A

Project Report

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

On

CONCRETE FILLED TUBES SUBJECTED TO IMPACT LOADING

in

MASTER OF TECHNOLOGY

By

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MAY 2019

CANDIDATE'S DECLARATION

I **Chetan Saxena,** hereby declare that the work presented in this dissertation entitled **"Concrete filled tubes subjected to Impact loading",** in partial fulfillment of the requirement forth award of the degree of **Master of Technology** submitted to DEPARTMENT OF CIVIL ENGINEERING **,Indian Institute of Technology Roorkee, India,** under the supervision of **Dr. P. K. GUPTA**(Professor)Department of Civil Engineering, IIT Roorkee. It is an authentic record my work done during the Summer semester of 2018-19.I have not submitted the matter embodied in this report for the award of any other degree or diploma.

Date:

Place: **Roorkee** **(CHETAN SAXENA)**

CERTIFICATION

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude and sincere thanks to my guide **Dr. P.K. GUPTA** (Professor)Department of Civil Engineering, IIT Roorkee, for being helpful and a great source of inspiration. I would like to thank him for providing me with an opportunity to work on this excellent and innovative field of research. His keen interest and constant encouragement gave me the confidence to complete my work.

I wish to thank him for his constant guidance and suggestions without which I could not have successfully completed this seminar.

Date:
Place: Roorkee **(CHETAN SAXENA)**

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CHAPTER I

INTRODUCTION

1.1 Concrete Filled Steel Tubes

What is CFST? CFST is a composite system that stands for Concrete Filled Steel Tubes. Composite system are the structures in which the components comprise of at least two different material having the different physical and chemical properties like Elasticity, density etc. CFST consists of a steel tube and concrete core. Steel tube is used as the outer material which is in-filled with concrete. CFST can be casted of desired cross-section but mostly square, rectangular and circular sections are used. A typical cross-section of CFST is shown in figure 1.1.

Being the composite material CFST owes the advantages of two different materials. Steel tube provides the confinement to the concrete core that enhances the properties of concrete and delayed the buckling locally of steel tubes. The steel at the outer perimeter of CFST performs most effectively in tension and bending. It also enhances the stiffness as the steel lies furthest from the centroid and the combination of this with the large modulus of elasticity. The concrete core gives the greater contribution to resisting axial compression. They are widely used in Multi-storey and highrise buildings as columns and beam-columns.

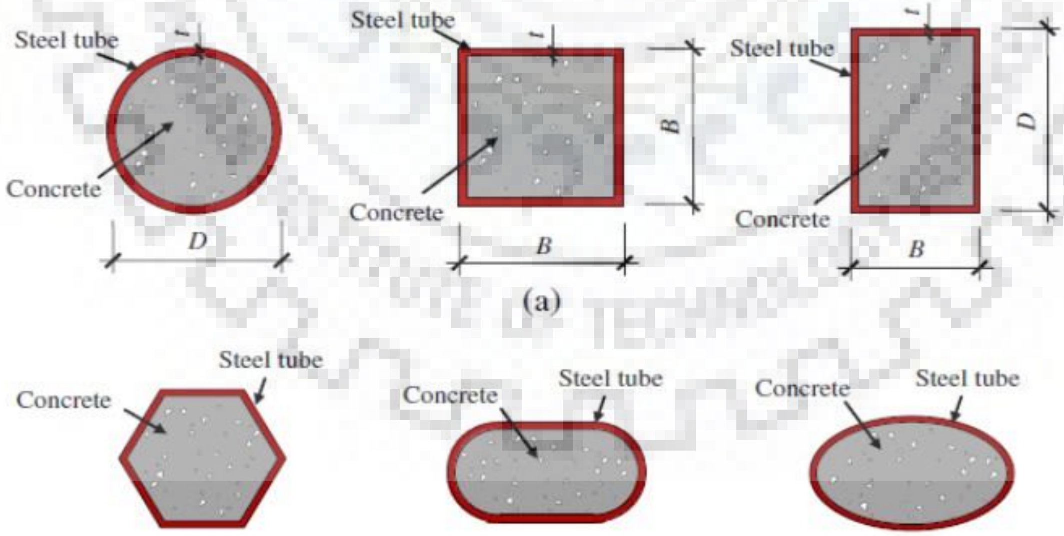
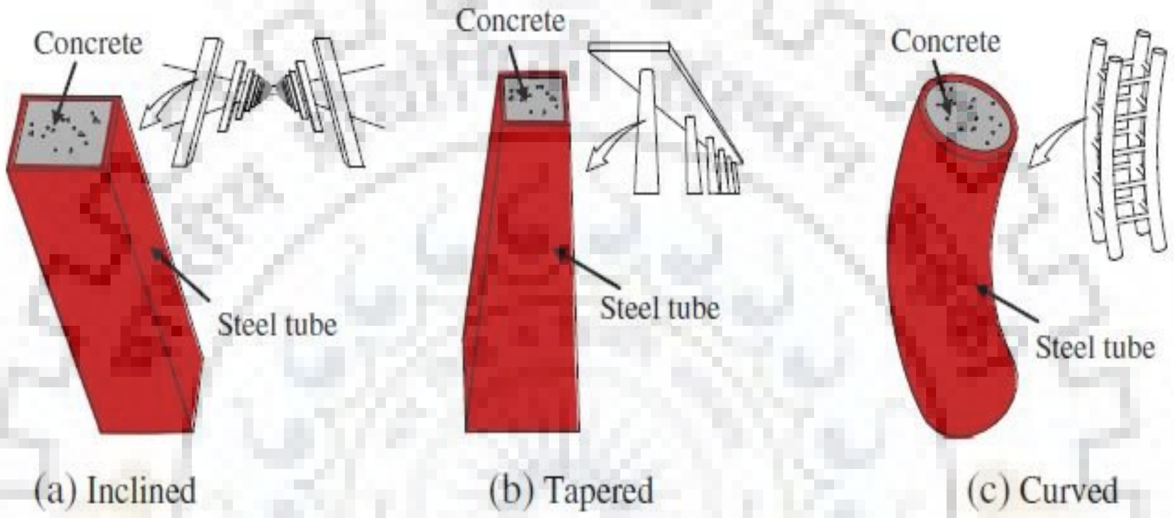


Figure 1.1: Various Cross sections of CFSTs

Most of the concrete fillsteel tubular members are prismatic but due to architectural requirement or structural requirement non-prismatic members or inclined members can also be used. Figure 1.2(a) shows incline CFST column that can be used in structures with irregular architecture. Figure 1.2(b) shows tapered concrete filled tubular section that can use for aesthetics or for economical purposes. Similarly, curved CFST members shown in Figure 1.2(c) can also be used as per the requirement.



(a) Inclined (b) Tapered (c) Curved

Figure 1.2:- Types of CFST section

1.2 Concrete Filled steel tube Columns

It is known that the concrete is much stronger in compression than in tension and further its strength is enhanced due to Bi-axial or Tri-axial restraints in CFST. And for steel it well known that it is strong in tension while in compression it may buckle locally. CFST takes advantage of the prominent behaviour of both steel and concrete. Researches on Concrete Filled Tubes (CFT) columns subjected to concentric compression examine the behaviour of CFT and found that the confinement of concrete results in an enhancement of the compressive strength, and development of hoop stresses in the steel casing which causes reduction in the yield strength of steel. After which more theoretical and experimental studies were performed on CFT and found that the calculated maximum load of circular CFSTs is greater than the nominal load and is the sum of both the component strengths[2]. Figure 1.3 shows the failure of concrete filled steel tube section and the corresponding concrete and steel tube.

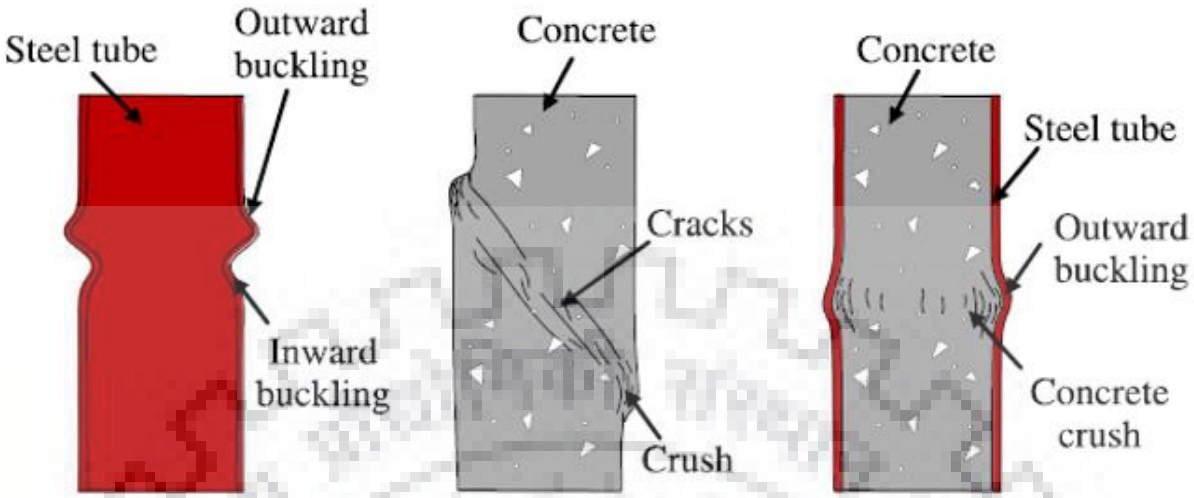


Figure 1.3:- Failure of CFST column and corresponding Steel Tube and Concrete

Although the confinement effect decreases with the increase in column length and ingeneral neglected for columns of practical length, it ensures that the column behaves in a ductile manner and that is advantageous in seismic applications.

1.3 Concrete Filled steel tube Beams

With the advancement in structural construction work, we are opting different techniques, material, strategies to strengthen the structural elements and try to be more cost effective. In this process of optimization of the construction work CFST beams provides a good option. Steel tube at the outer surface of concrete behaves as the reinforcement with increased lever arm than conventional reinforced concrete to resists the applied load that makes it more efficient. The exposure problem of concrete and spalling is also solved due to casing provided by steel tube to the concrete. Researches shows that CFT beams fail in very ductile manner and thus are advantageous in seismic regions[4]. Figure 1.3 shows the failure of CFST beam with corresponding failure of hollow steel tube and concrete in bending.

