

EXPERIMENTAL & NUMERICAL INVESTIGATION OF COLD-FORMED STEEL ON CASTELLATED BEAMS

Submitted in partial fulfilment of the requirements for the award of
Master of Engineering Degree 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

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of Dhaarini S T (39380005) who carried out the project entitled "Experimental & Numerical Investigation of Cold-Formed Steel on Castellated Beams" under my supervision from November 2020 to April 2021

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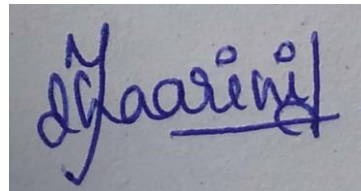
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DECLARATION

I Dhaarini S T hereby declare that the Project Report entitled "Experimental & Numerical Investigation of Cold-Formed Steel on Castellated Beams" done by me under the guidance of Mr. C. Manoj Kumaar at Sathyabama Institute of Science and Technology is submitted in partial fulfilment of the requirements for the award of Master of Engineering degree in Structural Engineering.

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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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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. In result of reduction of weight in the structures.

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.

1.2.1 *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.

1.2.2 Failure Modes of Castellated Beams:

Based beam geometry, web slenderness, hole opening, type of loading, and provision of lateral supports castellated beams undergo failure

The six different modes of failure of castellated beams are,

1. Vierendeel or Shear Mechanism
2. Flexural Mechanism
3. Lateral-Torsional Buckling
4. Rupture of Welded Joints
5. Web Post buckling
6. Web Post Buckling Due to Compression

Researchers study about these six different failure modes of castellated beam.

1.2.2.1 Vierendeel or Shear Mechanism:

Vierendeel or Shear failure is due to higher shear forces acting on the beam. Primary and secondary moments are developed in the two halves of the castellated beams when the beam is subjected to high shear forces. The primary moment is the conventional bending moment on the beam cross-section. The secondary moment, also known as the Vierendeel moment.

These moments lead to formation of plastic hinges at the corners of the holes. This plastic hinge changes the shape of the hole. Therefore, as the horizontal length of the opening decreases, the magnitude of the secondary moment will decrease. This failure mode is more for the beams with relatively short spans and long weld. For heavier shear forces the area around the hole develops more moment and beam becomes critical.

1.2.2.2 Flexural Mechanism:

This failure is occurred in beam due to pure bending. This failure occurs generally in solid beam also. The two halves develop tension and compression until they become plastic. The maximum in-plane carrying capacity of a castellated beam under pure moment loading was determined to be $M_p = Z' \times F_y$; where Z' is the full section plastic modulus taken through the vertical center line of a hole.

1.2.2.3 Lateral-Torsional Buckling:

Buckling is common failure in longer span beams. Torsional buckling occurs at the web of the beam. When lateral supports are inadequate in compression flange of the beam it tends for lateral torsional buckling. The reduced torsional stiffness of the web decreases the slender section properties which again causes this buckling failure.

1.2.2.4 Rupture of Welded Joints:

Castellated beams are welded for joining the two halves of the beam. Welding provides cent percent strength efficiency for the beam. When the welding joint length is more and when the horizontal shear stress developed in web exceed the yield strength of the weld leads to rupture of the weld at the web. This decreases the strength of the beam. To overcome this failure proper weld design should be carried out. The length of the welded joint is the main factor for this failure.

1.2.2.5 Web Post buckling:

In the opening of the castellated beam, at one inclined edge tension is developed and other include edge compression is developed under horizontal shear force. Due to this a double curvature bending over the height of the section is developed. Thus, a twisting effect at the web along the height is developed is the web post buckling. To overcome this failure the inclined edge degree can be reduced.

1.2.2.6 Web Post Buckling Due to Compression:

Buckling of the web post under large compression forces may even be due to shearing forces. Twisting alone cannot be the reason for buckling. This failure occurs when concentrated load is applied directly over a web-post. To overcome this failure mode adequate web reinforcing stiffeners can be provided.



Fig 1.1: Castellated Beam

1.3 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	%

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 LITERATURE REVIEW

D. Kerdal et al. (1984) conducted study on “Failure Modes for Castellated Beams”, in this study he studies about the failure modes of the beam experimentally and analytically. He considered plain webbed beams of castellated beams under shear stress. The failure modes like flexure mechanism and lateral torsional buckling occurred as it occurs in general solid beam. Virendeel mechanism, weld rupture and web post buckling behaviour were observed and studied. No appropriate results were obtained for web post buckling failure due to compression. He concluded that when the shear is dominant in the beam this failure modes are occurred.

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.

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 behavior 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 that castellated beam with circular openings.

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.

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.

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.

A. Aglan et al. (1974) conducted study on “Web buckling in castellated beams”, He studied about the the web buckling failure mode in castellated beams. Generally, this web buckling in castellated beam occurs when the shear stress is maximum. Thus, a castellated beam is modelled, and finite element analysis is made in ANSYS software and studied their buckling behaviour. The stress-strain curve of the material of the post is considered ideally elasto-plastic strain hardening was also studied. In relation with critical load and ultimate capacity of the castellated beam a simple approximation was given and results of several tests on castellated beams was compared to know in which beam failure occurred due to critical loads. He finally concluded that the castellated beam performs good when it carries a uniformly distributed load.

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.

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.

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

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.

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.

CHAPTER 3

AIM AND SCOPE OF STUDY

3.1 AIM

To study and determine the behaviour of built up I beam and Castellated beams experimentally and analytically.

3.2 STUDY OF WORK

In this work castellated beams are fabricated with cold rolled sheet and analysed. Totally 4 beams are fabricated and analysed, 1 normal I-Section beam and 3 Castellated beams are manufactured from that I section beam with variation in number of holes.

3.3 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.

3.4 SCOPE OF WORK

- The build-up I beam, and castellated beams will be validated by the finite element model using ANSYS software.
- The stress distribution, total deformation results will be obtained from the ANSYS software
- Experimental tested is conducted.

3.5 NOVELTY OF WORK

- Perforation is achieved by Castellation.
- Material used is Cold Rolled Steel Sheet.
- CR Sheet is fabricated into I-section.

3.6 NEED FOR STUDY

- Perforations in the web of the cold formed steel sections were made to accommodate many services like plumbing, electrical cables and wires, heating etc.
- The increase in depth of section will increase the moment bearing capacity.
- Cost effective.
- Weight is reduced

3.7 METHODOLOGY

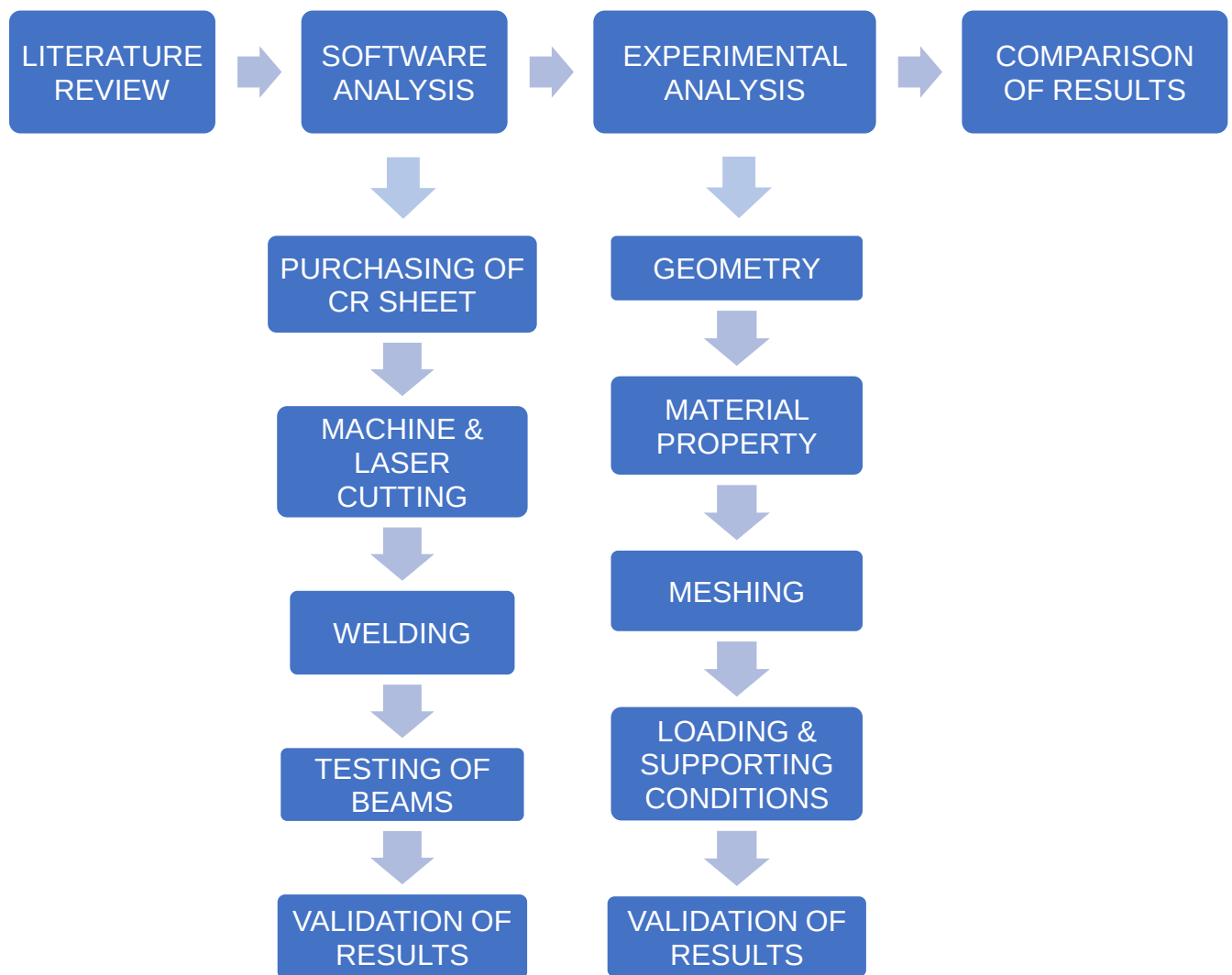


Fig 3.1: Methodology Flow Chart

CHAPTER 4

SPECIMEN SET UP

4.1 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 and depth 250mm. The 3 castellated beam CRCB-1, CRCB-2, CRCB-3 the opening dimension details are shown in Fig 4.1. The end distance for the beam is altered to attain 1300mm span. These castellated beams are compared with Buildup 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 4.1.

Table 4.1: 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
Spacing (s)	mm	-	150	100	75
End pitch (e)	mm	-	125	100	62.5
Number of openings		-	3	4	5

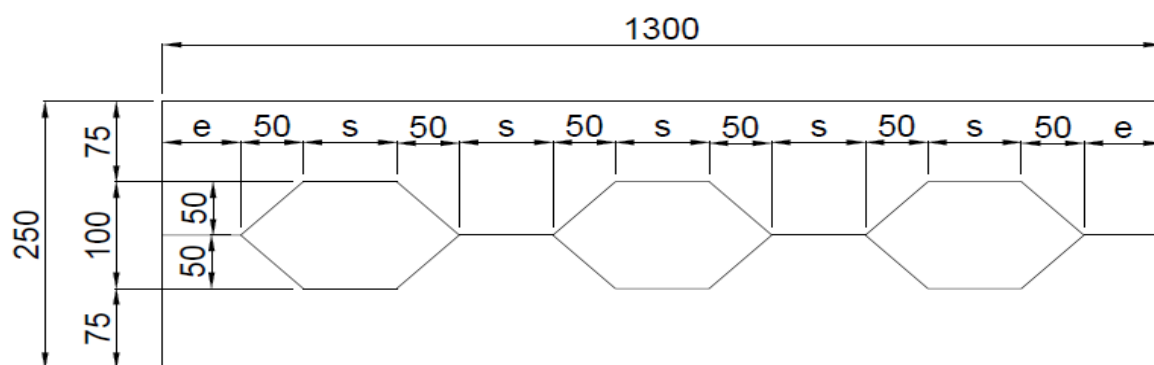


Fig 4.1: Dimensions Details of Perforations

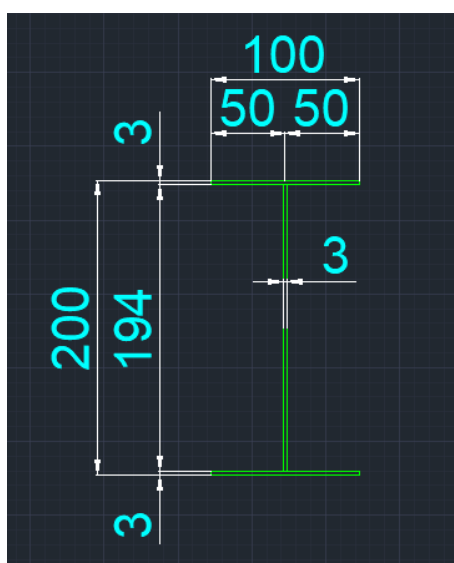


Fig 4.2: Dimensions Details of CRB (Side View)

