Study On Local Buckling Behaviour of Cfs Built-Up I-Beam with Web Stiffener

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***Abstract*— Built up steel beams composed of cold-formed sections are increasingly used in buildings because of their lightness and ability to support large spans. Cold-formed Steel members have thinner elements, resulting in peculiar failure modes such as local and distortional buckling, which are not common in hot rolled members. Therefore, detailed study was focused into local buckling behaviour of cold formed steel beams composed of four channel sections connected by self-driving screws at flanges. In this thesis, the numerical procedure was developed using ABAQUS software and verified by validating the paper "Behaviour and design of cold-formed steel built-up I-beams composed of four channels" D. Amali (2024). The dimensions of the specimens were selected based on Eurocode Specifications (EN 1993-1-3(2006)). The parametric study was conducted by using the validated numerical model for 15 cross sections. All the parametric model were analyzed for four points bending under simply supported condition. The sectional dimensions were varied based on four different aspect ratios and analyzed with three different yield stresses such as 250,350 and 450 MPa using ABAQUS software.**

I. INTRODUCTION

Cold-formed steel members as shown in Figure 1 are widely used in building construction, bridge construction, storage racks, highway products, drainage facilities, grain bins, transmission towers, car bodies, railway coaches, and various types of equipment. These sections are cold-formed from carbon or low alloy steel sheet, strip, plate, or flat bar in cold-rolling machines or by press brake or bending brake operations. The thicknesses of such members usually range from0.0149 in. (0.378mm) to about 1/4 in. (6.35mm) even though steel plates and bars as thick as 1 in. (25.4mm) can be cold-formed into structural shapes. The use of cold-formed steel members in building construction began in the 1850s in both the U.S. and Great Britain. However, such steel members were not widely used in buildings in the U.S. until the 1940s. At the present time, cold-formed steel members are widely used as construction materials worldwide.

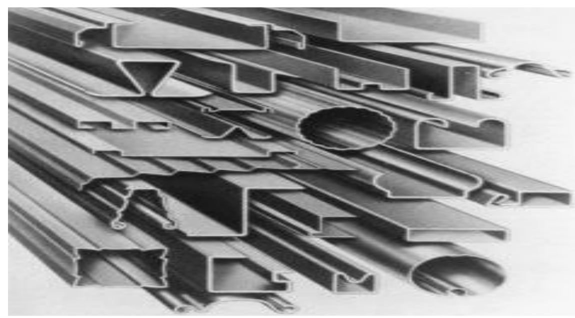

Figure 1: various shapes of cold-formed steel sections.

Compared with other materials such as timber and concrete, cold-formed steel members can offer the following advantages: (1) lightness, (2) high strength and stiffness, (3) ease of prefabrication and mass production, (4) fast and easy erection and installation, and (5) economy in transportation and handling, just to name a few. From the structural design point of view, cold-formed steel members can be classified into two major types: (1) individual structural framing members (Figure 2) and (2) panels and decks (Figure 3). In view of the fact that the major function of the individual framing members is to carry load, structural strength and stiffness are the main considerations in design. The sections shown in Figure 2 can be used as primary framing members in buildings up to four or five stories in height. In tall multi story buildings, the main framing is typically of heavy hot-rolled shapes and the secondary elements such as wall studs, joists, decks, or panels may be of cold-formed steel members. In this case, the heavy hot-rolled steel shapes and the cold-formed steel sections supplement each other. The cold-formed steel sections shown in Figure 3 are generally used for roof decks, floor decks, wall panels, and siding material in buildings. Steel decks not only provide structural strength to carry loads, but they also provide a surface on which flooring, roofing, or concrete fill can be applied. They can also provide space for electrical conduits.

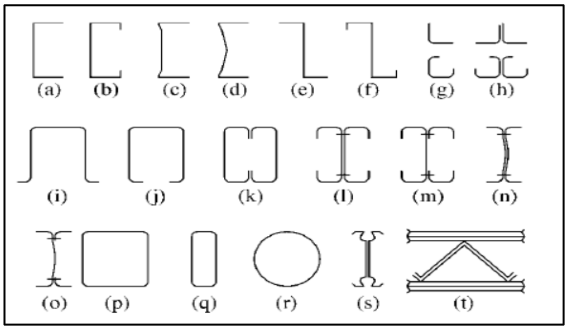

Figure 2: cold-formed steel sections used for structural framing.

