

EXPERIMENTAL AND ANALYTICAL ANALYSIS OF COLD FORMED STEEL CASTELLATED BEAM

Submitted in partial fulfillment of the requirements for the award of
Master of Engineering in Structural Engineering

By

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**DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited with Grade "A++" by NAAC
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

APRIL – 2024



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **A.PREM NARAYANAN(42380003)** who carried out the project entitled **"EXPERIMENTAL AND ANALYTICAL ANALYSIS OF COLD FORMED STEEL CASTELLATED BEAM"** under our supervision from September 2023 to April 2024.

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PLACE: CHENNAI

SIGNATURE OF THE CANDIDATE

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ABSTRACT

The cold-formed steel (CFS) is utilized in the construction industry due to higher strength to- weight ratio, lightweight, faster production, ease in fabrication, construction, transportation, and handling. When an I-beam is subjected to a longitudinal cut along its web in specified pattern that style beam is called Castellated beam. By this cutting pattern, the depth of the beam is increased. Castellated beams are the best solution to overcome the deflection criteria in safety check difficulty. In this project a cold rolled sheet is fabricated into normal I section beam and then converted into castellated beam. The main objective of the study is to examine the flexural strength, load-deflection, and load-strain behaviour of the castellated beams fabricated from cold rolled sheet. The analysis of beams is performed in Finite element method using ANSYS software and results are discussed for normal beam and 3 different cutting patterns of castellated beams.

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LIST OF ABBREVIATIONS

FEM	FINITE ELEMENT METHOD
CR2	COLD-ROLLED SHEET
CFS	COLF-FORMED STEEL
FEA	FINITE ELEMENT ANALYSIS
CRB	COLD ROLLED BEAM
CRCB	COLD ROLLED CASTELLATED BEAM
IS	INDIAN STANDARD
KN	KILO NEWTON
mm	MILLIMETRE
KG	KILOGRAM

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In this scientific world with many modern construction methodologies, many researchers are analysing all the structural components for its increased load capacity rate. In recent years cold formed steel sections are often used due to their properties. Cold formed steel structural members have high strength to weight ratio, and stiffness to weight ratio compared to hot rolled steel members. This increase in usage of cold formed sections lend to many innovations and researcher work about its effectivity.

Cold-rolled steel has smooth appearance than hot rolled steel sections. Cold-formed steel is used most since it is stronger than hot formed steel sections. Cold-formed steel (CFS) members are considered as the important load carrying members in building industries due to their unique material properties.

Castellated beam is one the innovation is construction field. These beams can be used as secondary beam in industrial building, parking garages. The novelty of the castellated beam is without increasing the self-weight if the for the beam the depth of the beam is increased.

Manufacturing of castellated beams is done by cutting the beam along the web in a "zig-zag" pattern, and then offsetting the two halves, and then welding the two halves together. Through this physical alteration of the material the stiffness of the beam is increased, without any changes to the material's weight. Compared to the original beam the newly cut castellated beam can withstand more vibration resistance due to its increased depth of the beam.

Mostly castellated beams can be used as secondary beams in all industrial structures in order to reduce the weight of the building. Since secondary beams carry load less than primary beams castellated beams can be effectively used as secondary beams.

1.2 CASTELLATED BEAM

A castellated beam is a beam in which the web is cut off, and the beam is separated into 2 halves. Then one half of the beam is offset over the other half forming a hexagonal opening. The extras from the ends are cut off. The two halves are then welded. This leads to increase in height of the section.

This joining of the two halves at the web pattern is called as castellated beam. These kinds of beams were initially developed in Europe in aim to reduce the usage of steel. After the world war, for reconstructions of all the buildings and due to minimal amount, they introduced these castellated beams. By reducing the cost of the material, they paid wages for their labours. So, with available steel sections they cut them into two halves and offset the half one of the beams over the other half of the beam. By this castellation they achieved a stronger beam with minimal usage of steel. Nearly 30% to 40% stronger beam.

1.3 ADVANTAGES OF CASTELLATED BEAM

- Increase of section height, results in the enhancement of moment of inertia, section modulus, stiffness, and flexural resistance of sections.
- Decreasing the weight of structures
- Optimum use of existing profiles.
- Recycling the used plate girders.
- Passage of services through the web openings.
- Decrease environmental impact.
- Reduce material consumption
- Faster erection
- In effect to advantages, comparing with normal I section, castellated beams undergo failure due to the perforations and welding in the web.

1.4 COLD FORMED STEEL SHEET

Cold Rolled steel sheet properties are referred as per IS 513:2008. In this study we have used a cold rolled sheet of grade IS 513 CR2 of 3mm thickness. The chemical composition of the CR2 (Drawing) is tabulated in Table 1.1 and the mechanical properties of the CR2 is tabulated in Table 1.2 as per IS 513:2008.

Table 1.1: Chemical composition of CR2

Chemical constituent	%
Carbon	0.12
Manganese	0.5
Sulphur	0.035
Phosphorus	0.04

Table 1.2: Mechanical Properties of CR2

Properties	Max value	Units
Yield stress	240	Mpa
Tensile strength	370	Mpa
Elongation	30	Mpa

The CR Sheet was available from 0.4mm thickness to 3mm thickness. To attain maximum strength 3mm sheet was chosen. The sheet was in silver colour. Due to its manufacturing process when it reacts in atmosphere soon it gets rusted. Hence to avoid rusting, beams are painted.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Many researchers have analysed and studied about the failure modes of Castellated beams and few studies are reviewed below. Perforations in the beams changes the stress concentration of the beam. Cold formed steel being a trend in recent days researchers are interested in studying the buckling behaviour of cold formed steel section with perforations. In variation of perforation in size, shape or depth height ratio, researchers are performed their study.

2.2 REVIEW OF LITERATURE

Hayder wafi al-thabhwee and Muslim Abdul-AmeerAl-Kannoon. (2021) conducted study on “ Behaviour and failure modes of tapered castellated steel beams” In this experimental the beams are created by cutting the webs of standard I-sections in a particular zigzag pattern and rejoining the two parts by placing variable expansion plates between web posts and welding them together. Generally, the depth of the mid-span will be increased. A standard I-section (IPE140) was selected as a parent beam to fabricate three TCB specimens and one prismatic castellated beam. The experimental results showed that the ultimate load capacity of the TCBs could be increased up to 140% of the ultimate load capacity of the parent section. The results showed that the allowable load at deflection ($L/360$) increased up to 183% of the allowable load for the control specimen at the same deflection. He concluded that web-post buckling and joint-weld rupture failure modes occurred in TCBs due to the formation of high shear forces that tried to twist the web posts.

Nan-ting Yu, et al. (2020) conducted study on “Distortional buckling of perforated cold-formed steel beams subject to uniformly distributed transverse loads.” In this paper the distortional buckling behaviour of perforated cold-formed steel beams with holes is explored. The effect of perforations on the critical stress is evaluated. A new model is deduced to predict the critical stress of distortional buckling by reducing the stiffness of the vertical spring. The Rayleigh-Ritz method is used to solve eigen value problems. In order to validate the analytical model,

finite element analyses have been performed by using ANSYS. He concluded that the distortional buckling stress of PCFS beams decreases with the increase of the diameter of the perforation. The equations for predicting the distortional buckling stress of PCFS beams have been derived using the energy method.

Tekcham Gishan Singh and Tak-Ming Chan. (2020) conducted study on “Effect of access openings on the buckling performance of square hollow section module stub columns.” In this paper a comprehensive parametric study to investigate the effects of various key geometric parameters, viz., shape, eccentricity (or location), size (or diameter) and height (or depth) of perforation; and cross-sectional thickness on the buckling capacity of (single) perforated module column subjected to compressive axial load using the commercial FE software ABAQUS. He concluded that Perforation eccentricity has minor influence on the critical buckling capacity of single perforated module stub columns.

Samadhan G et al. (2020) conducted study on “Structural behaviour of castellated steel beams with reinforced web openings.” In this research work, a nonlinear numerical analysis is carried out so as to observe the effectiveness of stiffeners provided around the periphery of the openings. From the results obtained it is found that robustness of castellated beams enhances by 44% as compared to conventional steel I beam. He concluded that the average increase in strength of castellated steel beams by provision of stiffeners around openings is 36% over unreinforced openings. The web buckling failure can be prevented by using stiffeners around the openings. The predominant failure mode is found to be Vierendeel mechanism for both reinforced and unreinforced web openings.

Hang fang et al. (2019) conducted study “Behaviour of octagonal high strength steel tubular stub columns”. In this paper Experimental investigations were conducted on cross sections with three nominal dimensions fabricated from different routes of welding or combinations of cold-bending and welding. Material properties and geometric imperfections of the cross sections were measured and are reported here. A total of 18 stub column tests were carried out; load-deformation histories and failure modes of octagonal high-strength steel tubular-section stub columns are presented and discussed. Nonlinear finite-element models were validated to replicate the stub column tests and subsequently applied

to carry out parametric studies for further investigating the structural performance of octagonal tubular cross sections with various slenderness values under axial compression. He concluded that finite-element modeling are used to evaluate the applicability of codified cross-section classification limits and various existing design methods to octagonal high-strength steel tubular cross sections under axial compression.

N. Degtyareva et al. (2019) conducted study on “Combined bending and shear behaviour of slotted perforated steel channels: Numerical studies”, To attain better thermal performance of profile Cold-formed steel studs and purlins are developed with staggered slotted perforations in webs. The perforations leads to energy efficiency of structures. The study showed that the staggered slotted perforations in the channel webs significantly reduced the combined bending and shear capacities.

Jinyou Zhao et al. (2019) conducted study on “Tests and Direct Strength Design on Cold-Formed Steel Channel Beams with Web Holes” in which they cold formed steel channel beams with perforations was tested for their flexural behaviour. Four-point flexure test was conducted on the specimens with varying size of holes. With variations in height to web depth ratio the perforations were drilled. From the results obtained it was evident that the flexural strength varies with height depth ratio. Due to the presence of perforations leads to local buckling or distortional buckling. He concluded that the moment capacity decreases with increase in size of perforations, and he proposed the modified DSM formulas for beams with web holes.

Samadhan G. Morkhade et al. (2018) conducted study on “Comparative Study of Ultimate Load For Castellated and Plain-Webbed Beams”, In this paper, an attempt is made by performing analytical investigation to compare a ultimate load behaviour of castellated and plain webbed beam. The steel I sections of ISMB 200 with simply supported boundary conditions subjected to concentrated load at midspan has been considered. The expansion ratio for castellated beam is taken as 1.5, 1.6, 1.7 and 1.8. The expansion ratio 1.5 means the depth of parent section has been increased by 50% i.e., CB300, CB320, CB340 and CB360 respectively for expansion ratio of 1.5, 1.6, 1.7 and 1.8. Finite element analysis

has been carried out by ANSYS version 12 considering both geometric as well as material nonlinearity. The ultimate load, deflection, and failure modes of castellated beam with various expansion ratios and plain webbed beam is noted.

Wei-bin Yuana et al. (2017) conducted study on “Distortional Buckling Of Perforated Cold-Formed Steel Channel-Section Beams With Circular holes In Web”, the numerical and analytical investigations on the distortional buckling of perforated cold formed steel channel-section beams with circular holes in web and from obtained results. He concluded that, when the size of the hole is increased the critical moment of distortional buckling of beam with perforations in web decreases. but the half wavelength associated with the critical moment increases with increased hole size.

Liping Wang et al. (2017) conducted study on “Design of Cold-Formed Steel Built-Up Sections with Web Perforations Subjected to Bending”, He studied the flexural behaviour of the beam by four point flexure test .For the built up cold formed steel sections with circular holes in the web. The specimen is modelled, and finite element analysis is performed for varying size of the hole. The built-up section was formed using two channels placing back-to-back as I Section and two channels placing face-to-face to form a box section. The moment capacities and failure modes were also studied. He concluded that there is a reduction of moment capacity and local buckling as the hole diameter to web depth ratio increases. The presence of web holes was also found to initiate the failure for all built-up open section beams in the tests.

Listiyono budi.et al. (2017).conducted study on “ Optimization analysis of size and distance of hexagonal hole in castellated steel beams” .In this paper the optimization analysis are then verified by implementing laboratory tested of 225 mm height castellated steel beam specimens. The specimens are modified from 150mm height IWF section profile. The model of castellated steel beams is divided into six different variation models which represent 45° , 50° , 55° , 60° , 65° and 70° opening angle of hexagonal holes. He concluded that the distance of each hole has an influence with location of maximum stress concentration. The maximum stress concentration was at the corner area of hexagonal holes for

wider hole distance holes. While the maximum stress concentration moves to the weld joint area in web post for shorter distance holes.

Liping Wang and Ben Young. (2015) conducted study on “Beam tests of cold-formed steel built-up sections with web perforations.” The aim of this study is to investigate the flexural behavior, including the ultimate moment capacities and failure modes, of built-up cold-formed steel members with circular web holes. A total of 43 beams having ten cross-section sizes with different hole diameters were tested under four-point bending. He concluded that when the hole diameter-to-web depth ratio (d_h/h_w) is 0.5, the influence of the holes on the moment capacities of beams is very small, however this is not the case when d_h/h_w further increases up to 0.7. Different approaches of determining the critical elastic local and distortional buckling moments including the influence of holes for the built-up open and closed sections were compared and discussed, and appropriate approach for built-up sections was recommended. The current direct strength method (DSM) was extended for the design of cold-formed steel built-up sections with holes in this study.

Ajim S. Shaikh and Harshal R.Aher. (2015) conducted study on “Structural Analysis of Castellated Beam.” In this paper the Main objective of perforated web is to increase the depth of section so that the moment of inertia parameter will be increase. The beam section obtained in such away can be even 50% deeper than the original section by increasing the depth, the section modulus is increased by about 2.25 times the section modulus of original beam section. Thus load carrying capacity of the beam increased by considerably. He concluded that The depth is the most important parameter which governs the sectional property of the section. For the serviceability moment of inertia plays very important role and moment of inertia of I-section is directly proportional to the third power of the depth.

Jamadar A.M et al. (2015) conducted study on “Parametric Study Of Castellated Beam With Circular And Diamond Shaped Openings”, he studied about the castellated beams with different shapes of holes like circular (cellular beam) and diamond shaped openings. With consideration of ratio of overall depth castellated beam to the depth of opening provided (D/D_o) and the ratio of spacing of opening to the depth of opening (S/D_o) the design of castellated beam is

analysed. For different size of opening the finite element analysis is carried out and behaviour is studied in ANSYS. Based on the equivalent stress failure criteria experimentally the beam was studied. He concluded that castellated beam with diamond openings shows better results than castellated beam with circular openings.

I Barkiah and ,A R Darmawan. (2013) conducted study on “ Comparative analysis of the flexural capacity of conventional steel beams with Castellated beams”. In this paper, the research compares the flexural capacity of conventional steel beams to the geometric effect of castellated beam with hexagonal opening angle variations. The aim is to gain the effect of the hexagonal opening angle on the bending capacity of the castellated beam. The research was conducted by numerical testing using ANSYS. He concluded that the geometric effect of a castellated beam can provide an increase in flexural capacity of about 8 to 19% compared to conventional steel beams. The optimum bending capacity is at the hexagonal opening angle of 450 to 500 . At the 600 opening angle, the castellated beam has decreased its flexural capacity.

V.B. Nguyen et al. (2012) conducted study on “Compression tests of cold-formed plain and dimpled steel columns”. In this paper compression and tensile tests conducted on cold-formed plain and dimpled steel column specimens. A total of 48 channel column specimens and 56 tensile specimens were subjected to testing . The study aimed to evaluate how the cold work during the dimpling process affected the dimpled steel column specimens by directly comparing their test results, including buckling and ultimate loads. He concluded that cold work resulting from the dimpling process significantly increased the buckling and ultimate STRENGTHS of dimpled column specimens. This strength increase resulted from plastic deformation occurring throughout the thickness of the dimpled sheet during the dimpling process.

Wakchaure M.R et al. (2012) conducted study on A “Parametric study of castellated beam with varying depth of web opening.”In this paper a steel section is selected, castellated beams are fabricated with increase in depth of web openings. Experimental testing is carried out on beam with two point load and simply supported conditions. The deflection at centre of beam are then compared

with each other with parent section for various parameters and for serviceability criteria .He concluded that castellated beam behaves satisfactory for serviceability up to maximum depth of opening $0.6D$.

M.R. Soltani et al. (2012) conducted study on “Nonlinear FE analysis of the ultimate behaviour of steel castellated beams”. He studied about the castellated beam model with geometric and material non linearities using ANSYS. The failure at the hexagonal opening and octagonal openings when the beam is subjected to flexure and shear force was studied. He concluded that failure in opening is occurred due to web-post buckling failure.