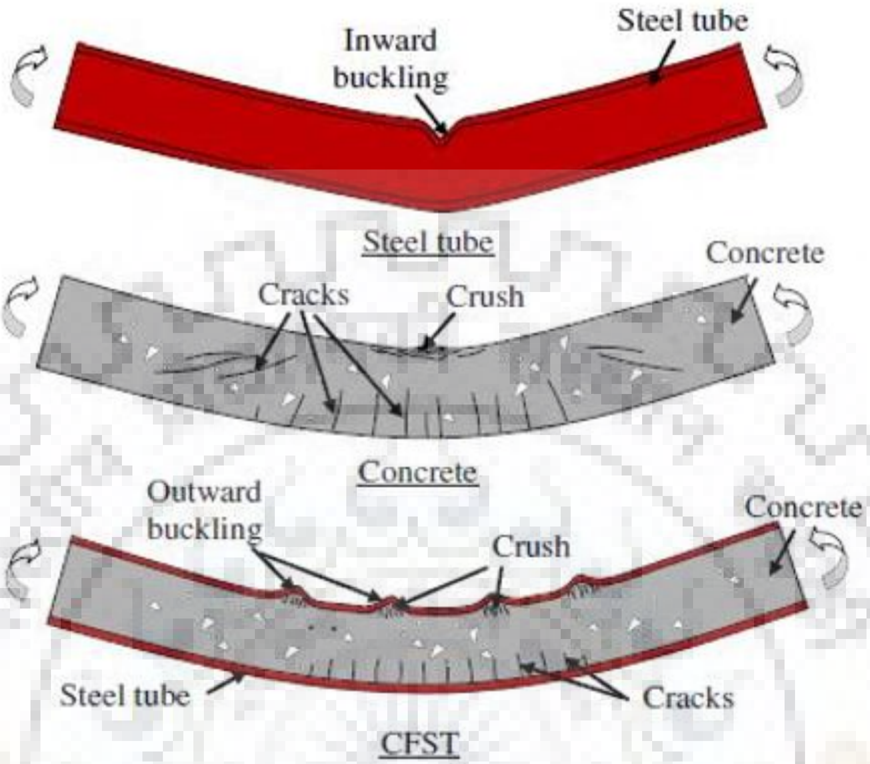


Figure1.3: Failure of CFST beam and corresponding Steel Tube and Concrete

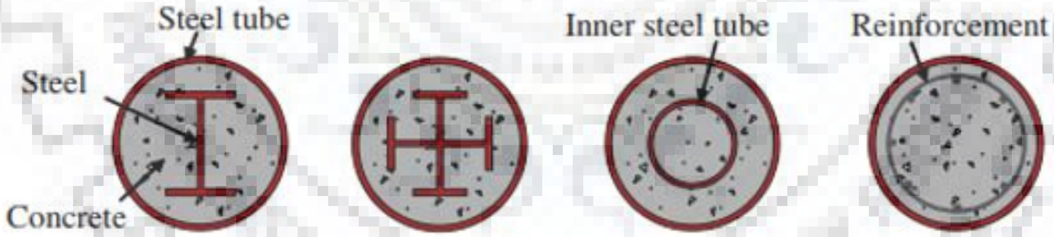


Figure 1.4: Reinforced ties arranged inside a tube (Huson-Teh, 2003)

CFST are usedin the different parts of the world for various applications like columns, beam-columns, towers etc. With the use of CFT time of construction also reduces as generally there is no reinforcement and formwork needed[3]. In case if reinforcement is needed, a secondary tube having a smaller cross-section can be inserted in between the tube and this arrangement is called double skin concrete filled steel tubes[5]. Sometimes reinforced ties (mechanical devices) also attached to the tubes to increase bond between steel and concrete as shown in figure 1.4.

1.4 Construction Examples China is using Concrete filled steel tubes from last 50 years. It was first used as the main compressive force resisting members (pillars) in subway stations in China. In recent decades, there is rapid increase in the pace of the concrete-filled steel tube construction. The CFST(s) are used as major compressive force resisting components in bridges and other structures. Some of the examples are presented below. During construction period of 1980s CFST were used in buildings just to avoid large size of columns. Several buildings were constructed in Beijing and Fujian. Earlier CFST Columns are usually used with either steel beam or concrete reinforced beams to form a composite moment resisting frame [8]. In very tall buildings this composite frame system is often used with the combination of other lateral load resisting system such as steel shear wall or RC core tubes as shown in figure 1.5. Test results shows that High stiffness and high ductility of CFST frame system performs well with RC core tubes or steel shear wall.

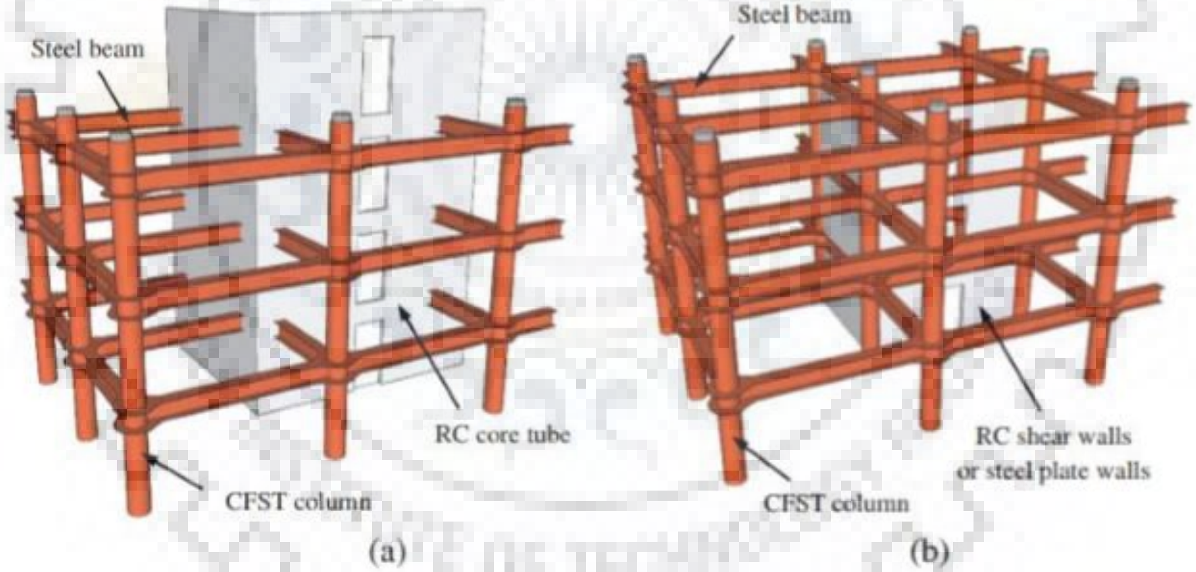


Figure 1.5 CFST systems with a) RCC core tube b) RC shear walls

1.4.1 SEG Plaza in Shenzhen

Shenzhen's SEG plaza was one of the earliest examples of Concrete filled tubular columns used in super high-rise buildings. The structure was 291.6m tall with circular CFST columns. Q345 steel was used with C60 grade of concrete [9]. The profile of the steel cross section was 1600mm x 28mm. If compared with the columns with hollow steel section, the steel usage for CFST columns was only half preventing the use of very thick plates. SEG Plaza is shown below in figure 1.6.

Figure 1.6 SEG Plaza in Shenzhen

1.4.2 Canton Tower in Guangzhou

Canton Tower consists of spaced lattice composite with RC core. The total height of the structure is 600meters with height of main body being 454meters. The structure has 24 inclined concrete filled steel circular tubes with maximum diameter and maximum thickness of the CFST being 2000mm and 50mm respectively. Figure 1.7 shows Canton Tower.

Figure1.7 Canton Tower in Guangzhou

1.4.3 Bridges

Concrete filled steel tubular sections are also extensively used as bridge piers, towers and arches in arch bridges, cable stayed or suspension bridges. Figure 1.8 shows the usage of CFST sections in bridges.

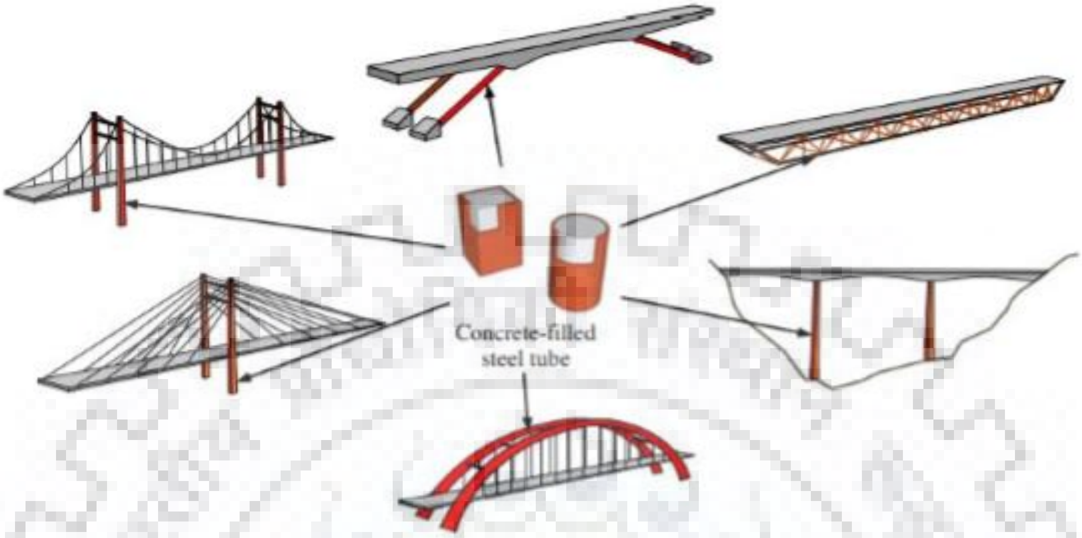


Figure 1.8 Usage of CFST sections in bridges

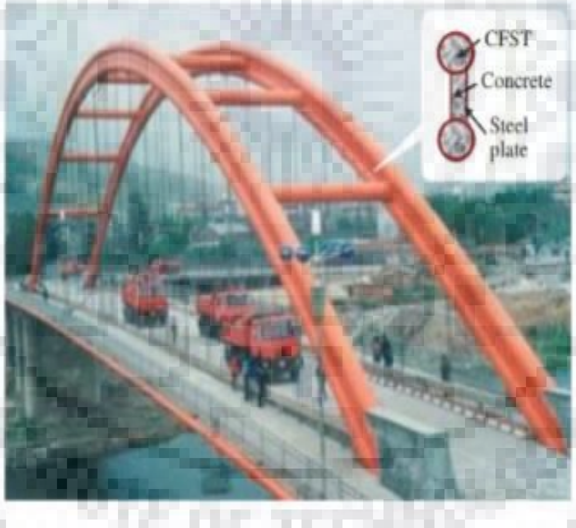


Figure 1.9 Wangcang Bridge China

Wangcang East River Bridge depicts the application of CFST section in bridges. It was made in 1992. The main arch's cross section in this bridge is in dumbbell shape as shown in figure 1.9 with total depth is 2 meters. Steel tubes having diameter of 800 mm and a thickness of 10 mm are used with hollow sections being filled with C30 concrete. The main span of Wangcang Bridge is 115 meters [9].

1.3 Advantages of CFT's:

1. Concrete filled tubes have very large ductility and high lateral resistance and are of great use in high seismic zone.
2. Due to in-filled concrete inside steel tube its strength increases due to confinement thus it is capable of taking same load at lesser cross section resulting in saving of material and reduction of dead load.
3. In case reinforced concrete confinement is not provided to cover material which results in spalling. While in CFT construction confinement is provide to whole concrete which protect it from external environment as well as from the spalling.
4. Using CFST results in faster construction as there is no or lesser formwork required.
5. Due to lesser or no reinforcement, it is easy to crush concrete and reuse aggregates.
6. CFST provides the solution for faster and economical construction.
7. CFST are very useful in high seismic regions due to their ability to dissipate more energy.
8. CFST is good for environment as concrete and steel are reusable.
9. CFST provides cost effective solution for high rise buildings

1.4 Limitations of CFT's:

1. Compaction of concrete is difficult especially when reinforced ties are provided in the steel tube. To minimize the effect of poor compaction high strength concrete with super plasticizers are used.
2. It is difficult to make connection between beams and columns.
3. Difficult to understand the exact behaviour of CFST section due to its composite nature.
4. Lesser works and researches have been done to understand the nature of composite structure completely.

CHAPTER II

LITERATURE REVIEW

To comprehend the behaviour of CFST before doing computational study, many researches were reviewed. How CFST behaves in axial compression or how it behaves in flexure, what are parameters that affects the load carrying capacity of CFST beams under impact, how does D/B ratio affect it or how does high strength concrete affect it. The CFST is an advanced composite material whose dynamic behaviour is dependent on several parameters like yield stress of steel, sectional diameter, impact velocity, boundary conditions, impactor mass, steel ratio and many others. Few important research works related to this dissertation work are presented below.

