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INVESTIGATIONS USING NUMERICAL AND EXPERIMENTAL METHODS ON COLD-FORMED CASTELLATED BEAMS

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Abstract

In this work, the performance of castellated metal beams that are elevated and standard is examined in the context of coupled distortional buckling and lateral torsional regimes. A precise nonlinear 3D finite element model was built to evaluate the beams. The original geometric flaw and the nonlinearities of the materials were considered in the investigation. The nonlinear simulation model was validated using tests on castellated beams of varied lengths and cross-sections. In this study, load-lateral deformation curves of cantilevered steel beams as well as interactions between failure loads and bending modes were investigated. The effect of modifications in cross-section shapes, beam size, and steel hardness on the stiffness and buckling performance of castellated steel beams was examined using a finite element analysis. The existence of web distortional buckling reduces the failure load of slender cantilevered steel beams considerably, according to the parametric analysis. It is also shown that the failure stresses of less thin castellated steel beams are greatly increased when high strength steel is used. The specification projections for castellated steel beams collapsing by web distortional collapsing, high strength cantilevered beams collapsing by lateral bending, and standard strength cantilevered steel beams collapsing by lateral torsional buckling are all shown to be cautious.

Keywords: Castellatedbeams,fourpointflexuraltest,structuraldesign,finiteelementmodelling.

1. Introduction

V. RautKaustabhKaustabhV.RautKaustabhV.RauCold-formsteelsectionsarenowfrequently employed in the fabrication of steel structures since they have shown to be moreefficient than hot-rolled sections. CSB became accessible to engineers with the advancementof electrical welding technologies in steel building. Misiunaite, Ieva Buildings typically usecold-formed features as structural features. The rise in slenderness of the cross-section causedby increased strength of the material in features with nominal geometry might induce a localrise in deflection owing to excessive tensile stress. Mario D'Aniello Steel hollow sections arebecoming increasingly popular in a variety of structural uses, owing to its dynamic, aesthetic,andoperational benefits.

Steel beams built of cold-formed hollow parts are rotationally stronger than wide flangeportions,thereforetheyrequirelessreinforcingtopreventlateral-torsionalbending.Castellated steel beams manufactured from conventional hot I-sections have many benefits,suchasgreaterflexingsolidity,largersegmentmodulus,optimisedself-weight–depthproportion,economicbuilding,easeofamenitiesthroughonlineopenings,andvisualstructural appearance, according to EhabEllobody 2011. MenkulasiFatmir Improved load deformation characteristics, stronger strength and rigidity,lower mass, and the capability to span up to 90 feet without field splicing are all engineeringadvantagesofcastellatedbeams.M.R.SoltaniCastellatedbeamsaregirderswithwebapertures that are commonly round or hexagonal in shape and spaced at periodic intervalsalong the beams. Castellated beams are made by dividing the net in a zig - zag pattern alongits centreline and then connecting the two halves back together, resulting in an improvementin bending ability and a reduction in the size, allowing them to be utilised for medium to longspan projects. Sonck, Delphine The improved strong-axis bending strength of cellular orcastellatedsectionsoverstandardI-sectionsectionsisitsprincipaladvantage.Sulaiman,Arizu When used in combinationwithothercomponents,cold-formedsteelstructuralmembers can become more efficient, but the key challenge in putting the ideas into practice is ensuring appropriate shear transmission between the concrete surface and the cold formedportion. Ying Ling Jin Five alternative aperture designs were tested to see which one resultedin the least amount of buckling moment drop. . Models with varying edge distances, differentnumbers of holes, variable opening width, and various sizes of openings were created usingopenings in the form of a C-hexagon. Bhat, Rujuta A. The performance of hybrid steel beamswith web holes has been examined analytically in this study. When hot rolled sections orhomogenous built-up sections fail to meet a design specification, hybrid beams are frequentlyused. 2013 EhabEllobody The finite element method might readily be adapted to investigatecolumns made of different materials or built from separate segments. Under order to examinethe column performance in severe fire circumstances, a deeper understanding of the buildingsystem of the columns in cold environment is also required. Ali Nadjai (Ali Nadjai) A total offour samples were examined under monotonic loads and at extreme temperatures, with twodistinct steel geometries and loading circumstances. All beams were constructed with pointedshear studs for a full shear connection between the steel beam and the concrete flange. S. Santosa After attaining the final value at a little rotation, the bending resistance of an emptythin-walledbeamoftenreducesdramatically.The current study uses nonlinear finiteelementanalysis to address thisintricate behaviorofthestructure.