M.R.Wakchaure et al. (2012) conducted study on “Finite Element Analysis of Castellated Steel Beam”, he studied about the deformation pattern of the beam under two point loading. He considered a simply supported castellated beam with two-point loading conditions. Castellated beam with varying depth of the bores the ANSYS model was generated, and deformation was studied. The deformation of castellated beam was compared with the parent beam. He concluded that Castellated beams can be used for moderately loaded longer spans where the design is controlled by deflection.

P.D.Pachpor et al. (2011) conducted study on “Finite Element Analysis And Comparison Of Castellated & Cellular Beam.”, he studied about the castellated beams with hexagonal openings and circular openings with same cross sectional area. He also studied for castellated beams with number of openings. All the support conditions, fixed, hinged and roller was considered. Totally 18 beams were studied for their deformation and stress pattern. The comparative study is carried out ANSYS. He concluded that deflection was maximum in circular openings than the hexagonal openings. The roller support showed better results compared to fixed and hinged supports. When the number of opening is increased the deflection of the castellated beam also increases.

2.3 SUMMARY

- Most of the researchers have studied on buckling behaviour of cold formed steel section with perforation and concluded that PCFS beams alter in their stress concentrations, flexural capacity and moment capacity influenced by there size of the perforation, depth and height ratio, diameter, and web height ratio. All researchers focused their studies with the existing sections as per code and built up their open and closed section.
- When it comes about Castellated beam failure modes are studied for rolled steel only. No researchers are used cold rolled sections for castellated beam. Hence behaviour of castellated beam can be studied for cold rolled sections.
- Due to easy availability of cold rolled sheet of varying sizes. The beams can be fabricated into I-sections with these cold rolled sheets and welded.

2.4 OBJECTIVE OF WORK

- To determine the stress distribution of the castellated beam around the openings.
- To examine the flexural capacity of the beam.
- To study the load-deflection behaviour of parent and castellated beam.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 INTRODUCTION

The specimen CRB, CRB, CRCB-1, CRCB-2, and CRCB-3 are fabricated and experimental tested to obtain better results. The CR sheet is purchased and fabricated into built up beams and then castellated. The fabricated beam is further tested in a loading frame and flexure test for beam is conducted and results are validated.

3.2 CR SHEET

CR Sheet of 1200mm x 2500mm is purchased and as per required size of flange and web the lines are marked. The Fig 3.1 shows the cold rolled sheet of 3mm thickness of grade IS 513 CR2.

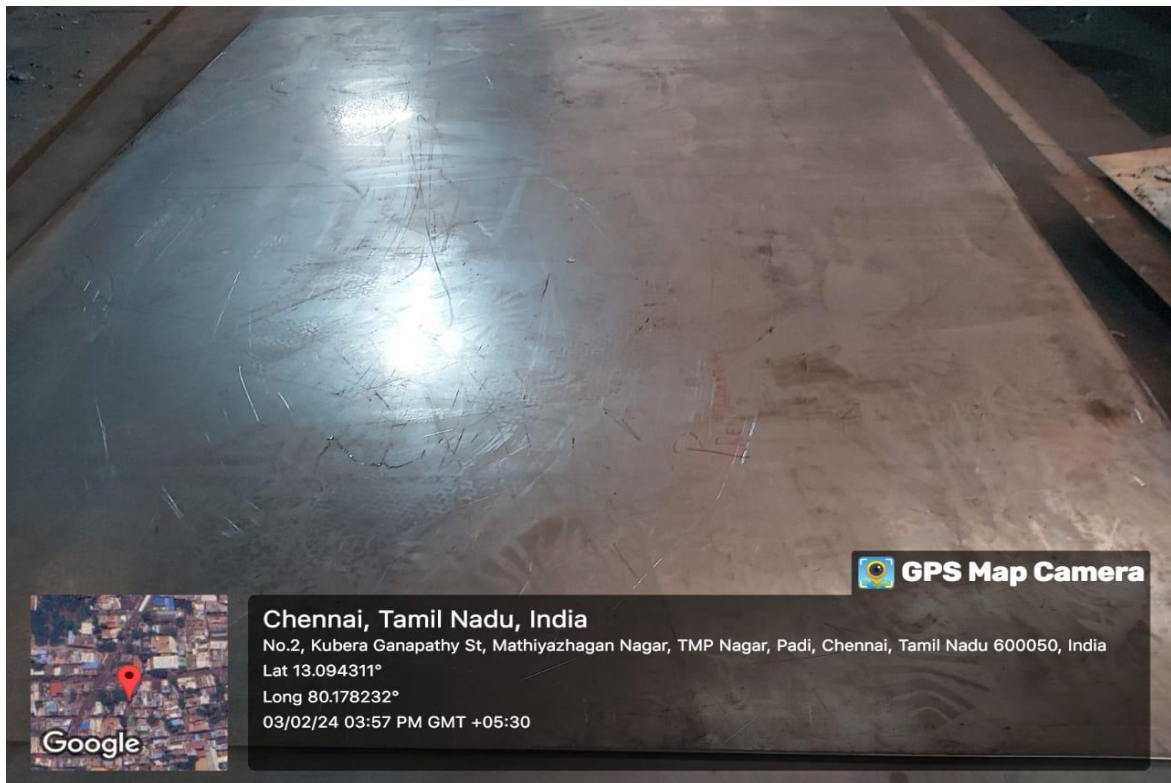


Fig 3.1: CR Sheet of 3mm thickness Grade IS 513 CR2

3.3 MACHINE AND LASER CUTTING

3.3.1 Machine Cutting

In CR sheet the straight cutting is done using machine cutting. The Fig 3.2 shows the machine cutting of CR sheet. The Fig 3.3 shows the output of CR sheet after machine cutting.



Fig 3.2: Machine Cutting of CR Sheet



Fig 3.3: Flange and Web CR Sheet

3.3.2 LASER CUTTING

In CR sheet the zig- zag cutting is done using laser cutting machine. The Fig 3.4 shows the laser cutting of CR sheet.

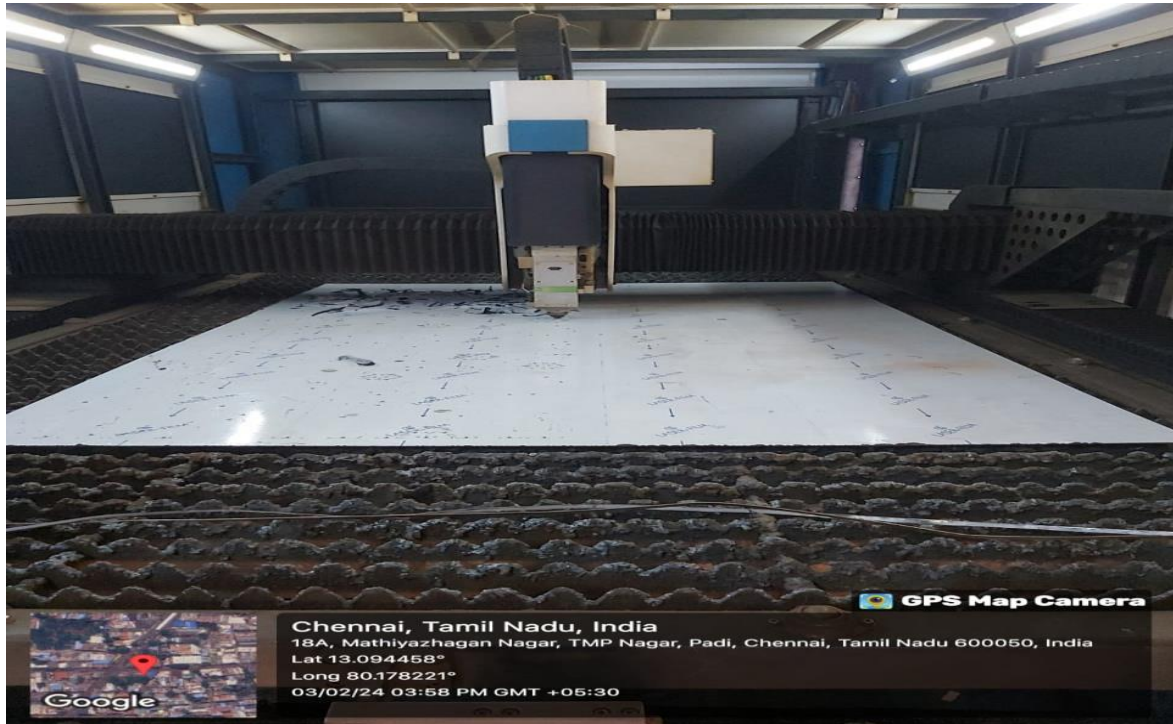


Fig 3.4: Laser Cutting of CR Sheet



Fig 3.5: Web after Laser Cutting of CR Sheet

3.4 WELDING

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by using high heat to melt the parts together and allowing them to cool, causing fusion.

The CR sheets are positioned and welded. Normal arc welding is done. On placing the flange and web perpendicular to each other fillet weld is given at the edges of the T joint.

Metal to be joined or surfaced by welding is the parent metal and metal added during welding is the filler metal.

Metal melted during the making of a weld and retained in the weld is called the weld metal.

Heat Affected Zone (HAZ) is the part of the parent metal metallurgically affected by the weld or thermal cutting heat, but not melted.

Boundary between the weld metal and the HAZ in a fusion weld is called the Fusion Line. Zone containing the weld metal and the HAZ is called the Weld Zone.

The surface of a fusion weld exposed on the side from which the weld has been made is called the Weld Face Zone on the side of the first run furthest from the welder is called the weld root.

Boundary between a weld face and the parent metal or between runs is called Weld Toe. This is a very important feature of a weld since toes are points of high stress concentration and often, they are initiation points for different types of cracks (e.g., fatigue cracks, cold cracks). To reduce the stress concentration, toes must blend smoothly into the parent metal surface.

Weld metal lying outside the plane joining the toes are Excess Weld Metal.



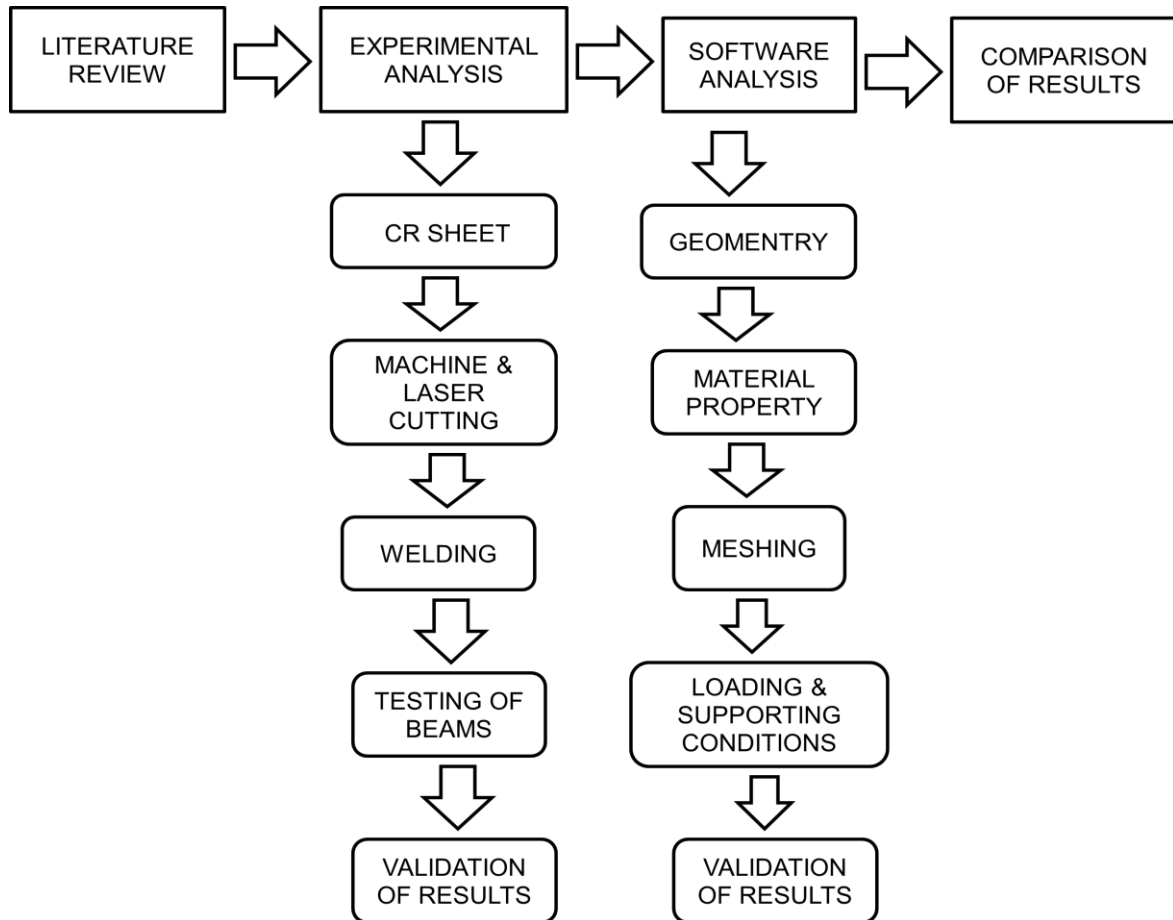
Fig 3.6: Welding of Beams

The specimen is welded and fabricated into a built up I section. The excess weld is grinded, and the beam are painted. The figure shows the welding of specimens. The Fig 3.7 shows the fabricated beams.



Fig 3.7: Fabricated Beams

3.5 METHODOLOGY



3.8 Methodology Flow Chart

3.6 ANALYTICAL MODELS

3.6.1 DIMENSIONS

A Total of 4 beams made of cold rolled sheet CR2 is fabricated and tested. For Castellated beam initially I-section is fabricated for 1500mm span and 200mm depth and then by method of castellation the span of all three castellated beam is 1300mm span and depth 300mm. The 3 castellated beam CRCB-1, CRCB-2, CRCB-3 the opening dimension details are shown in Fig 3.14, 3.15 and 3.16. The end distance for the beam is altered to attain 1300mm span. These castellated beams are compared with Build up I section (CRB) of span 1300 and depth 200mm. The dimension of the specimens, CRB (Cold Rolled Beam), CRCB-1

(Cold Rolled Castellated Beam-1), CRCB-2 (Cold Rolled Castellated Beam-2), CRCB-3 (Cold Rolled Castellated Beam-3) are given in Table 3.1.

Table 3.1: Specimen Dimensions

Specimen		Build up I-section beam	Castellated built up I-section Beam		
	Units	CRB	CRCB-1	CRCB-2	CRCB-3
Depth	mm	200	250	250	250
Breadth	mm	100	100	100	100
Span	mm	1300	1300	1300	1300
Web and Flange Thickness	mm	3	3	3	3
Expansion plate	mm	-	50	50	50
Spacing (s)	mm	-	150	100	75
End pitch (e)	mm	-	125	100	62.5
Number of openings	mm	-	3	4	5

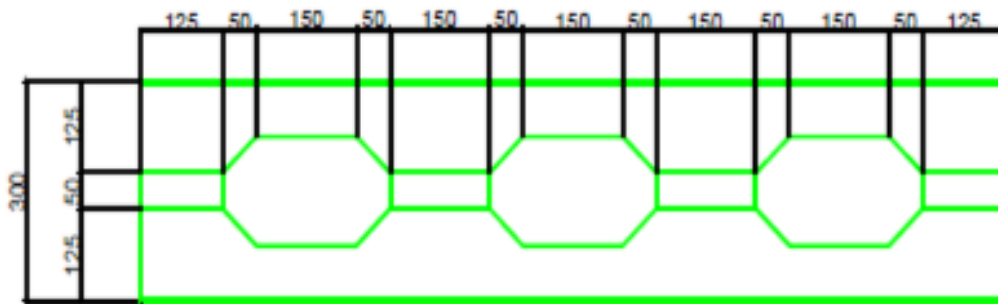


Fig 3.9: Dimensions Details of Perforations

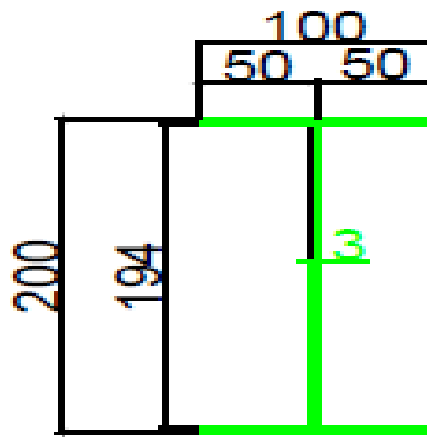


Fig 3.10: Dimensions Details of CRB (side view)

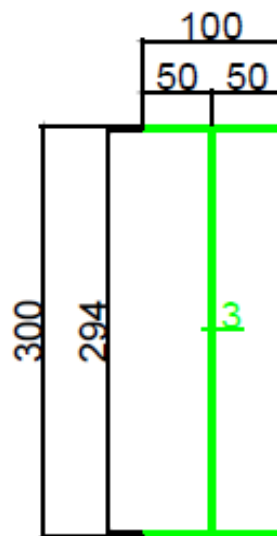


Fig 3.11: Dimensions Details of Castellated beams (side view)

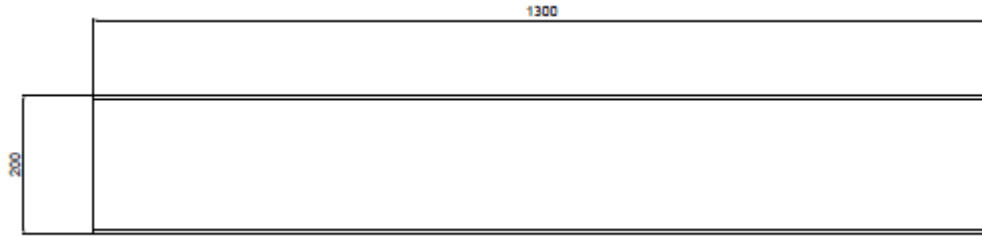


Fig 3.12: Dimension Details of CRB

3.7 METHOD OF CASTELLATION

Castellation is the process in which the web is cut longitudinally in zig zag pattern and offsetting the one half of the above the other and moved in desired length. The extended beam is cut off according to the required span of the beam. In this study Castellated beam initially I-section is fabricated for 1500mm span and 200mm depth and then by method of castellation the span of all three castellated beam is 1300mm and depth 300mm.

