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Investigation of the Flexural Behavior of Built-Cold-Formed Steel Channel Sections

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Abstract:

The recent trend in the structural steel sector has provided cold formed steel with significant prospects for quick growth and expansion. The escalation in the cost of this light gauge steel facilitated the pursuit of more research. The experimental setup chosen to examine the flexural behavior involved using a built-up back-to-back cold formed channel segment. Both lipped and unlipped channel parts were considered, with several cases taken into account. To conduct the study, the researchers utilized specimens that were both devoid of lips and have lips. Both an empirical research and a computational analysis were conducted for the objective of this study. An investigation was conducted to examine the performance of the specimens under both settings. It was discovered that the specimen with the lipped edge outperformed the other specimen at greater performance levels. The findings were shown in the form of a graph. The specimen underwent a finite element analysis using the ANSYS software. The findings of both the experimental inquiry and the numerical analysis were thoroughly analyzed during the subsequent debate. Subsequent investigation revealed that specimens measuring 2.5 millimeters in thickness had outstanding performance in the flexural test. Examining the specimen for variable thickness can also be done by making use of the lipped conditions that surround the specimen..

Keywords -Finite element Analysis, Flexural behaviour ,Light Gauge Steel, Unlipped channel sections, varying thickness.

1. Introduction:

Thin-walled cold-formed steel beams with open cross sections are becoming increasingly popular in civil engineering, automotive, aviation, vessel and railway industries. Cold-forming technology has many advantages, such as less energy needed, cheaper than traditional technologies, and can be used for sheet metals covered by anticorrosive coatings. However, they can be easily damaged and their load capacity and strength may be affected by small inaccuracies

CFS section has become increasingly popular due to its advantages, but proper analysis and evaluation of the structural responses of the closed section is needed for a secure design. CFS elements are increasingly being used as primary structural members in multi-story buildings.

Cold-formed steel (CFS) is used in many structures, such as columns, beams, rafters, purlins, trusses, and architectural decoration. It is thin compared to hot-rolled steel, and there are several types of C-section and Z-section sections. Experimental research is needed to optimise the elastic buckling strength of C-section and Z-section CFS beams.[1]

Cold-formed steel (CFS) channel beams with edge-stiffened web holes were subjected to bending, and the eXtreme Gradient Boosting (XGBoost) machine learning model was utilized in order to determine the moment capacity of these beams. Using an elasto-plastic finite element model, a total of 1620 data points were generated for the purpose of training the XGBoost model. When it came to the capacity at the present, the R2 score of XGBoost forecasts was somewhere around 99%. In order to assess the effectiveness of the existing design equations, a comparison was made between the findings produced from the XGBoost model and those obtained from the present equations. It was discovered that the moment capacities that were estimated using the existing design equations for un-stiffened holes (USH) and edge-stiffened holes (ESH) were found to be overly conservative by 38.3% and unconservative by 36.2% on average, respectively. Since this was the case, new design equations were suggested on the basis of the findings of the parametric research that was conducted using the XGBoost model.[2]

Through the development of a methodology to generate more effective bolted moment connections by utilizing optimized CFS beams with increased non-linear post-buckling behavior, the purpose of this work is to improve the seismic performance of moment-resisting frames that are constructed using the CFS material. ABAQUS software is used to build precise Finite Element (FE) models of a typical CFS bolted moment connection. These models are then validated based on the results of practical cycle tests. In order to optimize CFS bolted moment connections depending on either energy dissipation capacity or ductility, the Particle Swarm Optimisation (PSO) method is connected to the GMNIA ABAQUS finite element analysis.[3]

The behavior of cold-formed steel lipped channel beams that were impacted by local-distortional (L-D) interaction under non-uniform bending was the subject of an experimental inquiry that was carried out at The University of Hong Kong. The experimental examination is comprised of sixteen non-traditional four-point simply supported bending tests. These tests use twin lipped channel beams that are positioned in a "back-to-back" configuration and are laterally restrained at the loading points.[4]

Within the scope of this work, the in-plane behavior of built-up box beams with nested C and U sections is investigated while they are subjected to pure bending about strong and weak axes. The results of the tests are used to validate the development of a finite element model, which is then used for additional parametric analysis. There is evidence that components in built-up beams are able to resist the bending moment collectively, as seen by the stress distribution at the mid-span cross-section. It is determined if the capacity superposition approach or the equivalent method is more appropriate for built-up box beams that bend about the strong axis. For the purpose of calculating the flexural strength of built-up box beams that are bent about the weak axis, the corresponding box section is proposed.[5]

