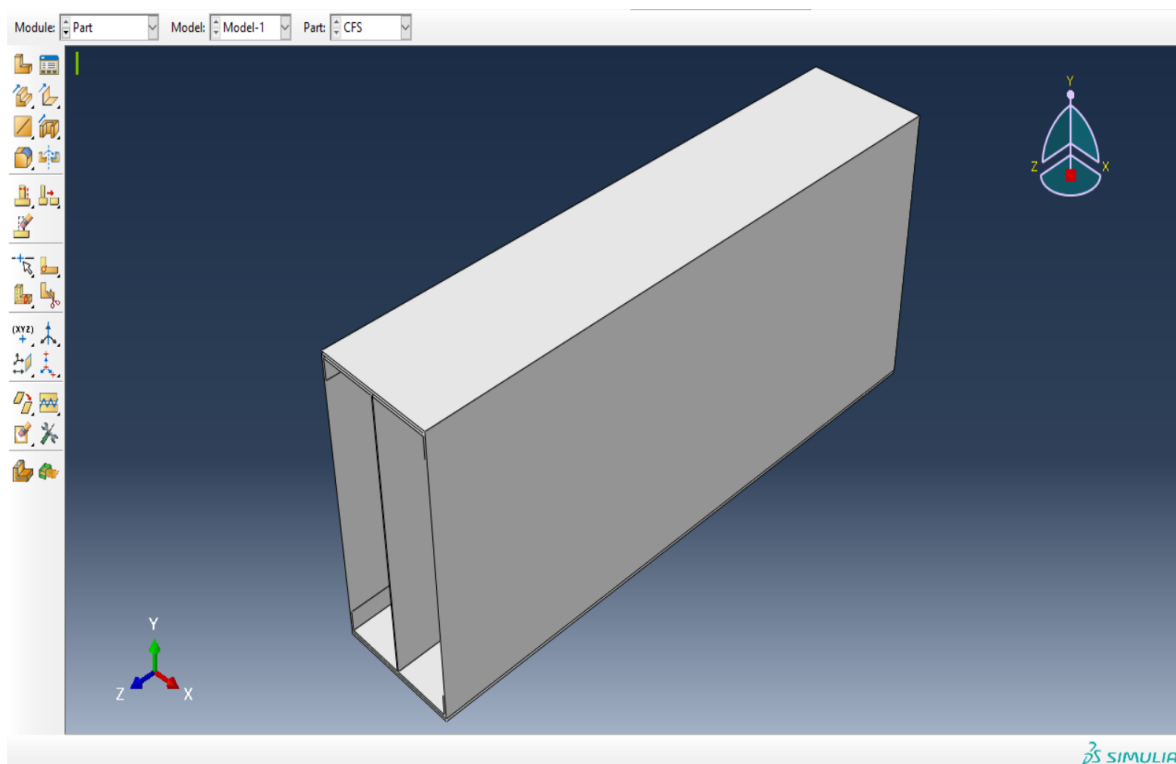


Fig. 4.3 Assigning of Geometry and material property

4.2.4 BOUNDARY CONDITIONS & LOAD APPLICATION

All the columns were assigned, pin end support condition. Displacements were added to the pin terminated support by constructing a reference point at the columns' top end. The CG of the columns were taken as points of reference. The MPC beam connector element was used to generate the screw fasteners between the back-to-back and flange-to-flange channel sections. Indicated as earlier, loading was assigned to the built-up portions' point of reference. Incremental application of load was done using the Riks method.

