FINITE ELEMENT ANALYSIS OF FAILURE MECHANISM OF STEEL CONCRETE COMPOSITE INTERFACE

THESIS

Submitted in partial fulfillment of the requirements for the award of the degree

of

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Under the supervision

of

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by

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

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HIMACHAL PRADESH, INDIA

2021

STUDENT'S DECLARATION

I hereby declare that the work presented in the Thesis entitled **"Finite element analysis of failure mechanism of steel concrete composite interface"** submitted for partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering, with specialization in Structural Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Mr. Kaushal Kumar, Assistant Professor.** This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my thesis.

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CERTIFICATE

This is to certify that the work which is being presented in this thesis titled "**Finite element analysis of failure mechanism of steel concrete composite interface**" in partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in "Structural Engineering" and submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Wasaf Javaid (192652)** during a period from July 2020 to May 2021 under the supervision of **Mr. Kaushal Kumar, Assistant Professor**, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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ABSTRACT

The steel–concrete composite beam bonded by adhesive has specific advantages over the traditional composite beam. In conventional steel concrete composite section shear connectors develop cracks in concrete due to stress concentration and significantly reduce the structure durability Adhesive bonding has recently emerged as an substitute to shear stud connection in steel-concrete composite flexural members. 3D finite element models are developed with the help of ABAQUS software. The steel and the concrete are assembled by adhesives. The interface between steel and concrete was modeled using a cohesive bond model. The results from the steel concrete composite section are presented in the form of stress-strain contours and load-displacement curves.

Keywords: Composite beams; Bonding; Finite Element analysis; Abaqus

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LIST OF ABBREVIATIONS

S.N0.	ABBREVIATIONS	DETAIL
1.	FE	Finite Element
2.	FEA	Finite Element Analysis
3.	FEM	Finite Element Method
4.	CZM	Cohesive Zone modelling
5.	CDP	Concrete damage plasticity
6.	3D	Three dimensional
7.	mm	Millimeters
8.	m	Meter
9.	GPa	Giga Pascal
10.	MPa	Mega Pascal

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CHAPTER 1

INTRODUCTION

The conventional composite beam made up of concrete slab, a steel girder and shear connectors are broadly used for constructional purposes. The combined action between the concrete and steel is attained by using headed studs as connectors, these studs are originally positioned in the fresh concrete and as concrete hardens, they act as stops in longitudinal and vertical directions. The relative slip that is going to occur at the interface of steel and concrete section is prevented for attaining the combination of complete section. Shear connectors which are used in the composite section causes concentration of stresses which lead to the growth of cracks, it also reduces the structure's durability. The fatigue life of structure is also reduced when connectors are welded with steel girder. Adhesive bonding method is developed for overcoming the weaknesses occurring in traditional composite beams. In this method steel girder and concrete are tightly combined with one another by adhesive joint and continuity of stress distribution is ensured over composite beams. So adhesive bonding helps in reducing the concentration of stresses that are developed from metal connectors and welding used for establishing the connection is also avoided. The steel girder easily gets corroded when used in construction so the protection against corrosion of steel is achieved by using adhesive connections as they are impermeable. Adhesive bonding also helps in using precast concrete slab which facilitates the process of manufacture and construction cost is reduced.

Proportioning of the amounts of the resin and hardener should be completed by the maker's directions. This is normally worked with the stockpile of estimated amounts, in the right extents, of base and hardener so the substance of one part can be exhausted into the other, typically hardener into resin, and afterward combined as one. An epoxy is characterized as material which contains at least two ethylene oxide terminal group that are fit for polymerization and consolidating with different particles to frame more intricate ones. Epoxy was first utilized in the development business as a glue in 1948 to bond two bits of solidified cement. It end up being a dependable underlying glue with the ability of being stronger than the solid it bond together. From that point epoxies are utilized in structural designing.

Appropriately utilized, epoxy can offer good compressive and tensile qualities and furnish a satisfactory bond strength with primary materials. After full curing is accomplished, the adhesive used builds up a compressive strength 3-5 times the tensile strength. The strength in compression and tension fluctuate from 10 to 200 N/mm^2 and 2 to 96 N/mm^2. The elastic modulus is somewhere in the range of 200 and 100,000 N/mm^2. Epoxy respond well to harsh natural conditions. They provide good resistance against the attack from alkali, oils and acids. A slight covering of a proper epoxy framework can deliver a surface impermeable to water even if it is constantly immersed.

The activity of holding two primary materials with an epoxy glue requires most extreme consideration. The failure may occur due to improper blending, surface not prepared properly and cured and also if workmanship is not up to mark. Surfaces to which epoxies are to be applied should be spotless and liberated from free and shaky materials.

Mechanical abrasion is done to uncover the coarse aggregates present in the concrete surfaces by scrapping the area. Laitance, dust and other free particles coming out because of the mechanical activity are removed from the surface by using compressed air and brushing with wire.

Steel surfaces might be sandblasted to eliminate the polluted outside layer. Impact cleaning buildups can be eliminated by compressing air. The corrosion is prevented by preparing the surface before the use of the glue.

To limit the air entrained in the joint, the epoxy should be applied to both surface to be joined with a roller or by a spray appliance at a thickness adequate to load up with abundance the space between the substrates. To guarantee a full and close contact between the substrate and to crush out the overabundance of adhesive and accomplish a uniform joint, a consistently conveyed pressure should be applied on the joint until curing is achieved.

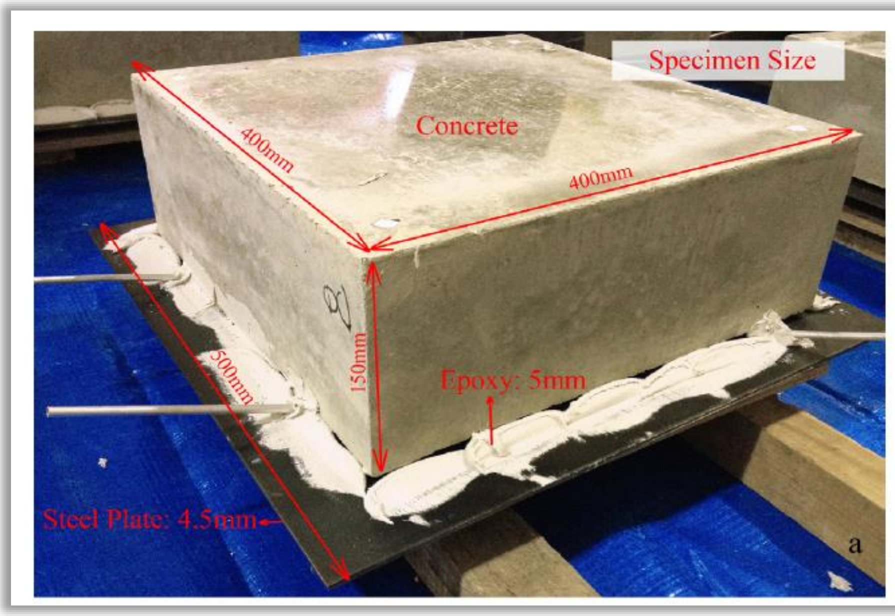


Figure 1.1. Steel-epoxy-concrete specimen
Y.Shen et al. / Case studies in Nondestructive Testing and Evaluation

1.1 OBJECTIVES

The objectives of this study are:

- To develop set of 3D finite element models, using Abaqus 6.14 to perform finite element analysis.
- To evaluate the stress-strain distribution in the composite section and effect of load on section using FEA.
- To analyze the load transfer mechanism between steel and concrete.
- To analyze the efficiency of joint between steel and concrete.
- To determine the failure mechanism at steel concrete interface.

CHAPTER 2
LITERATURE REVIEW

Bouazaoui et al. (2007) conducted studies on adhesive which is used for bonding concrete slab and steel girder together. The consequences of the main considerations such as nature of the adhesive and the uneven thickness of the adhesive joint on the efficiency and final load are observed. The concrete slab cracking and yielding of steel girder leads to the failure of composite beams. The crack in the concrete slab first appear at the centre of beam in transverse direction. The adhesive used in this beam did not show any failure. The findings obtained from the experiment indicate that by using bonded connection the concentration of stress decreases and across steel-concrete section, continuous transfer of stresses are obtained.

Zhao and Li (2008) In steel-concrete composite section, the linking of steel beam with concrete is established by steel shear studs. A three-dimensional model is generated using the finite element approach to analyze the nonlinear mechanical conduct and failure of the joined steel–concrete composite section. The findings shows 3 significant cause for the collapse section: local tensile stresses that result in cracking the concrete, crushing of concrete resulting from compressive stresses, and considerable yielding that occurs in steel beam during the global bending moment.

Zhan et al. (2016) performed the push-out experiments to determine the action of the interface between steel and concrete bound by bonding. Modes of failure, final loads and load-slip relationships are recorded and discussed. An empirical model is formulated to forecast the final load value and the load-slip relationship. The capacity at the interface of specimen increases as the thickness of epoxy is increased and when sample failed, small final slip was observed. The friction offered by the adhesive depends upon its elastic modulus.

Alachek et al. (2020) studied concrete bonded beams consist of hybrid pultruded glass fiber reinforced plastic materials and proposed that these beams have remarkable properties and are used as an economical structural alternative. The lack of a common procedure for measuring these hybrid beams means that the use of this technique in building work is far from being accomplished. The analysis is done to define the "Push out" scissor test in order to provide more details on the effect of the various geometric parameters on the adhesive joint.

Luo et al. (2012) carried out push out tests for evaluating the strength of adhesive connection which is used to connect steel and concrete together. The epoxy adhesive that was used found to be capable of providing bond strength of 6.36MPa at the joint of steel and concrete. The manner in which adhesively bonded composite beams act was found to depend immensely on the material characteristics of adhesive. The modulus of elasticity of adhesive material that is used for this type of connection should exceed 1000MPa for preferable performance of bonded steel concrete composite beams. The debonding failure that occurs in adhesively bonded steel-concrete composite section largely depends upon the strength in bonding and the area of bonding. The failure in debonding is prevented by guaranteeing an average bonding strength of 5MPa.

Souici et al. (2013) found that fully bonded link guarantees the continuous transfer of shear force across steel-concrete composite section. Results shows that it was difficult to guarantee a complete connection between concrete and steel by means of shear studs. The standard of connection between steel and concrete depends upon the quantity of shear studs utilized in the connection. The distribution of strain is different in bonded beam and the beam connected by studs. The deformation in bonded beam is less as compared to beam connected by studs.

Kumar et al. (2017) analyzed the behavior of mechanically connected composite connection and steel-concrete composite bonded by adhesive and provided a comparative relation between them when subjected to impact load. The quantity of blows for commencement of crack and ultimate failure were found. It was discovered that the adhesively fortified connection would oppose generally higher blows (twice) for commencement of crack. However, blows required for final failure were comparatively lesser. The composite connection of adhesive shows sudden failure in concrete while connection of mechanical connectors shows failure which is ductile in nature.

Bouazaoui et al. (2008) expressed that steel-solid composite frameworks incorporate the solid intensity of steel with the solid's solidness and compressive quality shaping an exceptionally conservative system. The utilization of steel-solid arrangement can increment further on the off chance that it is conceivable to advance the control of the breaking of a solid section, particularly at an initial stage. The consciousness of the toughness of fortified solid/epoxy frameworks is getting progressively significant. The utilization of these frameworks in applications, for example, a fiber-reinforced polymer to fortify solid structures is progressively mainstream. Untimely failure of the fortified framework may happen to pay little heed to the dependability of the material framework's individual parts, state the specialists. The examination shows a considerable lessening around 50%, in the crack obstruction of solid epoxy bond with chosen stickiness and temperature molding levels.

He. (2011) the need to fabricate lightweight structures and grow the application of lightweight structures in mechanical fields has prompted the wide utilization of glue holding. Late work on FEA of adhesively fortified joints is inspected concerning static stacking examination, natural conduct, weakness stacking examination, and cement reinforced joints' dynamic properties. It is presumed that the limited component investigation of adhesively reinforced joints will help future cement holding applications by permitting the framework boundaries to be chosen to give as huge a cycle window as workable for fruitful joint assembling. This will permit a few unique plans to be recreated to play out a determination of various plans prior to testing, which would be long enough to even consider performing or practically speaking it would be restrictively expensive.

Mohammad et al. (2015) FEA software using ABAQUS/Standard used to model and analytically evaluate the shear strengths and stress distribution of the interface by applying the 'push-off' test approach to experiment that is done. The analysis is done to explain the mechanism of the concrete-to-concrete bond's failure using FE modeling. Composite concrete-to-concrete applied to prefabricated concrete, and cast-in-place concrete topping has increased due to ease of use in bridge and building construction. A crucial part of this framework is to improve the composite action between the concrete layers for monolithic behavior. Thus, concrete-to-concrete interface behavior plays a significant part in providing a stiffer, stronger composite structure

Mustapha et al. (2011) introduced FEA displaying on a novel smaller than normal composite fuselage structure through ABAQUS/Explicit. The structure is a woven C-glass fiber/epoxy 200 g/m2 overlaid composite with orthotropic versatile properties and adhesively fortified butt joint.

Results recommend that the reproduction may repeat agreeable glue joint activities utilizing durable components and squashing modes.

Eberline et al. (1988) Suggested that the Epoxy joined steel plates can be effectively used to increase the live load capacity of concrete bridge. The strengthened member acquires increased flexural stiffness, resulting in a reduction in cracking and deflection. The fatigue life of bonded steel cover plates was increased to twenty times over that of welded cover plates.

FUJIYAMA et al. (2014) examined that the most well-known type of composite activity between the steel bar and the concrete is the shear connectors' mechanical activity. The shear connectors' primary objective is to withstand the shear powers of the steel-solid interface and forestall the vertical detachment between the section and the steel shaft. The head shear stud, which is similarly powerful in opposing shear powers every which way because of its roundabout shape, is the most generally utilized shear connector.

Lim and Bernard (2011) conducted FEA and presented the three dimensional demonstration of push-out tests. The Objective is to create models ready to replicate the principle highlights of the conduct of associations in composite structures. It is trusted that the model is going to be sufficient to be utilized in the displaying of genuine structures like bars or segments.

Jurkiewiez et al. (2011) Studies the static and sudden bending behavior of composite beam of concrete which has normal strength and has a bonding connection. Tests that were conducted includes tests of materials, push out tests and bending tests. 2 there-point bending tests directed on 4m range radiates affirm that the holding can make a huge plastic strain with no shear disappointment. The estimations are like the mathematical outcomes given by the nonlinear shaft or nonlinear FE models. Steel-concrete composite beam assembled with bonding and having concrete of standard strength found to have a similar behavior as shown by steel-concrete composite beam connected by studs which are used as mechanical connectors. Failure due to shear will not occur if the bonding joint is accurately designed.

Si Larbi et al. (2007) carried out investigation on the bonded connection at the interface of steel-concrete beam. The main attention is on the behavior of beam in static and instantaneous conditions. The ultimate shear stress is influenced by the treatment given to the surface, resin applied, joint thickness in bonding and it varies from 5MPa to 5.9MPa. Fortified associations show high inflexibility and about similar quality as the mechanical connectors. The danger of breaking in the solid piece is likewise significantly diminished, which could improve the life span of fortified steel-solid composite structures.

Meaud et al. (2014) Checked principle boundaries are solid sections and holding territory sizes. The conduct saw during push-out tests depends intensely on these boundaries. Besides, estimations are identified with mathematical outcomes got from 3-Dimensional Finite Element models representing the constituent materials' nonlinear conduct. Specifically mathematical outcomes propose that the shear pressure in the concrete along the holding joint and close to the interface isn't predictable and alters with the heap level assigned. Additionally, shear pressure can be joined by high pressure opposite to the interface, mostly because of conceivable grating between the lower part of solid sections and the unbending water powered press steel plate. This pressure incites useful twofold pressure in the joint and high disappointment load. Consequently, these estimations and mathematical outcomes show that the pressure circumstance in a push-out test is intricate, differs with the heap, and appears to be sure, not agent of a flexural part's pressure state. The push-out test can likewise characterize a Steel-solid holding association is useful in looking at changed glues or holding measures.

Espinós Capilla and Romero García (2013) expressed in their examination that a nonlinear, three-dimensional limited component model is given to test the imperviousness to fire of round cross-area pivotally stacked CFT sections. In view of a definite affectability examination, the estimations of the model's connected boundaries are picked. The mathematical model is approved against test fire tests, giving exact segment warm and mechanical reaction forecasts. This mathematical model is substantial for assessing the imperviousness to fire of unprotected CFT segments loaded up with typical quality concrete and thought pivotal burdens. A non-exact model for a pliable fragile bi-material interface is proposed. Such interfaces happen in Steel-Concrete (SC) composite divider modules, which make atomic and regulation squares. Comparable bimaterial interfaces may happen in geotechnical, aviation, earthenware production, and other composite applications. The examination recognizes the essential flaw modes related with such interfaces.

Triantafyllou et al. (2017). A numerical model that can approximate the flexural behavior of corroded reinforced concrete beams patches repaired and strengthened with carbon fiber reinforced polymer. Beams were studied to failure and these beams were subjected to four-point loading tests. The analytical load-deflection curves compared well with the corroded RC beams patch repairs' experimental flexural behavior and are reinforced with EBR and NSM CFRP laminates. The FE analysis may replicate the observed modes of failure, including crushing concrete after steel yielding and deboning.

Liu et al. (2016) suggested that the headed shear studs which are used traditionally in composite beams can be replaced by using high-strength friction-grip bolts (HSFGBs) as shear connections between the steel and concrete section. For construction purposes these beams can be classified as a sustainable and recyclable feature. FE analysis done to study the structural behavior of steel-concrete composite beams connected with HSFGB used as shear connectors. Three dimensional model is formulated and is used for the assessment of various effects like spacing of bolts, diameter of hole, bolt pretension and on the behavior of beam due to the reinforcement in longitudinal direction.

CHAPTER 3

FE MODELING AND MATERIAL PROPERTIES

3.1 INTRODUCTION

In this chapter modeling is done using Abaqus and the behavior of various materials involved in the models are also discussed. As discussed in Chapter 1, the objective of the research described in this thesis is to investigate the failure mechanisms in composite sections. The general method that was used in this research was to conduct computational simulations using the general purpose finite element analysis program ABAQUS. More specifically, analyses were conducted using ABAQUS Version 6.14, following the instructions in ABAQUS Documentations.

3.2 FINITE ELEMENT METHOD

Finite element method is mostly used to simulate the conduct of different structures and is among various numerical methods used to address a wide scope of complex engineering issues. FEM comprise of discretizing the structure's geometry into an arrangement of finite elements where every FE addresses isolated bit of the actual construction. The FEM permits settling in a discrete way an equation of partial derivatives which search for an estimated solution solid "enough". It is necessary for the user to have a careful comprehension of the conduct of various materials related with the actual problem and the interaction between them for FEM to be successful. Once analysis is completed a series of simultaneous equations can be explained to relate displacements and forces of the nodes and contours can be established in every element from where structure as a whole can be evaluated.

3.2.1 ADVANTAGES OF FEM

- The generalization of FE method makes it a robust and useful tool for a large variety of problems.
- Finite element method will be simply taken in physical terms yet it has a solid mathematical base. So Finite element method will be functional to any problem with

correct data of the physical system into account and might be resolved to a higher precision by the application of accurate mathematical tool.

- Structure's having Non-homogeneity are analyzed by simply allocating different properties to different components also the variation of properties within element is possible conferring to the polynomial applied.
- FEM is also capable enough to handle non-linear and time dependent system as it can easily accommodate complex geometry.

3.2.2 DISADVANTAGES OF FEM

- Finite element method solutions obtained will be accurate as long as the material properties are exact.
- The main disadvantage of finite element method is sensitivity of the answer on the geometry of the component such as quantity, shape, kind and alignment of used components.
- The Finite Element Method needs a large memory and time taken to complete the analysis is quite long.
- Finite Element Method results in a great quantity of numerical data and it is tough to distinct the specified results from this much amount of data.