The experimental results for cold-formed stainless steel lipped channel beams that include distortional-global interaction buckling are presented in this work. There were three different stainless steel alloys that were used, and coupon tests were carried out in order to assess the mechanical characteristics of the virgin sheet material as well as the work-hardened corner material of the press-braked sections. When the section capacity was being determined, a total of 32 specimens were subjected to four-point bending testing, and six of those specimens were also subjected to lateral bracing testing. In order to reduce the amount of uncertainty and to offer benchmark tests for analytical and numerical research, the remaining 26 specimens were put through trials in a test setup that had been specifically designed for the purpose.[6]

A research investigation on the structural behavior of cold-formed steel beams with C-, I-, R-, and 2R-shaped cross-sections at ambient temperature is also included in this study. There is a presentation of this research study. In order to evaluate failure loads and failure modes, four-point bending tests were carried out. Additionally, an appropriate finite element model was built in order to compare the findings of the experiments with the expected outcomes.[7]

The purpose of this work is to provide the results of an experimental and numerical investigation on cold-formed steel (CFS) built-up beams that were constructed using back-to-back sigma parts. For the purpose of preventing lateral torsional and local buckling, the research focuses on fifteen tests that are conducted with three various lengths and five different intermediate connection spacings. Laterally braced specimens are also used. Parametric investigations were carried out with the use of numerically verified models that had five distinct lengths, two distinct sheet thicknesses, and a range of distortional slendernesses. The direct strength method (DSM) developed by the American Institute of Steel and Iron (AISI) was used to compare the numerical findings with the design strength predictions. The comparison revealed that the design predictions are conservative in general, but they are too cautious for the low slenderness range.[8,9]

In addition to this, the research investigates the impact that non-uniform bending has on the behavior of cold-formed steel built-up section flexural members. On eighteen different specimens, four-point bending tests were carried out. The moment distributions of these specimens varied. After establishing finite element models for the built-up section flexural members, the models were calibrated based on the results of the experiments. Through the use of a parametric analysis, an additional three hundred numerical data of the built-up section beams under uniform and non-uniform minor axis bending were created.[10]

In order to attain more appropriate strength forecasts for the design of cold-formed steel built-up section beams, it was proposed that the design guidelines be updated. In addition to this, the work includes both numerical and analytical examinations on the distortional buckling of perforated cold-formed steel channel-section beams that have circular holes in the web.[11]

The purpose of this work is to report the results of an experimental investigation and a numerical analysis that was conducted on the bending strength and behavior of cold-formed steel beams with C-section and Σ-section sections that were equipped with Web holes and sophisticated edge stiffeners. Based on the findings, it can be observed that the stiffened web has a significant impact on the bending strength of the member. On the other hand, the stiffness of the web stiffeners of the Σ-section specimens mitigates the detrimental impact of the holes. In terms of buckling mode and bending strength, the findings of the finite element analysis demonstrate a good agreement with the results of the experiments.[12]

The web crippling behavior of unlipped and lipped channel and SupaCee sections is also discussed in the study. These sections are susceptible to web crippling failures because of the increased plate slenderness that they possess. In order to solve these deficiencies, new equations were developed in order to calculate the web crippling capacities of lipped and unlipped channel and SupaCee sections. These equations were derived by utilizing the web crippling capacity data obtained from trials as well as analytical finite element calculations. Additionally, appropriate web crippling design formulae that are based on the direct strength approach were created.Two of the most popular cold-formed steel forms that are used all over the world are plain C or Z-sections, as well as high strength SupaCee® and SupaZed® steel sections. Design procedures for these sections are often described in the North American Specification for Cold-Formed Steel Structural Members (NAS S100-2007) or the Australian/New Zealand Standard for Cold-Formed Steel Structures (AS/NZS 4600:2005). Both of these standards were developed in 2005. The recently created Direct Strength approach of design (DSM) is being developed for beams and columns, and the dependability of the approach is being taken into consideration and developed.[13]