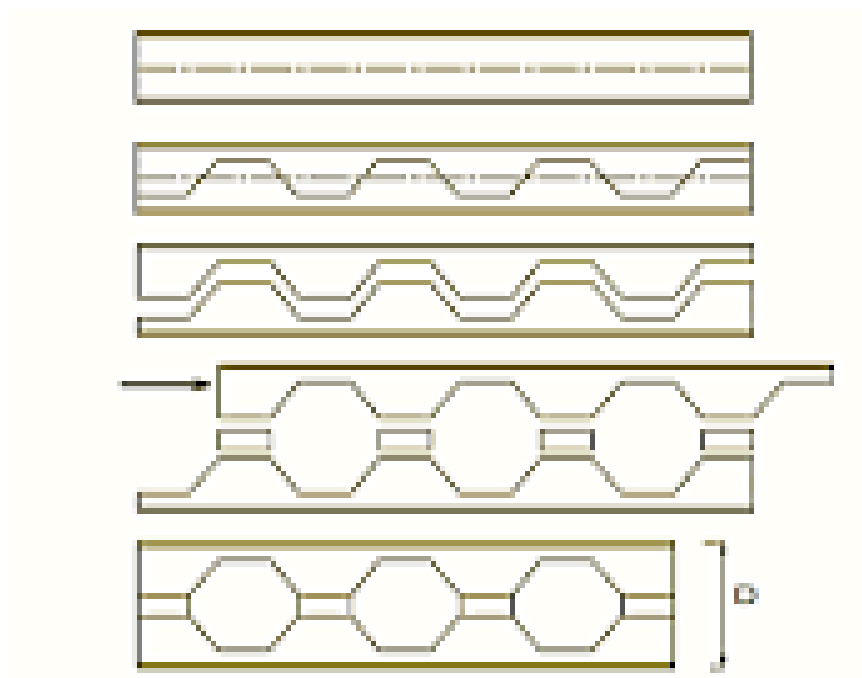


Fig 3.13: Method of Castellation

3.7.1 CASTELLATION OF CRCB-1

The zig-zag pattern is drawn on a built-up I SECTION beam of 200mm depth and 1500mm span. CRCB-1 beam consists of 3 openings with 150mm spacing and 125mm end distance with these parameters the zig-zag pattern is cut and then offset. An extension of 200mm from both sides is cut off. After an expansion plate of 50mm is placed on joining ends. Finally, after castellation CRCB-1 beam is of depth 300mm and span 1300mm.

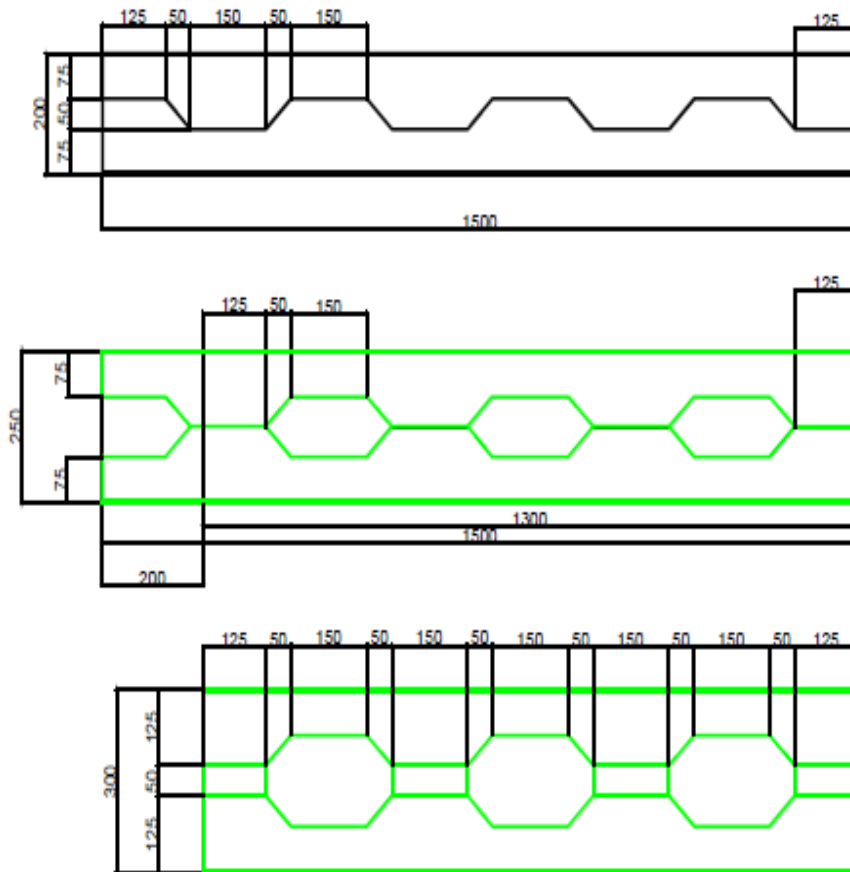


Fig 3.14: Method of Castellation of CRCB-1

3.7.2 CASTELLATION OF CRCB-2

The zig-zag pattern is drawn on a built-up I section beam of 200mm depth and 1500mm span. CRCB-2 beam consists of 4 openings with 100mm spacing and 100mm end distance with these parameters the zig-zag pattern is cut and then offset. An extension of 150mm and 200mm from either side is cut off. After an expansion plate of 50mm is placed on joining ends. Finally, after castellation CRCB-2 beam is of depth 300mm and span 1300mm.

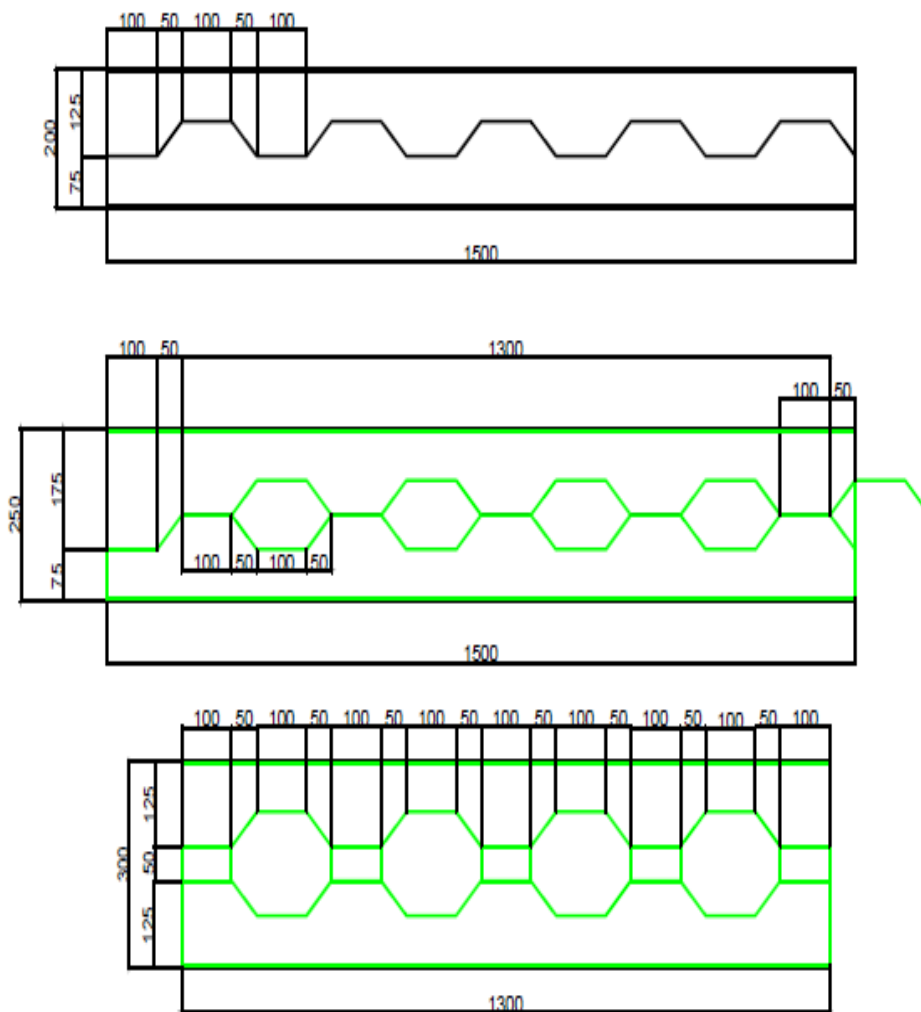


Fig 3.15: Method of Castellation of CRCB-2

3.7.3 CASTELLATION OF CRCB-3

The zig-zag pattern is drawn on a built-up I section beam of 200mm depth and 1500mm span. CRCB-3 beam consists of 5 openings with 75mm spacing and 62.5mm end distance with these parameters the zig-zag pattern is cut and then offset. An extension of 150mm and 200mm from either side is cut off. After an expansion plate of 50mm is placed on joining ends. Finally, after castellation CRCB-2 beam is of depth 300mm and span 1300mm.

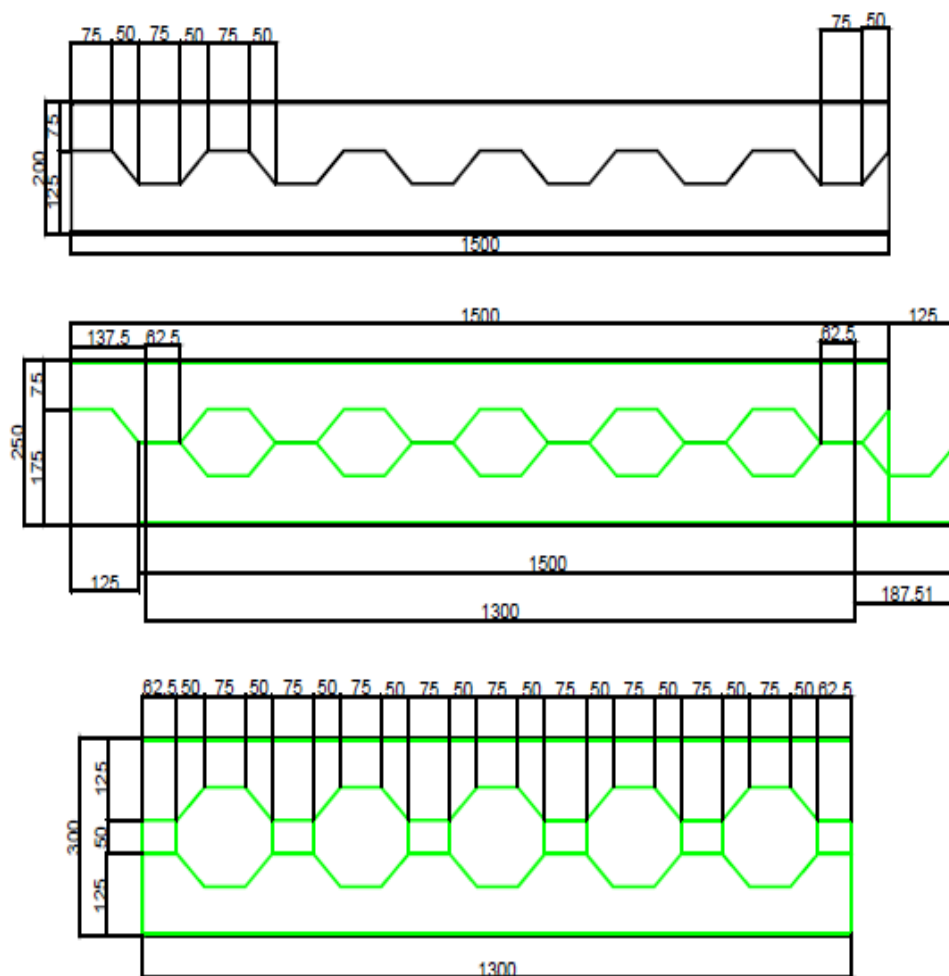


Fig 3.16: Method of Castellation of CRCB-3

3.8 TESTING CONDITIONS

The four-point flexure test is performed on the specimen and the total deformation of the specimen is studied for the applied load. The four-point flexure consist of 4 pins. 2 support pins and 2 loading pins. The support pins are placed 100mm from end the beam on both the sides. The loading pins are placed 466.67mm from the both the ends. The distance between both the loading pins is 366.67mm. The fig : 3.17 shows the four-point flexure test set up of the specimen.

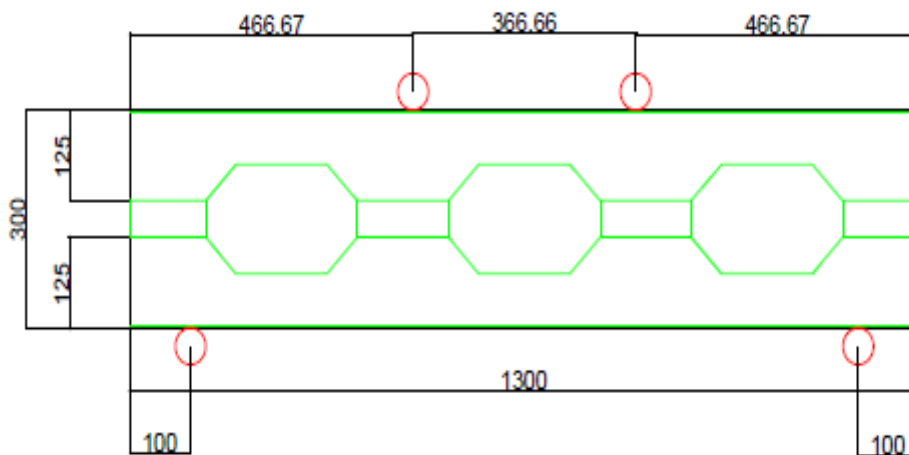


Fig3.17: Loading Set-up

3.9 ANALYTICAL INVESTIGATION

ANSYS Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analyzing strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Finite element analysis is performed for all the specimen is using ANSYS 2021 Workbench and their behaviour is studied.

3.10 GEOMETRY

Geometry of specimen CRB, CRCB-1, CRCB-2 and CRCB-3 is modelled in ANSYS, Design modeler. The Fig 3.18, 3.19, 3.20 and 3.21 shows the geometry of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.