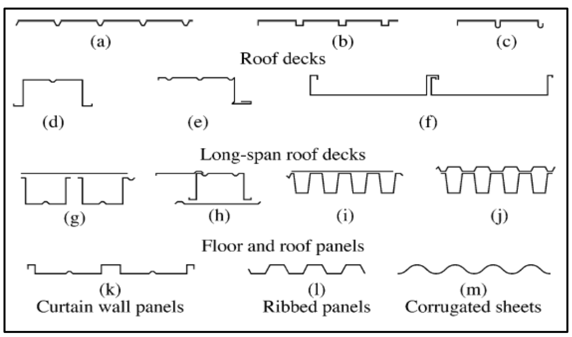

Figure 3: decks, panels, and corrugated sheets.

II. LITERATURE REVIEW

1) P. Manikandan M. Thulasi/13 February 2019, Investigation on cold formed steel lipped channel built up I beam with intermediate web stiffener. The FEM using ABAQUS software is perfect in predicting the strength and the behaviour of the beams. Therefore, the FEM developed can be used with a high level of assurance in predicting the capacity of the beams. Design of CFS built-up I beam with and without intermediate web stiffeners requires the consideration of FB and interaction of FB and LTB
2) Jia-Hui Zhang,BenYoung , A test program on cold-formed steel I-shaped open sections with edge and web stiffeners has been presented. The columns were compressed between fixed ends. The test specimens were brake-pressed from zinc-coated grades G500 and G550 structural steel sheets having nominal 0.2% proof stress of 500 and 550 MPa, respectively. Tensile coupon tests were conducted to determine the material properties of the test specimens at both flat and corner portions of the sections.
3) Jia-Hui Zhang, Ben Young, Numerical investigation and design of cold-formed steel built-up open section columns with longitudinal stiffeners shows that the design strengths PDSM-2t are unconservative for short columns and PDSM-s are generally very conservative for all series.
4) Jessica Whittle, Chris Ramseyer, the average axial capacity based on the modified slenderness ratio of SectionD1.2 is exceedingly conservative for built-up members, in general, greater than 70% conservative. The unity check range for all built-up members tested that the meet D1.2 provisionsis1.11–2.83. The value of 1.0 represents a legal built- up member according to the AISI Specification.
5) Meza et al. (2016) conducted experimental investigation between on buckling interaction individual components of built-up steel beams. An experimental program was carried out on built-up steel beams, assembled by bolting four plain channels together.
6) Carolina Barichello (2016) conducted study on behaviour and DSM design of cold Formed steel “s” type beams experiencing distortional failure. The analysed beams (i) are single-span members, (ii) are simply supported but they exhibit different end support conditions regarding warping and minor-axis flexural rotations and (iii) present different Cross-section dimensions and buckling lengths, which provide a wide range of geometrical relations that help understanding their behaviour.
7) Wang et al. (2015) They found that the local and distortional buckling behaviour of the built-up section beam specimens were found to be different from the single profiles. They considered, Young et al (2008) recommendation that local buckling stress could be enhanced by employing intermediate stiffeners to the slender plate elements of the sections. They conducted experimental investigation of simply supported

built-up section beams having intermediate stiffeners with different sectional configurations under both four-point bending and three-point bending.

8) Wang et al. (2015) conducted an experimental study on simply supported built-up section beams with various sectional configurations using intermediate stiffeners. Followed with the experimental Investigation and finite-element validation in the first part of this study, a numerical parametric study including a total I of ||3 different built-up section beams were conducted. These stiffeners were provided in the webs of built-up sections to improve the buckling strength since they are prone to local buckling and or distortional buckling.
9) Rui Bebiano et al. (2014) presented GBTUL T.08, a code to perform buckling and vibration analyses of open-section cold-formed members that is now available online 2s freeware This code, developed at the Department of Civil Engineering and Architecture of the Technical University of Lisbon (ICIST/IST UTL), constitutes the numerical implementation of a recent Generalized beam Theory (GBT) formulation - GRT is a thin that incorporates local deformation and discretizes a member deformed walled beam theory a buckling or vibration mode shape) into a linear combination of cross configuration (e.g., with longitudinally varying amplitudes. After Section deformation modes GBT formulation, one addresses presenting a very the GBTUL 1.0β graphic user brief overview of the interface and describes its main commands.
10) Luís Laím et al. (2013) did a research study on experimental and numerical investigation into the behaviour of CFS and concluded that compared to open mono symmetric sections built-up closed-form sections have more strength to weight The main purpose of this work was to evaluate the influence of different cross-sections, especially of compound cold-formed steel sections, the axial restraint to the thermal elongation of the beam and the rotational stiffness of the beam supports. The results showed above all that the critical temperature of a cold-formed steel beam might be strongly affected by the stiffness of the surrounding structure depending on the relation between its stiffness and the stiffness of the beam. They also concluded that open sections fail due to lateral-torsional buckling failures, whereas closed sections failed due to distortional buckling.