2. Experimentalplans

In this research, two quantity of C shaped cold formed steel section were **fabricated** from the**factory made** material with 200 and 250 mm in length. The different calculation parameterswereshown in table.1.

Table.1Specimendetails

Specimen	200– C– Section	250– C– Section
Sectiondescription(mm)	C-200x80x30x3	C-250x80x30x3
Area (mm^2)	1224	1524
Perimeter(mm)	822	928
I_{xx}(mm^4)	7622735	12901332
I_{yy}(mm^4)	1146024	1303482
R_{xx}	78.91	92.00
R_{yy}	30.59	29.24

Initially, the two same types of hexagonal pattern was drawn on the cold formed steelsections with the help of plasma torch. The hexagonal portion was cut away from the Cshaped cold formed steel section through the plasma arc cutting process. After this process,the hexagonal portionwas completely taken away from the coldformedsteel section.Thetwoedgesofthesteelsectionwascleanedwiththehelpoffinishing**tool**.Hexagonaldimension pattern verification also carried out on the C shaped cold formed steel section.After hexagonal dimension pattern verification process, the two portions of the C shaped coldformed steel section were welded together with the help of metal inert gas welding process.Finally, the assembled castellated beamsection were produced as per the testing requirements. The step by step specimen preparationprocesswereillustrated as imagesin figure.1(a) to figure.1(h) correspondingly.

Figure 1 (a) C shaped - Cold formed steel section (b) Cross sectional view- C shaped - Coldformed steel section (c) Plasma torch cutting pattern -1 (d) Plasma torch cutting pattern -2 (e)Hexagonal dimension pattern verification (f) Overall dimension verification (g) Castellatedbeam-assembled section(h)Primercoatedwithfinished coldformed metal surface.

Four point flexural test was performed on the well-produced C shaped cold formed steelsection using the universal testing machine.Theexperimental setup for four point flexuraltestwas depicted in figure.2 (a) to2 (d) respectively.

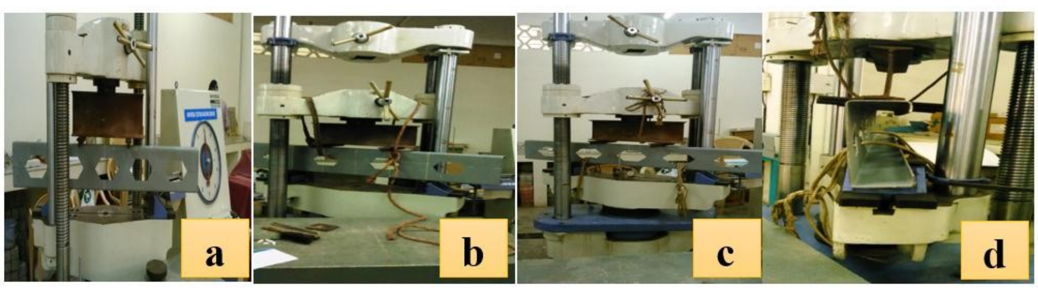

Figure2(a) Specimensettingupon instrument(b)Settingup deflectionmeter (c)Settingoutspecimen2 – 250 mm depth (d)Local bucklingcaseunder worstloadingstage.

The test is normally carried out using a predetermined test setup on a UTM. Two supportive pins are spaced evenly around the specimen, and different loading pins are spaced equally around the specimen. These two axial loads are gradually reduced from above till the sample fails.

2.1.Finiteelementanalysis

the necessary elements modelling capabilities by creating and resolving analytical models ofsimplyreinforced beam construction.