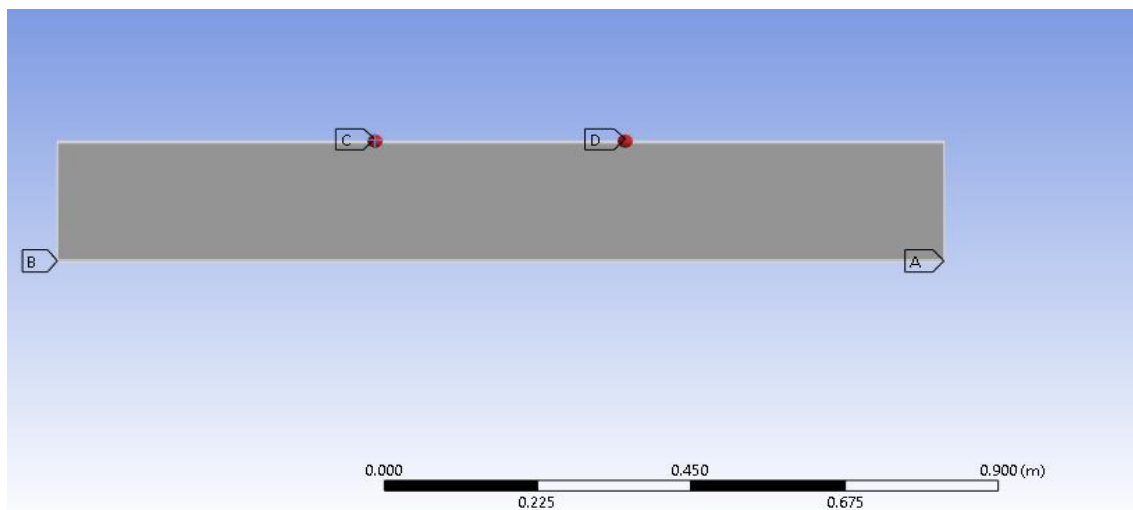


Fig 3.18: Geometry of CRB

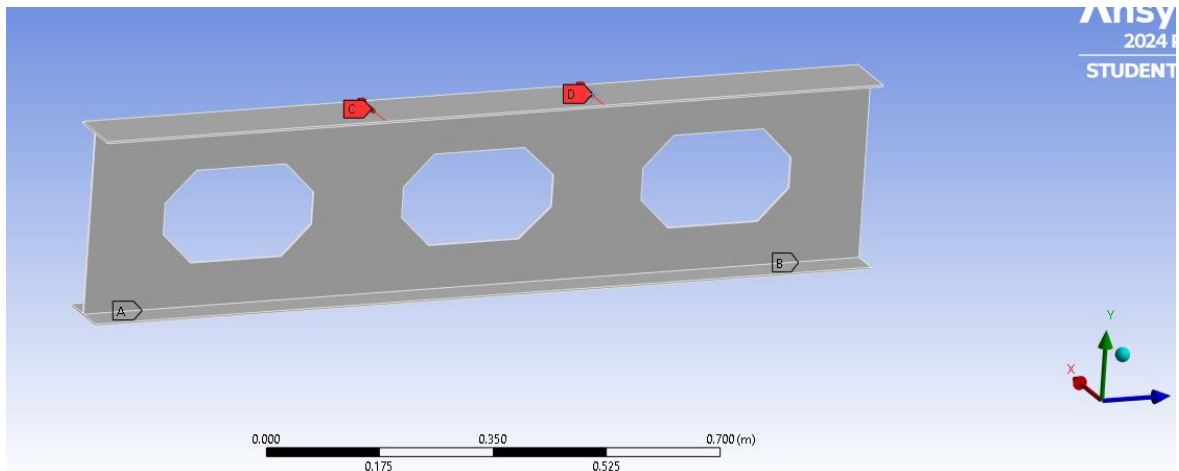


Fig 3.19: Geometry of CRCB-1

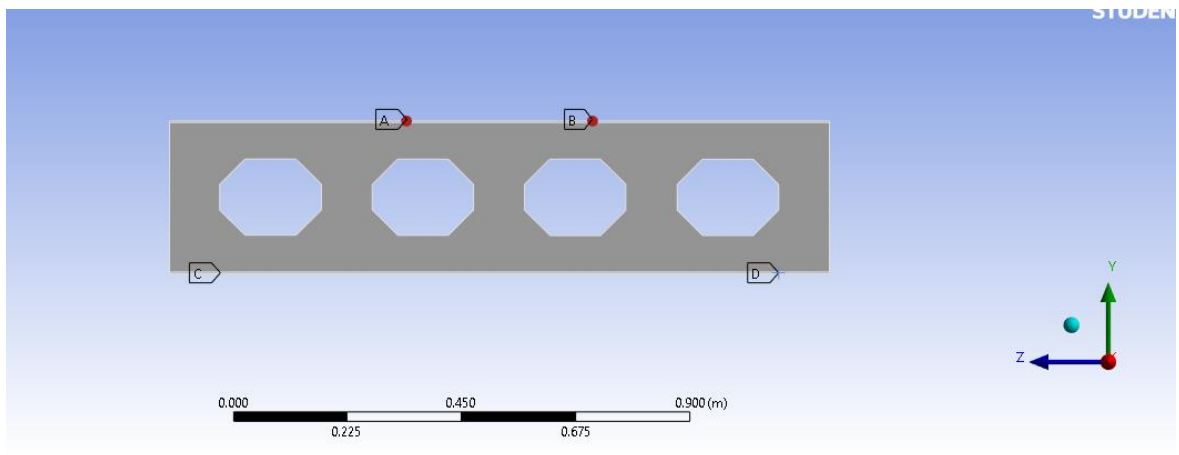


Fig 3.20: Geometry of CRCB-3

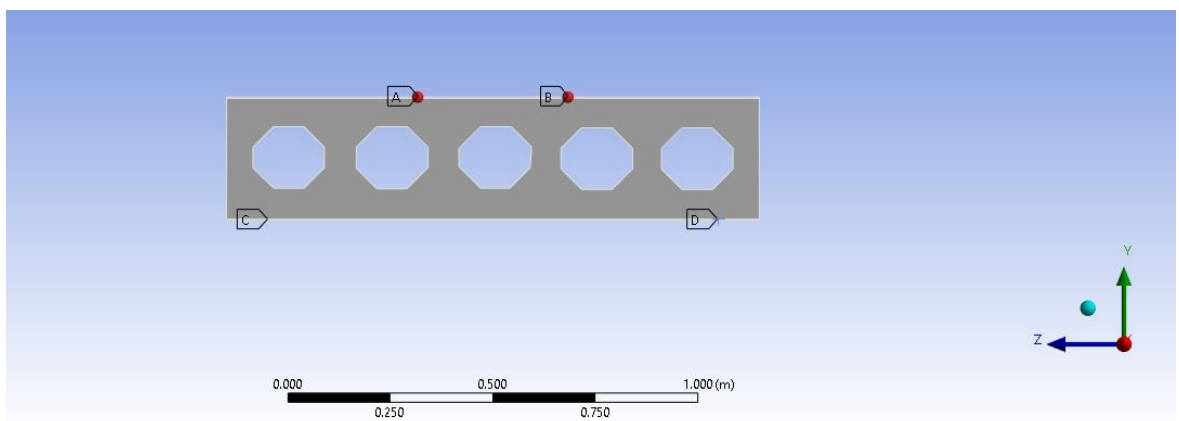


Fig 3.21: Geometry of CRCB-3

3.11 MATERIAL PROPERTY

In engineering data, the mechanical properties for cold rolled sheet as per code IS 513:2008, Table 3. For this work designation CR2 Drawing is used. The Fig 3.22 shows the material property window for Grade IS 513 CR2.

Properties of Outline Row 3: CR2 SHEET				
	A	B	C	D E
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Density	7850	kg m ⁻³	
4	Isotropic Secant Coefficient of Thermal Expansion			
6	Isotropic Elasticity			
7	Derive from	Young's Modulus and Poisson's Ratio		
8	Young's Modulus	2E+05	MPa	
9	Poisson's Ratio	0.3		
10	Bulk Modulus	1.6667E+11	Pa	
11	Shear Modulus	7.6923E+10	Pa	
12	Bilinear Isotropic Hardening			
13	Yield Strength	240	MPa	
14	Tangent Modulus	1450	MPa	
15	Tensile Yield Strength	240	MPa	
16	Compressive Yield Strength	240	MPa	
17	Tensile Ultimate Strength	370	MPa	
18	Compressive Ultimate Strength	0	MPa	

Fig 3.22: Material property for CR Sheet

3.12 MESHING

Ansys meshing capabilities help reduce the amount of time and effort spent to get to accurate results. In Finite Element Analysis (FEA) is an analysis solved using a method called the Finite Element Method (FEM). With the help of discretization or meshing (nodes and elements) Finite Element Method reduces the degrees of freedom. Thus, meshing is done to break up larger parts into small pieces each piece representing an element to solve the model using finite element method. One of the purposes of meshing is to make the problem solvable using Finite Element. Hence, we create a mesh which splits the domain into a discrete number of elements for which the solution is be calculated. The Fig 3.23, 3.24, 3.25 and 3.26 shows the meshing of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.

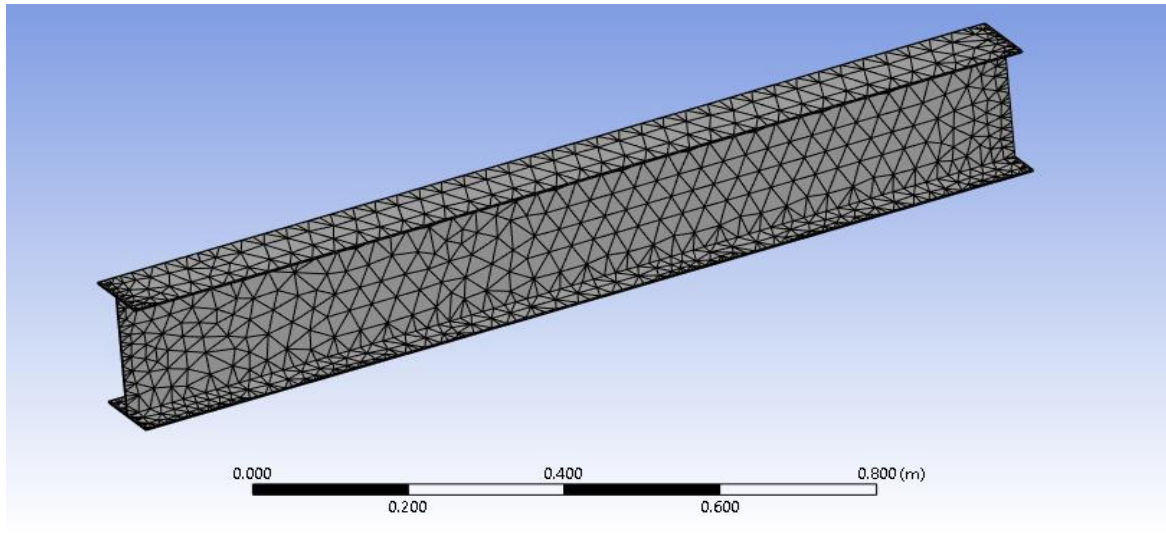


Fig 3.23: Meshing Details of CRB

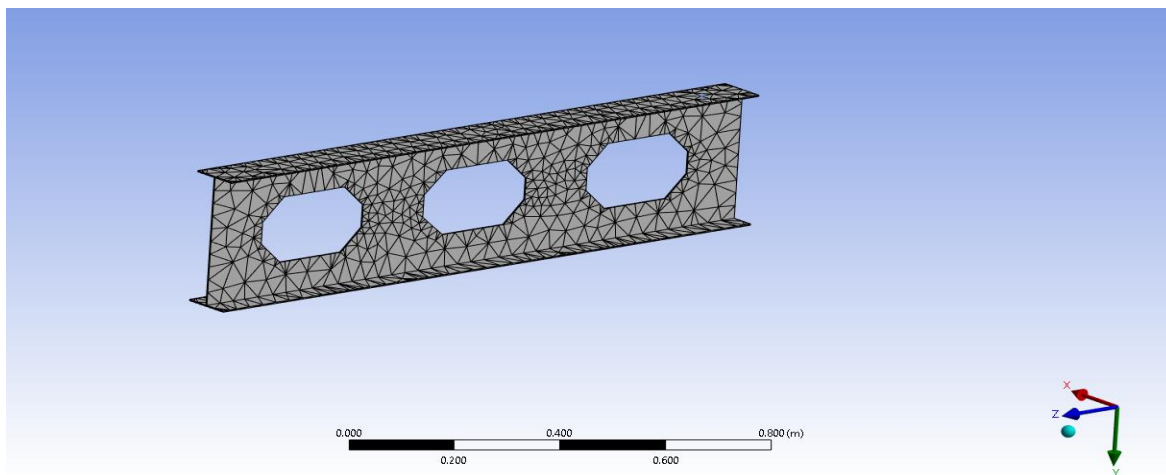


Fig 3.24: Meshing Details of CRCB-1

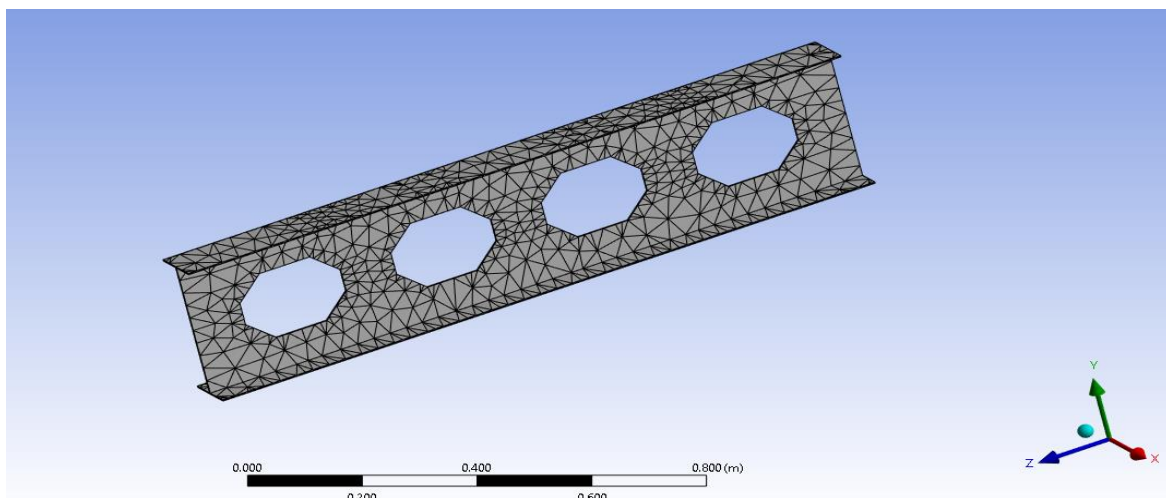


Fig 3.25: Meshing Details of CRCB-2

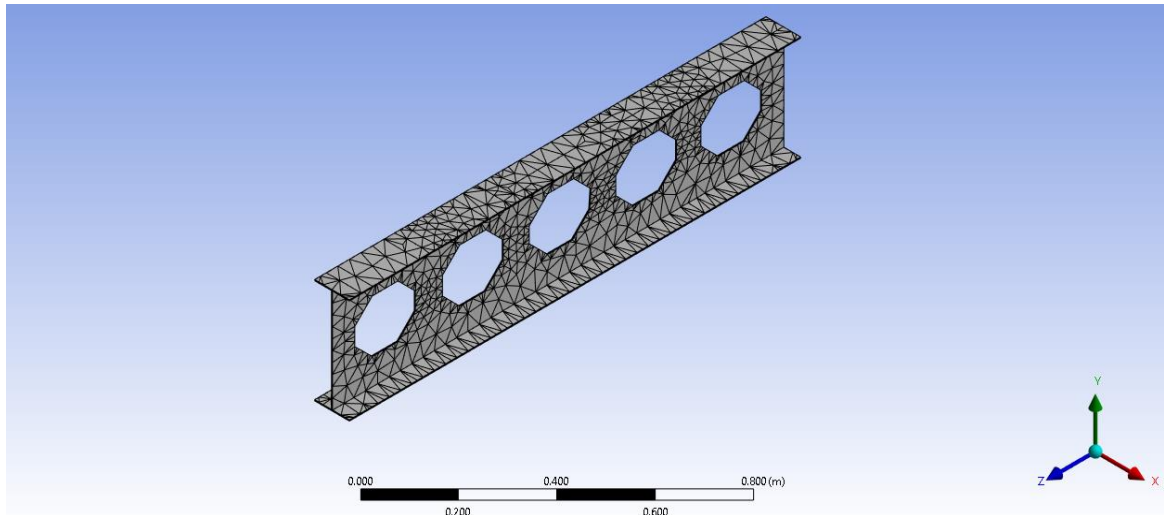


Fig 3.26: Meshing Details of CRCB-3

3.13 LOADING AND SUPPORT CONDITIONS

Loading and support conditions are assigned as per to perform the Four-point flexure testing with 2 support pins and two loading pins. A steel rod of 8 cm and 11cm diameter is designed as loading pins and support pins, respectively. The Fig 3.27 shows the loading and support conditions for CRB and this is also similar for all CRCB-1, CRCB-2, and CRCB-3.