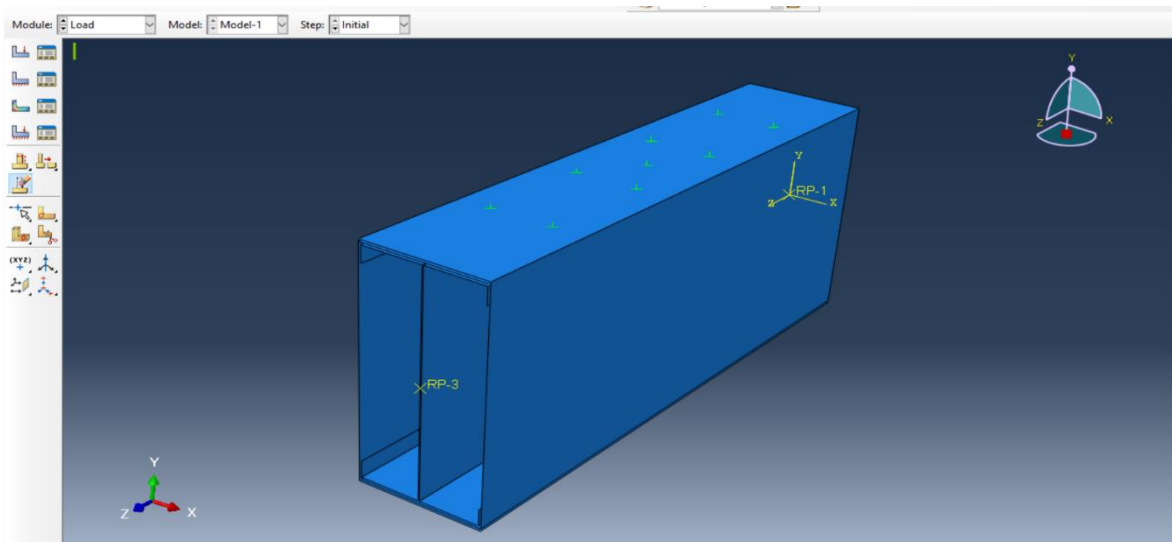


Fig 4.4 Assigning of Boundary condition and load application

4.2.5 CONTACT MODELLING

The linkage between the webs and flanges of the back-to-back and flange-to-flange channel sections was modelled using "surface to surface" contact. One channel section's web and flange were designed as slave surfaces, while another channel section's web and flange were modelled as master surfaces. no penetration was considered between the two contact surfaces. Fig 4.5 shows the assigning of surface-to-surface contact modelling in FE model.

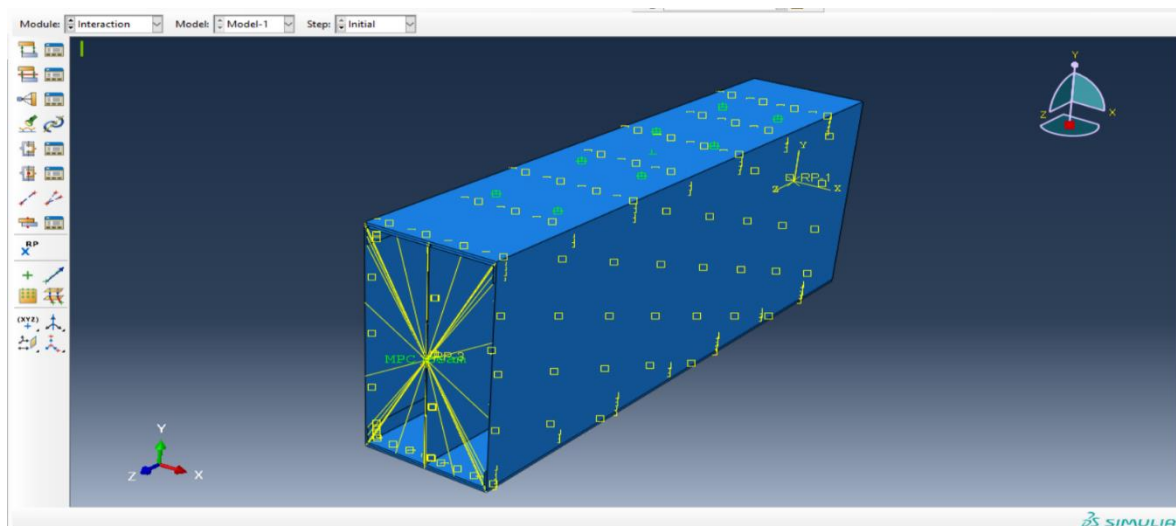


Fig. 4.5 Assigning of Surface-to-surface contact modelling

4.2.6 VALIDATION OF RESULTS

From the buckling analysis, the eigen values and the buckling modes are derived, which is linear analysis. From Riks method the non-linear analysis were performed, in which the load vs deflection is studied.

COLUMN HEIGHT mm	SLENDERNESS RATIO $\left(\frac{KL}{r}\right)_0$	MODIFIED SLENDERNESS RATIO $\left(\frac{KL}{r}\right)_m$	AXIAL STRENGTH, P_{FEA} kN
300	8.84	9.35	534.89
400	11.79	12.18	447.12
500	14.74	15.05	388.57
600	17.69	17.95	361.13
700	20.64	20.86	346.62
800	23.59	23.78	341.09
900	26.54	26.71	340.39
1000	29.48	29.64	340.16
1100	32.43	32.58	339.06
1200	35.38	35.51	333.91
1300	38.33	38.45	329.27
1400	41.28	41.39	324.66
1500	44.23	44.33	322.62
1600	47.18	47.28	319.88
1700	50.13	50.22	317.63
1800	53.08	53.16	315.70
1900	56.03	56.11	314.23
2000	58.97	59.05	312.93