The impact of the web's depth on the efficiency of various modelling methods is investigatedin particular. Steel beams with web holes have become increasingly popular in recent yearsfor structures such as industrial buildings and high-rise skyscrapers. There are a variety ofreasons why openings are made. An experimental examination was organised and carried outon various models in this regard. The goal of the project was to determine the maximum loadbehaviour and bending of steel beams with web holes. The finite element approach was usedto analyse all of the beams using the standard finite element analysis software ANSYS, andthefindings were compared to thoseexperimentallyobtained.

2.2.FiniteElementModelling

The goal of this research is to use finite element modeling to calculate the ultimate load-carrying capability of the castellated beams that were used in the experimental investigationfor comparison. To forecast their full reaction to increased external loading until they exhausttheir load-carrying capability, thefinite element approachwas applied.Using thefiniteelementpackageANSYS13.0,a3-Dfiniteelementmodelwasconstructedtodemonstrate the performance of a steel beam with web holes with a C-shaped cross section,which incorporated material and also geometric nonlinearity in the beam structure.

3. TYPICALPRE-ENGINEEREDBUILDINGSYSTEMSTAADMODEL

3.1.Dimensions of themodelling

ThefollowingdimensionsweretakenintoaccounttodesigntheentireSTAADmodel.Spanofthestructureis18.06m, length of the building is 24.72m, spacing between the bay sare 8.06m, spacing between the secondary beam sare1.25m (max), height of the structure is 6.10m, basic wind speed is 39m/s and mezzanine plat form height is 3.05 m.

3.2.ConnectionDetailing

Thecastellatedbeamwebportionconnectswiththecolumnorbeammembers(mainstructural element) using the cleat angle – 75x75x6 mm on having 2 No’s of 16 diameter bolt.The different three dimensional models of the pre-engineered building system STAAD modelwithcastellated beamwas represented infigure3(a) to 3(b)correspondingly.

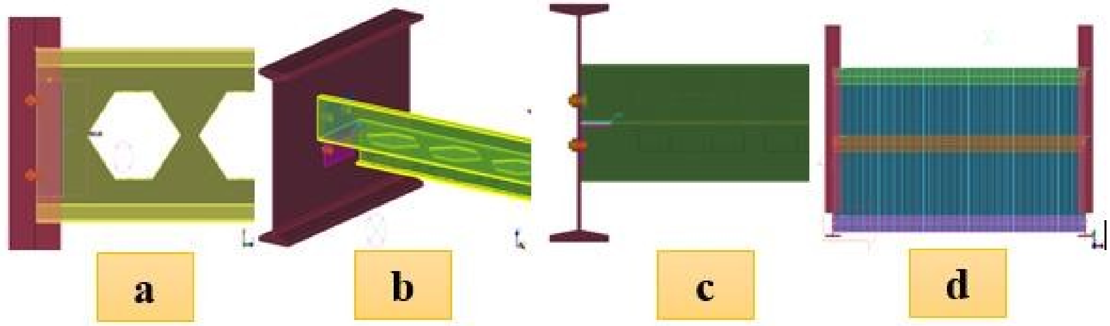

Figure3 (a) Secondarybeam column connectiondetailingin threedimensional (a) View-1(b)View-2(c) View-3(d) Deckingprofile model+Secondarybeam connectiondetails

3.3.STAADModelling

ATypicalPre-Engineeredbuildingmodelischosentomakeananalysisbasedonthewarehouse loading condition as pinned connection. The section properties of the hot & coldformed steel sections were compared for their deflection values, bending moment values,shear forces. Complete pre-engineered building system, which is modelled with the help ofSTAAD software is shown in figure.4 (a). Hot rolled steel section's complete dimensions andits geometric properties were illustrated in figure.4 (b) respectively. The complete dimensions& geometric properties of a cold formed steel sections and the graphical output representationof cold formed steel section were illustrated in figure.5 (a) and 5 (b) respectively. Similarly,different outcomes which are attained from the STADD modeling such as graphical outputrepresentation of hot rolled steel section were depicted in figure.6 (a) to 6 (c) respectively.Interaction values between the castellated beams and pre-engineered buildings, which wereaccomplishedfromtheSTADDmodelingforhotandcoldformedsteelsectionswererepresentedin figure.7(a) to 7 (b)respectively.