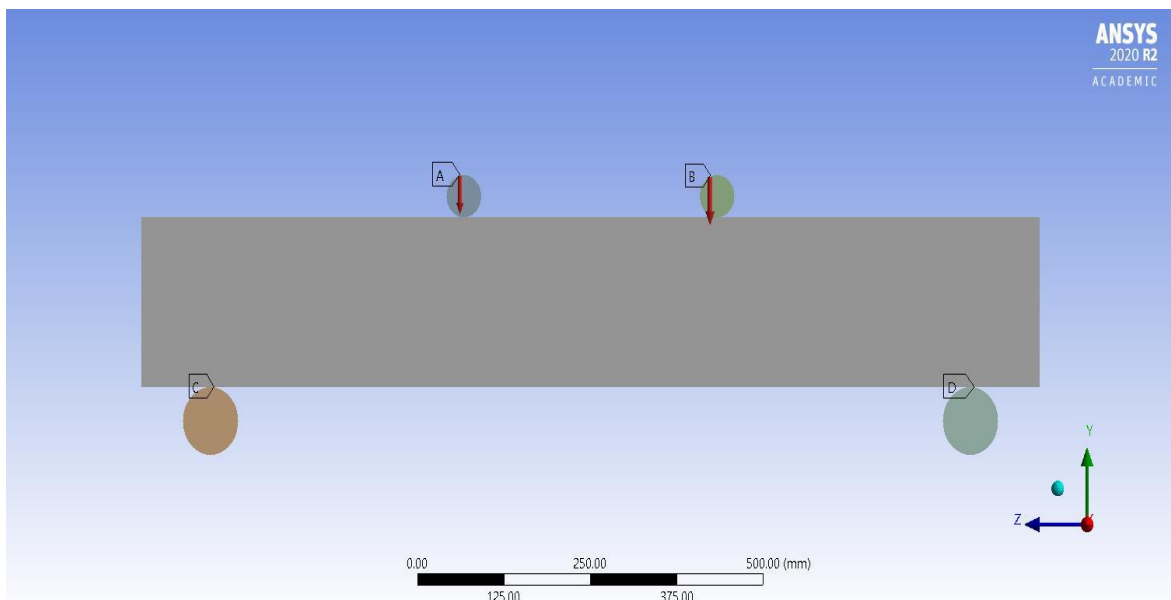


Fig 3.27: Loading Conditions

3.14 EXPERIMENTAL INVESTIGATION

The fabricated beams such as CRB, CRCB-1, CRCB-2 and CRCB-3 are placed in the flexure testing machine to find load deflection behaviour of each specimen respectively.

3.15 TESTING SET-UP OF BEAM

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

- Loading frame
- Support Pins
- Loading Pins
- Pivot Ring
- Three Digital Dial Gauges.
- Hydraulic Jack

The specimen was placed above the support pins with clear cover of 100mm from both the sides. The digital meter is used to determine the deformation occurred during the loading.

Above the beam the loading pins are placed 466.66mm from both the ends of the beam. Above the loading pins, a load distributor is placed to distribute equal loads to both the loading pins. The pivot ring is placed above the hydraulic jack and indicated the load applications.

The hydraulic jack is placed in between the distributor and pivot ring to have contact. The Fig 3.28, 3.29, 3.30 and 3.31 shows the experimental set up of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.



Fig 3.28: Testing Set-Up of CRB



Fig 3.29: Testing Set-Up of CRCB-1



Fig 3.30: Testing Set-Up of CRCB-2



Fig 3.31: Testing Set-Up of CRCB-3

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The specimen CRB, CRB, CRCB-1, CRCB-2, and CRCB-3 are fabricated and experimental test is conducted to obtain better results. The CR sheet is purchased and fabricated into built up beams and then castellated. The fabricated beam is further tested in a loading frame and flexure test for beam is obtained.

4.2 EXPERIMENTAL RESULTS

On gradually application of load the deformation of the beam is calculated from the average value obtained from the computerized digital meter. , The yield point is obtained to be 14kN, 16kN, 18kN, 16kN for CRB, CRCB-1, CRCB-2, CRCB-3. Fig 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7 and 4.8 shows the Yield point and local buckling respectively.

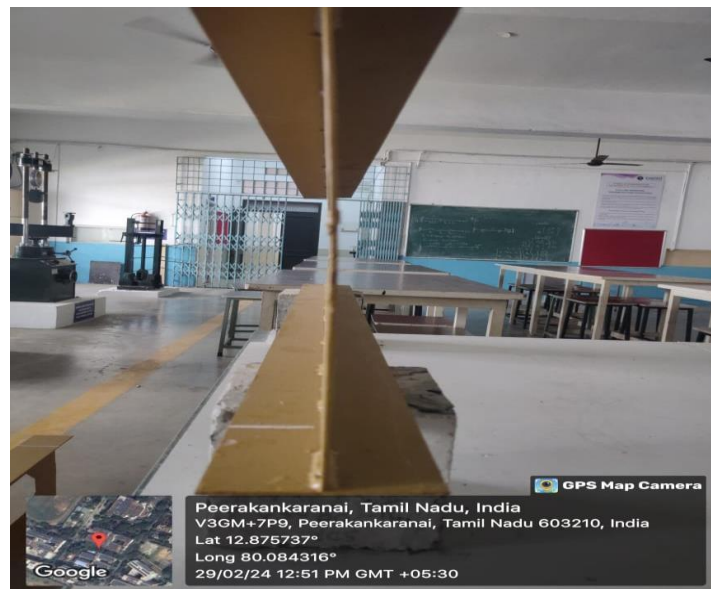


Fig 4.1: At Yield point of CRB



Fig 4.2: Local Buckling of CRB



Fig 4.3: At Yield point of CRCB-1

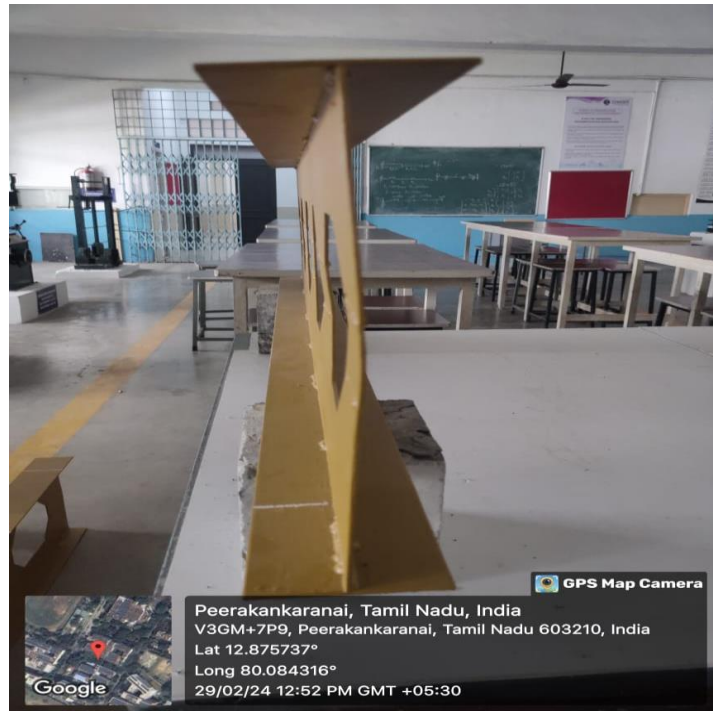


Fig 4.4: Local Buckling of CRCB-1

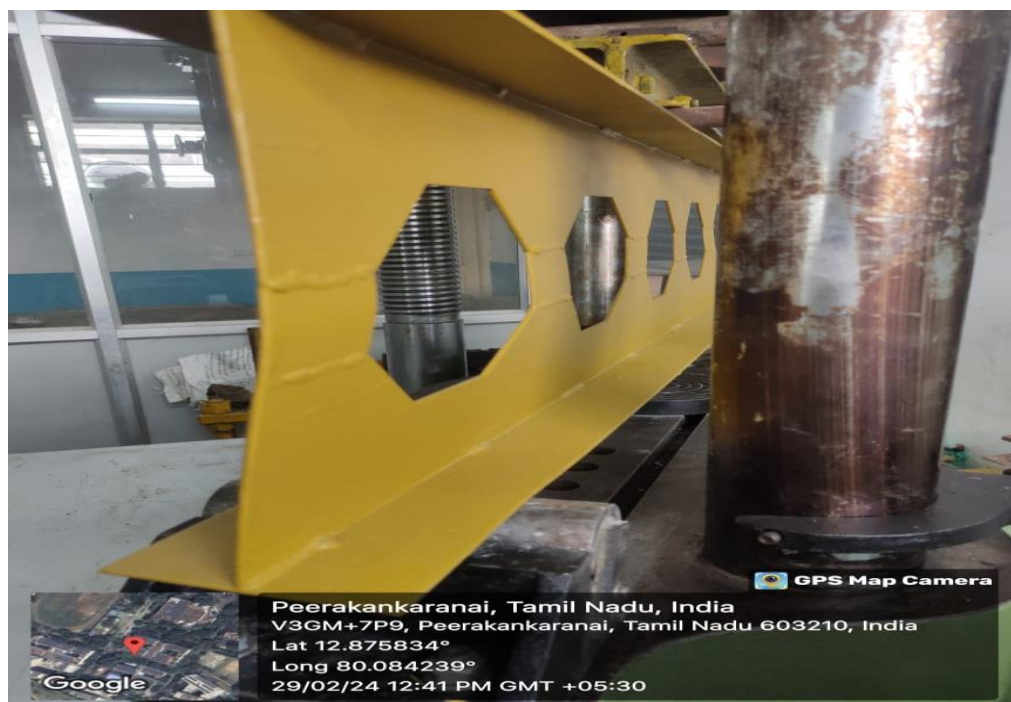


Fig 4.5: At Yield point of CRCB-2

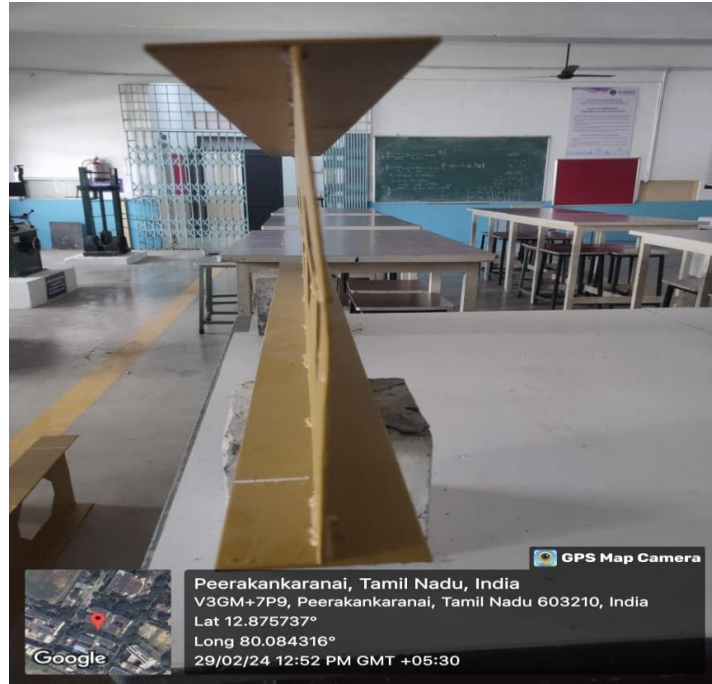


Fig 4.6: Local Buckling of CRCB-2

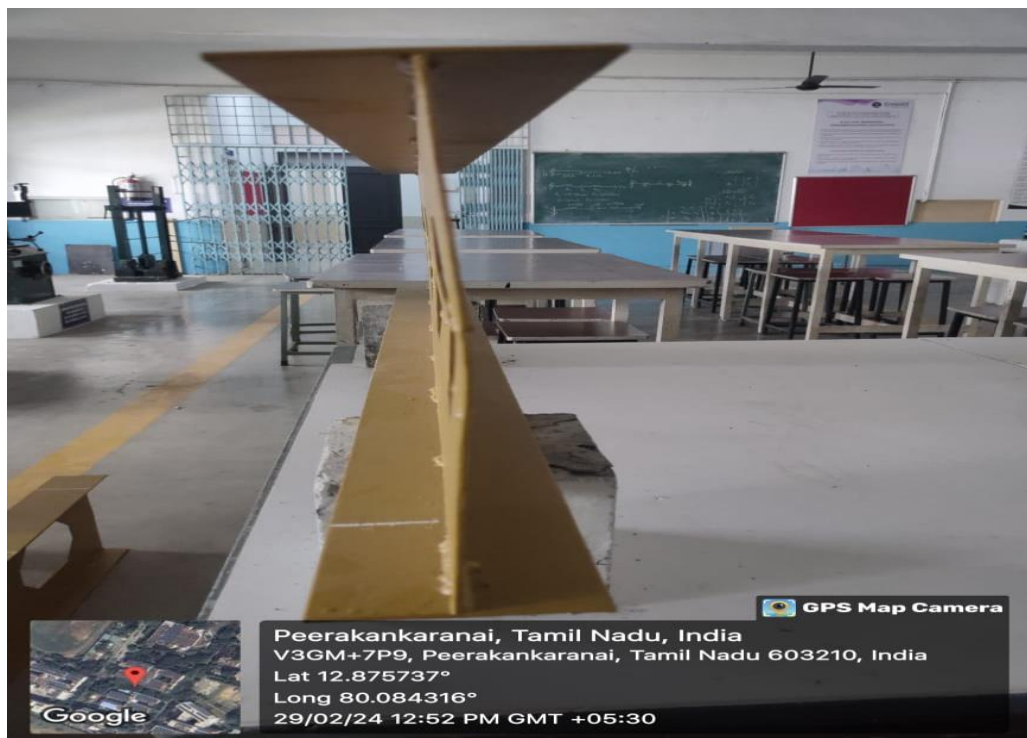


Fig 4.7: At Yield point of CRCB-3

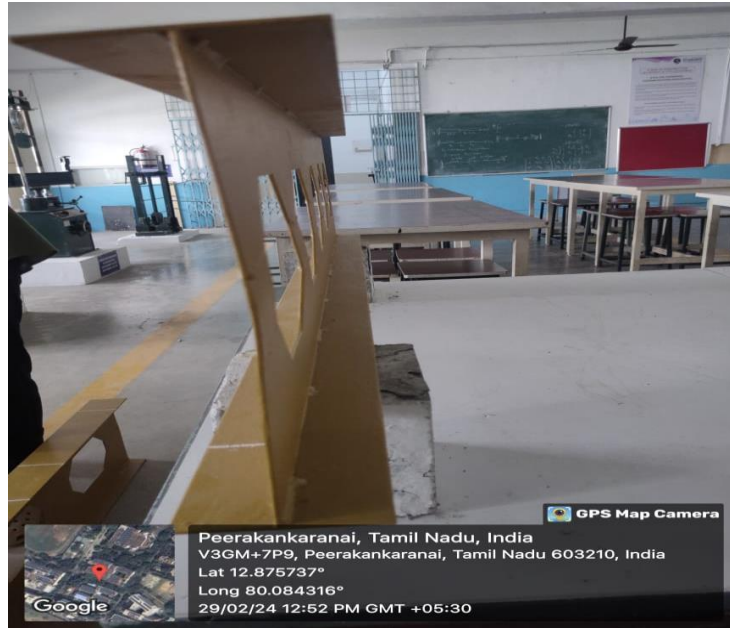


Fig 4.8: Local Buckling of CRCB-3

4.3 AVERAGE YIELD POINT IN EXPERIMENTAL RESULTS

From the specimens CRB, CRCB-1, CRCB-2 and CRCB-3, we get the experimental results of yield point from sample 1 and sample 2 respectively. The average of yield point is obtained in table 4.1 is shown.

Table 4.1: Tabulation of average experimental Yield Point

S.NO	SPECIMEN	YIELD POINT		AVERAGE OF YIELD POINT
		SAMPLE 1	SAMPLE 2	
1	CRB	1.63	1.59	1.65
2	CRCB-1	4.72	4.50	4.31
3	CRCB-2	5.20	5.12	5.40
4	CRCB-3	2.66	2.68	2.96

4.4 AVERAGE ULTIMATE POINT IN EXPERIMENTAL RESULTS

From the specimens CRB, CRCB-1, CRCB-2 and CRCB-3, we get the experimental results of ultimate point from sample 1 and sample 2 respectively. The average of yield point is obtained in table 4.2 is shown.