III. METHODOLOGY WORK METHODOLOGY

This project attempts to investigate on Cold-Formed Steel built-up I beam composed e four channel sections. The entire work is split up into different level and each level is assigned with a number of activities. The various levels of work are mentioned below.

LEVEL 1: Literature Collection
Various Studies are being conducted on behaviour cold formed steel sections by adopting different sections using available design methods. Some of the literatures which are relevant to this study are collected are presented.

LEVEL 2: Selection of Sections
The section dimension was selected based on north American specification for the design of cold-formed steel structural member-2012 edition. Euro code 03 and Australian / New Zealand standard code (AS/NZS 4600:2005).

LEVEL 3: Finite Element Modelling and Validation
A literature about cold-formed steel built-up beams has been selected and their experimental results have been validated with the Numerical analysis. Moment capacities, moment-deflection curvature and failure modes has been validated.

LEVEL 4: Numerical Study
For the selected sections, by varying the member slenderness different dimensions are chosen. All the selected sections by varying the D/B ratio, b/t ratio and varying the yield stress are modelled using ABAQUS software.

LEVEL 5: Conclusion
The results of numerical study are compared and the conclusions are drawn.

IV. SELECTION OF SECTION

As per European standards (EN-1993-1-3) for the design of cold-formed steel Structural members, the flat b/t limits are available for single section only. Based on the single section, suitable Built-Up section is selected.

V. SELECTION OF SECTION

The outer-to-outer dimensions of the built up I section is selected based on four different aspect ratios. The breadth to thickness ratio of sections is chosen such that the values fall equal to and lesser than the limits provided in Eurocode standards.

VI. CONSIDERED FOR STUDY

In this thesis, a numerical program was carried out on built-up steel beams, assembled by bolting four plain channels together as described in Fig. 5. The specimens were analysed in a four-point bending configuration and were designed to fail by local buckling of their Component sections along the constant-moment span. The built-up beams have a nominal distance between the end supports of 2400 mm. The specimens were loaded at two discrete locations, a distance of 700 mm apart.

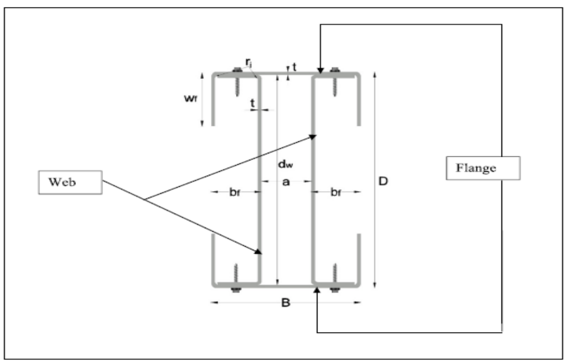

Fig 4: Cross Section of Built-up beam

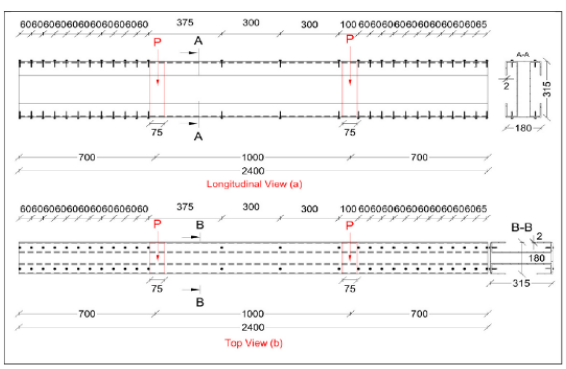

Fig 5: Specimen longitudinal view and Specimen top view

The Spacing between the connectors along the span was 60mm for all the specimens and hey were yield stresses - 250,350 and 450 MPa respectively.