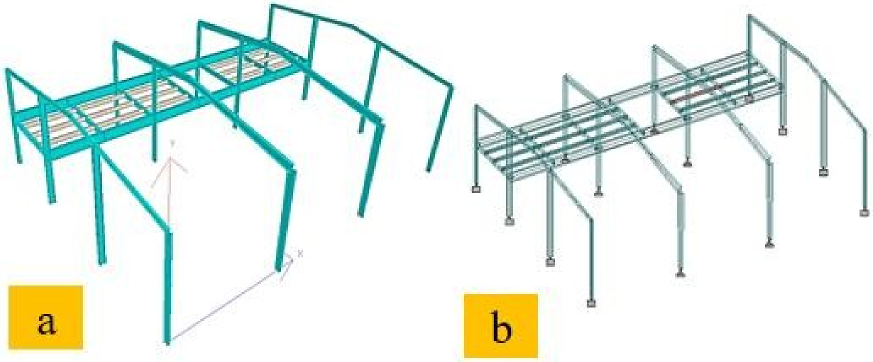

Figure 4 (a) Typical pre-engineered building system STAAD model (b) Dimensions & geometricpropertiesofa hotrolled steelsections

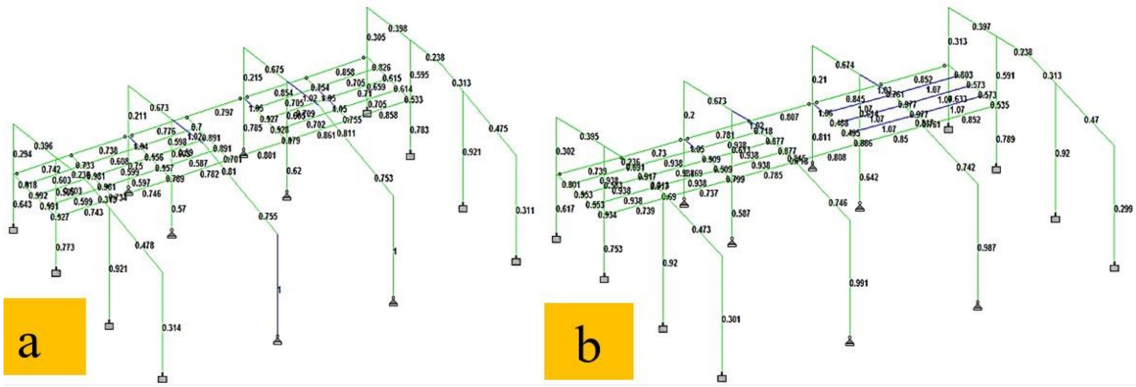

Figure7Interactionvalueof(a)Hotrolledsteelsections(b)Coldformedsteelsections

By using the STAAD modeling software, surface modeling of the castellated beams wereequipped and it was depicted in figure.8 (a). All the supporting conditions were assigned ontherequiredsidesoftheSTAADmodelledcastellatedbeams.Requiredpressureloadwasalso applied on the flange side of the beams. Figure.8 (b) shows the applied load model of theSTAADmodelledcastellatedbeams.Stressdistributionoverthebeamssurfacewascomputed for the applied load on the flange portion of the STAAD modelled castellatedbeams.Maximumstressdistributionovertheflangeofthecastellatedbeamswererepresented in figure.8 (c). Von-Misses yield stress formulation on the castellated beams webflange surface was computed in the STAAD software. Maximum stress indication of Von-Misses formulation for the STAAD modelled castellated beams were depicted in figure.8 (d).Stress distribution was found maximum in the exterior surfaces of the castellated beams alsotheminimumstress distributionwas noticedintheinteriorsurfaces ofthebeams flange.