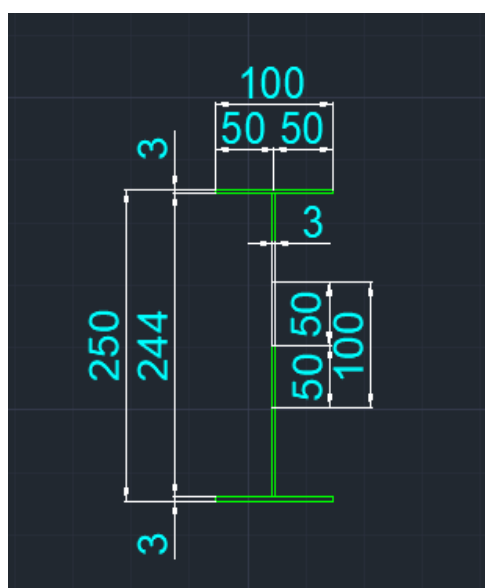


Fig 4.3: Dimensions Details of Castellated beams (Side View)

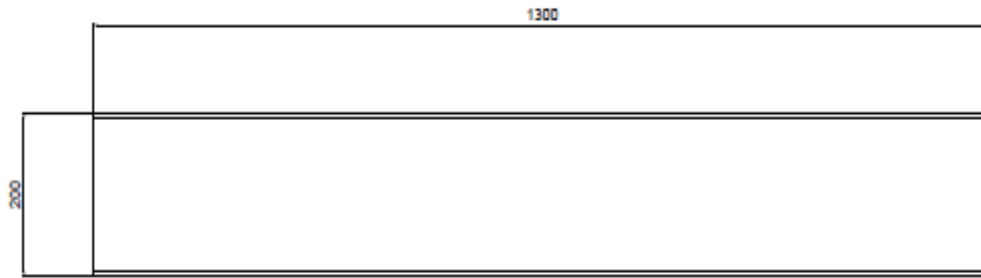


Fig 4.4: Dimensions Details of CRB

4.2 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 250mm.

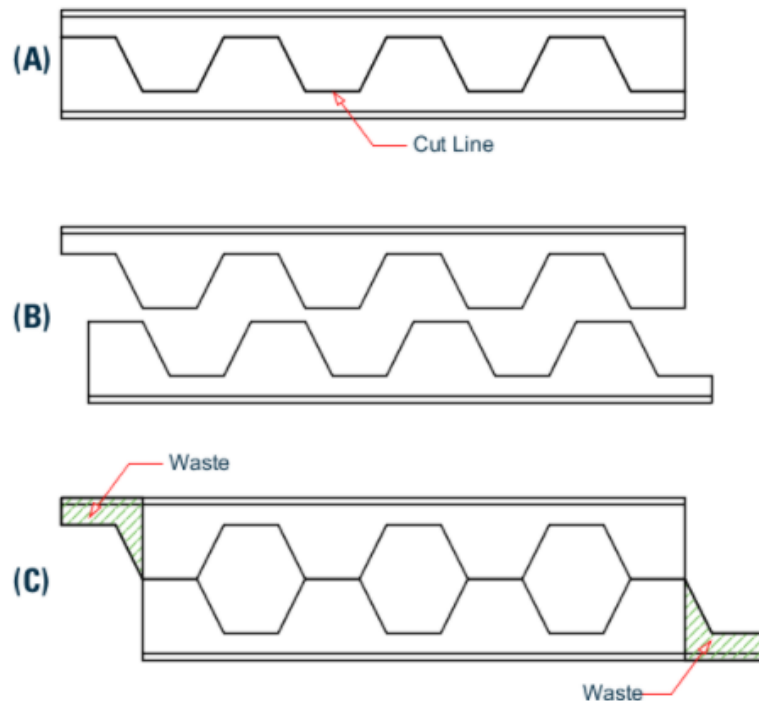


Fig 4.5: Method of Castellation

4.2.1 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. Finally, after castellation CRCB-1 beam is of depth 250mm and span 1300mm.

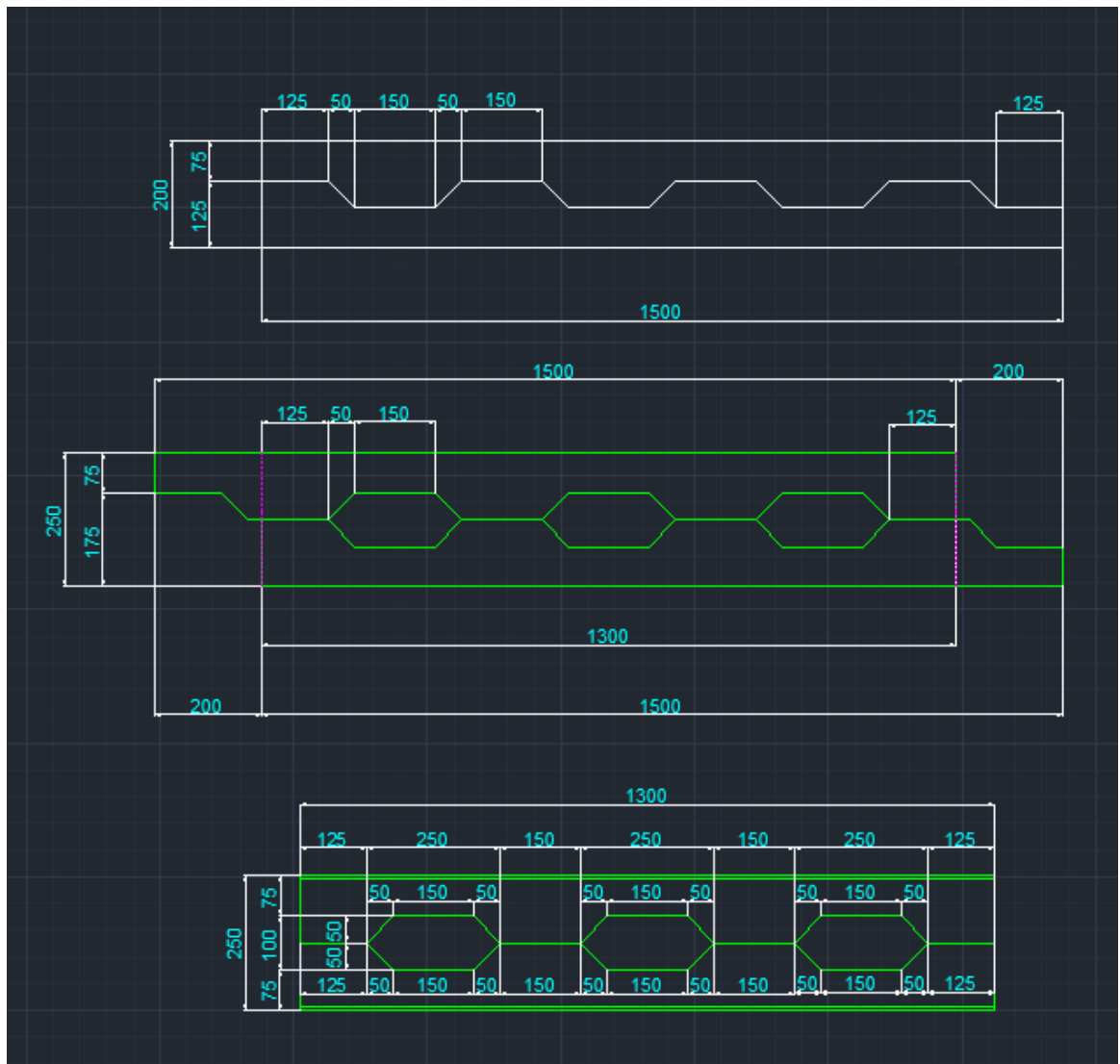


Fig 4.6: Method of Castellation of CRCB-1

4.2.2 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. Finally, after castellation CRCB-2 beam is of depth 250mm and span 1300mm.

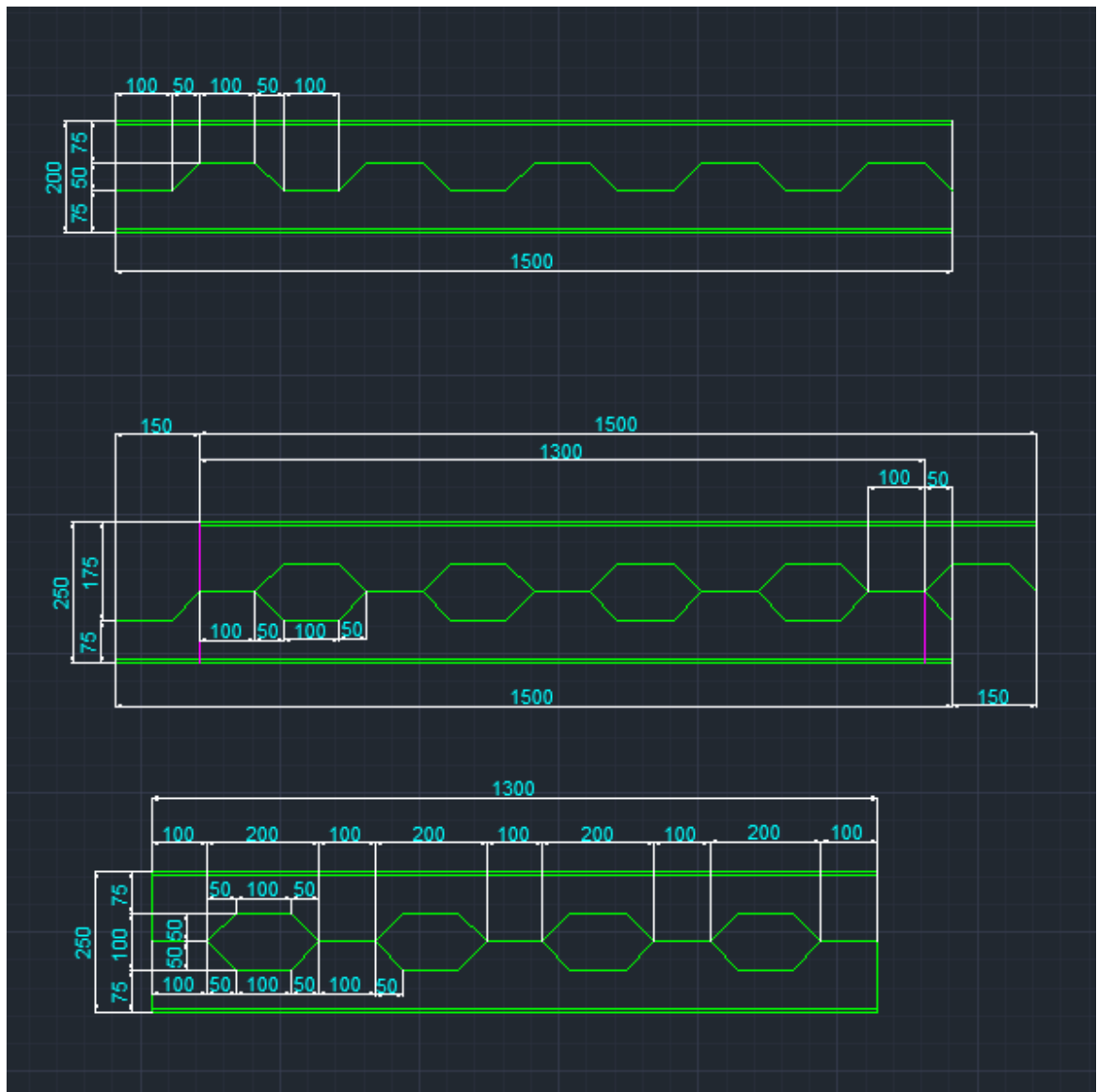


Fig 4.7: Method of Castellation of CRCB-2

4.2.3 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. Finally, after castellation CRCB-2 beam is of depth 250mm and span 1300mm.