3.3 ABAQUS SOFTWARE

In this study Abaqus/CAE 6.14 is utilized to demonstrate steel concrete composite. ABAQUS is a set of finite element analytical programs originally developed by Hibbitt, Karlsson & Sorensen, Inc. and currently maintained by SIMULIA Corp. ABAQUS is a general-purpose simulation tool, and can solve a wide range of engineering problems, including structural analysis and heat transfer problems. ABAQUS has extensive element and material libraries capable of modeling a variety of geometries and material constitutive laws. FE in Abaqus are combined by common nodes and collection of such nodes and finite elements forms the mesh. Quick and simple demonstration of a problem is done with problem ranging from easy to complex. Discretization of the whole model into finer mesh with high amount of components or coarse mesh when one utilizes less components and this influences the precision of the solution. Each analytical model in ABAQUS includes 11 modules: Part, Property, Assembly, Step, Interaction, Load, Mesh, Optimization Job, Visualization, and Sketch. To create a complete analysis model, it is usually necessary to go through most of these modules, as described below:

- Build up the geometry of the structure under a set of parts. (Part module, Sketch module, Mesh module)
- Create element sections (Property module)
- Introduce material data (Property module)
- Assign section and material properties to the Parts (Property module)
- Assemble parts to create the entire structure (Assembly module, Mesh module and Interaction module)
- Create steps and choose analysis method (Step module)
- Introduce load and boundary conditions (Load module)
- Create jobs and submit for analysis (Job module)
- Visualize the result. (Visualization module)

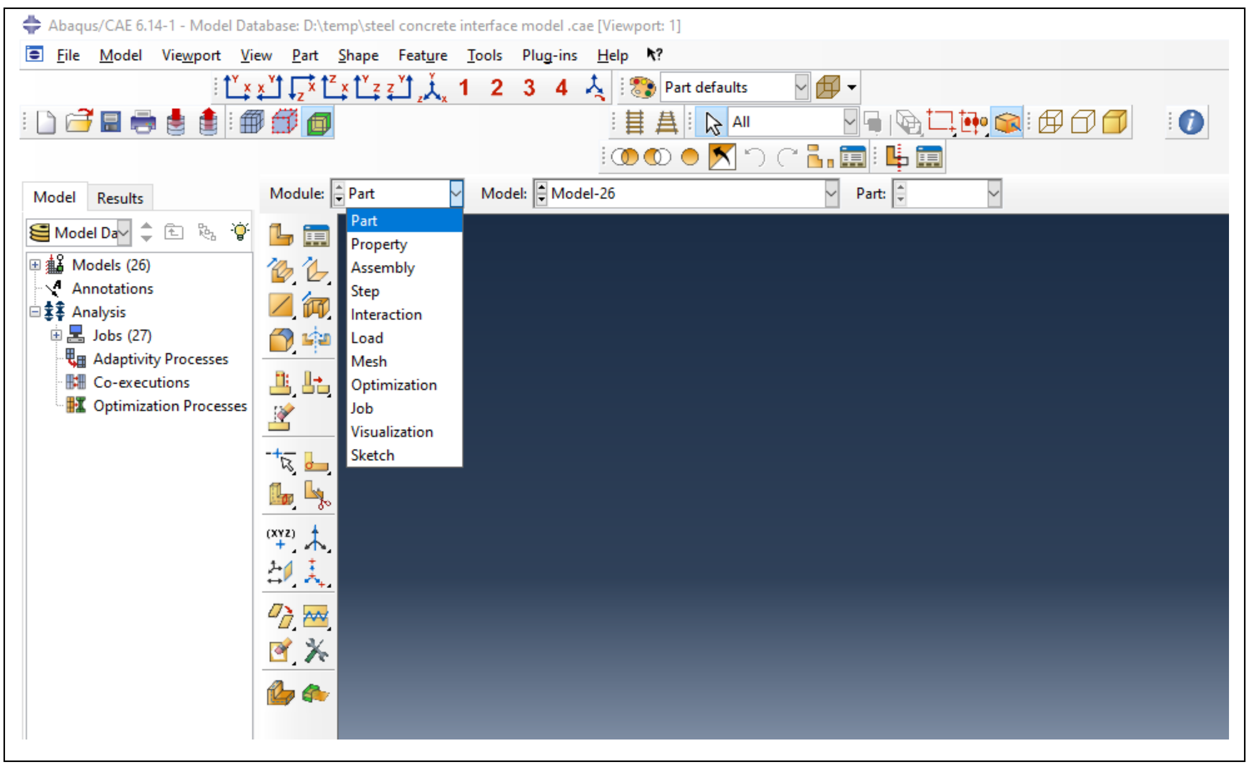


Figure 3.1. Abaqus user Interface

The flowchart depicts various steps that were followed from developing the model to visualization of results and extraction of output data.

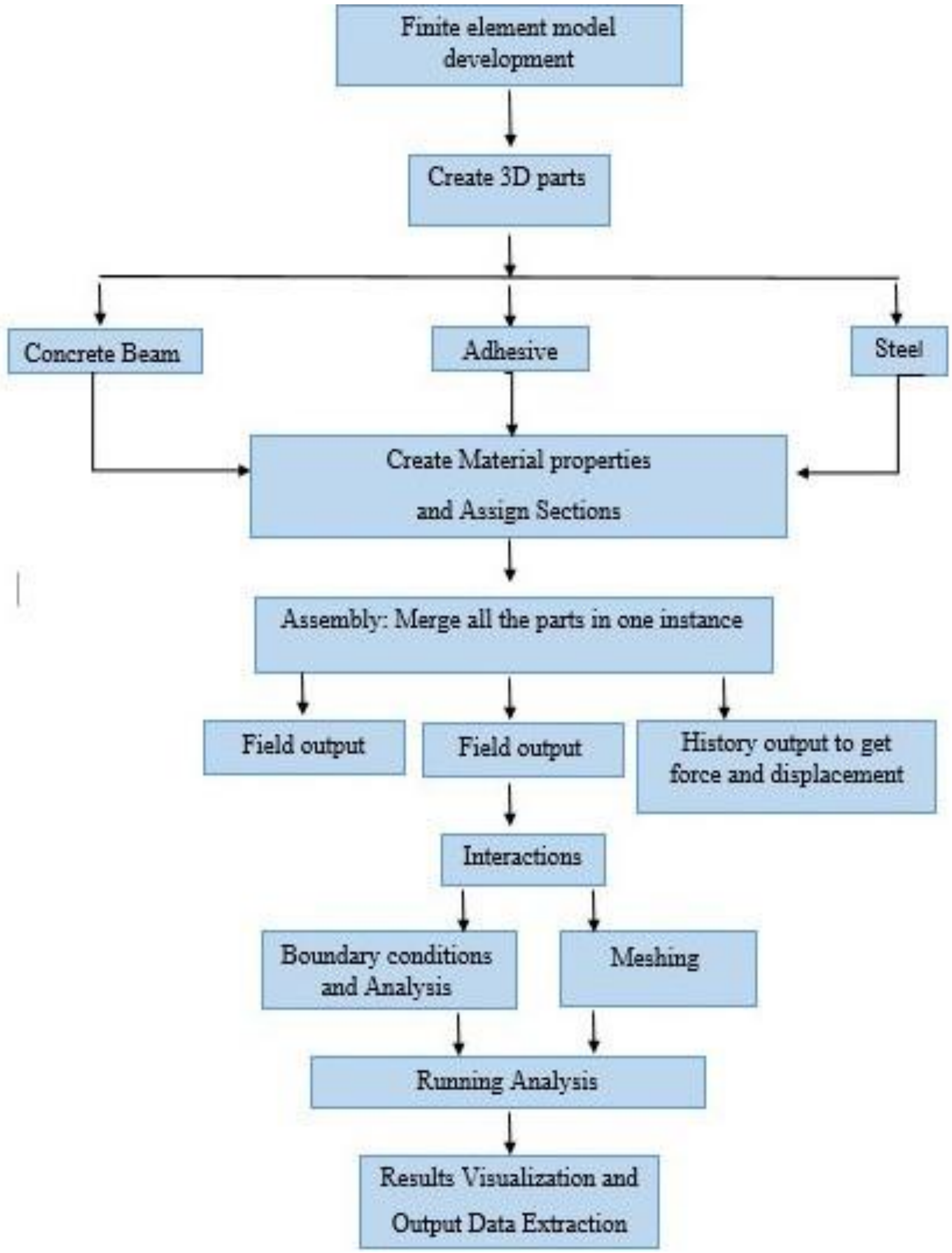


Figure 3.2. Development of FEM

3.4 MATERIAL PROPERTIES DEFINITION AND ASSIGNMENT

For a finite element model to be successful, it is important that material conduct be anticipated as precise as could be expected. This requires a sound determination of the constitutive relations. The following segment has different constitutive relationships that were utilized to get the vital input information for every material included in the study.

3.4.1 CONCRETE

Concrete is the utmost utilized primary material. The primary reasons that builds up this articulation are depicted momentarily as follows:

Economical perspective: the main factor which consistently depicts various new constructions is its expense. Construction resulting from concrete are half the price to steel construction.

Variety: Concrete can be employed to accomplish a large variety of shapes and sizes so resulting construction will be aesthetically pleasing.

Resistance to fire: Concrete structures can resist fire up to a time duration of 3 hours without requiring any exceptional means rather than structures constructed from steel.

Availability: The main ingredients for making concrete are cement, coarse aggregate like gravel and fine aggregates like sand are effectively found in the most areas.

Maintenance: The maintaining of structures made from concrete is easy and accordingly prompting a decrease in costs.

Nonetheless, as some other material, concrete has a few weaknesses. Among these while constructing concrete structures there is its need of being upheld by formwork, high unit weight, low strength in tension (0.1 - 0.2 times compressive strength) and usually while designing concrete structures the strength of concrete in tension is neglected. So by using lightweight aggregates its unit weight can be reduced and reinforcing is done in concrete to impart tensile strength, steel is commonly reinforced in concrete.

3.4.1.1 CONCRETE BEHAVIOUR

The behavior of the aggregate and paste is linear but resulting mixture is having a nonlinear behavior. This is often attributable to weak interface that exists between the paste or matrix and therefore the mixture referred to as interface transition zone. The nonlinearity of concrete may also be attributed to its porosity that causes non uniform stress distribution once concrete is loaded. Thus, its behavior for most part depends on the microstructure properties.

Though concrete exhibits nonlinearities and difficulties in modeling its behavior, it has become a well-liked material used everywhere due to its low price, the accessibility of its ingredients and developments in its technology. For the aim of this study, it is necessary to recollect that concrete cracking affects the deboning failure and that concrete behaves in a different way in compression and in tension and that makes it a complex material. Therefore, it's necessary to have a good understanding of its behavior when in service.

Concrete turns as a plastic material when state of mutiaxial stress is subjected on it. CDP model is used to model the behavior of concrete. The model of concrete is based on plasticity, continuum, and damage model. The model assumes that concrete mainly fails in tension by cracking and in compression by crushing. Simultaneously, elastic properties of concrete gets damaged because of cracking which prompts stiffness degradation. The flow surface (F) is influenced by the flow function characterized by 2 restraint invariants. The geometry is characterized in the deviation plan utilizing an input parameter Kc. The value of Kc is equal to 0.67 which is prescribed in Abaqus and gives dependable outcomes. The parameter fb0/fc0 characterizes state of the surface addresses proportion of opposition in uniaxial compression resistance and in biaxial compression and is equal to 1.16.

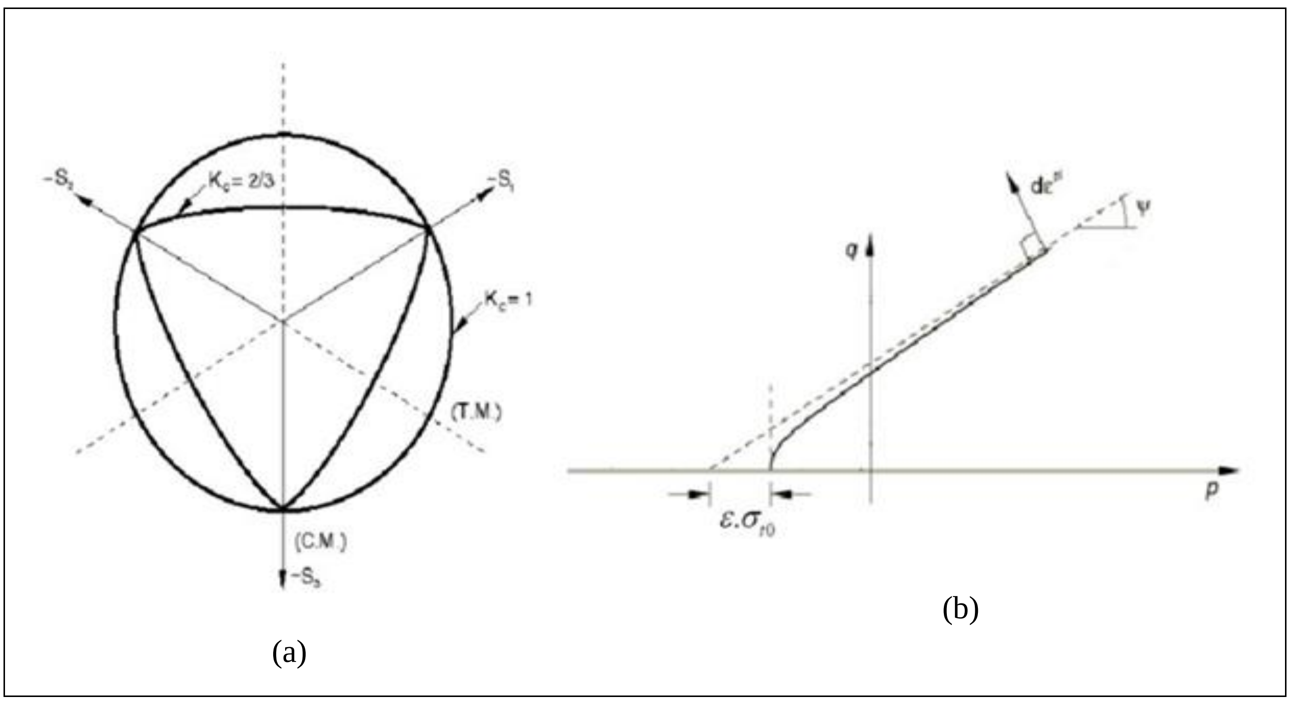
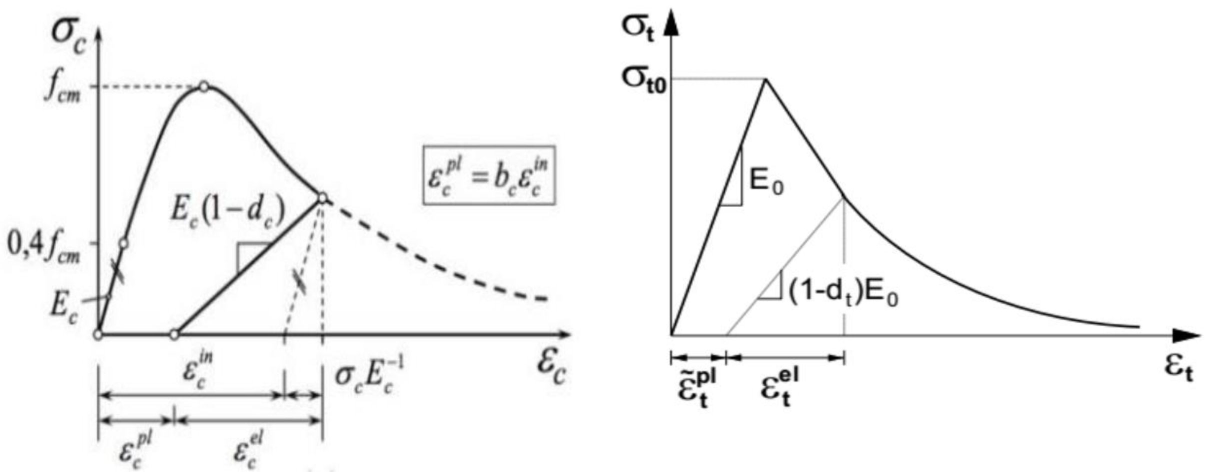


Figure 3.3 (a) Flow surface on a deviator plane (b) Potential surface area on a meridian

The stress strain relationship of concrete in the concrete damage plasticity model is explained in following figure:



(a) (b)

Figure 3.4. Stress-strain relationship of concrete (a) in compression (b) in tension

The development of the damage due to concrete compression is related to the plastic deformation which is determined by the inelastic deformation $\varepsilon_c^{in} = \varepsilon_c - \sigma_c E_c^{-1}$ using a factor bc which has the value 0 < bc ≤1. The value of bc assumed =0.7.

$$d_c = 1 - \frac{\sigma c E c^{-1}}{\varepsilon_c^{pl}\left(\frac{1}{b_c} - 1\right) + \sigma_c E_C^{-1}}$$

Similarly, damage parameter in traction of the concrete *dt* is governed by plastic deformation and is equals 0.1. In the phase of unloading all curves of unloading are estimated to return roughly to the origin, it remains only microscopic plastic deformations after unloading.

$$d_t = 1 - \frac{\sigma_t E_c^{-1}}{\varepsilon_c^{pl}\left(\frac{1}{b_t} - 1\right) + \sigma_t E_c^{-1}}$$

3.4.2 STEEL

Steel reinforcement utilized along with concrete is of little section when compared with the section of concrete and can accordingly expected to have just axial stiffness. Steel carries both tensile and compressive stresses. When a concrete section is cracked steel alone carries tensile stresses. In FEM steel is accepted to have a similar reaction in resisting compressive and tensile stresses. Typically, specimen of steel when subjected to uniaxial tensile test displays at first a linear elastic portion, a yield level, a strain solidifying range in which stress again increments with strain and lastly a range stress drops off until failure. In most of the studies linear elastic plastic model for steel is used.

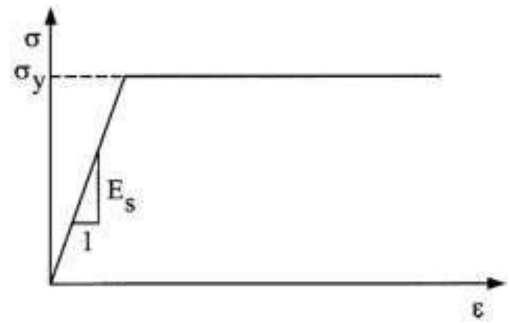


Figure 3.5. .Elastic plastic model for steel

The compatibility of the displacements compatibility of concrete and steel is guaranteed through the occurrence of steel components with the limits of the concrete components prompting a like order for the shape functions of elements of truss and concrete.

3.4.3 ADHESIVE: CONCRETE/STEEL INTERFACE

The interface between concrete and steel is made of an epoxy adhesive and modeling of interface is done by cohesive zone method. For modeling the adhesive the axial stiffness and shear is considered so as to capture its mechanical conduct. Cohesive elements in Abaqus are utilized for modeling adhesive. Cohesive element is being made out of two faces isolated by a thickness where the general movement of the two faces along the direction of thickness will represent opening or shutting of the interface and the position of top and bottom faces will change relatively when measured in orthogonal plane in respect to thickness and it addresses the behavior of cohesive element in transverse shear.

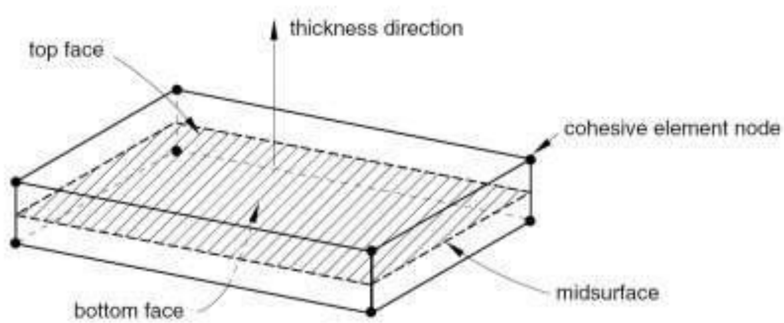


Figure 3.6. Representation of a 3D cohesive

Cohesive elements exert response in terms of traction separation in which linear elastic traction separation law is assumed before damage and after the peak damage evolution law is assumed.

3.5 STEEL CONCRETE COMPOSITE BEAM GEOMETRY AND MODEL CONSTRUCTION

The first FE model is construction of Steel concrete composite beam and validated with the **Bouazaoui et al.** (2007) test results. In this study the composite beam is made out of a precast concrete slab and a steel girder bonded by adhesive. This study is done for analyzing the mechanical behavior of the composite construction along with mode of failure and stress distribution. The study was done for determining the impact of some parameters like the nature of the adhesive and the abnormality of joints thickness in the longitudinal and transverse directions.

The composite beam geometry is shown below and consists of concrete slab and the steel girder bonded by adhesive. The length of beam is 3486mm and it is simply supported on a length of 3300 mm. The concrete slab is 70mm thick and 350mm wide reinforced with 4 steel bars having 6mm diameter and steel girder having a height of 220 mm and is 110mm wide. The composite beam is bonded by adhesive which has a thickness of 3mm.

