

Flexural Behaviour of Cold-Formed Ferritic Stainless Steel Build-Up Joist

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering in
Civil Engineering

by

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Dinesh Kumar M (39200013)**, **Harikaran A (39200018)**, and **Saran Kumar M (39200035)**, who carried out the project entitled "**Flexural Behaviour of Cold-Formed Ferritic Stainless-Steel Build-Up Joist**" under my supervision from December 2022 to April 2023.

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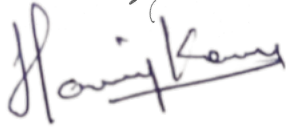
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DECLARATION

We, hereby Dinesh Kumar M (39200013), Harikaran A (39200018), and Saran Kumar M (39200035), declare that the Project Report entitled “Flexural Behaviour of Cold-Formed Ferritic Stainless-Steel Build-Up Joist” 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

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ABSTRACT

A number of reasons have led to the increased use of stainless steel in construction, because of its corrosion resistance, pleasing aesthetic appearance, and favourable material properties. In addition to its high Nickel content of approximately 8-10%, these products have a higher initial cost but lesser maintenance cost. There are different grades of stainless steel depending up on the composition of chromium and nickel. These grades offer the advantages of stainless steel, such as functional qualities and design. It should therefore be noted that ferritic stainless steel may be an alternative material for structural purposes due to its good formability and ductility. The cold-formed Ferritic stainless open web steel joists are investigated experimentally as well as analytically to examine their flexural behaviour. The four sections are fabricated using ferritic stainless-steel grade EN-1.4016/US-430 in accordance with Eurocode standard codal provisions. Using (ABAQUS/CAD), a finite element software, was able to create and shortlist the stronger built-up sections under four -point static loading. As part of the validation process of finite element analysis using software, the failure pattern of local buckling, load carrying capacity, deflections and lateral torsional buckling of four built up sections are compared with the experimental results.

Key words: Joist, Ferritic Stainless Steel, EN-1.4016, ABAQUS, Flexural Behaviour, Trapezoidal Section, Lateral Torsional Buckling.

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LIST OF ABBREVIATIONS

ACRONYMS	ABBREVIATION
mm	Millimetre
kN	Kilo Newton
%	Percent
F _y	Yield Stress
F _u	Tensile strength
TSJ	Trapezoidal Steel Joist
ISJ	I Steel Joist
TIG	Tungsten Inert Gas
WD	Diagonal Web Member
WV	Vertical Web Member
kg	Kilogram
CAE	Computer Aided Engineering
FEM	Finite Element Mode
N	Newton

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Steel has been a frequently used construction material with the development of efficient production methods such as the Bessemer process, that steel was produced on a mass scale in a cost-effective manner. Structural steel which is one of the basic materials used by structural engineers has exceptional strength, stiffness and ductility properties. These properties enable the steel to be readily produced in an extensive variety of structural shapes to meet the diverse requirements of a wide range of application. Characteristics such as strength, durability and temperature resistance can be tailored by appropriate selection of production process and material used in an alloy.

The steel structure may be divided into two categories namely, the structures constructed mainly of surface elements like steel sheets or plates, such as tanks, chimneys, roof covering, claddings, etc., and framed structures fabricated from linear elements such as tension, compression, and flexural members like rigid frames and trusses, etc.

1.2 COLD-FORMED STEEL

The steel is considered to be the most versatile of structural materials in view of its many desirable properties such as High strength-to-weight ratio, Invariability of properties, Elasticity, Long service life, Weldability, High toughness, Easy of alternation in existing structures, Construction advantages. And in general, steel has the following disadvantages High maintenance cost, High fireproofing cost, Susceptibility to buckling, Susceptibility-to-fatigue fracture, Residual stresses.

1.3 APPLICATIONS OF COLD-FORMED STEEL

Their extensive use worldwide is due to their versatility and suitability for range of lighter load bearing application. They are generally used for floor decking, built-up sections for primary beams, and building frames and bridges. Besides building industry, they are employed in motor vehicles, railway coaches, aircrafts, ships, grain bins and agricultural machinery. The manufacture of distinctive profiles coupled with attractive coatings have resulted in availability of highly pleasing design that can be used in practically every sector of building construction.

1.4 STEEL JOIST

The general term open web steel joist is named as OWES. It consists of couple of steel angle sections welded together to perform as a top chord and bottom chord which is assembled parallel to each other and the both members are attached together with the help of series of diagonal and horizontal web connectors.

The flexibility of their spans is improved for builders because to their enhanced strength. They can reach greater spans more effectively while perhaps removing the need for load-bearing interior walls, which can lower the total construction cost. On-site alterations are not necessary since Metal Web Joists are produced to size in-house. Since there is no need for drilling or notching, open web structures are incredibly popular with tradespeople. Additionally, bigger services like Mechanical Heat Ventilation Recovery systems may be accommodated by this framework. Since no on-site modifications are required, as was already noted, installation may proceed quickly.

Steel joists with open webs, also known as "bar joists," are extensively used as efficient structural components to hold roofs and platforms. Despite not being classified as structural steel; they are made solely by different proprietary structural member makers. The Steel Joist Institute (SJI) was founded in 1928 to ensure the quality and safety of these joists. It is responsible for establishing

standards for the design, production, and building of joists. SJI standards compliance guarantees that manufacturers satisfy the quality and safety criteria for construction projects. steel joists with open webs have numerous benefits over other structural components. For starters, they are lightweight but extremely strong, making them an excellent option for construction tasks. They are also adaptable, intended to meet the requirements of specific projects.

1.5 FERRITIC STAINLESS STEEL

Based on their chemical composition, stainless steels are divided into five major groups: ferritic, austenitic, martensitic, duplex, and precipitation-hardening. Austenitic stainless steels are the most frequently used in building due to their high ductility and acceptable mechanical strength.

Ferritic stainless steels, on the other hand, have a minimal chromium concentration of 10.5% and contain little nickel. This makes them price steady and affordable alloys than austenitic stainless steels. Despite their low nickel content, ferritic stainless steels provide an excellent mix of mechanical and corrosion-resistance characteristics, have a greater 0.2% proof stress in the annealed state, and are simpler to work and process than austenitic. Furthermore, comparable corrosion resistance to some austenitic grades can be obtained by raising the chromium content and including alloying elements such as molybdenum and niobium without sacrificing the original material cost.

By adjusting its chemical composition, stainless steel can meet a variety of requirements in terms of strength, corrosion resistance, and ease of fabrication. While austenitic stainless steels are frequently used in construction, ferritic stainless steels can be a viable alternative due to their lower initial material cost and good mechanical and corrosion resistance. Furthermore, by adjusting the alloying elements, ferritic stainless steels can achieve corrosion resistance comparable to some austenitic grades without sacrificing original material cost. As a result, when selecting stainless steel for a particular application, specific requirements and constraints such as mechanical and corrosion-resistant properties, fabrication ease, and material cost should be considered.

1.6 LITERATURE REVIEW

Karthik et al., (2022) conducted an investigation TIG technique and variable welding linear energy confined within the range of 45 J/mm to 80 J/mm to assess the structure and hardness of the heat affected zone and that of the weld in thin butt joints (1.0 mm) composed of Inconel 718. The test joints were put through optical inspections, macro and microscopic metallographic examinations, structural studies made using scanning electron microscopy, and hardness testing. The breadth of the weld and that of the HAZ (in the joints submitted to macroscopic examinations) increased as welding linear energy increased within the selected range. The joints formed with the greatest linear energy, 80 J/mm, showed the maximum widths of the HAZ, the weld face, and the weld root.

Karthik et al., (2022) conducted a study to evaluated the flexural response of cold-formed ferritic stainless steel closed-section built-up beams. The mechanical properties of the steel were assessed using coupon tests, which indicated an average Young's modulus of 213 GPa and ultimate strength of 407.5 MPa. The results suggest that the ferritic stainless steel tested is suitable for use in structural applications, as it exhibited good strength and ductility that met the criteria specified in EN 1993-1-4. The study provides valuable insights into the mechanical properties of ferritic stainless steel and its potential use in structural design.

L. Li et al., (2022) conducted a study that included a series of four-point bending tests and comprehensive parametric research to explore the flexural behavior of CFFSS SHS/RHS beams. The findings suggested that stainless-steel elements subject to bending can meet the slenderness limitations of EN 1993-1-4, while those subject to compression can meet the slenderness limits of 28.38.2 and 51 for classes 1, 2, and 3. The moment capacities for CFFSS SHS/RHS beams indicated by current design provisions were found to be fairly conservative. The study contributes to the understanding of the flexural behavior of CFFSS SHS/RHS beams and their suitability for structural applications.

Yousefi et al., (2022) conducted an investigation according to the AISI S100 design guidelines, the research evaluated eighteen unlipped channel sections ranging in height from 175mm to 250mm. To transfer symmetrical loads, the IOF

loading setup was used, with back-to-back unlipped channel sections bolted together in the center. The research adds to the development of unified design equations for cold-formed ferritic stainless steel unlipped channel-sections with web holes by providing valuable insights into the web crippling failure behavior of such sections. The results have far-reaching consequences for the design and construction industries.

Chen et al., (2022) conducted the study on fabrication and testing of perforated beams under four-point bending about the primary axis, without any shear failure of the RHS under two-point loading. The specimens were made of EN 1.4003 ferritic stainless steel, and finite element models were created to validate the experimental findings. Perforation had no impact on moment capacity as well as associated curving for hole diameters up to 20% of the web depth, according to the results. These findings add to our knowledge of the structure of cold-formed ferritic stainless steel RHS perforated beams and will have practical uses in engineering.

Behzadi-Sofiani et al., (2022) conducted a study to test the stability of stainless-steel angle sections such as austenitic, duplex, and ferritic stainless steel under uniaxial bending experimentally, and a finite element model was developed to validate the results. They propose two design methods which use the slenderness of members to improve the results and also local torsional buckling will still occur if the angle section goes under minor axis bending.

Borkowski et al., (2022) conducted a study to investigate the behavior of cold formed steel was examined, and a finite element model was also developed to determine the ultimate and post-ultimate behavior of thin-walled sections under eccentric compression. In total, twenty-two lipped channel section columns were tested with different eccentricities ranging from -60 to +60 from the center of the axis. Experimental and numerical results differed almost equally, varying by approximately 6 percent to 10.05 percent.

Pannuzzo and Chan, (2022) The main purpose of this research is to investigate the flexural performance of cold-formed sections with moderate heat-treatment, in particular, to evaluate the contribution of heat-treatment on rotation capacity of beam members and their applicability within the current design

standards total of 12 beam specimens were tested in three-point simply-supported beams configuration under monotonic loading, covering a variety of section slenderness. Width-to-thickness, b/t , and depth-to-thickness, d/t , were chosen as key parameters influencing the rotation capacity. The effect of member slenderness was also investigated. Failure modes, moment-rotation response and strain analysis provided indications about the inception of local buckling and the plastic hinge length. Most of the specimens are classified as class 1 according to Eurocode 3 and as compact section according to AISC 360–16 and, indeed, they easily achieved high rotation level. Yet, rectangular sections showed lower performance compared to the square sections with similar b/t ratio. Therefore, results suggest reconsidering the web-flange buckling interactions in the flexural behaviour.

Wang et al., (2022) investigated the compression behaviour of perforated cold-formed beams-columns with longitudinal web and complex edge stiffeners was experimentally studied between pinned-ends. It contained 16 single section and 8 built-up section specimens, respectively. Under the same conditions, the η of the DC1 section specimens was 20% to 71% higher than the C1 section specimens. The DC2 was 51% to 61% higher than the C2. Under different eccentricity loading (3 mm and 6 mm), the η of the DC2 was 11% higher than the DC1. The results showed that this form of longitudinal stiffeners and built-up sections could effectively improve steel utilization and load carrying capacity. According to the load–displacement curve, under the same conditions, the longitudinal stiffener can obviously resist the elastic deformation of the composite member. In addition, longitudinal stiffeners will cause more stress concentration around the sub elements and holes of the split member.

Dhaarini et al., (2022) conducted a study to investigate the Cold-formed steel beams were tested in this experimental and numerical study under four-point loading conditions, and a total of three castellated beams were compared with one standard I section. These particular cast-aluminum beams were typically employed as auxiliary structures to support floors or serve as bracing to increase the stability of steel structures. The load vs. deflection graph indicates poor performance for the castellated beams based on both test results. The I section's maximum load carrying capacity is 17 kN with a deflection of almost 1.5 mm. The load carried by

beams CRCB-1, CRCB-2, and CRCB-3, respectively, is relatively low at 14, 12, and 10, if we compare the same deflection for other castellated beams.

Hofmeyer et al., (2022) conducted a study about direct strength technique utilised for first generation trapezoidal steel sheeting was examined in the experimental and analytical studies. Models MA1 and MR1 are evaluated for all experiments mentioned in and are not failing by the yield eye mechanism. Each model is enhanced by multiplying by the average of the mechanism's experiment-initiation burden.

Q. Y. Li & Young, (2022) conducted a study to investigate the compressive strength of steel stanchions that were cold-formed was investigated in this study using numerical and analytical methods. It represents a typical sigma section. Bolts were used to join back-to-back sigma parts together in a building procedure. There was a total of four bolts available, two for each side of the mirror axis. The web connections primarily buckled during the loading procedure. A tensile coupon test was used for the Fe model's material property.

Abima et al., (2022) conducted a study to investigate the combined effect of tungsten inert gas and metal inert gas arc in achieving better mechanical and microstructural properties compared with the standalone tig and mig miller welding systems. The combined heat source had a maximum capacity of 400A. According to test findings, the TIG-Mig hybrid junction demonstrated superior tensile characteristics in comparison to TIG welded connections. Its hardness attribute is the lowest. This raises the welding's peak tensile strength and elongation %. Although TIG-MIG welding has a bigger heat affected area than Tig and MIG welding, this is because of the significantly higher exposure to heat treatment.

Liu J et al., (2022) conducted a study with the aid of hot-rolled material and TIG-welded materials, conducted a study to ascertain the small-angle neutron scattering investigation on phase separation in a super-duplex stainless steel at 300 °C. They claimed that TIG welding, particularly when aged over an extended period of time, can encourage phase separation and hardening in super DSS at the application temperature. Higher rates of phase separation are also caused by internal stresses in weldments exerted by the weldment in comparison to the base metal

Liu. H et al., (2022) conducted an investigation into the viability of TIG welding as-cast alloys, assessed the mechanical characteristics and microstructural quality of the welded joints produced by various welding currents. The alloy was successfully welded for the first time. When the welding current reached 100 A, the mechanical qualities of the weld joints were at their best. In comparison to the base alloy's as-cast values, the ultimate tensile strength, yield strength, and elongation were 224.8 MPa, 177.4 MPa, and 9.9%, respectively. These values represent 159.5%, 159%, and 43.8% of those of the base alloy. The welded joint's decreased elongation is within the permissible range.

Karthik and Anbarasu, (2021) conducted a study to investigate the mechanical properties of the steel, coupon tests were conducted according to Australian and Indian standards. The results showed that the Young's modulus and ultimate strength of the tensile coupon findings had average values of 213 GPa and 407.5 MPa, respectively. The study found that the steel's mechanical properties met the ductility criteria specified in EN 1993-1-4, indicating its suitability for use in structural applications. The findings of this study contribute to the understanding of the mechanical behavior of ferritic stainless steel in structural applications.

Zhu et al., (2021) conducted a study to investigate the behaviour of cold-formed steel OHS under bending. Further to this, the applicability of current design methods for engineering design of cold-formed steel OHS beams is assessed. A test programme has been designed to determine the flexural capacity and failure modes of cold-formed steel OHS beams using four-point bending tests. A total of three cold-formed steel OHS beams were tested. The newly generated data was used to evaluate the applicability and reliability of five design methods - European code (EC3), the North American Specification (AISI S100-2016), the Australian/New Zealand Standards (AS/NZS4600:2018), the direct strength method and the continuous strength method. Results show that the nominal moments predicted by the first three existing design codes are unconservative and the reliability indices of these methods are failed to satisfy the target value due to the scattered predictions; whereas, the DSM and the CSM approaches provide more accurate and consistent predictions

Roy et al., (2021) conducted a study to presents an experimental investigation on the flexural capacity of back-to-back built-up CFS channel sections under four-point bending. Two different types of cross-sections were considered and are referred to as BU75 and BU90 In total, 12 tests were conducted and are reported herein. The material properties were determined using tensile coupon tests and initial imperfections were measured for all test specimens. The effect of screw spacing and cross-sectional dimensions on flexural capacity was investigated Using the validated FE model, a parametric study was conducted to study the effect of screw spacing on the flexural capacity of built-up beams It was found that the flexural capacity of the BU75 test specimens increased by 15.6%, when the screw spacing changed from 1900 mm to 475 mm. On the other hand, for section BU90, the flexural capacity of the built-up beams increased by around 8%, when the screw spacing changed from 1900 mm to 475 mm.

Y. Zhou et al., (2021) clearly investigated the experimental tests in this study were conducted at the University of Sydney. A total of eleven welded stainless steel beam specimens were designed and fabricated with three grades of stainless steel. The stainless-steel welding consumables ER2209 and ER316L were used for the fabrication of duplex/lean duplex and austenitic beams, respectively. Gas metal arc welding was employed for all the fabrication with a throat thickness of 4 mm Welded lean duplex stainless steel beams displayed very similar structural responses with duplex stainless-steel beams, in terms of the initial stiffness, as well as the ultimate moment and the shear capacities. Moreover, the investigated specimens fabricated with A304, D2205 and LD2101 stainless steel exhibited great ductility when subjected to bending, and the rotation capacities (R) exceeded 8, which was much more than the classificatio limits (R = 3) for Class

Dissanayake et al., (2021) conducted an analytical study, cold-formed stainless steel has been tested using ABS to find the behaviour of hollow flange sections. It is simply defensible as the top and bottom flanges are made up of hollow tube sections, which are connected using a vertical web connector that is typically a plain sheet. For assigned boundary conditions, both the end supports were considered pin supports, and then the load was applied to the midspan of the

beam. In total, 51 different models of hollow flange sections were observed, with most of the stresses appearing to be distributed within the webs of the rhfb sections and the THFB sections having no clearly visible tension bands as a result of the creased anchoring provided by the flanges.

Gatheeshgar et al., (2021) conducted an investigation on both Experimental and numerical methods which is used to analyses how the cold-formed steel channel section behaved. Plumbing and drainage pipes are supported by this type of channel section. Perforations are typically provided on the section's flange to reduce the amount of material used. In this model, perforation was evaluated at both ends of the experimental configuration, and three different rows of perforation slots were evaluated for the numerical setup. A total of 288 models of straggled slotted perforation were used in this parametric study to take solid web channels into account. The findings indicate that the majority of failure modes take place at the support's edge.

Yan et al., (2021) conducted an investigation about the GTN damage model was used to evaluate ductile fracture simulations in this numerical experiment. The material behaviour of mild steels with a steel grade up to s460 is all that the Eurocodes allow for the steel construction. The S700 cold-formed high-strength steel is used as the basis for calibrating the TN damage model. A linear combination of the Swift model and the Voce model is used to obtain the undamaged material property.

Abou-Rayan et al., (2020) conducted an experimental research, six specimens were evaluated using three different types of controls, for a total of eighteen test specimens. Because the evaluated portions were slender, the experimental findings were gathered using four lateral restraints to avoid lateral torsional bending as an experimental condition, and the aqurate failure pattern was collected. and two failures were gathered from all models: local buckling at the compression flange and external local buckling at the pressure point.

Roy et al., (2020) presented an experimental and numerical investigation on the flexural capacity of back-to-back gapped built-up CFS channel sections under four-point bending. Three different types of cross sections were considered to form the built-up gapped sections: plain channels, channel sections with one web

stiffener and channel sections with two web stiffeners. In total, 18 laboratory tests were reported. The effects of web stiffener, link-channel spacing and gap between the back-to-back channels were investigated on the flexural capacity of the gapped built-up beams. The failure moment capacities, moment-displacement, and deformed shapes at failures are discussed for all test specimens. A non-linear FE model was then developed and validated against these test results. Both the FE and test results were compared against the designed strengths calculated in accordance with the current design guidelines by the AISI and AS/NZS. It was found that the AISI and AS/NZS can be conservative by as much as 27%, while predicting the flexural capacity of such back-to-back gapped built-up beams. This is because the effect of the gap between the back-to-back channels is not included in the design calculations.

Zhang et al., (2020) conducted a study about ferritic stainless steel and austenitic stainless steel were tested to determine the resistance of spot welding by combination of AA, AB, and BB were tested, A 220-Kw medium frequency direct current resistance spot welder was used to perform the welding tests in the similar and dissimilar ferritic AISI 430 and Austenitic AISI 304 stainless steels. Due to its columnar dendritic solidification mode, the nugget of the dissimilar 304/430 nugget has a strong texture consisting of α -ferrite columnar grains, with some γ -austenite and some α' -martensite dispersed over the grains' boundary zone. This mixed-phase nugget displays similar Vickers hardness with the 430/430 nugget but possess higher fracture toughness than its counterpart.

Kucukler, (2020) conducted an experimental study on the flexural buckling behaviour and design of in-situ columns made of duplex and ferritic stainless steel was done. The flange and web plates of the i-section columns were tested using a total of 16 different parts. The thickness of the web plate is given in this case to prevent flange and web plate overlap. Using the Euro code EN-1993-1-4 results in uneconomic and excessively conservative results when compared to the current stainless steel design requirements.

Zhou. x et al., (2019) conducted to investigate the flexural capacity of two different floor joist layouts. The study involved seven floor specimens with a span of 4.8m constructed using C-shaped joists spaced 400 mm apart, with 18 mm thick

sheathing between two 2.4 m long U-shaped spans. The study found that after applying about 70% of the ultimate load, the flange and web of the joist were locally buckled, with some twisting and tilting of screws seen in the top flange of the joist. The findings of FL-1 and FL-2 specimens were validated using screw spacings of 150/300 and 300/600, respectively. The results of this study have important implications for the design and construction of structures using these types of joists. By demonstrating the flexural capacity of different layouts, the study can inform decisions around the placement and spacing of joists to ensure their safe and effective performance under load. The study also highlights the importance of careful experimentation and testing in the field of structural engineering. Through rigorous analysis of the specimens and the validation of findings using different screw spacings, the study provides a comprehensive understanding of the performance of the joists under load. Overall, Xuhong Zhou, et al.'s study provides valuable insights into the flexural capacity of floor joist layouts and their behavior under stress. The findings of the study can be applied to the design and construction of structures, ensuring their safety and durability over time.

Khokhar et al., (2019) Bridging or bracing: is an essential component of the composite joist system that braces the joists against horizontal movement during erection, the placement of building loads, and to firmly stop the joist chords from out-of-plane or lateral movement when other methods are not available. Bridging can be cross, horizontal, erection, construction, stable, or uplift, and it must be anchored to a solid object such as a wall, girder, etc.