2.1 Lin-Hai Han (2004)

2.1.1 General

Lin-Hai Han conducts experiments on high strength concrete filled steel tubes subjected to transverse impact loading to understand the failure modes of both steel & concrete, impact force time behaviour. The cube strength was as high as 75 MPa. A FEA Model was established to predict behaviour under impact & data obtained from the experiments were used to verify the accuracy of model. Plastic hinges appeared in the impact area and local buckling deformations type failure were found in the compression zone and bottom of fixed ended sections. He developed a mechanics model based on the parametric analysis in order to find the moment carrying capacity of these high strength CFST members.

2.1.2 Experimental Investigation

Twelve specimens, including nine circular CFST specimens and three circular hollowasteel tubes were tested. The main test parameters included : boundary conditions, impact height, and weight of drop hammer. The diameter was 200 mm and thickness was 3.65mm .The average cube compressive strength and the elastic modulus of the concrete at 28 days were 68.3MPa and 36,800 N/mm^2. The mass of the drop hammer varies between 205 kg and 1115 kg.The boundary conditions were designed using special end plates with circular holes.[5]

Specimen name	Boundary condition	L (mm)	H(m)	V(m/s)	Energy(kJ)	Δ(mm) Measured	Δ(mm) Predicted
CC1	Fix-Fix	1800	1.0	4.43	465	64	63
CC2	Fix-Fix	1800	2.0	6.26	920	70	72
CC3	Fix-Fix	1800	4.0	12.34	1868	91	94
CS1	Fix-pin	1800	1.0	4.54	453	65	66
CS2	Fix-pin	1800	2.0	6.66	962	71	72
CS3	Fix-pin	1800	4.0	11.97	1768	102	108
SS1	Pin-pin	1800	1.0	4.67	483	105	113
SS2	Pin-pin	1800	2.0	6.98	957	122	124
SS3	Pin-pin	1800	4.0	12.56	1793	146	145

Table 2.1:- Detailed information and results of CFST specimens

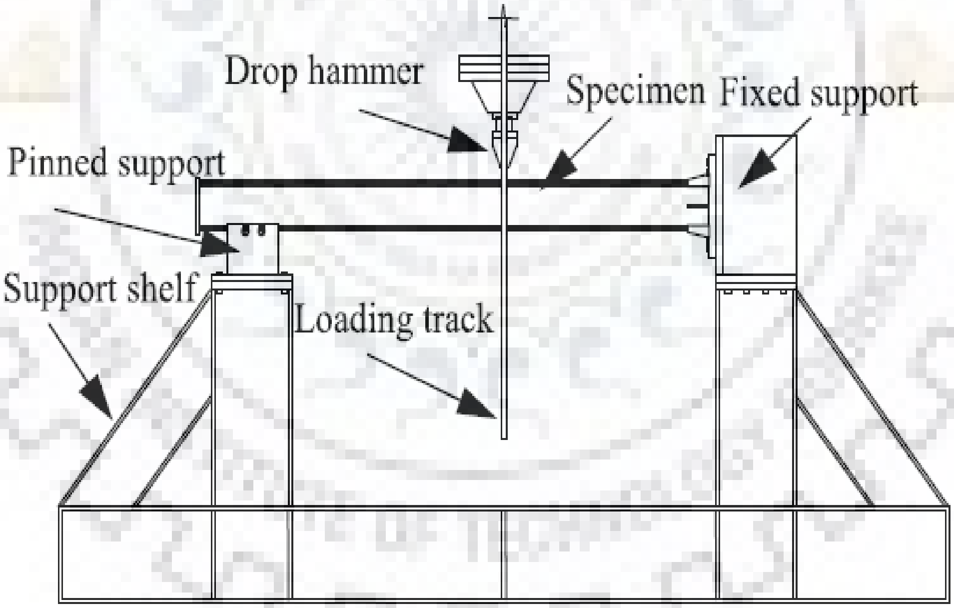


Figure 2.2:-Schematic diagram of the test setup

2.1.3 Conclusion

The following conclusions were drawn from this study:-

1. The test results reveals CFSTspecimens deform in a ductile manner and have good resistance under impact load.

2. The member shows quite different behaviour compared with the static load condition, including changes in internal force distribution, force state and flexural capacity.
3. A parametric study indicated that the yield stress of steel, ratio of steel, sectional diameter and impact velocity are the key parameters that influence the dynamic factor (ratio of flexural capacity of member under impact and static load) for the flexural capacity.

2.2 Chang Ming Hu(2017)

2.2.1 General

Chang Ming Hu investigated into the impact resistance of concrete cased concrete-filled steel tube (CFST) members with circular sections . A FEA model was established to simulate he impact behaviour of concrete-encased CFST under laterally low velocity impact within which combined effects of axial load and lateral impact were thought-about.
Experimental knowledge on reinforced concrete (RC), CFST and concrete-encased CFST members under drop forge impact were used to verify the accuracy of the FEA model and reasonable agreement was achieved for all 3 sorts of structures. The failure modes, sectional moment development, stress and strain development, as well because the contact behaviour between totally different components were analyzed to highlight the reasons behind the great impact resistance of the composite structure. The constant study conducted with the FEA model discoveredthat strength of steel, steel magnitude relation and section diameter were among the key parameters influencing the impact resistance.

2.2.2 Finite Element Analysis modelling

Chang Ming Hu developed a model to simulate the behaviour of totally different structures in the main concrete encased CFST member and a CFST member underneath a low velocity lateral impact as a result of it relates to the minor impacts that the structural parts like beams and columns bear. The major effects of strain rate effects and also the component erosion criteria of concrete once impact and the interaction between steel and concrete as well because the combined effects of axial load and lateral impact were taken care of. The steel tube was simulated with four node quadrilateral shell elements and the drop press, reinforcing bars, stirrups and also the concrete were simulated using 2 beam parts.[10]

Material modeling was done exploitation Continuous surface cap model was used to model each the outer concrete and also the core concrete of CFST.

Specimen name	N(axial load level)	H(m)	V_0(m/s)	E_0(kJ)	Δ (measured)	Δ (predicted)	Fm[kN] (measured)	Fm[kN] (predicted)
CFP1	0.3	1.0	4.43	465	64	63	160	142
CFP2	0.3	2.0	6.26	920	70	72	194	184
CFP3	0.3	4.0	12.34	1868	91	94	181	176
CFN1	0	1.0	4.54	453	65	66	454	452
CFN2	0	2.0	6.66	962	71	72	353	348
CFN3	0	4.0	11.97	1768	102	108	342	356
CTP-2	0.3	1.0	4.67	483	105	113	351	327
CTN-2	0	2.0	6.98	957	122	124	330	315

Table 2.3:-Detailed information and results of CFST specimens

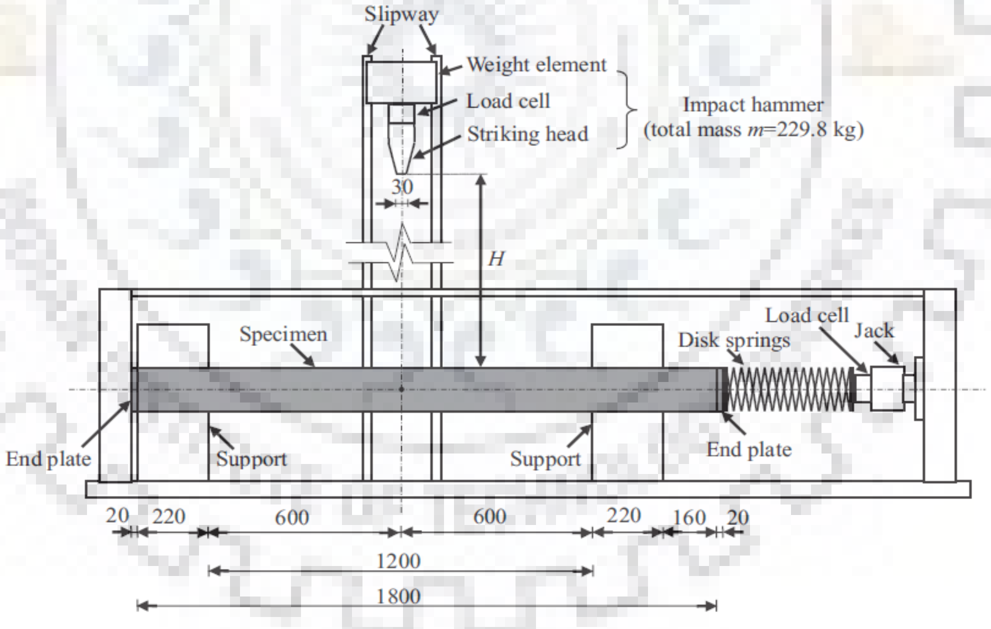


Figure 2.4:-Schematic diagram of the test setup

2.2.2 Conclusion

The following conclusions were drawn in this CFST under low velocity impact:-

1. The analysis showed that the composite action between the outer RC and core CFST is that the major reason behind the high impact resistance of the structure.

2. The outer steel section carries comparatively large amount of bending sagging moment brought by the impact thanks to its presence at the outer section, whereas the core CFST carries comparatively bit of bending moment and may still provide good axial resistance once the impact.

3. The outer steel section effectively protected the core CFST throughout the impact in terms of consuming disproportionately larger amount of impact energy and preventing the steel tube from native buckling.

4. Results showed that the impact resistance of the structure could be effectively enhanced when a steel tubes with higher steels strength, a larger steel quantitative relation or a big section diameter is used.

5. Different parameters, just like the concrete strength and reinforcement quantitative relation, also affect the impact resistance, but their influences are comparatively moderate. While the weight of the impact hammer has nearly no influence on the dynamic flexural capability,chowever, it shows that a better, impact velocity might bring a moderate increase of the dynamic flexural capability, that is thanks to the upper strain rate of steel and concrete.

6. Finally, it shows that influence of the axial load quantitative relation on thecimpact resistance of the composite member is analogous to its influence on the static flexural strength of the member with the increase of a comparatively tiny axial load ratio, the impact resistance of the member will increase, however a further increased axial load would induce a big drop of the impact resistance to the member, that is attributed to the high-level of compressive stress within the member before impact.

2.3 Rui Wang(2012)

2.3.1 General

Rui Wang conducted a series of experiments on various CFST specimens varying in their axial load carrying capacity, constraining factor &the energy due to impact. Twenty specimens were tested whose behaviour was studied like the failure modes of both steel & concrete, impact force time behaviour.The data obtained from the experiments were used in the developed FEA model to verify the model accuracy. There was in general a good agreement between the results. A full range analysis was also carried out to give more insight into the flexural capacity of CFST members under impact load.