Table 4.1: Numerical results of CFS built-up columns

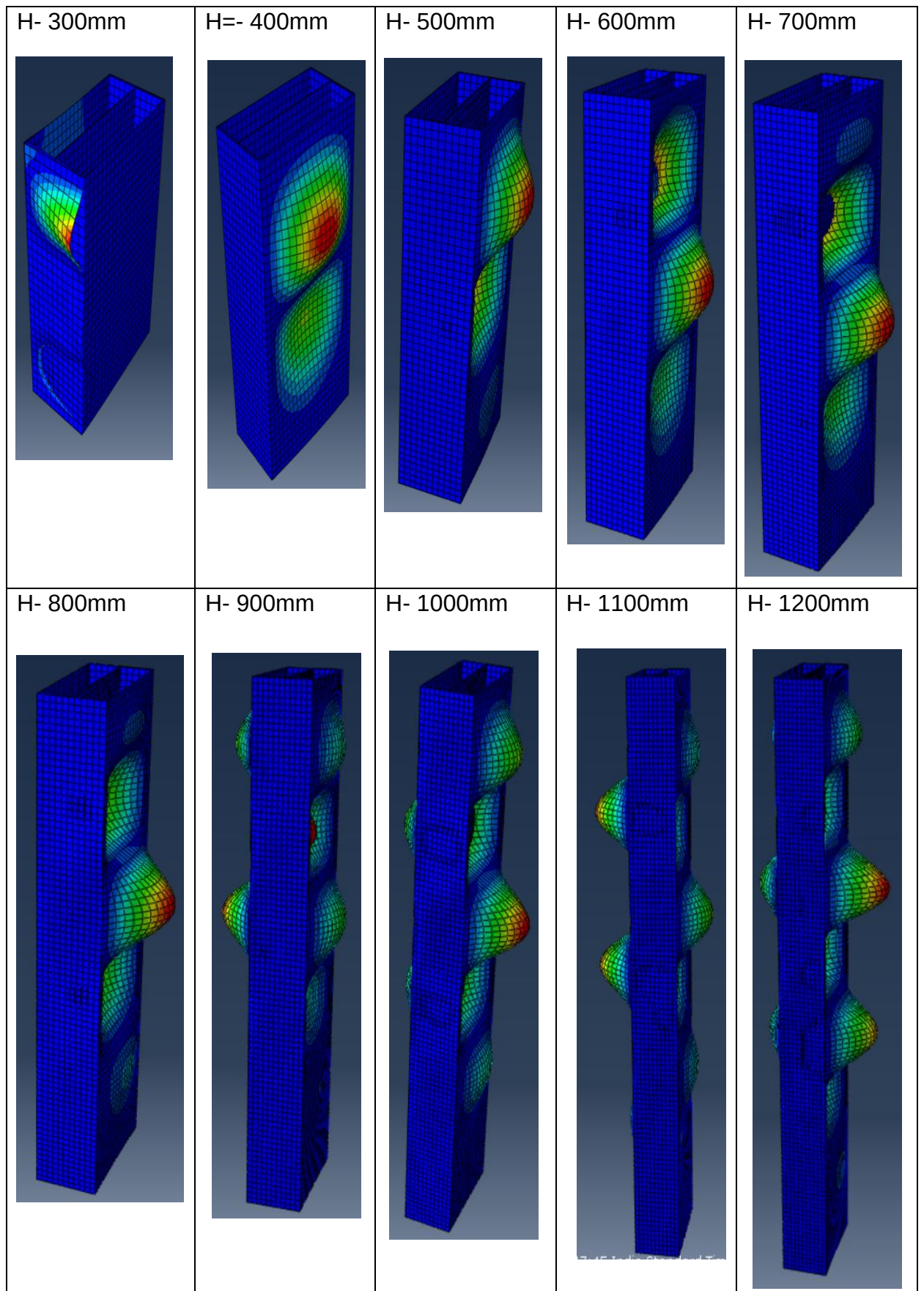


Fig 4.6 Buckling Images of column

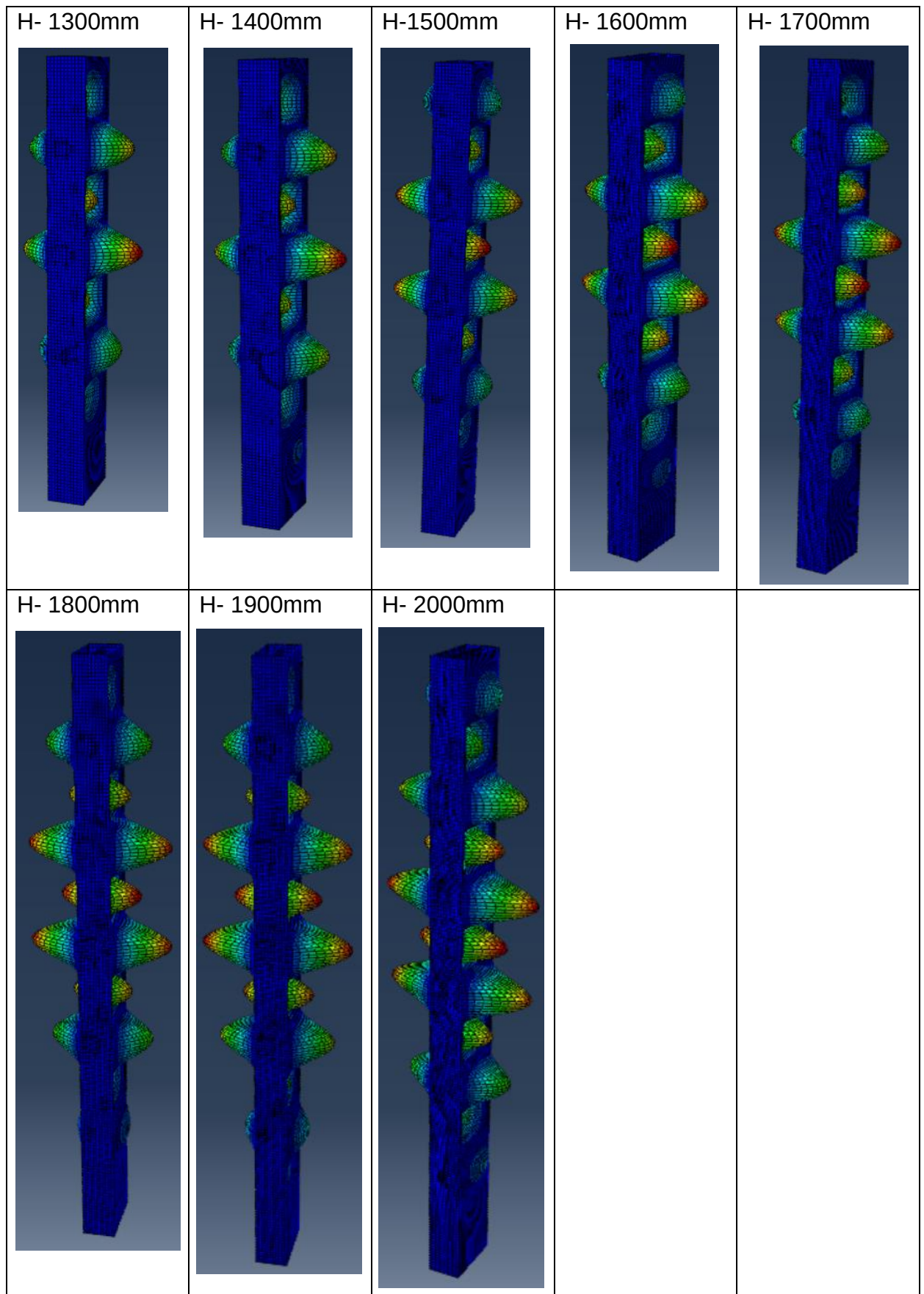


Fig 4.7 Buckling Images of column

CHAPTER-5

EXPERIMENTAL INVESTIGATION

5.1 INTRODUCTION

The CFS built-up columns of height 300mm, 500mm, 1000mm and 1500mm are fabricated and experimental tests are done for axial loading. The built-up columns are fabricated from the CR sheets of thickness 2mm. Its axial load carrying capacity, buckling behaviour and deformation are studied.

5.2 FABRICATION

CR sheet of grade IS 513 CR2 of thickness 2mm is bought. A total of 2 number of CR sheets of size 1200mm x 2400mm is bought. Desired cutting size of sections are marked in the sheets. Cutting and bending process is carried out in hydraulic machine. The sections of arranged by heights as per designed cross-section and screws are drilled. Two plates of size 300mm x 300mm are placed at top and bottom of each column and CO2 welding is done. This is done for equal transfer of load throughout the whole column.