In order to investigate the apex knee connection of a portal frame that was built using cold-formed back-to-back double-lipped C sections for both the rafter and the column, a nonlinear finite element parametric research was carried out. The primary objective of the study was to investigate the impact that various factors have on the ultimate capacity of the eave connection as well as the form of failure that it experiences. The ripping of the C-section web was one of the five mechanisms of failure that were detected. Other modes of failure were lateral out-of-plane buckling of the gusset plate, local buckling of the linked section, bolt bearing of the C-section web and the gusset plate, and connection buckling. It was noted that bearing failure is the predominant form of failure; nevertheless, in certain instances, lateral-out-of-plane buckling of the gusset plate produces premature failure of the connections at low values of applied loads might induce failure of the connections earlier than expected.[14]

There were a number of observations that were discovered, and some helpful recommendations for the most effective arrangement of the connection were proposed. For the purpose of calculating the resistance of the joint connection under moment, shear, and normal forces based on the bolt bearing failure for various bolt pitches, a straightforward interaction design process for particular configurations has been presented.[15]

The structural behavior of light gauge high strength cold formed steel sections, especially C and Z, in the construction sector is investigated in this work from a structural perspective. In order to postpone or remove early buckling modes, the researchers suggest unique sectional profiles and stiffening arrangements. This will result in an improvement in load bearing capacity and stiffness characteristics in comparison to traditional steel sections. The effectiveness of putting vertical stiffeners in the web of cold-formed C-section beams when they are subjected to local focused loading is another aspect of the study that is being investigated. For the purpose of determining the impact that stiffener shape has on the final crippling strength of the stiffened web, the researchers employed numerical modeling techniques within the framework of the finite element method (FEM). The results were compared to the ultimate web crippling capacity of beams that had not been stiffened, and the correlations between load and vertical web displacement and load and horizontal web displacement were determined. A set of recommendations for more study was developed based on the analysis of the results.[16,17]

Within the context of the construction sector, the study investigates the structural behavior of light gauge high strength cold formed steel sections, more especially C and Z. In order to postpone or remove early buckling modes, the researchers suggest unique sectional profiles and stiffening arrangements. This will result in an improvement in load bearing capacity and stiffness characteristics in comparison to traditional steel sections. The effectiveness of putting vertical stiffeners in the web of cold-formed C-section beams when they are subjected to local focused loading is another aspect of the study that is being investigated. For the purpose of determining the impact that stiffener shape has on the final crippling strength of the stiffened web, the researchers employed numerical modeling techniques within the framework of the finite element method (FEM). The results were compared to the ultimate web crippling capacity of beams that had not been stiffened, and the correlations between load and vertical web displacement and load and horizontal web displacement were determined. A set of recommendations for more study was developed based on the analysis of the results.[18-21]

Because of their high strength for low weight, simp le production process, and ease of transportation and erection, CFS thinwalled members are advant ageous
from an economical and efficient standpoint. The previous research on the flexural strength of assembled cold-formed steel sections discovered that the flexural capacity was greater than that of the individual cold-formed steel sections. So, in this study, a built-up cold-formed steel beam is chosen. The purpose of this research is to examine how a built-up cold-formed steel beam responds to flexure.

They are, however, prone to local, distortional, an d global buckling modes,which necessitates a diffic ult
optimisation process.

The outcomes of experimental research and finite element analysis are mostly taken into account. As a result, an analytical examination using FEA of back-to-back built-up cold-formed steel sections is conducted, and the results are explained in depth in this research report.

2. EXPERIMENTAL STUDY

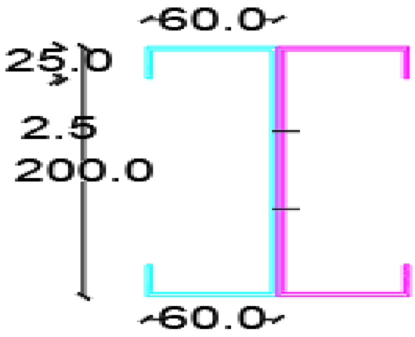
The primary objective of the current study is to ide ntify the buckling mode, deflection, stress, strain, a nd other parameters by an experimental test of col d-formed steel sections subjected to flexure. The test is carried out under prescribed conditions in a loading frame with a 100-ton capacity. Fig 1 shows the geometric details of the model. Bolted connection has been applied for the member connection.