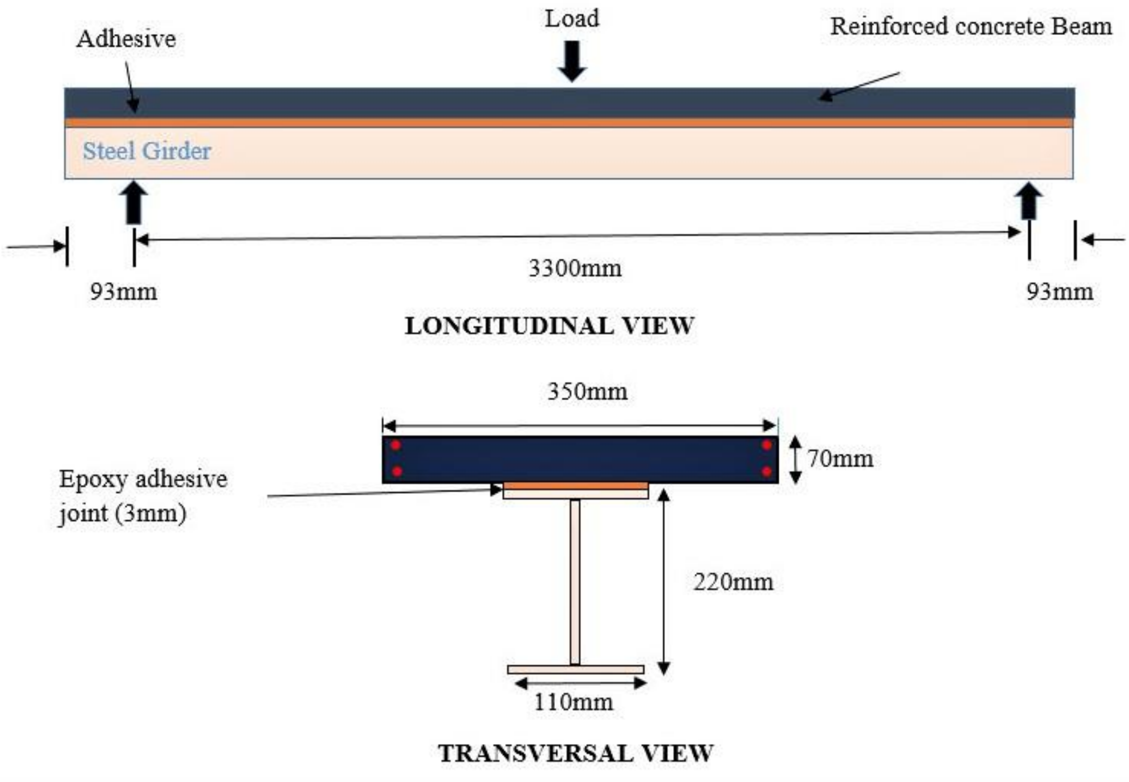


Figure 3.7. Geometry and reinforcement details of the modeled beam

All parts in Abaqus were made from a specific base component known as create part containing all type of information related to any kind of geometry and the standards that govern the geometry performance. The geometry of beam is made as a 3D deformable solid part. Partition of beam as shown in figure is done to enable it fix a rigid block over it so that loading can be applied over it.

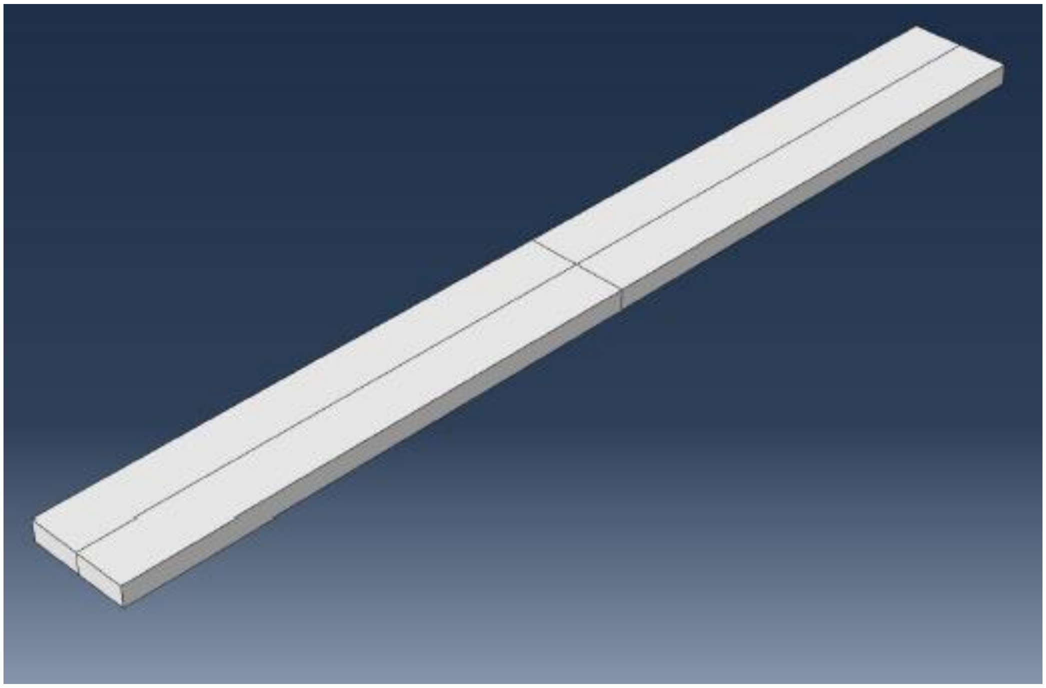


Figure 3.8. Partitioned concrete beam created in Abaqus

For a FEM to be effective, it is vital that the properties of material be anticipated as precise as could really be expected. Properties of concrete are assigned to the beam section having Young's modulus of 36600 and type is isotropic, various other properties are shown below:

Table 3.1. Concrete parameters

Dilation angle (ψ)	37
Eccentricity $(\in)$	0.1
Ratio of initial equibiaxial yield stress to initial uniaxial compressive stress (f_b0/f_c0)	1.16
K_c	0.667
Viscosity Parameter (μ)	0.01

Table 3.2. Stress strain values used as input for compressive behavior

Yield Stress(Mpa)	Inelastic strain
19.2	0.00E+00
20.72	3.30E-05
24.35	5.43E-05
27.71	8.33E-05
30.72	1.22E-04
33.81	1.59E-04
36.48	2.08E-04
38.95	2.62E-04
41.13	3.25E-04
43.04	3.95E-04
44.65	4.74E-04
45.96	5.62E-04
46.98	6.58E-04
47.64	7.64E-04
47.96	8.80E-04
48.00	9.29E-04
47.93	1.01E-03
47.51	1.14E-03
46.71	1.29E-03
45.42	1.45E-03
43.72	1.63E-03
41.56	1.81E-03
38.84	2.02E-03
35.64	2.23E-03
31.88	2.46E-03
27.44	2.72E-03
22.45	2.98E-03
16.79	3.27E-03

Table 3.3. Concrete compression damage input data

Damage parameter	Crushing strain
0.00E+00	0.00E+00
1.46E-03	1.01E-03
1.02E-02	1.14E-03
2.69E-02	1.29E-03
5.38E-02	1.45E-03
8.92E-02	1.63E-03
1.34E-01	1.81E-03
1.91E-01	2.02E-03
2.58E-01	2.23E-03
3.36E-01	2.46E-03
4.28E-01	2.72E-03
5.32E-01	2.98E-03
6.50E-01	3.27E-03

Table 3.4. Stress strain values used as input for tensile behavior.

Yield stress[MPa]	Cracking strain
3.50	0.00E+00
3.11	1.11E-04
2.72	2.22E-04
2.33	3.33E-04
1.95	4.44E-04
1.56	5.55E-04
1.17	6.67E-04
0.78	7.78E-04
0.39	8.89E-04
0.00	1.00E-03

Table 3.5. Concrete tension damage input data

Damage Parameter	Cracking strain
0.00E+00	0.00E+00
1.11E-01	1.11E-04
2.23E-01	2.22E-04
3.34E-01	3.33E-04
4.43E-01	4.44E-04
5.54E-01	5.55E-04
6.66E-01	6.67E-04
7.77E-01	7.78E-04
8.89E-01	8.89E-04

The above material properties were created in the property module of Abaqus and a solid homogenous section was created and properties were assigned to concrete beam through this created section.

The steel girder is modelled with 3D deformable solid part having a density 7.85e-9onnes/mm^3 and is of isotropic type.

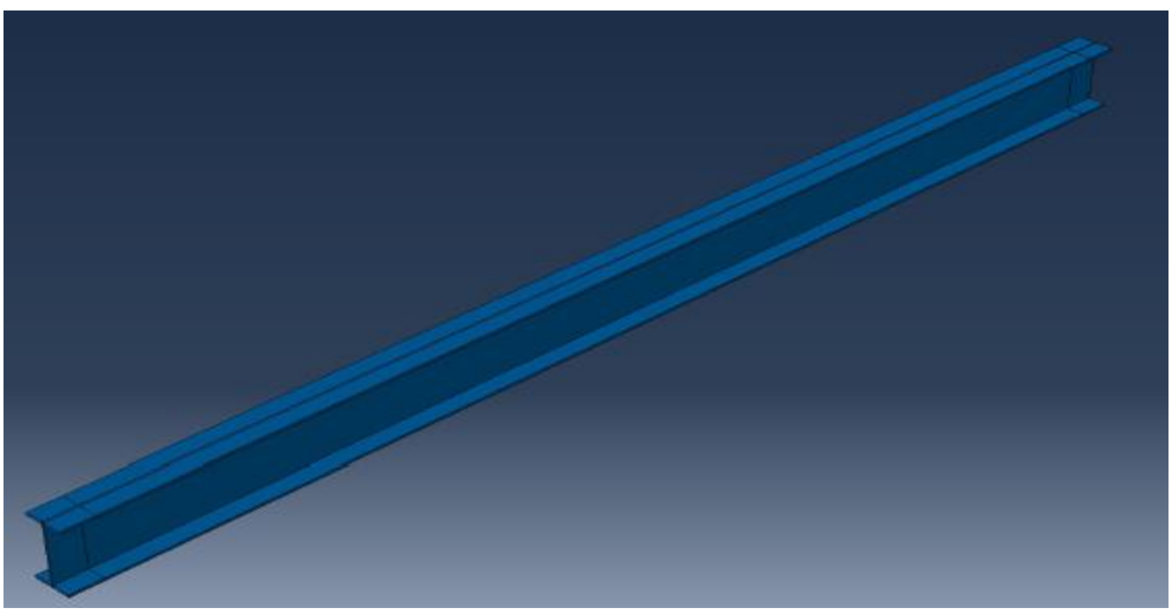


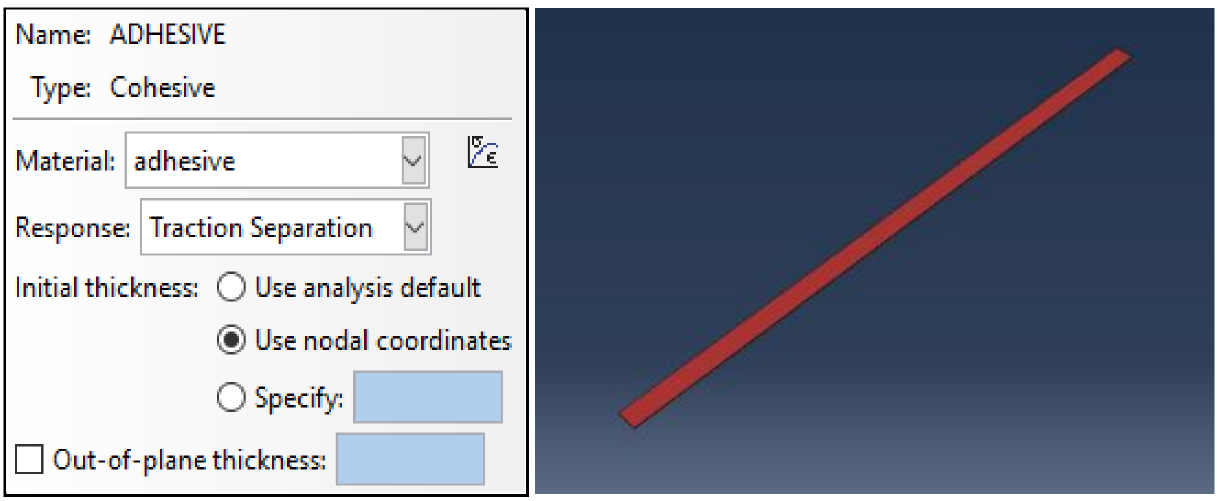
Figure 3.9.Steel Girder created in Abaqus

The steel girder is having a Young's Modulus of 20500MPa and a Poisson's Ratio of 0.3 and other properties are shown below:

Table 3.6. Stress-strain input value for Steel Girder

Yield Stress [MPa]	Plastic strain
470	0
490	0.024
510	0.049
520	0.074
540	0.099
570	0.124

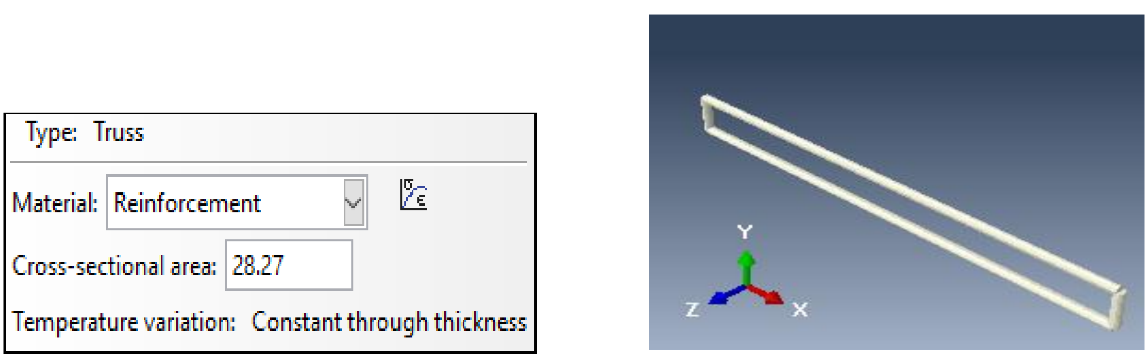
The adhesive is modelled with 3D deformable solid part, the type is traction and is modelled as cohesive element having Young's Modulus of 12300.



(a) (b)

Figure.3.10. (a) Section assignment of Adhesive (b) Adhesive modelled

Steel reinforcing bars are also modelled using 3D deformable part having diameter of 6mm and is created using truss feature.



(a) (b)

Figure 3.11. (a) Section assignment of steel (b) vertical stirrup created

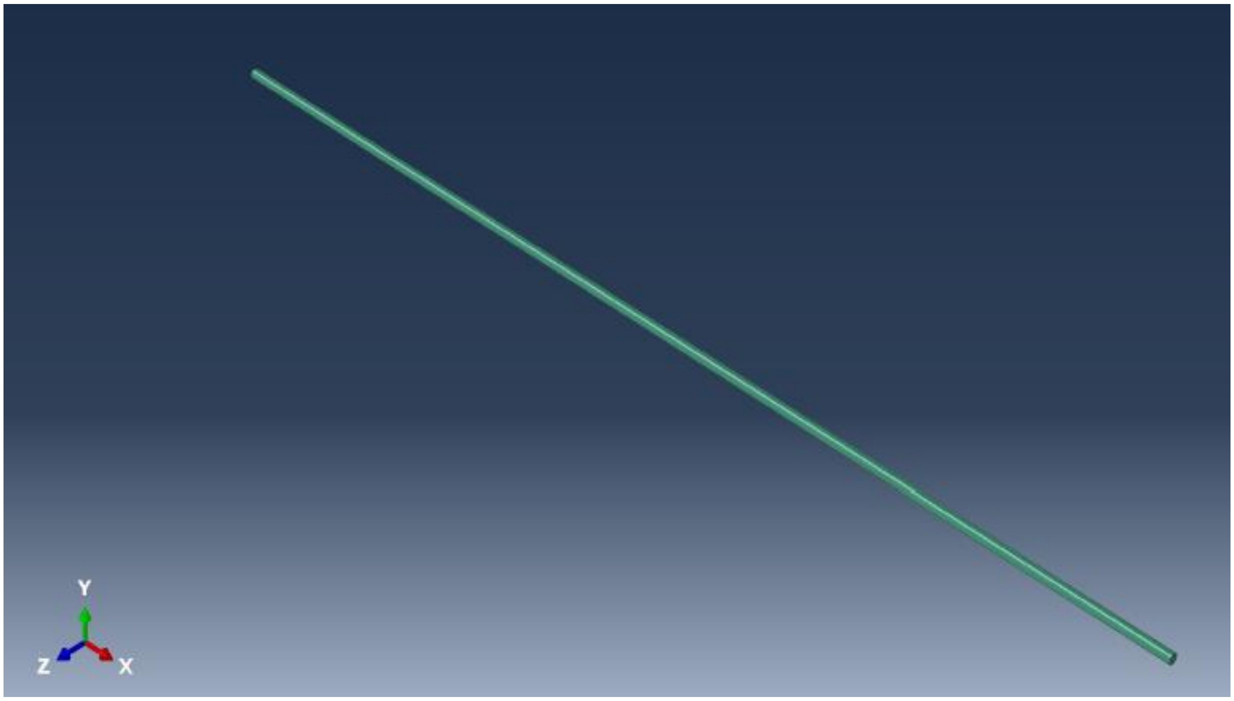


Figure 3.12. Steel modeled in Abaqus

Bilinear elastic perfectly plastic material is used to model steel reinforcing bars embedded in concrete. The properties are shown in figure below:

Table.3.7. Stress-strain value for reinforcing steel

Yield stress[MPa]	Plastic strain
251	0
264	0.024
295	0.049
316	0.074
326	0.099
334	0.124
336	0.149
339	0.174

Load is applied through a reference point created on a rigid part created from 3D discrete rigid solid part.

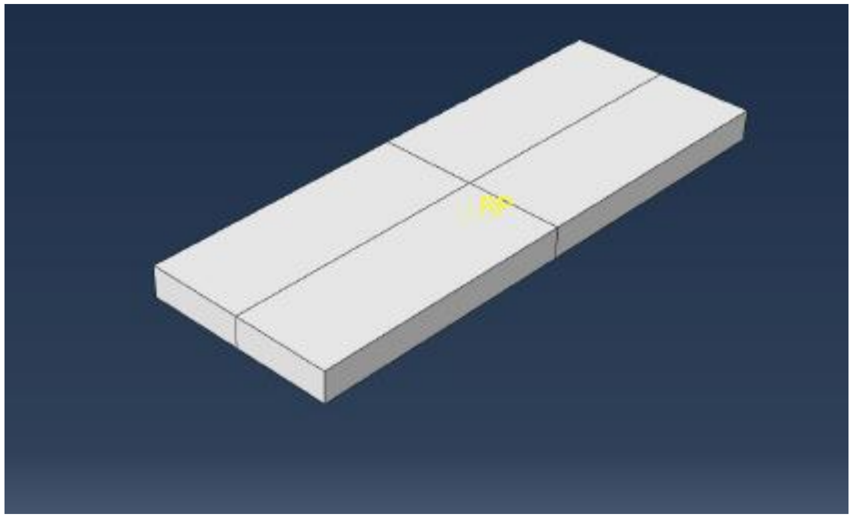


Figure 3.13. Rigid Part created in Abaqus

3.5.1 MODEL ASSEMBLY

Various parts that were created earlier and assignment of material properties were done. These parts are characterized by part instances, exist in local coordinates system and are independent of each other. For development of the complete model it was essential to accumulate all part instances. Assembling of all instances is completed in the assembly module also positioning and orientation of instances is done in the global coordinate system that are relative to one another.

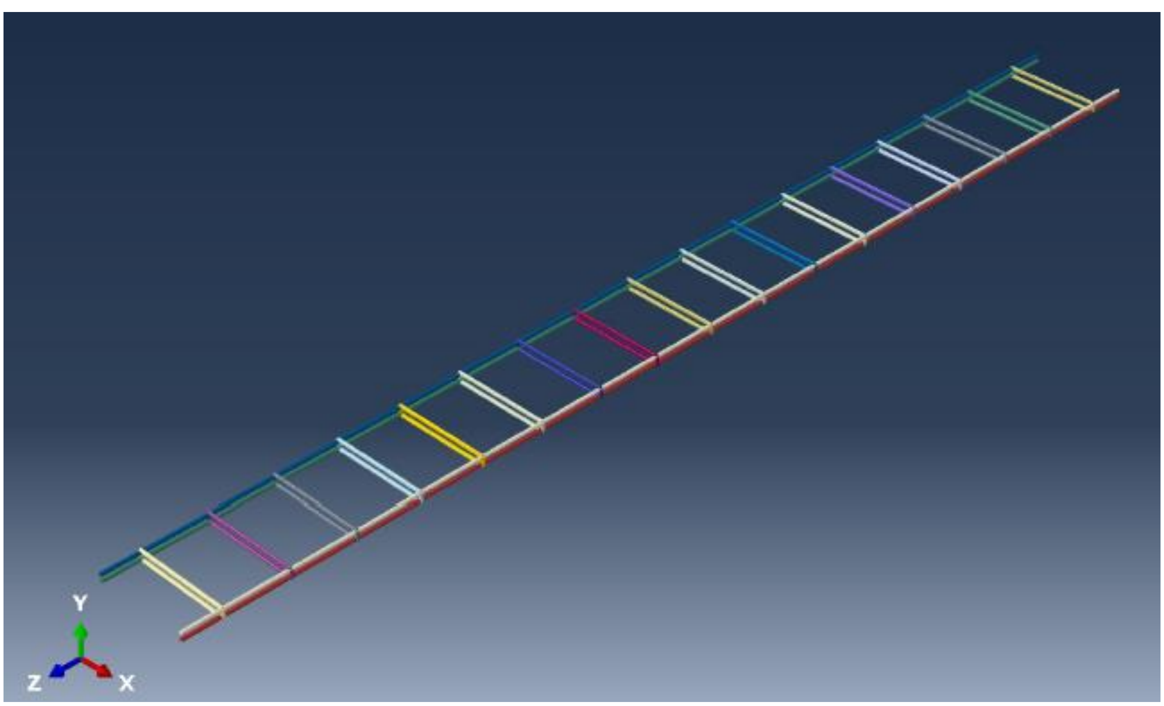


Figure 3.14. Reinforcement instances assembled in global coordinates system

In the Interaction module various interactions were defined. Surface to surface interaction is created between concrete with load cell and supports with steel girder with finite sliding having tangential and normal behavior. The interaction between adhesive with steel girder and concrete beam representing the interface is defined as a tie constraint with adhesive being the slave surface, steel and concrete the master surface. Embedded region constraint is used for representing the interaction between concrete and reinforcing steel. Embedded region is assigned to reinforcing bars and the host region being the concrete.

