

Flexural Behaviour of Cold-Formed Steel Built-up Beams Using Sigma and Channel Sections

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering in
Civil 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)**

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DEPARTMENT OF CIVIL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Govarthini K (39200017)**, **Venus D Rayan (39200043)** and **Nemat Bano (39200705)**, who carried out the project entitled "**Flexural Behaviour of Cold-Formed Steel Built-Up Beams Using Sigma and Channel Sections**" under my supervision from December 2022 to April 2023.

Internal Guide
(Dr. C. MANOJ KUMAAR)

Head of the Department

Submitted for Viva voce Examination held on 19.04.2023

Internal Examiner

External Examiner

DECLARATION

We, hereby Govarthini K (39200017), Venus D Rayan (39200043) and Nemat Bano (39200705) declare that the Project Report entitled “Flexural Behaviour of Cold-Formed Steel Built-Up Beams Using Sigma and Channel Sections” done by us under the guidance of Dr. C. Manoj Kumaar., M.E., Ph.D., at Sathyabama Institute of Science and Technology is submitted in partial fulfilment of the requirements of the award of Bachelor of Civil Engineering.

DATE: 13.04.2023

PLACE: Chennai

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SIGNATURE OF THE CANDIDATES

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Cold-formed steel structural elements are commonly made from steel plates, sheets, and strips. To make the necessary forms and shapes, the material is rolled and bent at room temperature. Cold-formed steel is used in the construction of steel wall studs, wall panels, and floor decks in buildings. The I, Channel, Zed, and hat sections are the beam shapes that are most frequently used. Cold-formed steel members are also used to manufacture grain bins, car bodywork, and storage racks in addition to buildings. These modifications were done in open-section CFS built-up beams, which don't have strong torsional stability. Comparing CFS built-up I-sections to closed-section CFS built-up beams, the latter exhibit better buckling response [1]. The experiment by (T-shaped of section used) utilized seven distinct types of specimens, including single and built-up beams that bent around strong and weak axes. According to the stress distribution at the mid-span cross-section, built-up box beam components can sustain the bending moment integrally [2]. The box header in wall framing, which is made of two equal-sized C-shaped members placed toe-to-toe in a box type configuration and fastened to both the wall top track and a track below, are two examples of typical uses for built-up box beams in cold-formed framing. The other example is the joint around floor opening, which is made by nesting C-shaped joists into a track and fastening them together along the top and bottom [3]. In order to establish a strong association between moment carrying capacity, FEA-identified failure processes, and experimental findings, cold-formed T-shaped built-up steel sections were numerically examined. The bending strength was assessed by changing the thickness and length using a validated finite element model [4]. The number of studies on the structural behaviour of cold-formed steel (CFS) beams has increased during the last few decades. The combination of instability phenomena including local, distortional, and lateral-torsional buckling is one of the most fascinating and difficult research issues [5]. These buckling modes, which may occur even before some of the cross-sectional components give, are primarily responsible for the ultimate strength of the compression elements. Among

of the key factors contributing to CFS members' increased vulnerability to buckling include their low torsional stiffness, extreme slenderness, and geometric flaws [6]. Accurate finished dimensions, Clean surface, Greater strength properties. To simulate the longitudinal slip mechanics of composite slabs in "pull-out" tests, a new method for creating 3D non-linear FEM models has been devised. Analysis of the sensitivities of shear resistance includes friction coefficient, embossing depth and slope, sheet thickness, inclination, length, width, and spacing of the embossments, as well as the angle at which the rib form is profiled. It has been developed and optimised to create a new steel sheet design. However, a number of pull-out tests and reduced "m-k" shear-bond bending tests have been performed to confirm and validate the results of the FEM and to assess several other factors. It was discussed how built-up beams made of channel sections that were bolted together and strengthened on both the inside and the exterior reacted to flexure. This study intends to examine how cold-formed steel I-beams with strengthened hollow tube flanges behave under flexural loads using various strengthening materials [7]. Since the corresponding ultimate loads are far greater than the associated ultimate bending moments, the longitudinal slide between the steel sheet profile and the concrete in composite slabs is typically an ineffective failure mode. This slip is connected to forces created during simple bending called longitudinal shear. Ungureanua et al. proposed a novel scientific method for connecting built-up beams formed from profile sheets for the web and thin-walled light gauge steel profiles for the flanges using resistance spot welding [8]. The evolution of particular strains in the various cross-sections of the tested beams as a function of the loading applied to them was another significant parameter taken into consideration in this investigation. The key finding was that, in contrast to open-section beams, the compressive and tensile behaviour of the flanges of the hollow beams was nearly similar up to the maximum load-carrying capacity [9]. Due to the significantly lower LB and TB when compared to the I beam without a web stiffener, the CFS beam made up of an I section of a lipped channel with an intermediate and edge web stiffener has a higher strength [10]. These built-up sections are used, among other things, as members in steel trusses, space frames, and portal frames [11]. Back-to-back built-up CFS channel sections' individual channel sections are kept from buckling by the inclusion of intermediate screw fasteners that run longitudinally [12]. Because it is necessary to compare the strain and stress levels before and after the reinforcement, the problem of

strengthening might occasionally be more complicated than constructing a new structure. Several literary works discuss thin-walled steel beams and the ways in which they lose stability. Examples include articles [13]. Fasteners like screws, bolts, welds, and clinches are regularly used to join the parts of the build-up sections together [14]. The flexural behaviour of the CFFSS closed built-up beam made of lipped channel sections was numerically examined under four-point bending and showed enhanced flexural behaviour [15].

1.2 ADVANTAGES OF COLD-FORMED STEEL

The advantages of cold-formed steel are given below

- **Cost-Effectiveness:** As per the study lumber cost increase 60% in 2021 and cold-formed cost increase only 20%. So cold formed steel is cost effective for building or other structure compared to other materials.
- **Non-combustible and Study:** Cold-formed steel has that ability to resist against the structure damages and other natural disaster (i.e.)– Earthquake, heavy winds, heavy snowstorms etc.
- **Environmentally Friendly:** Cold formed is made up of 67% recycled materials and 100% recyclable. At the end of life period it can be reused in different applications with multiple numbers of time.
- **Strength:** As per the study cold-formed steel is 20% more stronger than hot form determines the local buckling mode. Example: Cross-sectional dimensions and shape.
- **Lateral-Torsional Buckling-** Similar to solid web beams, this mode of failure is characterized by out-of-plane movement of the beam without any web distortions.

1.3 FAILURE MECHANISM

The main failure mechanisms are the following

- **Local Buckling-** A mode known as local buckling, which occurs before the material fails, is characterized by plate-like deformations or a geometric

instability. Local buckling occurs before the yield stress is attained because the plate components of cold-formed section plates are usually thin and have a high plate slenderness ratio.

- Lateral-Torsional Buckling- Similar to solid web beams, this mode of failure is characterized by out-of-plane movement of the beam without any web distortions. The majority of the time, larger span beams with insufficient lateral support to the compression flange are the cause of lateral torsional buckling. This buckling mode is caused by the web's reduced torsional stiffness, which is a result of the section's relatively deeper and slender characteristics.
- Flexural buckling- This type of buckling can happen to any compression part that experiences a deflection due to bending or flexure. There is approximately axis-based flexural buckling.
- Torsional buckling- This type of buckling occurs most frequently in compression materials that are doubly symmetric and have very small cross sections. That happens because of a turnabout the longitudinal axis. The majority of torsional buckling occurs in built-up sections; rolled sections seldom ever experience this.

1.4 REVIEW OF LITERATURE

Rafet Aktepe and Burcu Erdhal Erkal (2023) conducted a study on “Experimental and numerical study on flexural behaviour of cold-formed steel hat-shaped beams with geometrical imperfections: For the physical tests, ten various lengths of cold-formed hat-shaped beams are selected. Processing 3D point clouds created by laser scanners allows for the acquisition of the real geometry as well as the distributions of geometric imperfections. To acquire benchmark findings for numerical models, four-point bending tests are carried out. Following the calibration of the generated finite element models using the experimental data, a parametric study is conducted to determine how the length, thickness, lip width, return length, radius, and lip angle affect the behaviour of the beam. Additionally, the impact of imperfection modelling technique and geometric imperfection magnitude choices on member capacity is taken into account. The study's findings demonstrate that the

initial geometric flaws and input parameters used for the numerical models developed have a considerable impact on the flexural behaviour of CFS hat-shaped beams.

Mir Basar Suhaib and Mansoor Ahmad Tantray (2023) conducted a study on “Flexural Integrity Between the Channels of Built-up Cold-Formed Steel Beams: Both the screw spacing and the depth of the beams varied along their length. It may be inferred that flexural capacity is directly related to the reduction in screw spacing and increase in the number of screw rows since an increase in screw spacing causes an unfavourable separation. The capacities of all the screw-connected "semi-rigid" beams were tested against an idealised cross section that was generated for each web depth using FE modelling and assumed complete composite action. It was noted that the moment capacity reduction caused by the screw connection in built-up members was not taken into consideration by the design recommendations supplied in AISI S-100.

Paola Pannuzzo and Tak Ming Chan (2022) investigated on “Flexural Behaviour of Cold-Formed Steel Square and Rectangular Hollow Sections with Moderate Heat-Treatment: Besides experimental and numerical research, this study analyses the flexural behaviour of square and rectangular hollow steel sections (SHSs and RHSs) with subsequent heat treatment. First, an experimental programme consisting of three-point bending beam tests and tensile coupon testing on flat and corner sections was carried out. Under monotonic bending stresses, a total of 12 specimens were tested, representing various section slendernesses. The impact of the web-flange interaction on rotation capacity has been investigated through the evaluation of failure modes, moment-rotation curves, and plastic hinge lengths. To evaluate the appropriate moment and deformation capacity, numerical FE findings were successively integrated with experimental results. New cross-section classification limits have been recommended after an evaluation of the existing limits stated in Eurocode 3 and AISC 360-16.

Yulong He Orchid et al., (2022) investigated on “Experimental and Numerical Study on the Flexural Behavior of Cold-Formed Steel Multi-Limb Built-Up Section Beams: In this paper, tests and finite element (FE) modelling are used to explore the flexural behaviours of CFS four-limb built-up beams with sections. Four-point

bending experiments are used to determine the beams' flexural moment capacities and failure modes. The new open section beam's ultimate load capacity is discovered to be larger than that of the closed section beam, and the failure mode is local buckling of the upper flange and web. Then, a thorough parametric investigation is carried out using the FE models that were created and validated by the tests. The flexural moment capacity increases with web thickness and depth, according to numerical results. Finally, a simpler technique of calculation for the flexural moment capacities of closed and open section beams is suggested by taking into account, the reduction factor of gross section modulus of the built-up section.

James Daniels et al., (2021) investigated on “Flexural behaviour of cold-formed steel oval hollow section beams: In-depth analysis of the flexural behaviour and strength of cold-formed steel oval hollow section beams is presented in this work. As part of the experimental program, several four-point bending tests were performed. A non-linear finite element analysis was then used to simulate a total of 12 tested beams. After the newly created numerical model was validated, a parametric analysis was conducted to obtain a total of 36 numerical results in order to evaluate the structural response of the oval hollow section beams over a larger range of cross-section dimensions. According to the results, all three design standards give unconservative estimates, whereas the direct strength approach and the continuous strength method produce predictions that are generally accurate and reliable.

Ponraj Sankar L et al., (2021) conducted a study on “Numerical simulation of cold-formed T-shaped built-up steel sections under bending: The use of built-up beam sections in structural Cold-Formed Steel (CFS) construction is gradually rising. There is a rising need for cold-formed steel pieces. As a result, it encourages the creation of creative and affordable built-up beam sections. The flexural behaviour of novel built-up CFS T-shaped sections with web-mounted intermediate stiffeners is discussed in this work. Three samples were collected, and they underwent two-point load testing. The qualities of the material were ascertained by the use of a coupon tensile test. The experimental findings were used to create and validate a non-linear finite element model. It was noted that the experimental

findings and the moment carrying capacity and failure modes determined from the Finite Element Analysis (FEA) were closely correlated.

Chui Huon Ting et al., (2021) researched on “Flexural Behaviour of Back-to-Back Built-up Cold-Formed Steel Channel Beams: With the use of 12 experimental test findings, this research addresses this problem. With varying screw spacings of 1900 mm, 950 mm, and 475 mm, two distinct cross-sections—referred to as BU75 and BU90—were taken into consideration. Before to the bending testing, first geometric flaws were measured. The results of a nonlinear elasto-plastic FE model that was later created were in good agreement with those of the experimental test results. A comprehensive parametric analysis was carried out to examine the impact of screw spacing on the flexural strength of such back-to-back built-up CFS channel beams using the validated FE model. The outcomes of 108 parametric analyses are provided in total. The design strengths determined in accordance with the American Iron and Steel Institute (AISI) and the FE results were compared.

Man Tai Chen and Ben Young (2021) conducted a study on “Beam-column design of cold-formed steel semi-oval hollow non-slender sections: 140 short and long beam-columns loaded at various eccentricities, together with their 28 concentric loaded column counterparts, were the subject of a thorough parametric research that took into account a variety of cross-section geometries, member slendernesses, and loading eccentricities. The design strengths predicted by the American Specification, Australian Standard, as well as the European Code and North American Specification were compared with the numerical results acquired in this work along with the available experimental results. The design strength estimations are more accurately made thanks to changes made to the existing design rules. For cold-formed steel semi-oval non-slender sections exposed to combined compression and major axis bending in the positive direction, it is advised to use the modified ANSI/AISC360 design technique since it provides the most accurate design predictions.

Sudhakar D et al., (2021) investigated on “Behaviour of cold-formed steel hollow beam with perforation under flexural loading: The structural members in roof trusses, wall panels and claddings, storage racks, and support structures are frequently made of cold-formed steel (CFS). These days, CFS is recommended for

usage in building materials like beams and columns. Due to its extremely thin thickness, the perforated beam and column failed mostly due to severe buckling and distortion. Examining the flexural strength, failure mechanism, load-deflection, and load-strain behaviour of cold-formed steel hollow beams with or without web holes is the goal of the study. When compared to square hollow beams, the flexural strength of rectangular hollow beams rose by 41%. The experimental findings were used to validate the finite element model created with ANSYS. Good agreement between a nonlinear finite element model and experimental results.

Manoj Kumar C et al., (2021) experimental study on "Experimental Investigation of Cold-Formed Steel Castellated Beams: Because of its superior strength-to-weight ratio, ease of construction and transportation, cold-formed steel (CFS) is used in the construction industry. An I-beam is referred to as a "castellated beam" if its web has been longitudinally carved in a certain pattern. The depth of the beam is increased by using this pattern. The greatest way to get around the deflection criteria in safety is with castellated beams. In this project, a cold rolled sheet is first transformed, then it is made into a typical I section beam. Examining the flexural strength, load-deflection, and load-strain behaviour of the castellated beams made of CR sheet is the primary goal of the study. With the aid of the FE programme ANSYS, beam analysis is carried out, and the findings are explained for castellated beams.