2.1 Specimen fabrication

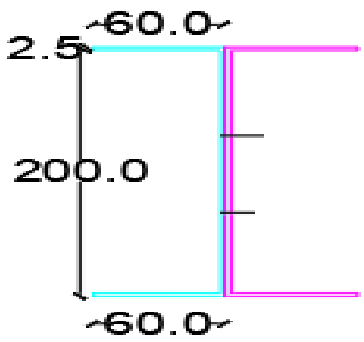
The beam's dimensions were back-to-back built up unlipped channel sections measuring 60X200X2.5 mm (BCWOL2.5/200) as fig1 and back-to-back built-up lipped channel sections measuring 60X200X2.5mm (BCWL2.5/200) fig 2. 4.6 grade M12 screws were used for fastening in both the specimens. The length of the beam was 3200mm.

Details	**BCWOL2.5/200**	**BCWL2.5/200**
Breadth	60	60

Depth	200	200
Thickness	2.5	2.5
Depth of the lipped channel	25	25
Length of the beam	3200	3200



Cross Section of the Specimen BCWL2.5/200



Cross Section of the Specimen BCWOL2.5/200

Experimental setup- BCWL2.5/200

Experimental setup- BCWOL2.5/200

shown in figures 1a and 1b, respectively. The alignments were scrutinised in great detail, and the strain gauges and deflection gauges were installed in the appropriate locations. In order to impart the axial load, a hydraulic jack was utilised. in order to determine the axial strain of the face

After the components had been assembled, dial gauges were installed on them. At the mid-position, an LVDT was used to measure the deflection of the built-up beams so that the local buckling and the site of load application could be determined. Before changing the loading rate in order to get a better understanding of the local buckling formation, the beam was originally loaded up to approximately the load that was expected to cause it to fail. When taking the appropriate readings, the proving ring, the LVDT, and the strain gauges are the instruments that are utilised. Graphs are used to display the results.

3. FINITE ELEMENT ANALYSIS

The behaviour of built-up steel sections under flexural loading was analysed using finite element models. This was done so that the behaviour could be predicted. The Indian standard code served as the source of the standards that were used in the construction of the various structures. In this section, several different sets of finite element models were explored, and various variables, such as changing section thickness and built-up sections without lips, were taken into consideration. For the purpose of the analytical investigation, the version 22R1 of the ANSYS finite element modelling application was applied.

The length of the beam was 3.2 metres. It was decided to make models of the most important aspects of the beam, such as the beam channels and the bolts. For the construction of the section of the beam member, the ANSYS element type SOLID185 was utilised. Beam 188 was utilised as the model's link element to represent the bolted connection. In this particular representation, a bolted connection was utilised in order to finish the connection between the built-up beam. Figure 3 displays a finite element model of cold-formed steel built-up sections. Figure 3: Cold-formed steel built-up sections. Table 2.

3.1 MATERIAL PROPERTIES

To determine, the yield strength and elastic modulus of the cold-formed steel, coupon tests were carried out. These values, which were determined through experimental testing, were entered into ANSYS as steel properties.

Description	
Youngs modulus	2.07X10^5 N/mm^2
Yield Strength	385 N/mm^2

Table 2 Material characteristics of CFS section

3.2 Modelling of Cold-formed Sections Using the FEM

Finite element models were created in order to investigate the behaviour of back-to-back cold-formed steel sections when subjected to flexural loading conditions. In the course of the experiment, the test subjects consisted of beams that either had or did not have lipped conditions in the flanges, in addition to variables of varying thickness. The finite element analysis was carried out with ANSYS version 21, which was employed.

3.3 Modelling of various types of materials

In the section of the report devoted to material modelling that dealt with finite element analysis, one of the key components that was taken into account was the mechanical properties of the steel. In order to properly account for this factor, it was required to acquire both the values of the bilinear stress-strain curve as well as other qualities such as elastic parameters such as the elastic modulus and Poisson's ratio through the tensile test. Only the values that were relevant were entered.