VII. LABELLING OF SPECIMEN

The specimens considered for thesis work are labelled based on height, breath of flange and thickness. The labelling of the specimens is done in such a way to self-describe about the specimen. Labelling is illustrated indicating outside dimensions of section with all values in mm, for example, in specimen 4C-100-150-1.5, the first term 100 indicates the outer width of the section, 150 indicates the overall height of the section and the first term 1.5 indicates thickness of plate in mm respectively.

VIII. PARAMETERS CONSIDERED FOR THE STUDY

The following properties were adopted during the analysis of the sections considered in the study.
Material Properties
Yield strength (fy) is 250, 350 & 450 N/mm²
Young's Modulus of elasticity (E) is 2.1 x 10° N/mm²
Poisson's Ratio is 0.3
Material model _ Elastic-Perfectly plastic.
Member Properties
Thickness of section (t) is l.5 and 1.25mm
Length of the specimen is 2400mm with constant moment span of 700 mm
End condition is simply-supported

IX. FINITE ELEMENT MODELIING (ABAQUS) AND VALIDATION GENERALS

Finite element analysis (FEA) is a computerised method lor predicting how a product reacts to real-world forces, vibration, heat, fluid flow and other physical effects, Finite element analysis shows whether a product will break, wear out or work he way it was designed. It is called analysis, but in the product development process, it Is Used to predict what's going to happen when the product is used. FEA works by breaking down a real object into a large number (thousands to hundreds of thousands) of finite such as little cubes. Mathematical equations help predict the behaviour of each clement. A computer then adds up all the individual behaviours to predict the behaviour of the actual object. The Finite Element Analysis is one of the common methods used to analyse static and dynamic. numerical method for solving engineering problems by mathematical equations. One of the purposes using finite element method is predict the performance of design, understand the physical behaviours of a modal and identify the weakness of the design accurately to obtain the safety. In this research, ABAQUS standard version 6.I3 is used as a finite element tool. Following the elastic buckling analysis, nonlinear analysis undertaken using the finite element models of the same tested specimens with appropriate support conditions. For this purpose, appropriate material properties, initially geometric imperfections are used. Nonlinear analysis results including the ultimate moment and moment-rotation curves are compared with corresponding experimental results. Finite element method with high accuracy and overcome the costs of full-scale experiments provide the desired response. Finite element analysis software used in this study is, ABAQUS/ standard. This chapter presents the details of the numerical analysis and their validation.

X. ABAQUS SOFTWARE

ABAQUS 6.13 is a software suitable for finite element analysis. It both can be used for static and dynamic problems. It accounts all types of non-linearities. The Abaqus product suite consists of four core software products. Abaqus/Standard, a general-purpose finite element program. Abaqus/Explicit, an explicit dynamics finite element program. Abaqus/CAE (Complete Abaqus Environment), an interactive environment used to create finite element models, submits Abaqus analyses, monitor and diagnose jobs, and evaluate results. Abaqus/Viewer, a subset of Abaqus/CAE that contains only the post processing capabilities of the visualization module.

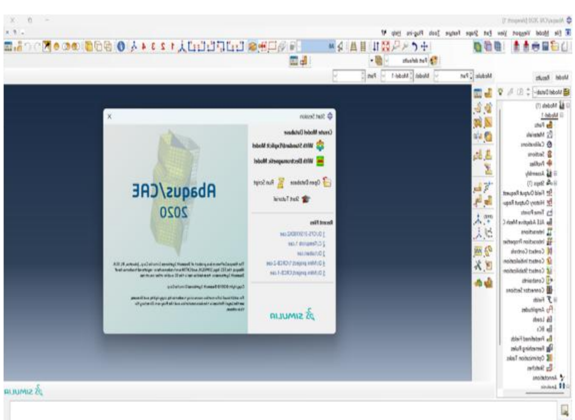

Fig 6: Abaqus software view port

XI. PROCESSING STEPS IN ABAQUS

The three common processing steps in Abaqus are:
1. Preprocessing (Abaqus/CAE)
2. Simulation (Abaqus /Standard or Abaqus /Explicit)
3. Post processing (Abaqus /CAE)

Preprocessing (Abaqus/CAE)
In this stage the model of the physical problem is defined and an Abaqus input file was created. The model is usually created graphically using Abaqus/CAE.
Simulation (Abaqus /Standard or Abaqus /Explicit):
The simulation, which normally is run as a background process, is the stage in which Abaqus/Standard or Abaqus/Explicit solves the numerical problem defined in the model.