Arun Prasad et al., (2020) investigated on "Analytical and Experimental Study on Cold-Formed Steel Built-Up Sections for Bending: The analytical and experimental investigation on the strength and properties of CFS bolted built-up sigma sections with various structural arrangements under bending is mostly covered in this work. In this study, FE modelling was carried out using the ANSYS workbench software to examine the local, flexural, and interaction of these buckling. Additionally, we put cold-formed steel built-up components with straightforward edge stiffeners in the centre through bending tests. The results show that the back-to-back connected built-up beam section offers a larger flexural capacity than the face-to-face built-up section when comparing both analytical and experimental tests. Additionally, expanding the bolt spacing increased the load-bearing capability of

back-to-back built-up beams with sigma sections. Additionally, it has been found that the position or bolt spacing plays a major role in a beam's flexural strength.

Suresh Babu S and Senthil Selvan S (2020) conducted a study on “Study on The Flexural and Compressive Behavior of Cold-formed Steel Sections with and Without Lips: Cold formed steel has seen significant expansion in the building industry in recent years. They are used much more frequently in steel buildings than hot rolled steel because they are lightweight and convenient to transport. Moreover, the cold-formed steel can be produced in a variety of appealing portions and shapes. In this study, various cold-formed steel section configurations are used as columns and beams. The sections come in a variety of configurations, including lip, stiffeners, and web spacing. The columns are evaluated for compressive behaviour while the beams are checked for flexural and torsional behaviour. The specimens were first analytically examined using finite element software, and the results were then compared to the outcomes of the experiments.

Ashraf M. Abou-Rayan et al., (2020) researched on “Experimental Investigation on the Flexural Behaviour of Steel Cold-Formed I-Beam with Strengthened Hollow Tubular Flanges: In this paper, an experimental investigation of the flexural behaviour of a steel cold-formed I-beam with reinforced hollow tube flanges is presented. The preparation and experimental testing of 19 cold-formed steel I-beams with hollow tube flanges involved four-point bending tests. 18 of these examples were strengthened by filling the tubular flanges with various materials, while one specimen served as a control specimen and was not strengthened at all. Two vertical weights were applied to each specimen until it broke. Vertical displacements and the mode of failure of the specimens were noted. The link between vertical load-deflection at mid-span has been examined to determine the impact of stronger materials. The Egyptian Code of Practice for Steel Construction (LRFD) was used to compare the bending moment capacities to expected values. The results show that while the design method of this code is conservative when compared to the results of experimental tests, it is not conservative when compared to the moment capacities of strengthened specimens made using sawdust and cement mortar.

Man Tai Chen and Ben Young (2019) investigated on “Structural behavior of cold-formed steel semi-oval hollow section beams: For all four-point and three-point bending configurations, a total of 20 beams were evaluated. Both positive and negative bends were made to the sections around the main axis. The tests were quantitatively reproduced using exact finite element analysis. Semi-oval hollow sections are not covered by the current design regulations for steel structures, including Australian/New Zealand standards, European codes, as well as American and North American specifications. The findings demonstrate that the design strength forecasts made by the current design methodologies for cold-formed steel semi-oval hollow section beams are often cautious and sporadic. In this paper, improvements to the Direct Strength Method and the Continuous Strength Method are offered. These improvements offer more accurate and trustworthy forecasts of design strength.

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Anbarasu M (2019) investigated on “Simulation of flexural behaviour and design of cold-formed steel closed built-up beams composed of two sigma sections for local buckling: The goal is to create precise finite element models for an I-beam constructed with CFS and subjected to a transverse load. The numerical model was created using the ABAQUS 6.13 finite element (FE) programme. The numerical models were discretized using S4R elements, end conditions that were easily

supported, and nonlinear analysis that took into account geometrical flaws, material nonlinearities, and contact nonlinearities. In terms of moment capacities, moment versus deflection curves, and specimen failure modes, comparisons with experimental results reported in the literature serve to validate the numerical model. The numerical parametric research has been carried out using the verified FE model for varied cross-section geometries and thickness of the built-up closed beam. With an increase in the compression flange width to thickness ratio, the moment capacity drops. In general, as the aspect ratio decreases, the section's moment of resistance rises. The adjustment in web stiffener depth has no discernible impact on the flexural strength of the built-up closed beams.

Mohammad Adil Dar et al., (2019) conducted a study on “Behaviour of partly stiffened cold-formed steel built-up beams: Experimental investigation and numerical validation: Many studies have concentrated on creating novel sectional profiles, where the section's geometry plays a crucial role in strengthening the inherent resistance of such sections against premature buckling, to address the numerous instability issues in cold-formed steel members. Yet, creating such novel shapes is not only difficult and time-consuming, but occasionally these parts are unable to fully mobilise their reserve strength. In order to mobilise the untapped reserve strength, a stiffening configuration of weaker zones is suggested. Under four-point loading, an experimental research was done on various simply supported cold-formed steel beams with appropriately suggested stiffening systems. The investigated cold-formed steel beams featured various width-to-thickness ratios, geometries, and stiffening configurations. Measurements and reports were made of the test strengths, failure modes, deformed forms, load versus mid-span displacements, and geometric flaws. Using the finite element programme ABAQUS, a numerical research on such stiffened cold-formed steel beams was conducted to further validate the test results.

Subramanian Narayanan et al., (2018) conducted a study on “Structural performance of cold-formed steel composite beams : The experimental investigation on various CFS composite beams with simply supported end conditions under four point loads is presented in this work. The models' physical characteristics and geometrical flaws were measured. The Australian/New Zealand Standard for cold-

formed steel buildings is used to compare the test strengths of the models to the design strengths anticipated by the standard. A specific testing equipment was also designed for evaluating long span beams in order to assure high accuracy testing. Here, test models, testing rig specifications, and test results are described. A comparison of the test results with a hot rolled piece is also provided to aid in the interpretation of the findings. The test results have demonstrated the potential of the suggested CFS composite beams in terms of both improved structural performance.

Luis Laim and Joao Paulo C Rodrigues (2018) researched on “Fire design methodologies for cold-formed steel beams made with open and closed cross-sections: The primary goal of this study is to propose, using European standards, a simpler fire design technique for single and built-up cold-formed steel beams. For this study, channel sections with (lipped and un-lipped) lips were used to create open and closed cross-sections. The innovative study done herein was based on existing experimental testing and shell finite element analysis utilising a sophisticated commercial programme. Following a comparison of the numerical results with the relevant European fire design guidelines, the necessary recommendations are provided. Depending on the relative slenderness and serviceability load of the beams, it was determined that these design guidelines were either dangerous or overly conservative. The new fire design methodology's accuracy was further shown through comparisons with numerical moment capabilities.

Mangala Gowri P and Manu S. S (2018) conducted a study on “Experimental Study on Flexural Behaviour of Cold-Formed Hollow Flanged Z–Sections: Loads operating on structures can generally be divided into three categories: vertical loads, horizontal loads, and longitudinal loads. Dead load, live load, and impact load are the three types of vertical loads. The safety is jeopardised if economy is taken into account and lighter loads are taken. Hence, maintaining a good standard without sacrificing economy or safety is essential for any structure. For the aforementioned goal, several Z-hollow flange cold-formed steel sections are taken into consideration in this work. Since hollow flanged sections are frequently used in roof trusses, where self weight is the main issue, they were chosen for this investigation. The sections

are put through flexural load testing to determine their load-to-weight ratio, which is used to rate the performance of the sections.

Seyed Mohammad Mojtab et al., (2018) conducted a study on “Strength and Deflection Behaviour of Cold-formed Steel Back-to-back Channels: A connector model is used to mimic the behaviour of a bolt bearing against a steel plate in the back-to-back portion. This model accounts for both slippage and bearing deformations. Six four-point bending tests on CFS back-to-back channel beams are used to validate the derived Finite Element (FE) models, and excellent agreement is discovered between the experimental and FE predictions. Comparing FE forecasts and tested findings reveals that while strain-hardening of CFS material at round corners has minimal effects, geometric flaws can modify FE predictions of final capacity by 7%. It is also demonstrated that EC3 calculates deflections using a decreased cross-sectional property, which can accurately anticipate deflections with a small overestimate (6%), at the serviceability load.

Helder D Carveiro et al., (2016) conducted a study on “Flexural behaviour of axially and rotationally restrained cold-formed steel beams subjected to fire: The findings of extensive experimental investigation on the flexural behaviour of cold-formed steel beams exposed to fire are presented in this work. The major goal of this research was to assess how varied cross-sections, particularly complex cold-formed steel sections, affected the thermal elongation of the beam, its axial constraint, and the rotational stiffness of its supports. The findings highlighted the possibility that, depending on the relationship between the surrounding structure's stiffness and that of the beam, the critical temperature of a cold-formed steel beam may be significantly influenced by that stiffness.

Alex. J and Iyyapan G.R (2016) investigated on “Behaviour of Cold-Formed Steel Built-Up I Section Under Bending: The region between the two point loads has the same moment and is referred to as a pure bending zone. By placing angle stiffeners 40 mm apart throughout the length of the sections, flexural strength is improved. For I and Channel sections, total stiffeners are provided at 24, and 12, respectively. Applications: Determine the behaviour of the channel and built-up I section with increasing web thickness, flange thickness, and rising stiffener dimension can be the focus of further research. Using diagonal stiffeners with

temperature effects, which may alter the behaviour of channels and built-up I section, is another helpful thing that may be done.

Yuan-Qi Li et al., (2016) conducted a study on “Investigation on flexural strength of cold-formed thin-walled steel beams with built-up box section: In cold-formed thin-walled steel frames, built-up sections are frequently used. The main focus of this study is on the in-plane behaviour of built-up box beams with nested C and U sections under simple bending about strong and weak axes. Seven different groups of specimens, comprising built-up box sections (CU) and individual sections, were subjected to the four-point bending test (C, U). The test findings are used to construct and validate a finite element model for additional parametric analysis. The discussion of test results and the outcomes of the numerical analysis is used to evaluate the reasonability of the capacity superposition method and equivalent method for built-up box beams bending about strong axis. To determine the flexural strength of built-up box beams bending about weak axes, the corresponding box section is suggested.

Manikandan P and S. Sukumar (2016) researched on “Behaviour of Cold-formed Steel Built-up Closed Section with Intermediate Web Stiffener Under Bending: Nine constructed beams in total, each with a different cross section geometry, are tested in a simply supported end condition with two-point loading. ANSYS is used to create a finite element model, which is then tested against experimental findings and determined to be quite accurate. The findings show that the intermediate stiffener's flange width and depth have a substantial impact on the member's strength and buckling behaviour. The strength predicted by the North American Iron and Steel Institute Standard for the cold-formed steel structure is compared to the experimental and finite element analysis results, and appropriate suggestions are made in light of the findings. Comparing the proposed design equation's accuracy against experimental data published by other researchers allows for this determination.

Wasim Reza and S. Senthil Selvan (2016) conducted a study on “Experimental Study on Flexural Behaviour of Cold Formed Steel Channel and I Sections Providing Angle Stiffener on the Web: With the aid of bolts placed in the section's web portion, built-up I sections are created utilising symmetric channel

sections. Angle stiffeners are provided with one of the constructed I section and C section to improve flexural strength. By placing angle stiffeners 40 mm apart throughout the length of the sections, flexural strength is improved. For I and Channel sections, total stiffeners are provided at 24, and 12, respectively. Determine the behaviour of the channel and built-up I section with increasing web thickness, flange thickness, and rising stiffener dimension can be the focus of further research. Utilizing diagonal stiffeners in conjunction with the temperature effect is another practical method that may change the behaviour of channel and built-up section.

Mohammed H Serror et al., (2016) investigated on “Experimental study on the rotational capacity of cold-formed steel beams: A web bolted, moment-resistant form of connection using a through plate has been adopted at the connection level. Without out-of-plane stiffeners, premature web buckling causes early strength loss in web bolted connections. In order to prevent web and flange buckling and to provide reasonably high moment strengths and ductility, out-of-plane stiffeners have been studied. The experimental results have been contrasted with the authors' numerical findings from a different paper work. The findings showed that increasing the flange bend count does not always improve behaviour. In contrast to the scenario without stiffeners, the employment of out-of-plane stiffeners can boost seismic energy dissipation, moment strength, and ductility.

Nicola Tondini and Andrea Morbiolo (2015) conducted a study on “Cross-sectional flexural capacity of cold-formed laterally-restrained steel rectangular hollow flange beams: The objective of this extensive experimental-numerical investigation was to evaluate the flexural performance of cold-formed, laterally-restrained, rectangular hollow flange steel beams. The findings are presented in this publication. (RHFBs). Two RHFBs of various sizes were chosen to serve as an example of the typical secondary beam found in modest steel-framed homes. Results of the experimental study, which included tests on full-scale specimens and material characterization, are reported in detail. Additionally, numerical work was done to create a model that could replicate the results of the experiments and be used to expand the known results over a wider range of slenderness using parametric analyses.

Helder David Craveiro et al., (2015) conducted a study on “Flexural behaviour of beams made of cold-formed steel sigma-shaped sections at ambient and fire conditions: This article details a series of flexural experiments performed on simply supported cold-formed steel beams made of one or two sigma-shaped profiles under both ambient and fire conditions. Under various thermal restraint situations, such as those with no constraints, partial axial restraints, and rotational thermal restraints on the beam supports, the critical temperature and time as well as the impact of the stiffeners on the beams were evaluated. The outcomes demonstrated that depending on the section form, beams with web stiffeners may exhibit various structural responses in fire. The beams that weren't axially constrained and didn't have web stiffeners displayed the best structural performance in a fire.

Yusuf A R Dar M et al., (2015) conducted a study on “Experimental study on innovative sections for cold-formed steel beams: C and Z are the two most often utilised cold-formed beam sections. However, there are some buckling modes in each of these portions. It is crucial to postpone or entirely eliminate the various buckling modes of cold formed sections for beams in order to achieve significantly improved structural performance in terms of strength and stiffness. This paper presents a variety of novel sectional profiles and stiffening configurations for cold formed steel beams that successfully delay or eliminate various modes of premature buckling, thereby significantly enhancing the load carrying capacity and stiffness properties of such novel cold formed sections compared to conventional cold formed steel sections typically used for beams.

Eapen Sakaria P et al., (2014) conducted a study on “Flexural Behaviour of Cold-Formed Steel Beams with End Stiffeners and Encased Web: Cold-formed high-strength steel members have become increasingly popular recently. The findings of an experimental research on the behaviour of cold-formed steel sections with plain web, end-stiffened web, and enclosed web are presented in this work. Studying and contrasting the moment-carrying capacities of cold-formed steel beams with plain webs and beams with end-stiffened webs and encased webs. The specimens were examined for their pure flexural behaviour under two-point loading. According to the study, sections with the plain web have a lower load-carrying capacity than cold-formed steel beams with end stiffened and encased web.

Sudha K and Sukumar S (2014) researched on “Behaviour of Cold-Formed Steel Built-Up I Section Under Bending: This study examines the behaviour and bending strength of cold-formed (CF) steel built-up flexural members using numerical and experimental methods. Eight specimens in two groups—four specimens in the first group with equal flanges and four specimens in the second group with asymmetrical flanges—have been constructed and tested. The experimental results highlight the buckling modes and how they affect the bending strength and behaviour of I sections made of CF. The finite element model simulations and analysis of the experimental results are done using the FEM programme ANSYS. The collected results and the outcomes of the experiment are in good accord.