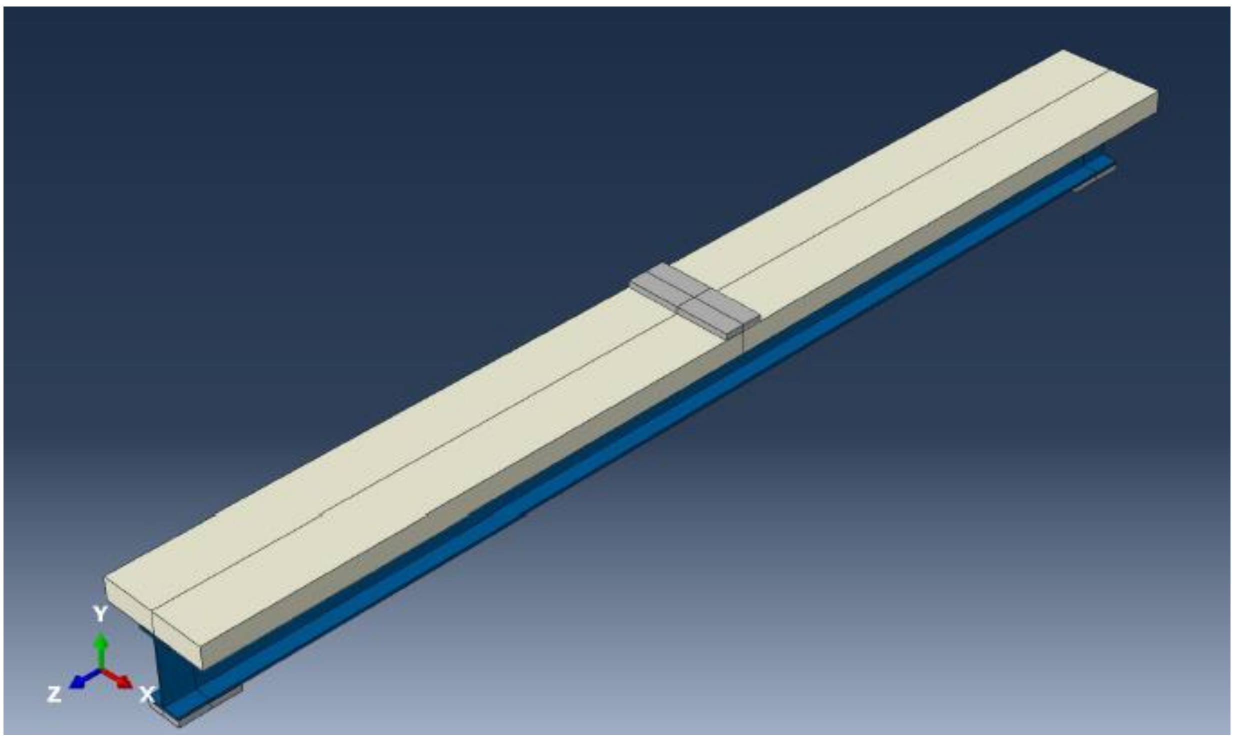
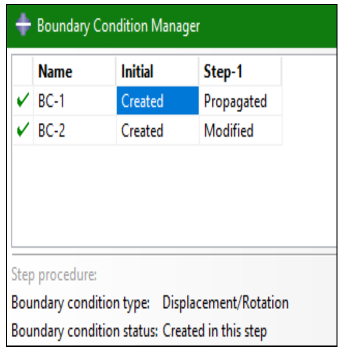


Figure 3.15. Assembly of full composite beam

3.5.2 ANALYSIS AND LOADING PROCESS

It is necessary to define steps in which boundary conditions are active throughout the analysis. In step module different output data is requested and various controls over the analysis process is done. Two steps were created in which initial step is always created by default and the other is static, general analysis step. Step having time period 1 is created with Nlgeom and automatic stabilization activated also the maximum number of increments 10000 with size of initial increment 0.001, minimum increment size is 1E-015 and size of maximum increment 1 are specified. In step, two types of output data were requested which are field and history output and visualization is done later. Field output data are for the whole model and for load displacement curve history output data is requested. The two boundary conditions defined in the initial step and a displacement is defined in negative y direction for load application.



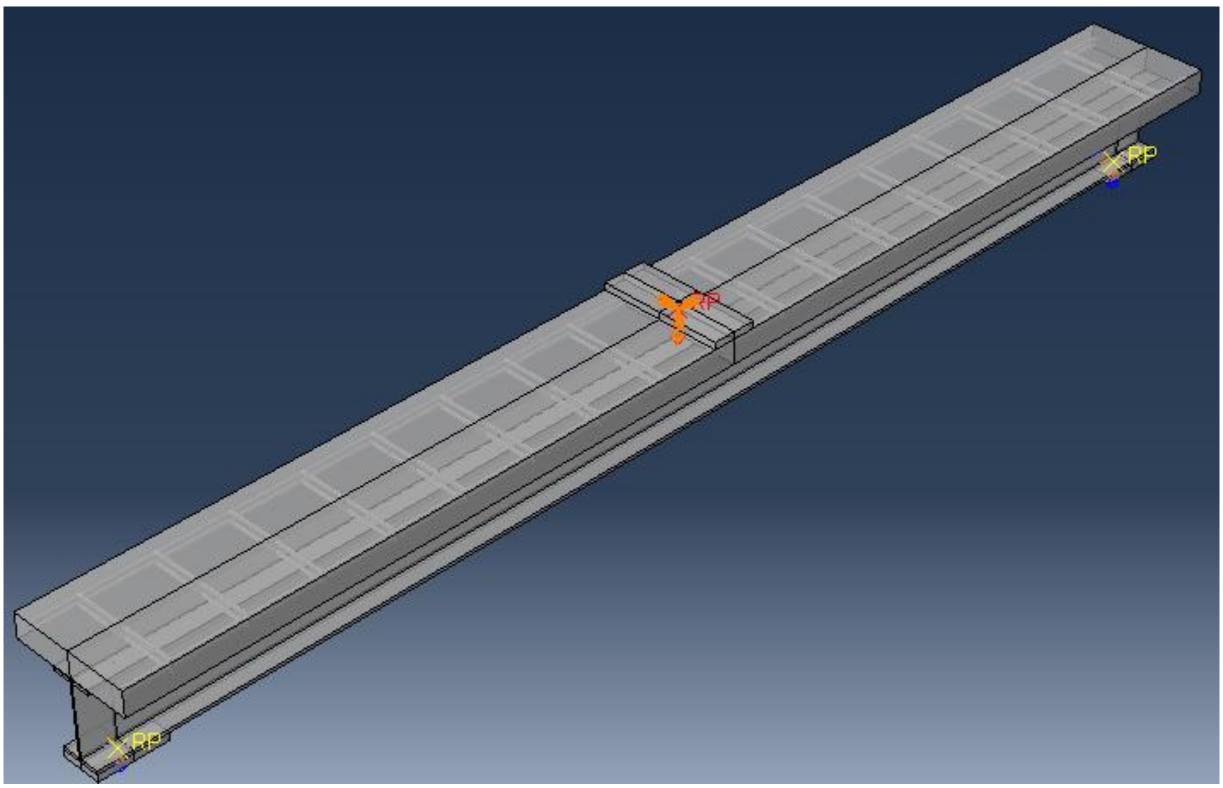


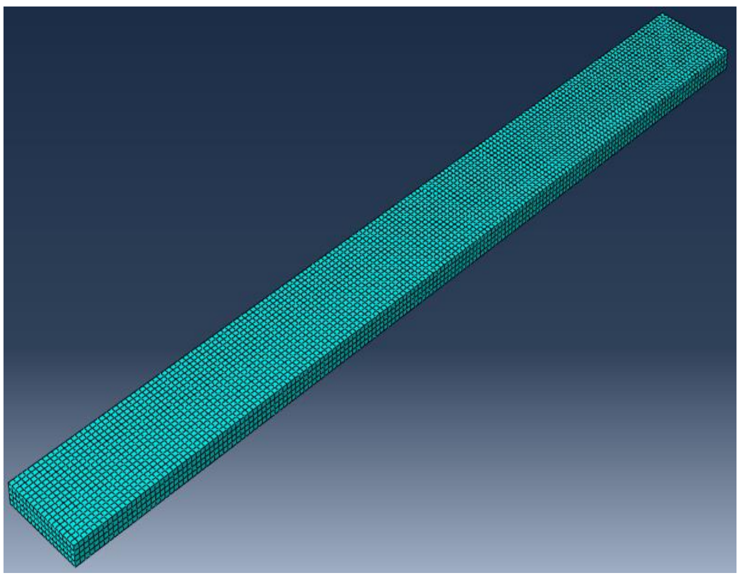
Figure 3.16. Boundary conditions in the model

3.5.3 MESHING

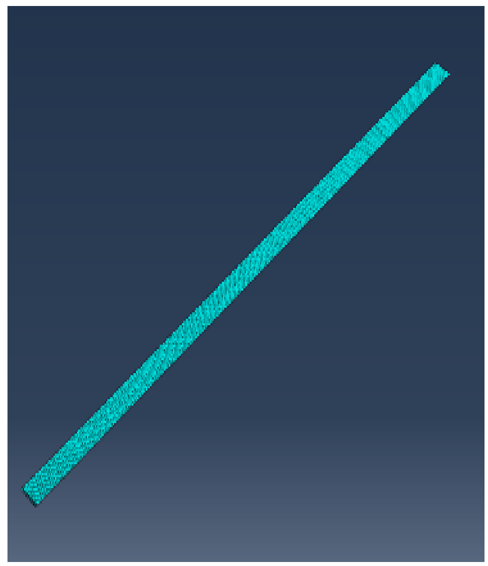
Meshing is dividing of structure into a large number of smaller components. This method is the crucial module in FE analysis as the accuracy of the result is largely governed by the quantity of components. Solid elements are 3D stress elements, the element is used is C3D8R which is linear--8-nodes-isoparametric 3D brick elements having reduced integration.

For generating mesh of steel girder and concrete beam structured technique is used and meshing of steel reinforcement and cohesive zone is done by free and sweep techniques. For meshing the interface between steel girder and concrete beam cohesive elements are used. The elements are the COH3D8 is 8-nodes 3D cohesive elements. Discrete rigid Element R3D4 which is 4- node 3-D rigid quadrilateral used for rigid part. Reinforcing steel is assigned with truss elements that have only axial stiffness and no bending stiffness. The elements used were T3D2 which are 2 node-linear 3-D truss elements.

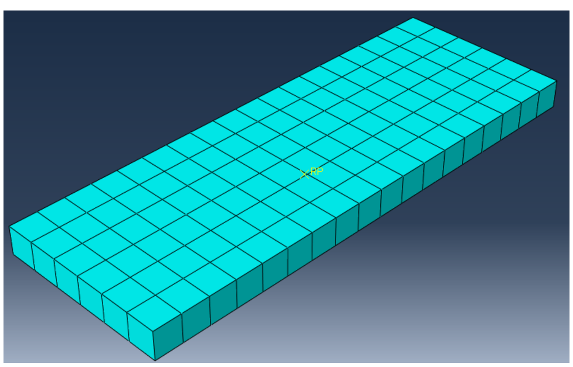
For meshing concrete beam uniform seeding is done with global size of 25mm. Total number of elements for meshing concrete are 12528. Adhesive is meshed with 10mm size mesh having 12782 elements. Steel girder is having a mesh size of 25mm with 2520 elements. Rigid block with a mesh size of 20mm with 288 elements. Support for the composite beam is meshed with 20mm mesh size having 168 elements. Stirrup and longitudinal steel bar is meshed with 10mm size mesh having 66 elements and 344 elements respectively.



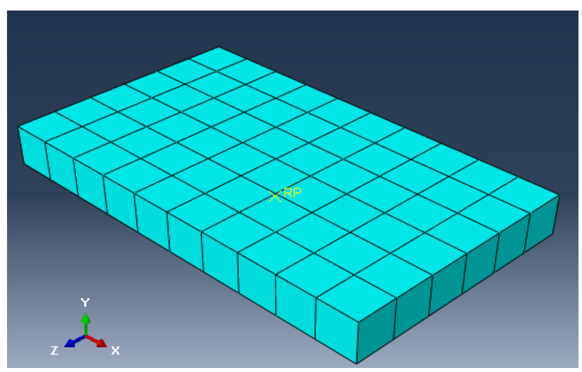
Concrete beam
C3D8R



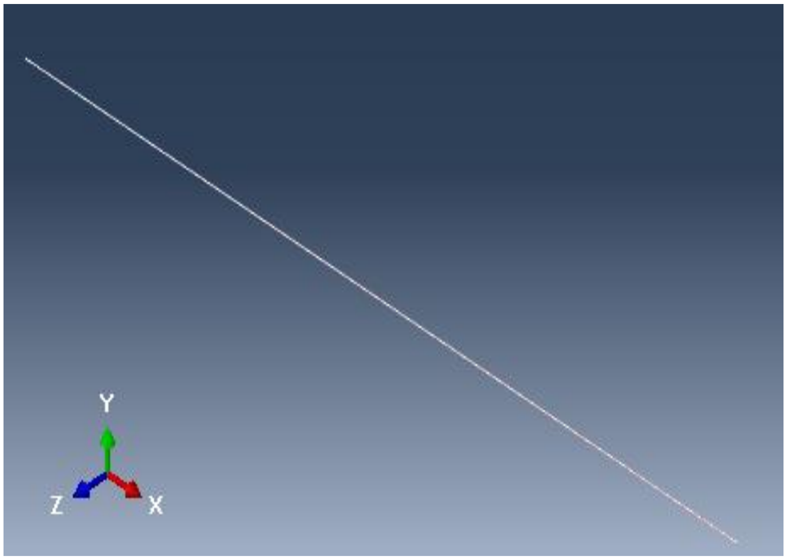
Adhesive COH3D8

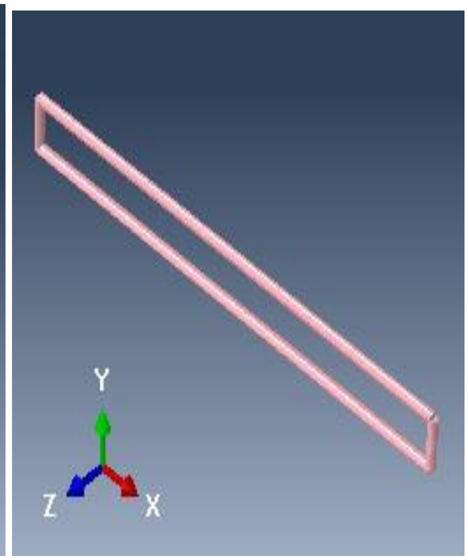


Rigid block
R3D4



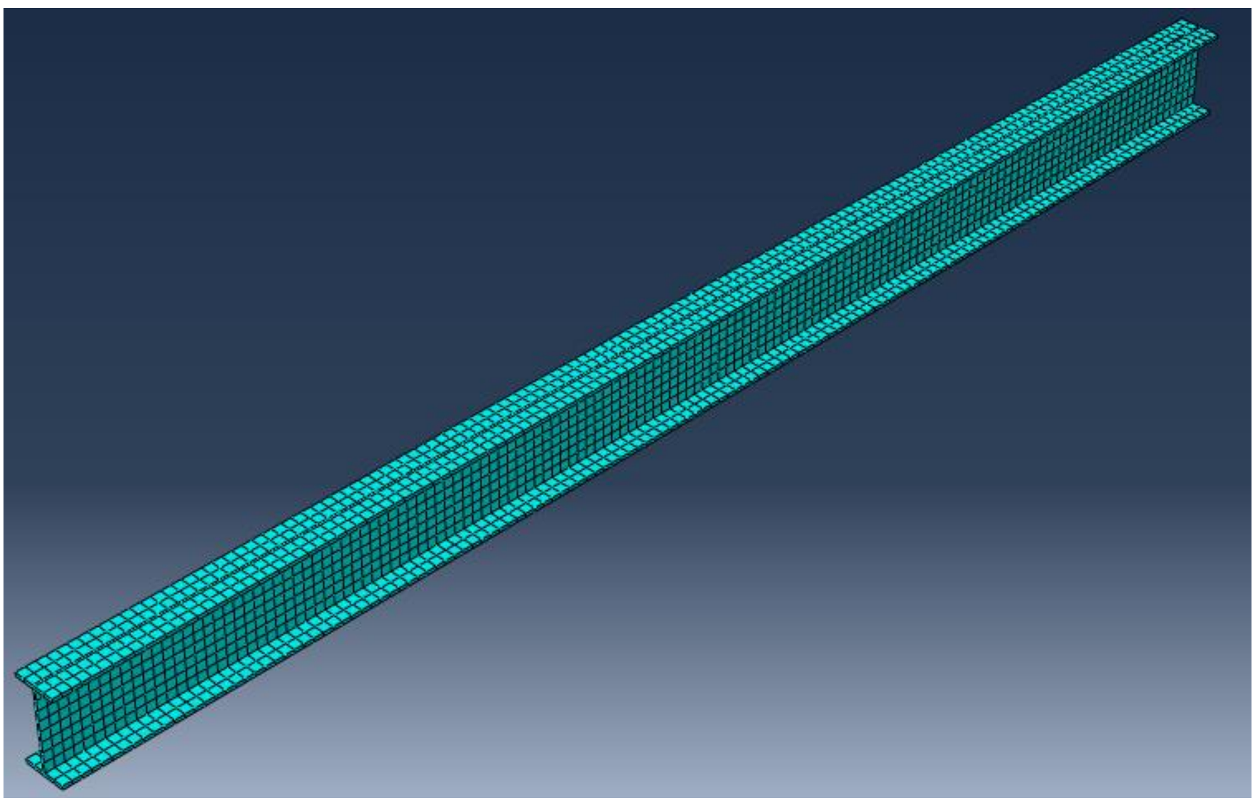
Support
R3D4





Steel bar
T3D2

Stirrup
T3D2



Steel Girder C3D8R

Figure 3.17. Meshing of different parts

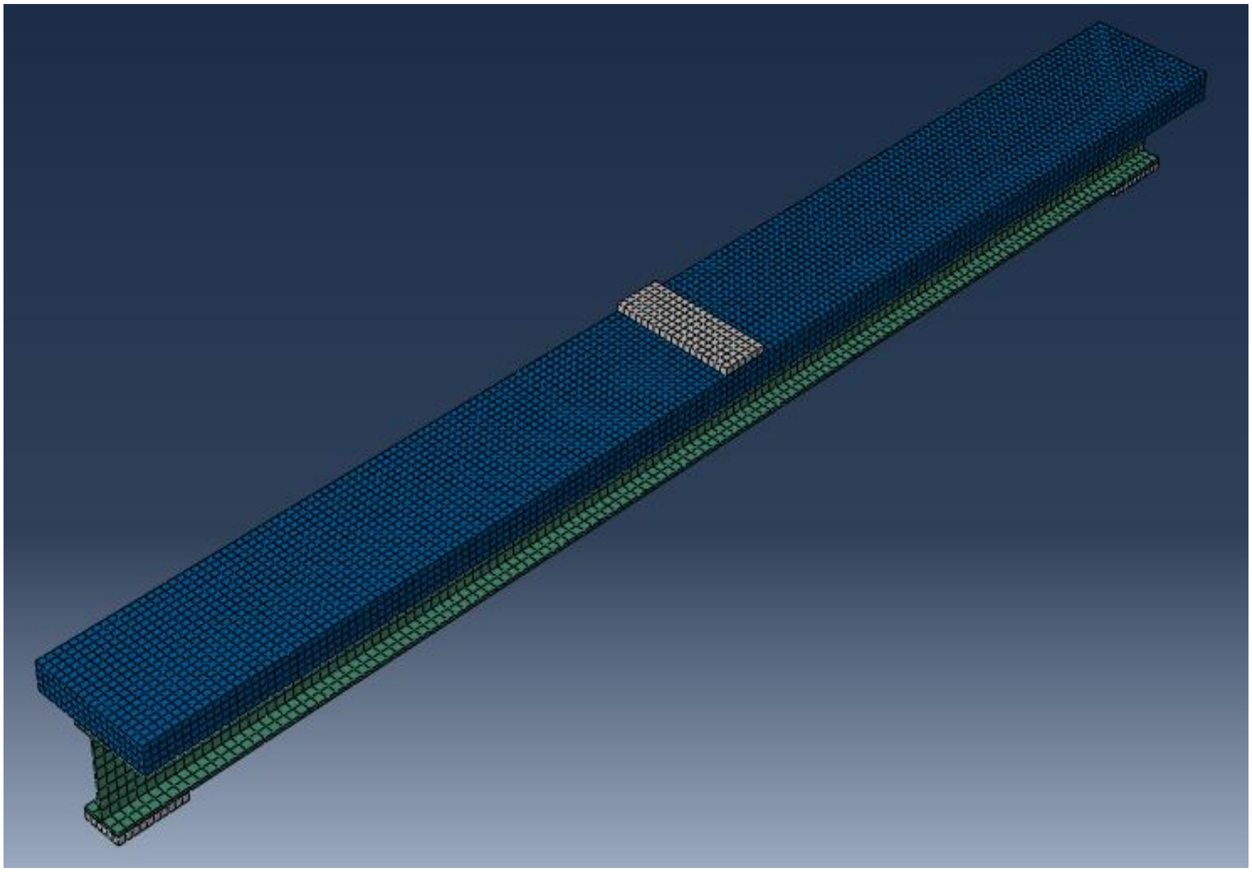


Figure 3.18. Meshed Steel concrete composite beam

The total number of elements used in the mesh are 35176. All the essential tasks that were involved in the construction the model are done and therefore the next step is to create a job and submit it for analysis. In addition to that the progress of the analysis is observed. Full analysis type is used in the job and also with analysis the input data connected to the model is written and thus the whole analysis is finished with that the results are written to the output database (ODB) available for visualization.