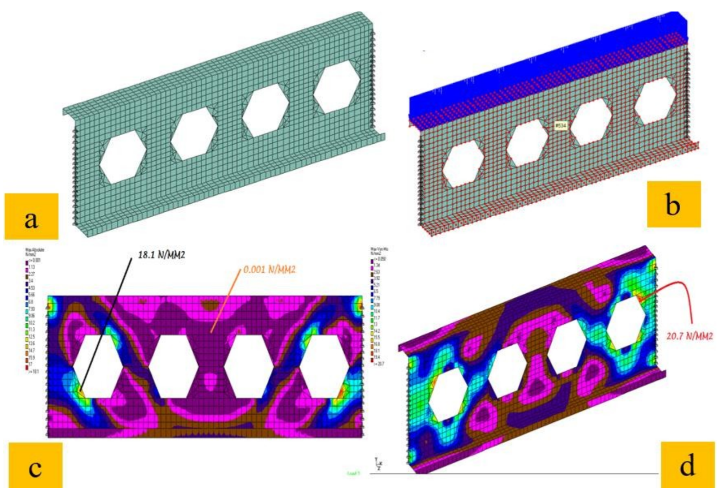

Figure 8 (a) Surface modelling& support condition in STAAD (b) Pressure load applied onthe section top flange (c) Stress indication – Max absolute case (d) Stress indication – MaxVon-Missesformulation

4. Resultsanddiscussions

4.1.Experimentalresults

Different outcomes that are perceived from the four point flexural tests were illustrated infigure 9 (a) to 9 (b) correspondingly. Deflection attained by the two different cold formedsteel section i.e, 200 and 250 mm length C steel sections due to the applied loads wererepresented as graph in figure.9 (a). It was observed that the load carrying capacity of the 250C shaped cold formed steel section is higher than that of 200 C cold formed steel section. Inconcern with the 250 C shaped cold formed steel section, the maximum load of 36000 N andmaximum deflection of 6.99 mm were observed during the four point flexural test. In concernwiththe200Cshapedcoldformedsteelsection,themaximumloadof22000Nandmaximum deflection of 6.35 mm were observed during the four point flexural test. It wasobserved that, when compared to 200 C shaped cold formed steel section, the load carryingcapacity of the 250 C shaped cold formed steel section is higher due to the increasing webdepth of the beam section. Stress and strain plot for the two differentcoldformed steelsection i.e, 200 and 250 mm length C steel sections were represented as graph in figure.9 (b)and figure.9 (c) correspondingly. Maximum stress value of 34.88 MPa was observed in 250 Cshaped cold formed steel section, which is higher than that of 200 C shaped cold formed steelsection.Inconcernwiththe200Cshapedcoldformedsteelsection,themaximumstressof 28.86MPaandmaximumstrainof0.0051wereobservedduringthefourpointflexuraltest.In concern with the 250 C shaped cold formed steel section, the maximum stress of 34.88MPa and maximum strain of 0.0069 were observed during the four point flexural test. Due totheincreasingwebareaofthe250Cshapedcoldformedsteelsection,itrevealsthemaximumstress and strain thanthatof200 C shaped cold formedsteel section.

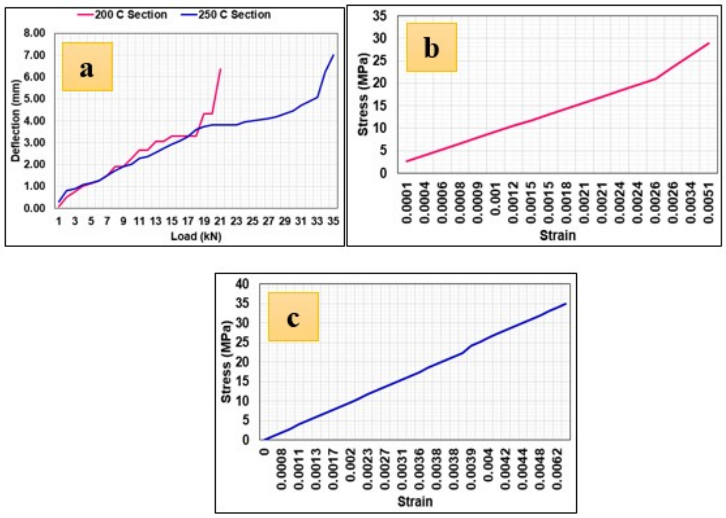

Figure 9 (a) Deflection vs load curves for 200 C Section and 250 C Section (b) Stress vsstraincurvefor200C Section (c)Stress vs straincurvefor 250CSection