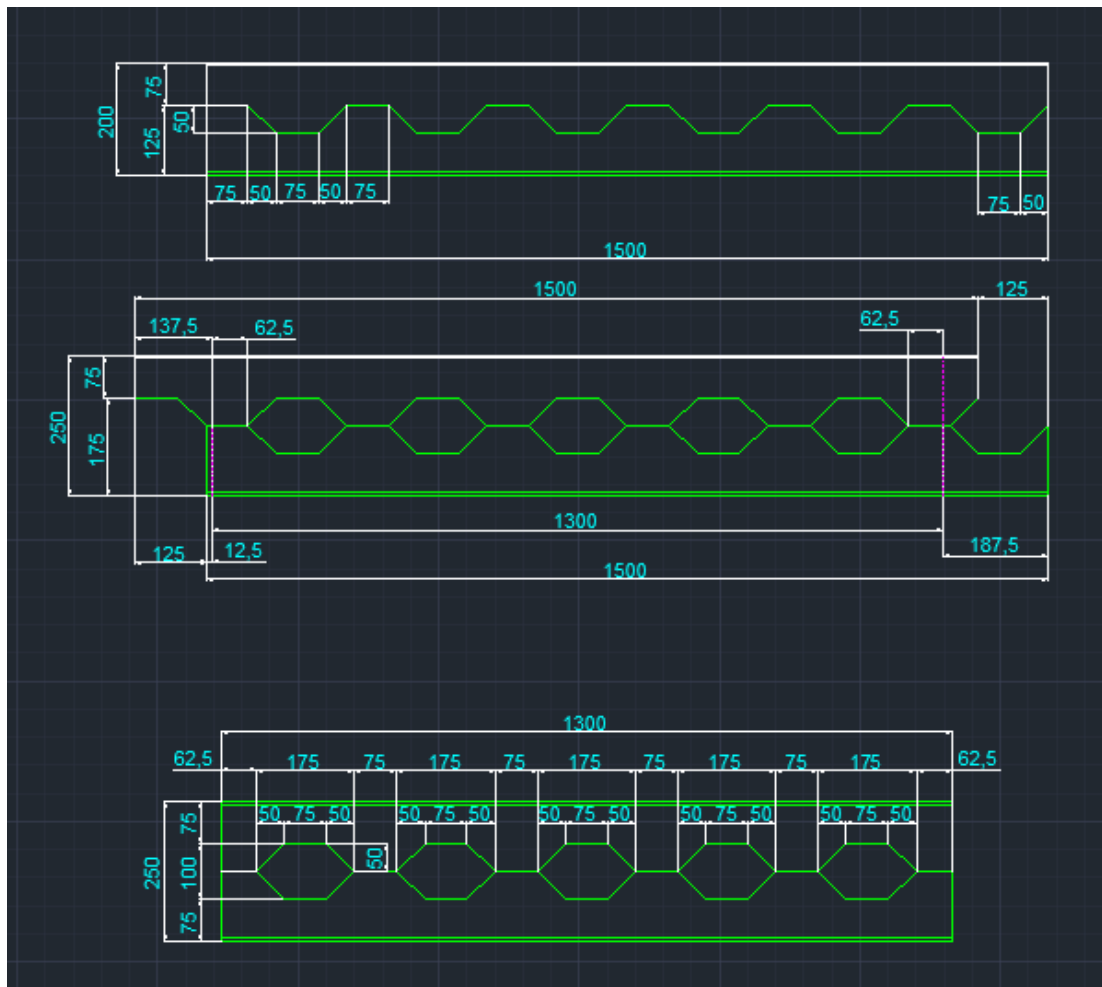


Fig 4.8: Method of Castellation of CRCB-3

4.3 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 shows the four-point flexure test set up of the specimen.

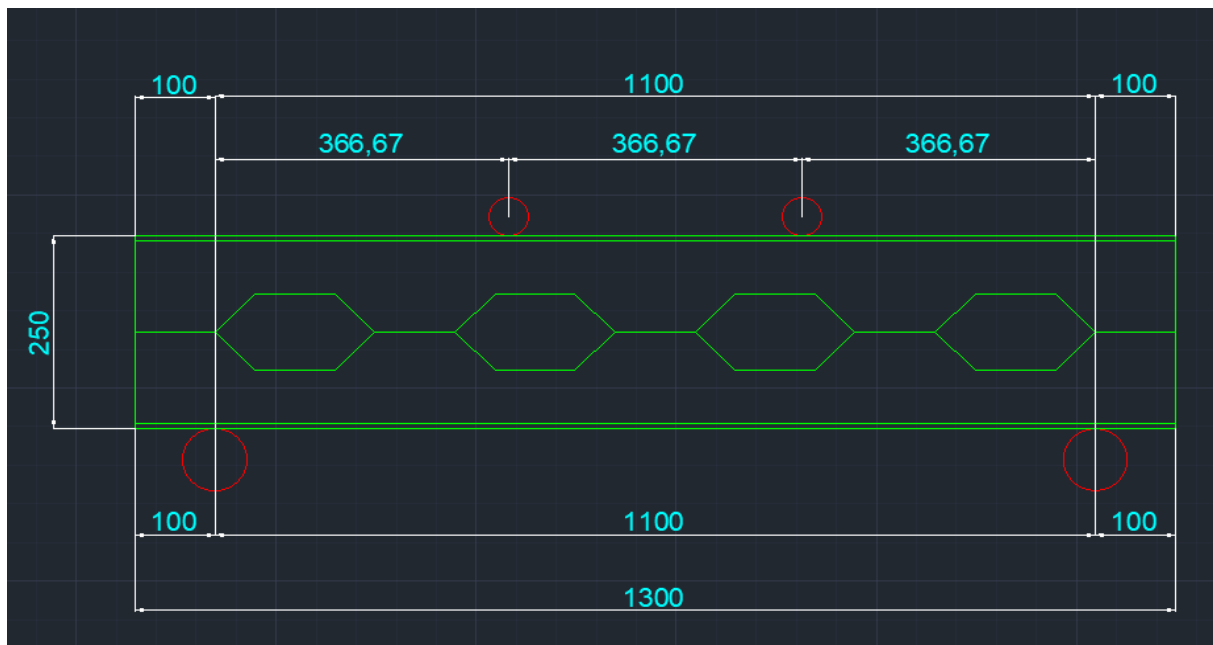


Fig 4.9: Loading Set-up

CHAPTER 5

ANALYTICAL PROCEDURE

5.1 INTRODUCTION

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 2020 Workbench and their behaviour is studied.

5.2 METHODOLOGY

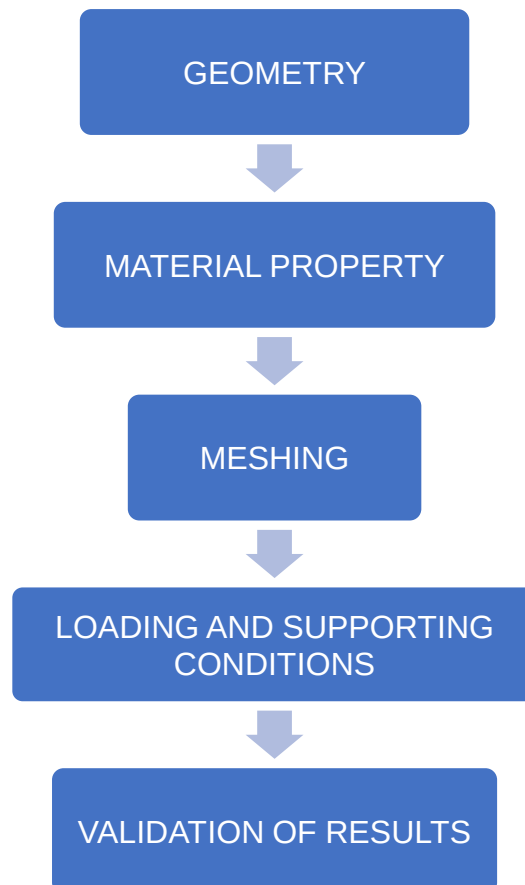


Fig 5.1: Software Analysis Methodology

5.3 GEOMETRY

Geometry of specimen CRB, CRCB-1, CRCB-2 and CRCB-3 is modelled in CATIA and imported to ANSYS, Design modeler. The Fig 5.2, 5.3, 5.4 and 5.5 shows the geometry of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.