2.3.2 Experimental Investigation

Total of 22 CFTs were tested to carry out the study. Sectional dimension and properties are tabulated in table below.There are two series of specimens, both of them varied in constraining factor. For the series I specimenconstraining factorξ=0.44& for the series II it is ξ=1.23. The yield stresses are 232 N/mm^{2}and 298 N/mm^{2}for series I and series II specimens respectively and the corresponding modulus of elasticity (Es)are1.92×10^5 N/mm^{2}and 2.01×10^5 N/mm^2, respectively. The average measured cube strength of concrete at the day of testing is fcu=58.7 N/mm^2.[8]

Specimen name	N(axial load level)	ξ	V_0(m/s)	W(kJ)	Δ (measured)	Δ (predicted)	Fm[kN] (measured)	Fm[kN] (predicted)
DBF14	0.3	0.44	3.9	1801	64	63	160	142
DBF15	0.3	0.44	5.4	2026	70	72	194	184
DBF16	0	0.44	7.6	2252	91	94	181	176
DBF17	0	0.44	9.8	6756	65	66	454	452
DZF22	0.3	1.23	4.4	11260	71	72	353	348
DZF23	0.3	1.23	5.2	11935	102	108	342	356
DZF24	0	1.23	8.8	13512	105	113	351	327
DZF25	0	1.23	9.5	15764	122	124	330	315

Table 2.5:- Information and results of CFST specimens

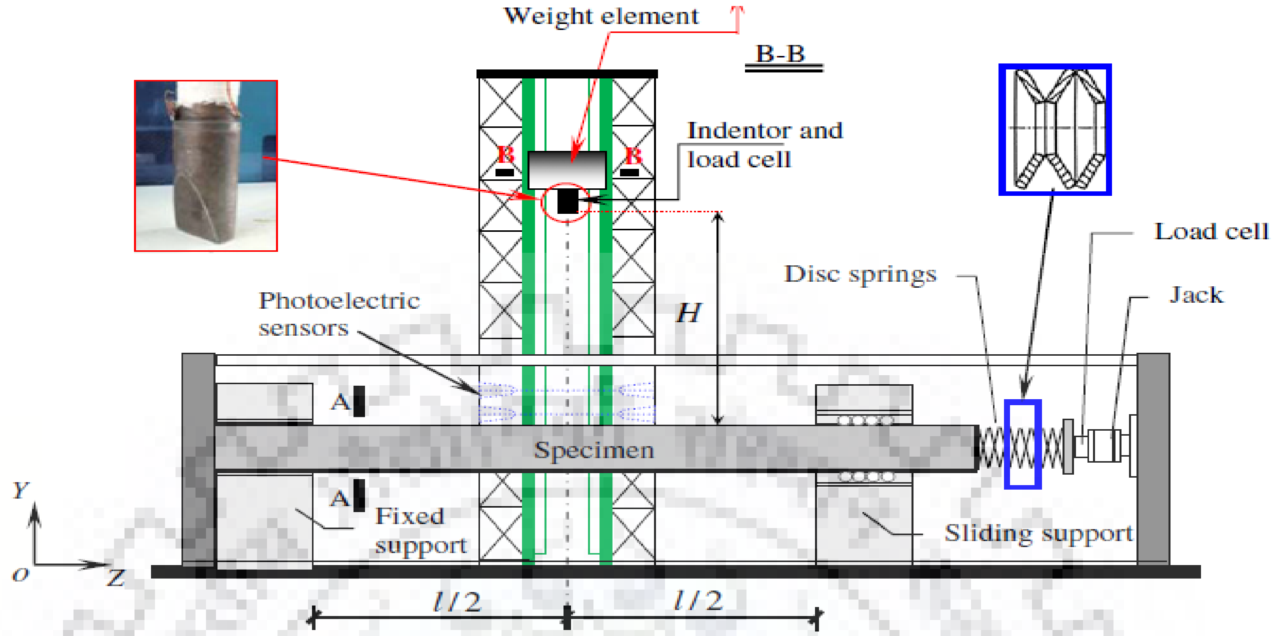


Figure 2.6:- Schematic view of experimental setup (*Rui Wang,2012*)

2.3.2 Conclusions

The following conclusions were drawn from this research work:-

1. The CFST specimens with larger limiting issue ξ=1.23 (series II specimens) behaved during very ductile manner underneath lateral impact whereas specimens with smaller limiting issue ξ=0.44 (series I specimens) usually behaved during a brittle mechanism.
2. The critical energy of fracture of the specimen exaggerated with the limiting issue (ξ).
3. The axial load has associate degree impact on the lateral deflections of CFST members underneath lateral impact.
4. For specimens with larger limiting issue (ξ=1.23), their impact force (F) curves may be usually divided into 3 stages, peak worth stage, platform stage and unloading stage. However, there was no obvious platform stage within the impact force (F) curves of specimens with smaller ξ (= 0.44). The axial load level (n) encompasses vital impact on the impact force curve of the CFST specimens.

CHAPTER III

FEM MODELLING

A three-dimensional finite element model is developed to study the behaviour of Concrete filled steel tubular members under pure bending the effect of change of various parameters is analysed using the developed three-dimensional model. Several finite element software are available to carry out the study on CFST members but the software used in this dissertation work is ABAQUS.

3.1 ABAQUS:-

Finite element model software ABAQUS is used to developed the three-dimensional finite element modelling of beams for this study. This software package has five different core software products CAE, Standard, Explicit, CFD, and Electromagnetic. For modelling and analysis of CFST beams ABAQUS CAE is used. Standard version uses the implicit integration scheme to analyze the finite element model. Explicit version uses as per the name suggest explicit techniques of integration for analysis. CFD and Electromagnetic are used for the computational fluid dynamic purpose and computational electromagnetic problems respectively[1].

3.2 Modelling:-

To Study the behaviour of beam in flexure impacttests were conducted on CFST beams as done in various literatures. The beams are modelled exactly as per the experimental setup from various literatures. A typical experimental setup of Han et al.[7] is shown in figure 3.1. The same loading setup is modelled in ABAQUS to get better accuracy of the results. Parameterslike boundary conditions, impactor mass, impactor velocity, sectional diameter and steel ratio required to trace the conduct of CFST members in ABAQUS are taken from various studies previously conducted on CFST members.

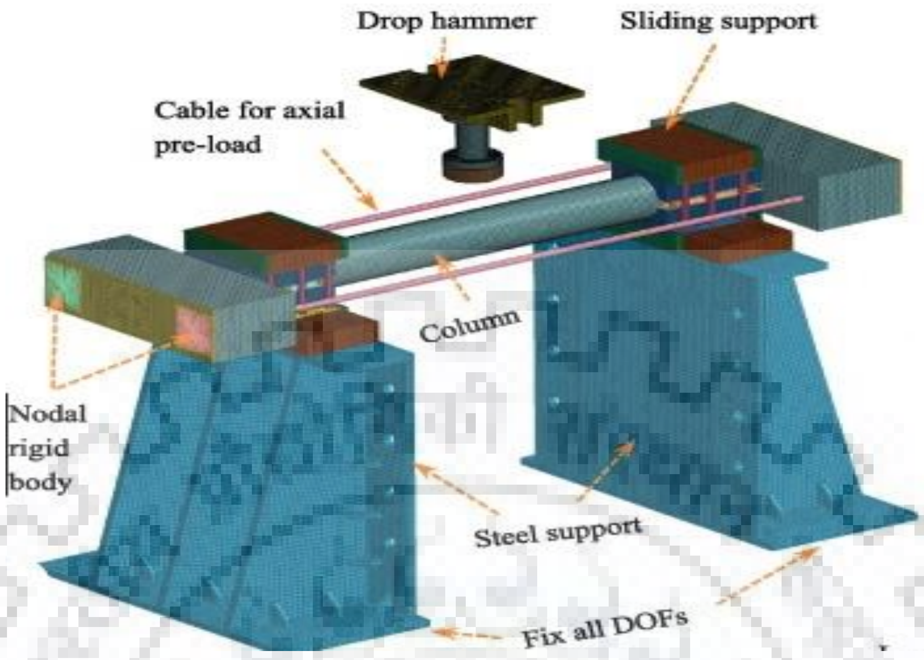


Figure 3.1:- Typical experimental loading setup

The setup is the assembly of different components and these different components were modelled as different parts in ABAQUS. Each part has unique property and has different element type. The interaction between each part of the model is defined carefully. An ABAQUS model of theCFST beam is shown in figure below.

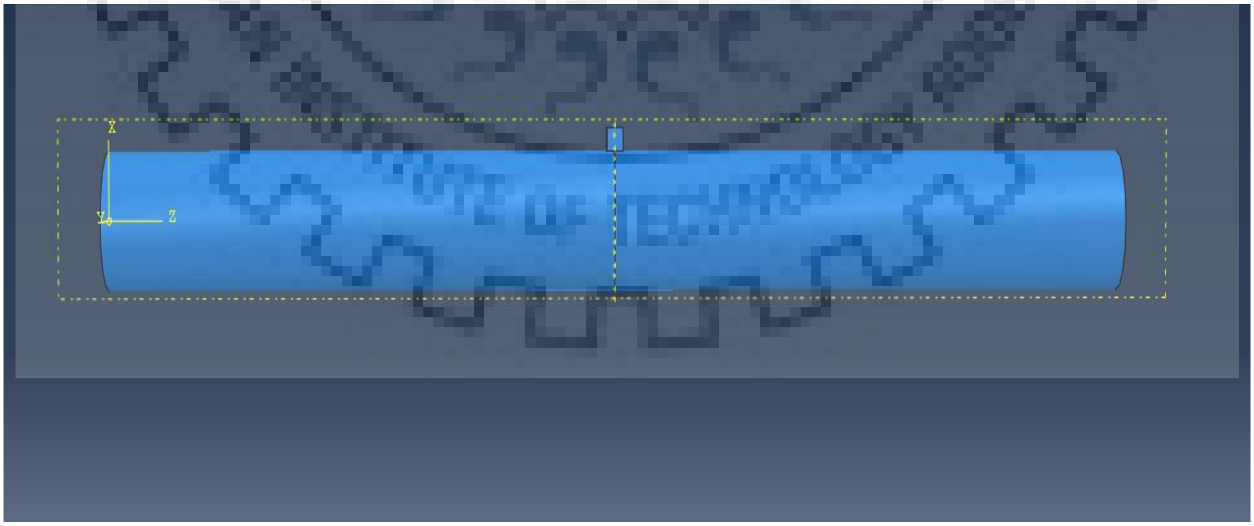


Figure 3.2:- Model of the loading setup

3.2.1 Geometry Creation:-

Experimental setup contains different components for example Concrete core, Steel Tube, Drop hammer. Each component was modelled as different part in ABAQUS. For concrete core and steel tube 3D modelling space was selected with deformable extrusion base. Both the part was assigned desired geometry as shown in figure below.

Figure 3.3:-Model of a) Steel tube b) Concrete

Different types of elements were tried to get the precise flexural behaviour of CFST section under impact. For concrete core and steel tube 3D 8 noded solid elements is found to be suitable for predicting the conduct of CFST beam. Convergence study was also carried out the find the optimal mesh size for concrete and steel tube. The results of the study depict that mesh size of 13 for steel tube and mesh size of 15 for concrete core produces optimal results with great convergence. To form loading assembly hammer was created and its center of gravity was marked which was made to fall on the given reference point on the CFST specimen. These parts were assigned rigid property.

3.2.2 Assembly:-

To form the complete experimental setup instances were selected from premade parts. Before this to form final assembly, partition of steel tubes and on loading rig is defined using datum points and planes. Several operations were applied on instances to assemble it into final setup. The final assembly is as shown in figure below.