Liping Wang and Ben Young (2014) studied on “Design of cold-formed steel channels with stiffened webs subjected to bending: Simple supported beams with various stiffened channel sections have been the subject of experimental inquiry. Reports were made on the moment capacities and observed failure modes under maximum loads. A nonlinear finite element model was created, and its strengths, failure modes, and moment-curvature curves were compared to the test findings. In order to evaluate the moment capacities and buckling modes of cold-formed steel beams with varied stiffened section shapes, the calibrated model was then used in a thorough parametric investigation. The comparison demonstrates that, for both local buckling and distortional buckling in this work, the design strengths predicted by the existing direct strength method (DSM) are conservative. In order to cover the novel stiffened channel portions examined in this work, the DSM is adjusted. The dependability study was also performed to assess the current and modified DSM.

Eapen Sakaria P et al., (2014) conducted a study on “Flexural Behaviour of Cold-Formed Steel Beams with End Stiffeners and Encased Web: Cold-formed high-strength steel members have become increasingly popular recently. The findings of an experimental research on the behaviour of cold-formed steel sections with plain web, end-stiffened web, and enclosed web are presented in this work. Studying and contrasting the moment-carrying capacities of cold-formed steel beams with plain webs and beams with end-stiffened webs and encased webs. The specimens were examined for their pure flexural behaviour under two-point loading.

According to the study, sections with the plain web have a lower load-carrying capacity than cold-formed steel beams with end stiffened and encased web.

Luis Simoes da Silva et al., (2013) conducted a study on “Experimental and Numerical Analysis on the Structural Behaviour of Cold-Formed Steel Beams: Based on the findings of an extensive programme of experimental tests and numerical simulations, a study on the structural behaviour of cold-formed steel beams with C-, I-, R-, and 2R-shaped cross-sections at ambient temperature is provided. First, a number of four-point bending tests were conducted to primarily evaluate the failure loads and modes of the beams. After that, a parametric research was conducted to look into how the thickness, height, and length of the beams affected its structural behaviour. Finally, an appropriate finite element model was created to compare with the experimental results.

Yeong-Huei Lee et al., (2012) conducted a study on “Experimental Investigation on Cold-formed Steel Beams under Pure Bending: The flexural behaviour of cold-formed double-lipped channels beams under pure bending action is discussed in this work. An I-shaped structural beam member is created by bolting together two channel sections back-to-back. Beam section thickness is 2 mm, and design yield strength is 350 N/mm². Because of the lateral instability of the cold-formed steel structural elements, all beams broke at local buckling at the top flange. Moment resistance for DC250 is 31.53 kNm, whereas it is 17.87 kNm for DC200. The experimental findings are contrasted with theoretical predictions of resistance based on British Standard and Eurocode. The comparison revealed that while the theoretical bending moment resistance is higher than the experimental moment capacity, the theoretical buckling moment resistance from Eurocode is lower.

Mammana O et al., (2009) conducted a study on “Experimental investigation on laser welded connections for built-up cold-formed steel beams: A wide experimental investigation on laser welded connections based on both lap-shear and tension tests was performed at the University of Naples. The aim of the study was to assess the possibility of using laser welding in innovative built-up cold-formed steel beams. The experimental programme was designed in order to evaluate the effects of different parameters on the strength and ultimate displacement of the selected connections. In particular, the influence of sheet thickness, gap, loading

direction, weld shapes and zinc coating were analyzed. The results of the experimental tests were compared with the predicted resistance values according to Eurocode 3, with the aim of validating for laser welding the mechanical models provided for spot welds.

Papia Sulthana et al., (2009) researched on “Flexural strength of cold-formed steel built-up box sections: The practical tests conducted by Beshara and Lawson Beshara B, Lawson TJ. Built-up girder screw connection variation flexural tests, Internal Report, Dietrich Design Group, 2002] were used in this study to validate the suggested finite element model of the built-up box sections. The adequacy of the finite element analysis's flexural strengths was then tested by contrasting them with the nominal strength determined using the existing design process. In order to determine the variables influencing the flexural strength of cold-formed steel built-up box sections, parametric studies for more than 30 specimens were conducted. The evaluation of the box section's flexural strength under eccentric stress is advised for use in current design practise.

Paczos P and Waseliwicz P (2009) conducted a study on “Experimental investigations of buckling of lipped, cold-formed thin-walled beams with I-section: Many diverse industries use thin-walled, open-cross-section beams that were cold-formed. Due to the configuration of their cross-sections, they frequently buckle in specific areas. The findings of experimental studies of lipped I-section beams are provided in this work. A concentrated force and bending moments have been applied to the beams. The critical load experimental values are contrasted with those determined by theoretical and FEM analysis.

Haiming Wang and Yaochun Zhang (2009) researched on “Experimental and numerical investigation on cold-formed steel C-section flexural members: There were 24 specimens in all, which were divided into 12 tests, comprising 6 pure bending tests and 6 non-pure bending tests. The experiments revealed local buckling, distortional buckling, and interactions between local and distortional buckling. The findings of the experiment demonstrate that the buckling mode and edge stiffener have a significant impact on the bending strength of the member. The bending strength under non-pure bending is higher than under pure bending, according to a comparison of the two bending states, but the increased magnitude

is connected to the buckling modes. Moment gradient effect has a significant impact on distortional buckling but has little impact on local buckling. The tests were modelled using ANSYS's finite element tool, and the results show good agreement with the experimentally in terms of bending strength and buckling mode.

Cheng Yu and Benjamin W. Schafer (2006) researched on “Distortional Buckling Tests on Cold-Formed Steel Beams: There aren't many experimental findings about cold-formed steel beams with unrestrained compression flanges. To determine the capacity in distortional buckling failures, a series of distortional buckling tests on cold-formed steel C and Z sections in bending were performed. These distortional buckling experiments also offer a direct contrast to the writers' earlier local buckling testing. Large strength decreases are seen in the tested specimens when distortional buckling rather than local buckling caused the failure, as is to be expected. The design requirements for the United States, Canada, and joint North America, which are known to concentrate primarily on local buckling, offered unreliable projections of the observed strength. The direct strength approach and the Australian/New Zealand Standard, which offer specific ways to determine the capacity in the distortional buckling mode, provided reasonably accurate and reliable predictions.

1.5 SUMMARY OF LITERATURE

All researchers built their open and closed sections and concentrated their study on the already-existing sections that followed the code. When it comes to a segment joining sigma parts with channel sections, no research is used. So, designed accordingly and section's behaviour can be researched for CFS, because CR sheets in a variety of sizes are readily available. These cold-rolled sheets have been used to build the beams into closed built-up symmetric as well as mono-symmetric sections.

1.6 AIM

The main objectives of the project are given below

- To create a model for a build-up beam section using cold-formed steel.
- To analyse the flexural behaviour of cold-formed build-up steel section

using ABAQUS software.

- To determine the load-carrying capacity of built-up cold-formed steel beams.

1.7 STUDY OF WORK

In this work built up beams are fabricated with cold rolled sheet and analysed. Totally 4 beams are fabricated and analysed, all 4 beams are built up I section with the use of channel section and sigma section connected back to back and connected toe to toe with the variation in size and shape.

1.8 SCOPE OF WORK

The following scope areas are given below

- The build-up beams will be validated by finite element model using ABAQUS software.
- Experimental tested is conducted.

1.9 NOVELTY OF WORK

Material used is Cold Rolled Steel Sheet. CR Sheet is fabricated into Built-up sections. Because beams are typically subjected to compressive loads, which can cause them to buckle if they are not slender enough to resist buckling, they are frequently designed as slender sections. A beam's slenderness ratio is the ratio of its effective length to its radius of gyration and is a measure of its resistance to buckling under compressive loads.

1.10 NEED FOR STUDY

The need for study of the project is given below

- Cold-formed Steel (CFS) sections provide the best choice not only for cost-effective structural systems but also an ideal choice for the desired fast-track construction.
- Col-formed steel may be the most cost-effective material for this application. However, more studies are required to fully understand the

benefits and limitations of this construction method.

- It has been found that fewer studies have been conducted on Joist made of light Gauge Steel.
- The increase in depth of section will increase the moment bearing capacity.
- To reduce weight.
- No material wastage.

CHAPTER 2

METHODOLOGY

2.1 METHODOLOGY

The methodology of the entire project work is depicted in the form of flow chart as shown in fig 2.1.

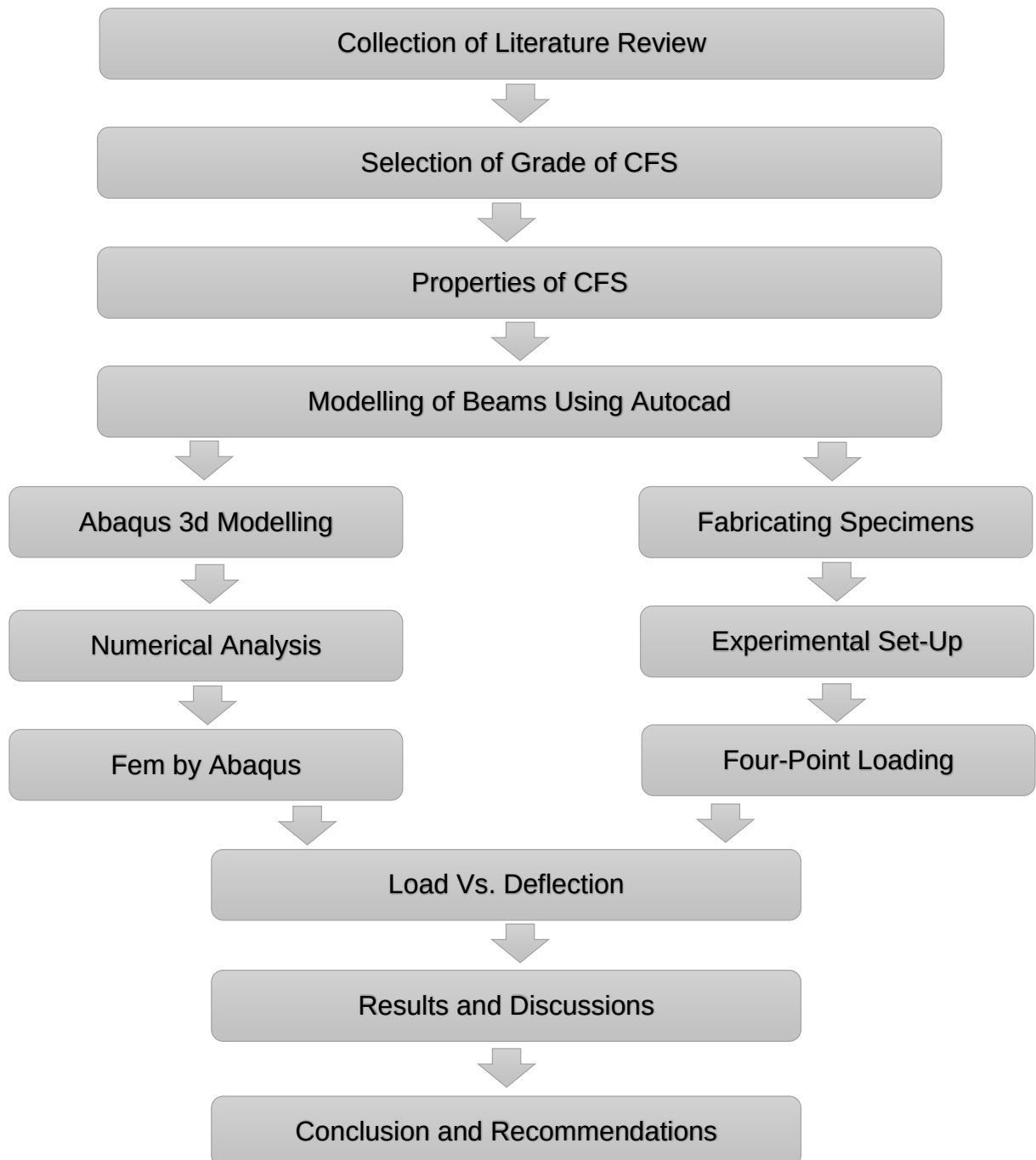


Fig 2.1: Flow Chart Showing the Methodology for the Works

2.1.1 COLLECTION OF LITERATURE REVIEW

For the purpose of gathering references for analytical and experimental work, literature from 2009 to 2023 was collected. For choosing the grade of steel and acquiring steel's characteristics like chemical composition and mechanical properties with the use of literature.

2.1.2 SELECTION OF GRADE OF CFS

On the behaviour of cold-formed steel in specific applications or environments, there may be a shortage of research or studies. Researchers may address this gap and offer valuable information on the behaviour of cold-formed steel by employing it as the main component in a study. Due to its desirable structural behaviour, cold-formed steel can be used in an array of sectors, such as infrastructure, transportation, and constructions. Researchers can assess its performance and applicability for particular applications by utilising it as the main component of a study. As CR2 sheets are locally available in market widely used in construction industry. CR2 is a drawing quality "D" grade as per Indian standard: 513 2008 specifications.

2.1.3 PROPERTIES OF CFS

The sheet of 2mm thick cold rolled sheet of grade IS 513 CR2. Nitrogen is an essential element for all life on earth, and it is used in a variety of industries for a wide range of applications. In the chemical analysis standards for grade IS513 CR2 sheets as per TDC No. AH03, nitrogen is composed of 90PPM. Table 2.1 and 2.2 shows chemical and mechanical properties of cold-formed steel sheet. The thickness of the CR Sheet ranged from 0.4 mm to 3 mm. 2 mm sheet was used in order to achieve the greatest strength possible. It was a silver-coloured sheet. Due to the way it was made, when it reacts with the environment it rusts quickly. As a result, beams are coated to prevent rusting.

Table 2.1: Chemical Composition of CR2

Chemical Constituent	%
Carbon	0.7
Manganese	0.5
Sulphur	0.035
Phosphorus	0.4
Silicon	0.05

Table 2.2: Mechanical Properties of CR2

Properties	Max Value	Units
Yield Stress f_y	240	Mpa
Ultimate Strength f_u	350	Mpa
Elongation %	30	%

2.1.4 MODELLING OF BEAMS USING AUTOCAD

The Sigma profile dimensions adhere to TS EN 1993-1-3 requirements. The dimensions of the sigma sections were designed. The sigma section in this instance is made for a depth of 240mm and a span of 1200mm, or 1.2m.

2.1.5 ABAQUS 3D MODELLING

The geometry of the specimens was modelled in ABAQUS Design Modeler with the help of a 3D Modeler. The 3D modeler was used to capture the exact dimensions of the specimens, ensuring that all measurements were accurate and precise.

2.1.6 NUMERICAL ANALYSIS

In the field of mathematics known as numerical analysis, continuous problems are approximated numerically. It involves developing techniques that provide close yet accurate numerical solutions, which is helpful when calculating the exact solution is difficult or impractically expensive.

2.1.7 FEM BY ABAQUS

By employing a software programme and the finite element analysis technique, two-dimensional models were created and rendered in three dimensions while being loaded under four points with two supports and two point loads.

2.1.8 FABRICATING SPECIMENS

Cutting, welding, and finishing constitute the three procedures involved in fabricating steel beams. Cutting involves using saws or other cutting tools to shape the steel to the desired length. The process of joining separate steel parts using a high-temperature welding operation to create a sturdy, long-lasting junction is known as welding. The final step in finishing is sanding any rough welds or edges to create a smooth, usable surface. For the necessary arrangement of the materials, two numbers of CR2 sheets of grade IS513 were purchased, and the machines were used for cutting and folding the sheets. The folded sheets were TIG welded separately from the connecting sigmas and channels, then painted for aesthetics.