Table 4.2: Tabulation of average experimental ultimate Point

S.NO	SPECIMEN	ULTIMATE POINT		AVERAGE OF ULTIMATE POINT
		SAMPLE 1	SAMPLE 2	
1	CRB	6.750	6.850	6.815
2	CRCB-1	4.275	4.250	4.262
3	CRCB-2	3.015	3.021	3.018
4	CRCB-3	5.018	5.026	5.022

4.5 LOAD VS DEFLECTION GRAPH

The load deflection graph for experimental results of CRB, CRCB-1, CRCB-2, CRCB-3 is plotted in line graph. The fig shows each the graph respectively.

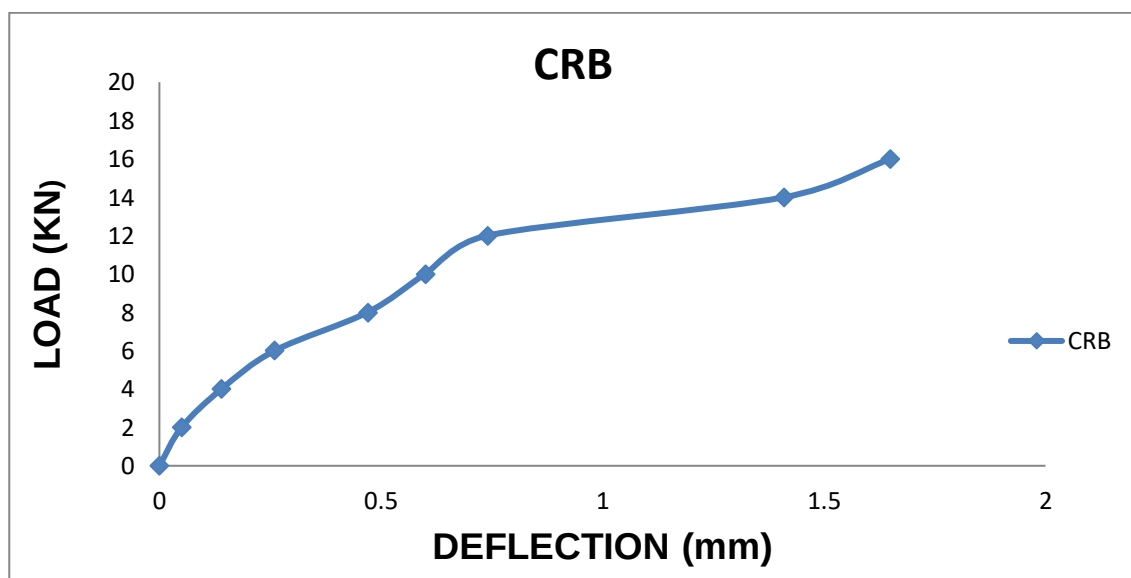


Fig 4.9: Load deflection graph CRB

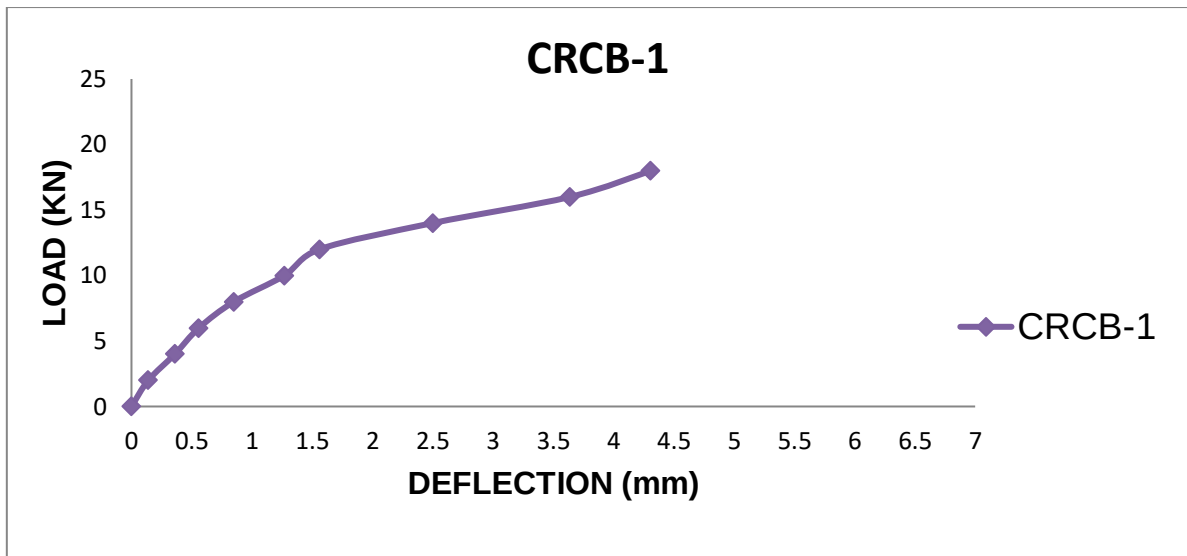


Fig 4.10: Load deflection graph CRCB-1

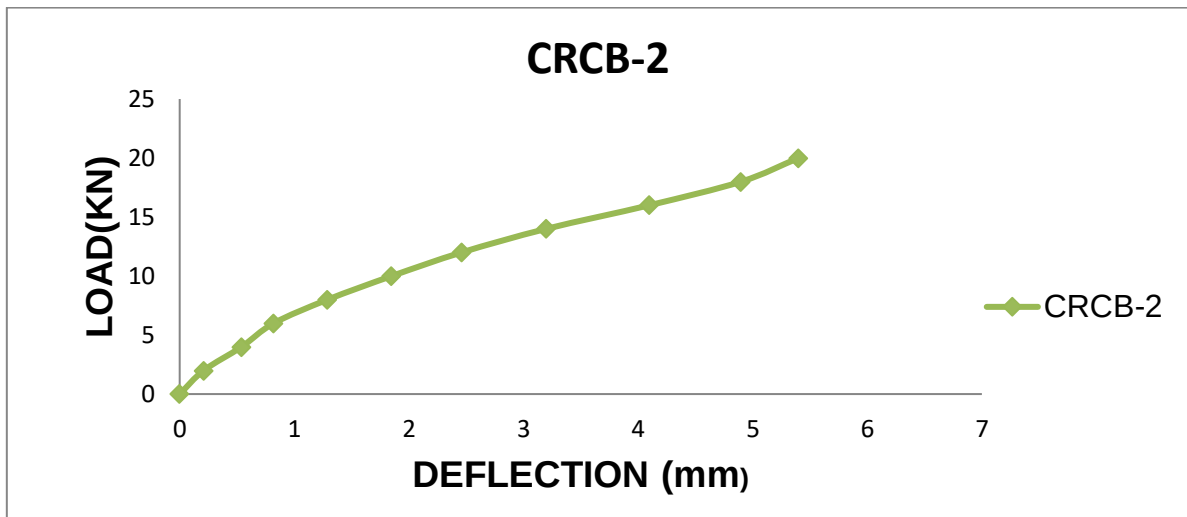


Fig 4.11: Load deflection graph CRCB-2

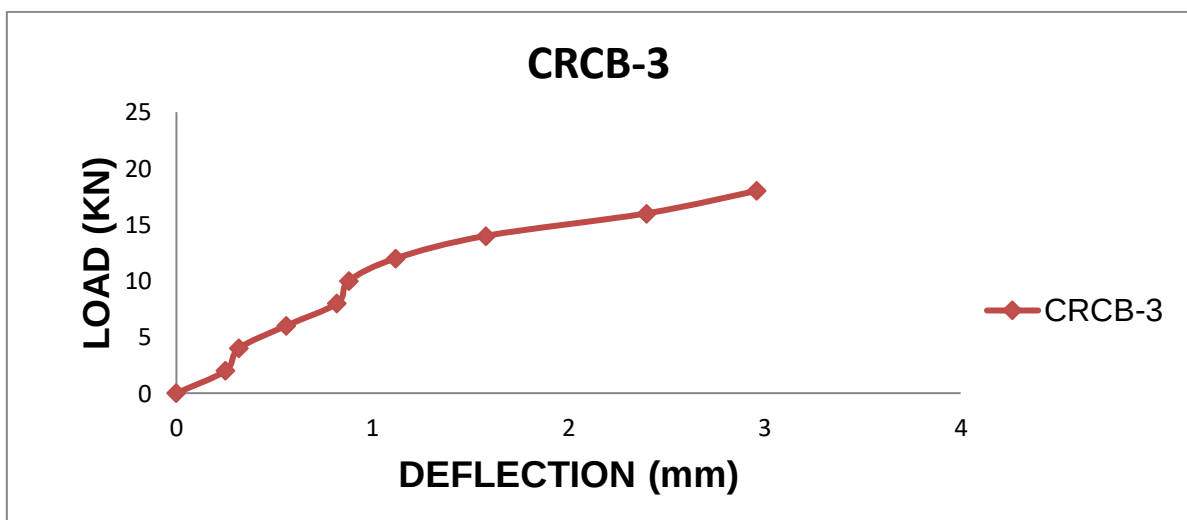


Fig 4.12: Load deflection graph CRCB-3

4.6 EXPERIMENTAL COMPARISON GRAPH

The yield point is obtained to be 14kN, 16kN, 18kN, 16kN for CRB, CRCB-1, CRCB-2, CRCB-3, respectively. The load deflection curve for all the specimen by experiment analysis is obtained as per graph in Fig 4.13. The maximum deflection is shown .

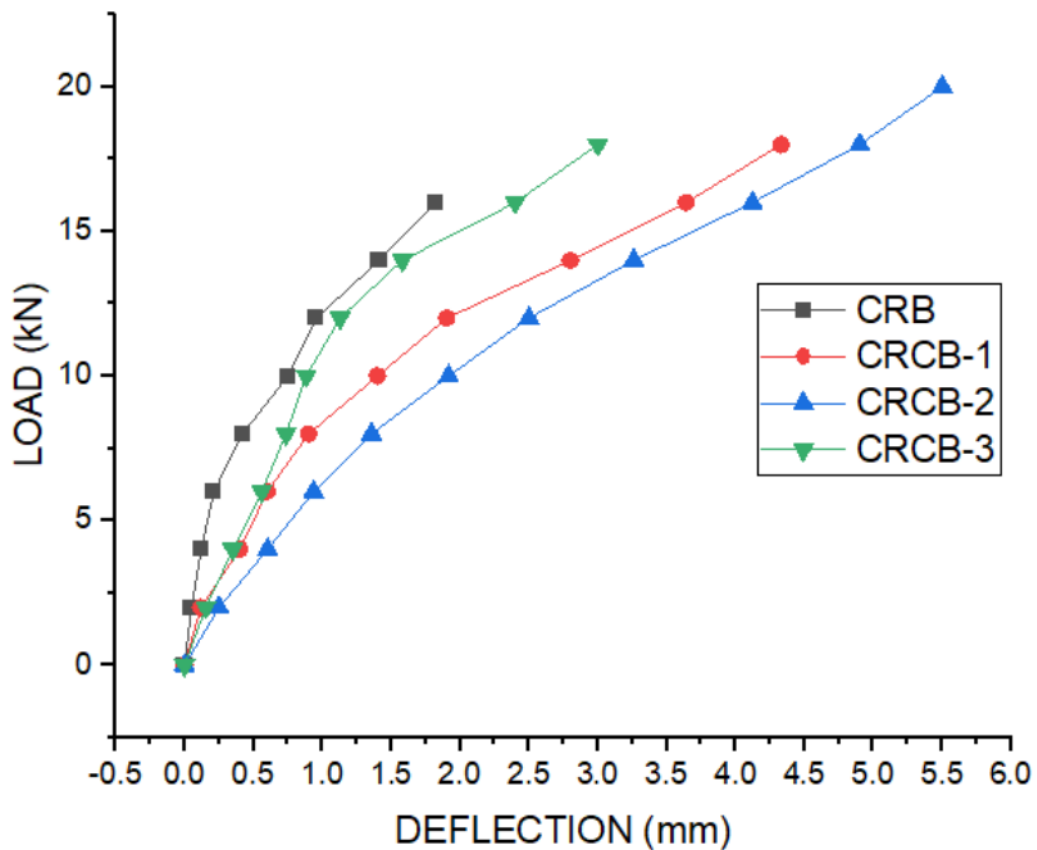


Fig 4.13: Comparison of Experimental Results of CRB, CRCB-1, CRCB-2, and CRCB-3

4.7 DUCTILITY FOR CR BEAMS

Ductility of CR beam can be found by ratio of ultimate point by yield point for specimens CRB, CRCB-1, CRCB-2 and CRCB-3 respectively. From table 4.3 we can find ductility of CR beams

Table 4.3: Tabulation of Ductility for CR Beams

S.NO	SPECIMEN	ULTIMATE POINT	YIELD POINT	DUCTILITY
1	CRB	6.815	1.65	4.130
2	CRCB-1	4.262	4.31	0.988
3	CRCB-2	3.018	5.40	0.558
4	CRCB-3	5.022	2.96	1.69

4.8 ANALYTICAL RESULTS

4.8.1 Total Deformation

The Total deformation of the beam is calculated for the gradually increasing load of 2 KN. The Fig 4.14, 4.15, 4.16 and 4.17 shows the maximum total deformation of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.