3.6 MODELLING OF STEEL CONCRETE COMPOSITE SECTION

The second model is Steel-concrete composite section bonded with adhesive and this model is developed to know the failure and how it is going to take place at the interface. All the processes are same as applied to previous model with difference in geometry and application of load.

Steel is modeled as 3D deformable solid part as shown in figure with length 200mm, thickness 20mm and width 25mm. The behaviour of material is elastic and isotropic with some properties are shown below.

Table 3.8. Properties of Steel

Young's modulus [MPa]	Poisson's Ratio
210000	0.3

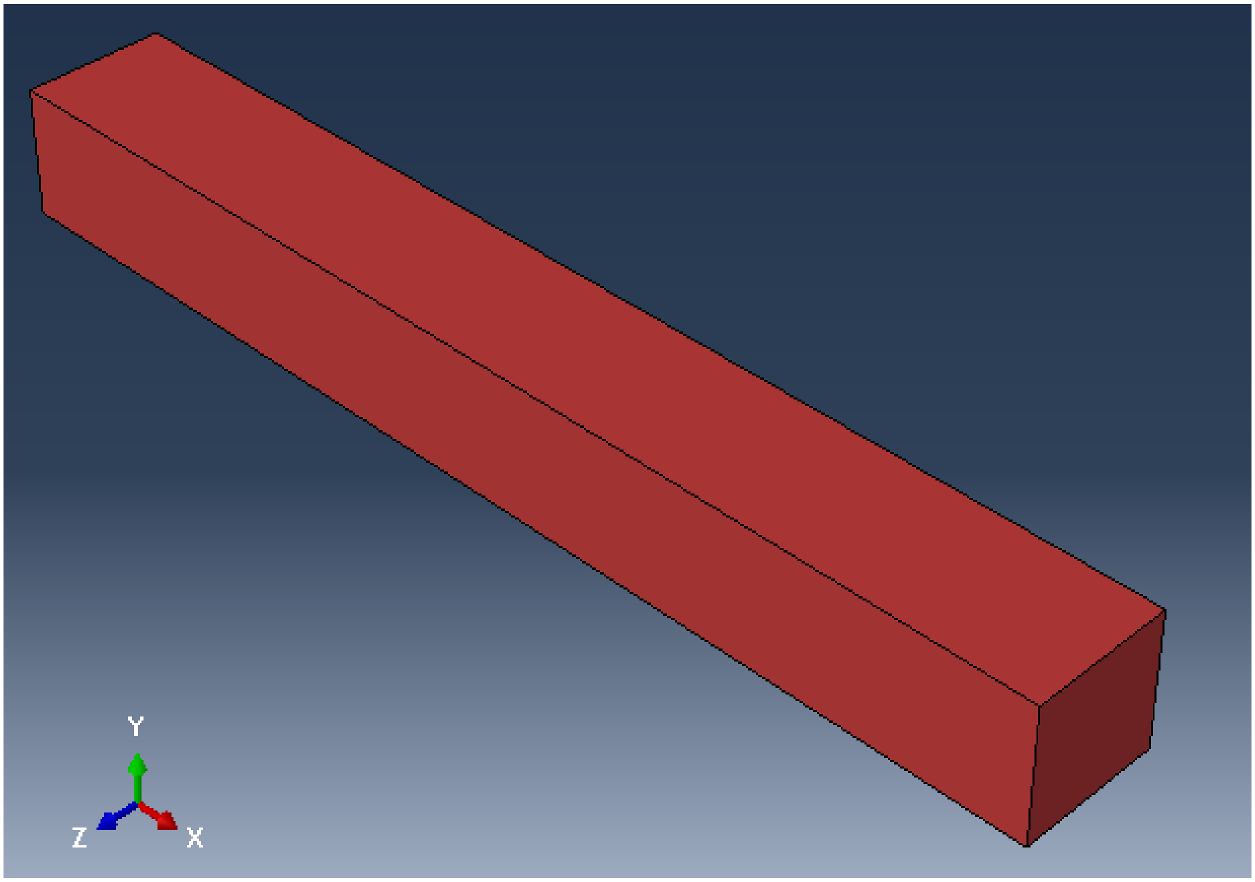


Figure 3.19. Steel Part created in Abaqus

Concrete is modeled as 3D deformable solid homogenous part as shown in figure with length and width same as steel part but its thickness of 30mm. The behavior of concrete considered is elastic and isotropic having some properties shown below:

Table 3.9. Properties of concrete

Young's modulus [MPa]	Poisson's Ratio
25000	0.2

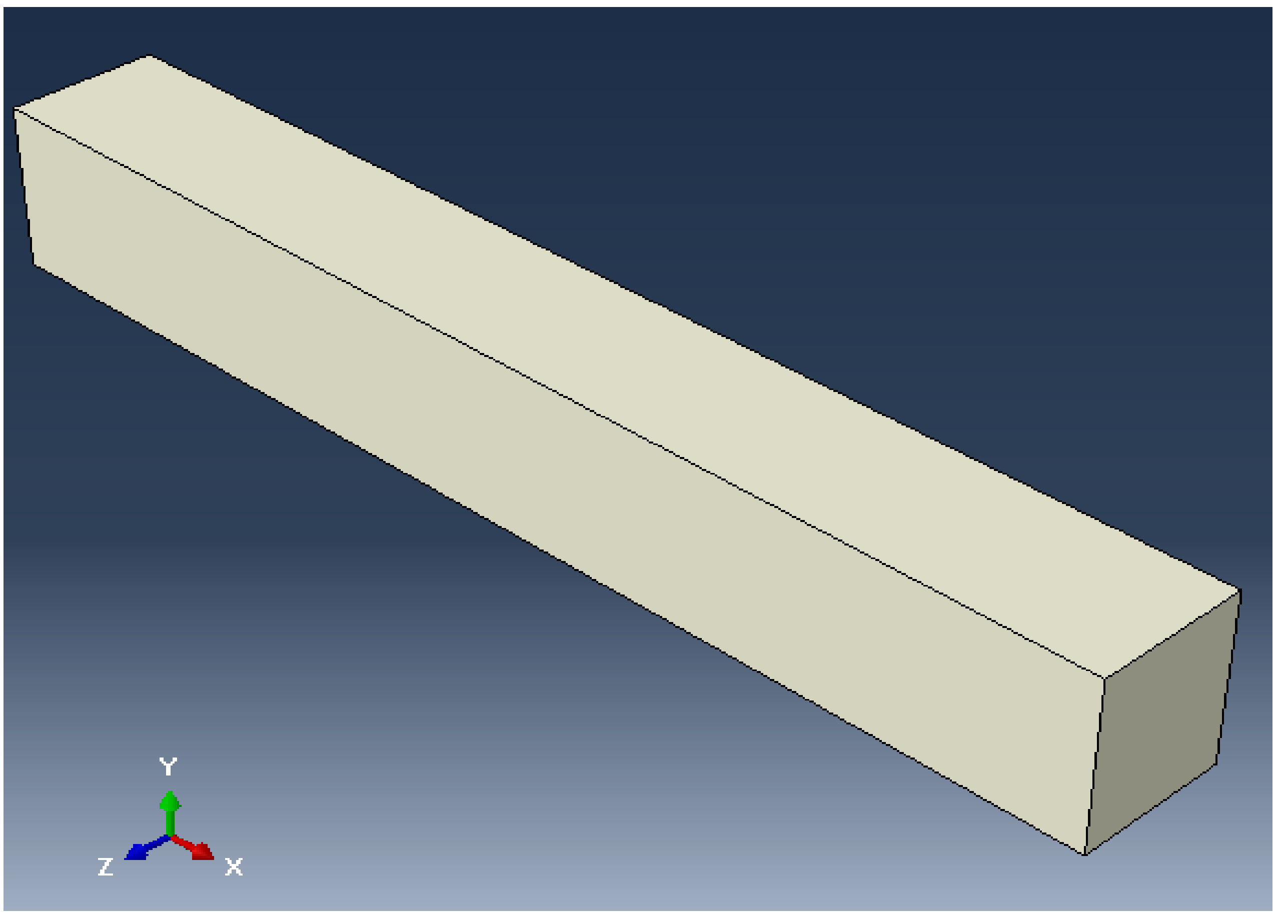


Figure 3.20. Concrete Part created in Abaqus

Adhesive is modeled as cohesive part having a length of 200mm, 25mm wide and 1mm thick. The behavior is elastic and traction type.

Table 3.10. Properties of Adhesive

E/Enn	G1/Ess	G2/Ett
1800	500	500

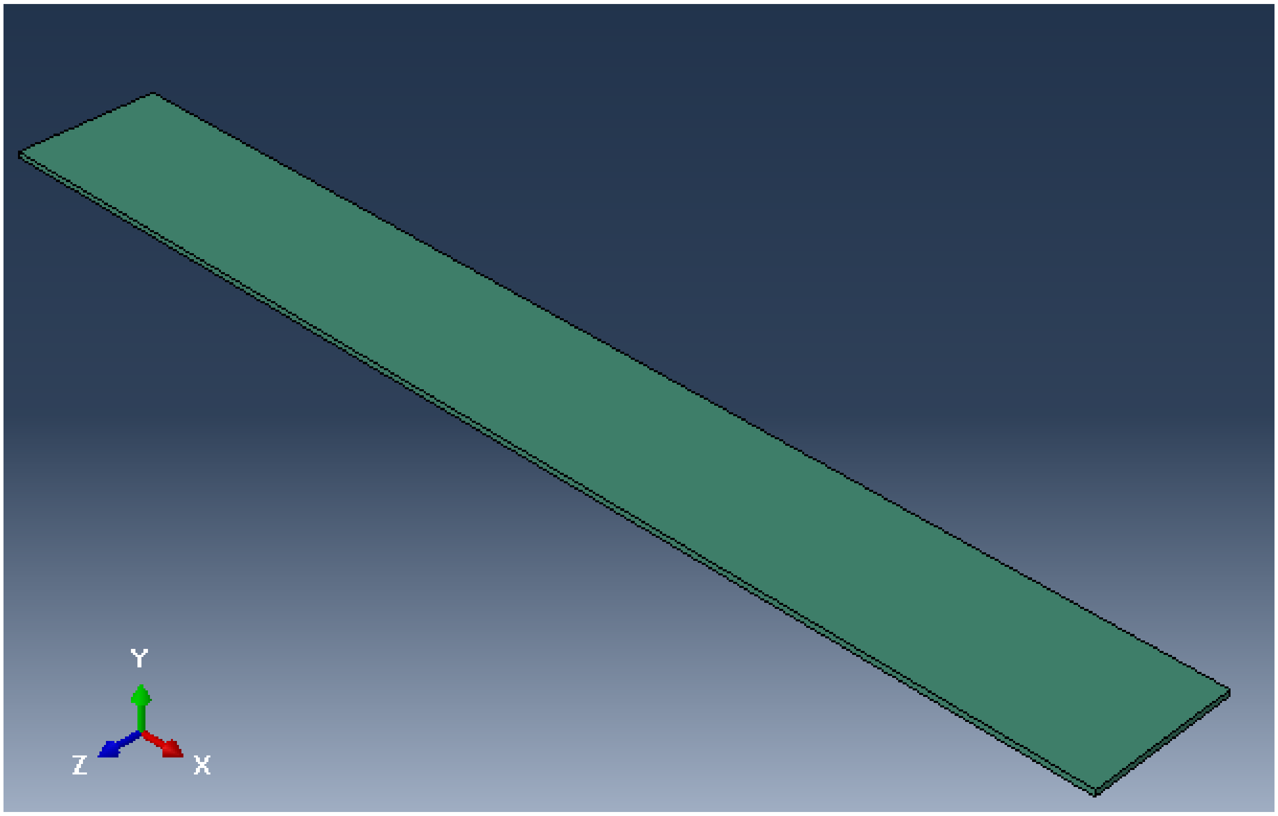


Figure 3.21. Adhesive part created in Abaqus

Material properties were assigned to these part instances and for constructing complete model it was essential to assemble these part instances. As discussed previously these part instances are assembled together through assembly module.

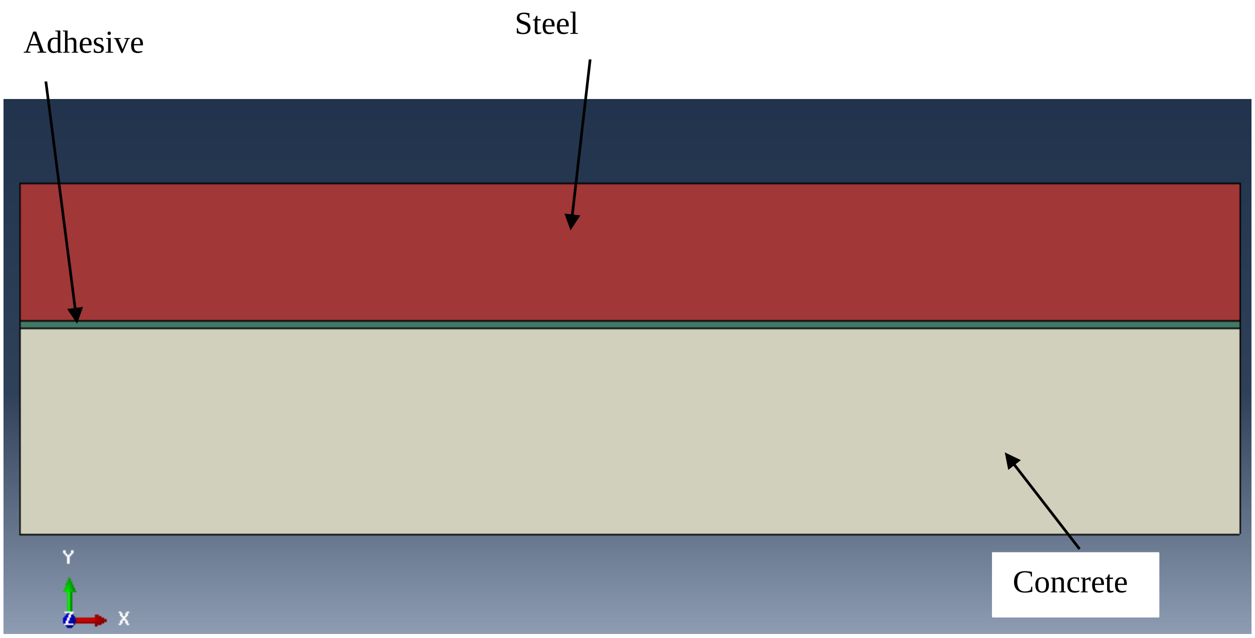


Figure 3.22. Assembly created in Abaqus

In the interaction module tie constraint is applied to establish the contact of adhesive with steel and concrete respectively. The adhesive is provided with the slave surface while steel and concrete are provided with master surface. Coupling constraint is applied over the steel surface for the loading purpose.

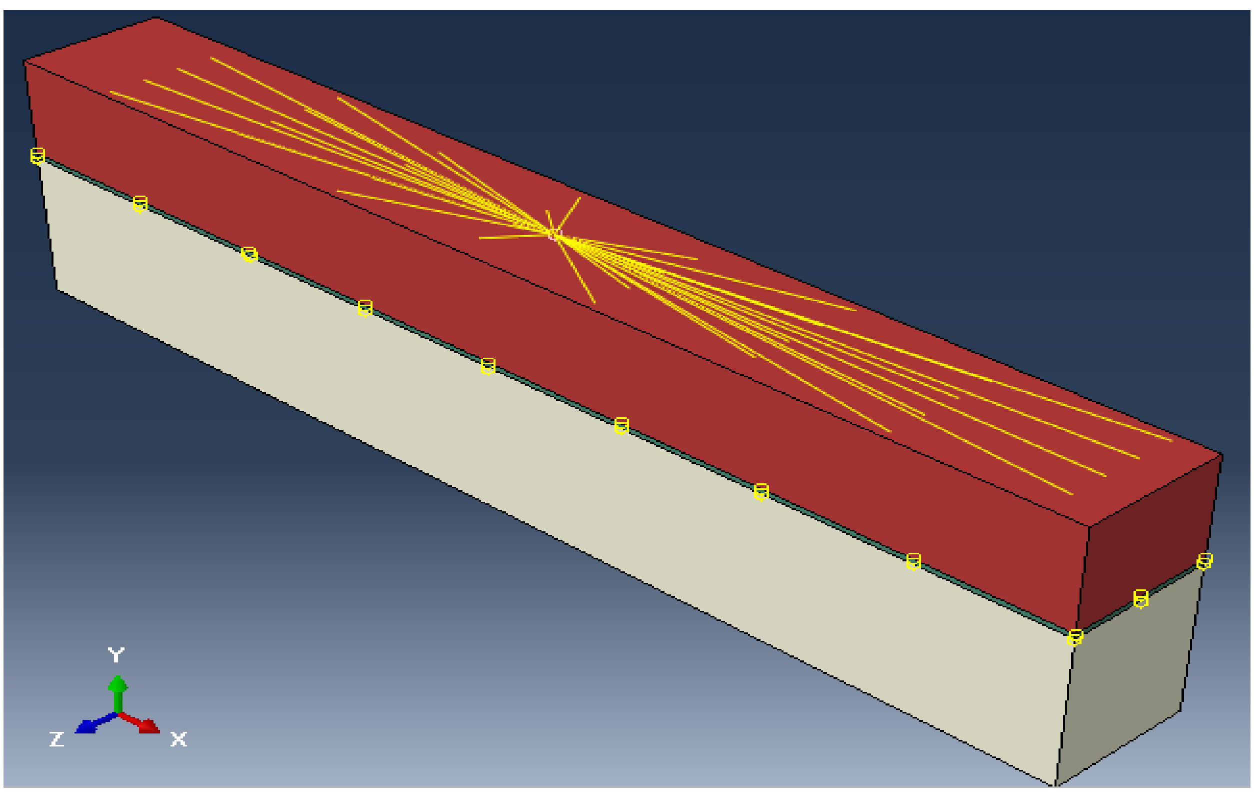


Figure 3.23. Assembly with interaction created in Abaqus

In step module two steps are created and different output data is requested in which initial step is always created by default and the other is static general analysis step. Step time period 1 is created with Nlgeom and the maximum number of increments 2000 with size of initial increment 1E-005, minimum increment size is 1E-015 and maximum size of increment 1 are specified.

Step Manager

	Name	Procedure	Nlgeom	Time
✔	Initial	(Initial)	N/A	N/A
✔	Step-1	Static, General	ON	1

Two Boundary conditions are applied to the model having one support reaction as encastre having (U1=U2=U3=UR1=UR2=UR3=0) and other boundary condition is displacement in initial step and modified in step-1.