Fig 5.1 CR sheet of 2mm thickness Grade IS 513 CR2



Fig 5.2 Marking for cutting sections

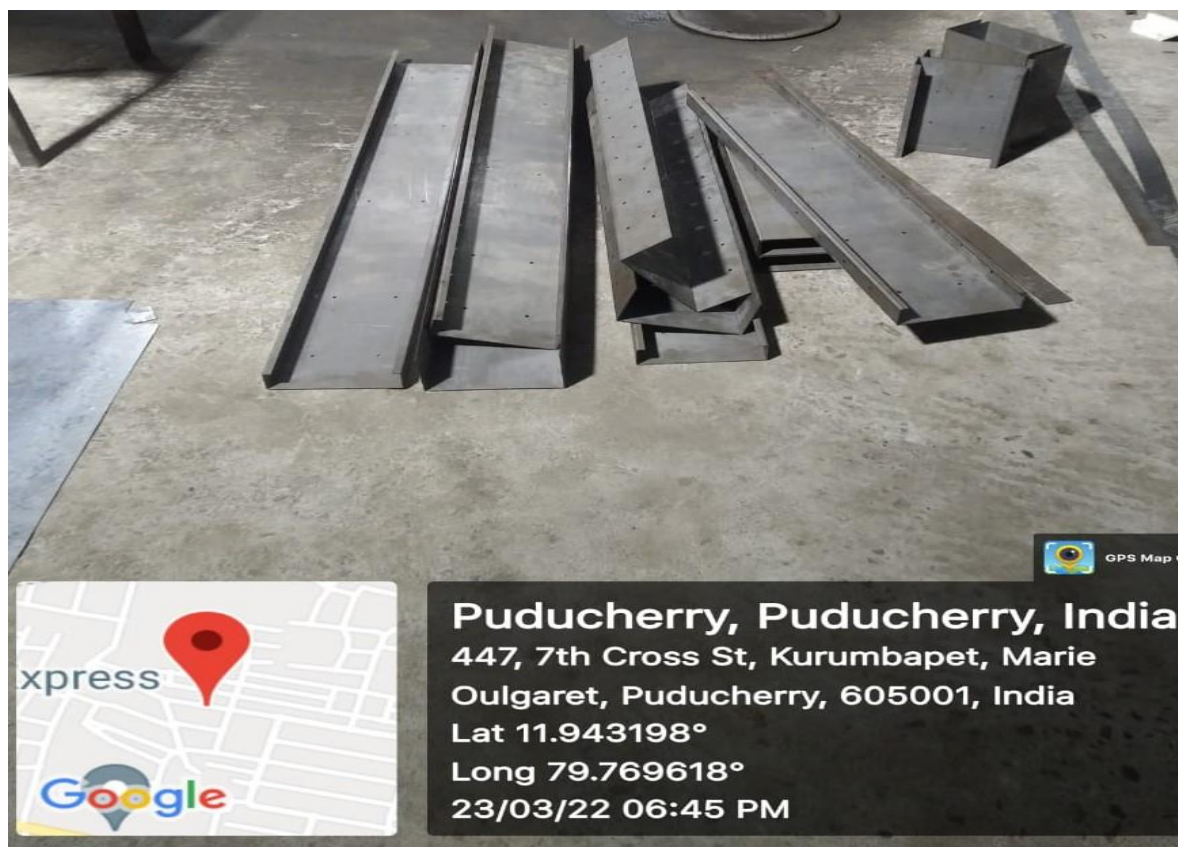


Fig 5.3 Cut and Bended sections



Fig 5.4 Built-up columns of height 300mm, 500mm, 1000mm and 1500mm

5.3 EXPERIMENTAL TESTING

All the four-column specimens of heights 300mm, 500mm, 1000mm, and 1500mm are tested for axial loading and two dial gauges are placed at the mid and end of the columns to determine the deflection for 300mm and 500mm columns. While for the other specimens of height 1000mm and 1500mm Linear Variable Differential Transformer (LVDT) is used. The specimen of the height of 300mm was tested using a compression testing machine (CTM) and the specimen of the height of 500mm was tested using universal testing machine (UTM). Where as the other specimens of height 1000mm and 1500mm was tested using column loading machine.