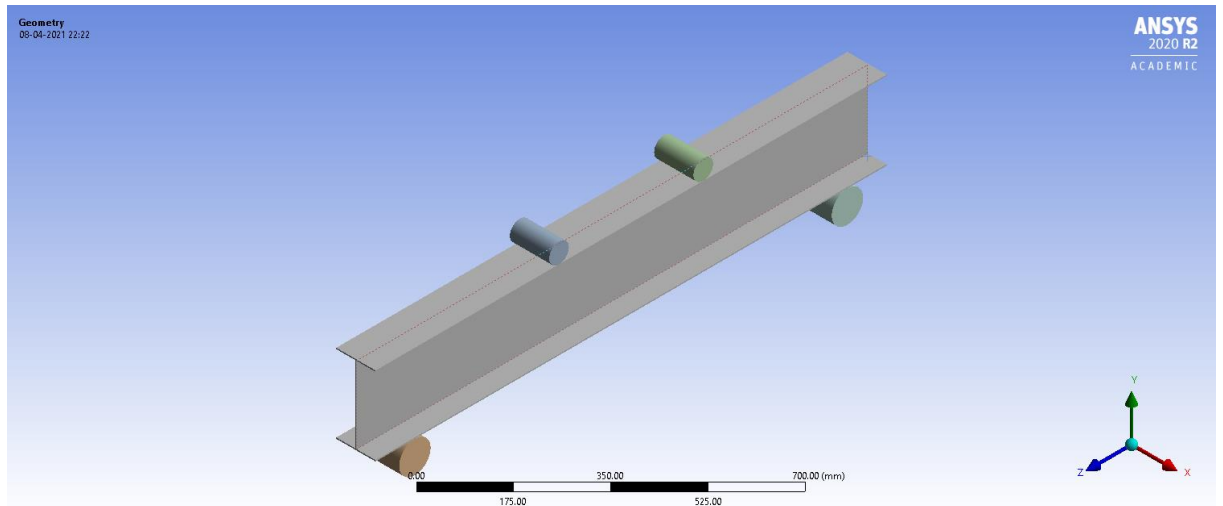


Fig 5.2: Geometry of CRB

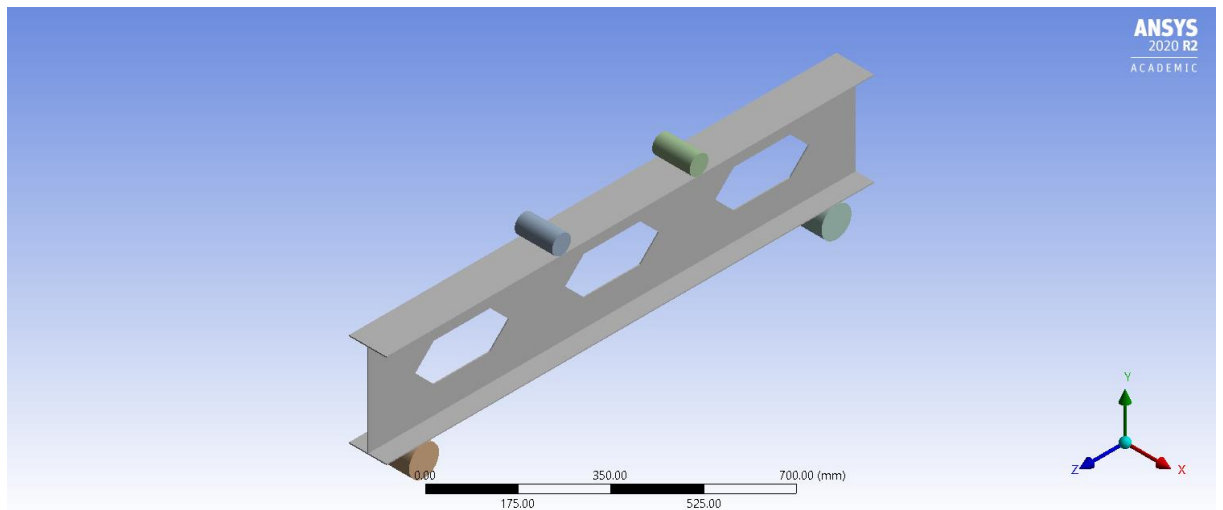


Fig 5.3: Geometry of CRCB-1

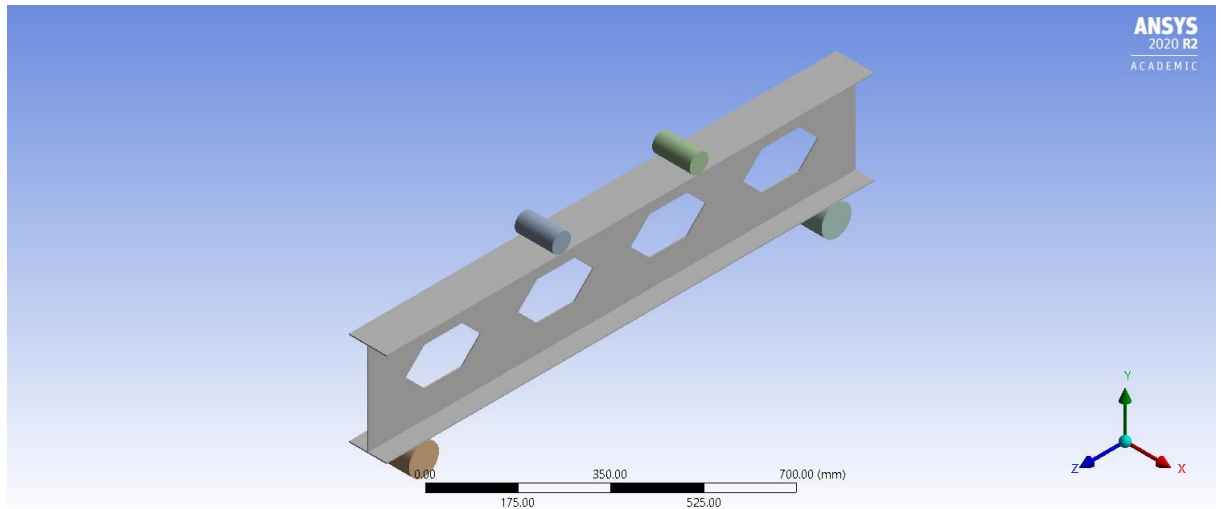


Fig 5.4: Geometry of CRCB-2

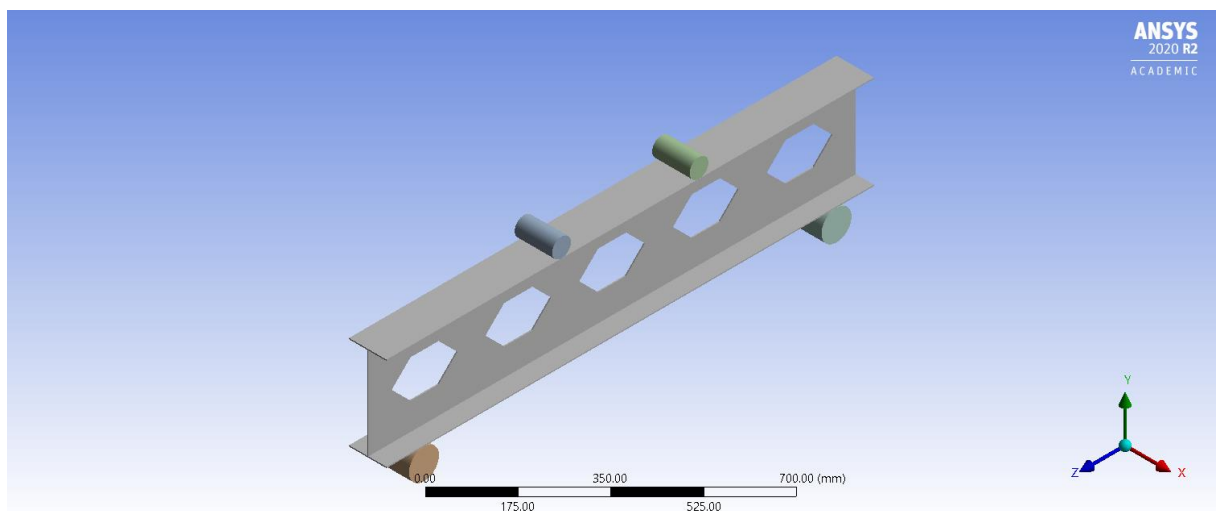


Fig 5.5: Geometry of CRCB-3

5.4 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 5.6 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	

Figure 5.6: Material Property for CR Sheet

5.5 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 5.7, 5.8, 5.9 and 5.10 shows the meshing of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.

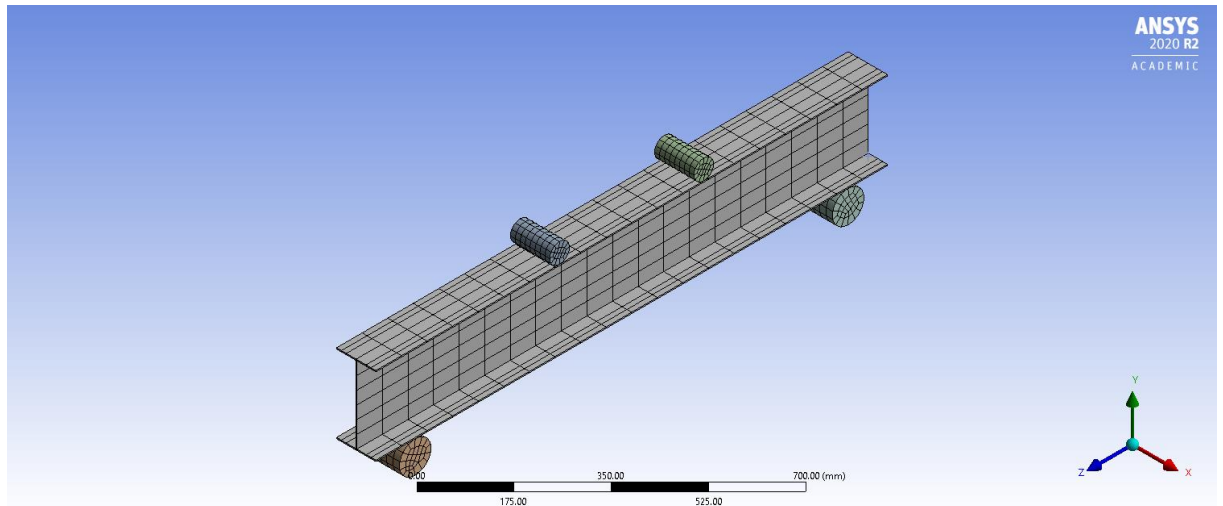


Fig 5.7: Meshing Details of CRB

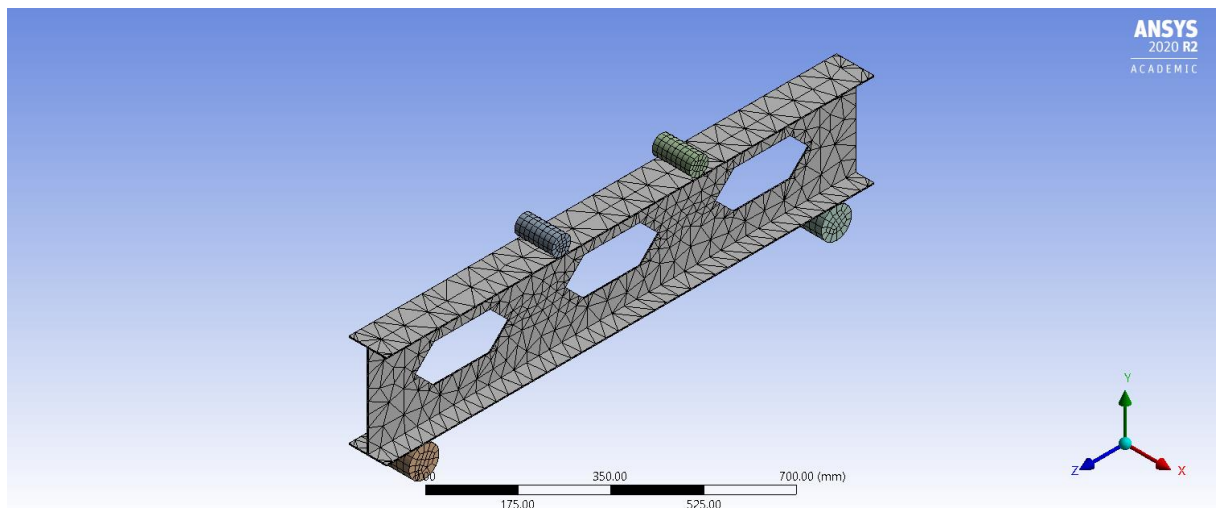


Fig 5.8: Meshing Details of CRCB-1

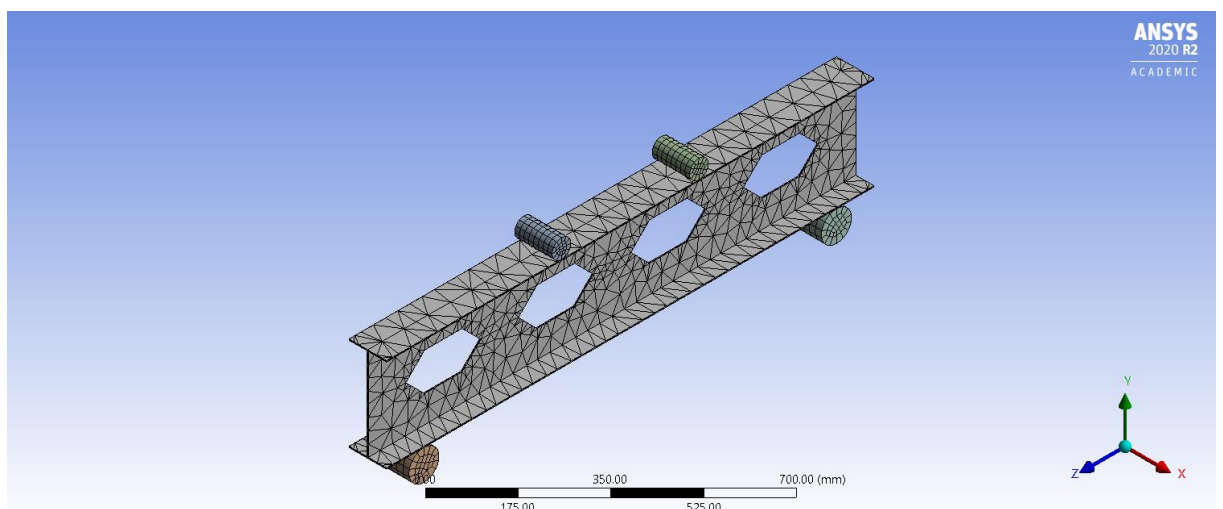


Fig 5.9: Meshing Details of CRCB-2

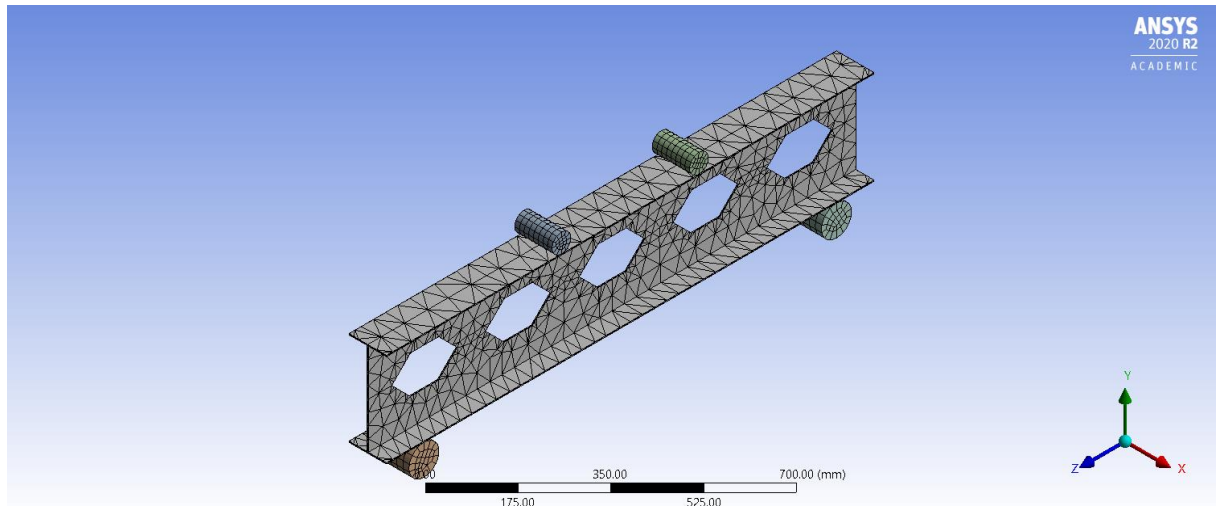


Figure 5.10: Meshing Details of CRCB-3

5.6 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 5.11 shows the loading and support conditions for CRB and this is also similar for all CRCB-1, CRCB-2, and CRCB-3.