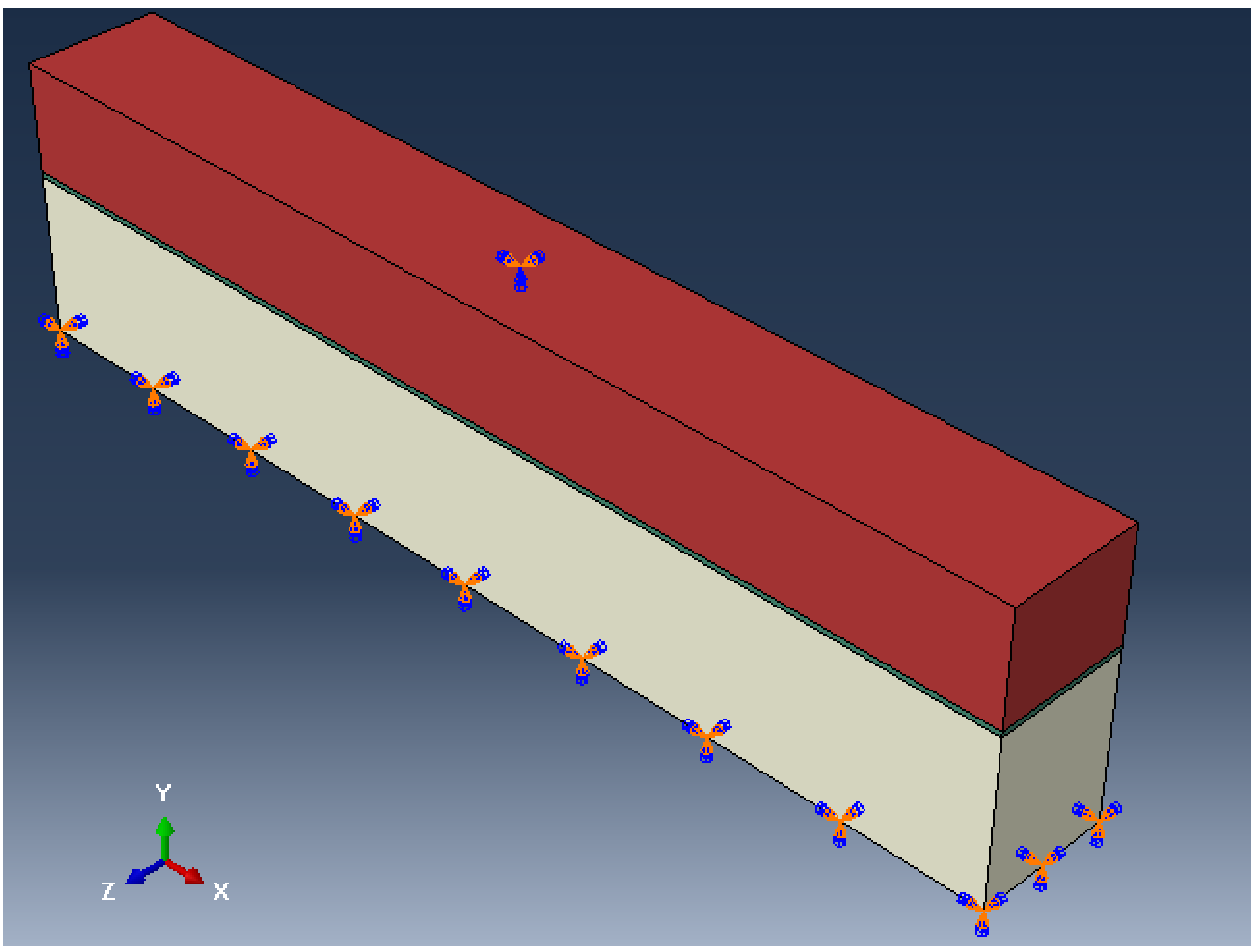
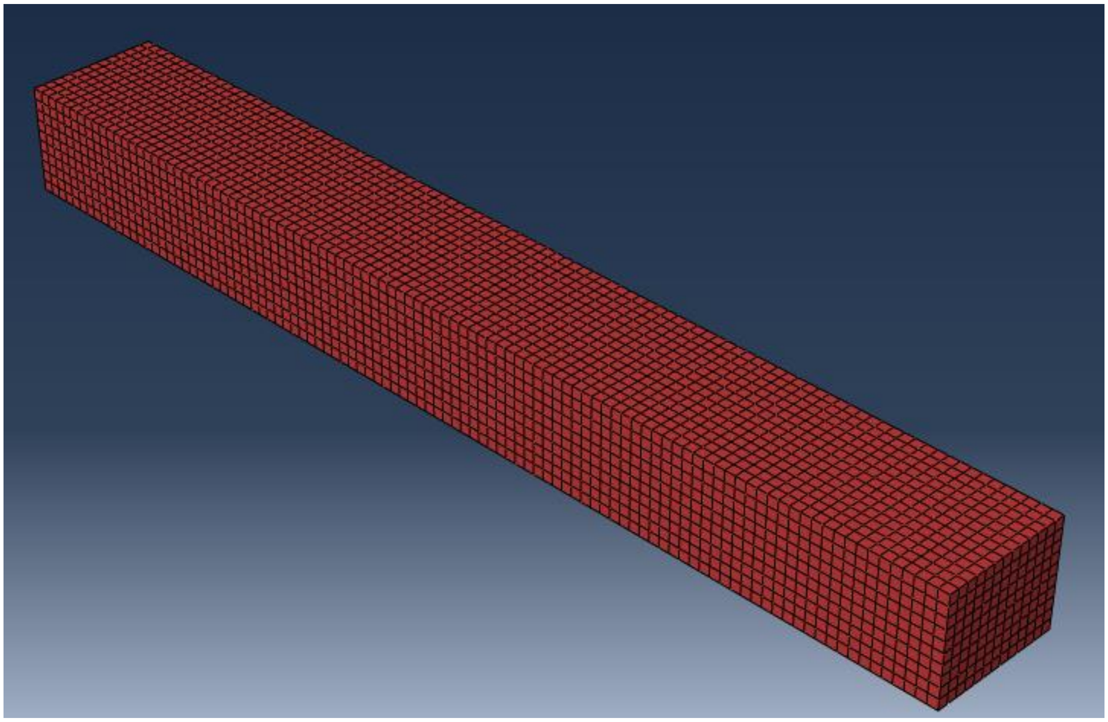


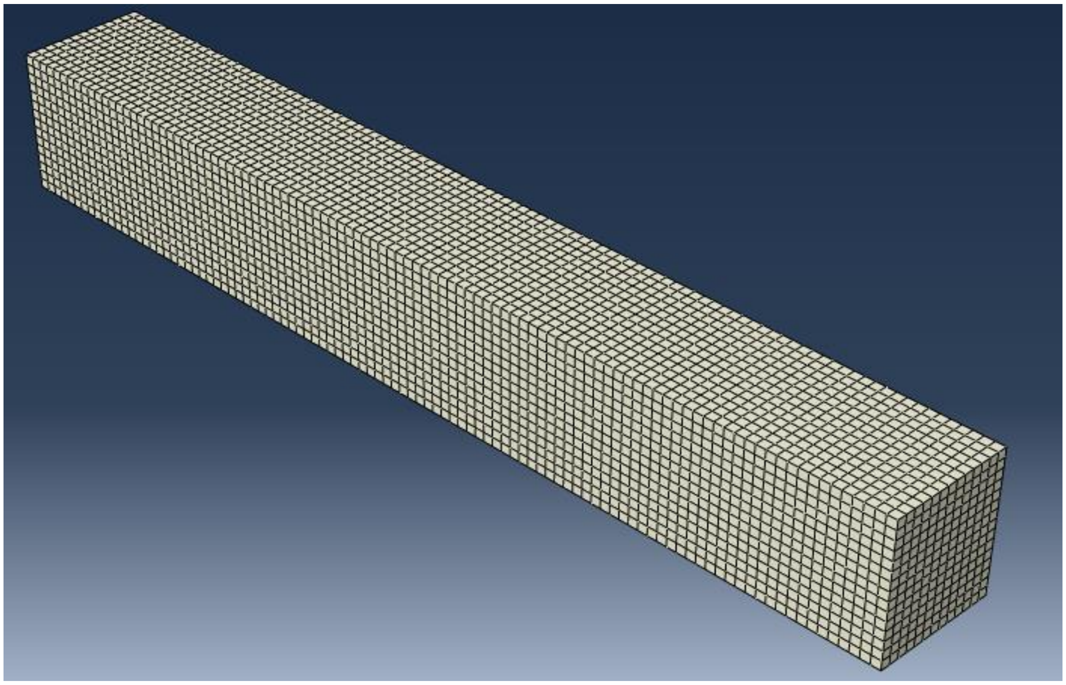
Figure 3.24. Boundary conditions on section created in Abaqus

Steel and concrete both are meshed with 2mm global size mesh having 32500 3D stress type elements (C3D8R: linear tetrahedral element).

Adhesive is meshed with 1mm size global mesh having 5000 cohesive linear type elements (COH3D8: linear tetrahedral element).

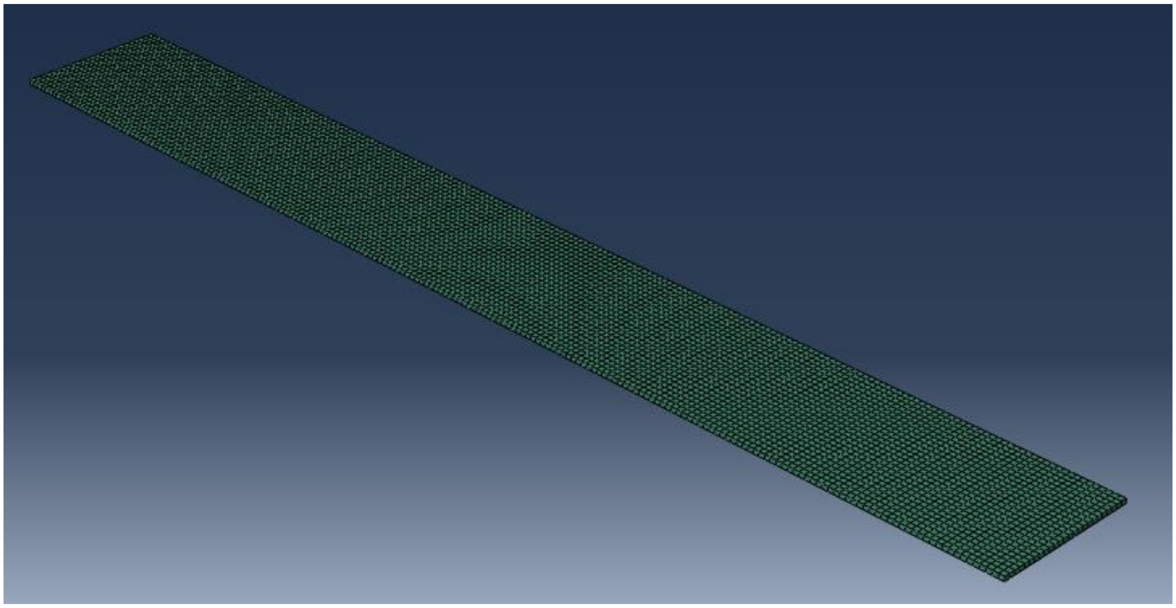


Steel C3D8R



Concrete

C3D8R



Adhesive

COH3D8

Figure 3.25. Meshing of different parts

The total number of elements in the meshed steel concrete composite are 37500. All tasks of modelling are done and it is submitted for analysis. The results will be discussed in the next chapter.

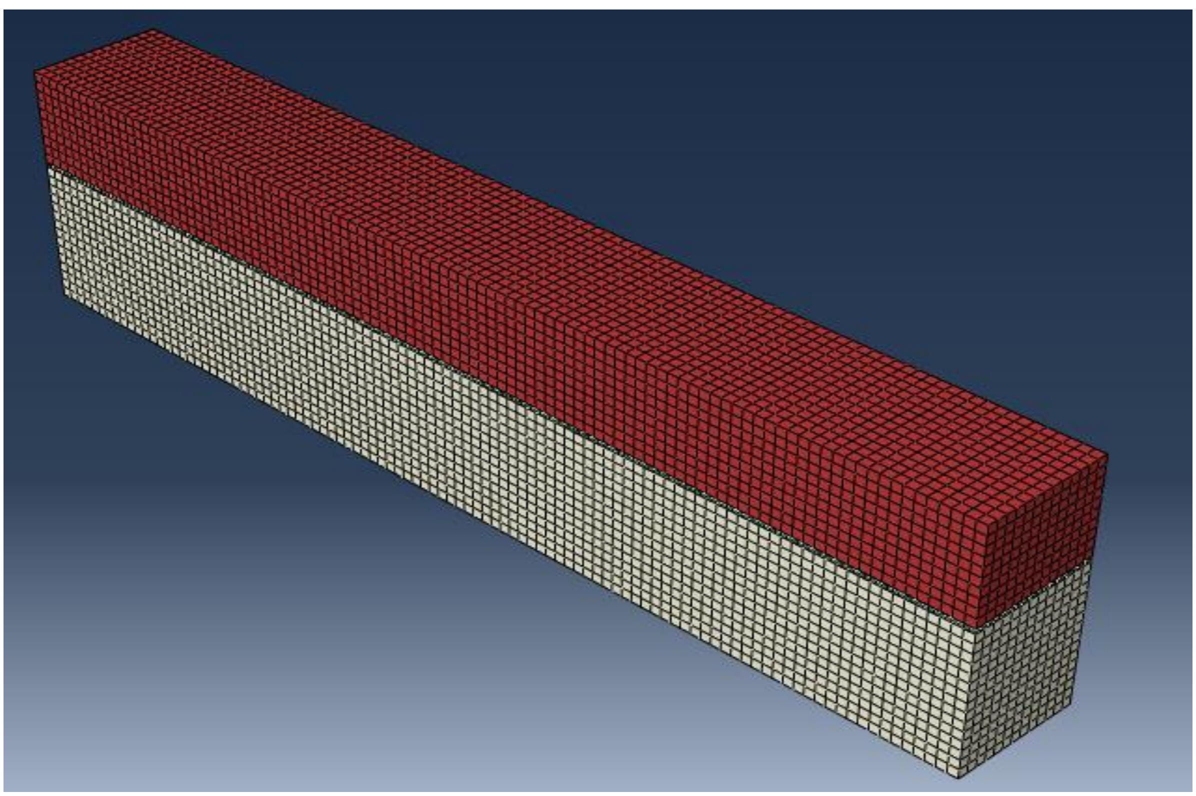


Figure 3.26. Meshed steel concrete composite section

3.7 SUMMARY

FEM is among different numerical methods used to solve a large range of advance engineering problems. It consists of discretizing a complex structure into finite elements and solves for every component to search out the response field of interest with comparatively high accuracy. However to achieve success in this method it's necessary for the user to possess systematic understanding of the behavior of various materials concerned within the physical problem and the contact between them. This chapter presents the nonlinear response of concrete and its cracking mechanisms. The behavior of reinforcing steel is idealized as elastic perfectly plastic and ways of modeling its contact with concrete are reviewed. The interface between steel and concrete composite constitutes a main component in the overall behavior of steel concrete composite. This chapter also mentioned the methodology used for finite element analysis of steel concrete composite section bonded by adhesive. Various steps and procedures are followed to framework the geometry of the models are mentioned. The various properties assigned to every material concerned are mentioned and presented. The assembly of various elements used to create the model is presented and the interactions between all the elements are mentioned. The interaction comprises of surface to surface, tie, coupling and embedded region. The discretization of the models into FE for analysis purposes was additionally checked out also boundary conditions applied to the model, loading pattern and various outputs that are requested are discussed. Static stress analysis type is used for analysis of models. The following chapter discusses the results of finite element analysis.

CHAPTER 4

OBSERVATIONS AND RESULTS

This chapter presents various observations and the results obtained from FE simulation carried out on Steel concrete composite section. Various contours of different outputs are established for every part and the whole model is evaluated. The following results are from first model.

The displacement obtained is shown in figure below and also load displacement curve is obtained.

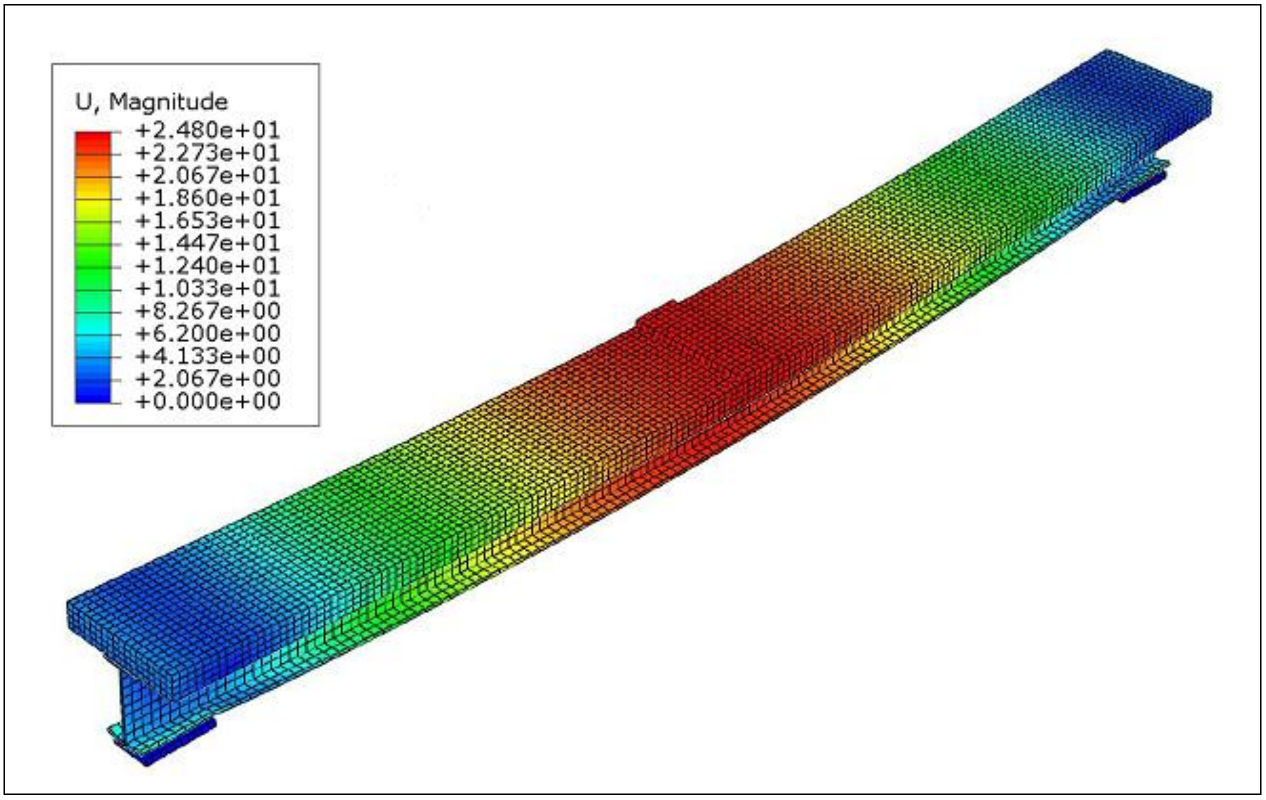


Figure 4.1. Displacement distribution in steel concrete composite section

- The displacement produced in composite section has a maximum value of 24.8mm at the mid-span and the displacement decreases as moved towards the end.

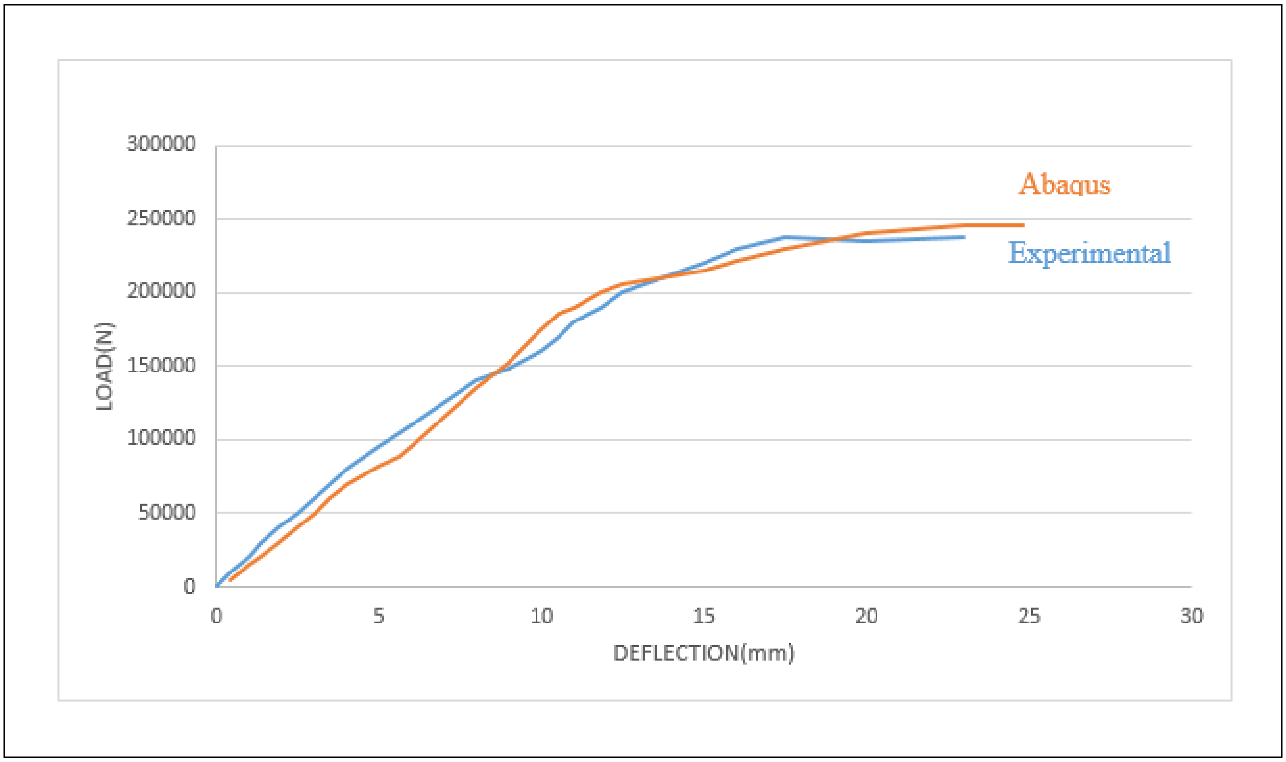


Figure 4.2. Load Displacement curve of steel composite section

The results obtained from FEM analysis are:

- The failure of steel concrete composite section is due to the yielding of steel and crushing of concrete at the mid-span and mainly due to bending.
- The adhesive used for bonding the beam is in condition that is unfavourable still the adhesive joint has no cracks subjected to maximum value of shear force .
- The ultimate load observed was 246 kN having maximum value of deflection 24.8mm. Adhesive's strength, nature and properties are very important in composite bonded structures and directly impacts the critical load of the composite section.
- By varying the adhesive's thickness in the range of 3 to 5 mm, the impact resulting from this variation on the critical load of the section is insignificant.