2.1.9 EXPERIMENTAL SET-UP

The built specimens were placed above the supports and the point loads were retained above the beam in a loading frame with a 500 kN capacity. I-Beam is positioned above the constructed specimen to distribute the load ultimately. A hydraulic jack is used to apply the load, and manual deflectometers were positioned beneath the beams to record the deflection values.

2.1.10 FOUR-POINT LOADING

A common method for analysing the flexural behaviour of materials, especially steel beams, is to set up an experiment and test it under four-point stresses. In the experimental setup, the test specimen, in this example a steel beam, is positioned on two supports that are spaced a predetermined amount apart. The specimen is then loaded with a force at two locations, typically spaced equally apart from the supports, in order to create a bending moment. The steel beam deflects as a result of the bending moment, and displacement sensors or LVDTs are used to measure the deflection. In order to determine the flexural behaviour of the material being tested, including the yield strength, ultimate strength, and deflection characteristics, load and deflection measurements are collected at regular intervals until the specimen fails. For the purpose of verifying the reliability and security of steel beams used in construction, this sort of testing is essential.

2.1.11 LOAD VS. DEFLECTION

As force is applied to a joint, deflection counteracts the force by absorbing it. The greater the deflection in a joint, the more load and stress it can withstand, which increases the longevity of the joint.

CHAPTER 3

MODELLING AND ANALYTICAL INVESTIGATION

3.1 MODELLING

The entirety of the model was created using their regular proportions; the Sigma profile dimensions adhere to TS EN 1993-1-3 requirements. The dimensions of the sigma sections were designed. The sigma section in this instance is made for a depth of 240mm and a span of 1200mm, or 1.2m. The sigma section was designed to be able to withstand the loads it was expected to carry. The calculations for the design were done using a spreadsheet and a mathematical model, which ensured that all calculations were done accurately and efficiently. This model was also used to determine the sigma section's load carrying capacity as well as its resistance to bending and shear forces. Additionally, the model was used to determine the necessary stiffness of the sigma section in order for it to be able to carry out its intended purpose. A prototype model of such sigma section was made after these calculations were finished so that it could be seen how it would appear in practice. The entire process of creating this model was done with precision and care; every detail was taken into account in order to ensure that it would meet all design requirements and perform as expected. Fig 3.1 represents the values through denotation and table 3.1 shows the clear cut dimensions of sigma.

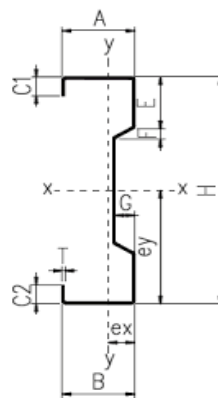


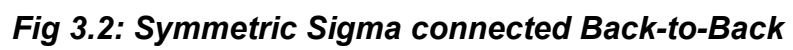
Fig 3.1: Sigma Section Dimensional Denotation

Table 3.1: Sigma Dimensions

Specimen	Units	SSBB	SSTT	MSBB	MSTT
Height	mm	240	240	240	240
Upper Flange Height	mm	60	60	60	60
Lower Flange Height	mm	60	60	40	40
Upper Lip Width	mm	16	16	16	16
Lower Lip Width	mm	16	16	16	16
Connection Surface	mm	65	65	65	E1=65 E2=45
Bending	mm	15	15	15	F1=21 F2=9
Depth	mm	25	25	25	G1=35 G2=15
Thickness	2	2	2	2	2

Four beams made of cold-rolled sheet CR2 have been built and tested, and a complete model has been developed using their standard dimensions. Usage of 2 mm sheets for fabrication, resulting in a total depth of 244 mm and then a length spanning 1200 mm. Tables 2.1 and 2.2 list the specimens' specifications as Symmetric Sigma connected Back-to-Back, Symmetric Sigma connect Toe-to-Toe, Mono-symmetric Sigma connected Back-to-Back and Mono-symmetric Sigma connected Toe-to-Toe. Similar dimensional two sigmas were joined back-to-back in model 1 and toe-to-toe in model 2 by the practice of tungsten inert gas welding, which is likely the mechanism employed for the grade IS 513, CR2 "D" sheets and

is incredibly beneficial with the intention of bending. Comparable channel pieces have been welded to the center line at the top and bottom of connected sigmas. Models 1 and 2 relate to one another in a symmetrical way. Models 3 and 4 are mono-symmetric in nature and have reduced bottom flanges of the sigma section along with different top and bottom channel dimensions. Chemical and mechanical characteristics for the cold-rolled sheet of CR2 are given in accordance with IS 513:2008. Silver-coloured 2mm sheet was used in order to achieve the optimum strength level. Materials were very quickly rusty during fabrication because to the mixing of the materials' makeup with the environment. The specimens were painted once the construction process was complete for aesthetic purposes. A Loading Frame of 500 kN capacity was used to test the specimens. To study the impact of the section's shape on the behaviour of the beam, tests were carried out on both symmetrical and mono-symmetrical specimens. The load was applied until failure happened at a steady pace. During testing, deflection, strain, and load values were recorded at regular intervals. The results obtained from the tests indicated that all four specimens had similar behavior up to a certain point after which they began to diverge. The SSBB and MSTT specimens showed higher load bearing capacity than the SSTT and MSBB specimens. Furthermore, it was observed that the MSBB specimen failed due to lateral torsional buckling while the other three specimens failed due to flexural failure. The results obtained from this study can be used in order to develop a better understanding of cold rolled sheet beams and improve their design process. It can also be used as a reference for future studies related to cold rolled sheet beams with different dimensions and materials. In addition, this study can help inform decisions regarding which type of beam should be used for certain applications depending on their requirements. SS refers to Symmetric Sigma and MS refers to Mono-Symmetric Sigma with toe to toe or back-to-back connections. Fig 3.2, 3.3, 3.4 and 3.5 represents 2D drawing with proper dimensions of SSBB, MSTT, SSTT and MSBB respectively.



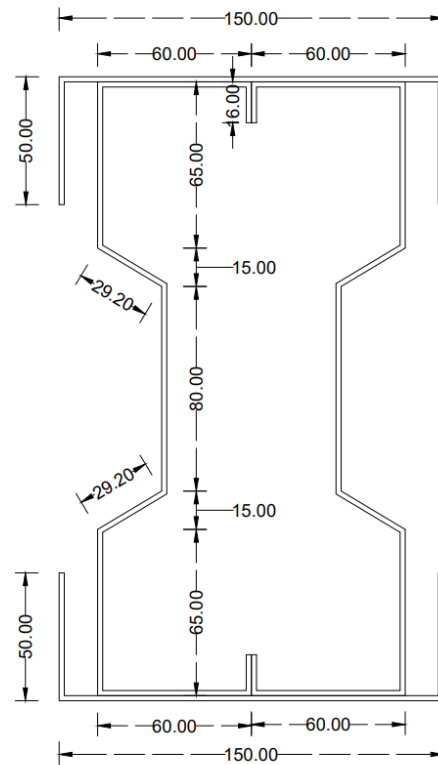


Fig 3.4: Symmetric Sigma connected Toe-to-Toe

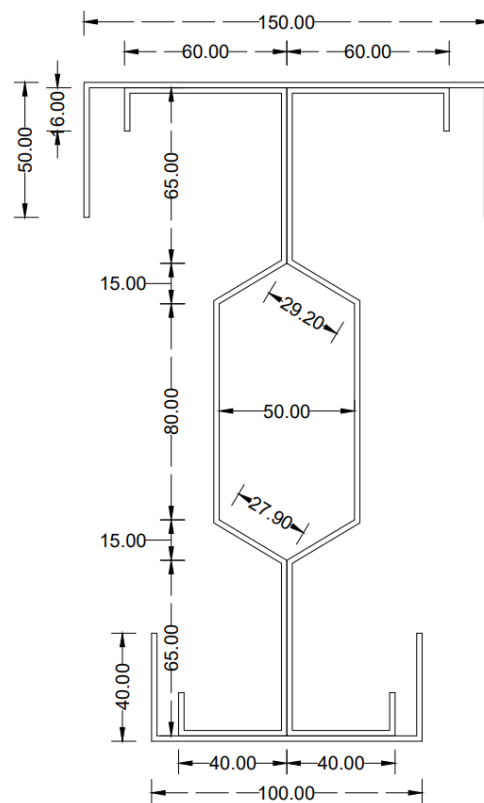


Fig 3.5: Mono-symmetric Sigma connected Back-to-Back

3.2 GEOMETRY

The geometry of the specimens was modelled in ABAQUS Design Modeler with the help of a 3D modeler. The 3D modeler was used to capture the exact dimensions of the specimens, ensuring that all measurements were accurate and precise. The fig 3.6, 3.7, 3.8 and 3.9 shows the geometry of the Cold Rolled Beam, SSBB, SSTT, MSBB and MSTT respectively, including their length and width as well as other features such as curvature or protrusions from their surface. All of these features were accurately modelled Design Modeler to allow for a precise simulation of each specimen's behaviour under different loading conditions. to develop an explicit model. There are 11 significant steps that must be covered when designing such a structure, and Abaqus is the best tool for the job. The part or section should be deformable-shell-extrusion in the designing area. Implement a homogeneous shell and create properties for our chosen actual content such as density, elasticity-modulus, young's and poison ratio. Edit the field output as necessary by bringing together the model's components or portions. By establishing MPC constraints for beams, in contact. The numerical outcomes of applying load and assigning mesh control the beam deflection are explicitly demonstrated. In order to develop an explicit model, there are numerous steps that must be covered.

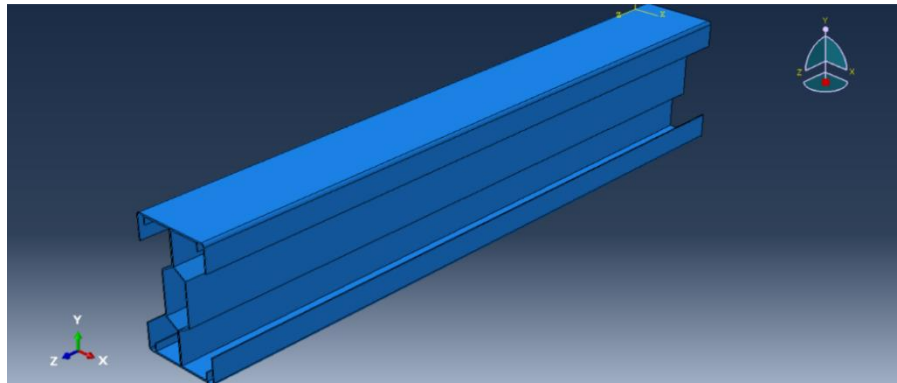


Fig 3.6: Geometry of SSBB

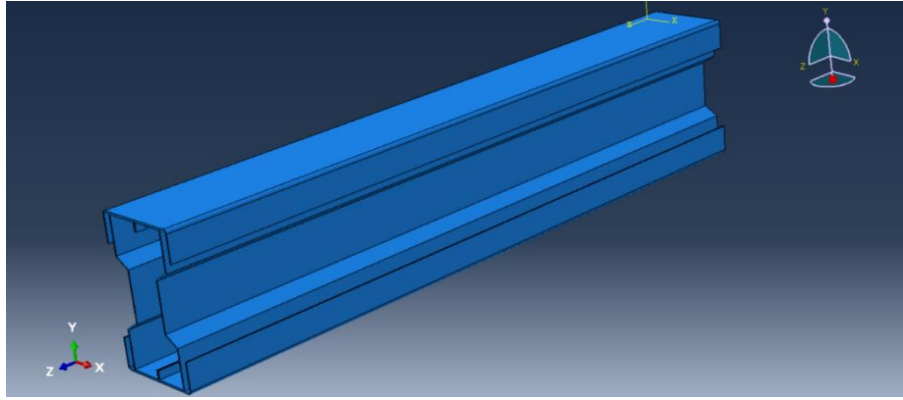


Fig 3.7: Geometry of SSTT

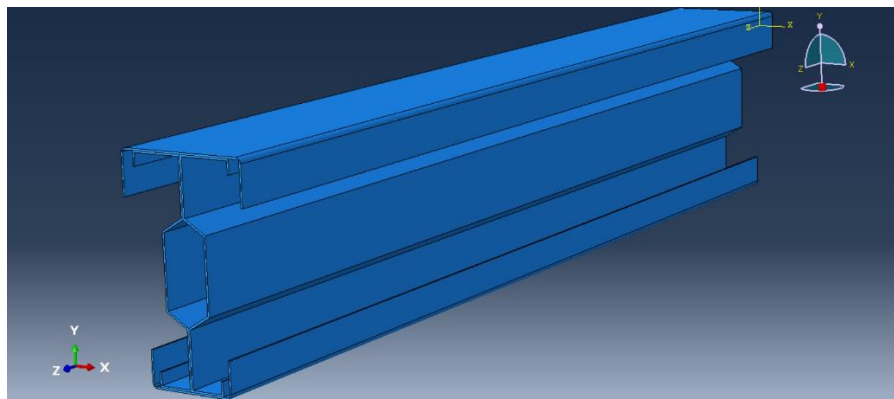


Fig 3.8: Geometry of MSBB

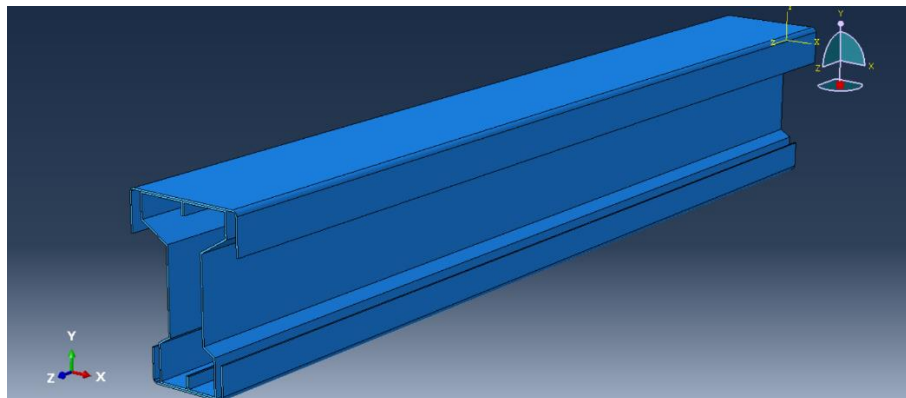


Fig 3.9: Geometry of MSTT

3.3 MATERIAL PROPERTY

The mechanical characteristics of cold-rolled sheet according to code IS 513:2008. The term CR2 Drawing is used for this work. The material property panel for Grade IS 513 CR2 is depicted in the table 2.1 and 2.2. It shows that the

yield stress, tensile strength and elongation of the material are all enhanced due to cold rolling process. A coupon test was conducted to find the tensile strength of material. The dimensions of the tensile coupon were collected from the ASTM (American society for testing and materials). According to ASTM standards E05 the tensile coupon dimension for a flat sheet is shown in the fig 3.10 and the strip model and its graph of strain vs. strain is depicted in the fig 3.11 and 3.12 respectively.