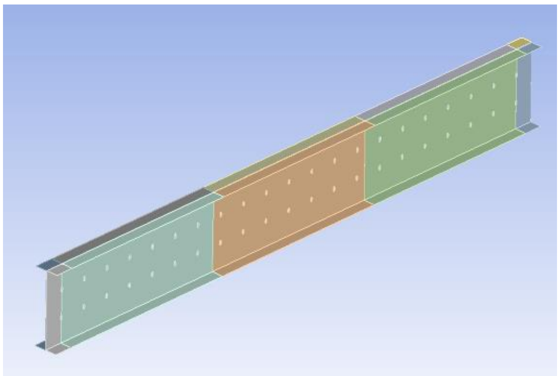


Fig 2 Modelling in ANSYS

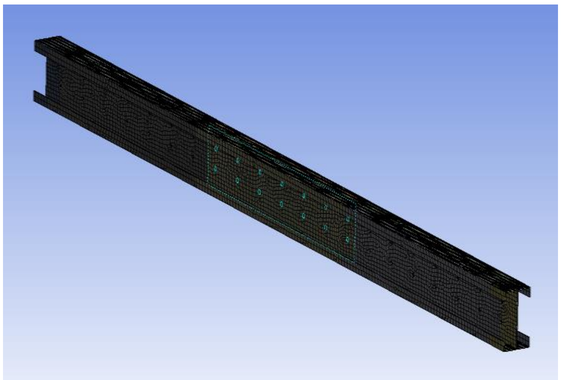


Fig 3 Meshing in ANSYS

3.4 Conditions of the load and the boundaries:

The loading and boundary conditions are extremely important aspects of the investigation in finite element analysis. In order to maintain consistency with the experimental setup, the loading points were positioned one metre apart from the support. A total of 2.5 kN was added to the load in the axial direction. In a manner analogous to this, the boundary conditions of the finite element analysis are what determine whether or not the displacement constraint and rotation constraint are accurate.

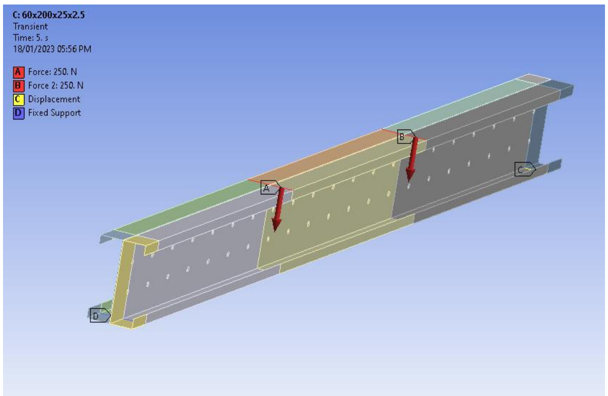


Fig 4 Loading and boundary conditions in FEA

The outcomes of the experiment with the BCWOL2.5/200 specimen are depicted in Figure 5. The load versus deflection curve was selected for use as a result of the findings. To record the deflection for the investigation, dial gauges were mounted in three separate locations on the specimen. These locations were chosen at random. Two of the three locations, at which the dial gauge and the mechanical gauge were fixed, were located close to the loading point, while the other location was located in the middle of the span. After compiling the data, a graph was created to show the results.