Post processing (Abaqus /CAE):
The results can be evaluated once the Simulation has been completed and the displacements, stresses, or other fundamental variables have be\n calculated. The evaluation generally done interactively using the Visualization module ot Abaqus/CAE or another Postprocessor. The Visualization module, which reads the neutral binary output database file, has a variety of options for displaying the results, including colour contour plots, animations, deformed shape plots, and X-Y plots.

Geometric nonlinearity:
It refers to stiffness changes that are independent of material properties. These stiffness changes can be related to geometric constraints and /or the magnitude of strains. change in geometry as the structure deforms is taken into account. Incorporated to the odes which are taken from buckling analysis.

Material nonlinearity:
Change in material properties such as Young's modulus variation as the structure deforms is taken into account. Material nonlinearities arise from the presence of time independent behaviour such as plasticity, time dependent behaviour such as creep and viscoelastic/viscos-plastic behaviour where both plasticity and creep effects occur simultaneously.

Boundary conditions non-linearity:
Change in contact edges in web and flange of the section as the structure deforms is taken into account.

Non-linearity due to contact conditions arises because the prescribed is placements on the boundary depend on the deformation of the structure.

XII. FINITE ELEMENT MODELLING

Finite element models were based on the centre line dimensions of the cross sections with the plate thickness.

Part module:
A part is a finite element idealization of an object. Parts are the building blocks of an assembly and can be either rigid or deformable. Parts are reusable; they can be instanced multiple times in the assembly.

Property module:
The material properties like young's modulus, Poisson's ratio, yield stress will be
defined to the sections.

Assembly module:
An assembly is a collection of positioned part instances. An analysis is conducted by defining boundary conditions, constraints, interactions, and a loading history for the assembly.

Part instance:
A part instance is a usage of a part within the assembly. All characteristics (such as mesh and section definitions) defined for ap art become characteristics for each instance of that part they are inherited by the part instances. Each part instance is positioned independently within the assembly.

Model Discretization:
The numerical models were discretized with the reduced integration four- noded shell element with reduced integration was selected from the ABAQUS element library. This element uses three translational and three rotational degrees of freedom at each node({S4R). The mesh size for the shell elements given is equal to the thickness of the section is found to hold good simulation results. Atypical finite element mesh of hollow column is shown in the Fig 7

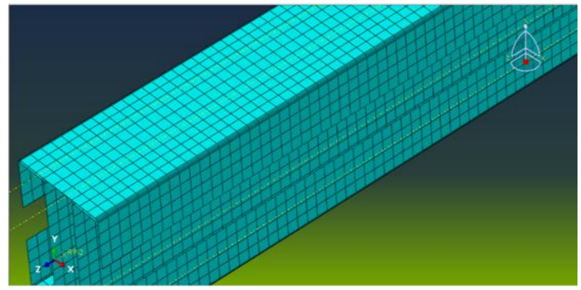

Fig 7: meshed model

Interaction module:
It defines the contact information of the section. In this module

- Reference points are created at both the ends & middle of beam.
- Constraints are created for various sections. The most commonly used section with Constraint, shown in Fig.8. Surface Coupling constraint is shown in Fig. 9