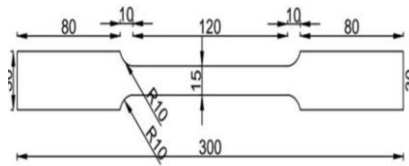


Fig 3.10: Coupon Sample Dimensions



Fig 3.11: Tensile Testing Strip

- Load at Yield: 6.154 kN
- Elongation at Yield: 2.686 mm
- Yield Stress: 205.15 N/mm²
- Load at Peak: 10.384 kN
- Elongation at Peak: 32.942 mm
- Tensile Strength: 346.117 N/mm²
- Load at Peak: 8.658 kN
- Elongation at Peak: 42.533 kN
- Breaking Strength: 288.583 N/mm²
- % Reduction Area: 35.20 %
- % Elongation: 32.94 %

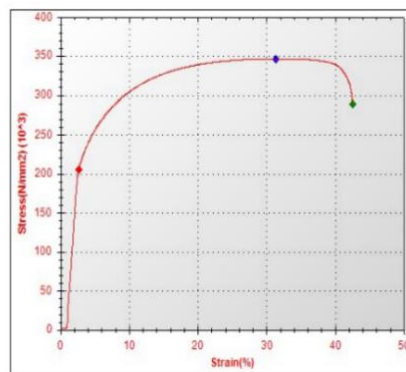


Fig 3.12: Tensile Coupon Sample Stress Vs. Strain Curve

3.4 MODELLING OF MATERIAL

The experimental work, which uses two sigma sections and two channel sectional beams, is simulated in the numerical research. Steel plates with two distinct kinds of aspects (steel component for supporting and steel component for loading plate and solid cold rolled steel element for other specimen components) are used throughout the modelling process for these beams. Two steel plates, which were utilized as supports and to support concentrated stresses on the model, had dimensions of (150X50X10) mm for length, width, and height, respectively. The plates used to assemble the steel, section were represented as solid elements as illustrated in fig 3.13. The elastic modulus and Poisson's ratio were predicted to be 200 GPa and 0.3 respectively, for all plates. The plates had been put together and joined at all the edges. The finite element model is generated and evaluated using software called Abaqus. The axis proportions of the centre segment have been employed to build the FE model. Many different types of finite element analysis were successfully performed. The buckling modes of the beams and the eigen values are identified first from buckling analysis, a linear analysis. Finally, using the Riks approach, a non-linear analysis of load versus deflection is calculated. The FE model was then used to recreate the experimental work using a boundary condition of fixed support at one end of the beam and roller support at the other end. At the centre of the beam, the load was applied as a focused force. The outcomes of the simulations were then contrasted with those of the experiments. The comparison revealed that the numerical and experimental results for both buckling and load-deflection curves were in good agreement. The findings of this study demonstrated that two sigma sections and two channel sectional beams can be used successfully in situations like bridges, buildings, etc. Where construction space is at a premium. The finite element model's correctness was also confirmed by the strong concordance between experimental and numerical results. This study is anticipated to yield useful knowledge on how to utilise such beams effectively while designing constructions with constrained space. Studying other beams or structures for various uses will allow this research to be expanded. Beam with its supports and loading points are shown in the fig 3.13. Fig 3.14, 3.15, 3.16 represents mass density, elasticity modulus and plasticity of the material property respectively.

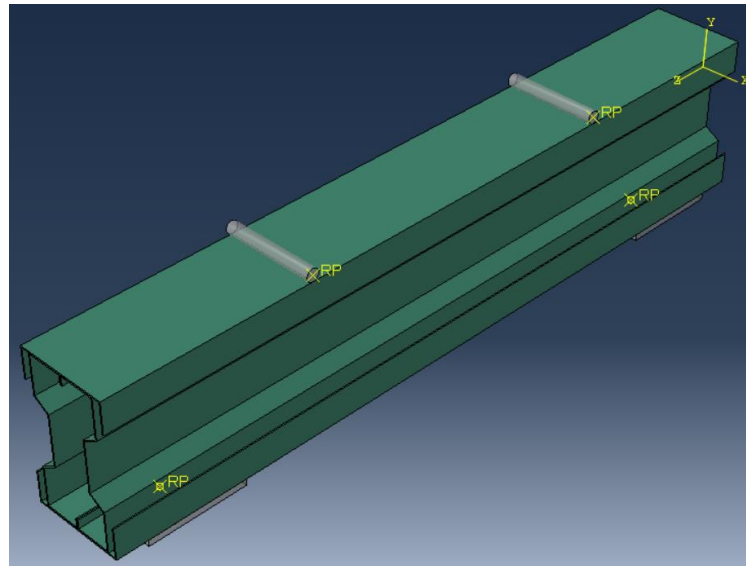


Fig 3.13: Abaqus Model for Control Beams

Density

Distribution: Uniform

☐ Use temperature-dependent data

Number of field variables: 0

Data

	Mass Density
1	7.8E-009

Fig 3.14: Mass Density of the Material

Elastic

Type: Isotropic

☐ Use temperature-dependent data

Number of field variables: 0

Moduli time scale (for viscoelasticity): Long-term

☐ No compression

☐ No tension

Data

	Young's Modulus	Poisson's Ratio
1	200000	0.3

Fig 3.15: Elasticity of the Material

Name: Material-1

Description:

Material Behaviors

Density

Elastic

Plastic

General Mechanical Thermal Electrical/Magnetic Other

Plastic

Hardening: Isotropic

☐ Use strain-rate-dependent data

☐ Use temperature-dependent data

Number of field variables: 0

Data

	Yield Stress	Plastic Strain
1	206	0
2	238	0.02
3	271	0.08
4	301	0.1
5	318	0.12
6	334	0.14
7	343	0.16
8	346	0.18

Fig 3.16: Plastic Modulus of Material

3.5 ASSEMBLY

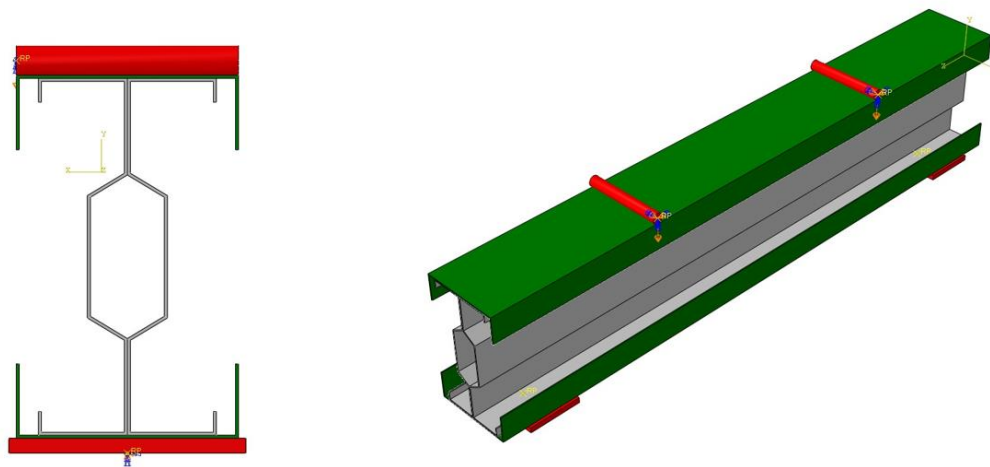


Fig 3.17: Assembly of Symmetric Sigma connected Back-to-Back

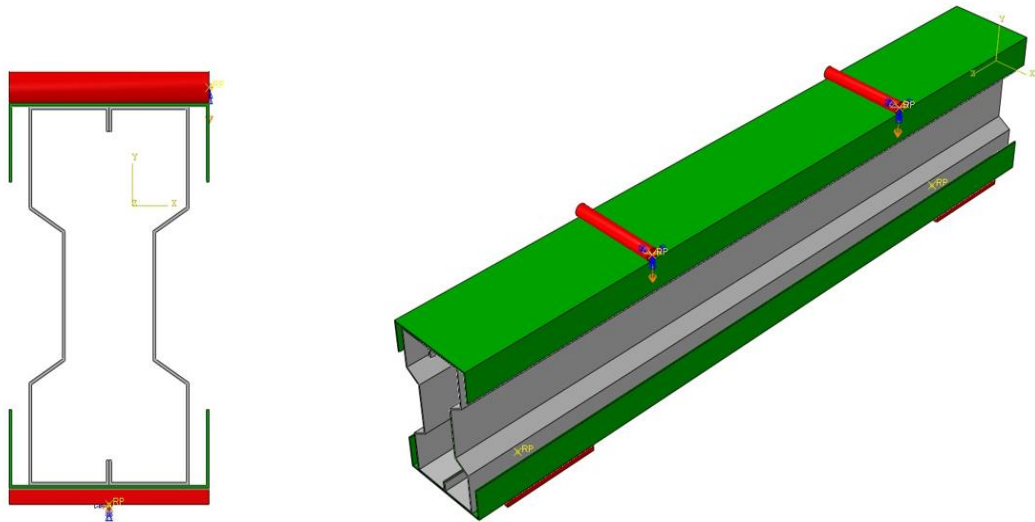
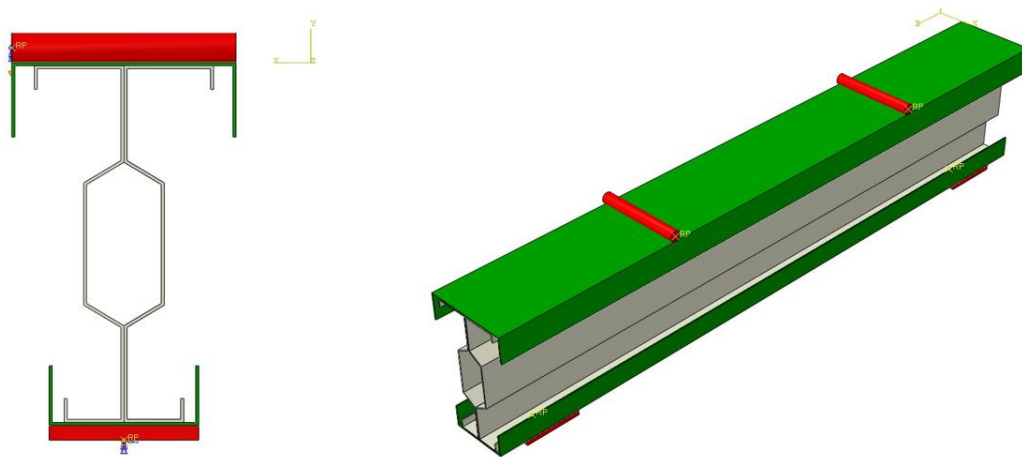


Fig 3.18: Assembly of Symmetric Sigma connected Toe-to-Toe



**Fig 3.19: Assembly of Mono-symmetric Sigma connected
Back-to-Back**

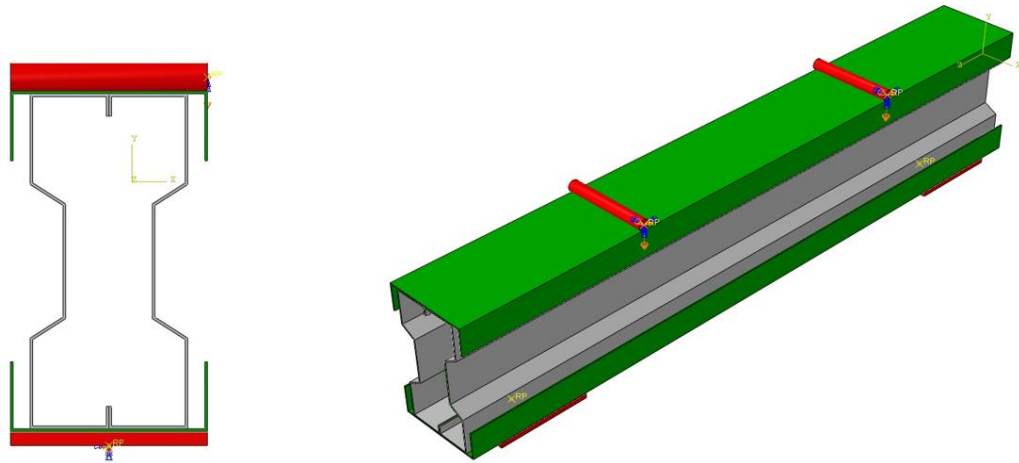


Fig 3.20: Assembly of Mono-symmetric Sigma connected Toe-to-Toe

3.6 BOUNDARY CONDITIONS

Two steel plates were positioned ($L/3$) apart from the supports to guarantee that the models reacted similarly to the trial prototypes. This was done to guarantee that the boundary conditions of the experimental prototypes were met. All specimen models were then constrained using displacement of the boundary condition to determine the correct outcome. Each specimen was restrained in two directions: the z and y axes ($U_z=U_y=0$) at a hinge support placed 50 mm from the beam's end and the y and x axes ($U_y=U_x=0$) at a roller support placed at a distance of equal seen between two. The specimens were also constrained to prevent any vertical deflection, which could affect their performance. Additionally, all specimens were tested under different loading conditions to ensure that they behaved as expected. To further analyze their behavior, strain gauges were attached to each specimen model to measure any changes in their shape or size due to deformation caused by loading. After each test was completed, all data was collected and analyzed using specialized software tools which allowed us to compare our results with those of other experiments conducted on similar materials. With this information, we could make informed decisions about how best to optimize our models for maximum performance and durability. The specimen is put through a four-point flexure test, and the overall amount of deformation is investigated for the imposed force. There are two pins in the four-point flexure. 2 loading pins and 2 support pins. The loading pins are measured for center of reference is where the support pin is positioned. The loading pin is 600mm from the ends on both sides. Following that, a force is

provided to each end of the specimen when it is loaded in the middle of the loading pins. The specimen is subjected to a linear application of force, after which the degree of deformation is determined. The results of this test are used to calculate the material's elastic modulus and flexural strength. In addition to this, other factors such as yield strength, creep strain, and fatigue resistance can be determined from this test. The four-point flexure test is an essential tool for engineers when designing components that require high levels of strength and stiffness. The loading condition is mentioned below in the fig 3.21.

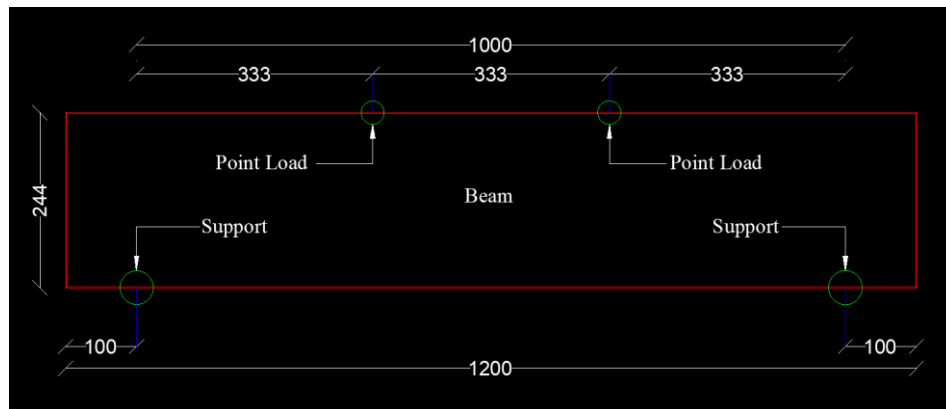


Fig 3.21: Loading Set-up

3.7 MESH OPTIMIZATION

Mesh size selection is important in finite element modelling. Prior to the research, a sufficient pre-analysis of the different mesh densities was carried out to identify the ideal density to provide the required precision based on the complexity of the analysis. Results can converge well if the beam is split up into a large enough number of pieces. This was mostly achieved when reducing the mesh size had little effect on the performance. Convergence studies were performed on open beams with channel and sigma sections and a variety of mesh densities; 900 elements were generated on the channel part and 1200 on the sigma portion. For the entire specimen, 4200 elements throughout total have been synthesized. As a result, the number of grid corresponding to this number—equivalent to 20 mm—was applied in the verified investigation of the analyzed specimens. The numerical outcomes produced by the finite element model were then correlated to the outcomes of the mesh size choices. It was discovered that the accuracy of the numerical findings often enhanced as the mesh size shrank. This was particularly true for models with

intricate geometries and peculiar material properties. Moreover, utilising more elements increased the finite element model's accuracy. It was found that the mesh density had a significant impact on the numerical findings' rate of convergence and that larger mesh densities produced faster convergence rates. Also, it was shown that models with more intricate geometries and material properties possessed accuracy that was improve with a higher element count. In order to ensure reliable results, it is thus recommended to use a high enough number of elements to reach an acceptable level of accuracy. Additionally, it is also important to consider other factors such as boundary conditions and contact conditions when selecting an appropriate mesh size for a given problem. Finally, it is essential to consider computational time when selecting an appropriate mesh size for finite element simulations as well as performing convergence studies with different mesh densities to determine an optimal value. The finite element model showing results is clearly depicted below in the fig 3.22.