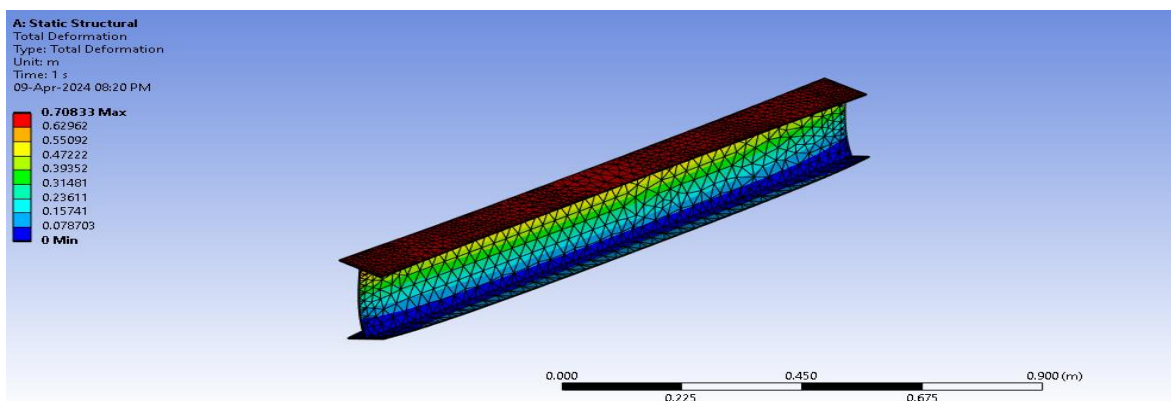


Fig 4.14: Total Deformation of CRB

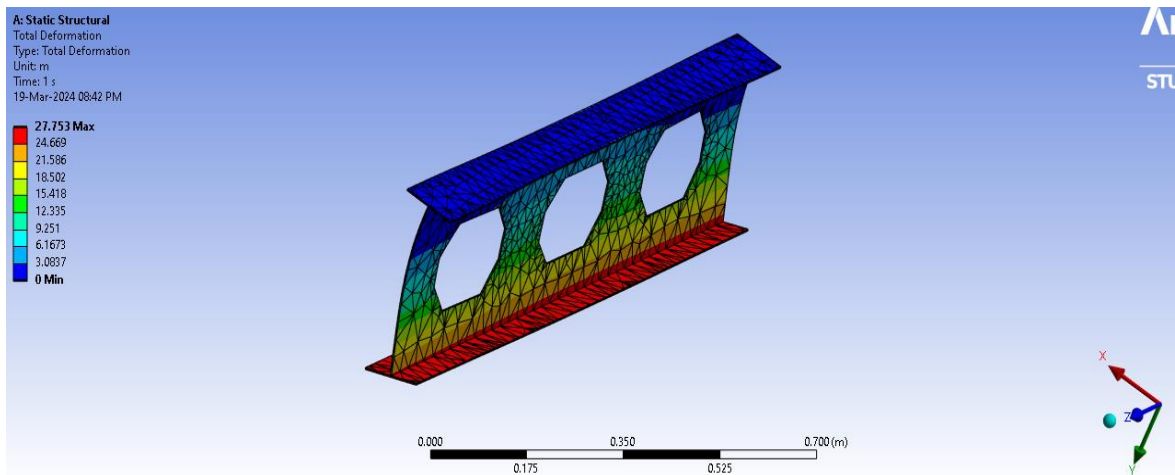


Fig 4.15: Total Deformation of CRCB-1

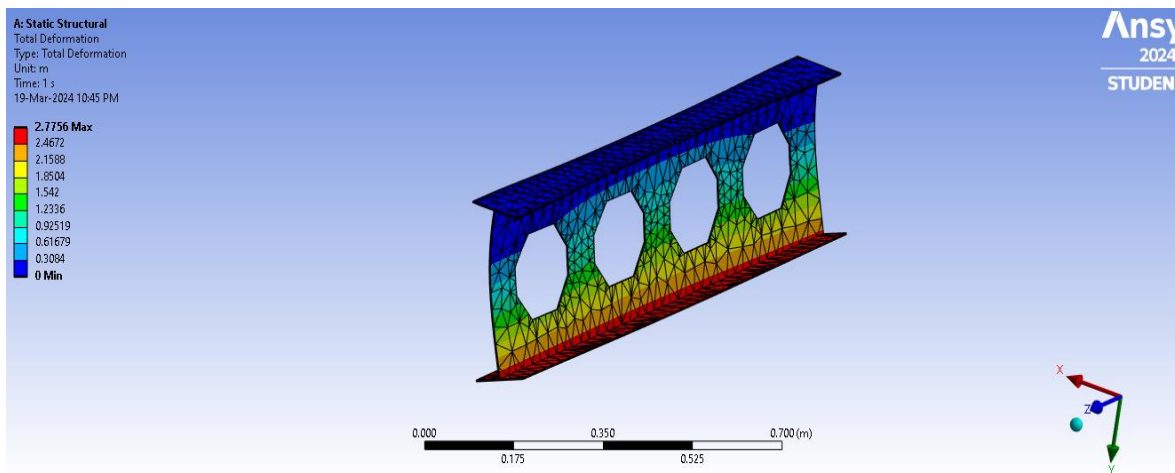


Fig 4.16: Total Deformation of CRCB-2

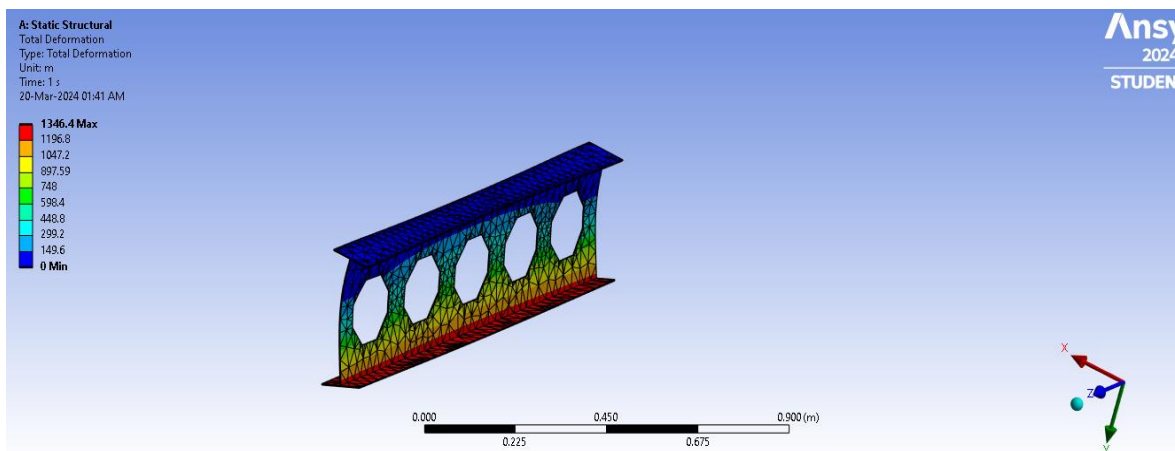


Fig 4.17: Total Deformation of CRC

4.8.2 EQUIVALENT STRESS (VON MISES)

The Equivalent stress (von mises) of the beam is calculated for the load at the yield point. The Fig 4.18, 4.19, 4.20 and 4.21 shows the Stress concentration of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.

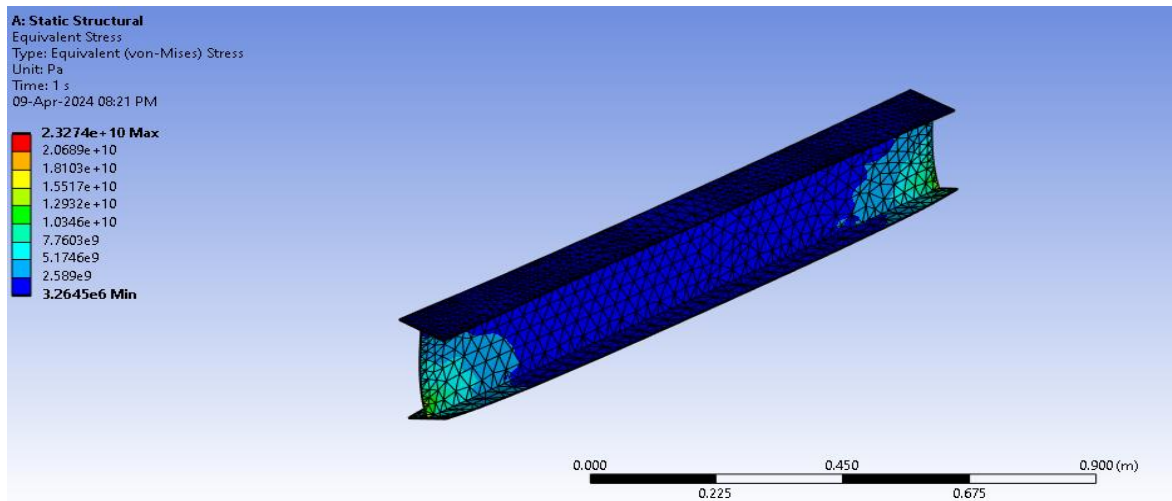


Fig 4.18: Stress Concentration of CRB

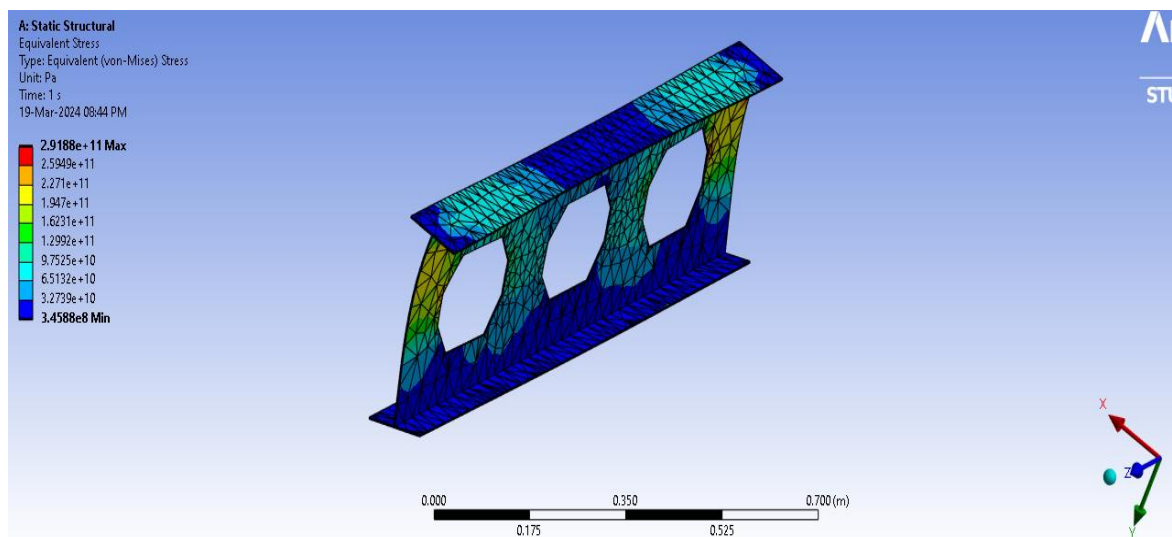


Fig 4.19: Stress Concentration of CRCB-1

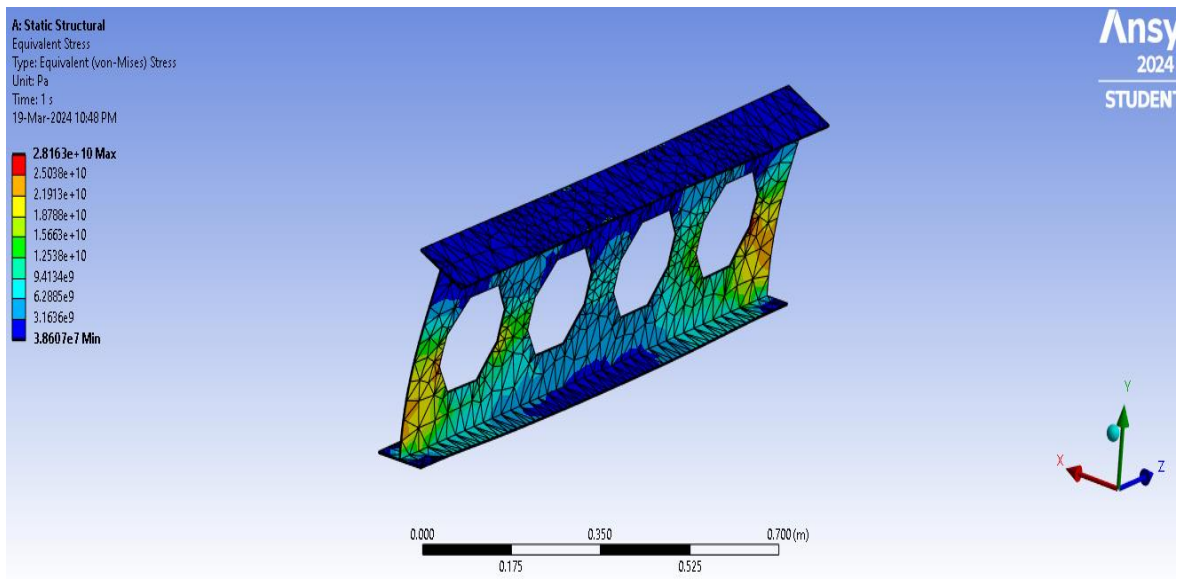


Fig 4.20: Stress Concentration of CRCB-2

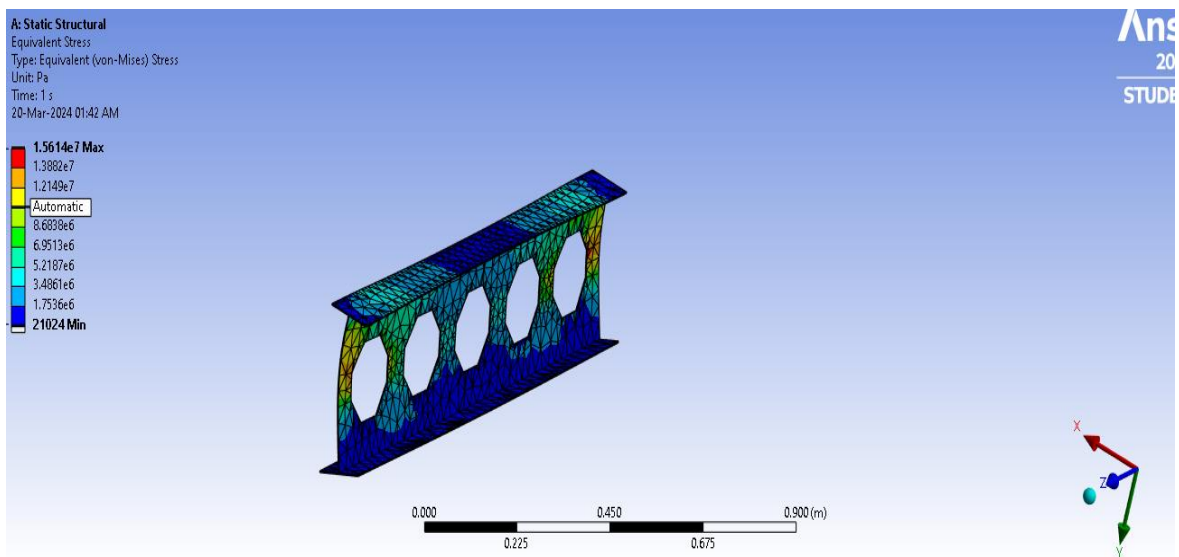


Fig 4.21: Stress Concentration of CRCB-3

4.9 AVERAGE YIELD POINT IN ANALYTICAL RESULTS

From the specimens CRB, CRCB-1, CRCB-2 and CRCB-3, we get the numerical results of yield point from sample 1 and sample 2 respectively. The average of yield point is obtained in table 4.4 is shown.

Table 4.4: Tabulation Of average analytical Yield Point

S.NO	SPECIMEN	YIELD POINT		AVERAGE OF YIELD POINT
		SAMPLE 1	SAMPLE 2	
1	CRB	1.54	1.52	1.52
2	CRCB-1	3.96	3.80	3.83
3	CRCB-2	4.74	4.80	4.89
4	CRCB-3	2.65	2.72	2.75

4.10 LOAD VS DEFLECTION GRAPH

The load deflection graph for numerical results of CRB, CRCB-1, CRCB-2, CRCB-3 is plotted in line graph. The fig shows the each graph respectively.