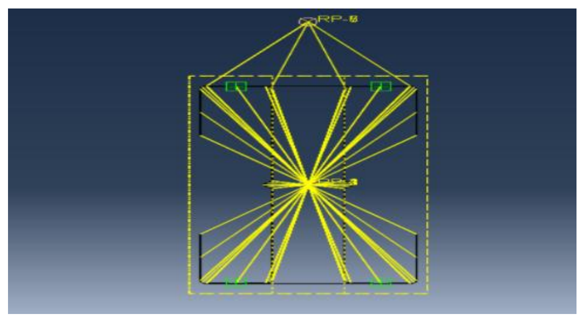

Fig 8: Section with constraints

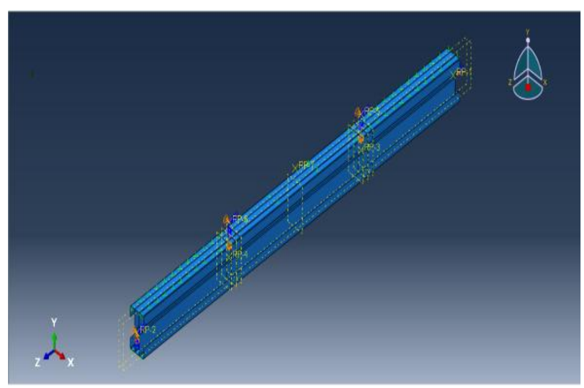

Fig 9: Loading and Boundary condition

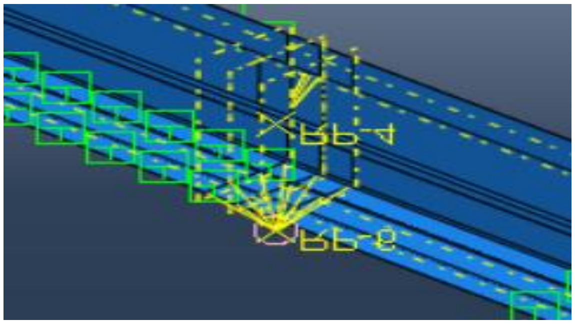

Fig 10: Surface Coupling

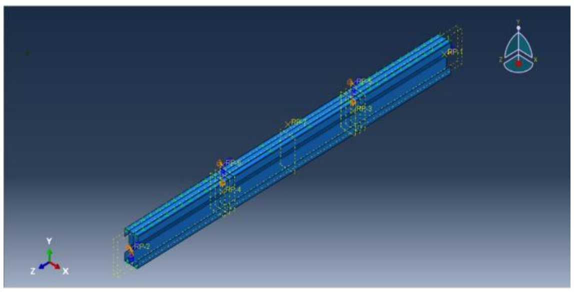

Fig 11: Loading conditions

The Boundary condition introduced to the Transverse centroid node is shown in Fig.10. load is represented as a concentrated nodal force. It is disturbed to the loading points through coupling constraints. The simply supported end conditions of the beam are modelled as prevented from rotations about the y and z-axis. and translations x, y and Z-directions. The load will be applied at the reference point (in the z-axis direction) as shown in Fig.11.

XIII. PROCEDURE FOR ANALYSIS

Analysis procedure

- The section was created based on the centre line dimensions.
- The material properties like young's modulus, Poisson's ratio, yield stress were defined and assigned to the sections.
- Then sections were assembled together using part instance.
- The section was converted into a finite element model by using mesh module.
- The reference points and constraints were created at both the ends.
- Then the boundary conditions were defined at both the ends based on the support condition.
- Unit load was applied at reference point.
- Then the Eigen value buckling analysis was performed and deformed mode shape was obtained.
- Geometrical (local) imperfection was considered for this deformed shape and fed as an input for the non-linear analysis.
- Then the non-linear analysis was performed and a graph was plotted between the moment and rotation.
- From this graph the ultimate moment capacity (in KNm) of the section and its Corresponding rotation (in rad) was obtained.

XIV. VALIDATION OF LITERATURE

For validation of numerical model, experimental results obtained from the test results reported by Meza et al. (2016) were used. The numerical model used for simulations is presented here after. Figure 12 Represents the built-up section geometry and fastener position respectively reported by Meza (2016). Figure 12 presents the measured dimensions of tested specimens and material property respectively reported by the author.

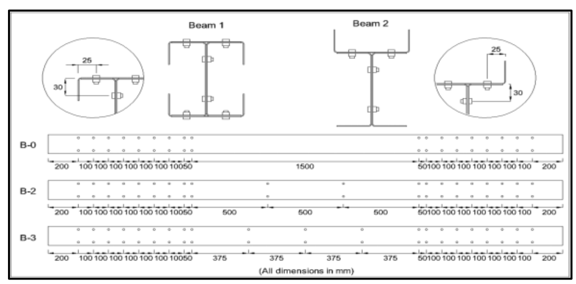

Fig 12: Built up cross section geometry and Connector Spacing

The validation has been done using ABAQUS software. In this paper an experimental program carried out on built-up steel beams, assembled by bolting four plain channels together, was described. The specimens were tested in a four-point bending configuration and were designed to fail by local buckling of their component sections along the constant-moment span. The specimens were tested with three different connector spacings and each test was repeated in order to gain increased confidence in the results. The built-up beams had a total length of 3400 nm, with a nominal distance between the end Supports of 3000 mm. The specimens were loaded at two discrete locations, a distance of 1600 mm apart. The portion of the beam within these loading points constituted the constant moment span, while the portions of the beam which fell outside this region are referred to as the shear spans. The built-up specimens were designed with zero, two or three equally spaced connectors along the constant moment span. The finite element model of the specimen was done using ABAQUS software by adopting the specified dimensions. The connector spacings were varied as given in the paper.