Pelletier & Doudak, (2019) In this study they have tested three engineered wood I-joist to find the behaviour of torsional buckling under different conditions. By changing different types of support conditions, the amount of lateral torsional buckling has been reduced significantly but it is not restricted completely

Hou et al., (2018) Using coupon tests to assess the steel's mechanical properties. The tests showed that the Young's modulus and ultimate strength of the steel were 213 GPa and 407.5 MPa, respectively. These results indicate that the ferritic stainless steel is suitable for use in structural applications, as it exhibits good strength and ductility. Additionally, the study notes that the mechanical

properties of the steel met the ductility criteria specified in EN 1993-1-4, a European standard for designing steel structures. Overall, the findings suggest that ferritic stainless steel is a viable material option for building structures.

Arrayago et al., (2016) conducted a study on ferritic stainless steel. The experimental study is to determine the experimental behavior of RHS and SHS beam-columns. In total, twelve specimens were tested. Five different hollow cross-sections have been tested under pin-ended conditions with a nominal length of 1500 mm. In this study, uniform bending moment distributions are provided.

Nguyen et al., (2013) In this work, the compressive strength of steel stanchions that had been cold-formed was examined using numerical and analytical data. This is a commonly constructed sigma section. Bolts were used to join sigma parts back-to-back in a construction procedure. On each side of the mirror axis, a total of four bolts were offered. The web connections buckled the most throughout the loading procedure. A tensile coupon test was used to determine the material property of the FE model.

Kim et al., (2009) This study is proposed to investigate the nonlinear dynamic analysis of two types of models using SAP2000 and ABAQUS software to create 2D and 3D models, respectively. The study involved rotating hinges to evaluate the structural performance in terms of local buckling and determine the rotation moment capacity of the interior and outside columns. Simulation data was used to generate graphs for roof drift and base shear. This research provides valuable insights into the structural behavior of buildings under dynamic loads and can aid in the design of more resilient structures.

Lakkavalli and Liu, (2006) gone through a study about proposed composite longitudinal shear transmission processes between steel and concrete, resulting in surface bonding among concrete and embedded steel C-sections. Three kinds of enhancement prefabricated in the embedded flanges of the bolts were tested and found to be useful to different degrees. The actual ultimate capacities of slab examples were compared to hypothetically computed values based on push-out test findings. The research discovered that the push-out test results were conservative, with the predicted capacity based on push-out test results being roughly 16% less than that of large-scale test results on average. These results

have significant consequences for the construction of composite steel-concrete structures.

Lakkavalli and Liu, (2006) investigated a series of bending and push-out tests was carried out and the influence of the spacing of fasteners and structural adhesive at the interface of board-beam were investigated. It was found that the maximum degree of shear connection achieved by employing the structural adhesive alongside the screws which increased the stiffness and ultimate capacity by 40% and 100% over the bare CFS beam, respectively. In this study, the behaviour of U-shaped shear connector is investigated through a series of push-out tests. This shear connector can be used in the composite CFS beams to accommodate the composite action between concrete slab and CFS beam. In the specimens by 2 mm CFS thickness, the axial tensile force in the screws which was as a result of screws tilting, was critical; therefore the use of the head washer in these specimens can prevent the pullover failure in the shear connection.

EN 1993-1-4: Eurocode 3-(2006) In this code book in table 2.1. It is given that the Ferritic stainless-steel grade 1.4016(430) for cold rolled strip with less than 6 mm thickness the nominal value of the yield strength f_y is 260 N/mm², and the Ultimate tensile strength f_u for structural stainless Steel Will be 450 N/mm². Then in page number 12 the provision for design by calculation given in Part 1.4. if visual distortion of flat elements of the cross-section are unacceptable under the serviceability loading, a limit of b/t is less than or equal to 75 may be applied. The fig clearly state that Maximum width-to-thickness ratios should be less than or equal to 400.

EN 1993-1-4: Eurocode 3-(2006) In the Table A.1. The codebook given a suggestion for grades of stainless steel for atmospheric applications clearly. From the that, it is state that Steel grade EN-1.4016 Ferritic stainless steel should not be used for cosmetic applications and definitely should be avoided. So, as this study towards the investigation on testing for stainless steel joist that can be used for floor purpose as they mentioned that Ferritic stainless steel can be used as indoor applications only for example: In rural area

EN 1993-1-4: Eurocode 3-(2006) For the welding connections codebook suggested that the stainless steel, while welding reduce the corrosion resistance

of steel. This is known as weld decay, It is because of heating and cooling cycle involved in welding affects the microstructure of all Stainless steels, but some grades are affected more than others. So, it is essential that suitable welding procedures and consumables are used and that the welding is carried out by suitable skilled welders. Single sided partial penetration butt welds should not be used in heavily polluted environments or in aggressive marine environments. Intermittent welds should not be used where crevice corrosion is likely to occur.

Lahti K, Hanninen H et al., conducted a study three-point bending nominal stress range fatigue of stainless-steel fillet weld was tested using two stainless steel grand ferritic martensitic and austenitic materials. Especially Ferritic material EN1.4003 have been tested. It has been modified form conventional 12% Cr stainless steel by decreasing the carbon content to well below 0.03%, which is regarded as the limit for low-carbon steels. Then the amount of titanium is limited because of the tendency of titanium to form brittle carbide phase in the heat affected zone of a welded joints. In this study they conclude that if the throat thickness is increased, failure is more likely to occure at the weld tow, Wld tow failure have 59 MPa., which is fairly close to the Eurocode 3 class 56 for a butt-welded RHS Joints.

LoadTables_K_LH_DLH-Series_0820, n.d. Steel joist institute provided a standard load table for open web steel joist and K-Series Joists. Based on a 50ksi maximum yield strength – and all the loads are given in the pounds per linear foot. According to that it is easy to understand the load carrying capacity of the joist span varies from ten ft. to sixty feet. And also, they have provided the Metric Load Table for open web steel joist, K-Series, based on a 345 MPa as maximum yield strength and load are shown in kilonewton per meter

Fortan et al., n.d. conducted a study to describe twenty-four specimens were tested for test the behaviour of welded specimen made of 3 different stainless-steel grads. They are EN 1.4307 (304L), and EN 1.4404 (316L), Austenitic grades and EN 1.4062 duplex grade were tested. The results were compared to 70 experiments on welded stainless-steel samples, gathered from the literature. A relatively high scatter was found among the different sources as well as different between grades and loading directions. A reliability study was then

performed in agreement with EN 1990.2002 Annex D on the complete experimental data pool and recommendations for the correlation factor are then provided.

Tawfic and Amoush, n.d. conducted an investigation in order to determine the compressive strength of axially loaded steel section columns, this study offers both numerical and analytical findings. This is a commonly constructed sigma section. Bolts were used to join back-to-back sigma sections together throughout the building process. There were four bolts altogether, two on each side of the mirror axis. Most buckles during the loading procedure occurred on the web connectors.

Bock et al., n.d used Cold-formed stainless steel which is considered to be the most versatile structural materials in view of its many desirable properties such as High strength-to-weight ratio, Invariability of properties, Elasticity, long service life, weldability, high toughness, easy of alternation in existing structures, construction advantages. Ferritic stainless steel, in particular, consists primarily of chromium (min. 10.5%), leaving nickel as the secondary alloying element. Consequently, they are inexpensive alloy and much stable in price.

1.7 AIM

The objective of this study had four major steps to be followed which are mentioned below in points.

- To create a model for a built-up open web steel joist using Cold formed Ferritic stainless steel.
- To analyses the flexural behavior of steel joist using ABAQUS.
- To test the fabricated steel joist.
- To compare the Finite element model and Experimental test results

1.8 NEED FOR STUDY

There is a need for more research on the use of Joists made of Light Gauge Steel, particularly Trapezoidal Cold Formed Steel Joists. These types of Joists can span very long distances without intermediate supports, reducing the need for beams and lowering project costs. Ferritic stainless 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.
- Joist can be used for very long span without any intermediate supports up to 60' to 96'.
- Instead of beam, I Joist can be used to reduce the intermediate supports.
- That can reduce the total cost of the project.
- Comparatively, ferritic stainless-steel material can reduce project costs more than other stainless-steel materials.
- So, there is a need to study about Trapezoidal Cold Formed Steel Joist.

1.9 SCOPE OF WORK

The scope of the work is to conduct an investigation into Light Gauge Steel Joists using Ferritic stainless-steel material. The main focus of the study will be on the flexural behaviour of the Joists, and this will be analysed using the limit state method. The European Standard provisions will be followed throughout the research project. By conducting this study, a better understanding of the performance of Light Gauge Steel Joists and Ferritic stainless-steel material can be gained, which may contribute to the development of more cost-effective and sustainable construction methods in the future.

- Investigating Light Gauge Steel Joists
- Using Ferritic stainless-steel material
- Focusing on investigating flexural behaviour
- Utilizing the limit state method
- Following European Standard provisions

1.10 NOVELTY

Typical steel joists are made up of horizontal structural members that span an open space, often between beams and joist girders. Which is made up of top and bottom chords that are connected by a single w-shaped web series. In our study, instead of providing a single series of web connections, two series of web

connectors will connect the top and bottom chords. And mainly, the top chord is replaced with trapezoidal sheeting and the bottom chord with the modified lipped channel section. The web connectors are made up of two different members: the diagonal web connectors are equal-angle sections, and the horizontal connectors are unlipped equal channel sections.

Floor joists can fail in a variety of ways, including local torsional buckling. Floor joists can also fail due to shear failure, deflection failure, and bending failure. "Local torsional buckling" occurs when a joist twists out of plane, typically close to the supports, as a result of a combination of bending and torsional stresses. The joist may fail if it was not constructed to withstand this load. To prevent local torsional buckling, floor joists can be designed with a suitable cross-sectional shape and size, and the spacing between the joists can be changed to provide sufficient support. Additionally, proper installation of bridging or blocking can assist in preventing joist twisting.

Bridging, also known as blocking, is a technique for preventing local torsional buckling in floor joists. Bridging is the installation of diagonal braces at mid-span across adjacent floor joists that transfer loads from one joist to another and prevent them from twisting out of plane. The floor joists become more rigid and resistant to twisting and buckling when bridging or blocking is installed. This is because diagonal braces help to transfer and distribute loads between joists, reducing localized stresses that can cause torsional buckling.

Bridging or blocking also helps to keep the joists vertically aligned, which is important for preventing lateral buckling. Lateral buckling occurs when joists deflect laterally as a result of bending stresses, leading to further instability and failure. Overall, bridging or blocking is an effective technique for preventing local torsional buckling in floor joists and should be considered in floor system design and installation.

Because joists 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 joist'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. A joist with a low slenderness ratio is less likely

to buckle and can support heavier loads. if a joist is too slender, it may buckle under compressive loads, causing it to fail. To prevent this, joists are frequently braced or reinforced to increase their buckling resistance. Bridging and blocking can stiffen joists and reduce their effective length, whereas adding flanges or reinforcement can increase the radius of gyration of the joist.

Designing a joist as a non-slender section will have advantages as they can able to support higher loads without the need for additional bracing or bridging. However, Non-slender sections such as trapezoidal joists can completely restrict the lateral torsional buckling without the help of bridging or bracing, even though non-slender sections tend to be heavier and the number of joists required for the span and the use of bridging will reduce the cost of construction.

CHAPTER - 4

METHODOLOGY

2.1 METHODOLOGY FLOW CHART

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

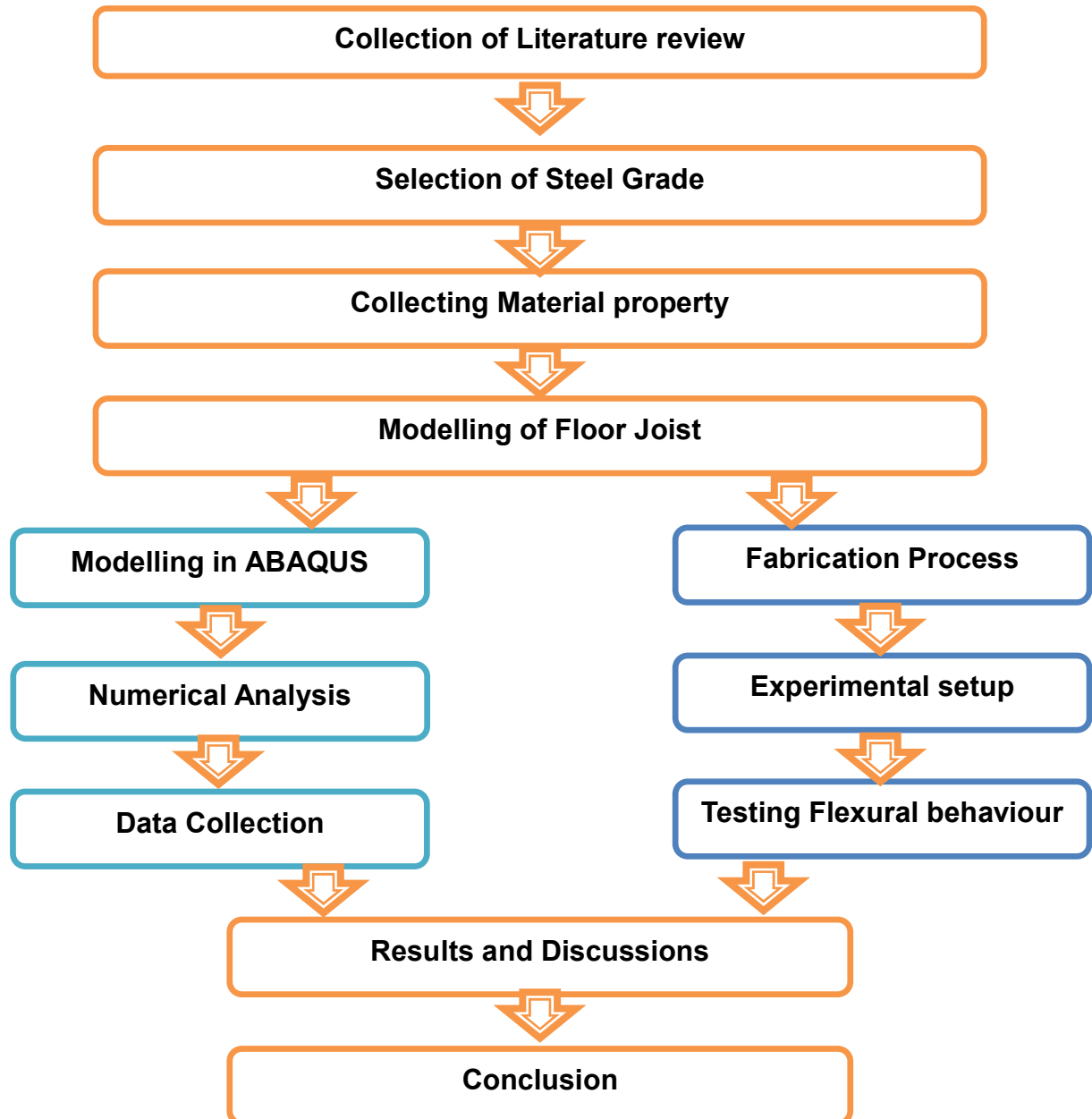


Fig 2.1: Flow chart represents the Methodology of work flow carried

2.1.1 *Collection of Literature Review*

An in-depth literature review has been conducted to determine the gaps in the recent studies. The paper was collected from 2023 to 2000 to gather information and determine the type of field and work for this project.

2.1.2 *Selection of Steel Grade*

There may be a lack of research or studies on the behaviour of ferritic stainless steel in certain applications or environments. By using ferritic stainless steel as the primary material in a study, researchers can fill this gap and provide valuable insights into its behaviour.

Ferritic stainless steel has good structural behaviour, making it suitable for use in various applications, including construction, transportation, and infrastructure. By using it as the primary material in a study, researchers can evaluate its performance and suitability for specific applications.

Ferritic stainless steel has excellent corrosion resistance, which makes it suitable for use in harsh environments, such as marine or chemical processing applications. By studying its corrosion resistance properties, researchers can better understand how it can be used in these types of applications.

2.1.3 *Collecting Material Property*

EN-1.4016 ferritic stainless steel has a density of 7.7 g/cm³ and a melting point of 1420-1510 °C. It normally has a yield strength of 240-270 MPa and a tensile strength of 450-680 MPa. The steel has a Brinell hardness of 155-185 and an elongation at break of 20-30%. Thermal parameters include a thermal conductivity of 26-30 W/(mK) and a coefficient of thermal expansion of 10-12 10(-6)/K. Its electrical resistivity is normally between 0.6 and 0.7. These values are provided or collected from the nominal values provided on the Euro code books.

2.1.4 Modelling of Floor Joist

To model a steel floor joist, first establish the scope of the project and choose appropriate modelling software. Then chosen programme to generate a 3D model with all essential elements and connections. Examine the model for collisions between the joist and other building components, and check that it fulfils design criteria.

2.1.5 Modelling in ABAQUS

Modelling in Abaqus entails developing a virtual version of a physical system or structure. It entails generating a geometry, assigning material qualities, specifying boundary conditions, and creating a mesh that separates the geometry into distinct components. Abaqus has a large choice of material models to choose from, as well as several options for defining boundary conditions, such as fixed displacement, applied force, and temperature. Abaqus is capable of addressing difficult nonlinear problems involving huge deformations, material nonlinearity, and contact. The software includes post-processing capabilities for visualising and interpreting simulation results, such as contour plots, animations, and graphs, making it a strong tool for modelling and analysing physical systems.

2.1.6 Numerical Analysis and Data Collection

Numerical analysis is a mathematical strategy for solving mathematical problems that employs numerical methods and computer simulations. It is frequently utilised in scientific and technical research and applications such as finite element analysis and computational fluid dynamics. The practise of acquiring and measuring information from various sources is known as data collection. It is a critical element of research that entails developing adequate data collection methods, selecting acceptable tools for analysis, and interpreting the results. Data gathering in scientific research can take several forms, including surveys, experiments, and observational studies. Numerical analysis and data collection are both useful tools for academics in a variety of domains.

2.1.7 Fabrication Process

Steel joist fabrication requires three steps: cutting, welding, and finishing. Cutting involves shaping the steel to the required length with saws or other cutting equipment. Welding is the technique of putting individual pieces of steel together with a high-temperature welding procedure to form a strong, long-lasting junction. Finally, finishing is sanding any rough edges or welds to achieve a smooth, ready-to-use surface. To ensure that the final steel joist is of the greatest quality and matches the design parameters, all three of these procedures demand a high level of competence and precision.

2.1.8 Experimental Setup and Testing

Experiment setup and testing under four-point loads is a standard approach for determining the flexural behaviour of materials, particularly steel joists. The test specimen, in this case a steel joist, is placed on two supports that are positioned a fixed distance apart in the experimental setup. A loading equipment is then used to deliver a force to the specimen at two places, normally equidistant from the supports, to induce a bending moment. The bending moment causes the steel joist to deflect, and the deflection is monitored using displacement sensors or LVDT. The load and deflection data are gathered at regular intervals until the specimen fails, and the resulting data is utilised to establish the flexural behaviour of the material under test, including the yield strength, ultimate strength, and deflection characteristics. This type of testing is critical for ensuring the quality and safety of steel joists used in construction.

2.1.9 Results and Discussion

It is critical to compare computational and experimental results when analysing the behaviour of steel joists under load. Before testing, numerical models anticipate flexural behaviour, and the findings are compared to experimental data for correctness. A high level of agreement between numerical and experimental data suggests that valid modelling techniques will be used in future designs. Discrepancies suggest that assumptions need to be refined, retested, or reevaluated. Quality input data and correct

assumptions are required for numerical models, both of which affect accuracy. Design correctness and structural safety are ensured by comparing numerical and experimental data. To discover areas for improvement in design, modelling methodologies, or testing procedures, the results should be extensively analysed.

CHAPTER - 3

EXPERIMENTAL INVESTIGATION

3.1 GENERAL

The purpose of this chapter is to describe the material properties used in this work in detail. The experimental design includes four specimens that were studied in this study. The arrangement of diagonal and horizontal web connectors distinguishes three specimens from one another was a typical floor joist. The in-depth explanation of the experimental setup, instrumentations, and testing procedures adopted all the specimen are presented in this chapter.

3.2 EXPERIMENTAL PROGRAM

The non-slender section was cast and tested to predict the behavior of an open-web steel joist. The primary goal of this study is to determine whether the trapezoidal joist can prevent lateral torsional buckling. Four built-up ferritic stainless steel open web steel joists were adopted in this study with two different variables.

- Type of specimen: one of the total Joist were casted using standard design principles, while the other three were casted into a modified trapezoidal joist
- The Span to depth ration of steel open web joist: As floor joists behave as secondary beams, the standard span-depth ratio will be 18 to 20. In this study, for the experimental and numerical investigations, the span-to-depth ratio is maintained as per the availability of testing equipment
- Type of web members: In total, two types of steel sections were used to fabricate the web members of open web steel joists: equal leg angle section as the diagonal web member and channel section as the vertical member.
- Type of Loading: All the four open web steel joists were tested under four-point static loading.

The following schematic diagram, Fig (3.1) is used for better understanding of experimental testing.

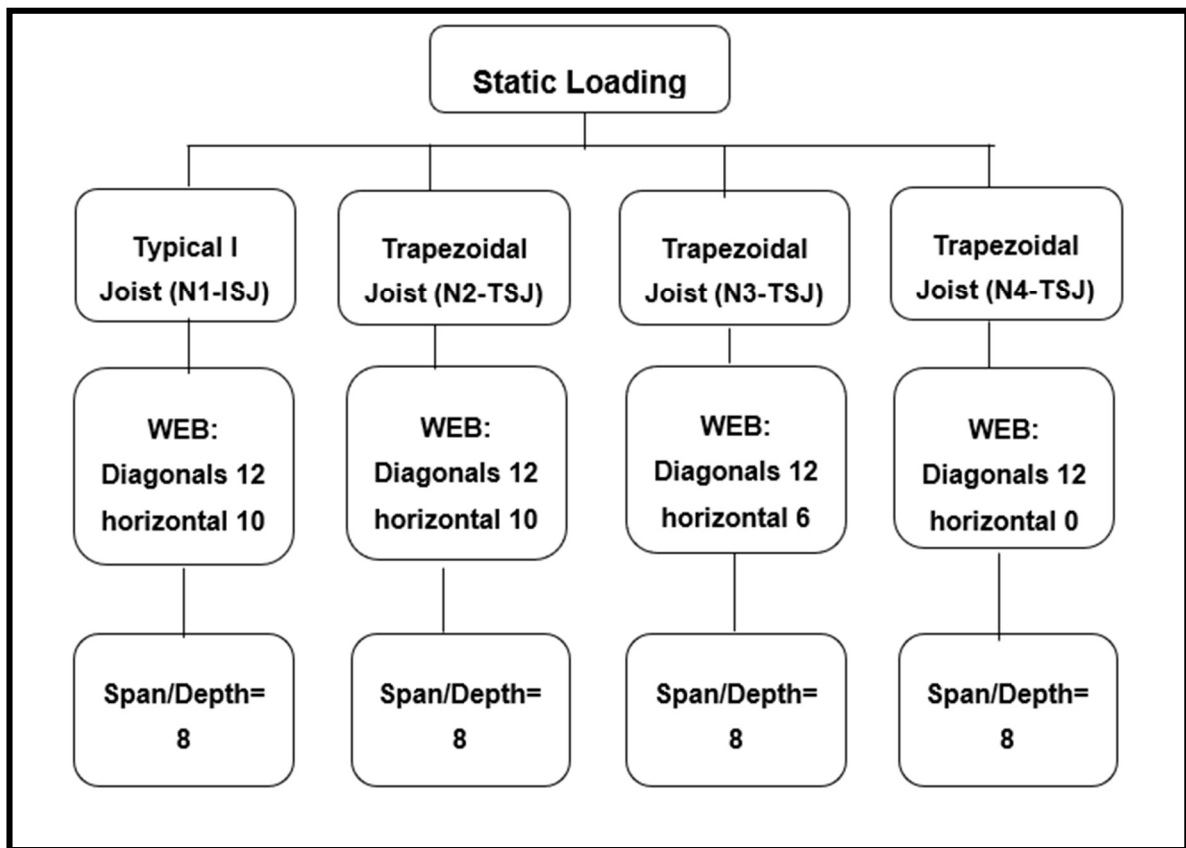


Fig 3.1 Experimental work flow

3.3 MATERIAL PROPERTIES

3.3.1 Ferritic Stainless Steel

The nominal values for cold rolled strip thickness less than 6 mm ferritic stainless-steel grades have been given in EN 1993.1.4.2006 that has been given in the table 3.1 The chemical and mechanical properties of steel grade EN-1.4016 were tested to find the actual mechanical properties of the collected material.