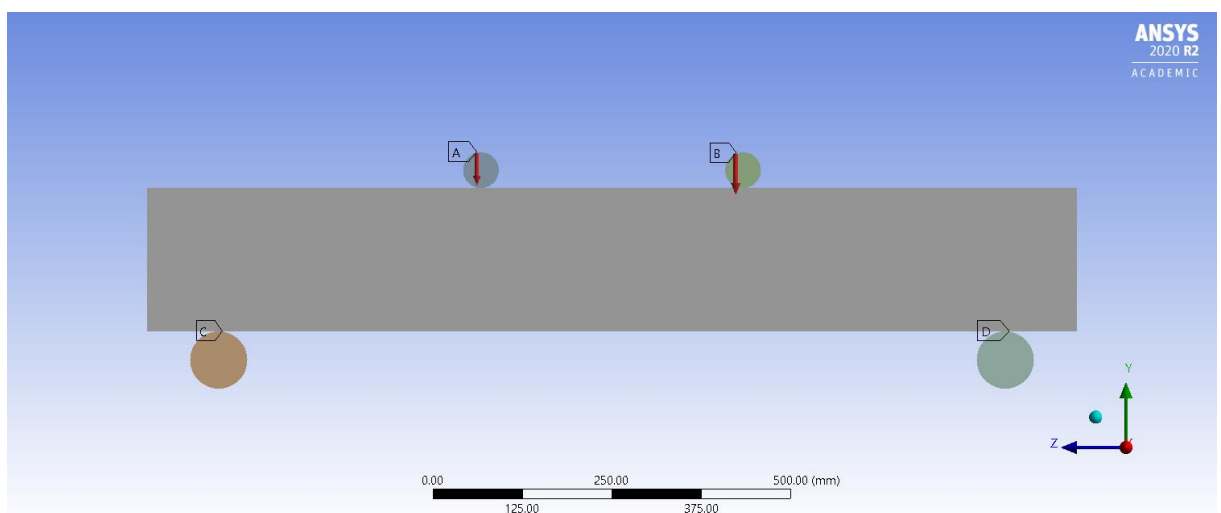


Fig 5.11: Loading Conditions

5.7 VALIDATION OF RESULTS

5.7.1 Total Deformation

The Total deformation of the beam is calculated for the gradually increasing load of 2 KN. The Fig 5.12, 5.13, 5.14 and 5.15 shows the maximum total deformation of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.

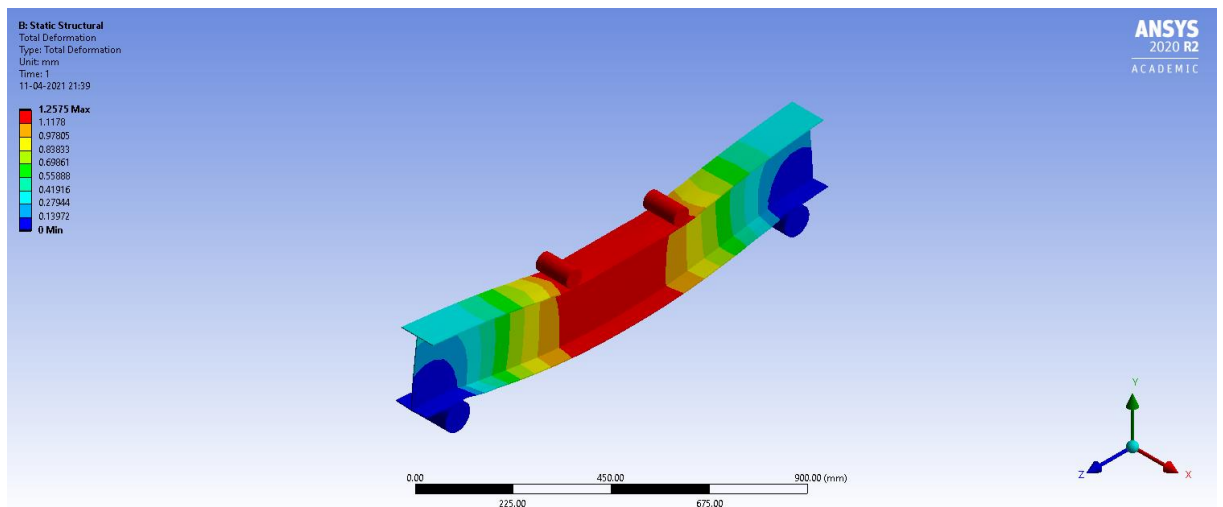


Fig 5.12: Total Deformation of CRB

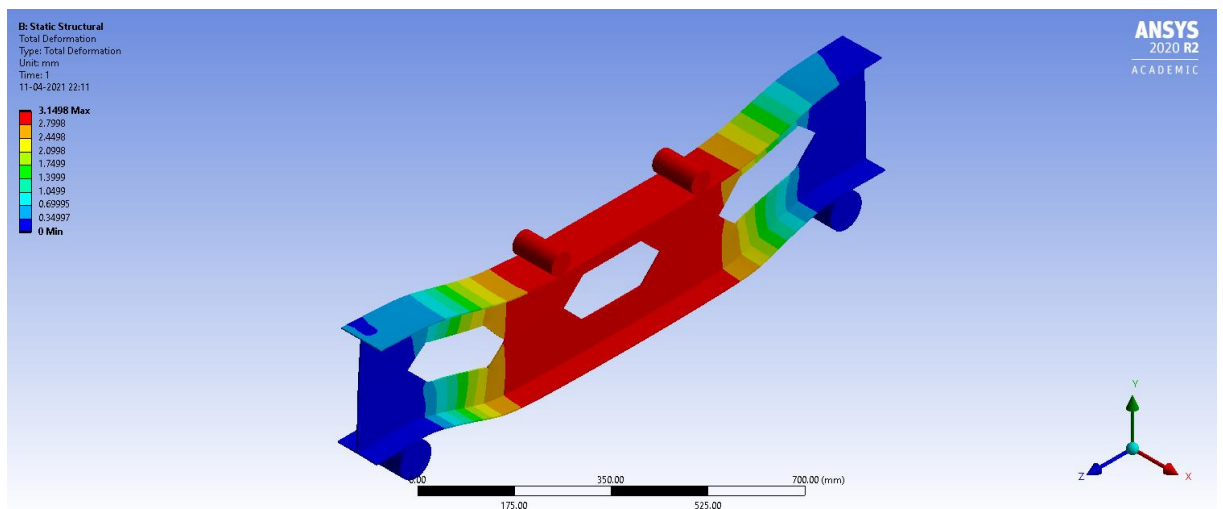


Fig 5.13: Total Deformation of CRCB-1

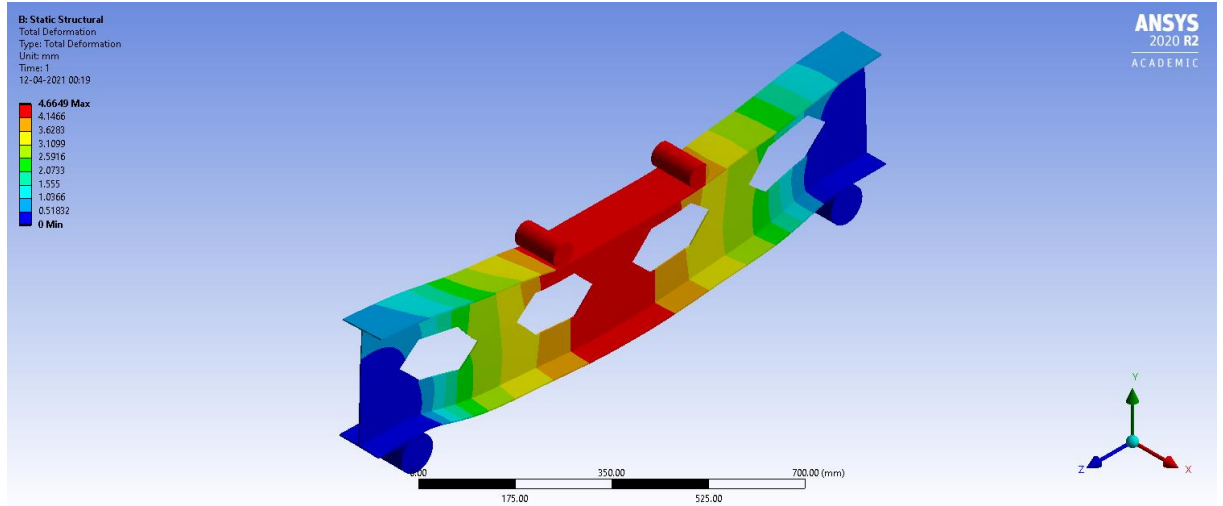


Fig 5.14: Total Deformation of CRCB-2

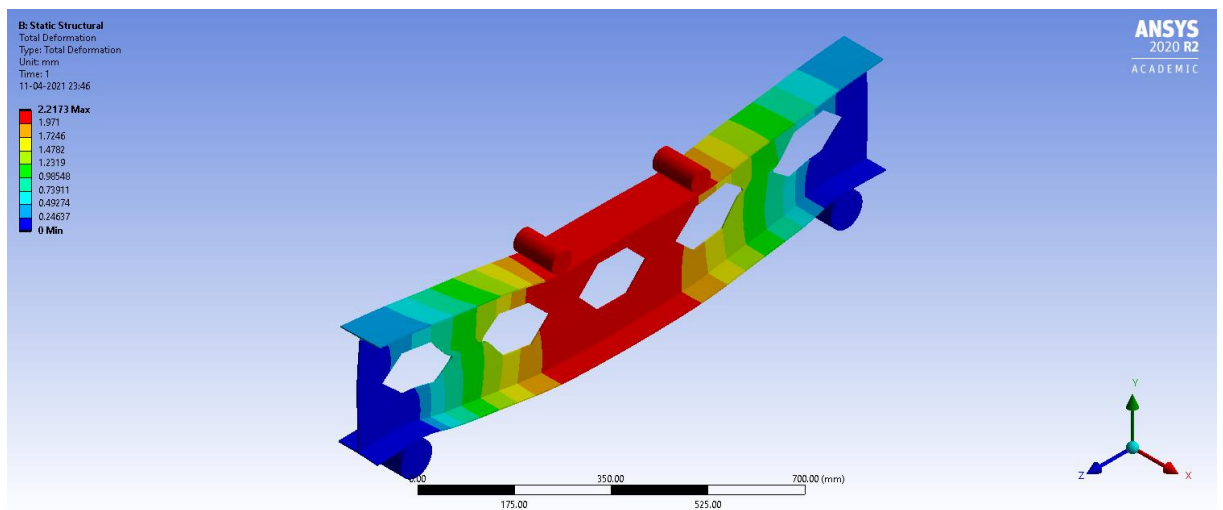


Fig 5.15: Total Deformation of CRCB-3

5.7.2 Equivalent stress (von mises)

The Equivalent stress (von mises) of the beam is calculated for the load at the yield point. The Fig 5.16, 5.17, 5.18 and 5.19 shows the Stress concentration of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.