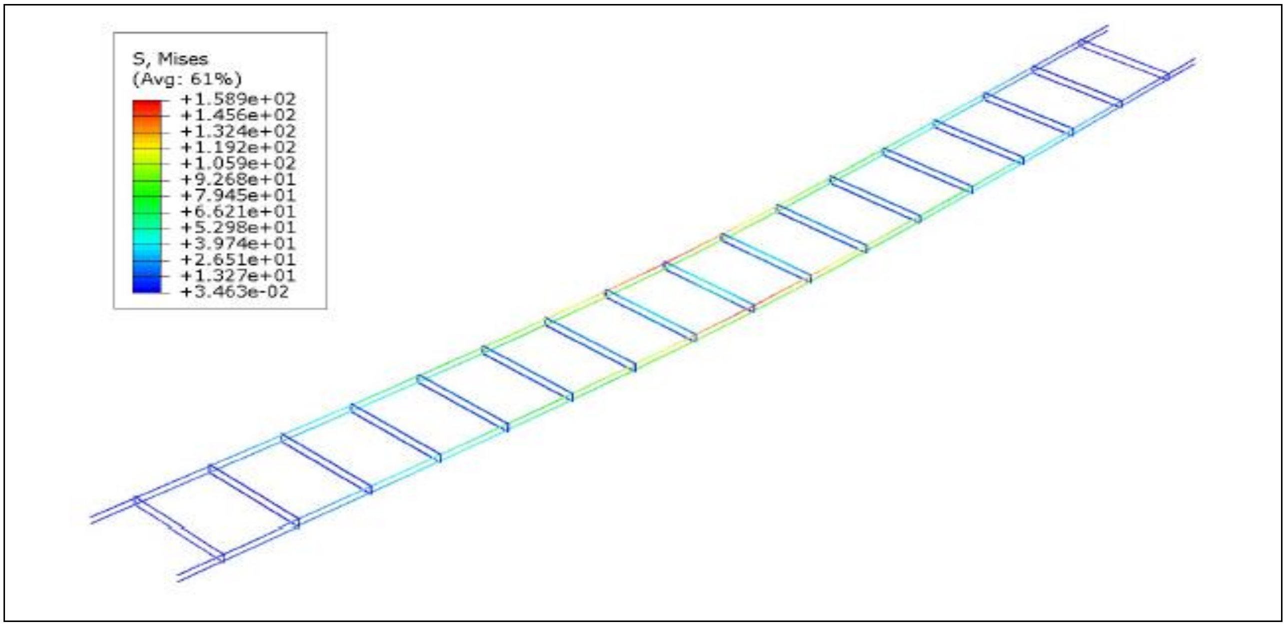


Figure 4.3. Stress distribution in reinforcement steel

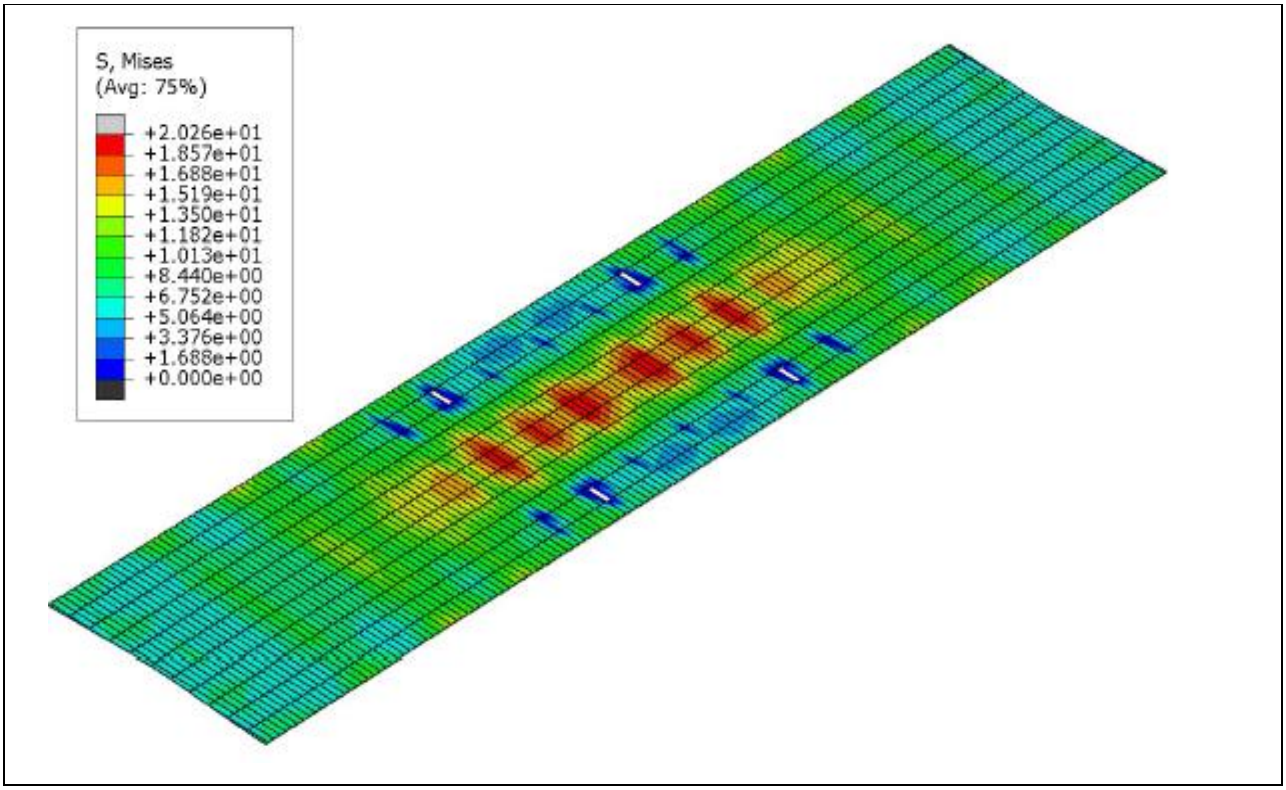


Figure 4.4. Stress distribution at the interface

Von Mises stresses are shown in the figures below:

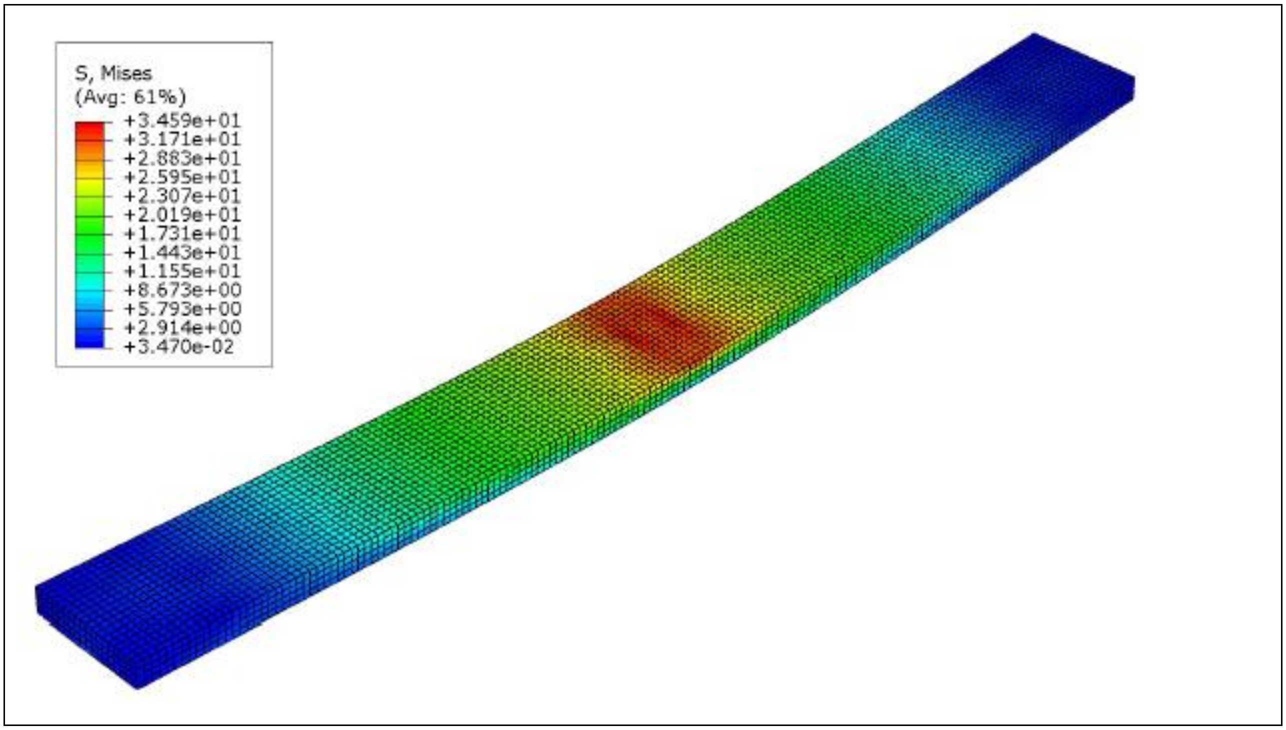


Figure 4.5. Stress distribution in concrete section

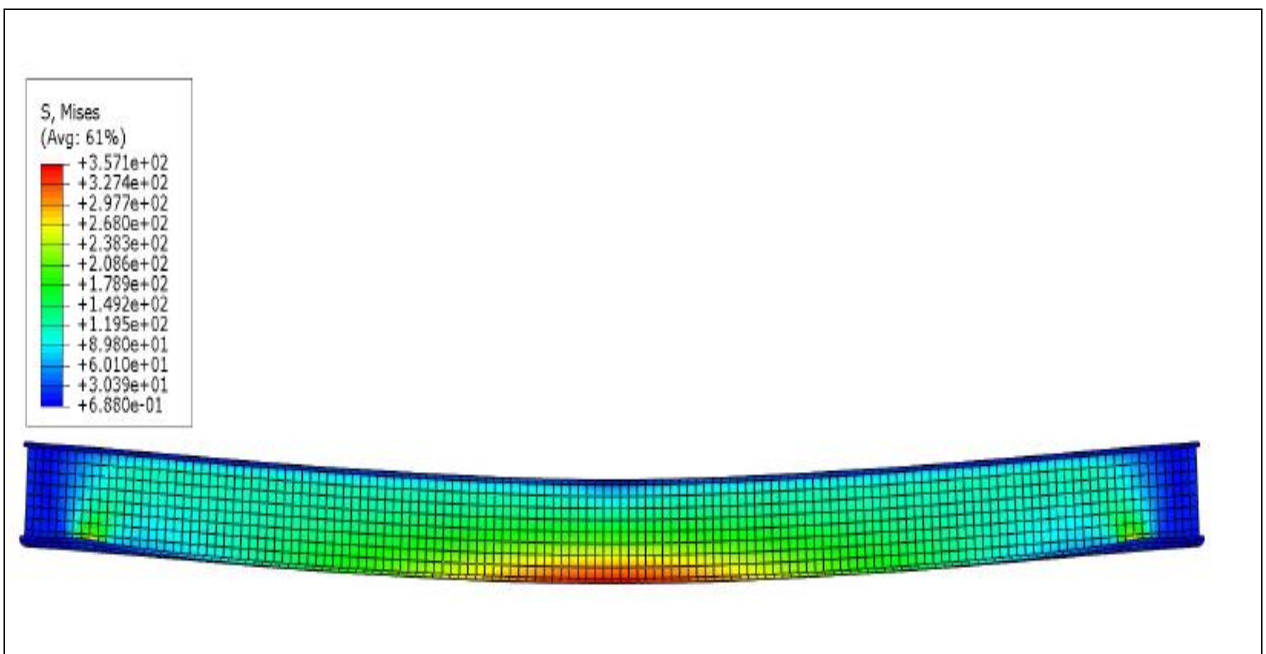


Figure 4.6. Stress distribution in steel girder section

The figures of all results for the second FE model includes von Mises stress, strain and displacements are shown below:

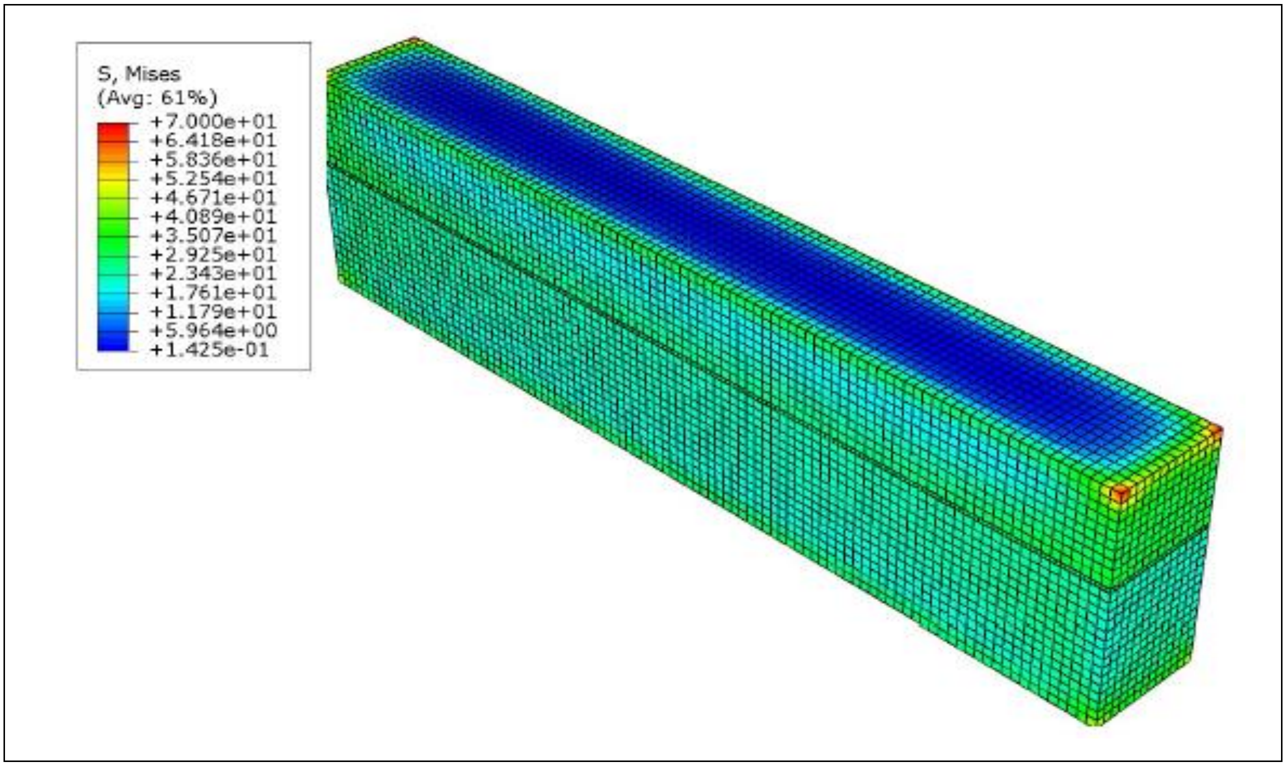


Figure 4.7. Stress distribution in steel-concrete composite section after application of load

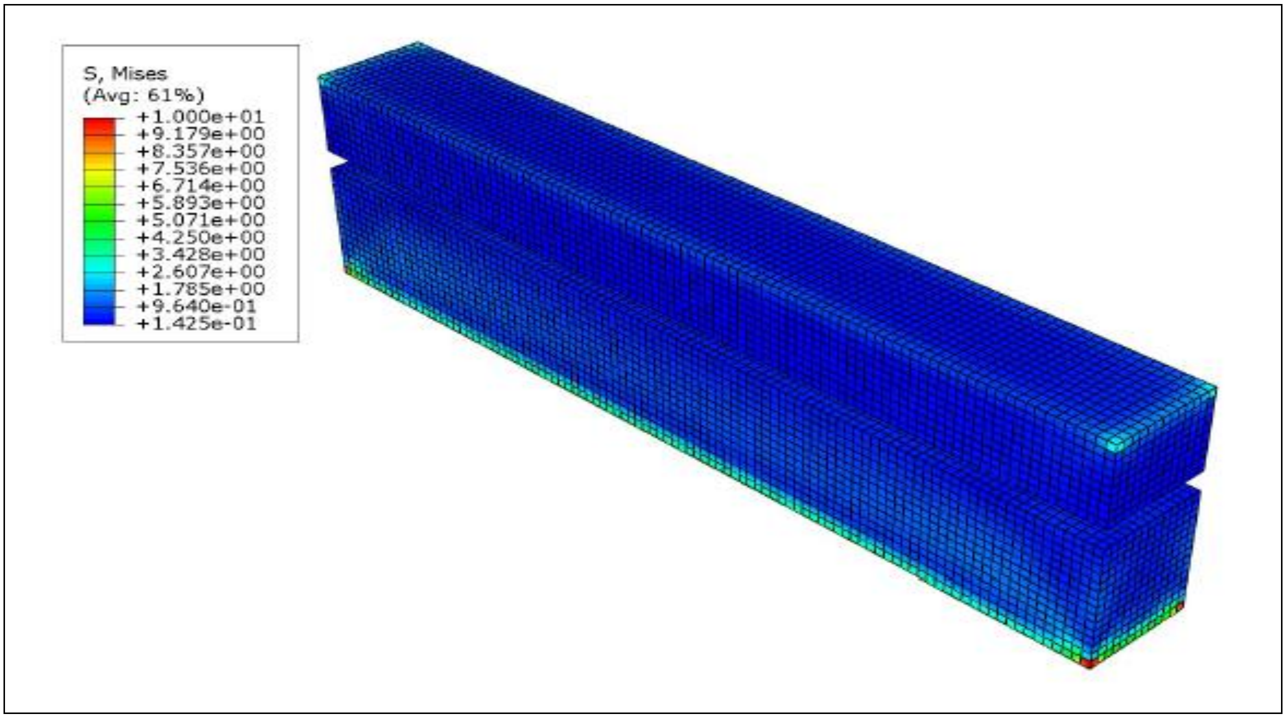


Figure 4.8. Stress distribution in steel-concrete composite section after section is separated

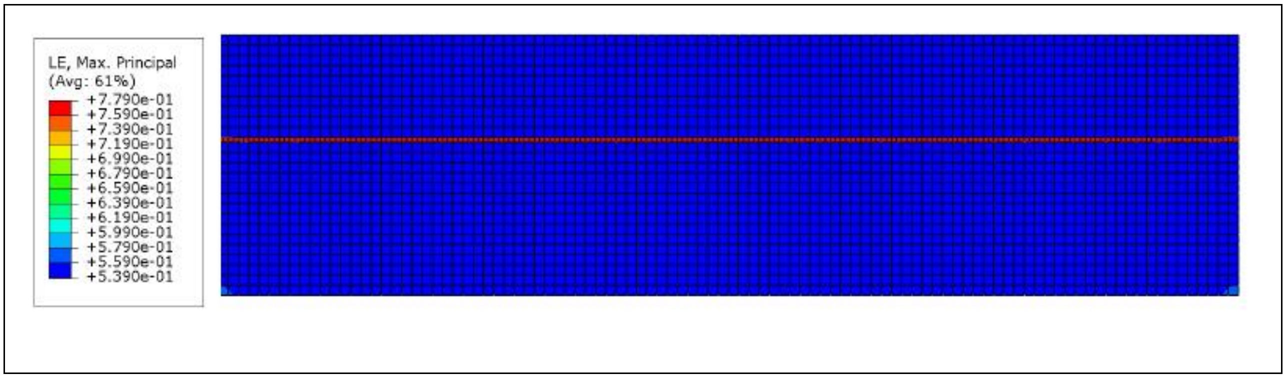


Figure 4.9. Strain distribution in steel-concrete composite section after load is applied