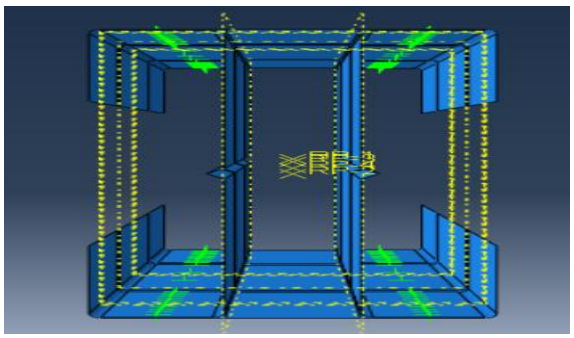

Fig 13: Cross Section of the ABAQUS model

The results of an experimental program on six built-up cold-formed steel beams, tested in a four-point bending configuration, have been presented in the paper. The numerical investigation of the tested specimen is done using software and the results were obtained.

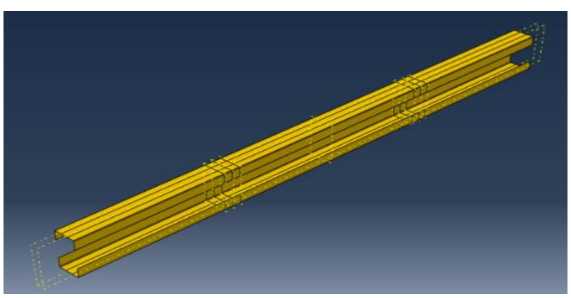

Fig 14: Material properties

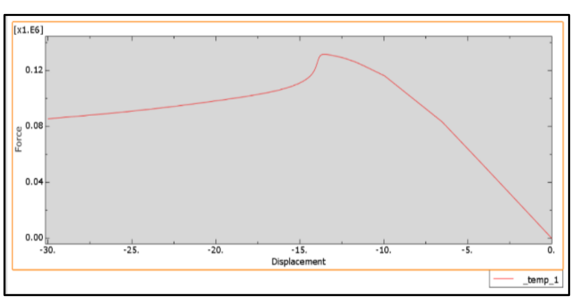

Fig 15: force displacement curve

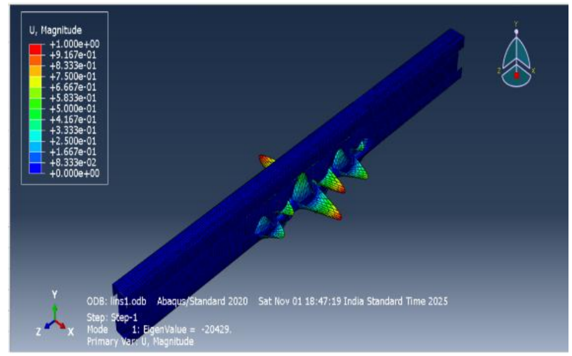

Fig 16: linear analysis

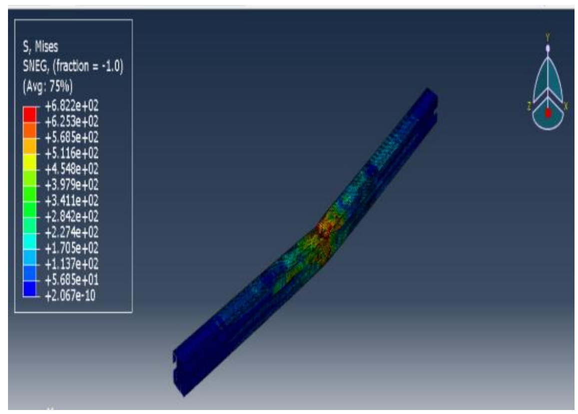

Fig 17: non-linear analysis

S No	Section	Fy N/mm2	Λ1	Ultimate Moment Capacity, M_{fea}
1	FC-100X200X1.5	350	0.37	11.45
2	FC-100X200X2.5	350	0.44	12.85

Table 1: moment capacity

XV. CONCLUSION

In this thesis, the load carrying capacity and failure modes of built up I sections have been studied numerically. Procedure for analysis using ABAQUS software was studied. All the specimens have been modelled and analysed using ABAQUS v6.13 software.

A Nonlinear finite element analysis was developed and verified against the experimental results obtained by validation Upon validation of FE model; the numerical study was conducted to investigate the structural response of built-up beam.

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