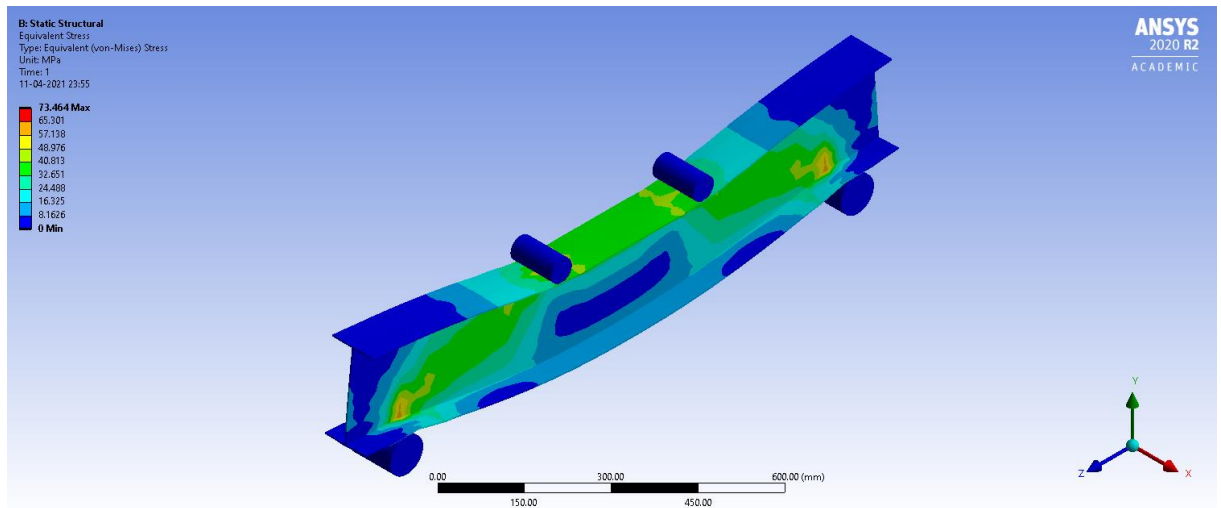


Fig 5.16: Stress Concentration of CRB

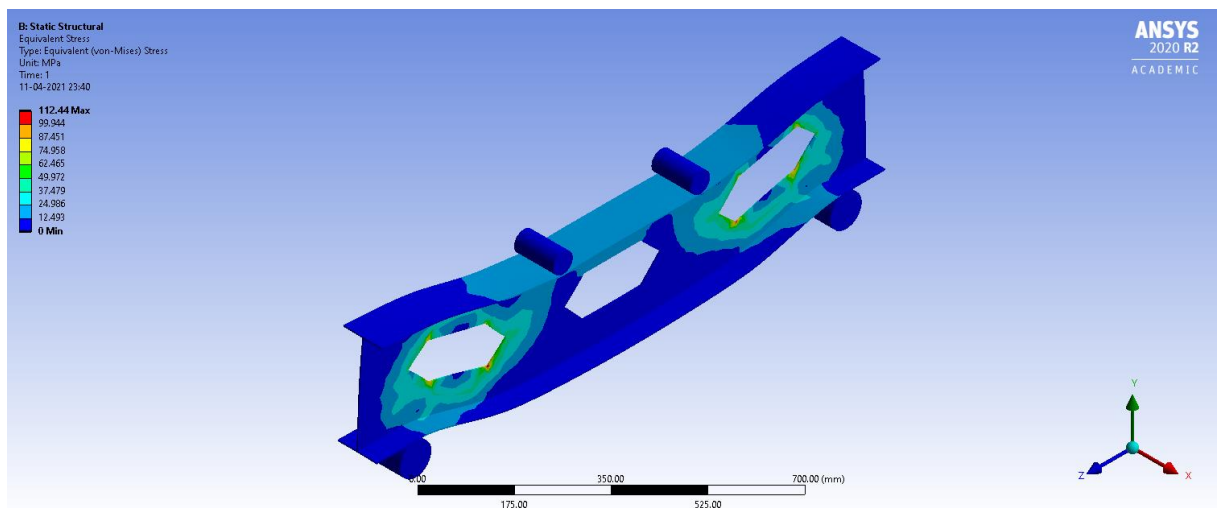


Fig 5.17: Stress Concentration of CRCB-1

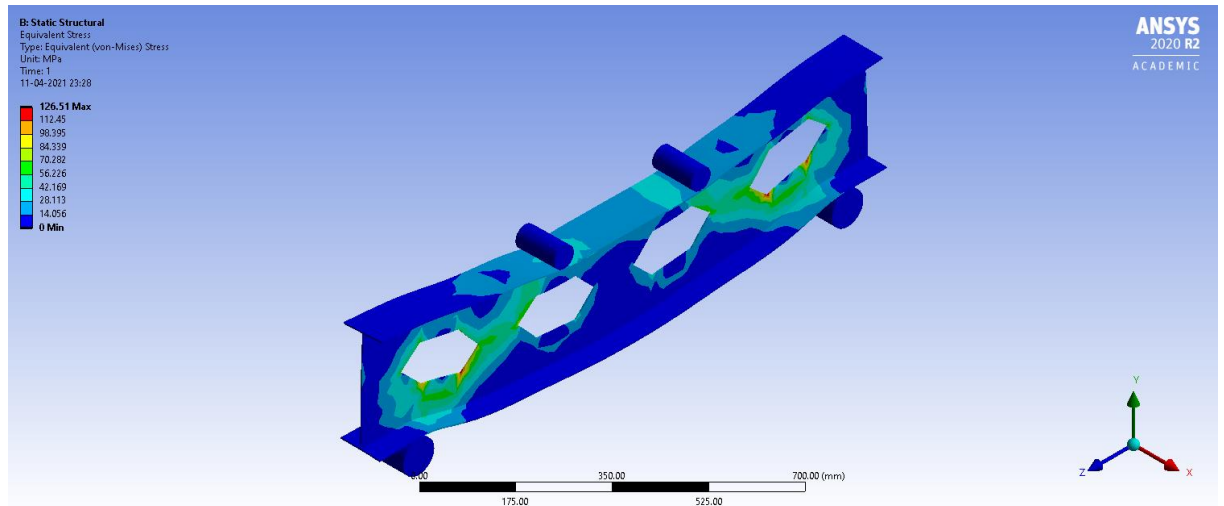


Fig 5.18: Stress Concentration of CRCB-2

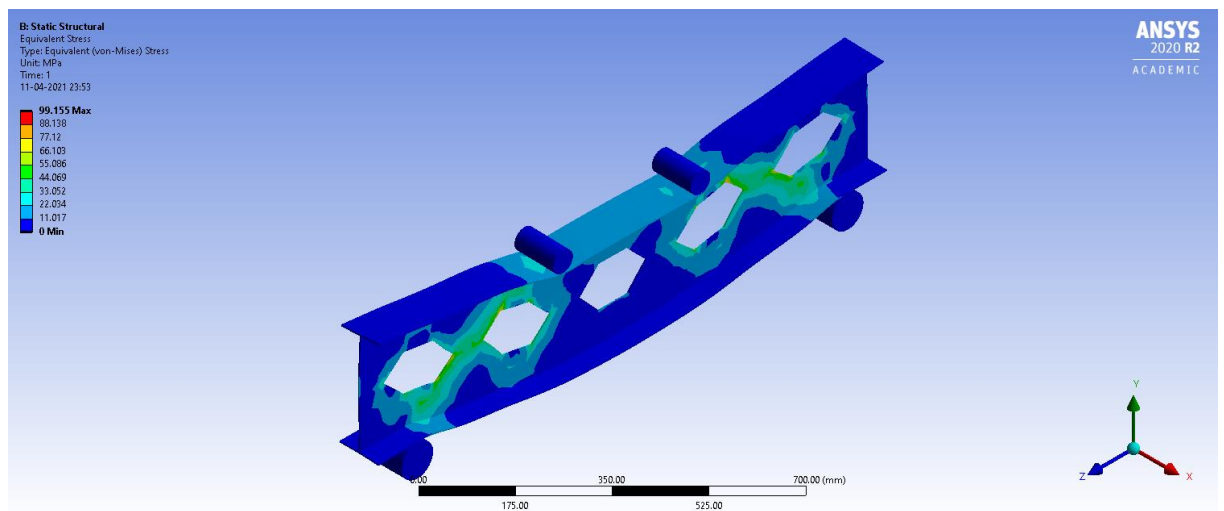


Fig 5.19: Stress Concentration of CRCB-3

CHAPTER 6

EXPERIMENTAL PROCEDURE

6.1 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.

6.2 METHODOLOGY

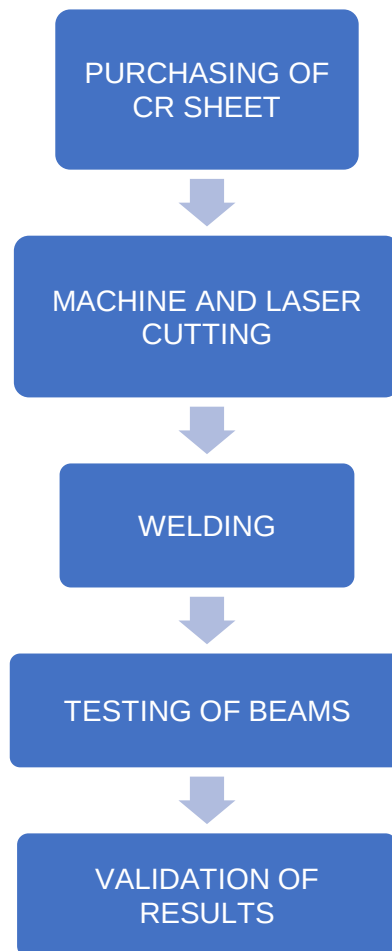


Fig 6.1: Experimental Analysis Methodology

6.3 PURCHASING OF 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 6.2 shows the cold rolled sheet of 3mm thickness of grade IS 513 CR2.



Fig 6.2: CR Sheet of 3mm thickness Grade IS 513 CR2

6.4 MACHINE AND LASER CUTTING

6.4.1 Machine Cutting

In CR sheet the straight cutting is done using machine cutting. The Fig 6.3 shows the machine cutting of CR sheet. The Fig 6.4 shows the output of CR sheet after machine cutting.

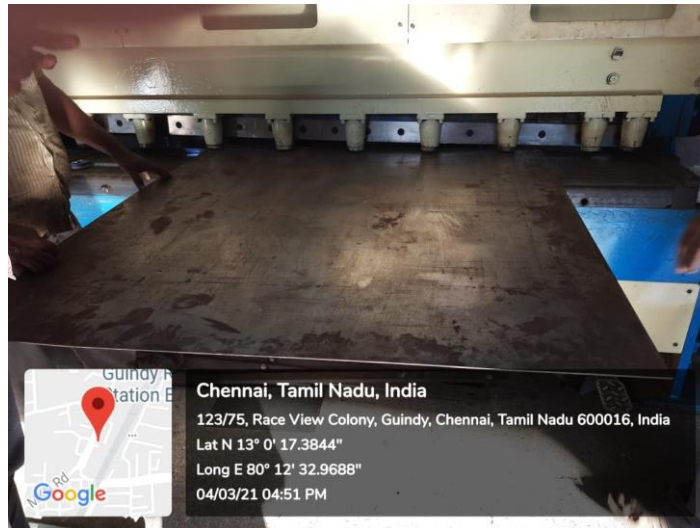


Fig 6.3: Machine Cutting of CR Sheet



Fig 6.4: Flange and Web CR Sheet

6.4.2 Laser Cutting

In CR sheet the zig zag cutting is done using laser cutting machine. The Fig 6.5 shows the laser cutting of CR sheet.



Fig 6.5: Laser Cutting of CR Sheet

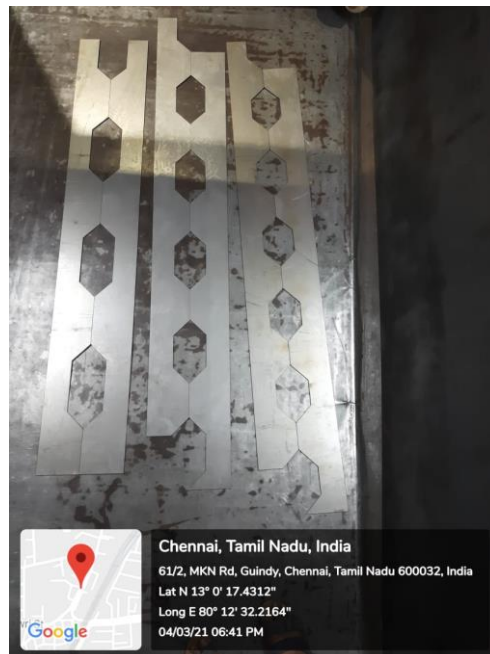


Fig 6.6: Web after Laser Cutting of CR Sheet

6.5 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. The Fig 6.7 shows the typical detail of fillet weld.