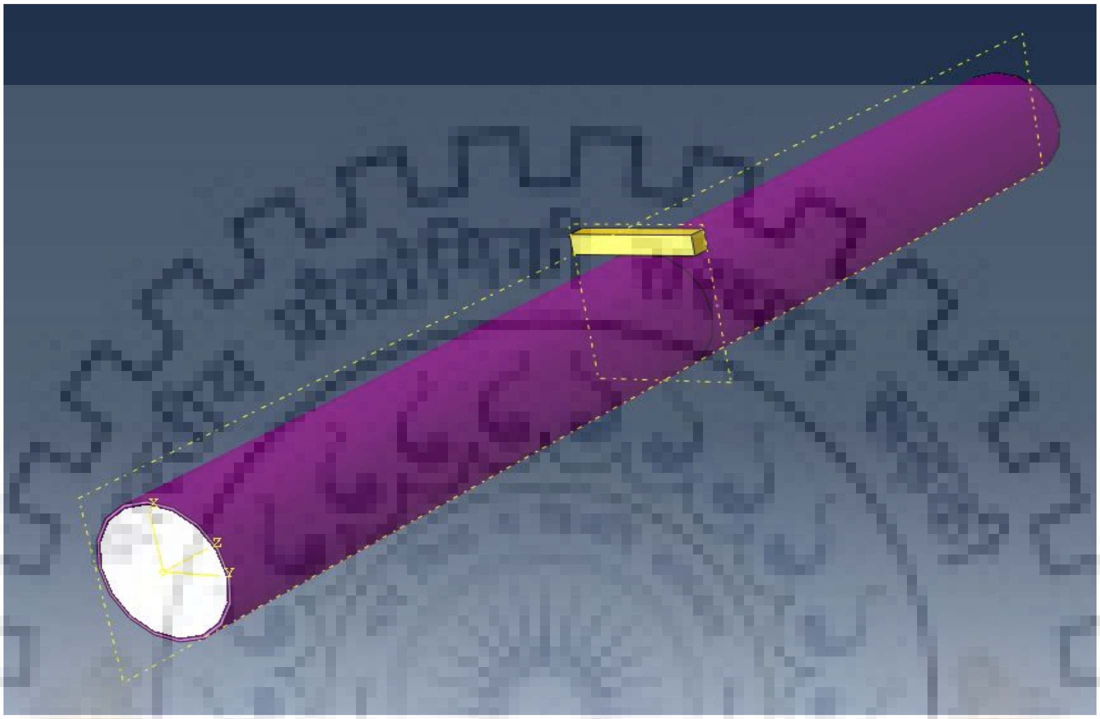


Figure 3.4:- Final assembly of the various parts in ABAQUS

3.2.3 Interactions:- To find out the optimum result the interaction between steel tube and concrete plays crucial role. Surface to surface contact property with finite sliding formulation is used between steel tube and concrete core throughout this dissertation work. To define the interaction between steel tube and concrete in ABAQUS, it first needs proper selection of surfaces which will interact during the applied load. Inner surface of steel tube and outer surface of concrete is selected for the definition of property with steel surface as master surface and concrete surface as slave surface. Tangential Friction coefficient of 0.25 is used while in case of normal behaviour hard contact pressure-over closer is used.

3.2.4 Boundary conditions and Loading:-

To Study the behaviour of beam in flexure impact tests were conducted on CFST beams in accordance of various literature. Fixed-fixed conditions was applied at the ends of the beam with one end having no translation and other end having translation in order to provide axial load which is similar to the sliding support of roller in the literature. Displacement controlled loading is applied on predefined reference point which is at center of the specimen.

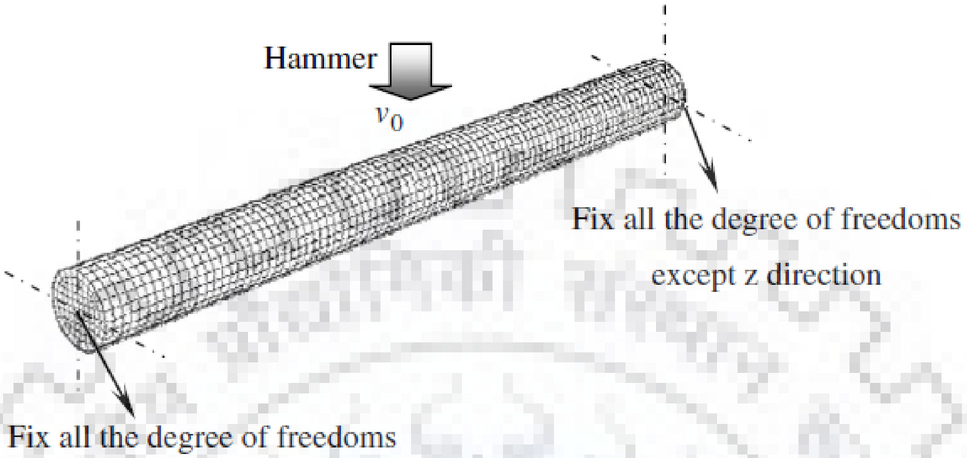


Figure 3.5:- Boundary conditions

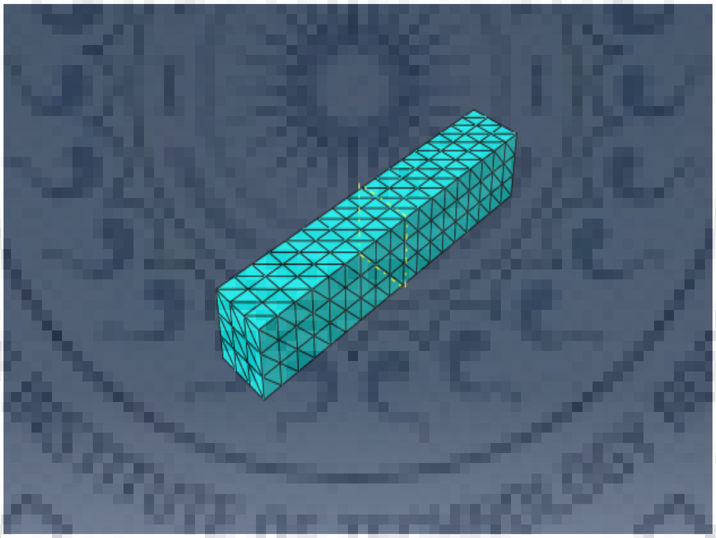


Figure 3.6:-Impactor(Meshed drop hammer)

3.2.5 Material modelling:-

Since the study presented in this dissertation work is entirely on composite sections so the enhanced property of individual component plays a crucial role. The outer diameter of the tube is taken as 200mm and its thickness is taken as 2mm.The average cube compressive strength and the elastic modulus of the concrete at 28 days were 68.3MPa and 36,800 N/mm^2. The mass of the drop hammer varies between 205 kg and 1115 kg.The enhanced strength of concrete is directly dependent on the confinement provided by the steel tube. To take care of it a confinement factor ξ is introduced [12].It can be seen the larger the area of steel tube or the yield strength of steel greater will be the confinement. ξ (Confinement factor) is defined as

$$\xi = \frac{A_s \cdot f_{sy}}{A_c \cdot f_{ck}}$$

As and Ac are the area of cross-section of steel tube and area of cross-section of concrete. fsy represents the yield strength of concrete and fck represents the characteristic compressive strength of concrete.

Material model presented in Han et el. is used for steel tube. Typical stress-strain curve for steel is shown in figure

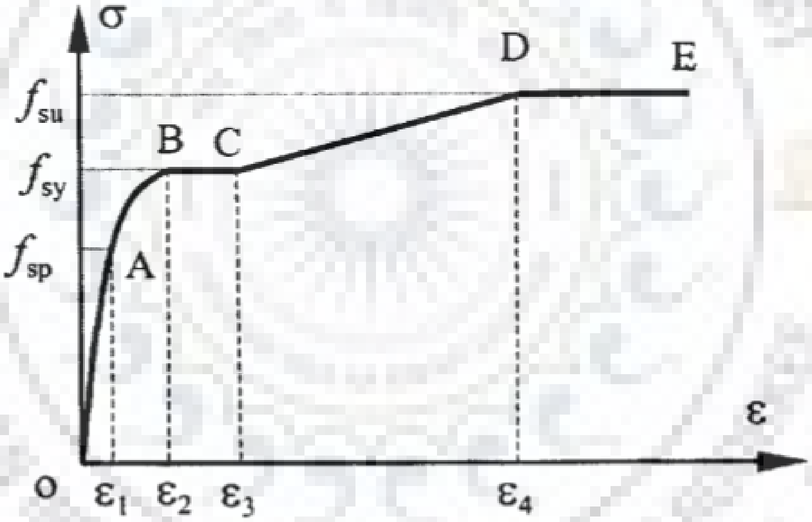


Figure 3.7:-Stress strain curve of steel

Stress-strain curve of steel is divided into five stages. OA represents the linear elastic part of curve. AB represents non-linear elastic behaviour of steel. BC is the stage of yielding of concrete.CD represents strain hardening with DE showing no increase in stress even due to increase in strain in steel. Detailed expression of stress-strain curve of steel are given in Pan (1998).[11]

$$\sigma = E_s.\varepsilon \qquad \text{for } \varepsilon < \varepsilon_1$$

$$\sigma = -A.\varepsilon^2 + B.\varepsilon + C \qquad \text{for } \varepsilon_1 < \varepsilon < \varepsilon_2$$

$$\sigma = f_{sy} \qquad \text{for } \varepsilon_2 < \varepsilon < \varepsilon_3$$

$$\sigma = f_{sy} . \{1+0.6\, \frac{\varepsilon-\varepsilon 3}{\varepsilon 4-\varepsilon 3}\} \qquad \text{for } \varepsilon_3 < \varepsilon < \varepsilon_4$$

$$\sigma = 1.6\, f_{sy} \qquad \text{for } \varepsilon > \varepsilon_4$$

Modulus of elasticity of steel tube was taken as 200,00MPa and the modulus of concrete is taken depending on the characteristic strength of concrete. Poisson's ratio of 0.3 is used for steel while poison ratio of 0.2 is used for concrete. For concrete plastic model Concrete Damage Plasticity (CDP) model is used provided by ABAQUS/Explicit with dilation angle 20^0 based on the studies carried by Han et al. This package was chosen in order to simulate the fracture conditions of the steel tube. The studies carried by Han et. alshows that dilation angle 20 works well in predicting the behaviour of CFST members.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 General

FEM model was developed to study the behaviour of CFST members.The confining effect, composite action and behaviour of CFST under bending predicted by these finite element model were verified with the experimental results published in different research papers. For verification of FEM model, experimental results of different specimen from two research paper were used and verified. Different parametric studies were carried out using verified FEM to study the effect of Grade of concrete, grade of steel and the effect of bottom thickness on CFST members.

1.2 Validation Lin-Hai Han (2004)

The impact force vs time curve of the two specimens are being validated. The curve reaches a peak stage instantly after the impact then the specimen deforms and the further the impact force almost becomes constant for a longer duration as compared to peak stage which is referred to as plateau stage. The curve finally descends sharply and descends to zero.

Table 4.1:- Specimen dimensions and their respective deflections

Specimen label	Boundary condition	L(mm)	H(m)	Initial impact Velocity(m/s)	Impactor mass(kg)	Δ(mm) Measured	Δ(mm) Predicted
CC1	Fixed-fixed	1940	5.5	9.21	465	64	63
CC2	Fixed-fixed	1940	2.5	6.40	920	70	65

The figure 4.1 below compares the impact force of the literature which is being validated against the predicted FEM results obtained.