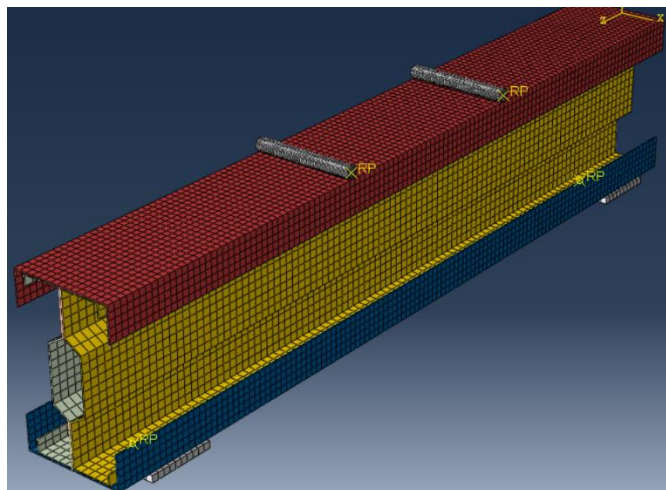


Fig 3.22: Finite Element Model

3.8 INTERACTION CONTACT MODELLING

The connection between the webs and flanges of the back-to-back and toe-to-toe channel sections as well as the sigma section was simulated using "surface to surface" contact. The web and flange of one channel segment were modelled as slave surfaces, while the web and flange of another sigma section were modelled as master surfaces. Between the two contact areas, no penetration was taken into account. Fig depicts how surface-to-surface contact modelling is assigned in a FE

model. The contact properties between the surfaces were assigned in the FE model. The coefficient of friction was assumed to be 0.2 and stiffness was taken as 100 KN/m. The mesh size used for the FE model was 0.5 mm and a convergence criterion of $1e-3$ was set for all elements. The FE model was then solved using an iterative solver, with a maximum iteration limit of 1000. Due to the usage of surface to surface contact, the FE model's results revealed that the stresses in both webs and flanges were less than those found in experimental tests. Furthermore, it also showed that there is an increase in stress concentration at certain points where two or more web/flange surfaces are in contact with each other due to their geometrical imperfections. This could be further studied by implementing a more refined mesh size for better accuracy. Overall, this research demonstrated that surface to surface contact modelling may be utilised to accurately mimic the connection between webs and flanges of back-to-back and toe-to-toe channel sections as well as sigma sections. Surface-to-Surface contact modelling is clearly shown in the fig 3.23 below.

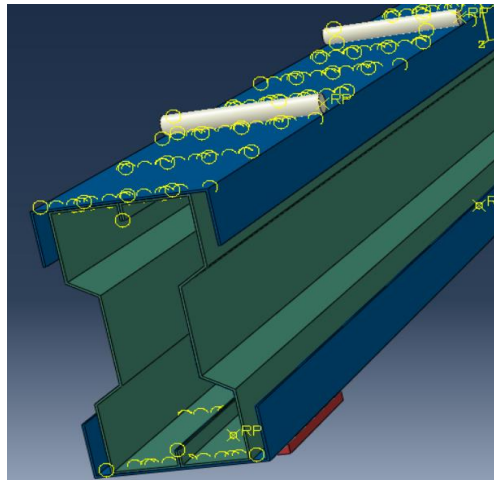


Fig 3.23: Assigning of Surface-to-surface contact modelling

3.9 VALIDATION OF RESULTS

3.9.1 Total Deformation

Calculated for a load of 2 KN which thus accumulates gradually is the total deformation of the beam. The maximum total deformation of the SSBB, SSTT, MSBB, and MSTT is illustrated in Fig 3.24, 3.25, 3.26 and 3.27 respectively.

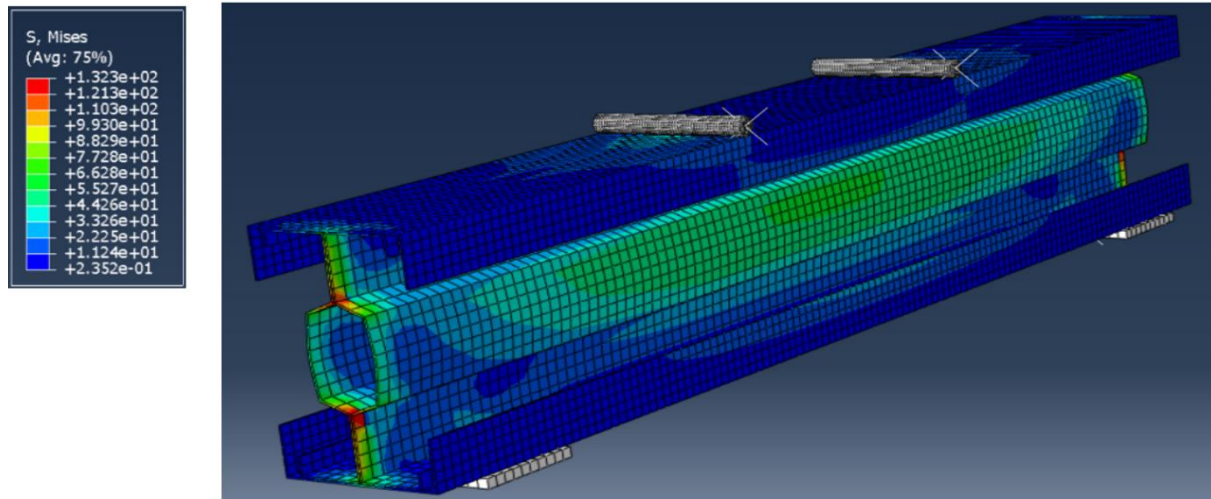


Fig 3.24: Total Deformation of SSBB

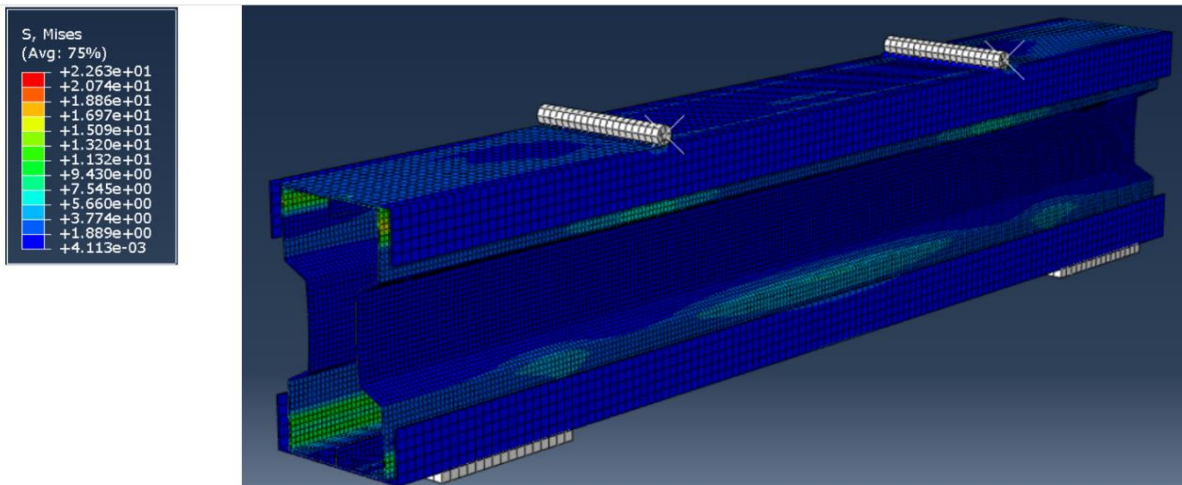


Fig 3.25: Total Deformation of SSTT

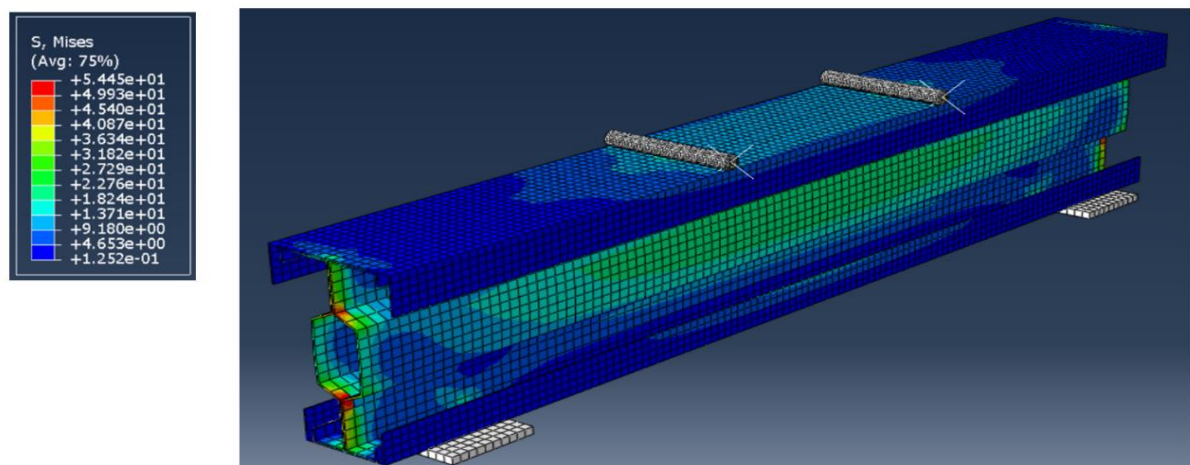


Fig 3.26: Total Deformation of MSBB

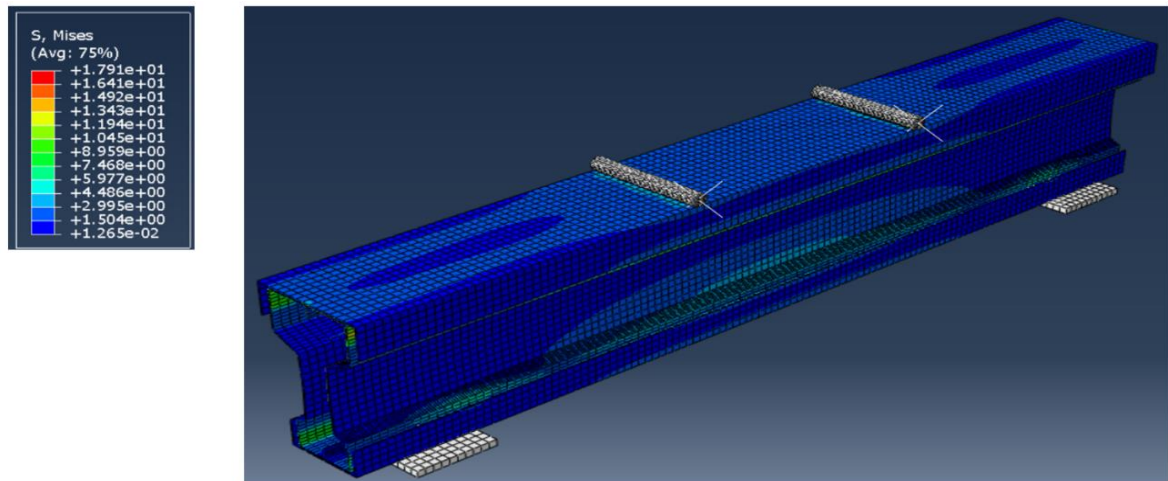


Fig 3.27: Total Deformation of MSTT

3.9.2 Equivalent Stress (Von Mises)

For the load at the yield point, the equivalent stress (von mises) of the beam is derived. The stress concentration of the SSBB, SSTT, MSBB, and MSTT is shown in Fig 3.28, 3.29, 3.30 and 3.31 respectively.

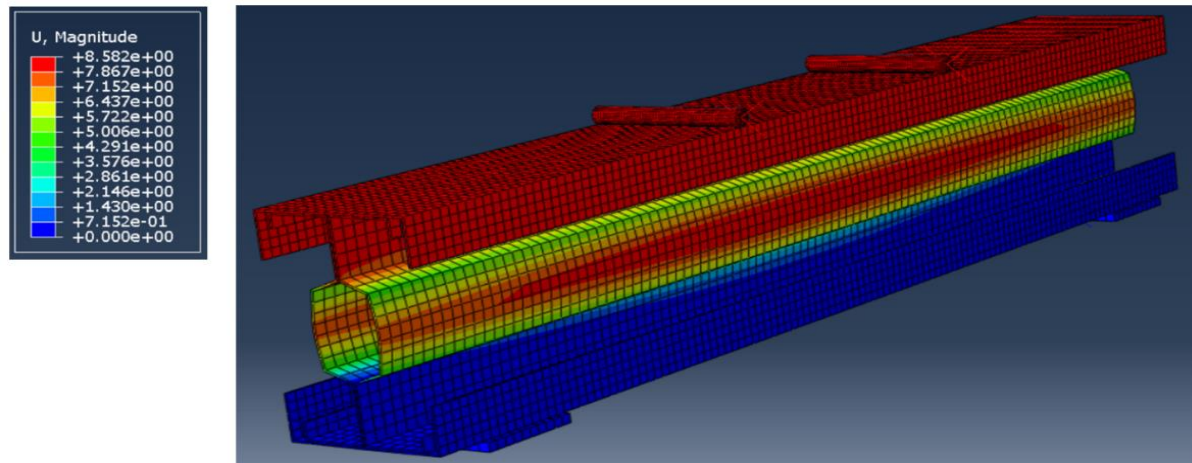


Fig 3.28: Stress Concentration of SSBB

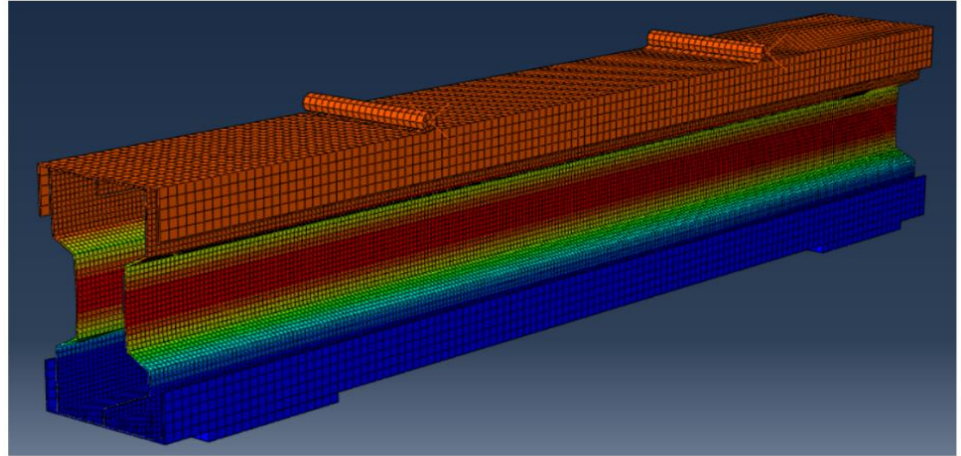
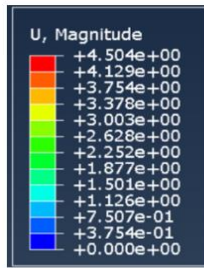