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.

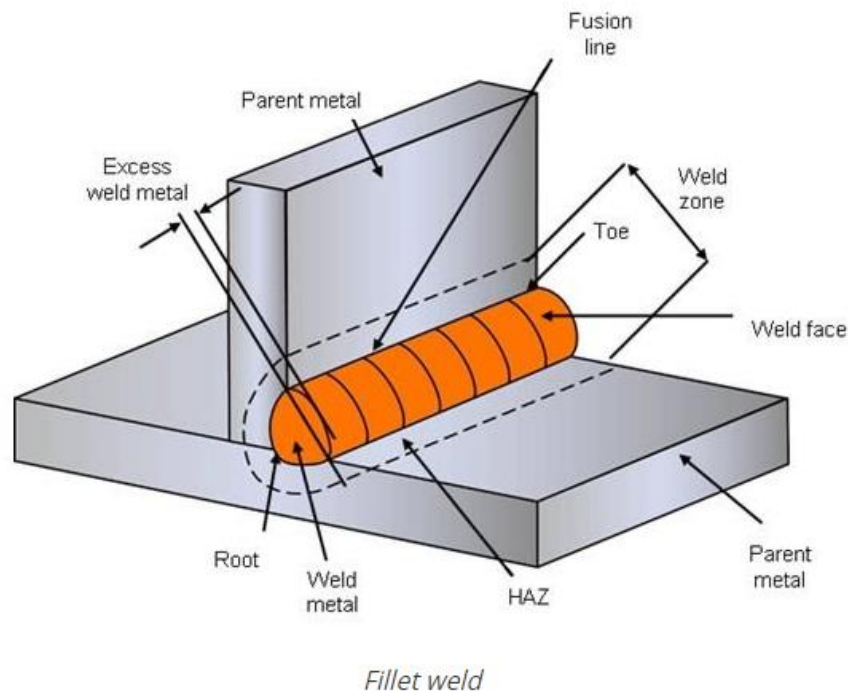


Fig 6.7: Typical Detail of Fillet Weld

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 6.8 shows the painted fabricated beams.



Fig 6.8: Arc Welding of Beams



Fig 6.9: Fabricated Beams

6.6 TESTING OF BEAMS

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 three-dial gauge are placed below the beam in equal distance 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 6.10, 6.11, 6.12 and 6.13 shows the experimental set up of the CRB, CRCB-1, CRCB-2, and CRCB-3, respectively.



Fig 6.10: Testing Set-Up of CRB

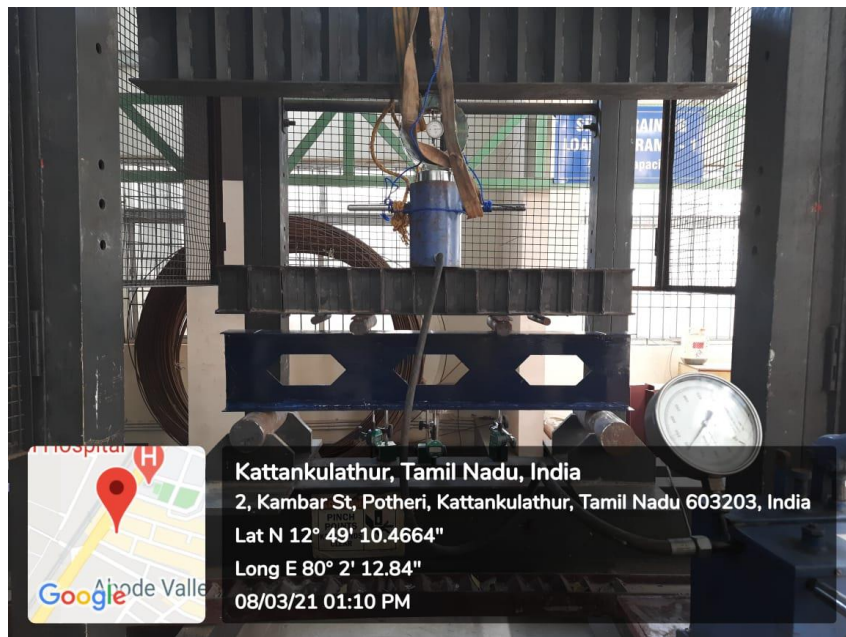


Fig 6.11: Testing Set-Up of CRCB-1

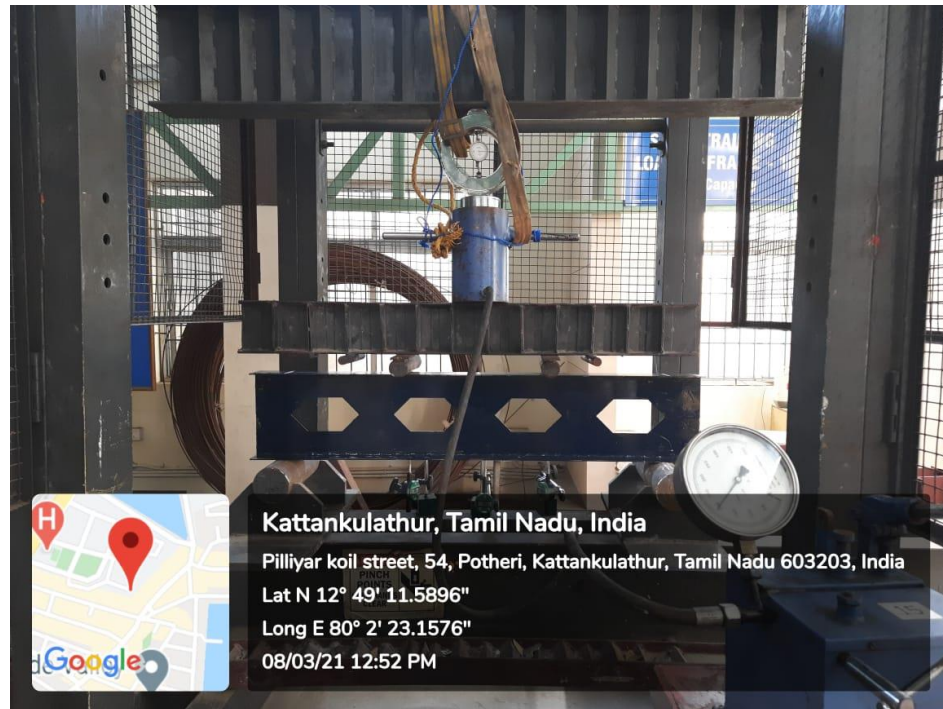


Fig 6.12: Testing Set-Up of CRCB-2

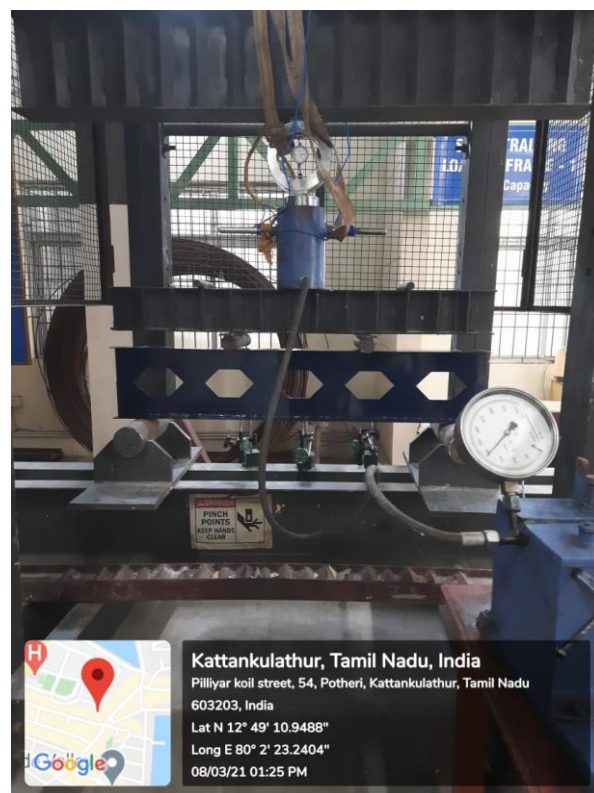


Fig 6.13: Testing Set-Up of CRCB-3

6.7 VALIDATION OF RESULTS

On gradually application of load the deformation of the beam is calculated from the average value obtained from the three dial gauges.

6.7.1 CRB

From the results obtained in CRB, the yield point is obtained at 14KN. Fig 6.14 and 6.15 shows the Yield point of CRB and local buckling of CRB, respectively.



Fig 6.14: At Yield point of CRB



Fig 6.15: Local Buckling of CRB

6.7.2 CRCB-1

From the results obtained in CRCB-1, the yield point is obtained at 16KN. Fig 6.16 and 6.17 shows the Yield point of CRCB-1 and local buckling of CRCB-1, respectively.



Fig 6.16: At Yield point of CRCB-1



Fig 6.17: Local Buckling of CRCB-1

6.7.3 CRCB-2

From results obtained in CRCB-2, the yield point is obtained at 18KN. Fig 6.18 and 6.19 shows the Yield point of CRCB-2 and local buckling of CRCB-2, respectively.



Fig 6.18: At Yield point of CRCB-2



Fig 6.19: Local Buckling of CRCB-2

6.7.4 CRCB-3

From the results obtained in CRCB-3, the yield point is obtained at 16KN. Fig 6.20 and 6.21 shows the Yield point of CRCB-3 and local buckling of CRCB-3, respectively.



Fig 6.20: At Yield point of CRCB-3

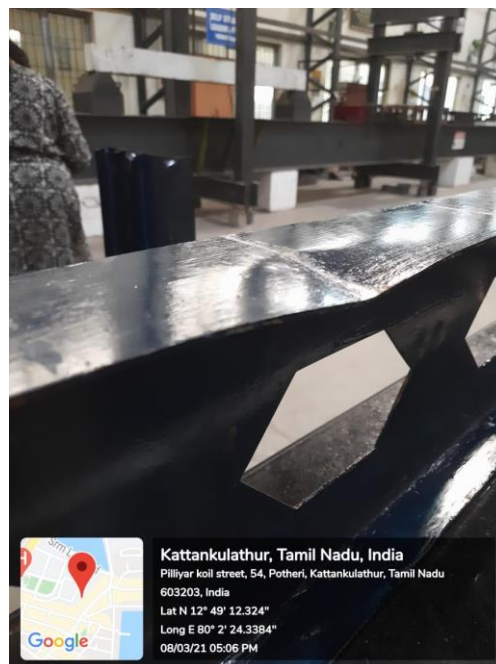


Fig 6.21: Local Buckling of CRCB-3

CHAPTER 7

RESULTS AND DISCUSSION

7.1 ANSYS RESULTS

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 7.1. The maximum deflection is seen in CRCB-2.