Fig 5.5 300mm Column testing setup in CTM



Fig 5.6 Buckling of 300mm Column

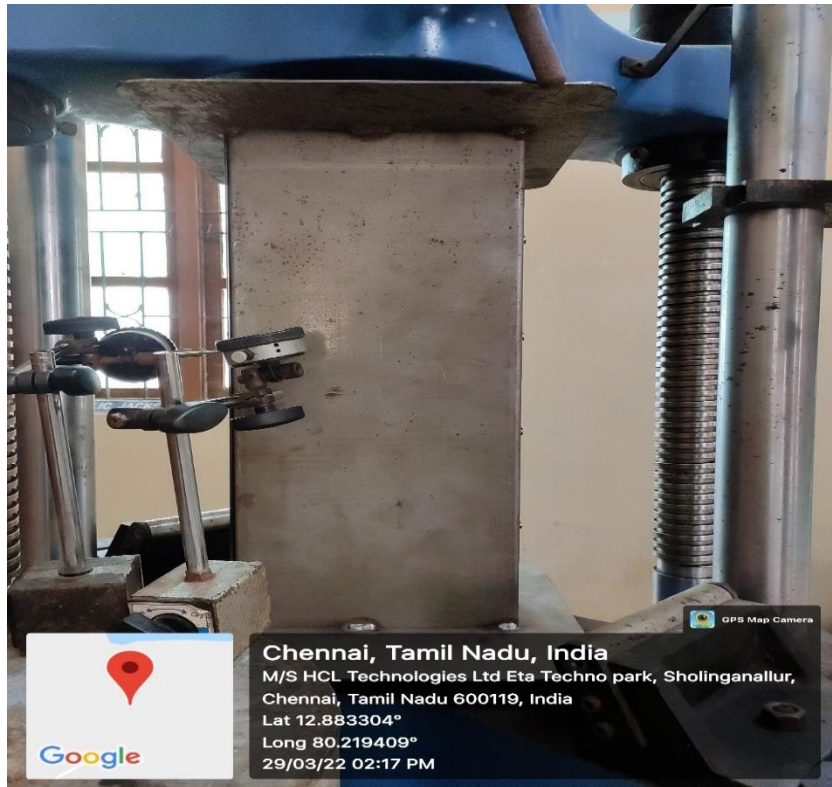


Fig 5.7 500mm Column testing setup in UTM

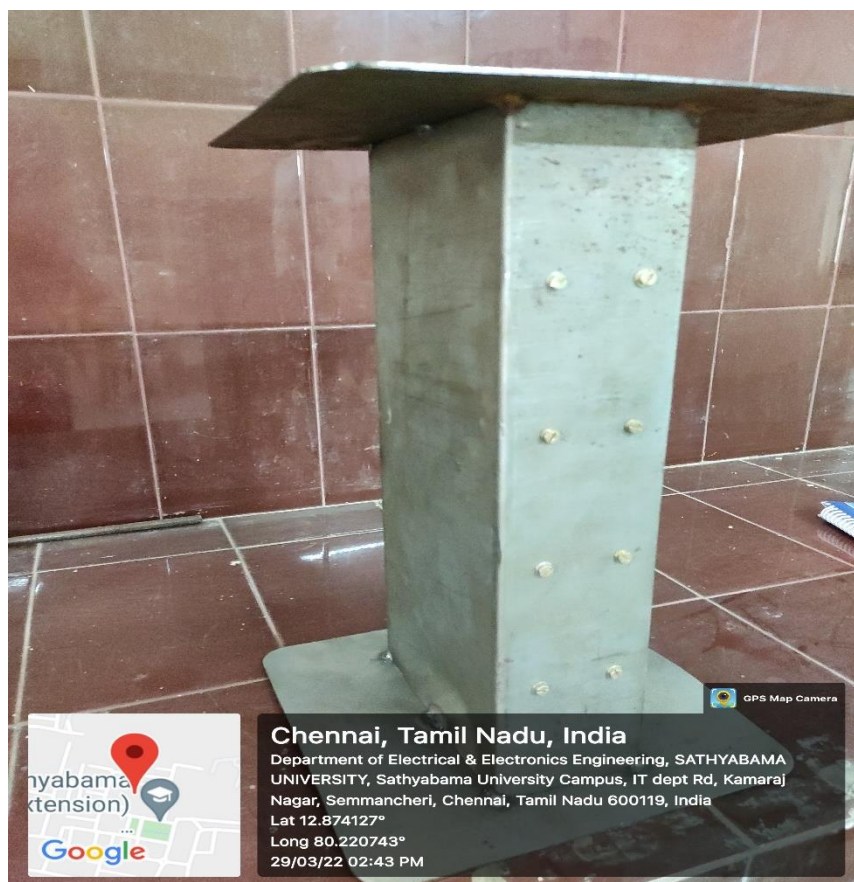


Fig 5.8 Buckling of 500mm Column

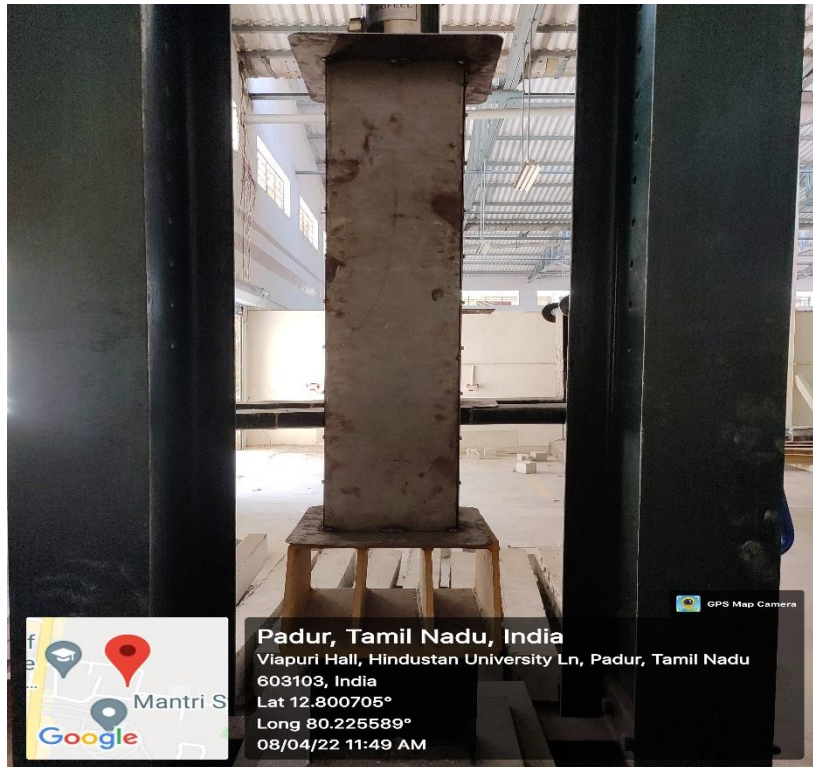


Fig 5.9 1000mm Column testing setup in Column Loading Machine

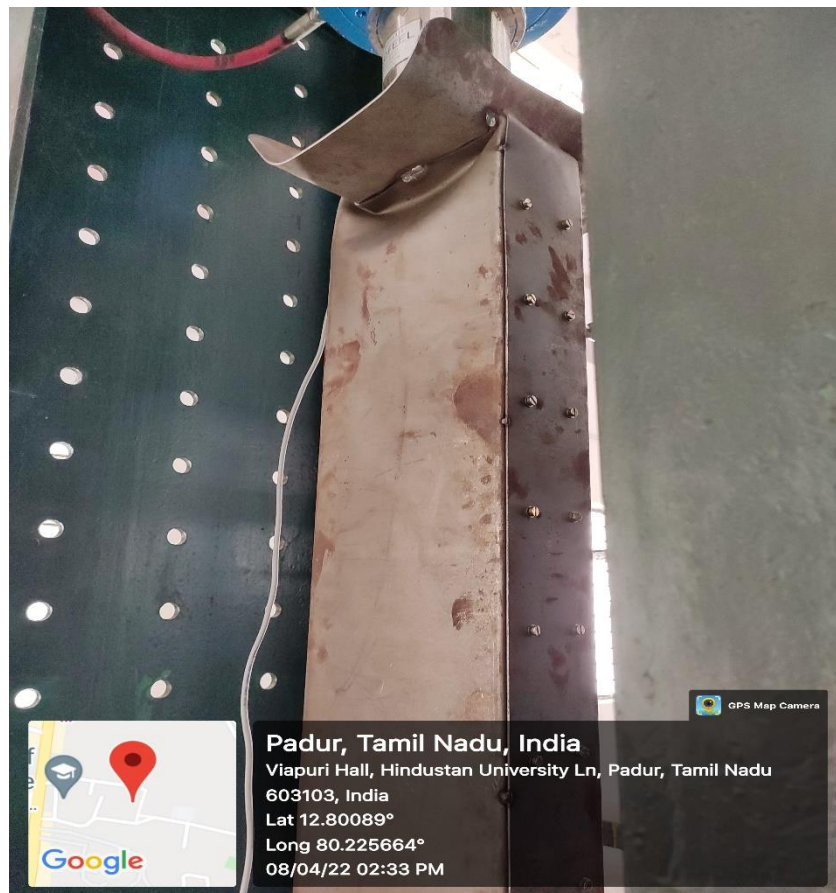


Fig 5.10 Buckling of 1000mm Column



Fig 5.11 1500mm Column testing setup in Column Loading Machine



Fig 5.12 Buckling of 1500mm Column

CHAPTER-6

RESULTS AND DISCUSSION

6.1 RESULTS

The experimental investigation was carried out for the columns of height 300mm, 500mm, 1000mm, and 1500mm. The experimental and FEA results are compared. Fig 6.1, 6.2, 6.3, and 6.4 are four graphs that shows the load in kN vs deflection in mm for the column heights of 300mm, 500mm, 1000mm and 1500mm respectively. Also, table 6.1 shows the comparison of experimental and FEA load values of the columns respectively.