Table 3.1 Mechanical and chemical properties EN-1.4016

Mechanical Properties			
Type of Stainless Steel	Grade	Cold Rolled Strip	
Ferritic Stainless Steel	1.4016	Fy	Fu
		N/mm ²	N/mm ²
		260	450
Chemical Properties			
Ferritic Stainless Steel	1.4016	Materials	Percentage
		Carbon (C)	0.0 - 0.08
		Chromium (Cr)	16.00 - 18.00
		Manganese (Mn)	0.0 - 1.00
		Silicon (Si)	0.0 - 1.00
		Phosphorous (P)	0.0 - 0.04
		Sulphur (S)	0.0 - 0.02
		Iron (Fe)	Balance

3.3.2 Tensile Coupon Test

To determine the actual strength of all the parts of the built-up sections of joists, such as the top chord (TC), bottom chord (BC), and vertical web members (WV), and the diagonal web member (WD), measurements were taken.

The tensile coupon test involves testing the steel strip using an universal testing machine to determine the yield strength (Fy), ultimate tensile strength (Fu), elongation percentage, modulus of elasticity, and fracture toughness of the specimen. The dimensions were collected from the standard ASTM E8/E8M-21a code book for tensile testing that has been updated in 2021. The testing setup is shown in the fig.3.2.

To reduce human error during the tensile coupon test, multiple coupons were tested to determine the true mechanical property. In this study, four

coupons were tested, each from TC, BC, WV, and WD, to improve the accuracy of test results.

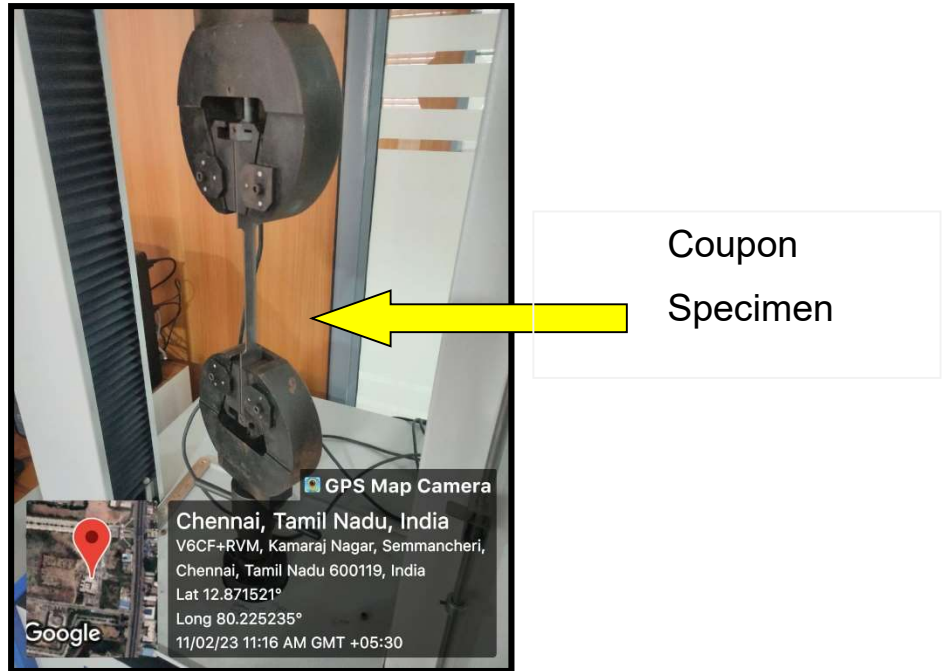


Fig 3.2 Universal Testing Machine capacity 50 kN

Table 3.2 Tensile test results.

Specimen	F_y , (N/mm ²)	F_u (N/mm ²)	Elongation %
Top Chord	332.333	480.017	23.73
Bottom Chord	333.433	484.25	24.7
Vertical Web Member	310.933	448.95	28.57
Diagonal Web Member	302.05	445.85	28.8
Average	319.68725	464.76675	26.45

*Testing of all the four specimens were conducted at the Sathyabama Institute of Science and Technology Sathyabama Centre for Advanced Studies.

In the table 3.2 detailed mechanical property of ferritic stainless-steel sheet was compared between chord and web specimen It shows that there is a significant increase in yield stress with 8.1%, Tensile strength with 7.6% and Breaking strength with 3.6% and in contrast elongation percentage increased in web member with 4% difference. All the test results and graph were attached in Fig. 3.3, 3.4, 3.5, and 3.6

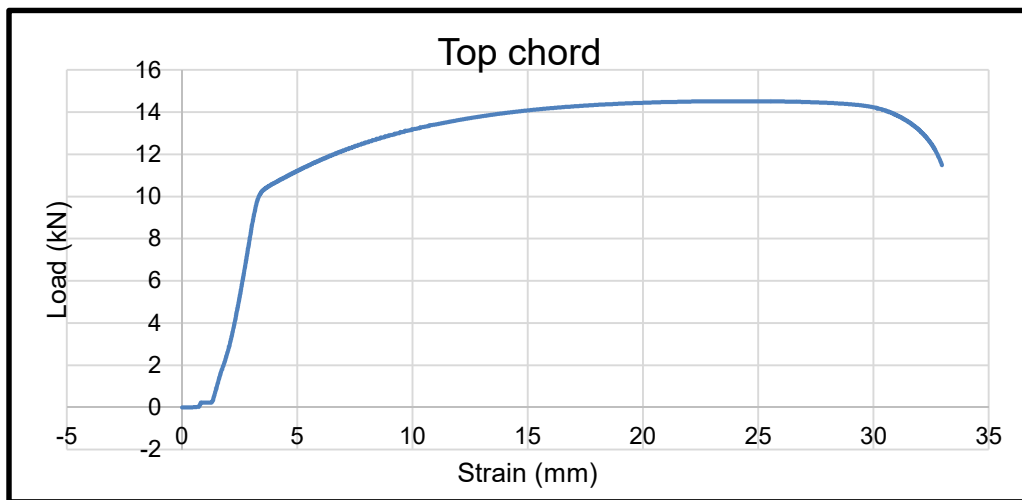


Fig 3.3 Top chord tensile coupon test

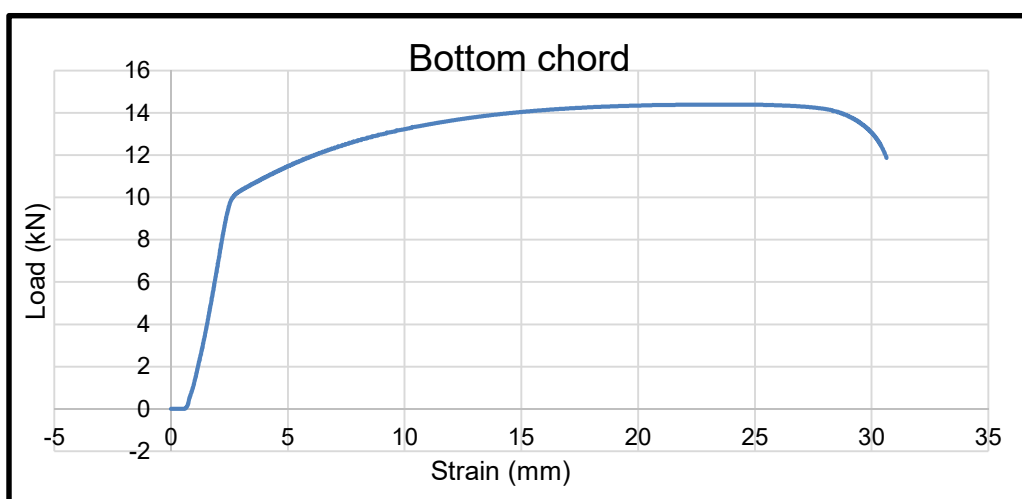


Fig 3.4 Bottom Chord tensile coupon test

The test was performed on specimens collected from both the top and bottom chords. The top chord had a yield strength only 0.003% higher than the bottom chord, and the tensile and breaking strengths were only 0.83% higher. Additionally, the elongation value was around 1.24% higher. Overall, the results indicate that both the top and bottom chords performed similarly in the test as mentioned in Fig 3.3 and 3.4.

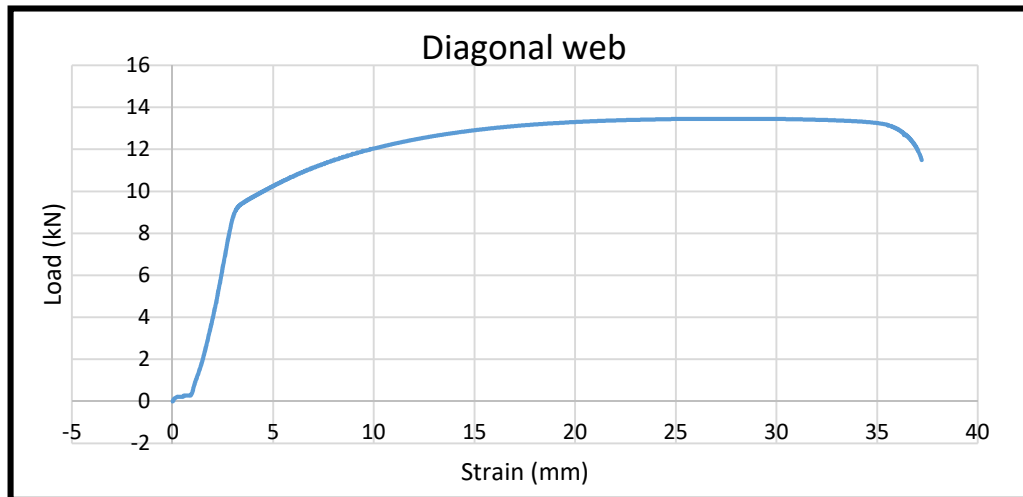


Fig 3.5 Top chord tensile coupon test Diagonal web member

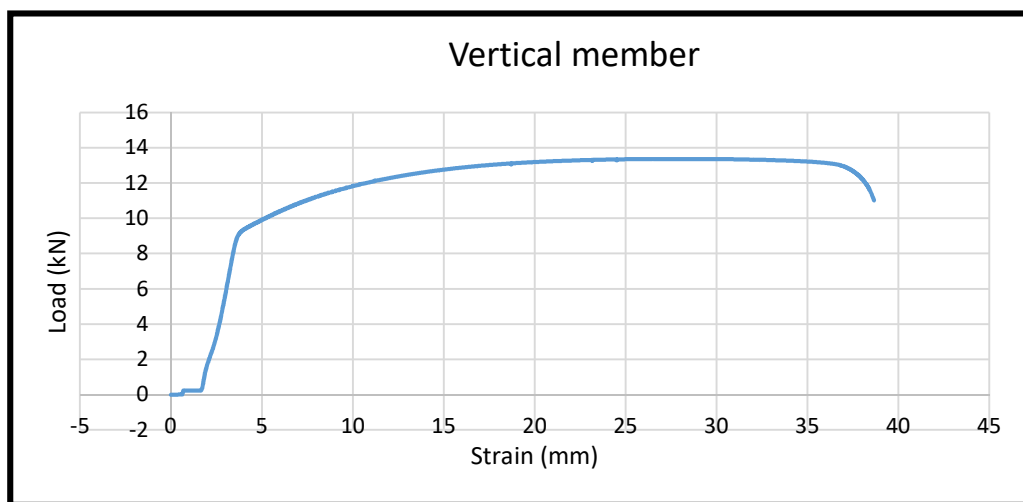


Fig 3.6 Vertical web member tensile coupon test

The test was performed on specimens collected from both diagonal and vertical web member. The WV had a yield strength only 2.5% higher than the WD, and the tensile and breaking strengths were only 0.61% higher. Additionally, the elongation value was around less than 0.1% variation. Overall,

the results indicate that both the top and bottom chords performed similarly in the test as mentioned in Fig 3.5 and 3.6.

3.4 METHODOLOGY OF FABRICATION

The joist being a built-up section, the process of fabrication contains a series of steps to be followed, such as designing, cutting, folding, assembling, welding, performing a quality check, et cetera. Which can reduce its strength and durability. When a component or structure is improperly fabricated, it may not be able to withstand the forces and stresses it is designed to handle, which can increase the risk of failure or collapse.

3.4.1 Collection of *Materials*

The materials needed for the fabrication process were obtained from the local market. Two sheets were purchased, each with dimensions of 4 feet in width and 8 feet in length, a thickness of 2 mm, and a weight of 50 kg with a properly certified and tested grade EN-1.4016.



Fig 3.7 Collection of Ferritic stainless sheet EN-1.4016

3.4.2 Dimension of Test Specimen

In general, two types of test specimen were used. Among them only one will be a typical standard floor joist and remaining three specimens were modified into trapezoidal joist. The materials required for the fabrication process were purchased locally. Two sheets with dimensions of 4 feet wide by 8 feet long, a thickness of 2 mm, and a weight of 50 kg with a properly certified and tested grade EN-1.4016 were purchased.

The modified three-trapezoidal section will have three different web connection arrangements between the bottom and top chords. According to the design guidelines, a vertical web with a length of 155 mm and a channel section was provided, followed by a diagonal web member with three different lengths of 220, 230, and 240 mm and an angle section. The top chord is composed of trapezoidal sheeting, while the bottom chord is composed of a lipped channel section. As shown in Fig 3.8, 3.9, 3.10, 3.11.

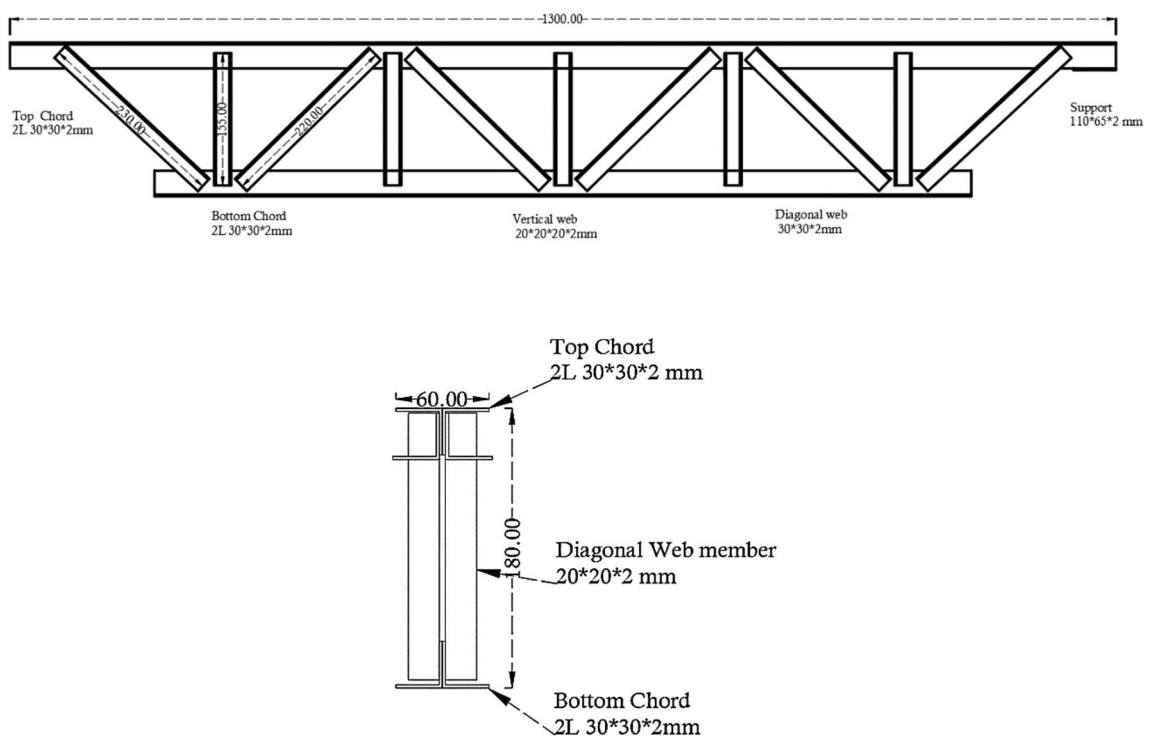


Fig 3.8 Dimensions of (N1-ISJ)

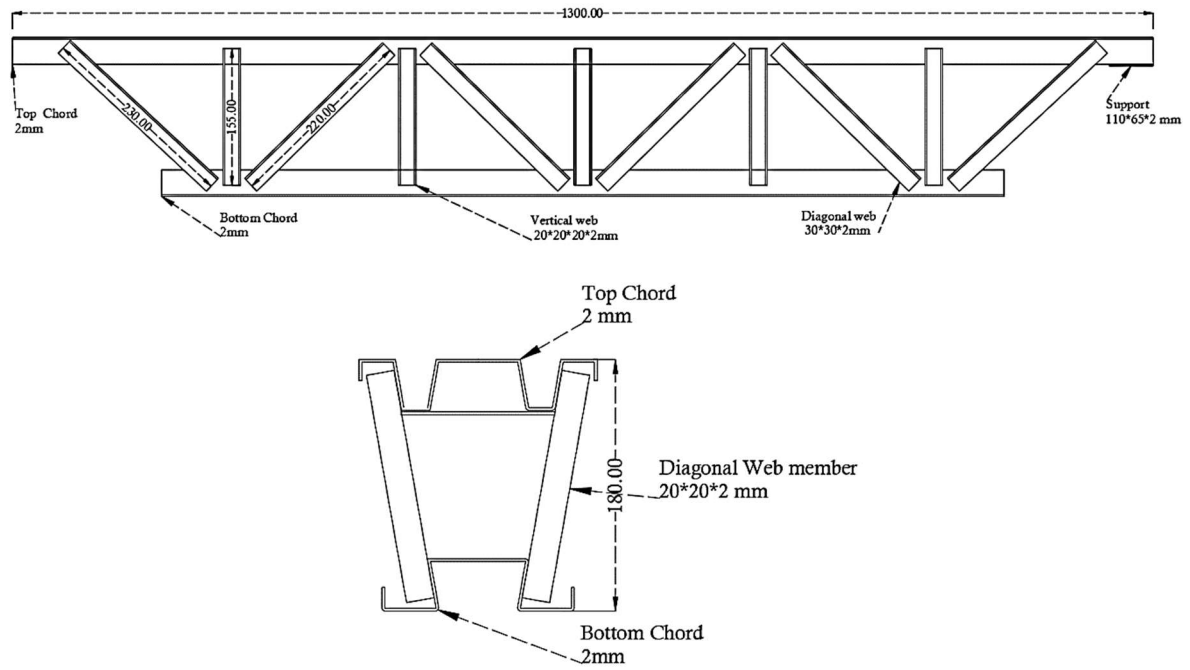


Fig 3.9. Dimensions of (N2-TSJ)

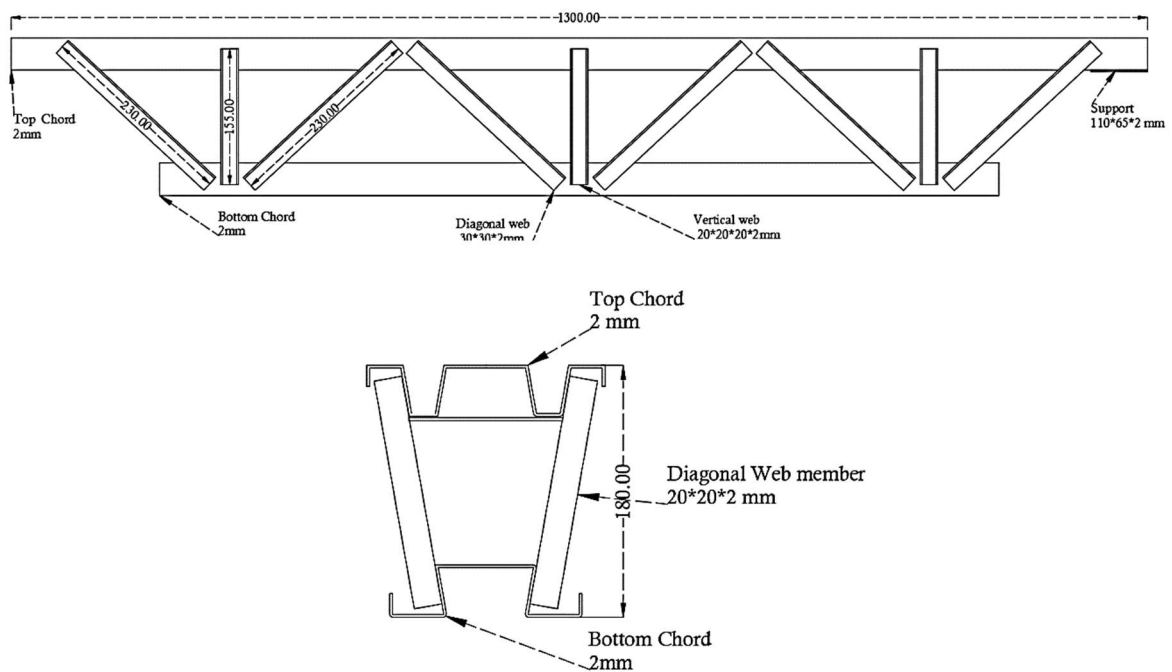


Fig 3.10 Dimensions of (N3-TSJ)

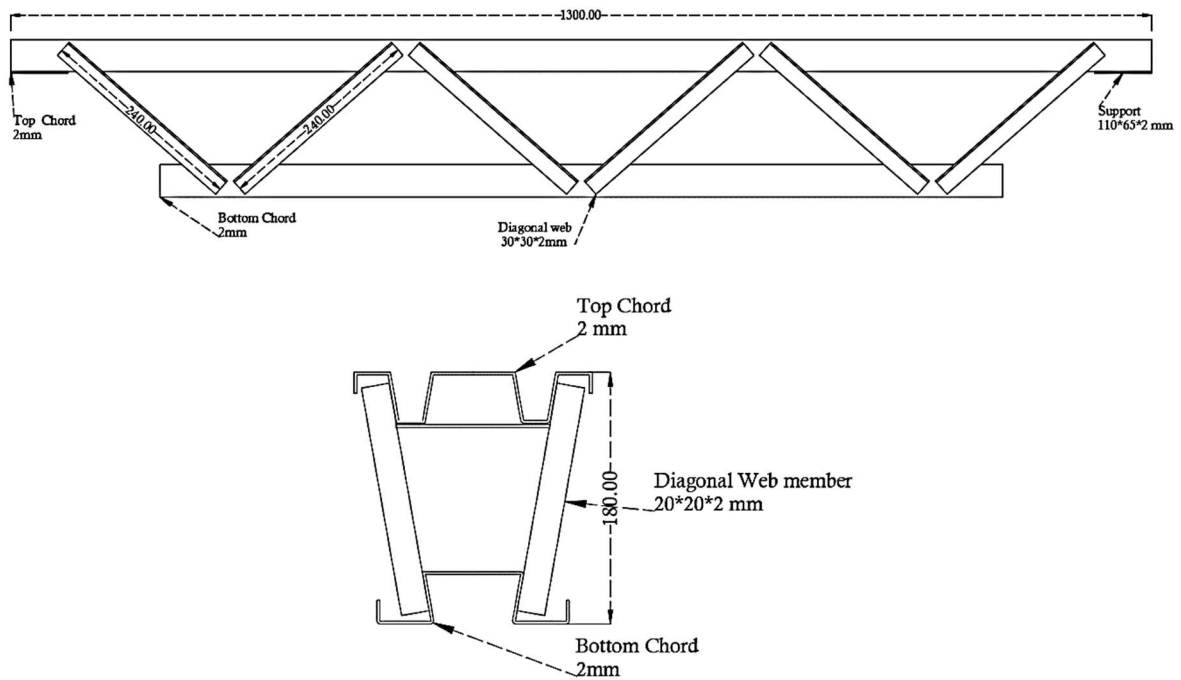


FIG 3.11 Dimension of (N4-TSJ)

3.4.3 Folding and Welding

The folding process were done manually for reducing the human error proper measures were taken the folding angle varies from eighty degree to hundred-degree angles all the specimens were folded as the dimensions as provided as shown in the fig 3.12

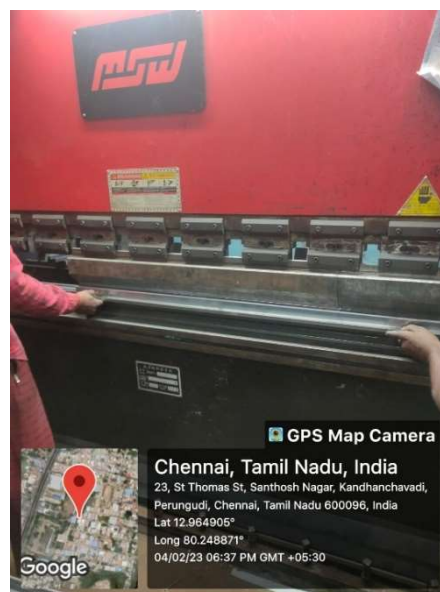


Fig 3.12 Folding process

Tungsten Inert Gas (TIG) welding is a type of welding process that uses an inert gas, argon, to shield the welded area from the surrounding atmosphere. This welding technique is commonly used for thin sections of stainless steel, aluminium, and nonferrous metals. This type of welding requires a high level of accuracy, skill, and patience, and as a result, it is time-consuming work when compared to other types of welding procedures.