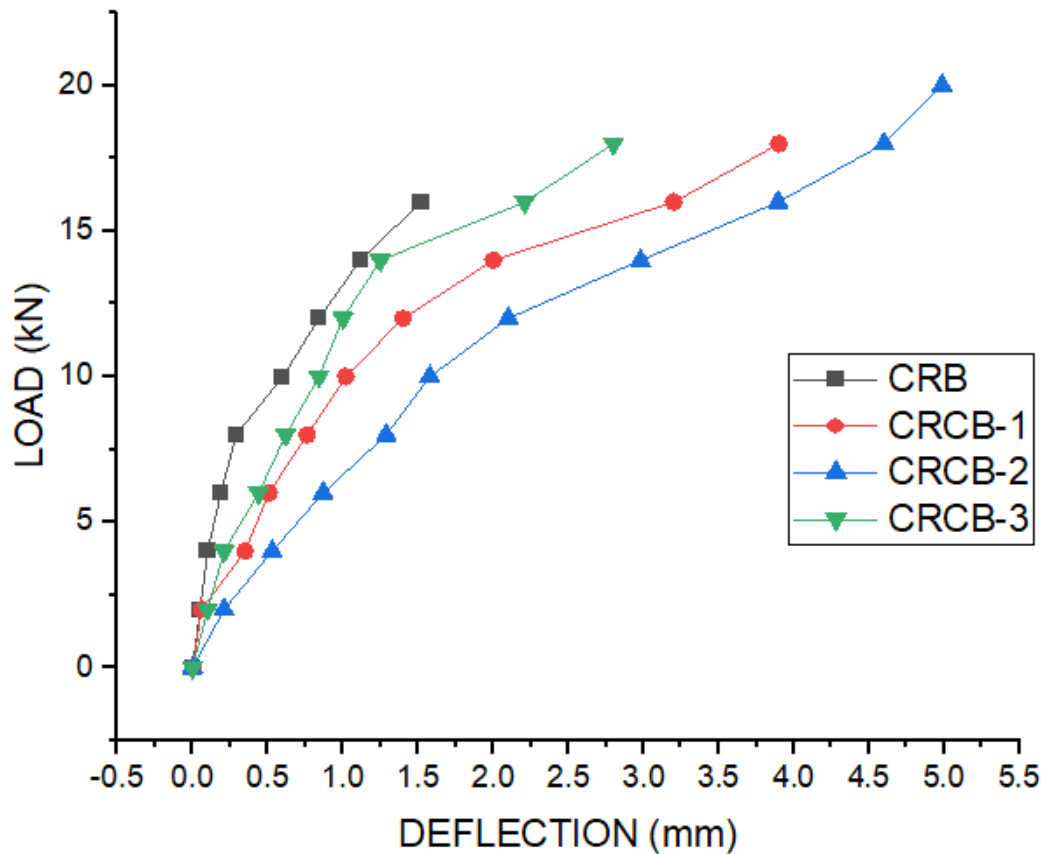


Fig 7.1: Comparison of Analytical Results of CRB, CRCB-1, CRCB-2 and CRCB-3

7.2 EXPERIMENTAL RESULTS

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 7.2. The maximum deflection is seen in CRCB-2.

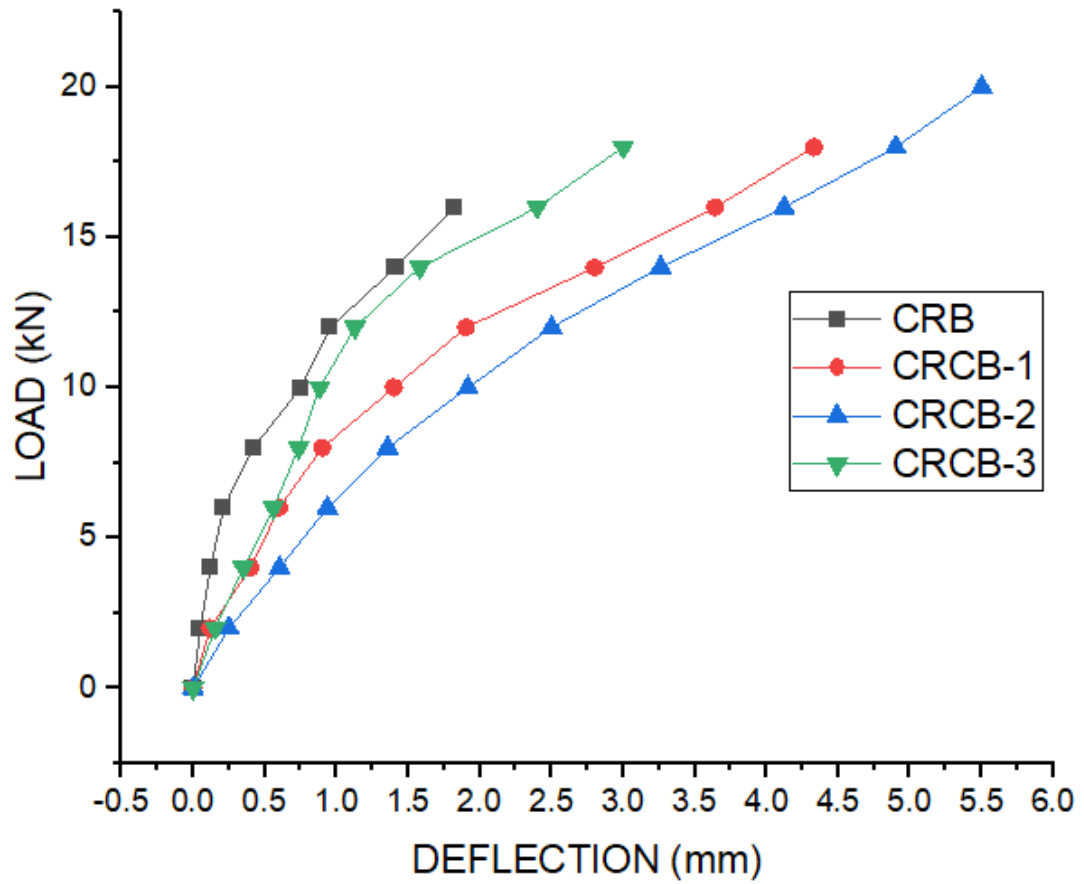


Fig 7.2: Comparison of Experimental Results of CRB, CRCB-1, CRCB-2, and CRCB-3

7.3 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 7.3. The total deformation comparison between ANSYS and Experiment at its yield point is shown in Fig 7.4.

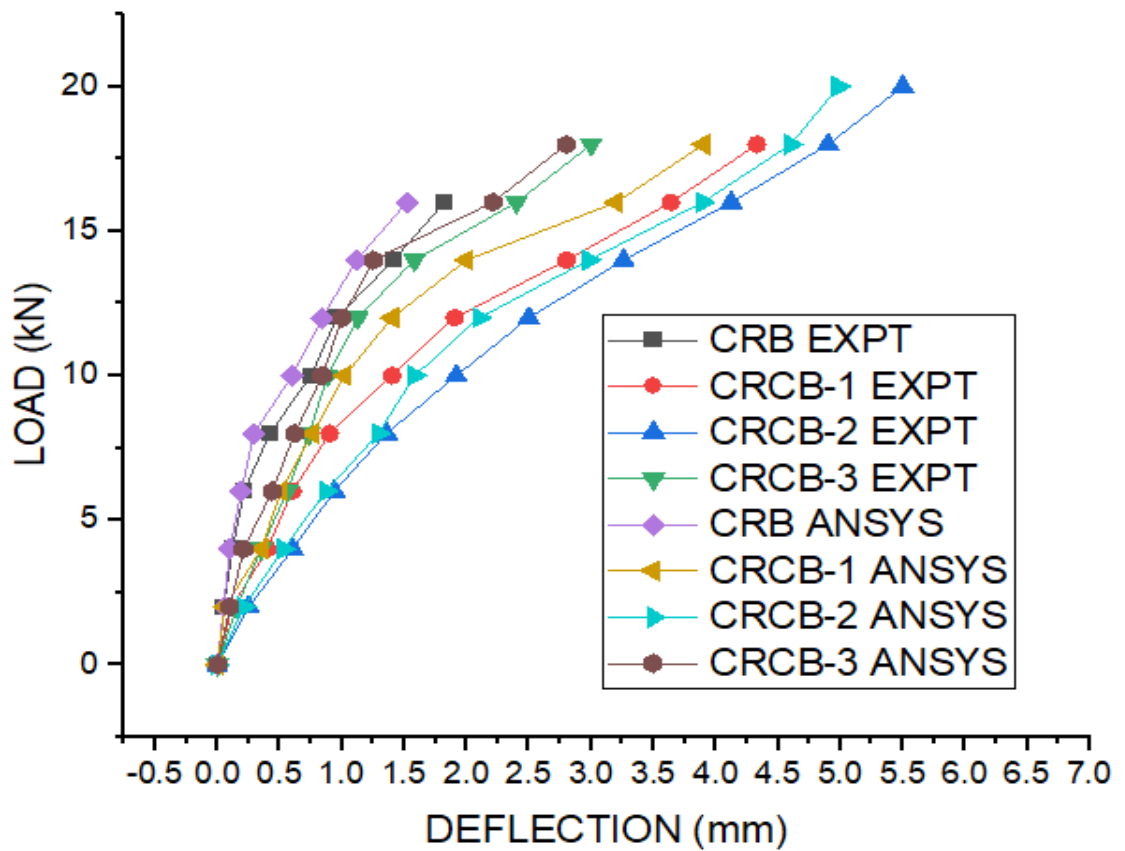


Fig 7.3: Comparison of Experimental and Analytical Results of CRB, CRCB-1, CRCB-2, and CRCB-3

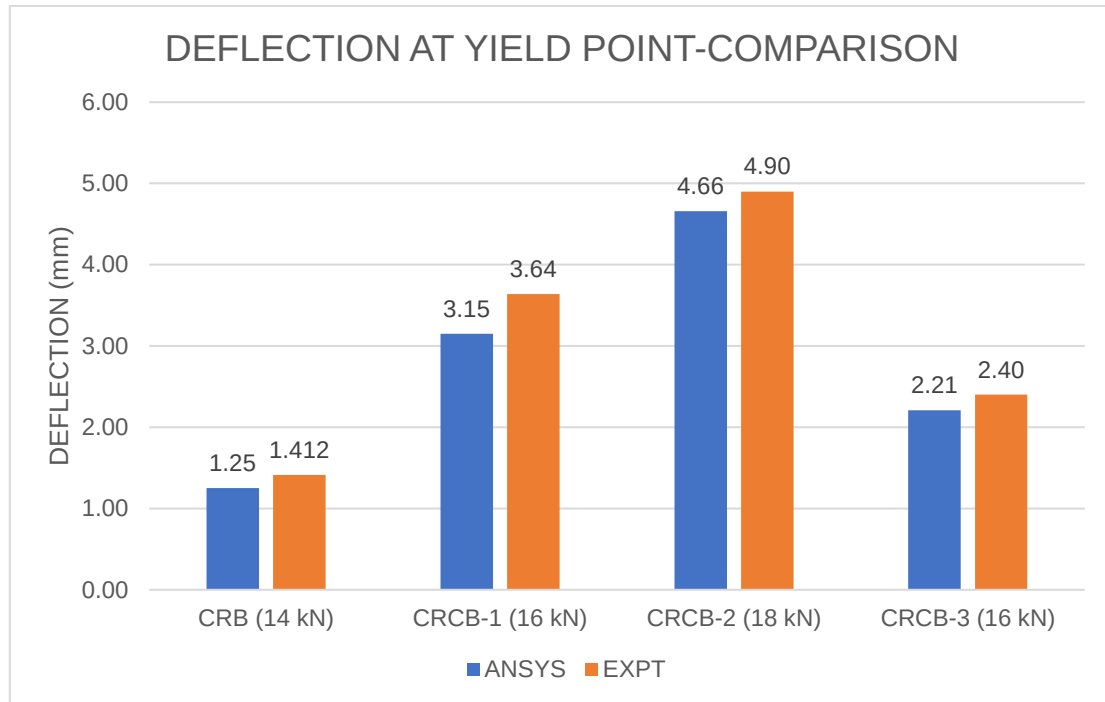


Fig 7.4: Comparison of Experimental and Analytical Results of CRB, CRCB-1, CRCB-2, and CRCB-3 of Deflection at Yield Point

Table 7.1: Tabulation of Experimental and Analytical Results of CRB, CRCB-1, CRCB-2, and CRCB-3

Load	Deflection							
kN	mm							
	Experimental Results				Analytical Results			
	CRB	CRCB-1	CRCB-2	CRCB-3	CRB	CRCB-1	CRCB-2	CRCB-3
0	0	0	0	0	0	0	0	0
2	0.05	0.12	0.25	0.15	0.05	0.06	0.21	0.10
4	0.12	0.40	0.60	0.35	0.10	0.35	0.53	0.21
6	0.21	0.60	0.94	0.56	0.19	0.51	0.87	0.44
8	0.42	0.90	1.36	0.74	0.29	0.76	1.29	0.62
10	0.75	1.40	1.92	0.88	0.60	1.02	1.58	0.84
12	0.96	1.90	2.50	1.13	0.84	1.40	2.10	1.00
14	1.41	2.80	3.26	1.58	1.25	2.00	2.98	1.25
16	1.82	3.64	4.12	2.40	1.52	3.14	3.89	2.21
18		4.33	4.90	3.00		3.90	4.66	2.80
20			5.50				4.99	

7.4 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 is 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-2 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 8

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 effected 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. 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.

CHAPTER 9

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