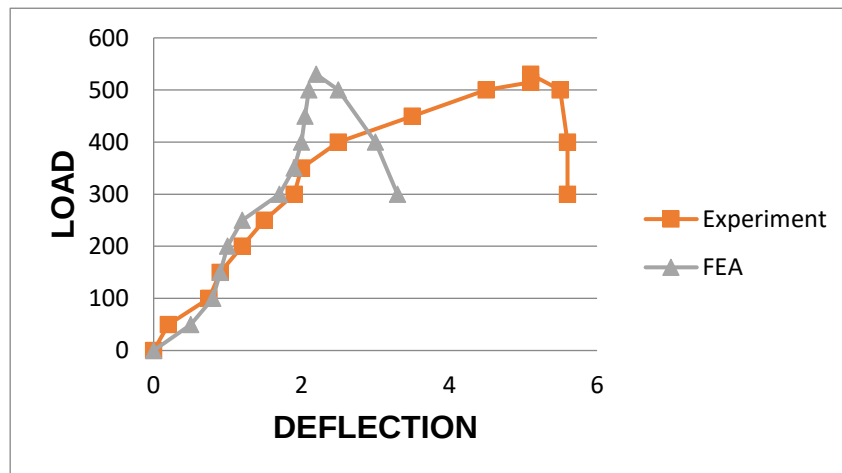


Fig 6.1 Comparison of Experimental and FEA results of 300mm height Column

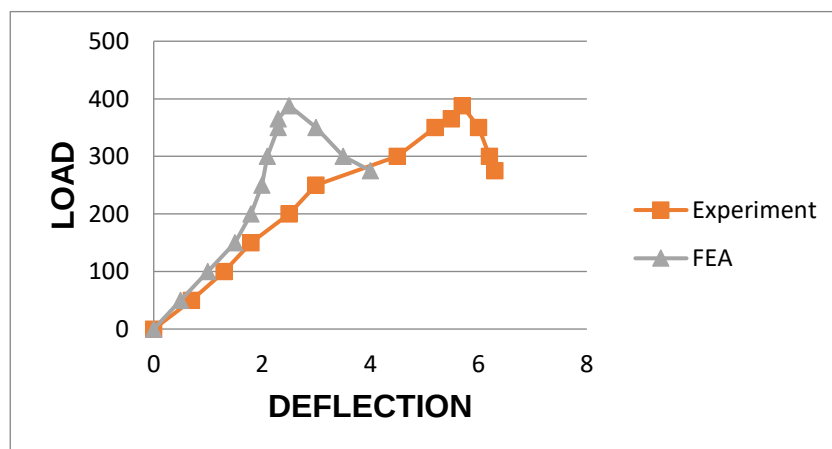


Fig 6.2 Comparison of Experimental and FEA results of 500mm height Column

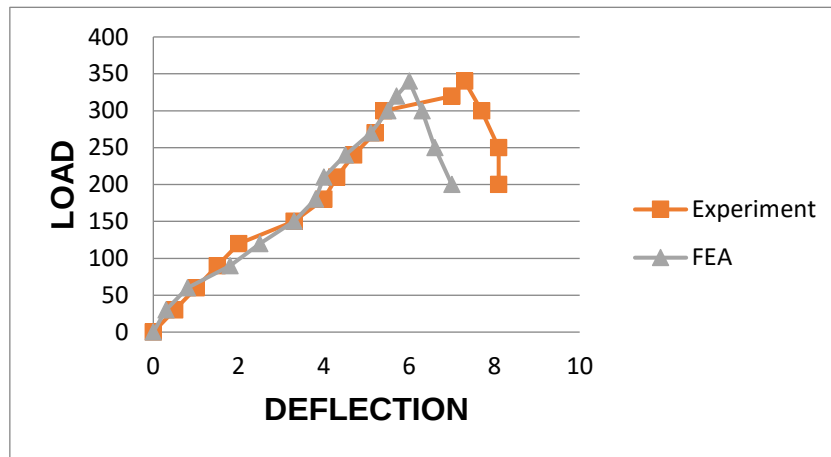


Fig 6.3 Comparison of Experimental and FEA results of 1000mm height Column

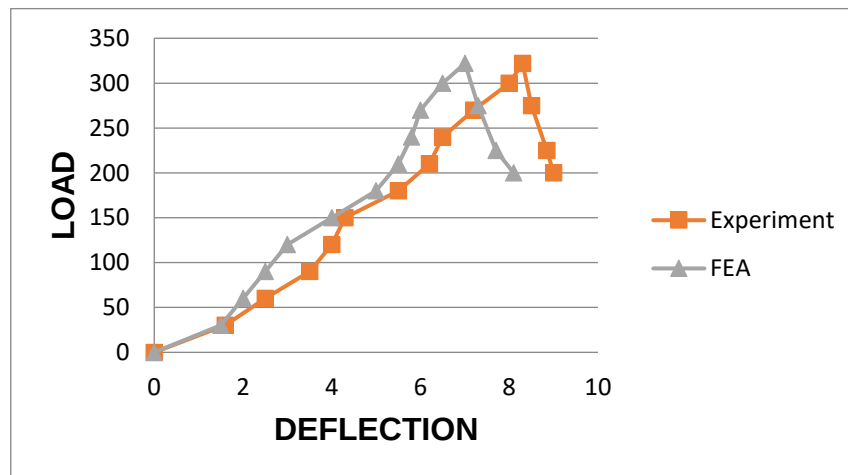


Fig 6.4 Comparison of Experimental and FEA results of 1500mm height Column

HEIGHT mm	FEA LOAD kN	EXPERIMENTAL LOAD kN
300	534.89	515.5
500	388.57	365
1000	340.16	319
1500	322.62	303

Table 6.1 Comparison of Experimental and FEA Axial Capacity of Columns

6.2 DISCUSSIONS

- The difference in axial strength outcomes of the experimental and finite element model is about 3% to 6%. From this, the FEA results show good acceptance with the experimental values, and hence FEA from Abaqus 4.16 software is reliable for the determination of axial strength of the column.
- The slenderness ratio of all the columns analyzed lies between 8 to 60. The height of the columns was 300mm to 2000mm with 100mm increment of each column respectively. Hence this cross-section of the built-up column can be mainly used as a stub column, short column, and intermediate column only.
- As specified in the cross-section the vertical spacing of the screws was 100mm which did not fail while the experimental testing of the columns.
- The load vs deflection graphs of the columns shows that the maximum deflection of experimental investigation is greater than the FEA results. The deflection variation between experimental and FEA are about 50% for 300mm column, 44% for 500mm column, 14% for 1000mm column and 10% for 1500mm column. Therefore, for lateral deflection of the column FEA results are not reliable.
- In the case of 300mm and 1000mm height columns, local buckling occurred at both top and bottom while experimental testing. Whereas for the remaining two columns of height 500mm and 1500mm local buckling occurred only at the bottom.
- Due to the increase in the slenderness ratio, the change in the failure pattern doesn't seem to improve for all the columns. The failure mode was either local buckling or a combination of local and flexural buckling for all the columns.
- When compared to the previous studies, the axial load capacity of the built-up column has improved without the application of stiffeners.
- The performance of this cross-section is better when compared to the built-up columns using battens.

CHAPTER- 7

CONCLUSION

In this study, 4 experiments and 18 FE models of numerical studies were carried to understand the axial load carrying capacity and structural behaviour of the designed CFS built-up column with varied heights. The failure modes, axial load carrying capacity and load against lateral deflection were discussed. The FE model shows good agreement with the experiment outcomes. Since the modified slenderness ratio of the all the columns fall under 8 to 60, the CFS built-up column can be used as stub columns, short columns and intermediate columns in construction.

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