Fig 3.13 TIG welding process

3.4.4 Experimental Setup

All of the joists were tested under static loading with the same loading configuration. Three manual deflection metres were placed at the bottom of the bottom chord strain gauge; they are not provided to determine the strain of the steel joist. To minimise error, one deflection metre was placed in the middle of the span, and the other two were placed 200 mm apart from the middle of the support is clearly demonstrated in fig 4.14, and 4.15.

For one end of the support roller's boundary conditions. The roller support is provided to allow moment in the transverse direction and reaction force in the longitudinal direction of the beam, preventing the structure that

holds the support below the roller support from collapsing. A hinged support, on the other hand, is provided to allow rotational force in perpendicular or transverse directions.

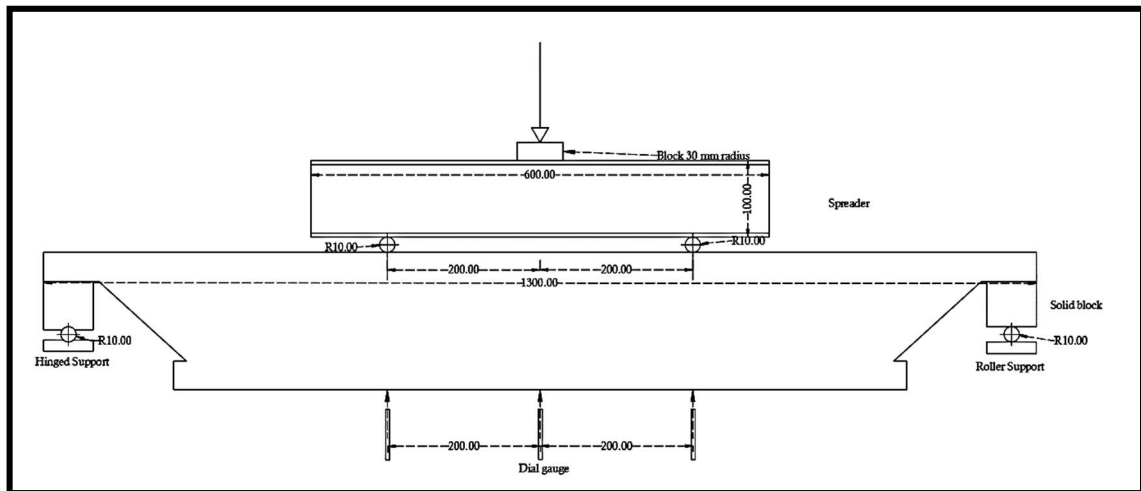


Fig 3.14 Experimental Loading setup



Fig 3.15 Experimental Setup in real time

3.5 EXPERIMENTAL TEST SETUP

The results of the experimental work are presented and discussed in this section of the paper. The detailed measurement of deflections, ultimate loads, and failure patterns of open web steel joists will be presented at the end of the section.

3.5.1. *I Joist – (N1-ISJ)*

The I joist is made up of six diagonal web (WD) connectors on each side and five vertical web (WV) members. The joist's clear span is 1200 mm, and 75 mm seating has been welded back-to-back on the top chord of the joist for support on both sides.

The total weight of the joist after fabrication is 8.45 kg, and the detailed setup is shown in the fig-3.16



Fig 3.16 Experimental setup (N1-ISJ)

3.5.2. Trapezoidal Joist (N2-TSJ)

In trapezoidal steel joist from the cross section view the web connector (WV, WD) were tilted eighty degrees outside from the centre of the joist to form trapezoidal joist as shown in fig 3.17.

The joist consists total of six diagonal web member WD on each side and five horizontal channel section were welded on each side of the joist. Then for the support 110*65*2 mm sheet were welded on both end of the joist which help to support joist in the position.

The final weight of the specimen (N2-TSJ) is exactly 12.95 kg which is almost fifty percentage higher than the Model 1



Fig 3.17 Experimental setup (N2-TSJ)

3.5.3. Trapezoidal Joist (N3-TSJ)

The joist consists total of six diagonal web member WD on each side and three horizontal channel section were welded on each side of the joist. Then for the support 110*65*2 mm sheet were welded on both end of the joist which help to support joist in the position as shown in fig 3.18

The final weight of the specimen (N3-TSJ) is exactly 1.25 kg the weight reduction is because in total four vertical channel web member (WV) have been reduced.



Fig 3.18 Experimental setup N3-TSJ

3.5.4. Trapezoidal Joist (N4-TSJ)

The joist consists total of six diagonal web member WD on each side and only in this N4 specimen no vertical web (WV) has been provided as per design criteria. The final weight of the specimen (N4-TSJ) is exactly 11.35 kg the weight reduction is because of removal of all vertical channel web members (WV) as shown in fig 3.19



Fig 3.19 Experimental setup (N4-TSJ)

CHAPTER - 4

NUMERICAL INVESTIGATION

4.1 GENERAL

This chapter presents a finite element analysis to investigate the behaviour of the open web steel joists under static loadings, and compares the results with the experimental data. After demonstrating the accurate reflection of the finite element models as test cases, a parametric study was carried out from the viewpoint of time saving and cost.

A finite element program named (ABAQUS), which was originally released in 1978, was used to perform this analysis. The comparison between the finite element program (ABAQUS) analysis and the experimental test was made in terms of the load capacity, deflection and stress distribution for both static and impact loadings.

4.2 FINITE ELEMENT MODELLING

Various items concerned with the commercial software ABAQUS/CAE 2019 should be addressed to develop the three-dimensional Finite Element models of composite open web steel joists as follows.

- Elements type.
- Material property.
- Constraints and interaction between surfaces.
- Boundary conditions and load application.
- Meshing.
- Running the analysis.

In the finite element models loading conditions were considered including static loading. A detailed description of the aforementioned items is given in the following sections:

4.2.1 *Element Type*

Various components of the composite open web steel joist should be modelled namely top chord, bottom chord, equal leg angle, channel section

and supports. Hence these elements have been modelled using different element type as follows.

Discrete Rigid Body which is shown in fig 4.1 is a 3D model which is not under gone any type of stress with in the body is called as discrete rigid body. This type of element is used in loading support in all the model. This type of element will be hollow on the inside and will not have any mass or material property and the base feature will be converted into shell after extrusion.

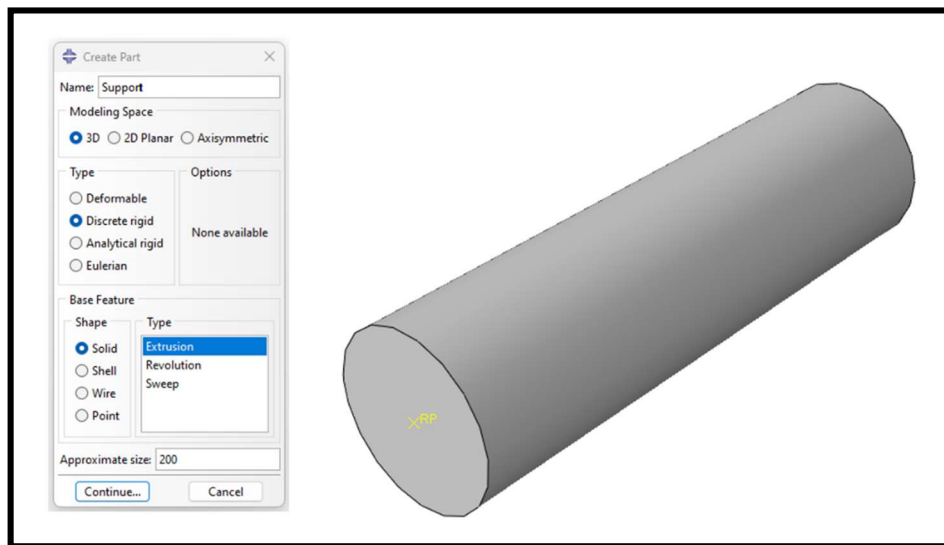


Fig 4.1 Discrete rigid body

Deformable body which is shown in fig 4.2, 4.3, 4.4, and 4.5 a 2d part which will undergo all type of stress and strain when an external force is applied. This type of part is used in all elements of specimen such as top chord, bottom chord and web connectors and end supports etc.

Material properties such as Young's modulus, Poisson's ratio, and yield strength are assigned to the elements to define the behaviour of the body. The boundary conditions, such as fixed displacements or applied loads, are also defined to simulate the deformation of the body under different loading conditions. Abaqus provides a range of element types and material models to accurately simulate and analyse the behaviour of deformable bodies under various loading conditions.

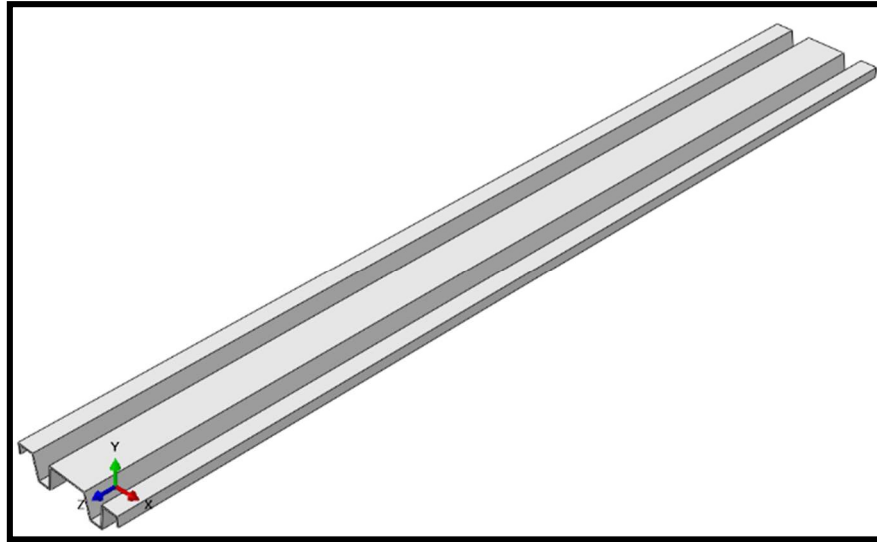
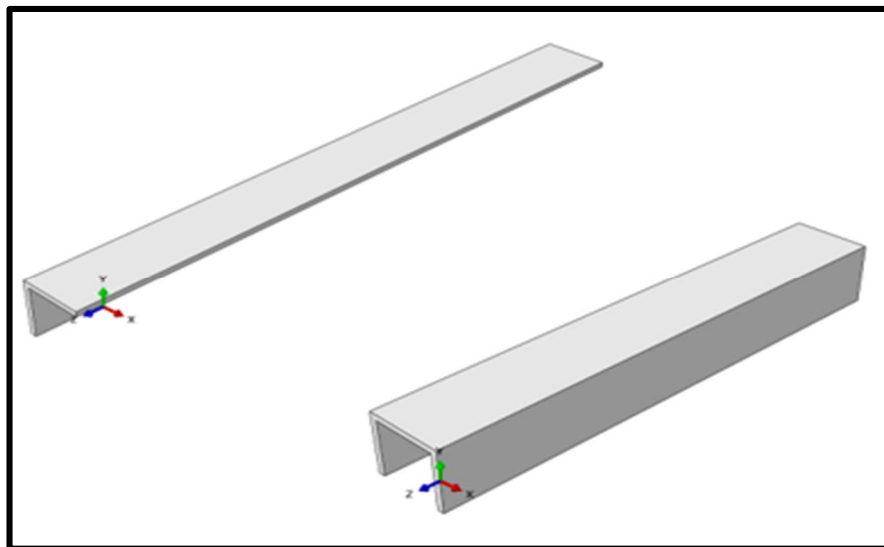


Fig 4.2 Top chord length- 1300 mm



**Fig 4.3 Equal leg angle and Channel section (220, 230, 240 mm)
For model (N1, N2, N3, N4)**

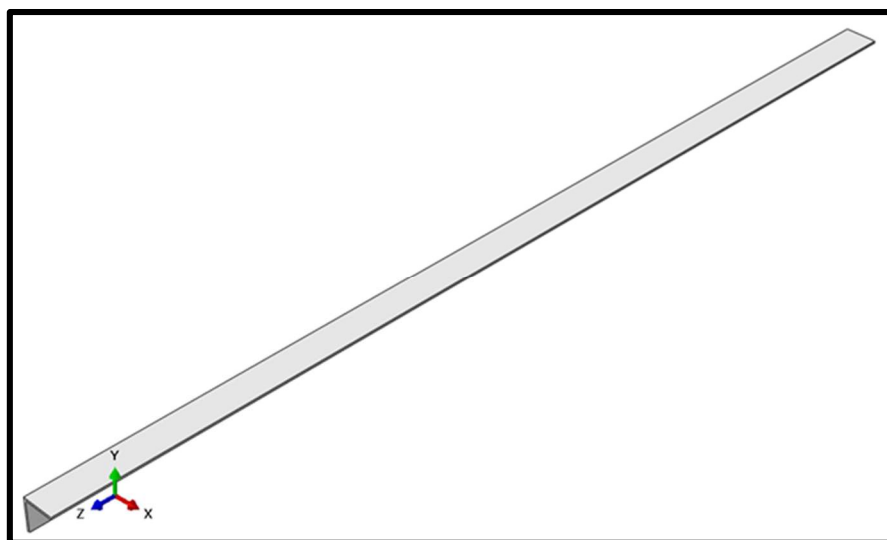


Fig 4.4 Equal angle Top chord 1300 mm, Bottom chord-960 mm

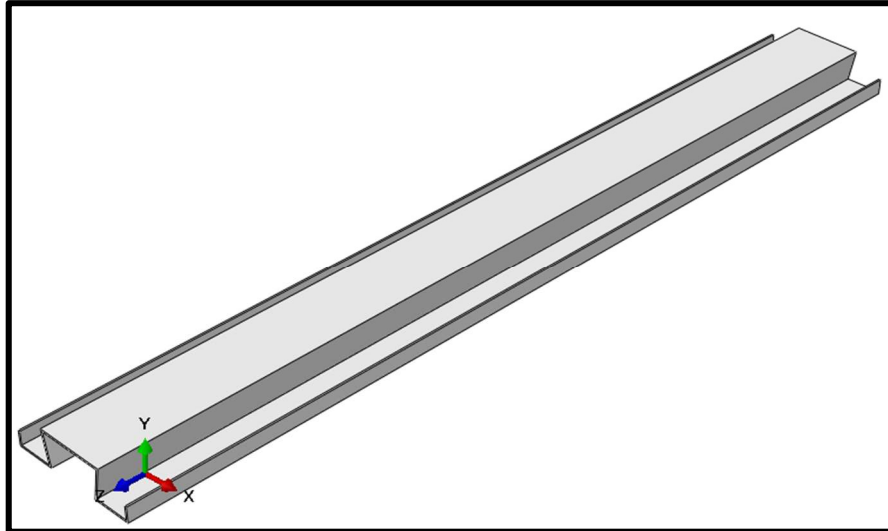


Fig 4.5 Bottom chord length- 960 mm For model (N2, N3, N4)

4.2.2 Material Property

The correct material model for the material being used Material modes in ABAQUS include linear elastic, nonlinear elastic, plasticity, and others. The two main steps of applying material to the model created in Part 2 are defining and assigning. The Mass density of all the specimen were is mentioned as 7.8E-009 which represent the Ferritic stainless steel EN-1.4016 as 7800 kg/m³. The young's modulus is equal to 200000 and poison's ration is 2.8 The data which is used in ABAQUS is mentioned on table 4.1.

Table 4.1 Material Property Used in Abaqus

Yield stress kN	Plastic strain mm
215	0
225	0.02
235	0.05
250	0.08
270	0.1
300	0.12
350	0.14
380	0.16
450	0.18

4.2.3 Interaction

The contact between the loading 10 mm dia bar and the top chord is considered as a surface-to-surface contact the friction coefficient is assigned as 0.1. The master surface will be outer surface of 10 mm dia bar and slave surface will be top surface on the top chord. This condition is applicable for all the surface will be top surface on the top chord. This condition is applicable for all the specimens tested in this study. For the contact information between top chord and loading bar the below fig 4.6 represent the property of surface.

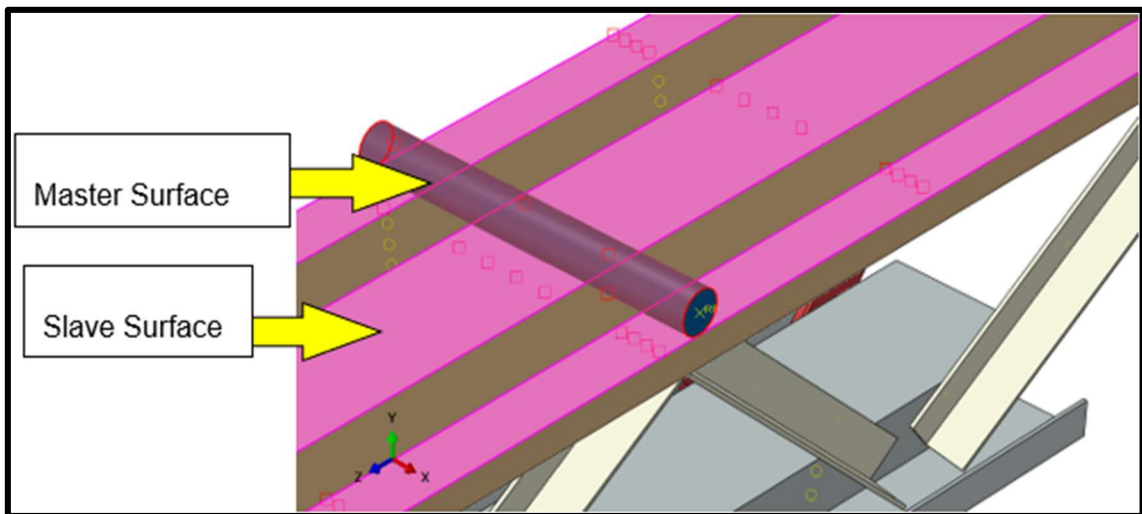


Fig 4.6 Surface to surface contact

Surface was applied with two contact properties. NORMAL BEHAVIOUR and TANGENTIAL BEHAVIOUR. In order to prevent penetration into each other a HARD contact property is provided and the PENALTY friction formulation for tangential response with 0.1 coefficient.

To represent the TIG welding tie contact is used between the parts of welded connection of the specimen.

In this study, the “Tie” constrain was chosen to simulate the interaction contact between different surfaces. The basic rules for this constrain are the “master surfaces, which assigned to the stronger material in comparison to other material slave surface. Therefore, here it is considered as the top and bottom chord as master surface and the remaining vertical and diagonal web connection and supports were considered as slave surface

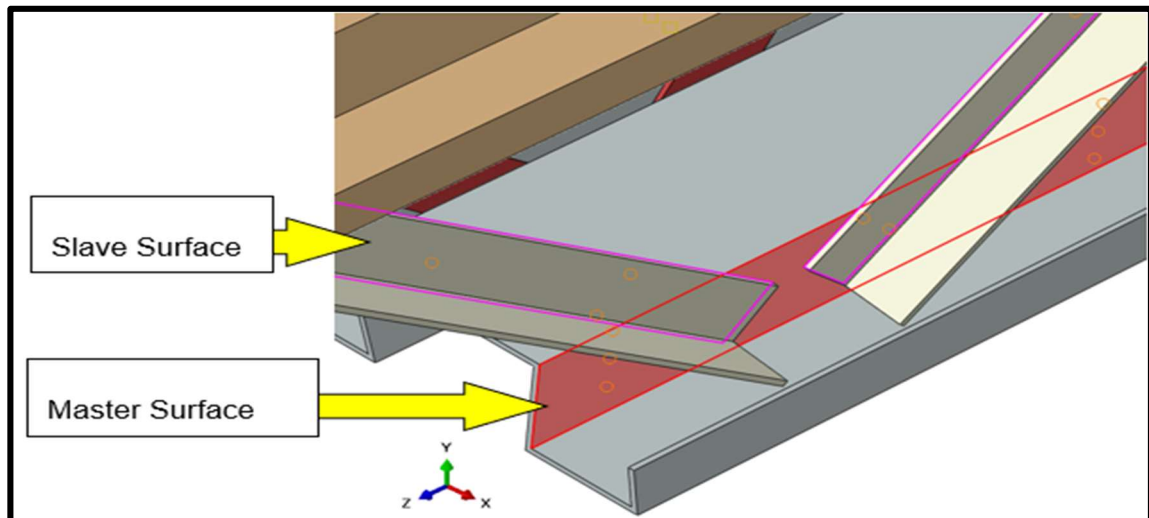


Fig 4.7 Tie constrain (Contact)

The welded region like between top, bottom chord and web member will not under go any type of separation at the location during simulation process.