Fig 3.29: Stress Concentration of SSTT

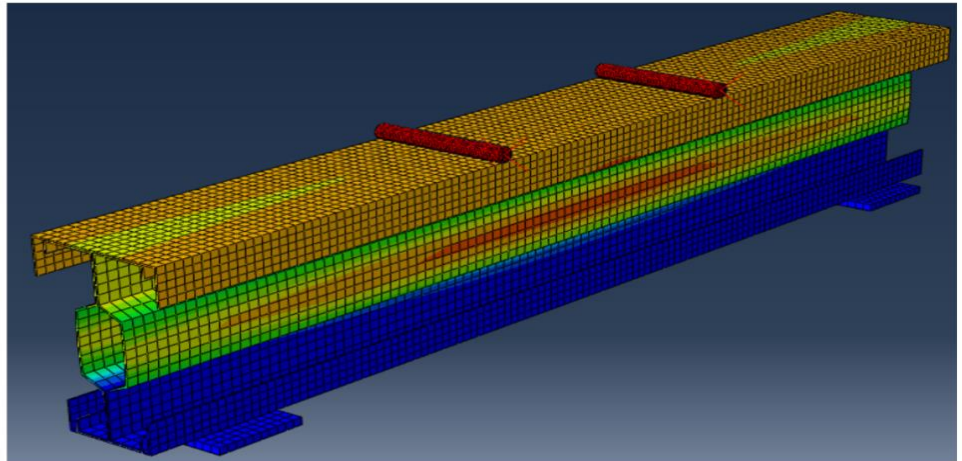
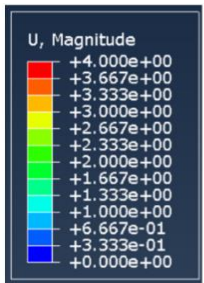


Fig 3.30: Stress Concentration of MSBB

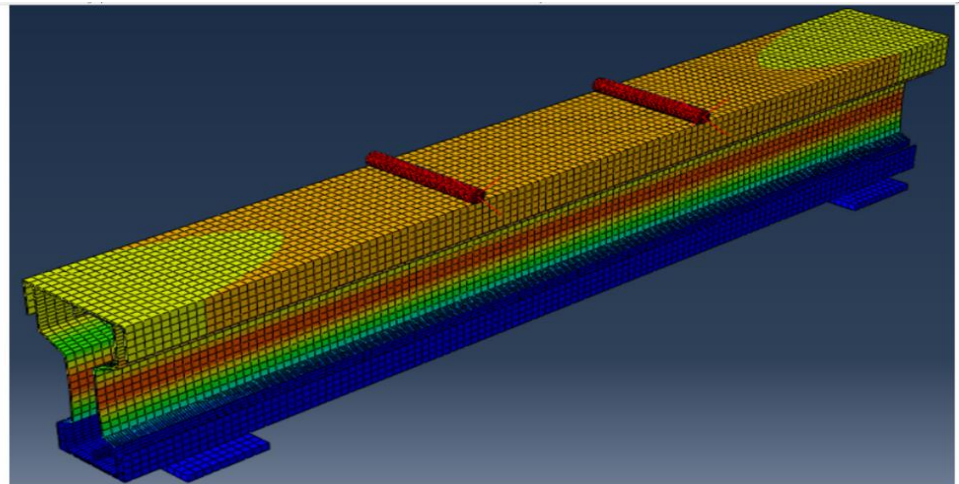


Fig 3.31: Stress Concentration of MSTT

CHAPTER 4

EXPERIMENTAL INVESTIGATION

4.1 PURCHASING OF CR SHEETS

Cold formed steel sheets sized 1200 x 2400 mm are purchased and cut to the precise dimensions necessary for the arrangement. Sheets undergo the process of it being cut after just being marked for their appropriate size. The cold-rolled sheet of grade IS 513 with such a 2mm thickness is depicted in Fig 4.1.

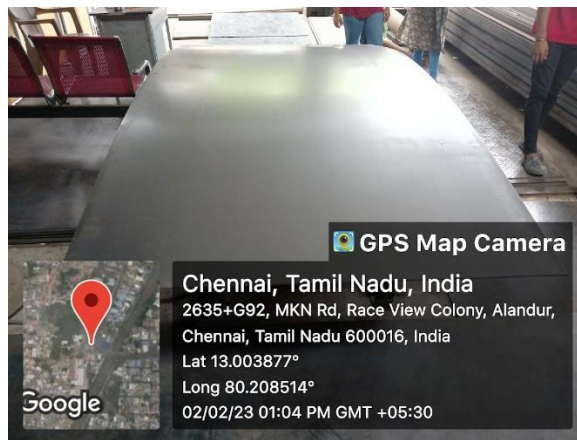


Fig 4.1: Cold-Formed Steel Sheet of 2mm Thickness of Grade IS 513

4.2 MACHINE CUTTING

CR sheet is cut into straight pieces that used a machine. The drawing depicts the cutting machine used to cut the CR sheet. The fig 4.2 depicts the consequence of the CR sheet following machine cutting.



Fig 4.2: Machine Cutting of CR Sheet

4.3 FOLDING OF SHEETS

According to the design specifications, CR sheets have been folded into Channel portion and Sigma section.



Fig 4.3: Folding of Sheets

The four specimens were all altered in the same way, to ensure that the measurements taken from each sigma section were accurate. The alteration involved folding each specimen so that the total depth of the sigma section was maintained at 240mm. This allowed for a more consistent and reliable measurement of each specimen. To ensure accuracy, a series of tests were conducted on each specimen to measure the changes in depth, width and thickness. The results of these tests showed that all specimens had been altered in a similar fashion and that the measurements taken. Fig 4.3 shown the folding of sheets above.

Table 4.1: CR2 Sheet Measured Values in Folding

Specimens	Units	SSBB	SSTT	MSBB	MSTT
Height	mm	240	240	240	240
Upper Flange Height	mm	59	60	58	60
Lower Flange Height	mm	59	60	38	40
Upper Lip Width	mm	18	16	16	16
Lower Lip Width	mm	17	15	17	16
Connection Surface	mm	62	60	62	E1=60 E2=42
Bending	mm	16	17	15	F1=20 F2=11
Depth	mm	27	27	25	G1=34 G2=17
Thickness	mm	2	2	2	2

4.4 WELDING

Welding is the process of connecting two or more metals by heating process. TIG or tungsten inert gas, uses a non-consumable tungsten electrode to create an arc and join metal. It requires the use of shielding gas, most commonly pure argon or argon mixed with helium. The process of TIG welding is one that requires great skill and precision. It is important to ensure that the electrode is held at the correct angle and distance from the work piece, as well as ensuring that the gas flow is consistent. The arc must also be maintained correctly, with a steady arc length being necessary for a successful weld. The filler rod must also be fed into the weld pool correctly, with it being important to ensure that it melts into the weld pool evenly and

completely. The speed of welding and the size of the weld pool must also be considered carefully in order to achieve a strong and reliable weld. Welded sigma sections are shown clearly in the fig 4.4.



Fig 4.4: TIG Welding

Following the welding of two sigmas, the channel and sigma section are connected by drilling a hole from the top/bottom channel to the sigma section at a distance of 75 mm on either edge of the border. The specimen was connected by tig welding in 15 distinct destinations. The specimen is welded and fabricated into a built up I section. The excess weld is grinded, and the beam are painted for aesthetic appearance. The fig 4.4 shows the complete fabricated specimens.



Fig 4.5: Fabricated Beams of SSBB, SSTT, MSBB and MSTT

4.5 TESTING OF BEAMS

The flexural set-up of the experimental investigation work is depicted in shown in fig 4.6.

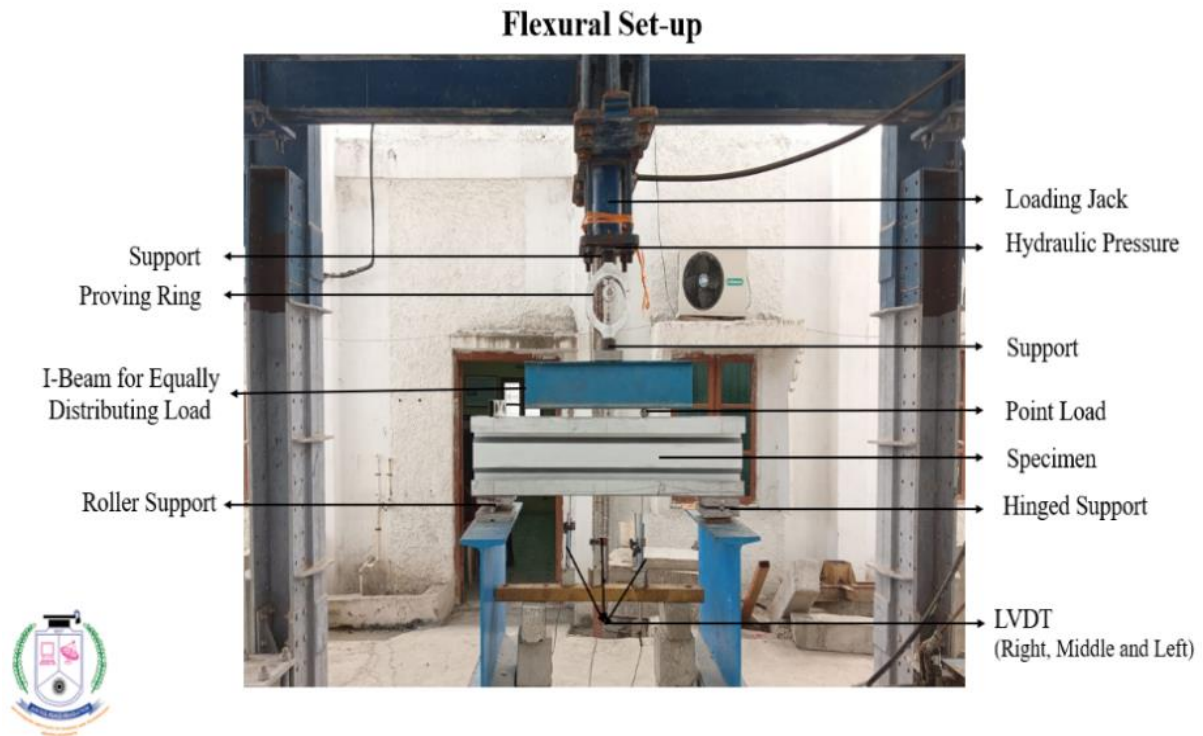


Fig 4.6: Flexural Set-up in Loading Frame

Four-point flexure test was conducted on every specimen. The set up consists of the following

- loading Jack,
- Hydraulic Pressure,
- Proving Ring with Dial Gauge,
- Support, I-Beam for Equally Distributing Load,
- Point Load, End Support (Roller Support and Hinged Support),
- LVDT.

At a distance of 100mm centre to centre from end, the beam specimen is held at one end by a hinged condition and at the other end by a roller condition. A point loads are offered at 333 millimetres in the top of the beam. Placing the proving ring below the hydraulic pressure at a centre of specimen at a distance of 600mm.

To improve the height from the specimen to proving ring we provided a support/weight. Total span of specimen is 1200mm after holding supports there is 1000mm, in which length is divided for $1/3$ and kept for two point loads.

4.6 VALIDATION OF EXPERIMENTAL RESULTS

4.6.1 *Mono-symmetric Sigma connected Back-to-Back*

Attained failure in the welding at a load of 17.699 kN. Weight of the specimen is 22.7 kg. Fig 4.7 and 4.8 depicted the clear image of the beam before and after applying the load in MSBB respectively.



Fig 4.7: MSBB Before Applying Load



Fig 4.8: MSBB After Applying Load

4.6.2 Symmetric Sigma connected Toe-to-Toe

Web buckling attained at a load of 17.699 kN. Weight of the specimen is 24.730 kg. Fig 4.9 and 4.10 depicted the clear image of the beam before and after applying the load in SSTT respectively.



Fig 4.9: SSTT Before Applying Load



Fig 4.10: SSTT After Applying Load

4.6.3 Mono-symmetric Sigma connected Toe-to-Toe

Web buckling found at a load of 16.814 kN. Weight of the specimen is 22.590 kg. Fig 4.11 and 4.12 depicted the clear image of the beam before and after applying the load in MSTT respectively.



Fig 4.11: MSTT Before Applying Load



Fig 4.12: MSTT After Applying Load

4.6.4 Symmetric Sigma connected Back-to-Back

Found web buckling at a load of 17.56 kN. Weight of the specimen is 24.740 kg. Fig 4.13 and 4.14 depicted the clear image of the beam before and after applying the load in SSBB respectively.

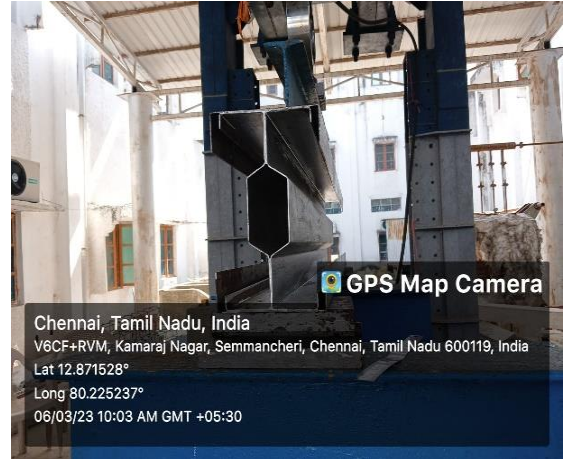


Fig 4.13: SSBB Before Applying Load

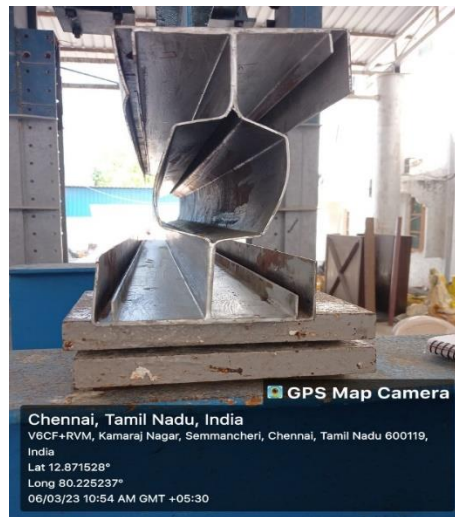


Fig 4.14: SSBB After Applying Load

CHAPTER 5

RESULTS AND DISCUSSION

5.1 ANALYTICAL RESULTS

The yield point is obtained to be 20 kN, 6 kN, 8 kN, 15 kN for SSBB, SSTT, MSBB and MSTT respectively. The load vs. deflection curve for all the specimen by ABAQUS is obtained as per graph in Fig 5.1. Minimum load carries maximum deflection which is seen in SSBB.