4.Experimental Results

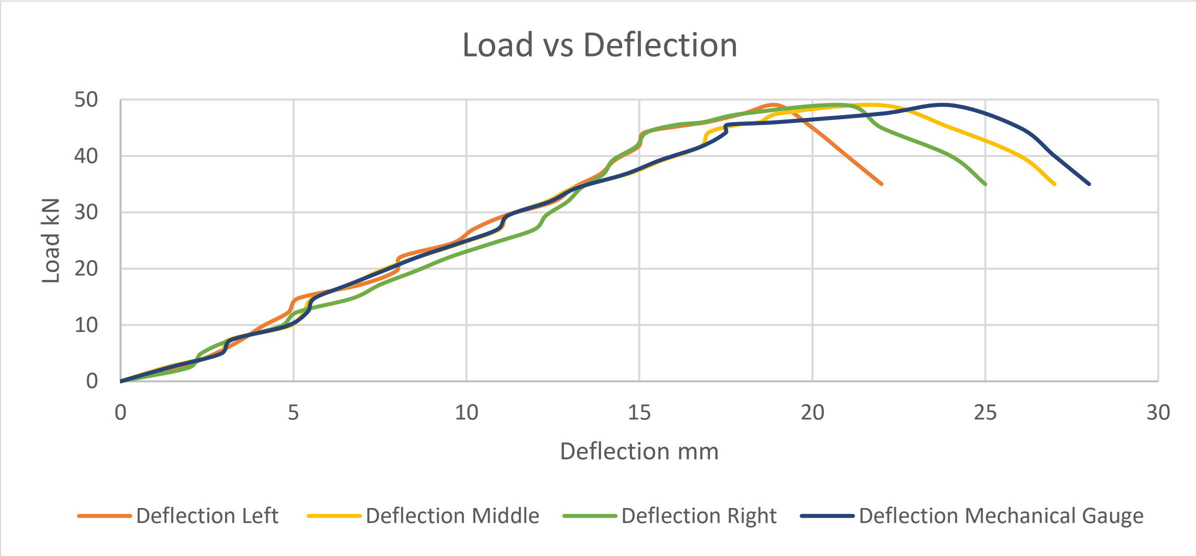


Fig 5 Load vs Deflection for BCWOL2.5/200mm

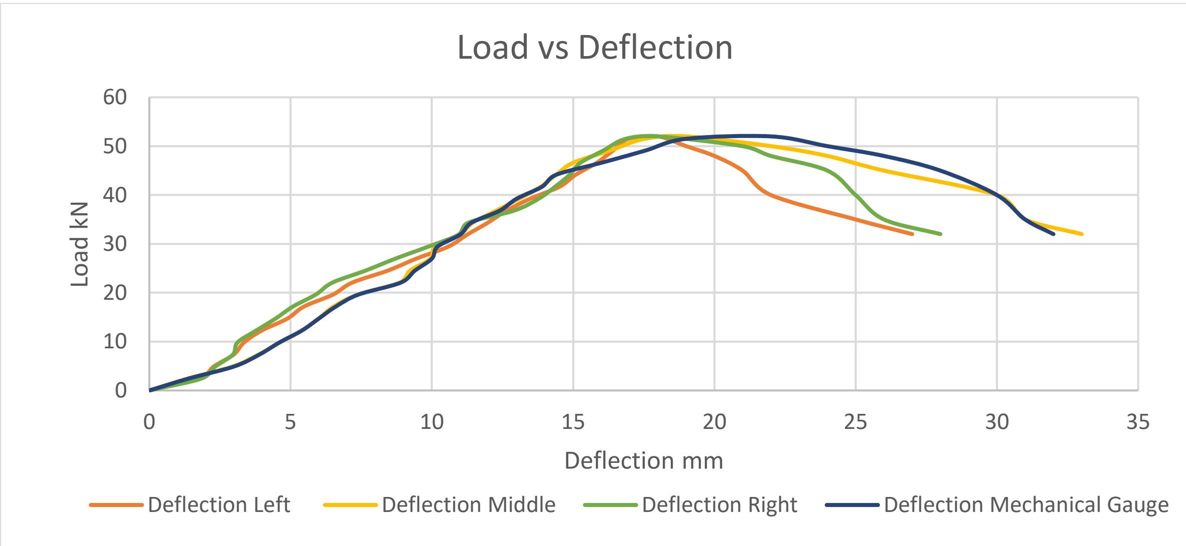


Fig 6 Load vs Deflection for BCWL2.5/200mm

5. FINITE ELEMENT RESULTS

The following information regarding deflection and stress was derived using numerical analysis with the ANSYS finite element tool, and it is presented as a graph for your convenience.

6. THE RESULTS AND DISCUSSION

6.1 Load versus Deflection,

The experimental load-deflection curves for a cold-formed steel beam without a lip that is and 2.5mm thick are shown in Figures 7. Figure 5 shows the experimental load-deflection curves for a cold-formed steel beam with a lip that has a thickness of 2.5mm.

Figure 7a and 7b shows the results of Finite element modelling load-deflection and stress distribution for a cold-formed steel beam with a lip that is and 2.5mm thick.