4.2.4 Boundary Conditions

For the boundary conditions in ABAQUS as all beam are tested in static loading conditions which is defined as STATIC, GENERAL in ABAQUS. As the loading specimen 10 mm dia is considered as DISCRETE RIGID BODY with shell type so, it is assigned with a reference point (RP) at each centre of the two specimens.

As the joist were tested as roller and hinged support under static loading, therefore Hinged support the end is restricted force by x, y, and z in translational direction and moment by y and z direction. On the other hand, for roller support restricted force by x and y direction then moment in y and z direction.

For the supports as the supports were welded with the specimen in fabricated model to replicate the exact property of contact between support and specimen. In ABAQUS the Tie constrain is assigned to them. In that support is a major component transfer all the loads to the end support so support plate is the master surface and the specimen will be the slave surface.

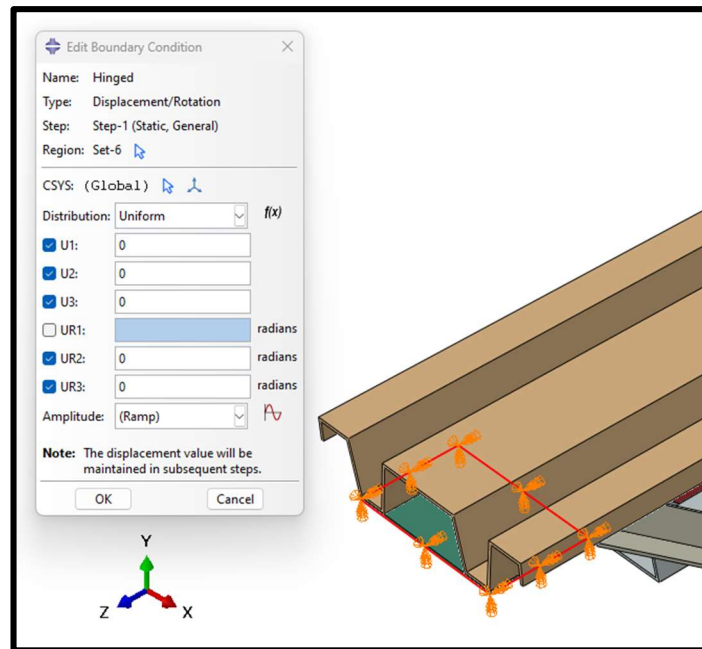


Fig 4.8 Hinge Support

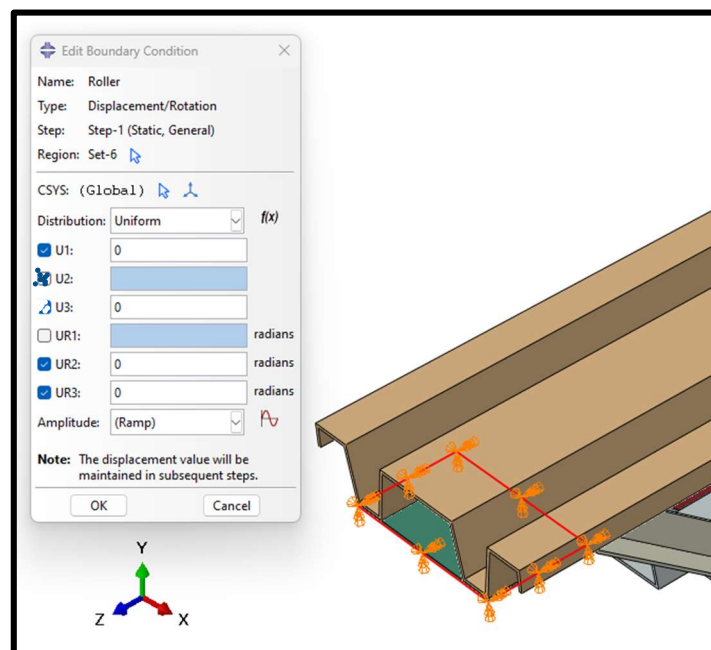
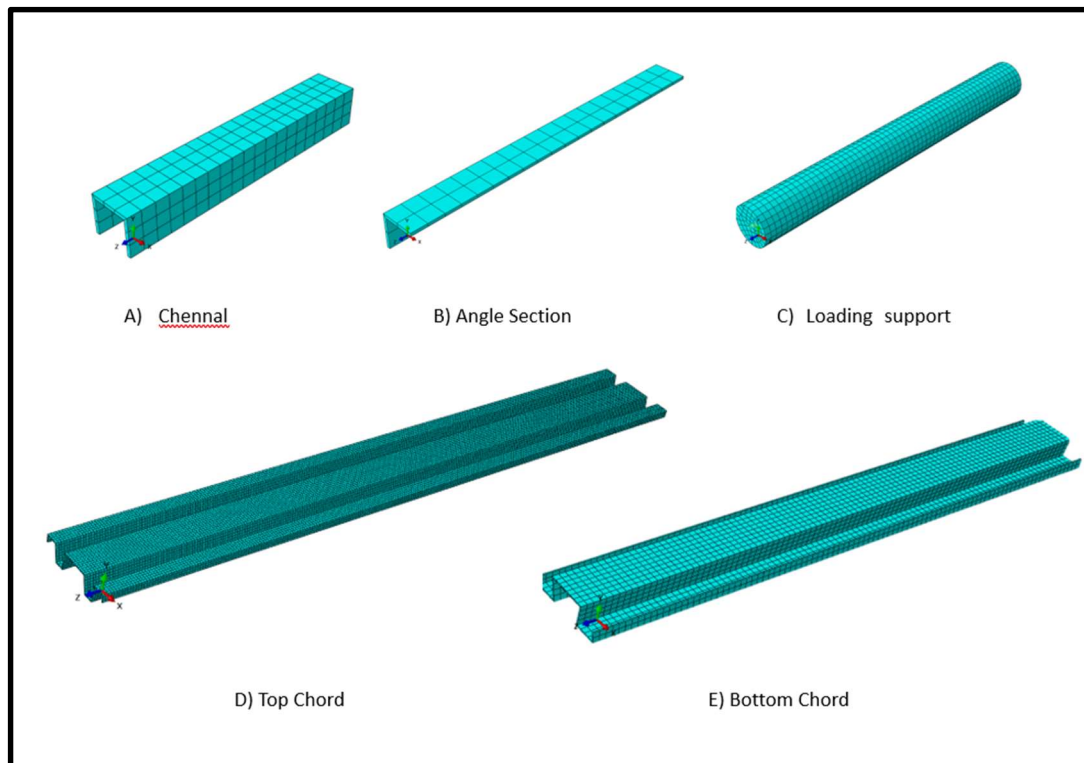


Fig 4.9 Roller Support

4.2.5 Meshing Optimization

A prior study is carried out to select a suitable mesh size for the stainless-steel joist based on the computational efficiency, meshing accuracy to compare with experimental study. The size is chosen between 5 to 20 mm according to the type of mesh and different angles of specimen.

Structural angle for right angle folding and sweep mesh for less or greater



than right angle is used as shown in Fig 4.10.

Fig 4.10 Meshing of the steel joist components

4.2.6 Running Analysis

The last step before post processing with ABAQUS is submit and run the analysis job associated with the model.

4.3 STATIC ANALYSIS RESULTS

The finite element results of the open web steel joist subjected to static loading are presented in terms of load-deflection and ultimate loads, maximum deflection and distribution of stresses.

4.3.1 The Ultimate Load And Maximum Deflection Relation

The load and deflection defined by the FEA simulation and all reports have been given below, the results shown finite element analysis correlated

with the experimental results, and the ultimate load carrying capacity is almost similar but the load-deflection curve in experimental results were linear on the other hand finite element modal results were shows a non-linear graph.

Group	Steel Joist	Experimental ultimate load (kN)	FEM Ultimate load (kN)	Difference (%)
Static Loading	N1-ISJ	19.5	20.8	7%
	N2-TSJ	30.9	28.1	-9%
	N3-TSJ	29.7	28.9	-3%
	N4-TSJ	27.4	26.9	-2%

Table 4.2 Comparison of ultimate loads in between experimental and FEM

Table 4.3 Comparison of Deflection in between experimental and FEM

Group	Steel Joist	Experimental Deflection (mm)	FEM Deflection (mm)	Difference (%)
Static Loading	N1-ISJ	8.7	9.2	6%
	N2-TSJ	10.5	10.9	4%
	N3-TSJ	13.5	13	-4%
	N4-TSJ	9.77	9.5	-3%

4.3.2 Finite Element Model Assembly

In Abaqus, parts can be created individually, and then combined using the assembly module. The assembly module allows users to position and orient the different parts in relation to one another, define contact and interaction between parts, and assign boundary conditions and loads to the assembly. All the four-model assembly were done accurately as it helps to transfer the load without any error which has been shown in figs-4.11, 4.12, 4.13, 4.14.

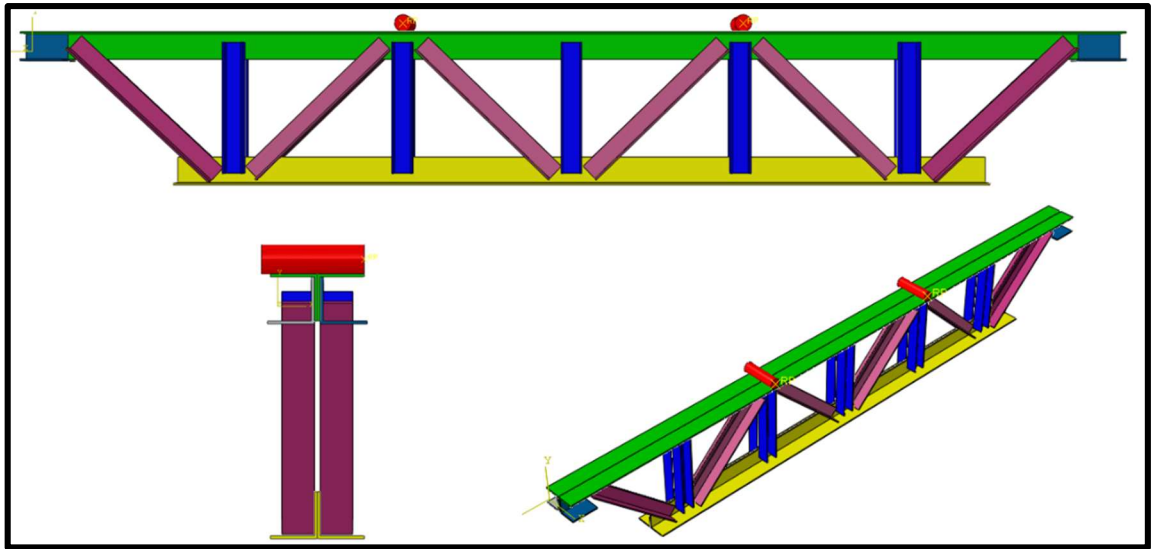


Fig 4.11 Part and assembly of steel joist (N1-ISJ)

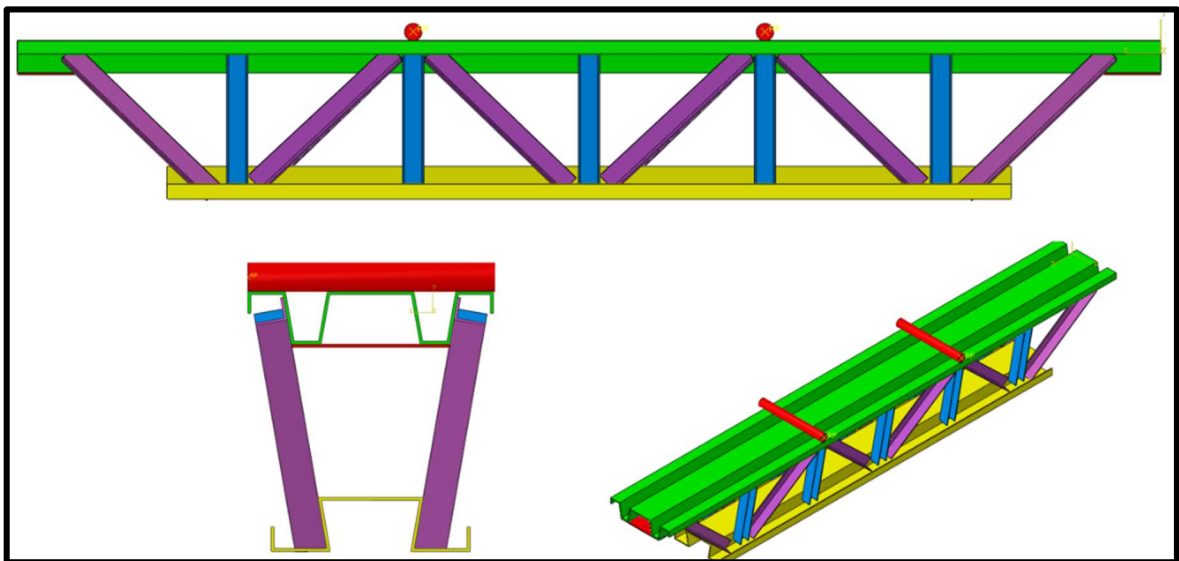
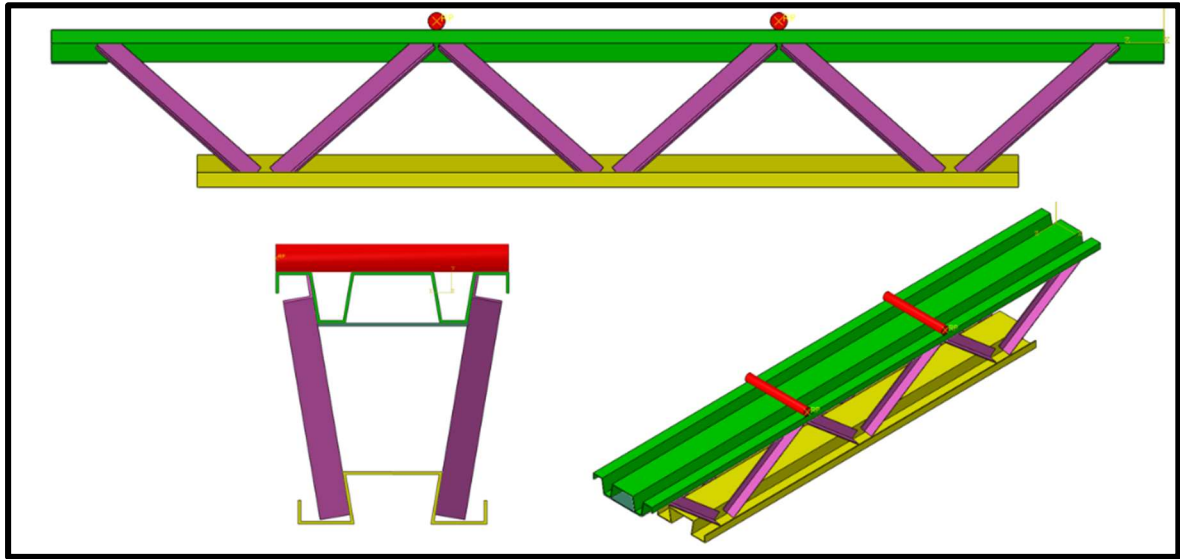
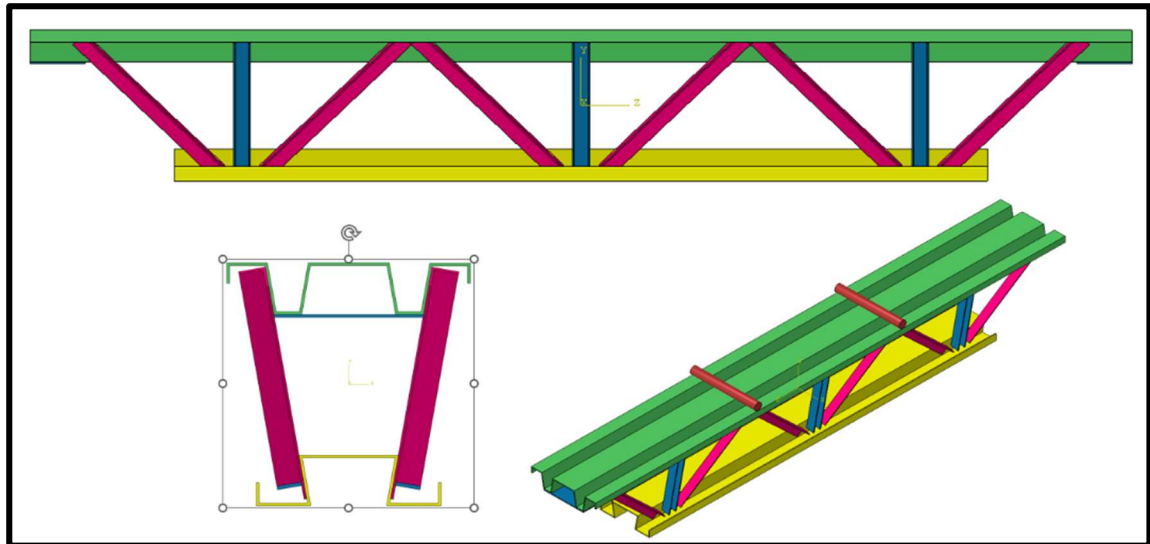


Fig 4.12 Part and assembly of steel joist (N2-TSJ)



***Fig 4.13 Part and assembly of steel joist
(N3-TSJ)***



***Fig 4.14 Part and assembly of steel joist
(N4-TSJ)***

CHAPTER - 5

RESULTS AND DISCUSSION

5.1 GENERAL

This chapter discuss and compare the experimental and numerical results collected during the study.

5.2 EXPERIMENTAL RESULTS

In general, all the specimens have a similar stress-strain curve. The specimen (N1-ISJ) has a maximum load carrying capacity of 20 kN, and the specimen N2-TSJ has a maximum load carrying capacity of 40 kN.

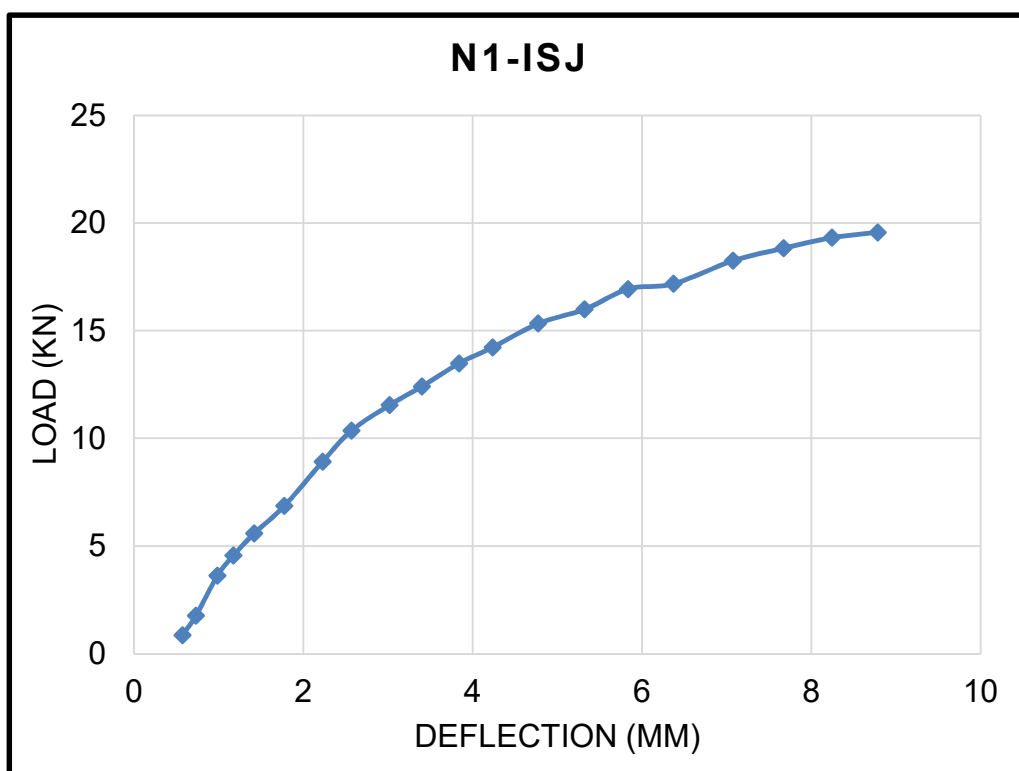


Fig 5.1 Exp test results at the mid span (N1-ISJ)

The ultimate load carrying capacity of the above specimen is 19 kN with deflection of 8 mm at the mid span of the joist as shown in fig 5.1

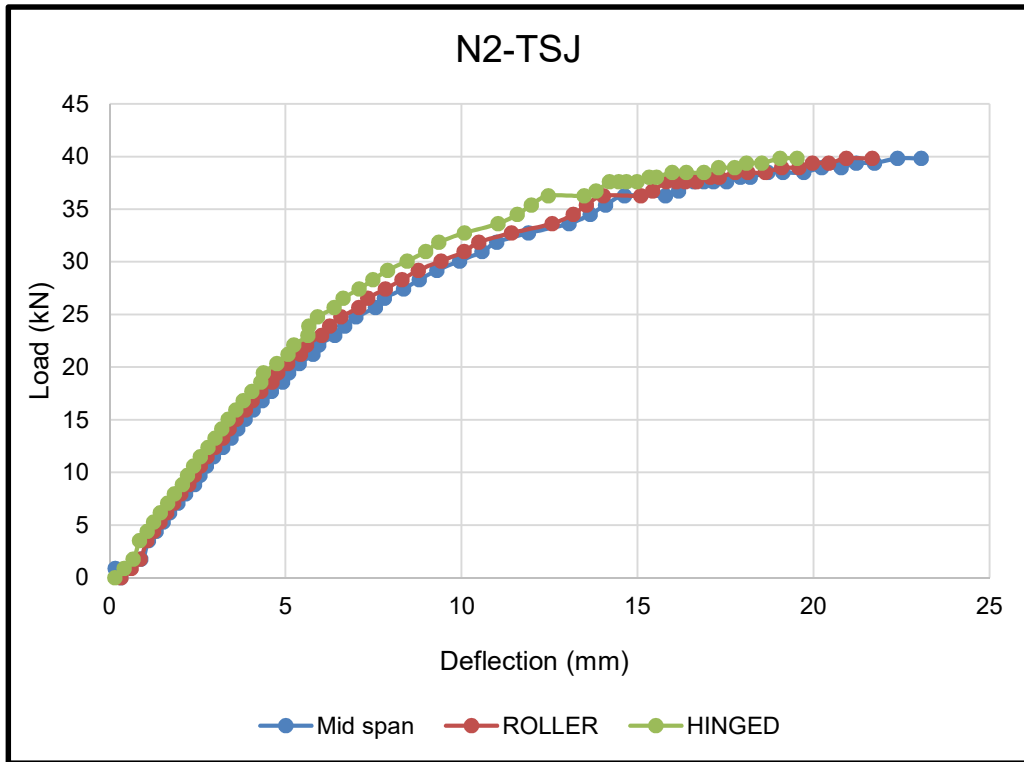


Fig 5.2 Exp test results at the mid span (N2-TSJ)