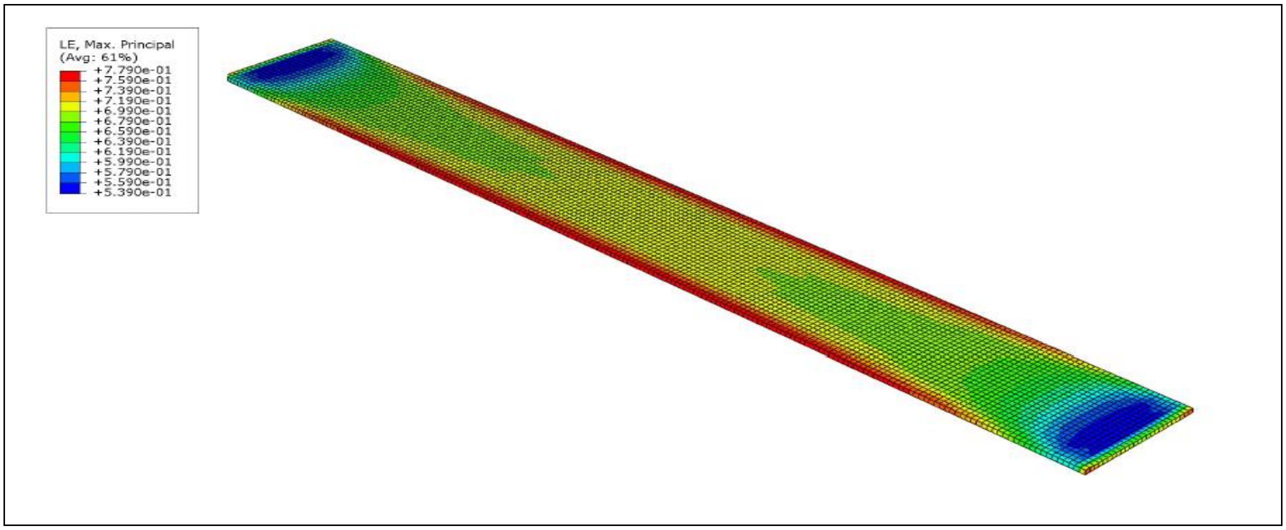


Figure 4.10. Strain distribution in interface after load is applied

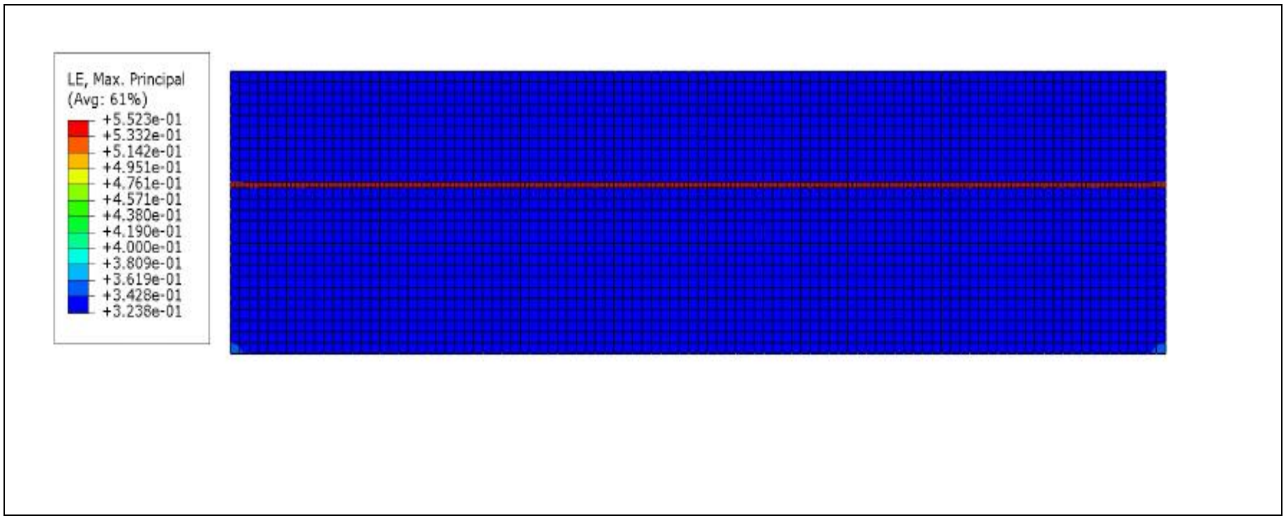


Figure 4.11. Strain distribution at the section before adhesive is failed

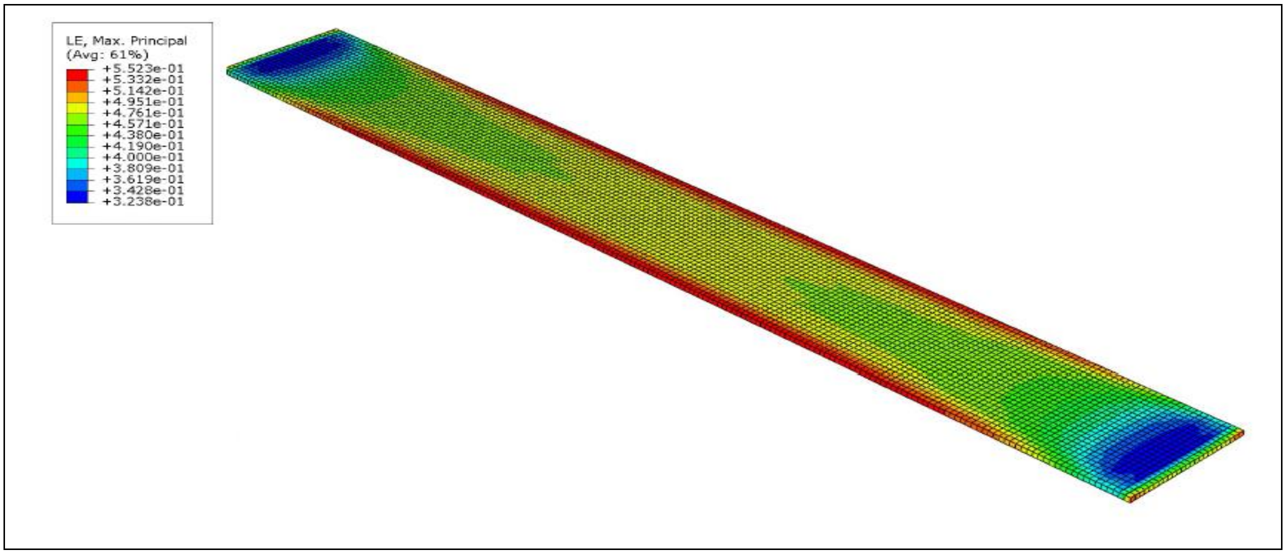


Figure 4.12. Strain distribution at interface before adhesive is failed

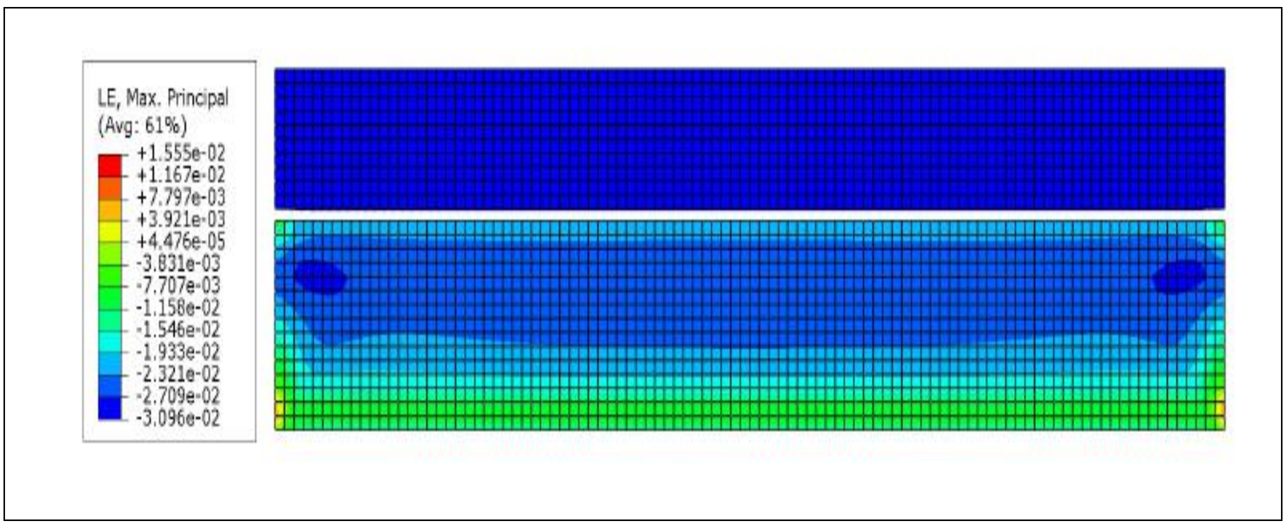


Figure 4.13. Strain distribution at section after adhesive is failed

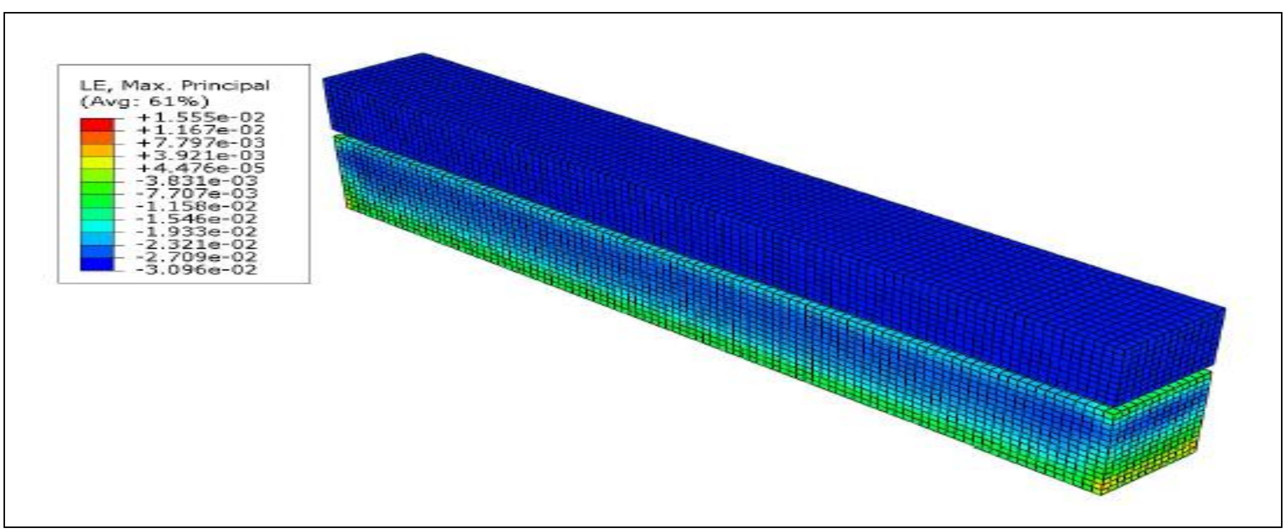


Figure 4.14. Strain distribution at section after adhesive is failed

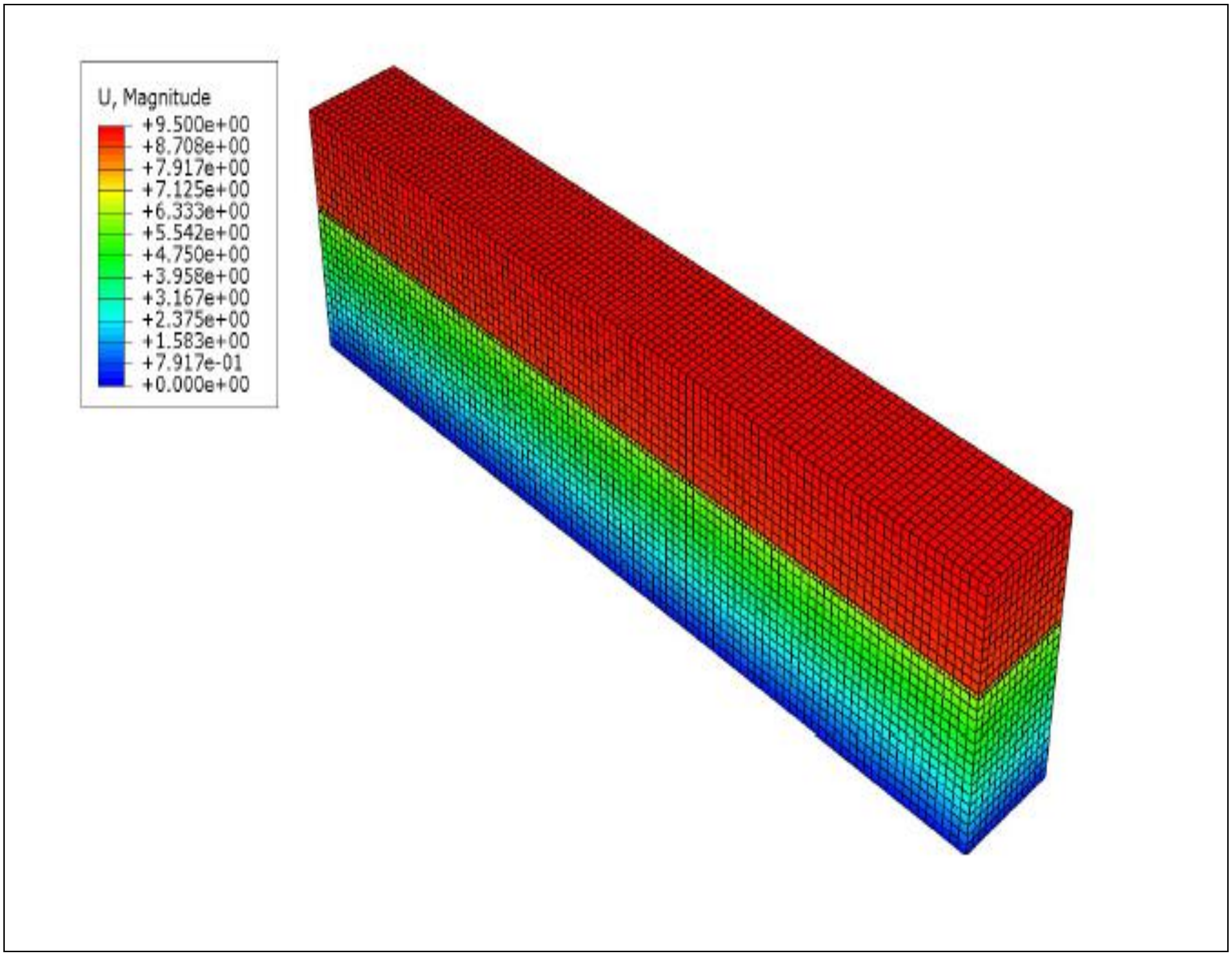


Figure 4.15 Displacement distribution in composite section

- The figure 4.15 shows the disribution of displacement in the composite section.
- The maximum deflection that occurs is 9.5mm.
- As bottom part of concrete is clamped it shows no deflection.

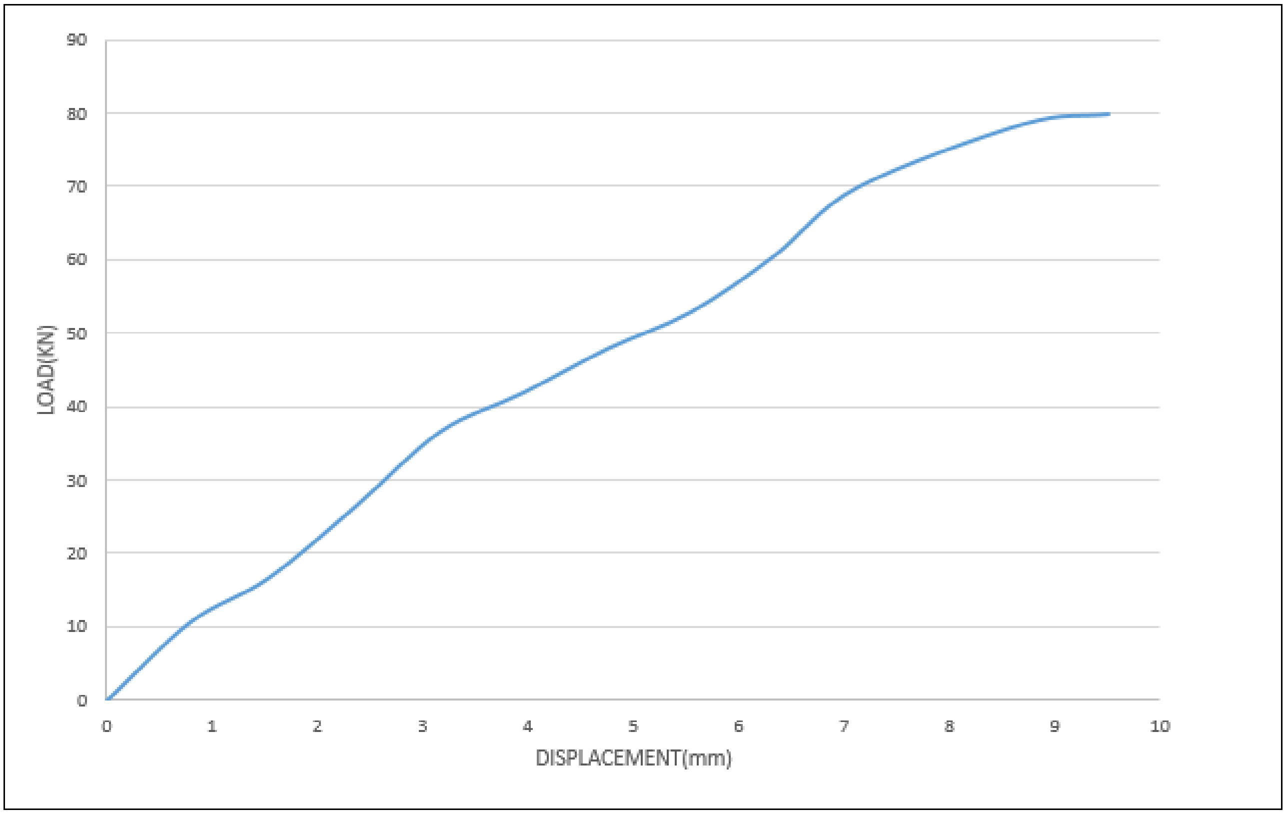


Figure 4.16. Load Displacement curve in composite section

- The ultimate load observed was 80 kN in the composite section and the strength of the connection depends upon the adhesive properties.
- The displacement produced has a maximum value of 9.5mm.

CHAPTER 5

CONCLUSIONS AND DISCUSSIONS

In conventional steel concrete composite section shear connectors develop cracks in concrete due to stress concentration and significantly reduce the structure durability. Adhesive bonding has come out as a substitute to shear stud connection in steel-concrete composite sections and used to assemble the steel girder and concrete slab together. Two three-dimensional finite element models are constructed with the ABAQUS software and parametric investigations are conducted.The interface between concrete and steel girder was modeled using a cohesive bond model. The main objective of this thesis was to examine numerically the behavior of composite sections joined by adhesive. Modeling of steel-concrete section in FE software is successful when thorough constitutive models are provided to signify the response of different materials once they are subjected to loading. The behavior of concrete in compression and tension, reinforcing steel and interface material was captured using satisfactory material constitutive models . Various parts that make the whole model were created in Abaqus and assignment of material properties were done to the parts and are assembled together. Interaction between materials were created, boundary conditions and type of analysis were specified and in addition to that different output data were requested. The steel concrete composite section was then discretized into a number of FE connected by nodes and solution for nodal displacement fields were obtained.

- The failure of steel concrete composite section in first model is from the yielding that takes place in steel and concrete crushing at the mid-span and mainly due to bending.
- The ultimate load observed was 246 kN with maximum deflection of 24.8 mm in first model while 80kN in case of second model . The strength of the adhesive as observed from the results plays a very important role in composite bonded structures. Nature and the adhesive properties directly impacts the critical load of the steel-composite beam.

Steel-concrete when used as a composite section proved to be stiffer and stronger than steel and concrete alone. Steel-strong composite structures are an atypical and proficient kind of improvement used in extensive combination of essential sorts. Today, steel-strong composite are getting reasonably standard in the authentic progress industry under lightweight, strong, building affiliations all around coordinated, and goes after concerning saving in labor cost and improvement time. The connection between steel and concrete affects the performance of composite section and it acts as the main hindrance in this section. The connection between steel and concrete should be fit for transferring the stresses from steel to concrete and it should withstand the applied load at the interface. Previous studies are limited as the proper implementation of epoxy resins as a connection between steel and concrete has not been done. FEA of adhesive joints is evaluated concerning static stacking examination, natural conduct, weariness stacking examination, and cement bond joints' dynamic properties. Awareness of the durability of concrete/epoxy joined framework is important. Reliability of the material system's individual components do not ensure that untimely failures of joined framework may not occur. There is considerable decrease around fifty percent in the fracture resistance of the concrete-adhesive joint with chosen humidity and temperature molding levels. Information will fill as a reason for use in the design improvement of material frameworks containing such interfaces to improve durability. In externally reinforced concrete beams debonding is one of the key failure mechanisms that occurs along the concrete interface. In the case of a continuous steel-concrete composite beam, an important part of the web is subjected to compressive stresses at a negative moment. This limits the ability of the cross-section to rotate, thereby preventing it from achieving its ultimate power. Ongoing work on FEA of adhesively bonded joints is evaluated in this paper concerning static stacking examination, natural conduct, weariness stacking examination, and composite bond joints' dynamic properties. It is inferred that the FEA of adhesive joints will help future adhesive holding applications by permitting the framework boundaries to be chosen to give as huge a cycle window as workable for fruitful joint assembling. The utilization of lightweight materials in modern field and the need of lightweight structures has prompted adhesive bonds' wide use. The joints study will allow a couple of unmistakable designs to be mirrored to play out a decision of various plan plans prior to testing, which would take too long to even think about performing or in practical terms it is restrictively costly.

CHAPTER6

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