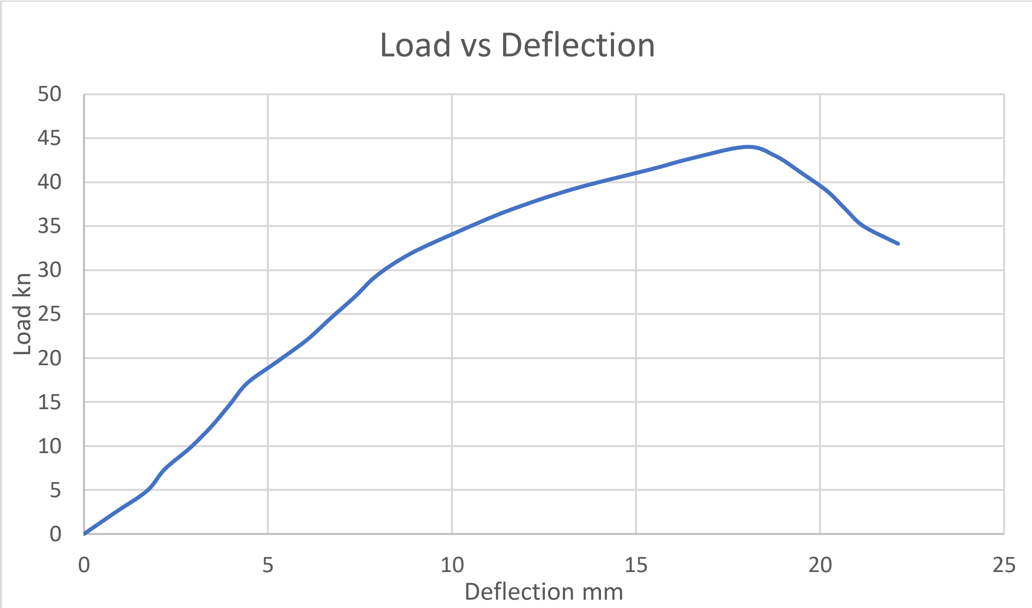


Fig 7 Load vs Deflection for BCWOL2.5/200mm

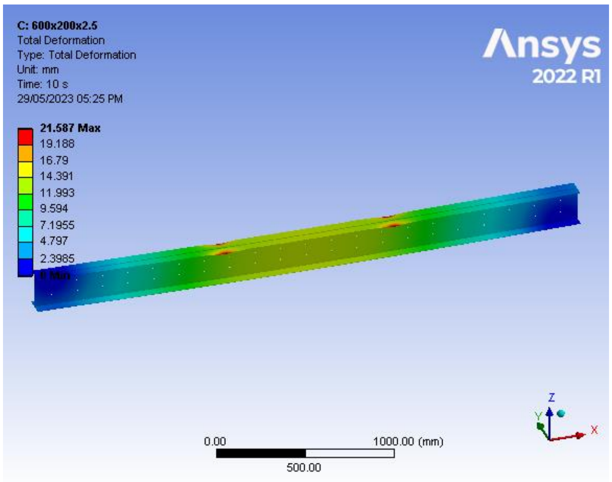


Fig7a Deflection analysis in ANSYS BCWOL2.5/200mm

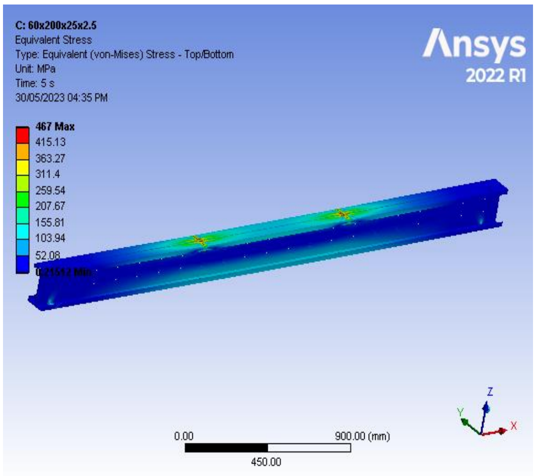


Fig 11 Stress analysis in ANSYS BCWOL2.5/200mm

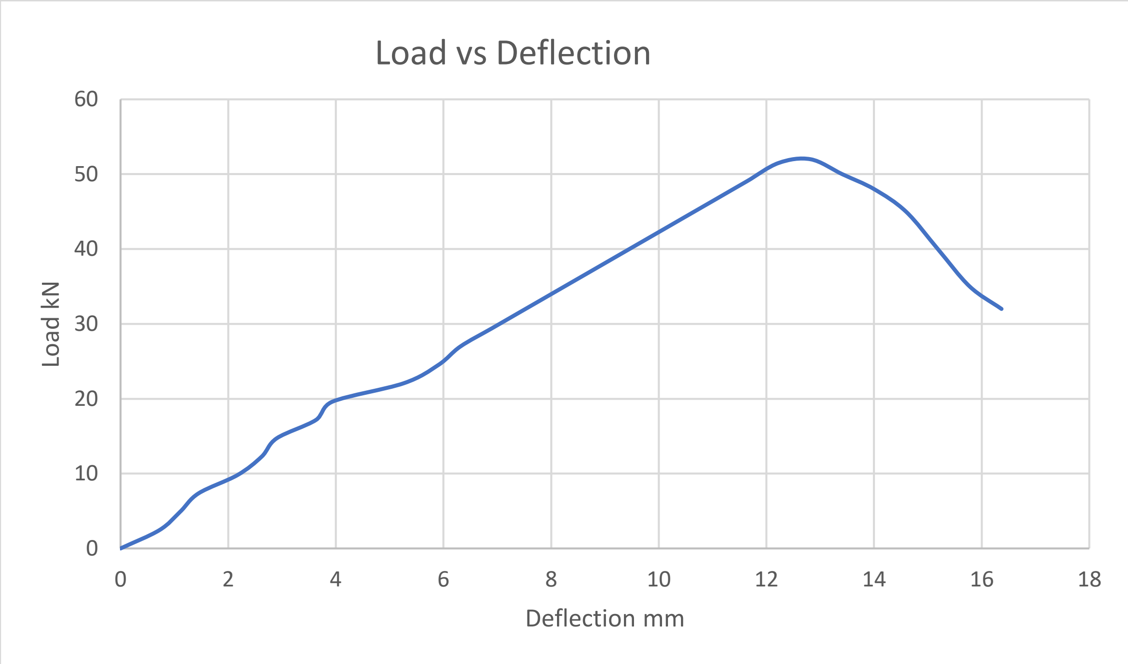


Fig 8 Load vs Deflection for BCWL2.5/200mm

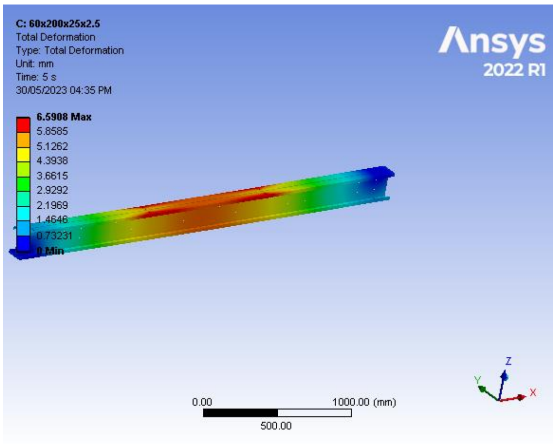


Fig 8a Deflection analysis in ANSYS BCWL2.5/200mm

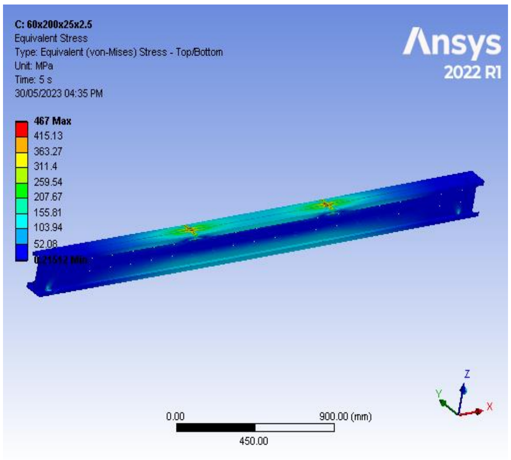


Fig 8b Stress analysis in ANSYS BCWL2.5/200mm

Figures 7 and 8 show the numerical load-deflection curves for the cold-formed steel beam that does not have a lip with a thickness of 2.5mm specimen. Figures 8a and 8b also show the numerical investigation load-deflection curves for the cold-formed steel beam that does have a lip with a thickness of 2.5mm specimen.

The specimen that had a lip with a thickness of 2.5 mm failed at a load of 52 kN ultimate load with a central deflection of 6.5 mm, whereas the specimen that without lip with a thickness of 2.5 mm failed under a load of 44 kN final load with a central deflection of 8.8 mm as per the investigation.

7. Conclusion

The findings of the inquiry showed that the load vs. deflection behaviour patterns of the specimens were virtually the same in both the experimental and the finite element calculations. The following is an account of the findings that were discovered:

1. The ultimate load bearing capacity of a 2.5 mm thick cold-formed built-up steel section with lip is 8% more than that of a 2.5 mm thick cold-formed built-up steel section without lip. The difference in the ultimate load carrying capacity between the two sections is due to the lip.
2. In addition, it was obvious that the specimen BCWL2.5/200mm could sustain greater weight than the specimen BCWOL2.5/200mm, which served as

a good demonstration of how to apply the appropriate thickness of beams. This was demonstrated by the fact that the specimen BCWL2.5/200mm was able to support more weight than the specimen BCWOL2.5/200mm.

3. There is a high degree of concordance between the findings of the numerical analysis and the findings of the experiment.

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