The ultimate load carrying capacity of the joist N3-TSJ is 30 kN and the deflection is 16.5 mm at the mid span of the joist shown in fig 5.3

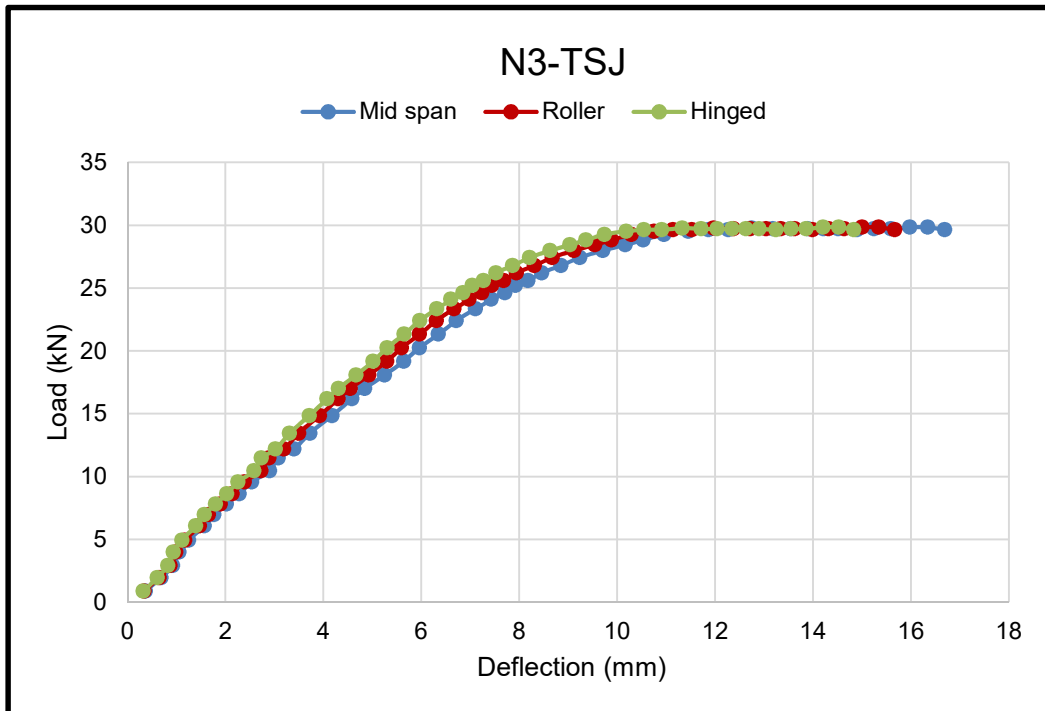


Fig 5.3 Exp test results (N3-TSJ)

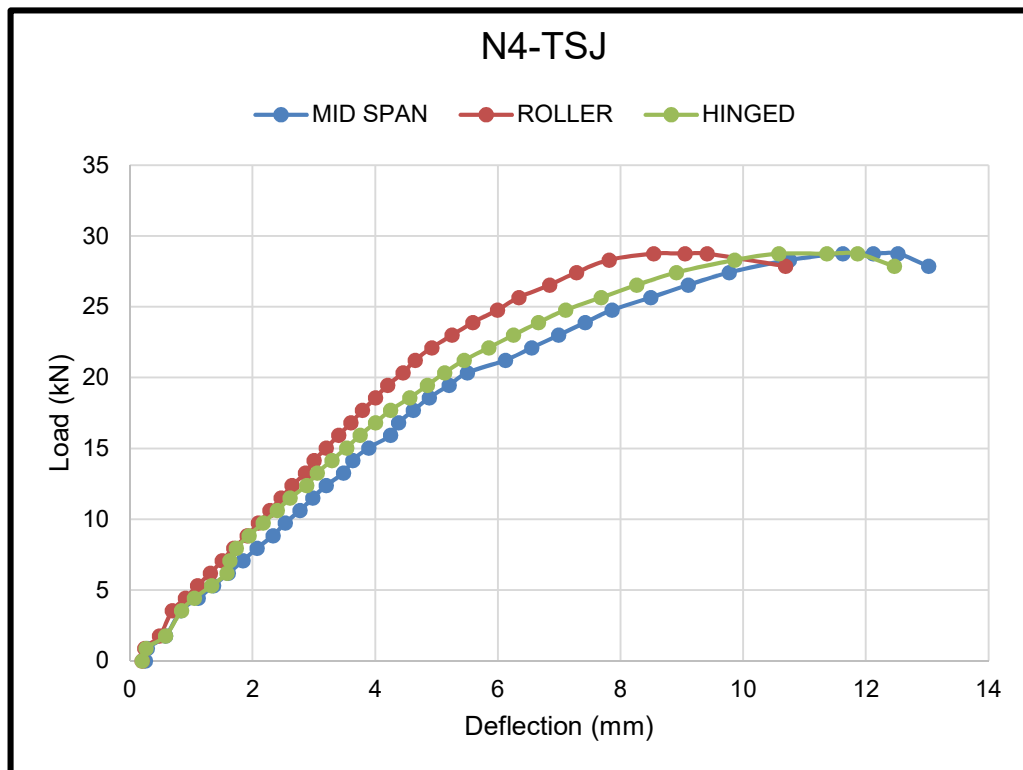


Fig 5.4 Exp test results (N4-TSJ)

The ultimate load carrying capacity of the joist N2-TSJ is 30 kN and the deflection is 13.2 mm at the mid span of the joist. From the graph Fig 5.4 it is clearly visible that there is a sudden drop in load at the end it is due to the fracture at the welded area between the bottom chord and angle web connector.

The strength-to-weight ratio is calculated for all the specimens according to the results mentioned in Table 5.1 below. Specimen (N2-TSJ) is 33.24 percent more economical compared to the typical I-joist specimen (N1-ISJ).

Table 5.1 Ultimate load carrying capacity and mass of the sp

Model	Max load carrying capacity kN	Mass in kg	Mass in kN
N1-ISJ	19.5	8.45	0.0828945
N2-TSJ	39.82	12.95	0.1270395
N3-TSJ	29.85	12.2	0.119682
N4-TSJ	28.76	11.6	0.113796

Table 5.2 Strength by weight ration specimen.

Model	Load/weight ratio	Percentage different compared to N1-ISJ
N1-ISJ	235.2387673	0%
N2-TSJ	313.445818	33.24%
N3-TSJ	249.410939	6.02%
N4-TSJ	252.7329607	7.44%

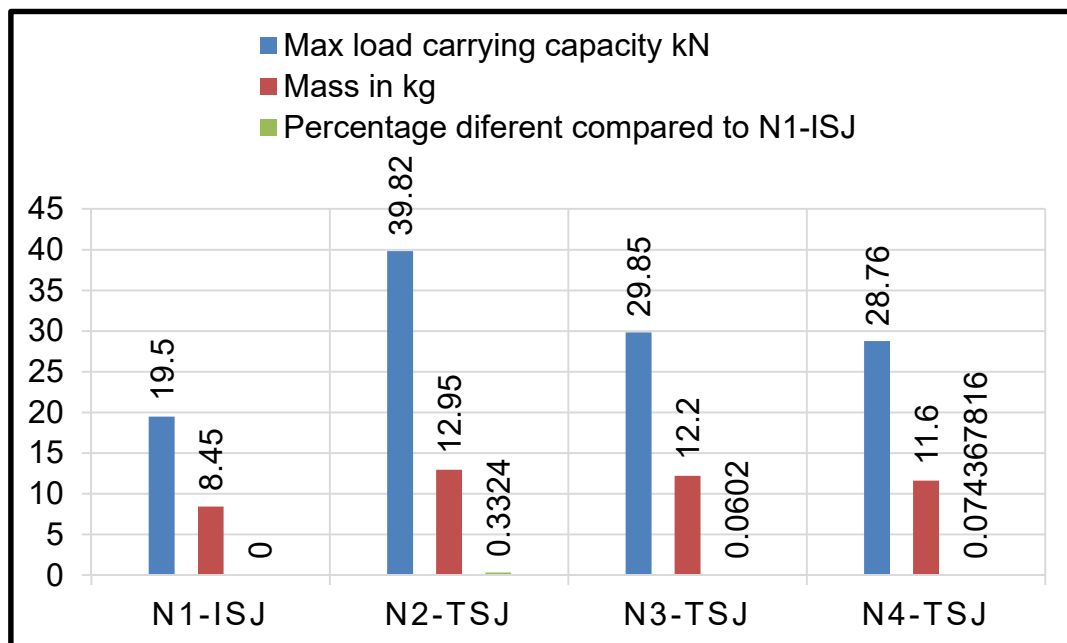


Fig 5.5 Strength by weight ratio bar chart

For the floor joist in general the allowable deflection is 0.003 times of effective span of a joist. the effective span is 1200 mm for this length the allowable deflection is 3.7 mm. from the experimental results up to 3.7 mm deflection graph is shown down in the fig 5.6. and strength by weight ratio is given in fig 5.5

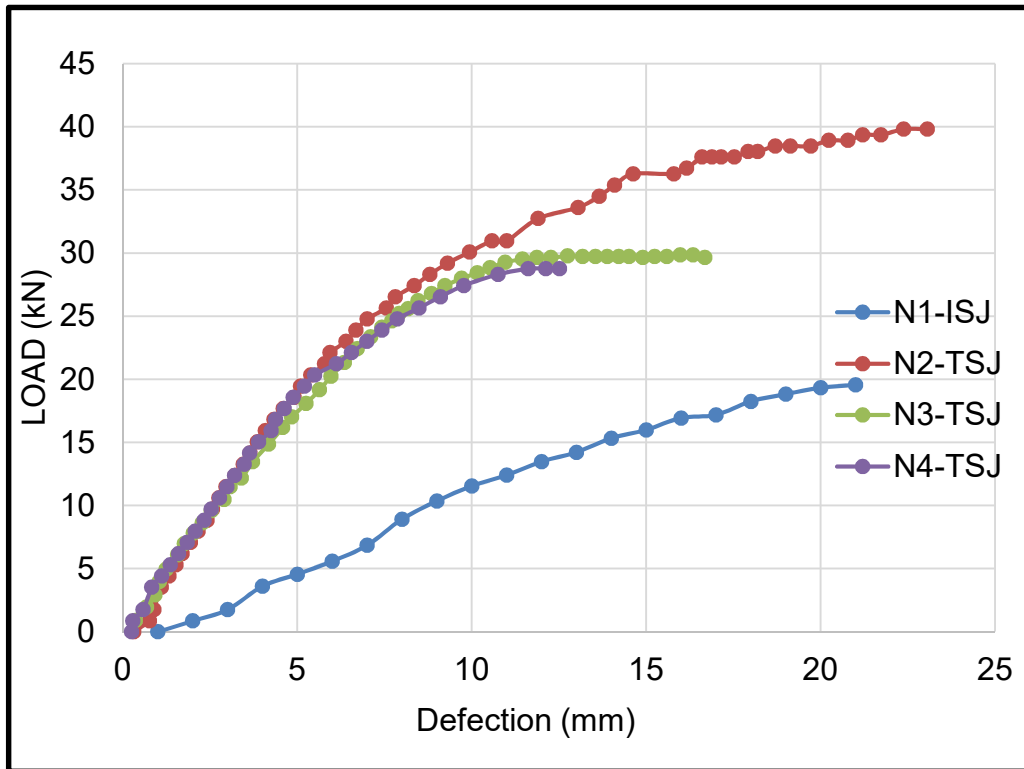


Fig 5.6 Load vs deflection curve (N1, N2, N3, N4)

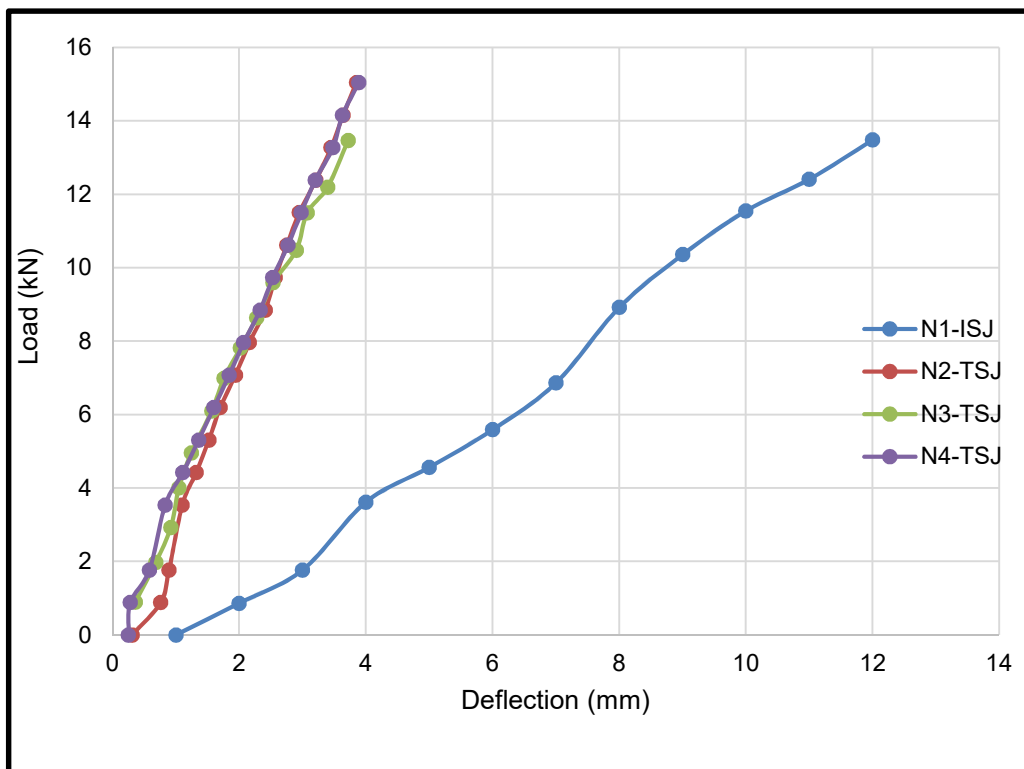


Fig 5.7 Load vs deflection curve up to allowable deflection

When absorbing trapezoidal joists N2-TSJ performed well compared to the other two, it was because the brittle failure didn't happen at the welded area, but on the other hand, both N3-TSJ and N4-TSJ attained fracture at the welded area. In this type of ferritic stainless-steel grade EN-1.4016, the brittle failure happened as expected at the welded region.

The plastic region difference in stress strain graph Fig 5.7 is because of lateral torsional buckling in (N1-ISJ). This is because it is a slender section which cannot resist lateral rotational moment and the top chord is free to move in lateral direction. When load is applied on the top chord the lateral torsional buckling happened.

5.3 NUMERICAL RESULTS

The ultimate load carrying capacity, deflection, and lateral torsion buckling will all be thoroughly explained in this part. The ultimate strength and deflection values are given in the Table 5.3

5.3.1 Load-Deflection Relation

Once the simulation is completed, the load-deflection relationship can be plotted using the Abaqus post-processing tools. The relationship can provide valuable insights into the behaviour of the structure under different loading conditions, including its stiffness, strength, and failure modes.

The load-deflection relationship is a critical aspect of structural design and analysis, and Abaqus provides powerful tools for accurately simulating and analysing this relationship.

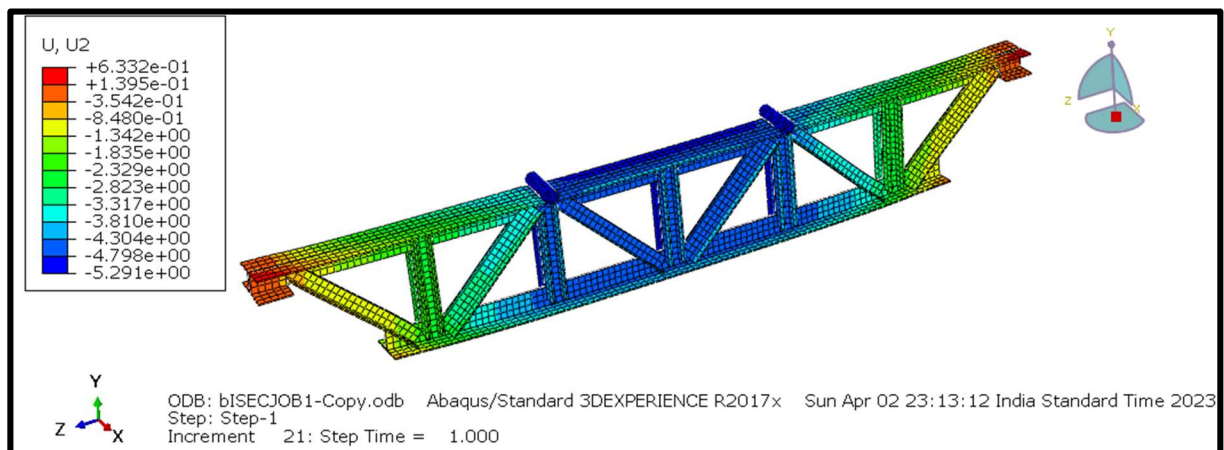


Fig 5.8 Deflection diagram in y-axis (N1-ISJ)

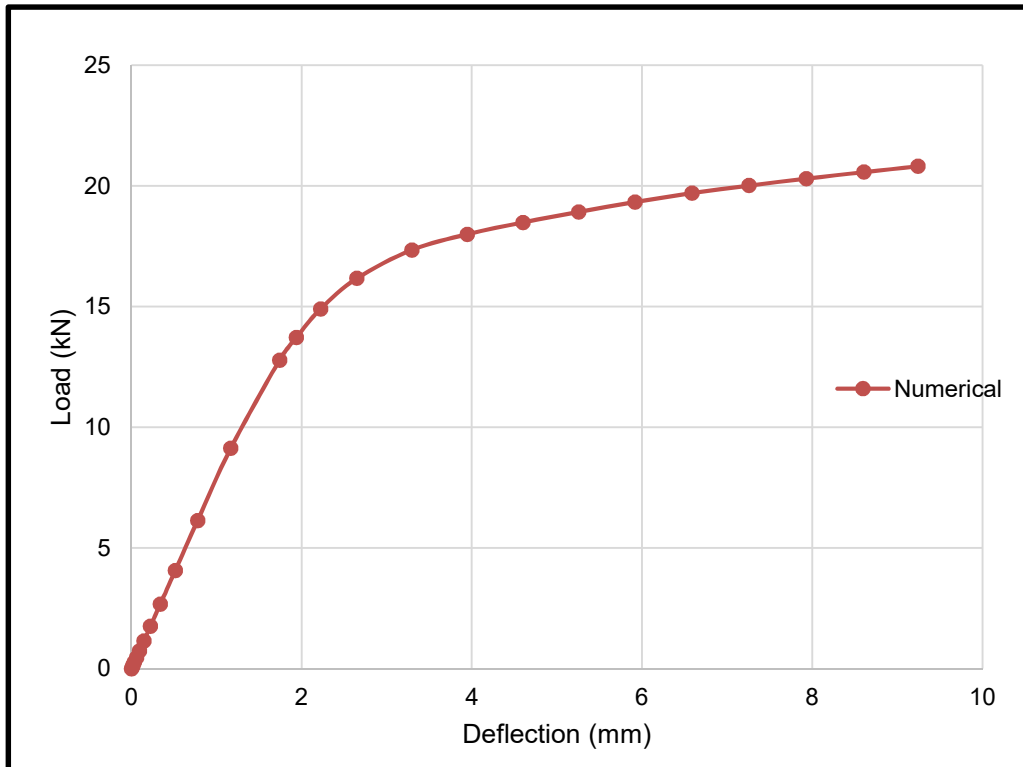


Fig 5.9 Finite element model load deflection relations for specimen (N1-ISJ)

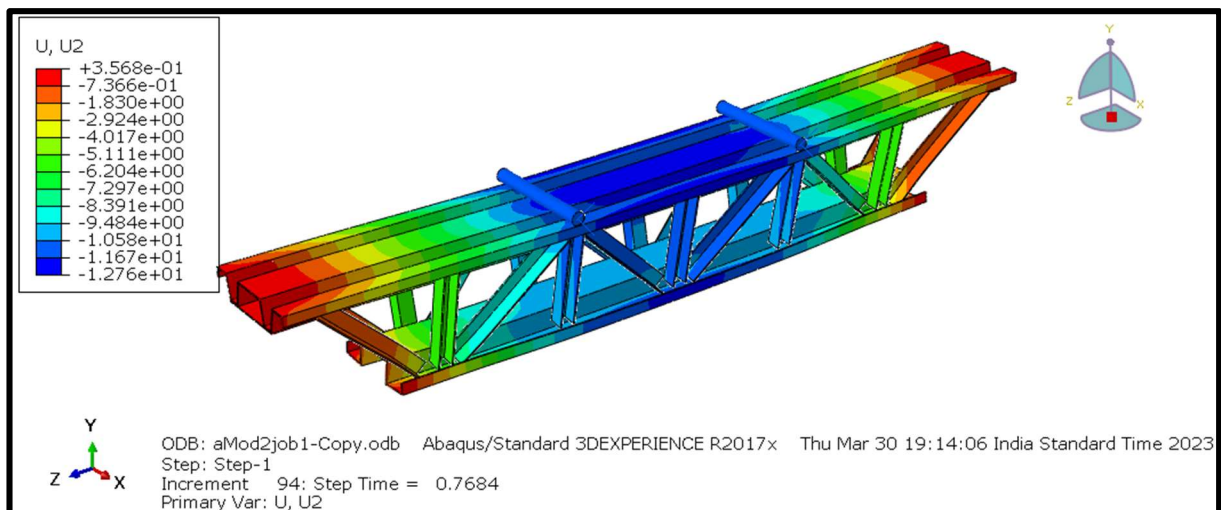


Fig 5.10 Deflection diagram in y-axis (N2-TSJ)

The rainbow colour plot of deflection depicts the magnitude and distribution of deflection across the structure. This data can be utilised to identify areas of excessive stress or strain, locate possible failure locations, and optimise structure design.