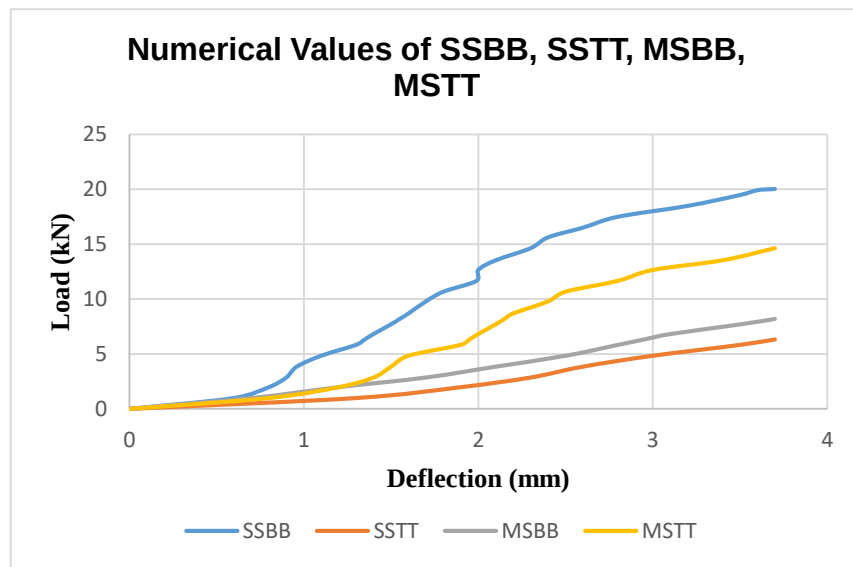


Fig 5.1: Comparison of Analytical Results of SSBB, SSTT, MSBB and MSTT

5.2 EXPERIMENTAL RESULTS

The yield point is obtained to be 20 kN, 6 kN, 8 kN, 15 kN for SSBB, SSTT, MSBB and MSTT respectively. The load vs. deflection curve for all the specimen by experiment analysis is obtained is shown clearly in the graph Fig 5.2. The minimum deflection is seen in SSBB with maximum load.

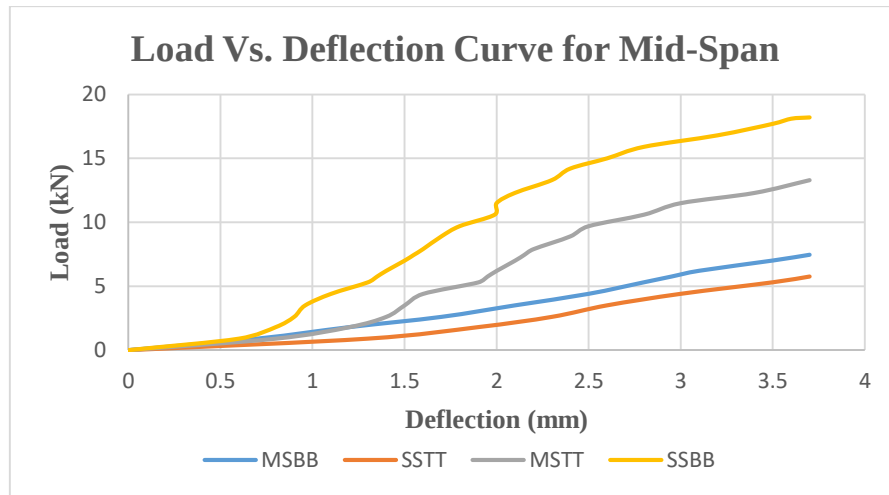


Fig 5.2: Comparison of Experimental Results of SSBB, SSTT, MSBB and MSTT

5.3 COMPARISON OF RESULTS

The yield point is determined to be 20 kN, 6 kN, 8 kN, 15 kN for SSBB, SSTT, MSBB and MSTT respectively, from both Experimental and Analytical Results. The load deflection curve for all the specimen by Experiment and Analytical analysis is shown in Fig 5.3 and table 5.1, 5.2 represents strength/weight ratio and comparison of results between analytical results and experimental results respectively. Fig 5.4 represents the maximum load carrying capacity with respect to maximum permissible limit of $l/325$.

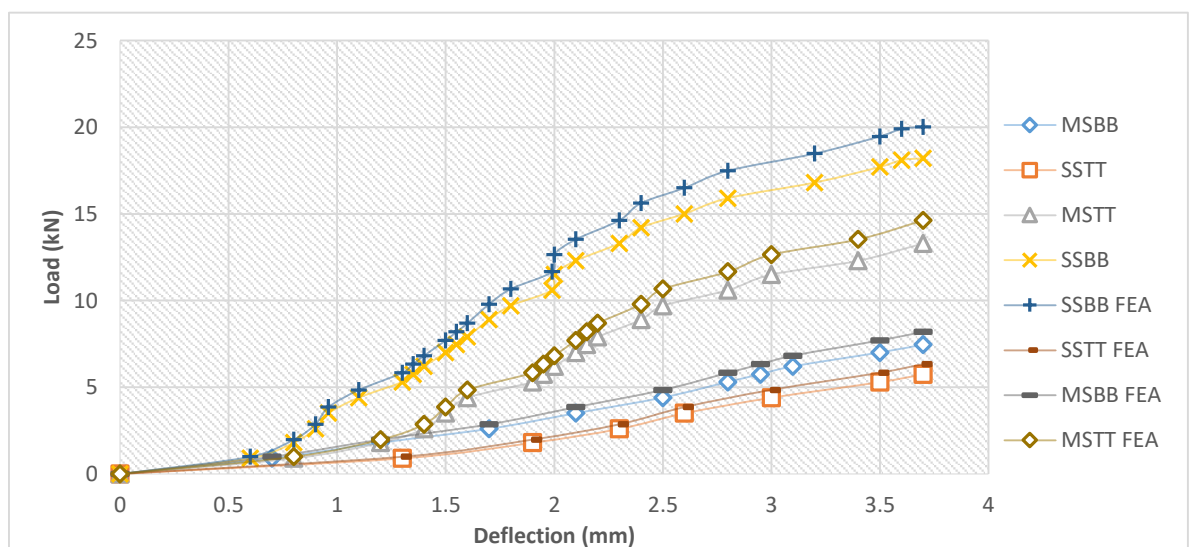


Fig 5.3: Comparison of Experimental and Analytical Results of SSBB, SSTT, MSBB and MSTT

Table 5.1: Strength/Weight Ratio

Beams	Maximum Load (kN)	Mass (kg)	Weight (kN)	Strength/Weight Ratio
MSBB	7.45	22.7	0.222687	33.45503
SSTT	5.75	24.73	0.242601	23.70144
MSTT	13.3	22.59	0.221608	60.01591
SSBB	18.2	24.73	0.242601	75.02021

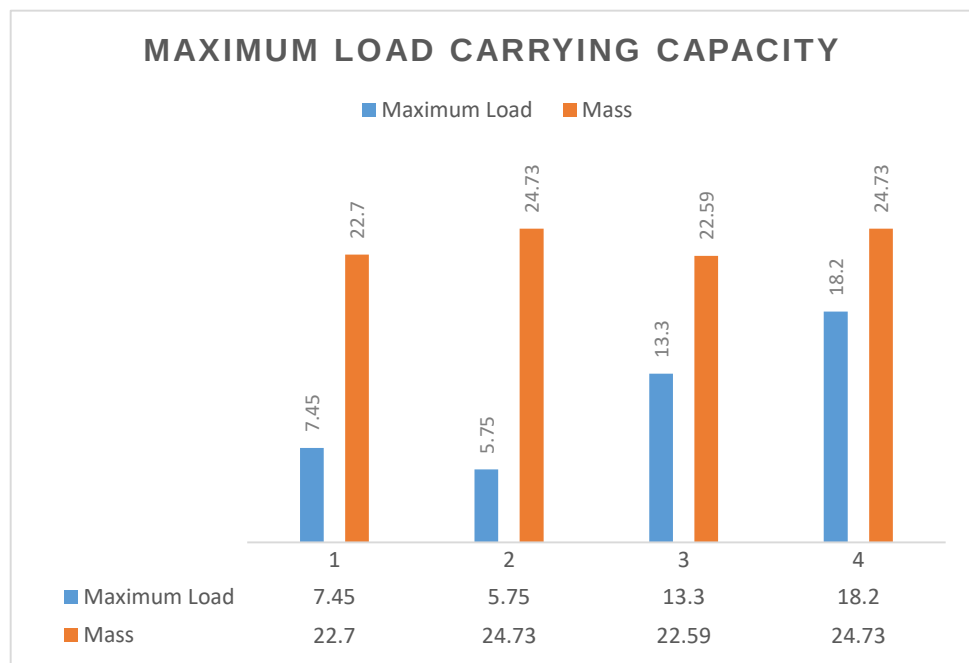


Fig 5.4: Strength/Weight Ratio Bar Chart

Table 5.2: Tabulation of Experimental and Analytical Results of SSBB, SSTT, MSBB and MSTT

LOAD	DEFLECTION							
kN	mm							
	EXPERIMENTAL RESULTS				ANALYTICAL RESULTS			
	SSBB	SSTT	MSBB	MSTT	SSBB	SSTT	MSBB	MSTT
0	0	0	0	0	0	0	0	0
2	0.85	2.1	1.45	1.9	0.85	2.1	1.45	1.3
4	1.03	2.8	2.3	1.55	1.03	2.8	2.3	1.55
6	1.375		3.025	1.975	1.325	3.6	2.875	1.925
8	1.65			2.3	1.525		3.6	2.125
10	1.895			2.65	1.75			2.45
12	2.05			3.2	1.995			2.9
14	2.35				2.2			3.55
16	3				2.5			
18	3.55				3			

5.4 DISCUSSIONS

In experimental and analytical results as per the maximum permissible limit of deflection is obtained. Local buckling for SSBB, SSTT, MSBB & MSTT are obtained. All the beams were tested up to considerable formation of local buckling. However, the beams are compared by the load carrying capacities with respect to permissible limit of vertical deflection as per IS 800:2007. The mass of MSTT is 8.65 % lower than that of SSTT due to reduced width of lower flanges of sigma section in MSTT. However, MSTT carried more load than SSTT by 131% due to increased width of middle portion of web. The mass of MSBB is 8.21 % lower than that of SSBB due to reduced width of lower flanges of sigma section in MSBB. However, SSBB carried more load than MSBB by 144% due to absence of lateral buckling in SSBB but MSBB failed predominantly in lateral buckling. The SSBB beam carried

more load than SSTT by 216% having same mass. The back-to-back connected web portions provided along the major axis of the SSBB beam transferred more load due to increased thickness of web plates. Bulging and separation of web portion of sigma section has been observed in local buckling failure in the symmetric segment. In Mono-Symmetric Back-to-Back connection along with a bulging of sigma section lateral buckling is occurred in the top flange. With mass being constant, The MSTT beam carried load more than that of MSBB by 78%. This is due to the opening of sigma sections in the box region of MSBB. In the web section of the symmetric sigma connect back-to-back, local buckling is seen. Following this specific stress, lateral distortion occurs along the x-axis. Due to insufficient welding, the top and bottom of the sigma section separated from the joints of the web opening. The web section of the mono-symmetric sigma coupled toe-to-toe exhibits local buckling. Lateral distortion in the x-direction is examined once a specific load is applied. Welding or providing stiffener can be used to resist lateral distortion. Spot welding or giving stiffeners to fill the space in the sigma from top to bottom can be done in beams when sigmas are connected Back-to-Back and Toe-to-Toe. Because our beams spans 1200 mm and the maximum permissible limit of deflection is $l/324$, according to IS 800:2007 with revisions, the maximum deflection is 3.7 mm. The results of the study indicate that the structural behaviour of sigma sections and channel sections is highly dependent on the thickness of the web and flanges, as well as the aspect ratio of the cross-section. The most economic section in terms of Strength/weight ratio is SSBB and the second most economic section is MSTT with a 36.8% reduction in load-carrying capacity.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

- The structural behaviour of cold-formed, thin-walled closed built-up beams, which consists of sigma sections [3] and channel sections were investigated in this paper. Nonlinear shell FE models were first developed in the finite element package ABAQUS [14] for CFS closed built-up beams predisposed to local buckling.
- Prior to four-point bending tests, all test specimens had their initial flaws measured. For each test specimen, the failure modes, moment capacity-displacement behaviour, and distorted patterns at failure are addressed.
- In investigations with sigma separation, specimens of the web part of the non-welded sections exhibited lateral-torsional buckling. The FE models were validated against reported test results in the literature. The finite element analysis parametric study was extended to built-up beams with different cross-section geometries, aspect ratio, and plate slenderness of the compression flange and yield stress values were chosen for local buckling failure, yield stress was varied from 250 to 550 MPa.
- The results of the study indicate that the structural behaviour of sigma sections and channel sections is highly dependent on the thickness of the web and flanges, as well as the aspect ratio of the cross-section.
- The most economic section in terms of Strength/weight ratio is SSBB and the second most economic section is MSTT with a 36.8% reduction in load-carrying capacity.
- In conclusion, SSBB beam, which is better employing in the field as an intermediate beam for a roof construction, can be a significant beam that carries weight and distributes to the columns if the span is smaller than typical.

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ABSTRACT

The study on the flexural behaviour of cold-formed steel built-up beams using Sigma and Channel sections is carried out experimentally and analytically. In light gauge steel structures, flexural members are generally made of I sections and Box sections. The built-up sections are designed with channels acting as flanges and sigma sections acting as webs. These sections are taking the forms combining both the I section and Box sections. Four categories of built-up sections are modelled using Abaqus CAE software. According to the American Society of Testing and Materials (ASTM), the Coupon test is conducted to determine the mechanical properties of steel sheets. The sections are fabricated out of 2 mm thick sheets and welded using Tungsten Inert gas (TIG). Based on the outcomes of the finite element analysis performed using ABAQUS, 4 sections are fabricated. The beams are experimented under a four-point load test in the loading frame of capacity 500 kN to study their flexural behaviour. As a result, the load vs. deflection pattern for all specimens is plotted and compared with the numerical results. In addition to it, the buckling mode of failure is observed and compared with the predicted mode of failure obtained from the Abaqus software. The results are validated and inferred to summarise the suitability of each beam based on their load-carrying capacities and strength-to-weight ratio.

Key Words: Cold-Formed Steel, Grade IS513, Flexural Behaviour, Abaqus, TIG Welding, Built-up Sections.

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LIST OF ABBREVIATIONS

FEM	Finite Element Method
TIG	Tungsten Inert Gas
CR2	Cold-Rolled Sheet
FEA	Finite Element Analysis
SSBB	Symmetric Sigma connected Back-to-Back
SSTT	Symmetric Sigma connected Toe-to-Toe
MSBB	Mono-symmetric Sigma connected Back-to-Back
MSTT	Mono-symmetric Sigma connected Toe-to-Toe
kN	Kilo Newton
mm	Millimetre
Kg	Kilogram