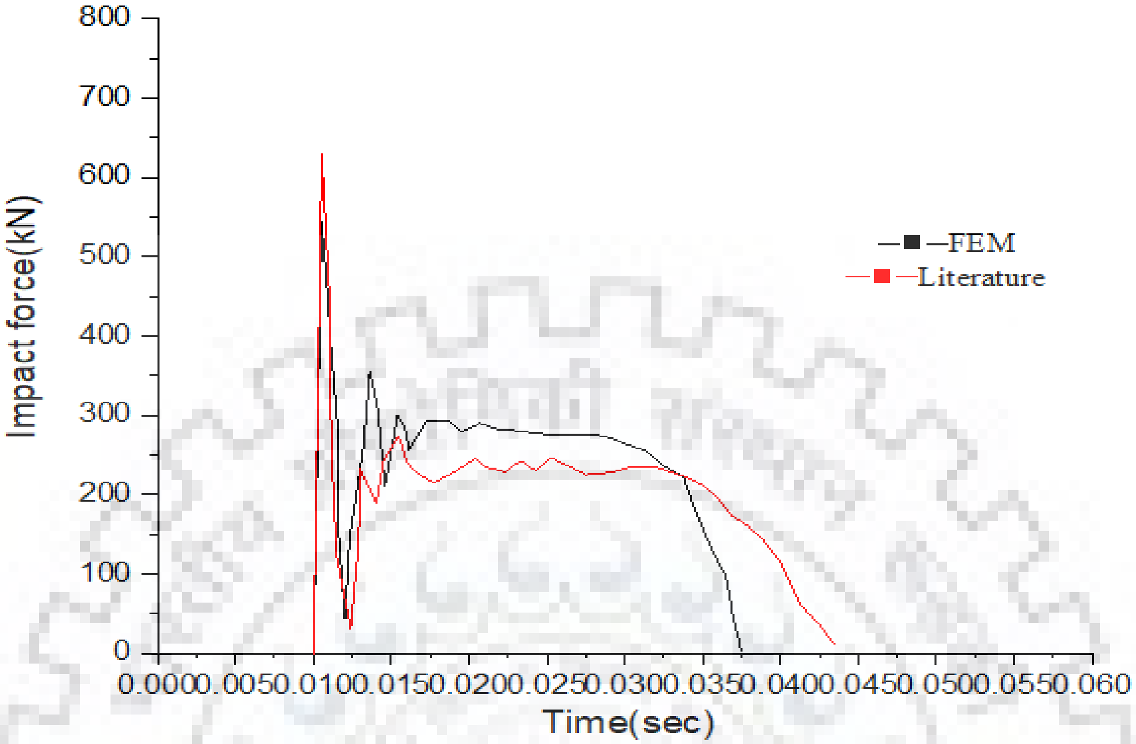


Figure 4.1:- Impact force(F) vs time (t) curve of CC1 specimen

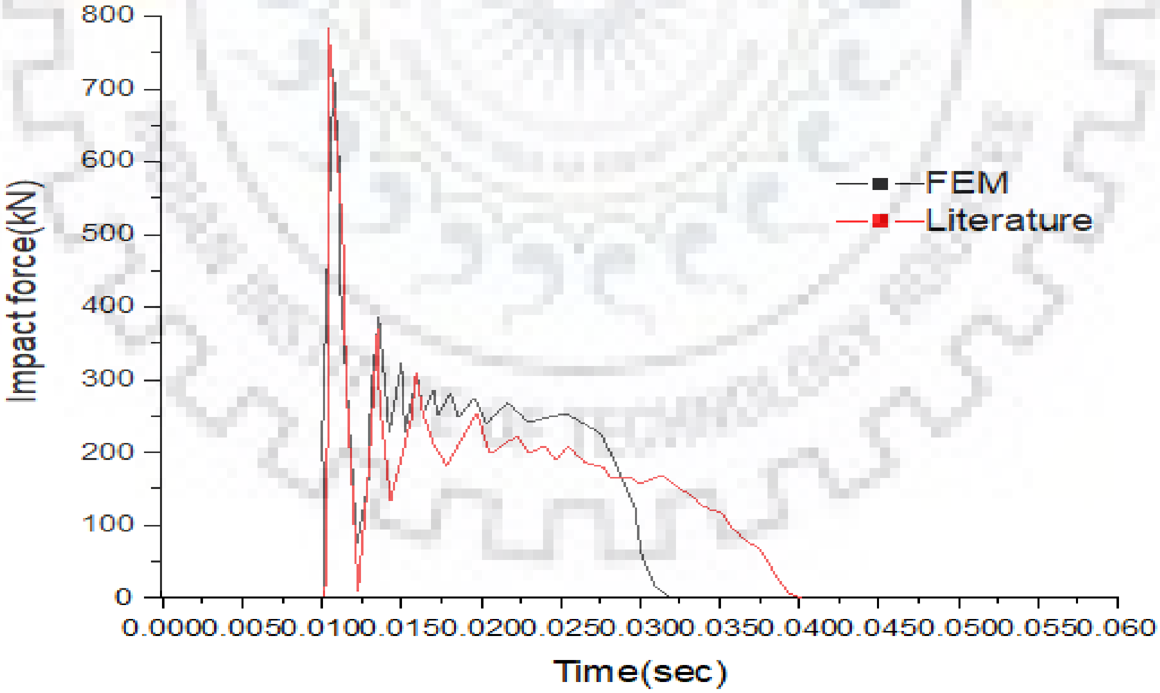


Figure 4.2:- Impact force(F) vs time (t) curve of CC2 specimen

The mid span deflection increases rapidly instantly after the impact and the kinetic energy dissipates. The gradient of the curve decreases and the maximum value of deflection is achieved when velocity becomes zero, also the specimen rebounds.

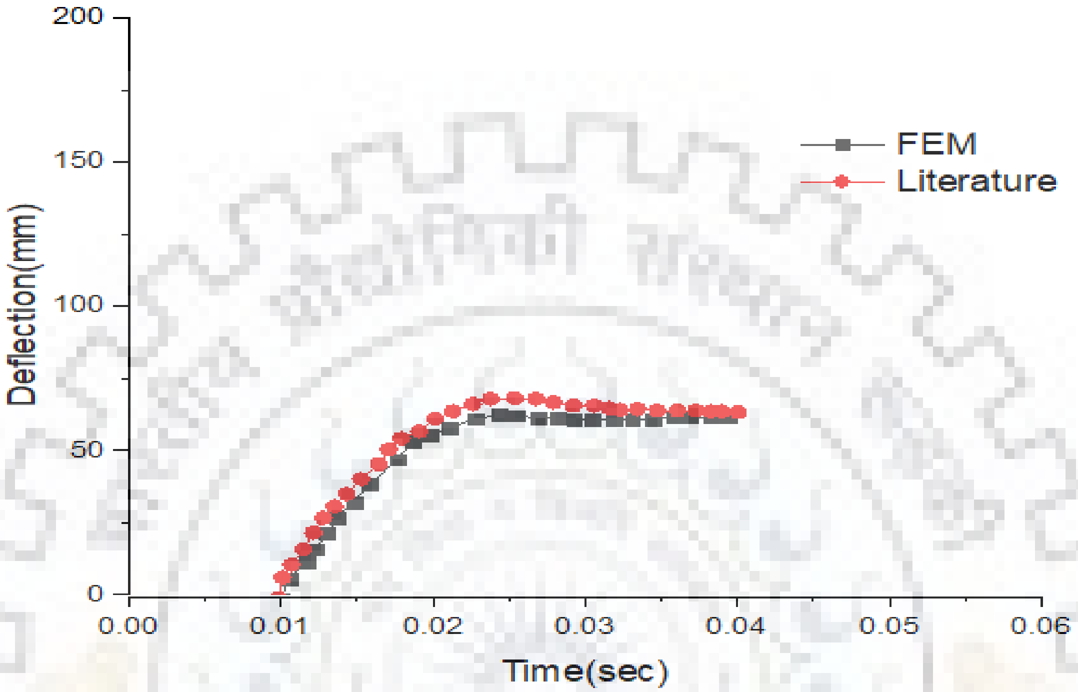


Figure 4.3:- Deflection(mm) vs time(sec) for CC1 specimen

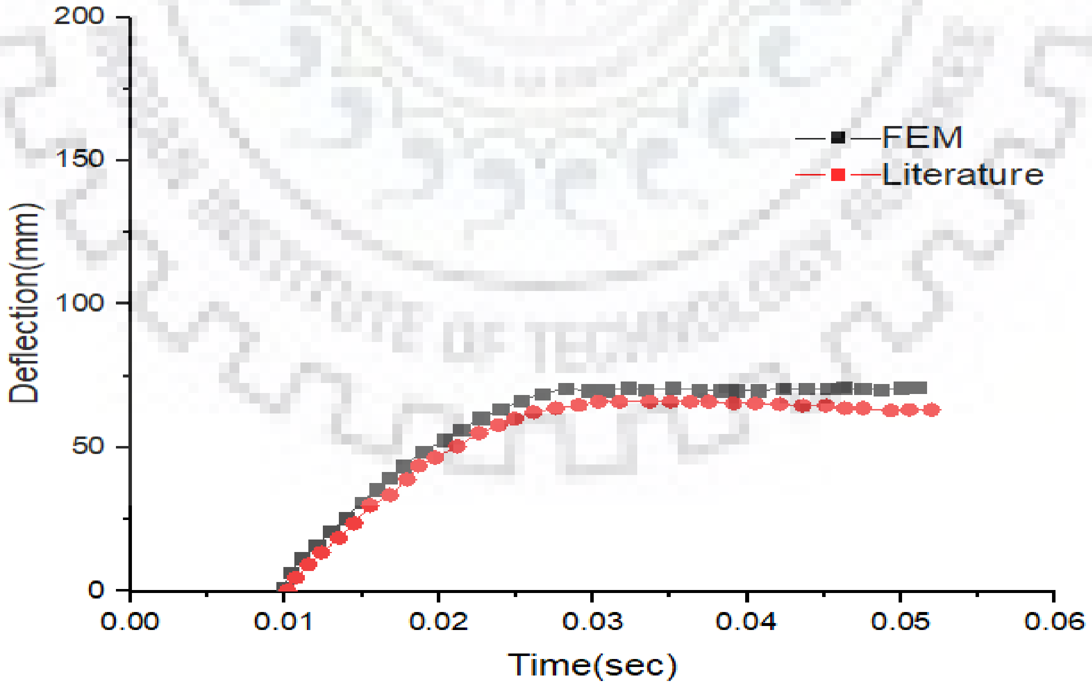


Figure 4.4:- Deflection(mm) vs time(sec) for CC2 specimen

1.3 Validation Chang Ming Hu (2017)

Two specimens from this literature were taken which are being validated with FEM model to check its accuracy. The two parameters namely impact force and mid section deflection are being validated. The impact force showed three stages the peak stage, the almost constant region or the plateau stage and the descending stage.

Table 4.2:- Specimen dimensions and their respective impact force and deflections

Specimen label	n(axial load level)	L (mm)	H(m)	V(m/s)	Energy(kJ)	Δ(mm) Measured	Δ(mm) Predicted	Fm (Measured)	Fm (Predicted)
CFP1	0.3	1800	1.0	4.43	465	64	63	24	24
CFP2	0.3	1800	2.0	6.26	920	70	65	52	46

The figure 4.5 below compares the impact force of the literature which is being validated against the predicted FEM results obtained.