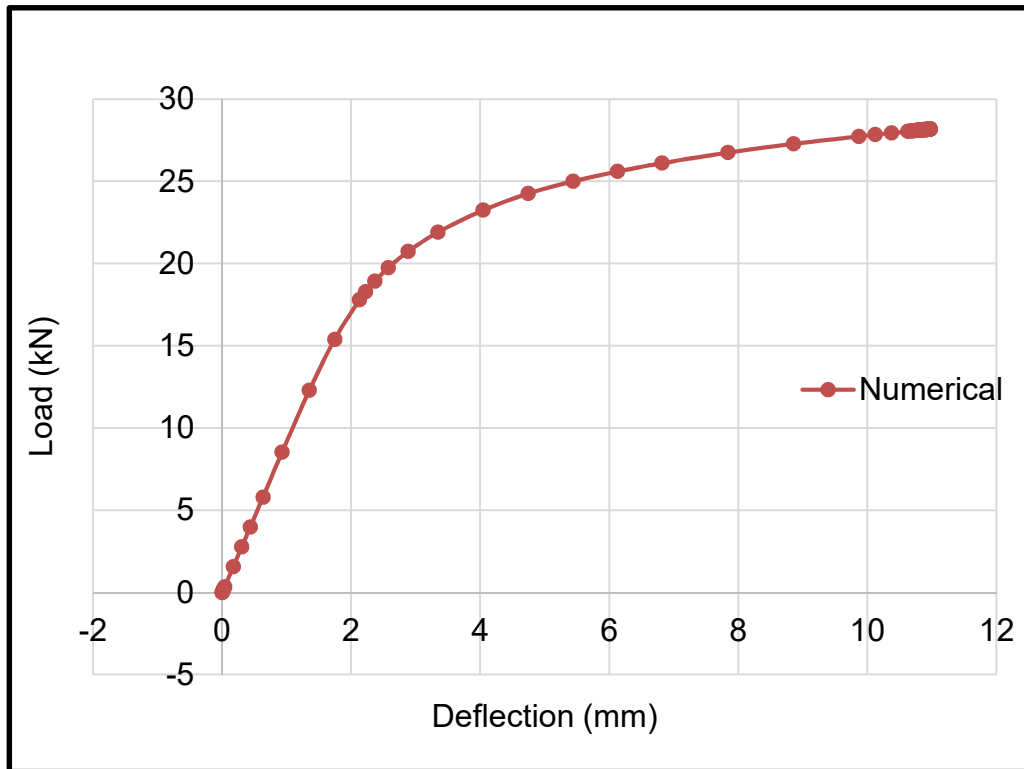


Fig 5.11 Finite element model load deflection relations for specimen (N2-TSJ)

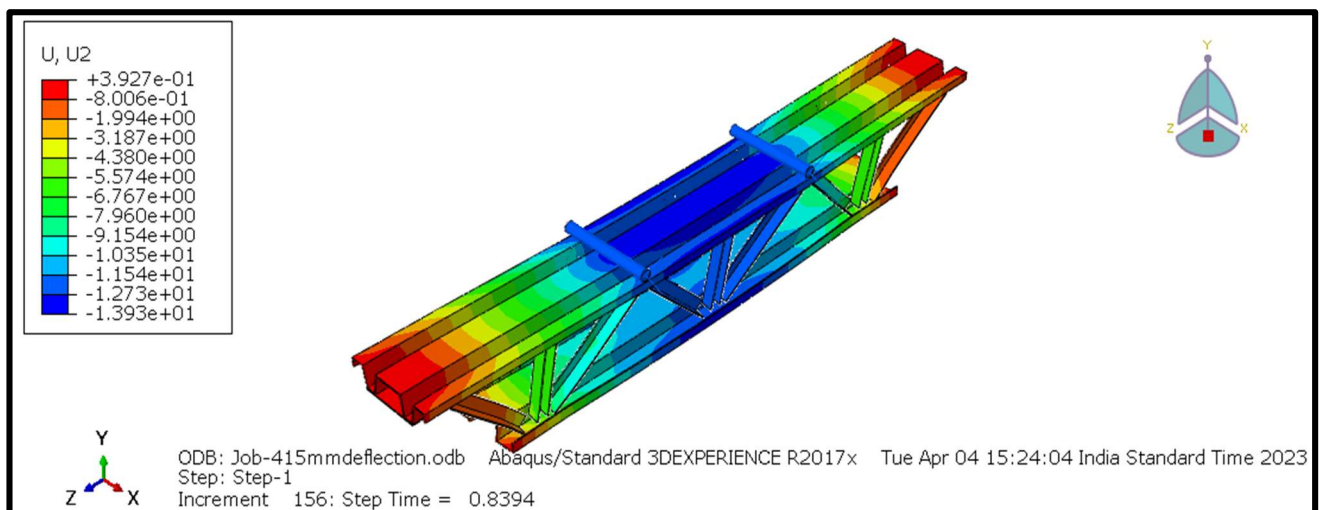


Fig 5.12 Deflection diagram in y-axis (N3-TSJ)

For the Joist N3-TSJ the deflection at the mid span is around 13 mm as form the deflection diagram represented in fig 5.12. At the top chord the deflection at the middle is around 15 mm deflected.

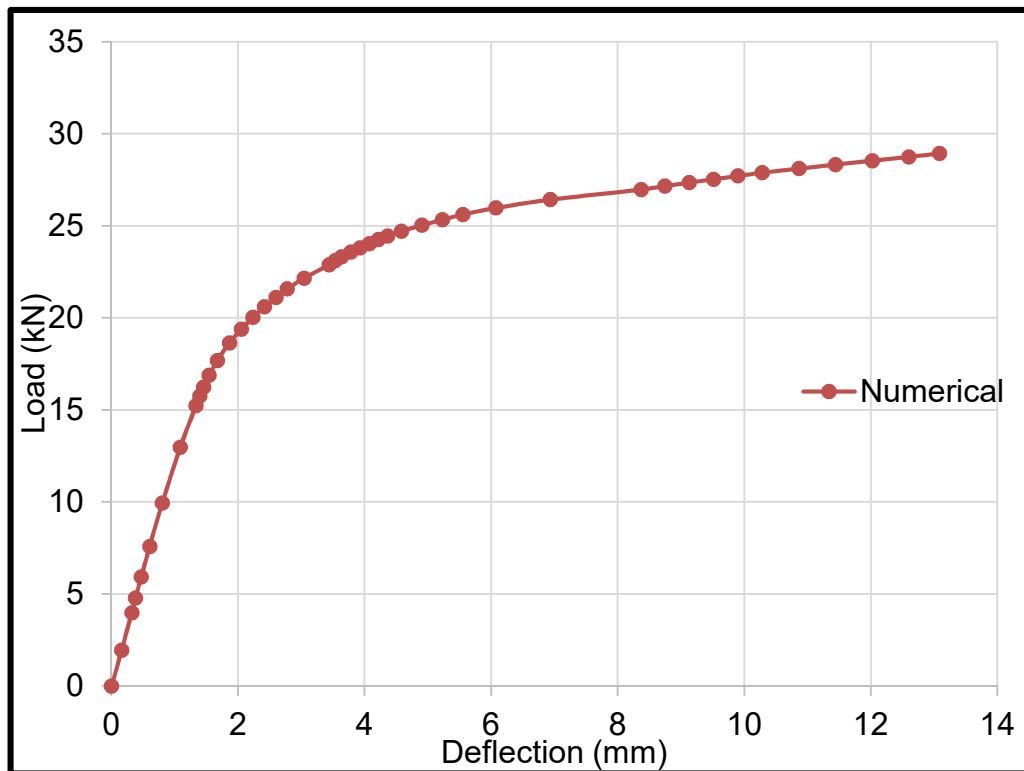


Fig 5.13 Finite element load deflection relations for specimen (N3-TSJ)

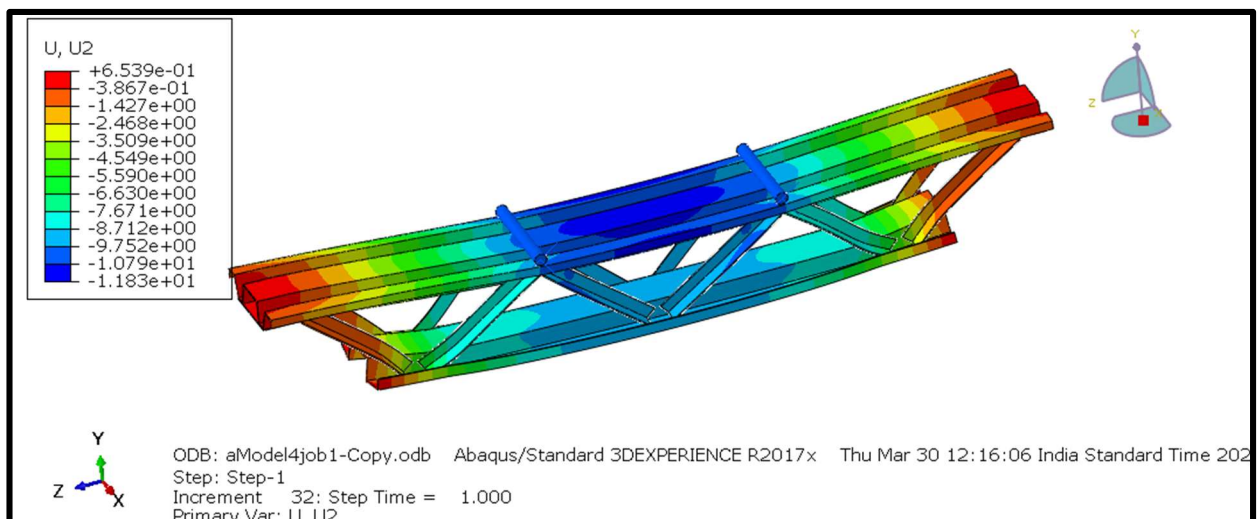


Fig 5.14 Deflection diagram in y-axis (N4-TSJ)

In the model 2 N4-TSJ for the deflection diagram fig 4.21 at the bottom chord didn't deflect as much as top chord. In the top chord deflection is around 12 mm and at the bottom chord deflection is around 9.5 mm as the

stress strain graph data in fig 4.22 is collected from the bottom chord the deflection value is considered as 9.5 mm only.

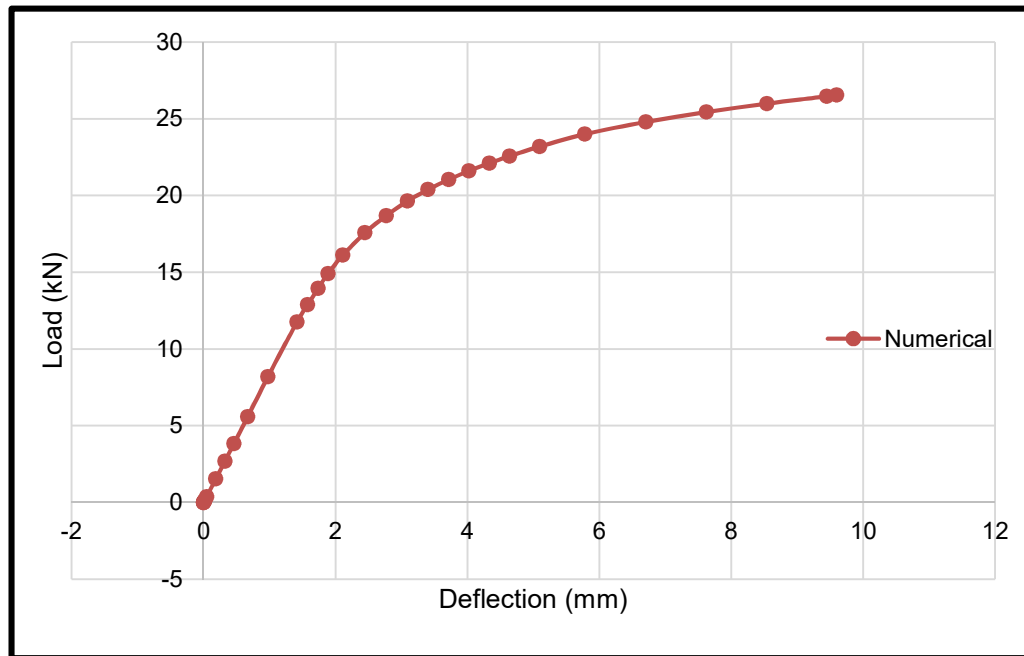


Fig 5.15 Finite element model load deflection relations for specimen (N4-TSJ)

5.3.2 Stress Distribution Diagram

The stress distribution through the parts of stain less steel joist is listed down below. Von Mises stress distribution was used to show high stress zones for each specimen as presented below figs 4.23, 4.24, 4.25, 4.26. It is recognized that the greater stress is in red in colour and the lesser stress are in deep blue in the colour

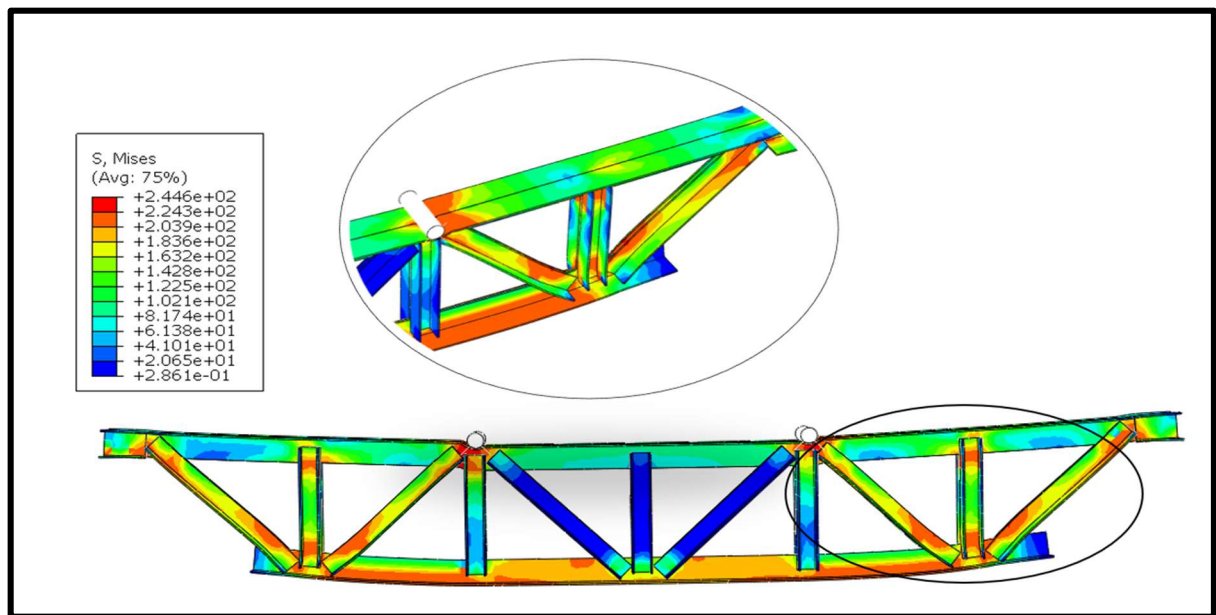


Fig 5.16 Von Mises Stress (N/mm²) Distribution of specimen (N1-ISJ)

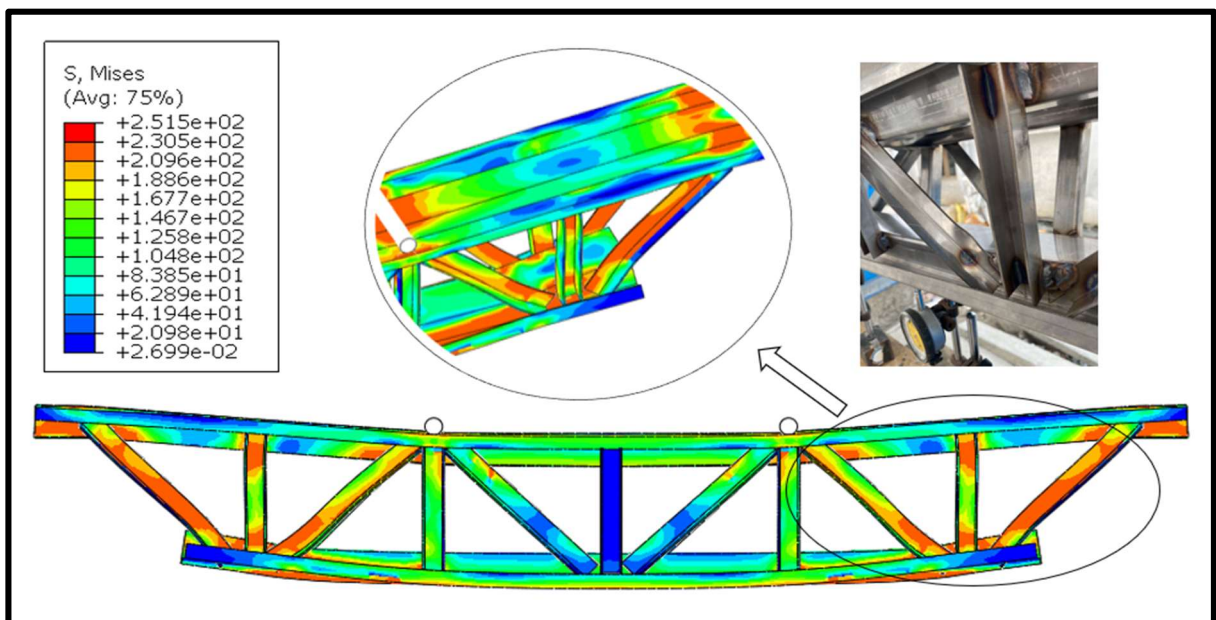


Fig 5.17 Von Mises Stress (N/mm²) Distribution of specimen (N2-TSJ)

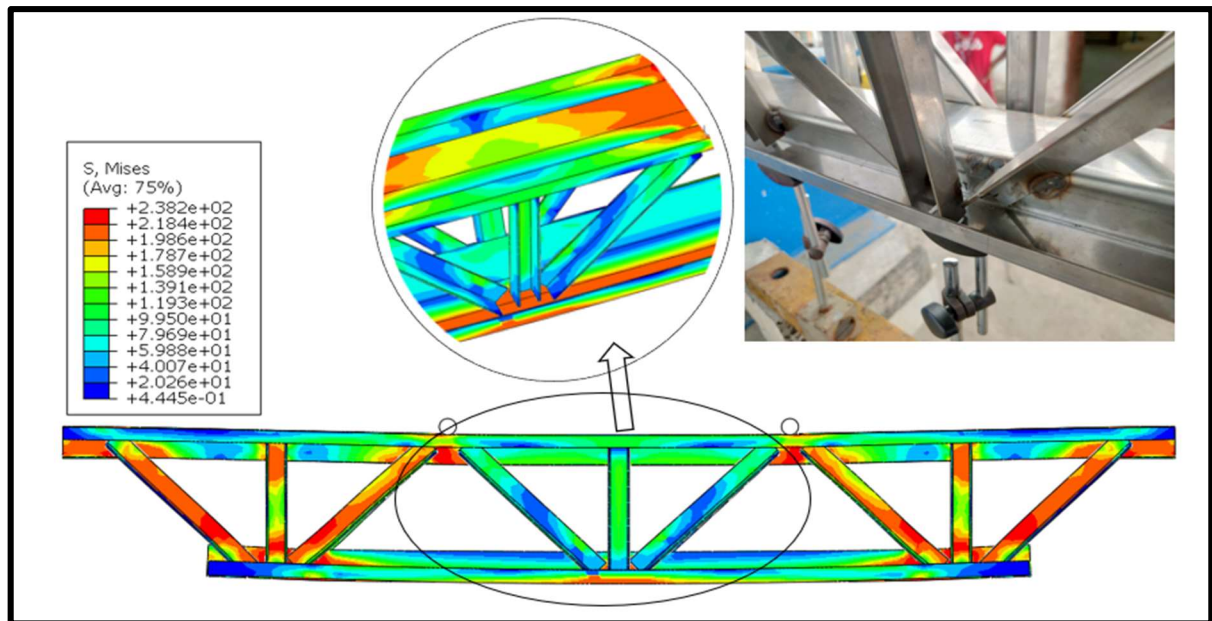


Fig 5.18 Von Mises Stress (N/mm²) Distribution of specimen (N3-TSJ)

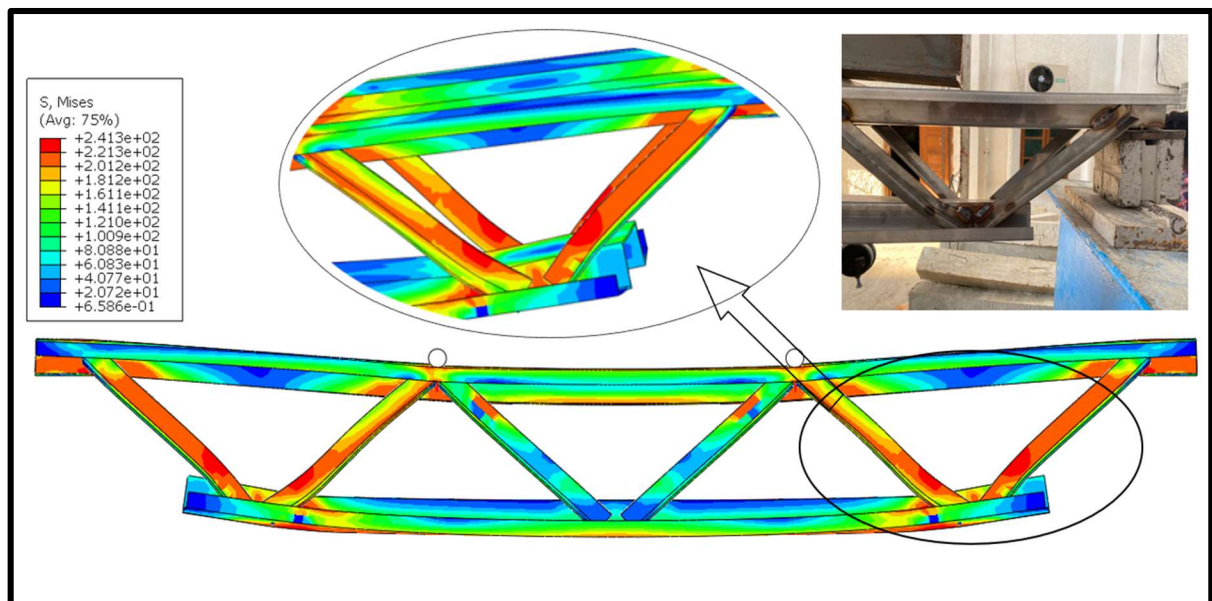


Fig 5.19 Von Mises Stress (N/mm²) Distribution of specimen (N4-TSJ)

Table 5.3 Analytical results load carrying capacity and deflection (N1-ISJ, N2-TSJ, N3-TSJ, N4-TSJ)

Steel Joist	Ultimate Load Carrying Capacity (kN)	Deflection (mm)
N1-ISJ	20.8	9.2
N2-TSJ	28.1	10.1
N3-TSJ	27.3	11.3
N4-TSJ	27.3	12.1

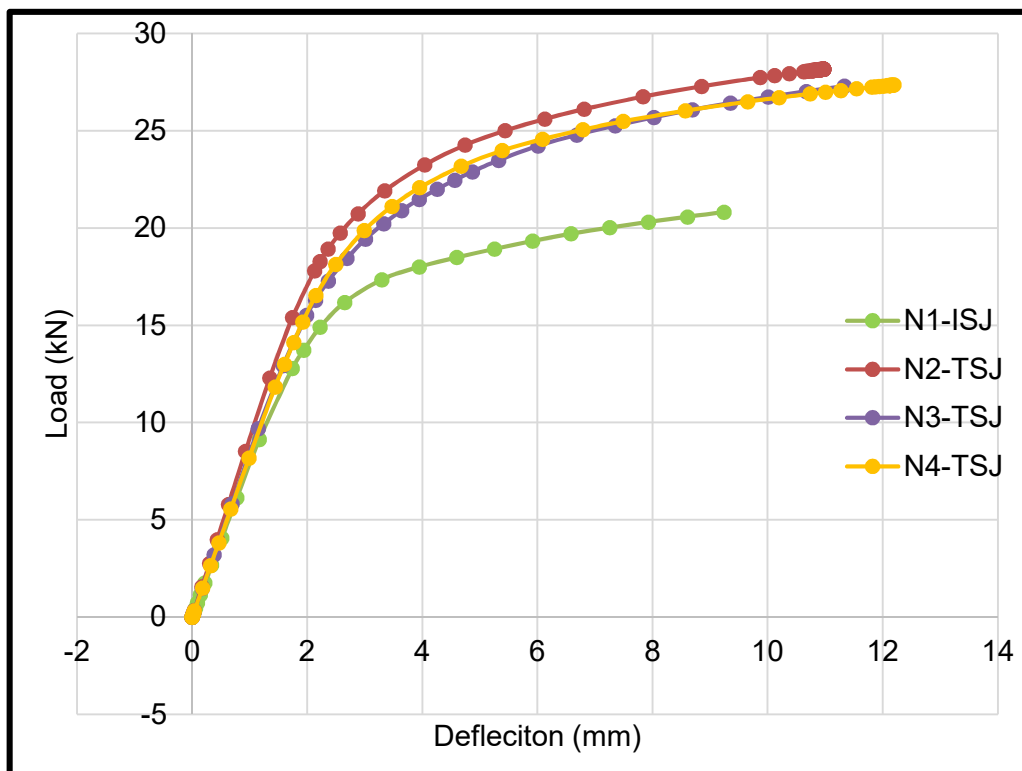


Fig 5.20 Comparison of Analytical Results of load-deflection (N1-ISJ, N2-TSJ, N3-TSJ, N4-TSJ)

5.4 COMPARISON OF EXPERIMENTAL AND NUMERICAL RESULTS

The load deflection curve for all specimen by experiment and analytical results is shown in fig 5.21. It helps to understand the behaviour of trapezoidal and normal floor joist.