4.2.FiniteElementAnalysisResults

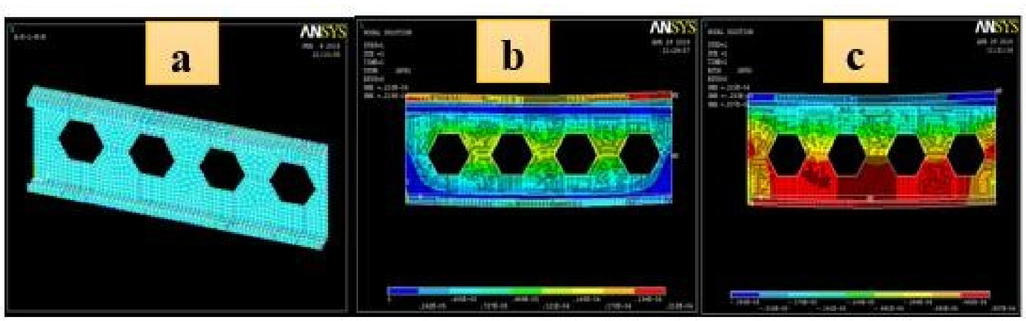

Figure10(a)ThreedimensionalareamodelviewinANSYSwindow(b)Displacementvectorco ntourplot(c)X-componentdegree offreedomsolution

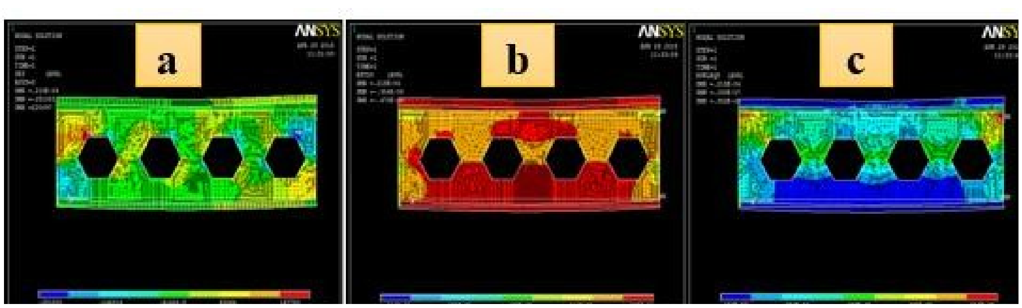

Figure 11 (a) XY shear stress contour plot (b) Third principal total mechanical strain (c) Von-Misseselastic strain

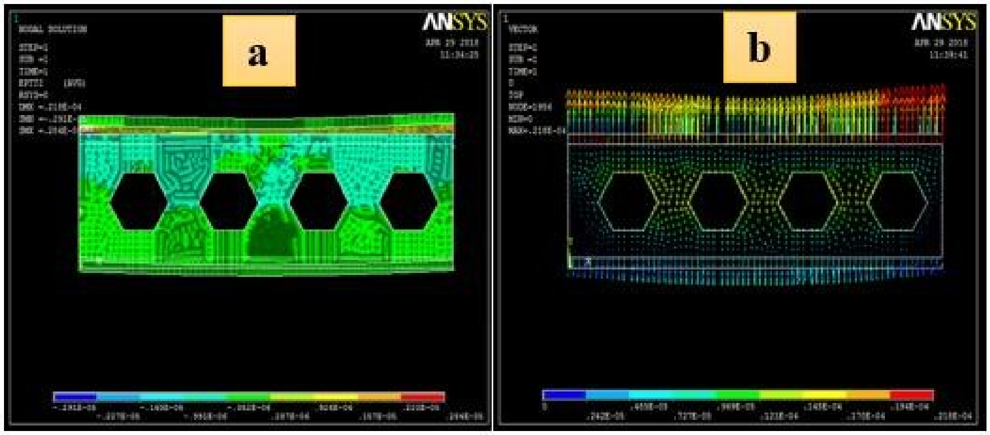

Figure12(a) Z-Componenttotalmechanicalstraincontourplot(b)Predefinedvectorplotofthesection

Fromtheaboveexperimentalandanalyticalresults,thediscussionareasfollows:Onreplacing the hot rolled steel secondary members to cold formed steel sections the structuralweightwill be optimized withretainingsame structural performance.