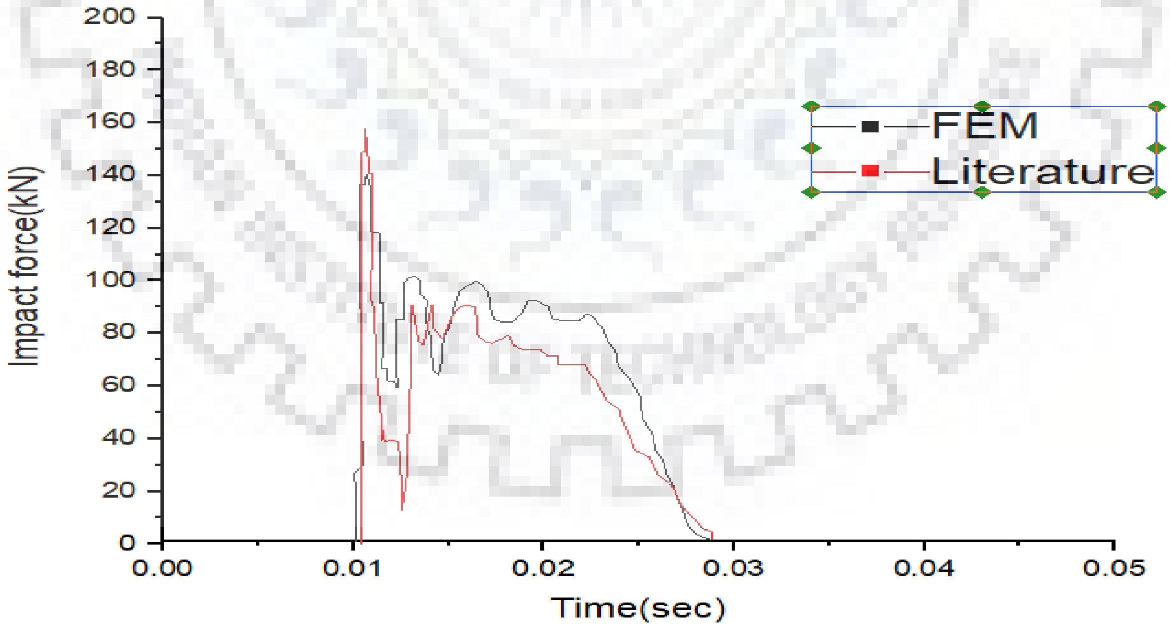


Figure 4.5:- Impact force(F) vs time (t) curve of CFP1 specimen

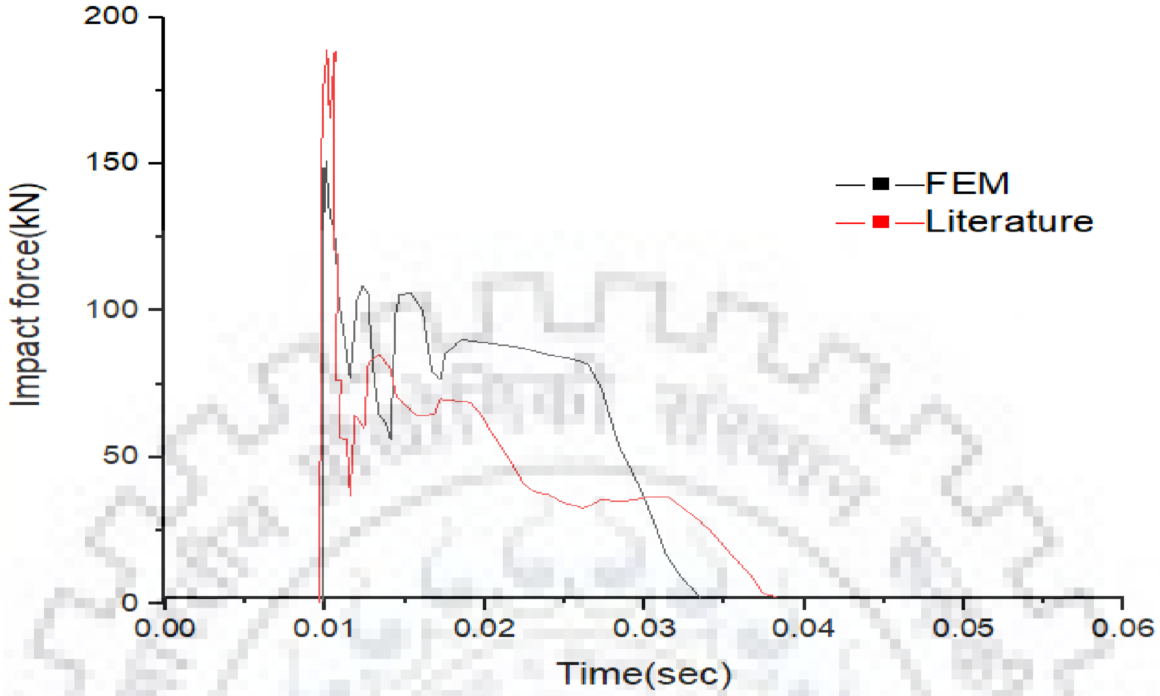


Figure 4.6:- Impact force(F) vs time (t) curve of CFP2 specimen

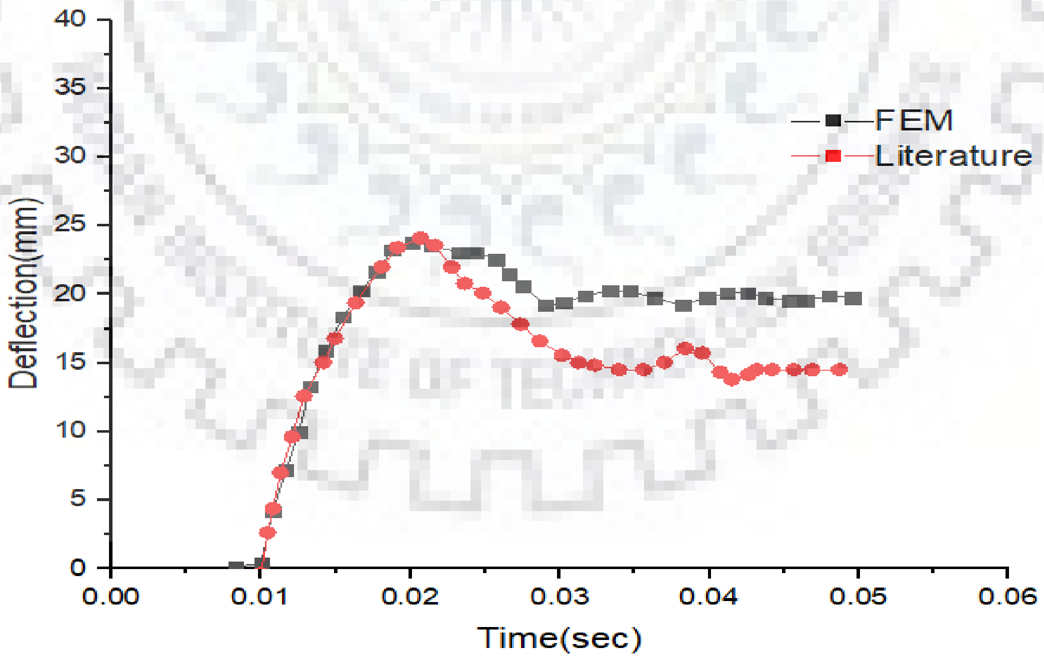


Figure 4.7:- Deflection(mm) vs time(sec) for CFP1 specimen

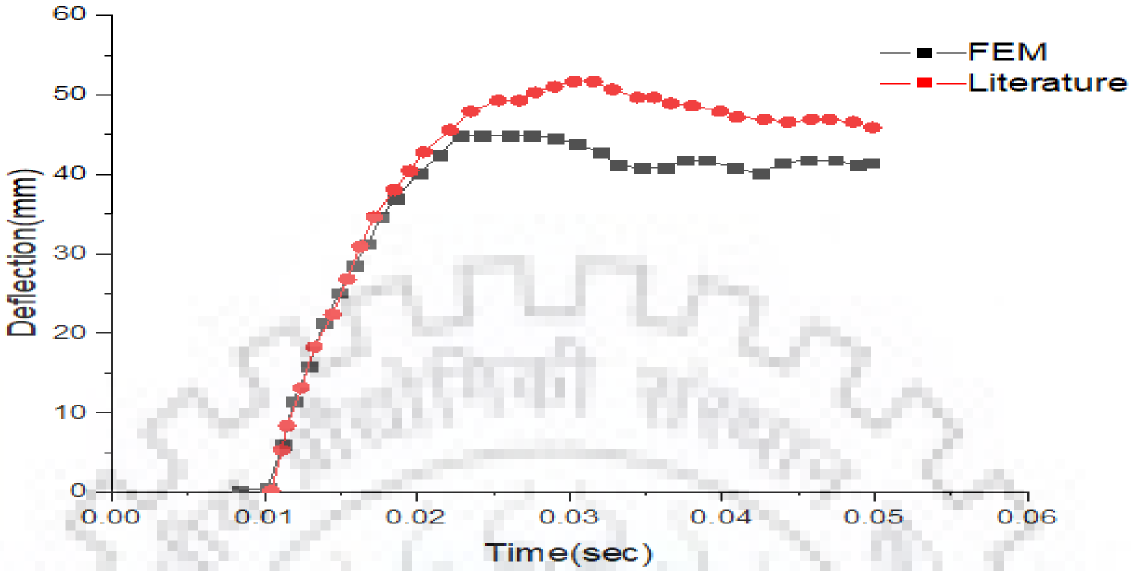


Figure 4.8: Deflection(mm) vs time(sec) for CFP2 specimen

1.4 Parametric study 1: Effect of yield stress of steel

Owing to the advantage of two different material CFST members will be affected by the property of individual members. In order to increase the efficiency of the composite section, effect of material, geometric property and loading conditions in the experiment need to be varied and its effect on the dynamic flexural capacity needs to be studied.

Table 4.3: Specimen dimensions and their respective parameters

Specimens	A1	A2	A3	A4	A5
Dimensions(mm)	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940
f_y(MPa)	250	300	350	400	450
f_{cu}(MPa)	30	30	30	30	30
Impactor mass(kg)	800	800	800	800	800
Impact Velocity(m/sec)	15	15	15	15	15
Max moment M_u^d(kN-m)	310.5	319.8	327.9	335.6	351.5
Percentage increase(M_u^d)	2.91%	2.53%	2.55%	2.34%	4.73%

In order to understand the effect of yield stress on dynamic flexural resistance of member several parameters are being kept constant as shown in table 4.3. The graph reveals the trend of mid span sectional moment resistance with variation in yield stress of steel.

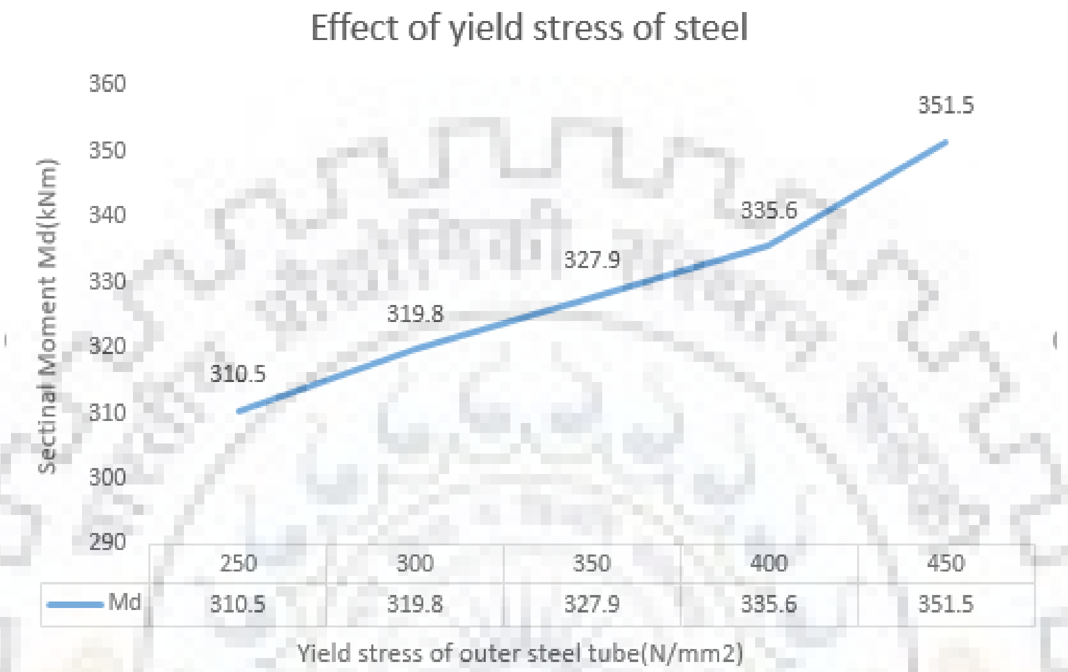


Figure 4.9: Influence of outer steel tube

The trend found is too obvious and the flexural resistance may be supposed to consist of two components. Firstly, the resistance provided by the outer steel tube and secondly the resistance provided by the concrete core. The flexural capacity obviously increases as the strength of steel that is the first component increases.The impact force is found to have increased simultaneously its duration decreases as the contact is more rigid. The mid deflection is obviously lowered as yield stress increases reflecting that the composite has better impact resistance. The dynamic flexural capacity also increases but at a slower pace as inferred from above. This can be reasoned out simply as more is the yield stress, more is the rigidity ultimately leading to more dynamic resistance and hence leading to more sectional moment.