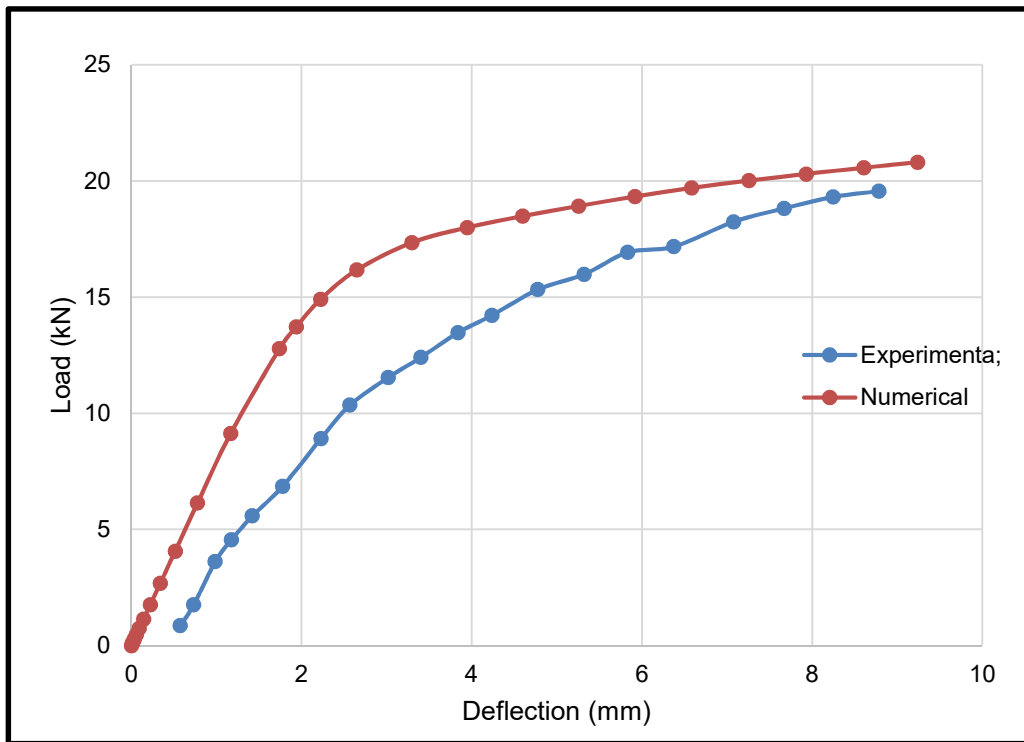


Fig 5.21 Comparison of Experimental and Analytical Results of load-deflection (N1-ISJ)

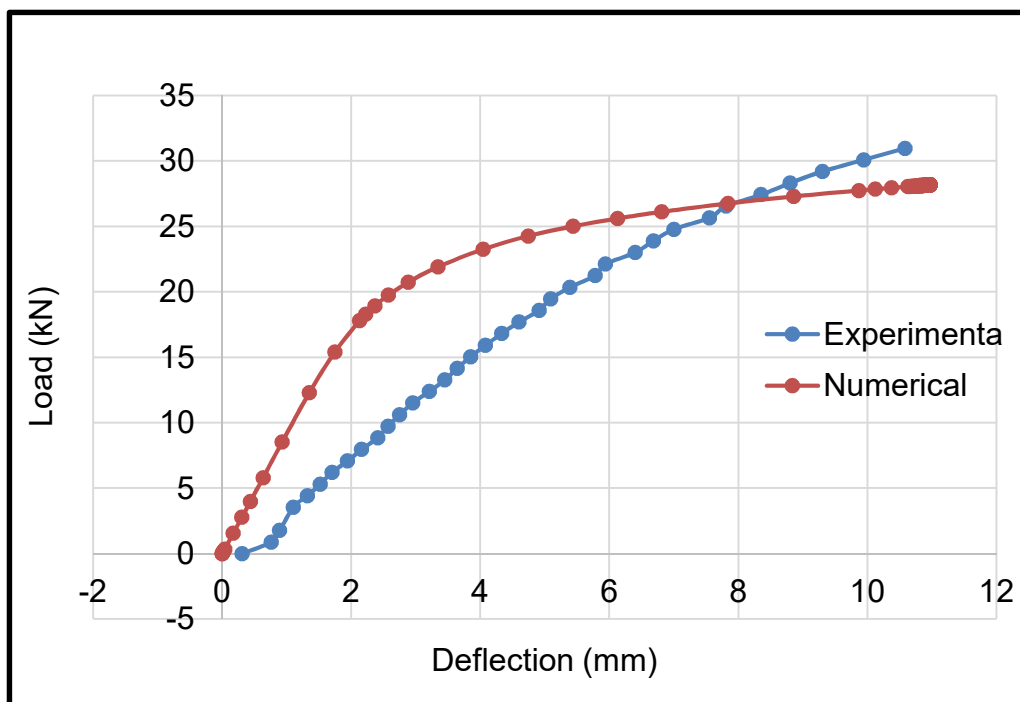


Fig 5.22 Comparison of Experimental and Analytical Results of load-deflection (N2-TSJ)

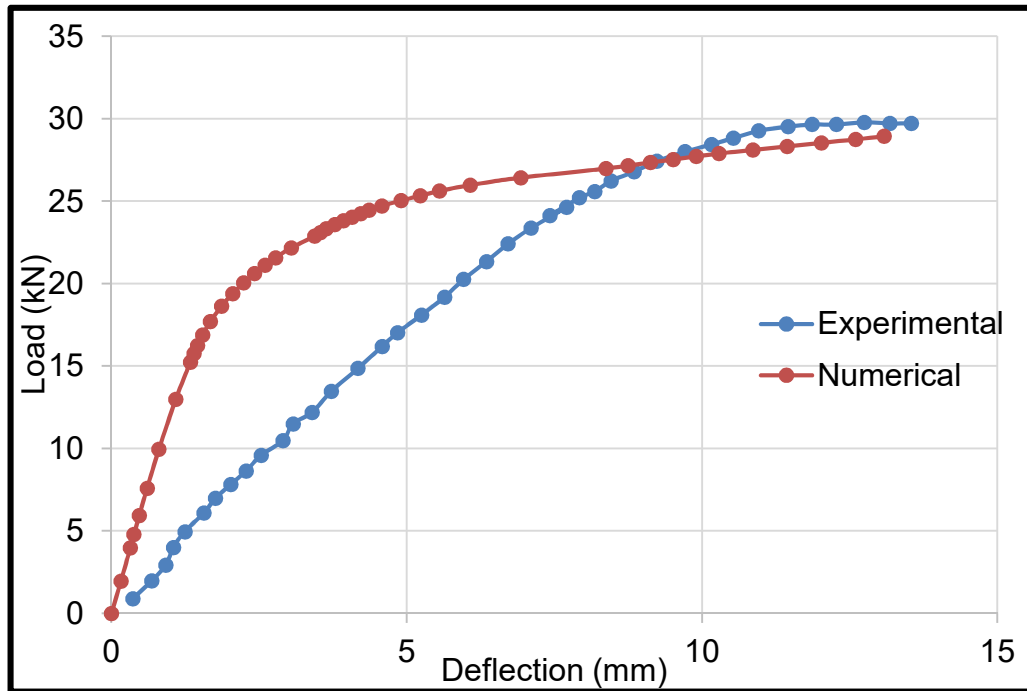


Fig 5.23 Comparison of Experimental and Analytical Results of load-deflection (N3-TSJ)

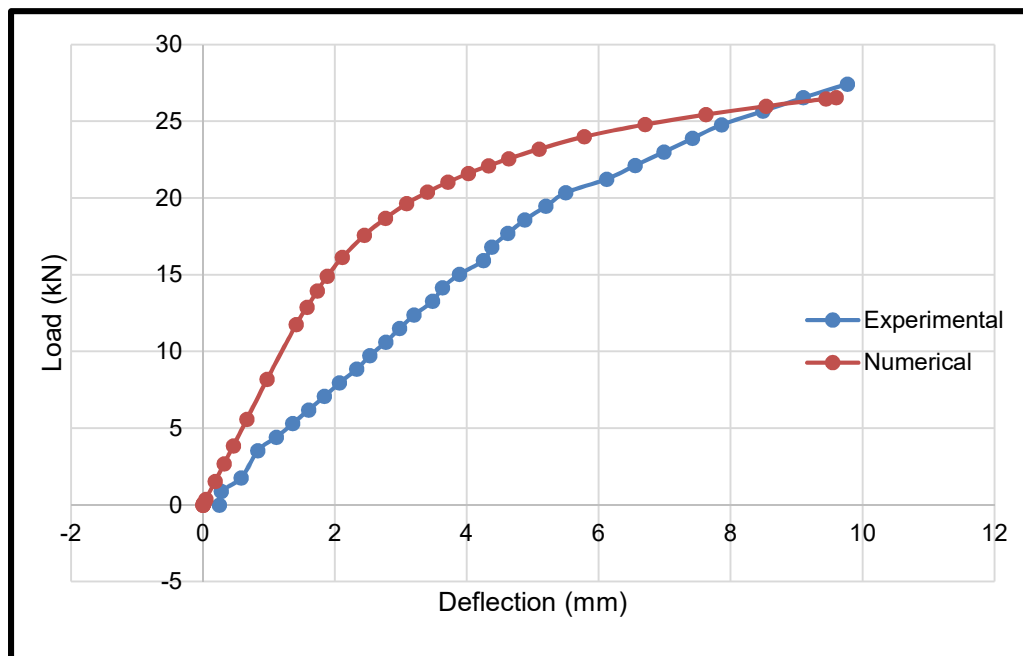


Fig 5.24 Comparison of Experimental and Analytical Results of load-deflection (N4-TSJ)

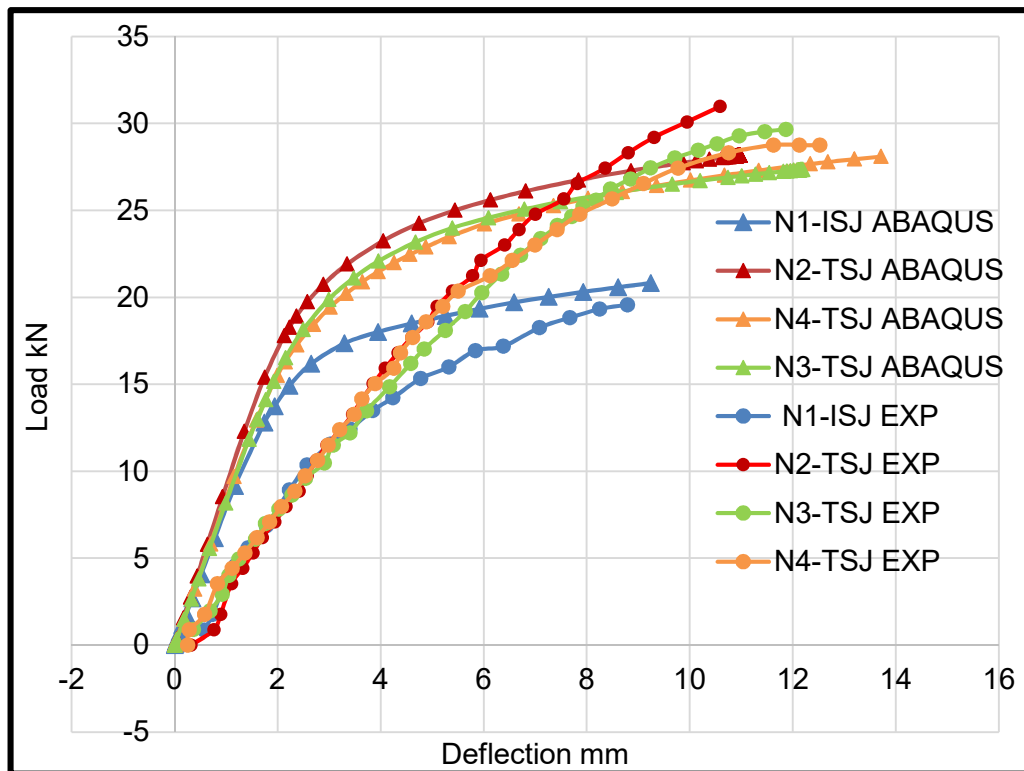


Fig 5.25 Comparison of Experimental and Analytical Results (N1-ISJ, N2-TSJ, N3-TSJ, N4-TSJ)

5.4.1 Lateral Torsional Buckling (N1-ISJ)

As this model joists are often designed as slender sections because they are typically subjected to compressive loads, which can cause them to buckle if they are not slender enough to resist buckling.

Here in this model when the load is applied on the top chord it is most likely to buckle outside the neutral axis because top chord is a primary compression member. Therefore, the ultimate load carrying capacity have been reduced.

The fig 5.26 shows the lateral torsion buckling on both experimental and analytical investigation.

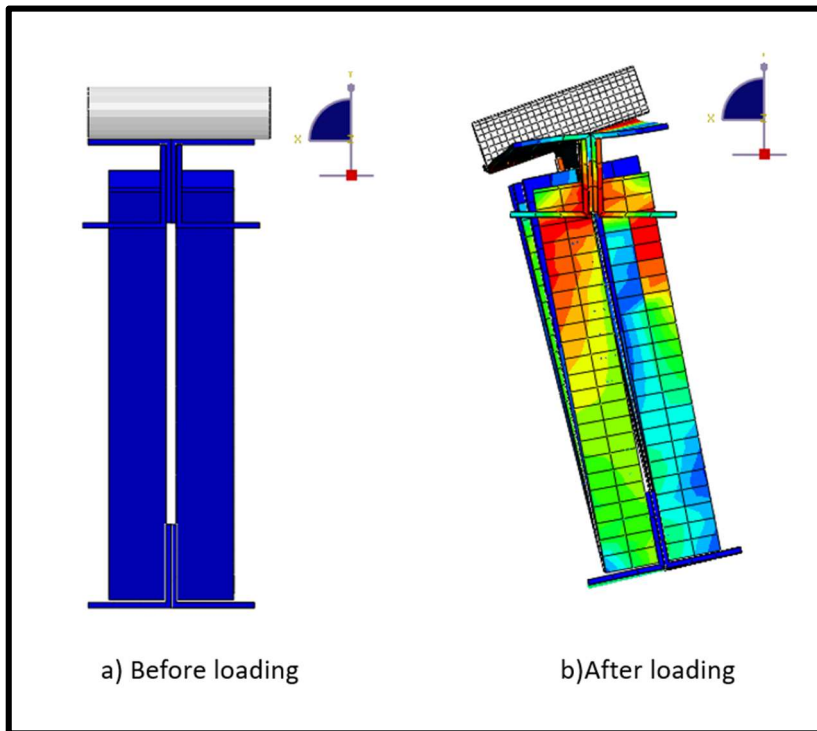


Fig 5.26 Cross section View (N1-ISJ) Buckling out sided the plain

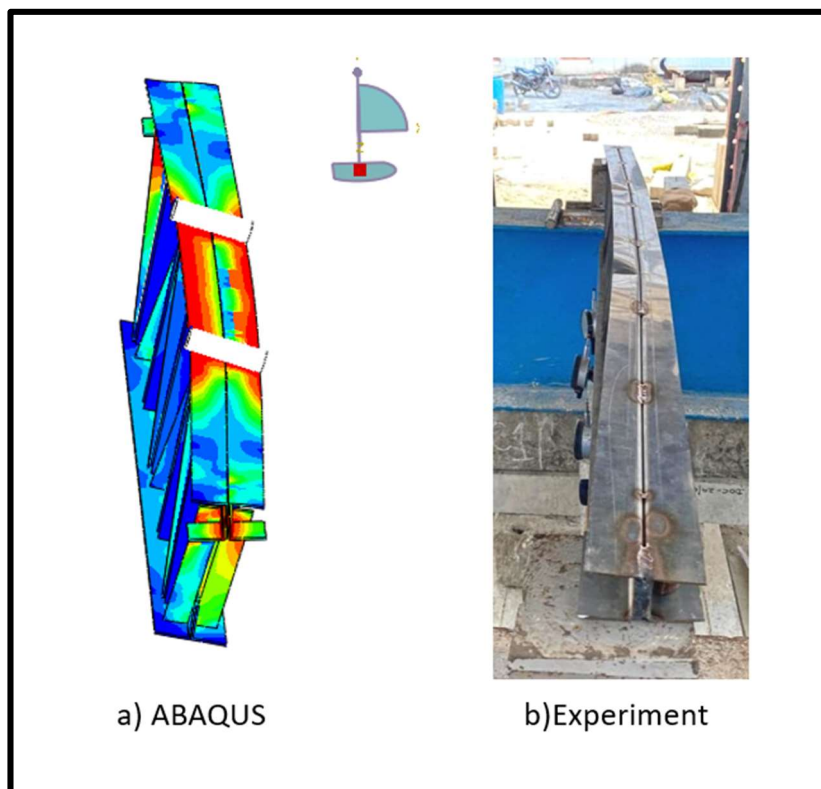


Fig 5.27: ABAQUS and Experimental model (N1-ISJ) failure due to lateral torsional buckling

5.5 DISCUSSION

The detailed explanation of the results that are collected from the experimental and numerical key results were discussed by points below:

Comparing Trapezoidal joists to Typical I Section floor joists, they generally outperformed the latter. It is as a result of the N1-ISJ's I section's slenderness ratio, which caused it to buckle outside of the neutral axis. Four different models' experimental findings were contrasted with one another. When compared to joist N2-TSJ, joist N1-ISJ's maximum load carrying capacity is 50% less. Even though both have similar web arrangements and the mass difference is only 41% higher in N2-TSJ, this clearly shows that N2-TSJ is more economical model. when compared to joist N3-TSJ, joist N1-ISJ's ultimate load carrying capacity is 36% less. N3-TSJ is clearly more economical even though it only has a 28 percent mass difference and four vertical web connectors that are less in number. compared to joist N4-TSJ, joist N1-ISJ has a 33 percent lower ultimate load carrying capacity. Even though the mass difference is only 25% higher in N4-TSJ and the number of vertical web connectors was reduced, this clearly shows that N4-TSJ is more economical. The next comparison is done using numerical model results all three trapezoidal model were compared with I section floor joist. compared to joist N2-TSJ, joist N1-ISJ has a 33 percent lower ultimate load carrying capacity. and 33% less when compared to joist N4-TSJ, and 28% less while compared to joist N3-TSJ. All the graph comparison can be seen in fig 5.25 While the difference between the numerical and analytical results is not large, it is clear from the graph that trapezoidal joists have performed well in experimental results. In contrast, Model N1-ISJ Finite Element Model has performed well, which may be related to the fact that lateral torsional buckling occurred more frequently in experimental results, as shown in fig 5.27 when applying load to the joist. According to the graph in Fig. 5.6, the relationship between N1-ISJ joist load and deflection is linear, and according to observation made throughout the experiment and test processes, buckling only occurred on the top chord and no parts of the joist structure were fractured. There is lateral torsional buckling as the mode of failure as shown in the fig 4.27. Models N2-TSJ and N3-TSJ were unsuccessful owing to brittle fracture as shown in fig 5.18 and 5.19, which is a failure mode where the welded region separates from the bottom chord and vertical web

connector. Due to faulty welding technique, the material at the welded zone becomes harder as a result of a sudden shift in temperature during welding process. On the other hand, in model N4-TSJ, brittle fracture didn't occur. Instead, the model experienced buckling at the diagonal web connectors that are provided on both ends. Based on observation, this is because the web connectors are inadequate to support the load that the top and bottom can support easily. It is evident from the stress distribution graphic provided in fig 5.19 that the tension in the top and bottom chords is not distributed equally.

CHAPTER - 6

CONCLUSION

- Tensile coupon tests were carried out for accuracy purposes to define the material properties of cold-rolled ferritic stainless steel on ABAQUS for that a total of four specimens were cut down from each area of the specimen before the tensile test was carried out.
- The ASTM E8/E8M standard for cold rolled stainless steel, which gives the dimensions for the tensile coupon test specimen.
- A loading frame with a 500 kN capacity was utilised to evaluate the flexural behaviour of the joists and for the support condition, one end will have a roller support, while the other end will have a hinged support.
- To investigate the flexural behaviour of joists during four-point static loading, a proving ring is used to gauge the load applied to the joists and to calculate their values obtained simultaneously the deflection values were collected from the bottom of the joist, there were three dial gauges: one at the middle of the span, one on the left-third of the span, and one more on the right-third of the span.
- The floor joist finite element model was accurately created, and all other modelling procedures were carried out as described in chapter 4 after the model was assigned with the material properties obtained from the tensile coupon test.
- Using the data gathered, a thorough comparison is made between experimental and numerical study. The results are all reported in chapter 5.
- To conclude, the ferritic stainless-steel grade that is used can be used for structural applications, but it's not recommended to go with the welding process; instead, bolted connections or Revit connections are recommended.
- To conclude the flexural behaviour of trapezoidal floor joists, their load carrying capacity is relatively high, and their strength by weight ratio is also 30 percent higher than that of the standard joist section. So, this type of joist section will have considerable cost effectiveness.

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