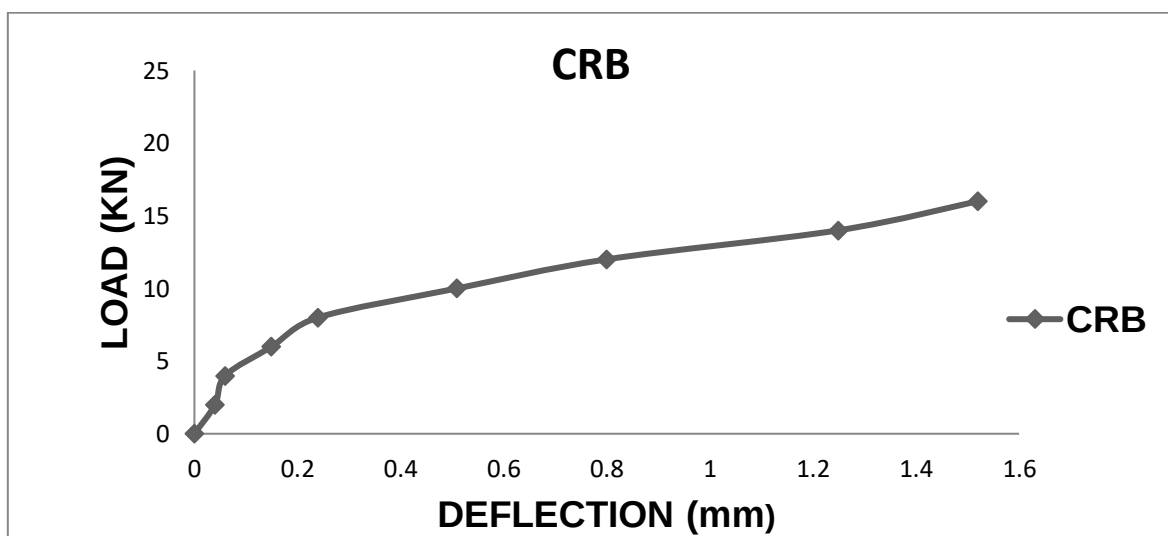


Fig 4.22: Load deflection graph CRB

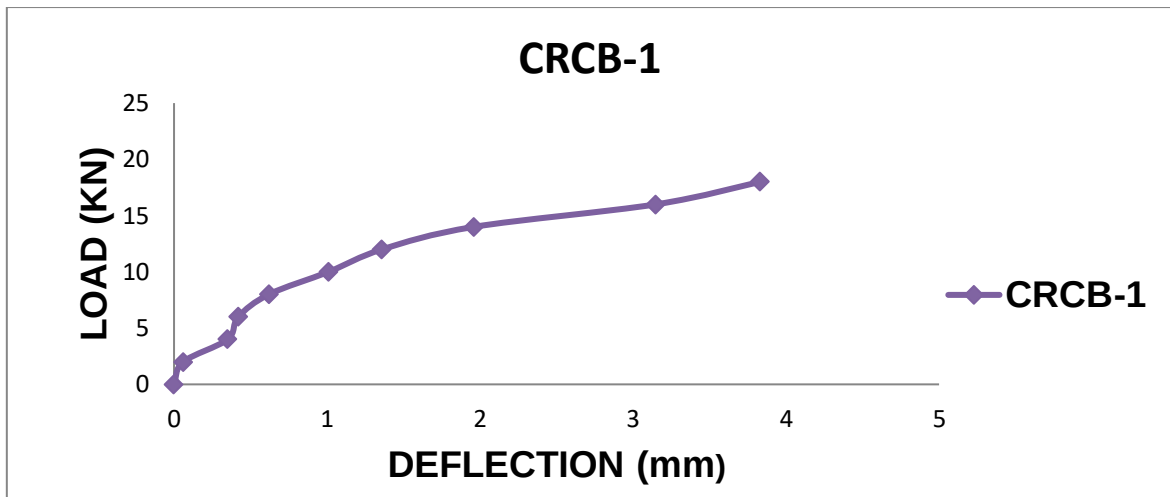


Fig 4.23: Load deflection graph CRCB-1

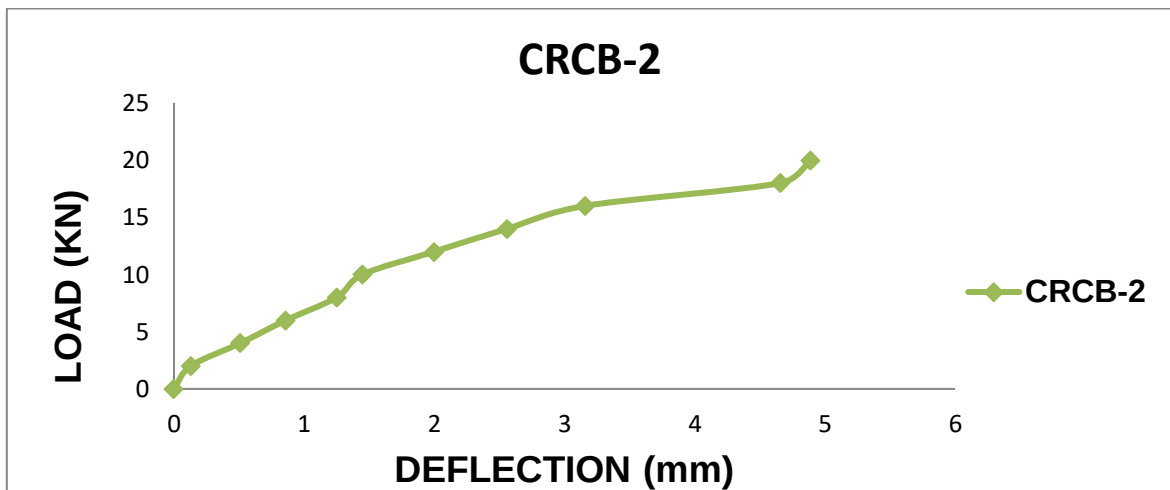


Fig 4.24: Load deflection graph CRCB-2

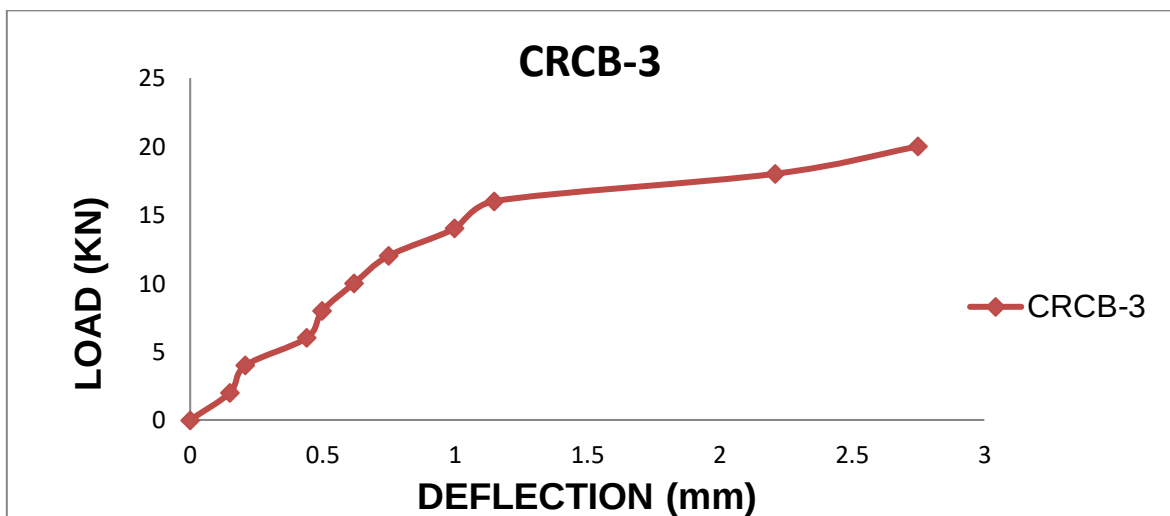


Fig 4.25: Load deflection graph CRCB-3

4.11 ANALYTICAL COMPARISON GRAPH

The yield point is obtained to be 14kN, 16kN, 18kN, 16kN for CRB, CRCB-1, CRCB-2, CRCB-3, respectively. The load deflection curve for all the specimen by ANSYS is obtained as per graph in Fig 4.26. The maximum deflection is seen in CRCB-2.

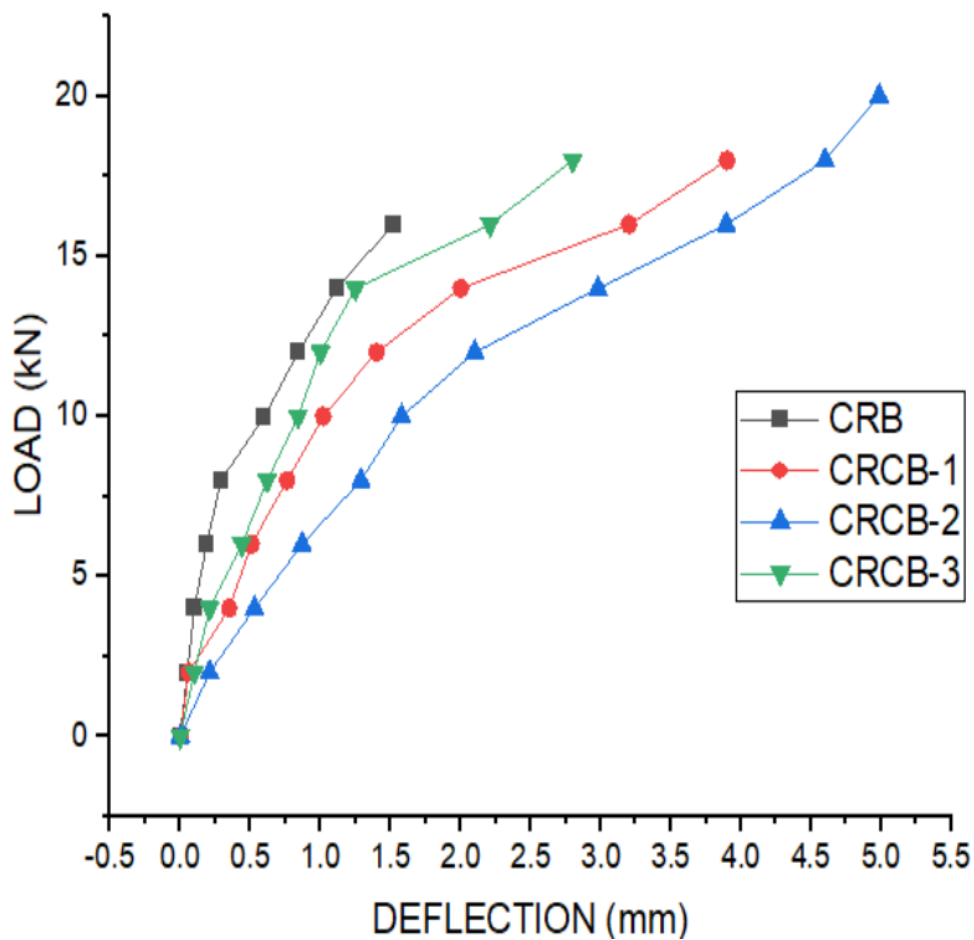


Fig 4.26: Comparison of Analytical Results of CRB, CRCB-1, CRCB-2 and CRCB-3

4.12 COMPARISON OF RESULTS

The Yield point is determined to be 14kN, 16kN, 18kN, 16kN for CRB, CRCB-1, CRCB-2, CRCB-3, respectively from both Experimental and Analytical results. The load deflection curve for all the specimen by Experiment and Analytical analysis is shown in Fig 4.27. The total deformation comparison between ANSYS and Experiment at its yield point is shown in Fig 4.28.

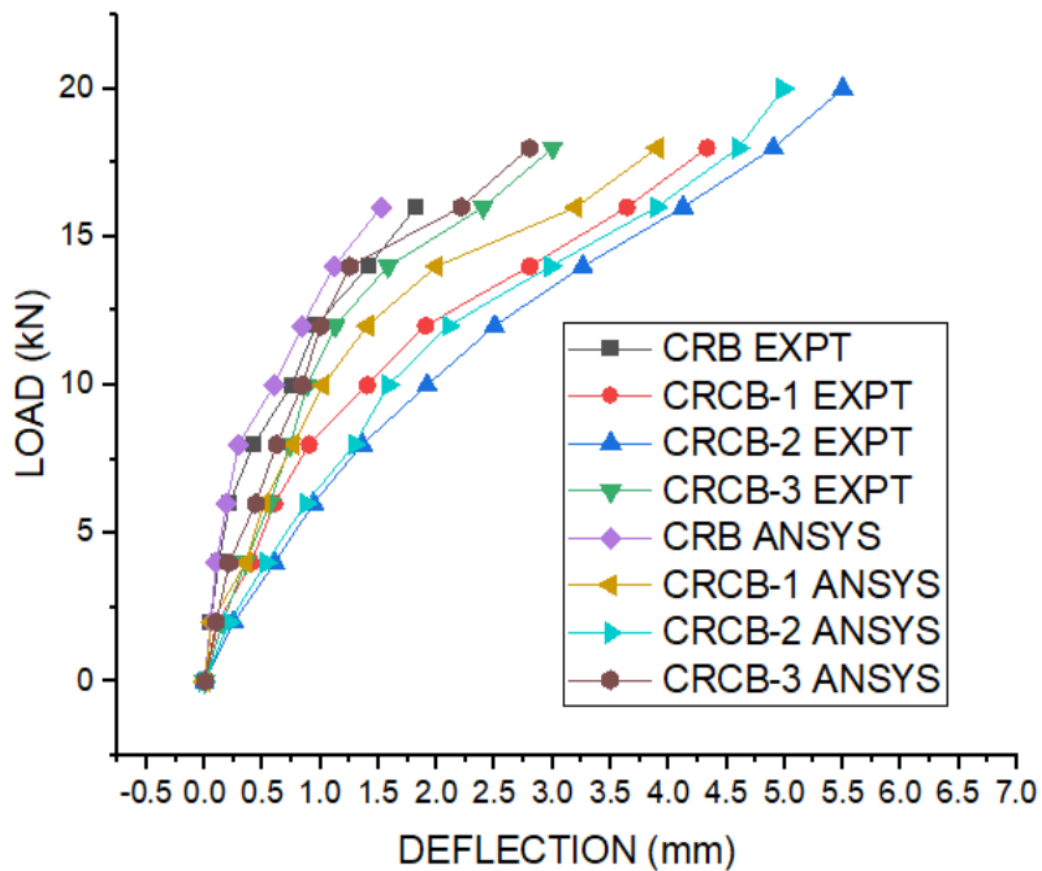


Fig 4.27: Comparison of Experimental and Analytical Results of CRB, CRCB-1, CRCB-2, and CRCB-3

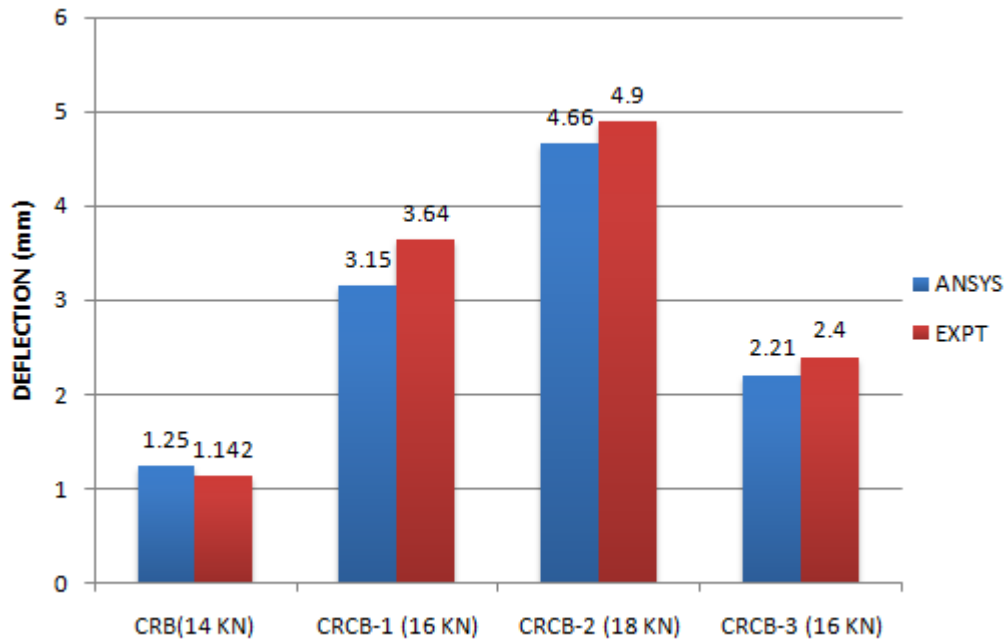


Fig 4.28: Comparison of Experimental and Analytical Results of CRB, CRCB-1, CRCB-2, and CRCB-3 of Deflection at Yield Point.

Table 4.5: Tabulation of Experimental and Analytical Results of CRB, CRCB-1, CRCB-2, and CRCB-3

S.NO	SPECIMEN	YIELD LOAD		% OF YIELD LOAD
		EXPERIMENTAL RESULTS	NUMERICAL RESULTS	
1	CRB	16.25	16.50	1.83% DECREASE IN LOAD
2	CRCB-1	18.50	18.25	3.15% DECREASE IN LOAD
3	CRCB-2	20.21	20.18	0.14% INCREASE IN LOAD
4	CRCB-3	18.61	18.23	2.04% INCREASE IN LOAD

4.13 DISCUSSION

In experimental and ANSYS results the yield state for CRB, CRCB-1, CRCB-2, CRCB-3 is obtained at 14 kN, 16 kN, 18 kN, 16 kN, respectively. Local buckling for CRB, CRCB-1, CRCB-2, CRCB-3 beams are obtained at 16 kN, 18 kN, 20 kN, 18 kN, respectively.

- The total deformation for CBCR-2 is maximum among all specimens. The local buckling was seen in top flange during plastic state for all specimen and CBCR-1 had more local buckling since load was applied above the holes.
- Local buckling at bottom flange was seen only during elastic state.
- Web crippling in all specimens was observed near the mid span during elastic state. All the 3 castellated beam (CRCB) behaviour is better than CRB.
- Among the castellated beams, CBCB-3 withstands higher load because of equal spacing and end pitch distance throughout the span. CRCB-1 and CRCB-3 have different end pitch hence they withstand load smaller than beam with CBCB-2.
- End pitch in castellated beam depends upon the required span.
- Comparing the ANSYS and experimental results the total deformation is 2% higher in experimental results.
- The maximum stress concentration is seen near the hexagonal perforations formed due to castellation in CRCB-1, CRCB-2, CRCB-3.
- Increase in depth of section increase the load bearing capacity and deformation as obtained in built-up I-section and built-up castellated beams.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY OF THE WORK

The Popularity Of Cold-Formed Steel (CFS) Sections In Construction Is Growing Due To Their Advantageous Characteristics. Increase In Depth Of Section Increase The Load Bearing Capacity And Deformation As Obtained In Built-Up I-Section And Built-Up Castellated Beams. Due To Easy Availability Of Cold Rolled Sheet Of Varying Sizes. The Beams Can Be Fabricated Into I-Sections With These Cold Rolled Sheets And Welded. Overall, The Study Suggests Promising Methods For Enhancing The Performance Of Castellated Beam In Construction.

5.2 CONCLUSION

- The structural performance of castellated beam is studied, and it is more evident that without increase in self weight of the structure the depth is increased. This savings effect depend on such factors as span, loading and depth requirements.
- From this analysis, it was observed that as the size of opening increases, stress concentrations increase at the hole corners.
- There is 2.04% increase in yield load in CRCB-3 compared to other castellated beam.
- The ductility in CRCB-3 is higher compared to other castellated beams.
- The results also confirm that the flexural stiffness of castellated beams varies as the size of opening increases.
- In order to save material and minimize the self-weight of the buildings, Castellated beams can be used for secondary beams
- . Finally, the performance and benefits of castellated beam is understood, and this will be used in generally construction practice to reduce the self-weight.

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