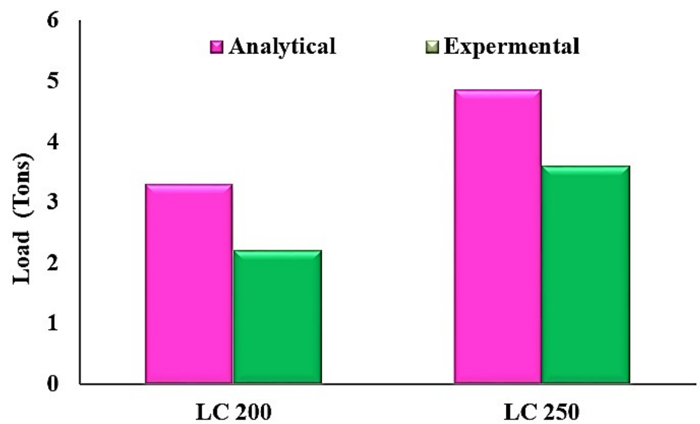

Figure13Comparisonchart forload carryingcapacity

On member design the equivalent commercial section has identified to match the requirementof the replacing sections. The graphical results that obtained from the model had resembledthe same behaviour for their corresponding codal provisions. The geometrical parameters iscompletely satisfied by the light gauge section having 3 mm metal thickness. The weightreductionofthesectionbyretainingthesectionalpropertiesisaround65%oftheconventionalsecondarybeams.Theareamodelforthefiniteelementanalysisiscarriedoutby the software ANSYS by interconnecting mesh through the key points. The Critical stressregions were identified to sort out the points in stress reduction connection methodology. Inthe behaviour of top deflection values for the applied load were calculated. The critical stress regions were pointedand special attention is carried to overcome the same. The load carrying capacity of thememberswasclearlyidentifiedthroughthefourpointflexureloadingtest.Thesheartransformation behavior is investigated between the web in plane model as well as web inparallel plane alignment. On introducing the web parallel arrangement the web buckling shallbe very much minimized when comparing with the web in plane model. The load carryingcapacity of the members is enhanced to 1.65 times when we increasing the depth having theincrement of 50 mm depth. Section will not undergoes any yielding limit, before which thesection fails by local flange/ web buckling through which the section stability can be ensuredwith connections. From the above investigation the cold formed steel sections is sufficient inreplacing the secondary conventional I beams of the mezzanine steel structures. From theabove plate & member modelling the behaviour of castellated beam had studied, on applyingloading to both hot rolled steel & cold formed steel the difference in strength, cost savings arecomparatively good in cold formed sections. The values of bending moment, shear force,deflection are all within the limits of Indian standards. The observed stress results in differentaxisarein thespecifiedrange.

5. Conclusion

The optimized sectional properties for the cold formed steel section (3 mm thickness) wereobtained based on the experimental & analytical investigation. The transformation in thesesections is necessary to meet the industrial requirements in the point of safe & economicaspects. On comparing the above stated experimental & analytical results the variation isaround 25-30 % which is due to the boundary condition preference in site and applied formatin Experimental testing series. The further study can be made using I, Z, Sigma sectionsinstead of C section to know the exact behavior of formed profile dimensions as discussed.The castellated beam is solving the purpose of industrial needs such as service pipe lines,ducts lines, cable trays, electrical cables etc. and also in terms of structural the increase insectional properties without increase in section weight contributes a lot in savings. The choiceofwebalignmentispreferablyparallelarrangementwhichisconcludedfromtheexperimental results.

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