1.5 Parametric study 2: Effect of cube strength of core concrete

The effect of yield stress showed direct relation towards flexural resistance, now the second material of the composite that is the core concrete is being varied in its strength keeping all the others parameters yield steel, impactor mass, impactor velocity constant.

Table 4.4: Specimen dimensions and their respective parameters

Specimens	B1	B2	B3	B4	B5
Dimensions(mm)	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940
f_y(MPa)	250	250	250	250	250
f_{cu}(MPa)	30	40	50	60	70
Impactor mass(kg)	800	800	800	800	800
Impact Velocity(m/sec)	15	15	15	15	15
Max moment M_u^d(kN-m)	326.7	327.8	328.3	328.6	329
Percentage increase(M_u^d)	0.33%	0.15%	0.16%	0.09%	

The cube strength has very little effect on the dynamic flexural resistance of specimen. The impact force also does not show much change and similarly the mid span deflection. This can be attributed to the fact that most of the section moment is being resisted by the outer steel tube and the remaining moment to be resisted by concrete is relatively low and hence its strength does not show any significant change in the dynamic flexural resistance. This also reveals that the flexural moment resisted by concrete is small in comparison to the steel tube. The moment varies slightly in the range of 326-329 kN-m. Also the concrete’s ability to resist moment has increased because of the confinement provided by the outer steel which would have not been enhanced and the concrete core resisted the local indentation at the location of falling hammer.

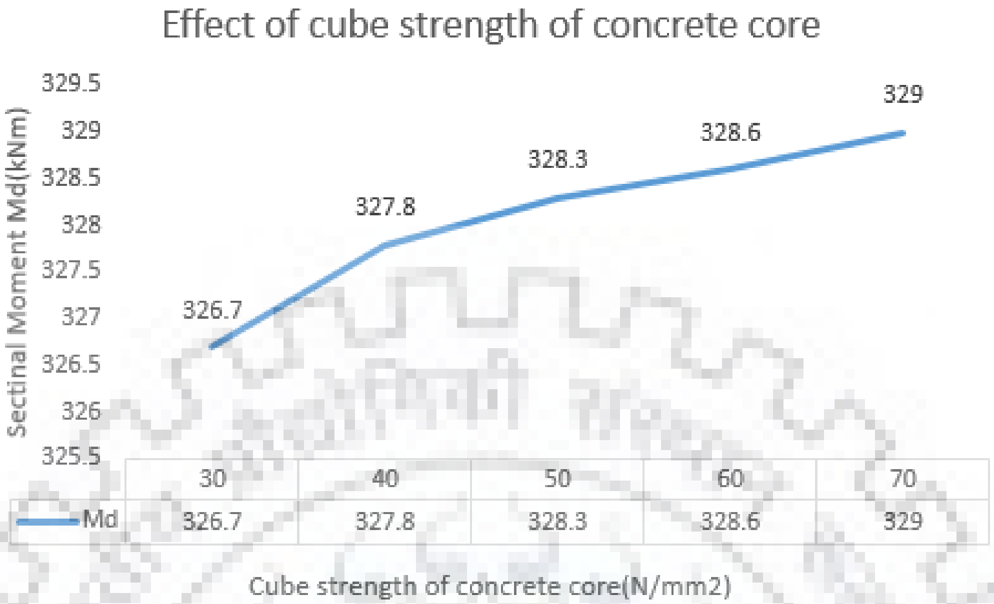


Figure 4.10: Influence of cubic strength of core concrete

1.6 Parametric study 3: Effect of Sectional diameter

The effect of geometrical may also have a significant role in the dynamic flexural resistance of specimen. Hence in this parametric study outer sectional diameter is being changed and rest of the parameters including material properties and the impact loading conditions are kept constant. The sectional diameter is being varied from 200-400mm.

Table 4.5: Specimen dimensions and their respective parameters

Specimens	C1	C2	C3	C4	C5
Dimensions(mm)	200 x 2 x 1940	300 x 2 x 1940	400 x 2 x 1940	500 x 2 x 1940	600 x 2 x 1940
f_y(MPa)	250	250	250	250	250
f_{cu}(MPa)	30	30	30	30	30
Impactor mass(kg)	800	800	800	800	800
Impact Velocity(m/sec)	15	15	15	15	15
Max moment M_u^d(kN-m)	312.8	367.4	415.8	455.4	480.3
Percentage increase(M_u^d)	17.4%	13.1%	9.5%	5.4%	

The sectional diameter increases the dynamic impact flexural resistance of the specimen because if diameter is increased keeping the thickness constant the concrete core inside increases providing it the additional resistance, but the effect of concrete core has less resistance as shown in the second parametric study. Hence it is increasing very gradually.

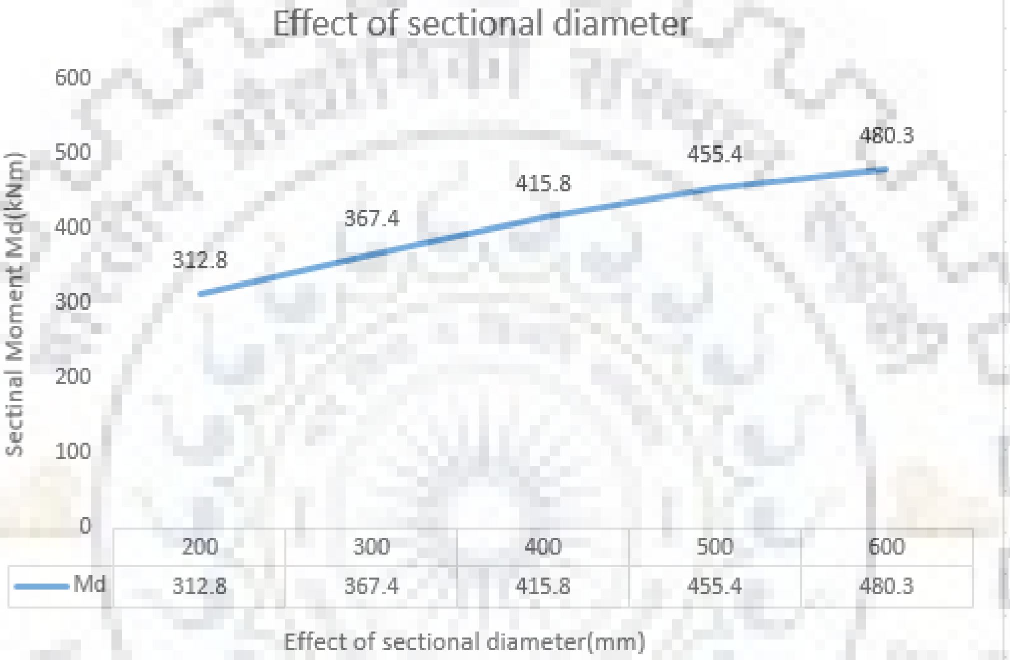


Figure 4.11: Influence of sectional diameter

1.7 Parametric study 4: Effect of impact velocity

The effect of loading conditions is also important in order to understand the dynamic flexural resistance of CFST specimen. Hence in this parametric study the impact velocity is being changed in the range of 4 to 20 m/s keeping all the other parameters material properties and the geometrical properties constant.

Table 4.6: Specimen dimensions and their respective parameters

Specimens	D1	D2	D3	D4	D5
Dimensions(mm)	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940	200 x 2 x 1940

f_y(MPa)	250	250	250	250	250
f_{cu}(MPa)	30	30	30	30	30
Impactor mass(kg)	800	800	800	800	800
Impact Velocity(m/sec)	4	8	12	16	20
Max moment M_u^d	215.8	260.4	285.7	294.6	299.5
Percentage increase(M_u^d)	20.66%	9.71%	3.12%	0.15%	

The dynamic flexural resistance is found to increase sharply on increase the impactor velocity at the beginning. The reason may be the strain rate effects,we know that strain rates of the material are larger under high velocity impact which causes the flexural capacity of the member to increase. As the rate of strain increases the dynamic flexural resistance is found to increase but upto a certain limit. The mid span deflection and the duration of the impact force is also found to have increased. The gradient of the graph shown below decreases with increase in the impactor velocity which points out to the fact that increment in dynamic flexural resistance is limited and cannot increase indefinitely.

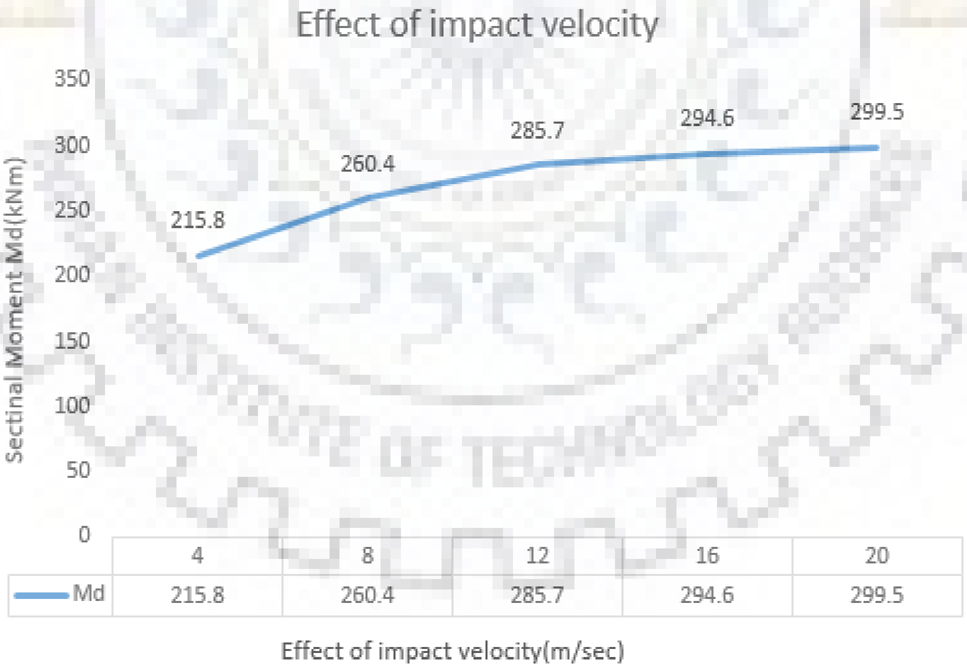


Figure 4.12: Influence of impact velocity

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The main objective of this dissertation work was to develop a three dimensional finite element model to understand the conduct of concrete filled steel tubular section under dynamic impact bending. FEM software ABAQUS was used to develop the three dimensional model of circular beam. Flexural conduct of model under impact of drop hammer was investigated through dynamic bending test in ABAQUS/Explicit. The FEM results were compared with previously done experimental results which were available in different literatures and were found to be in good agreement. Parametric analysis to find out the dynamic flexural behaviour of CFST members under impact has also been carried out.

5.2 Conclusion

FEM model developed genuinely helped in understanding the behaviour of circular CFST beams under impact.Further parametric studies carried on the composite member provides us with the insight of the effect of various parameters that can alter the dynamic moment capacity of the mid span section(since it is the most critical). The parametric study helped in drawing the following conclusions:-

- Concrete filled steel tubes beams has a advantage of enhanced strength of concrete due to confinement and delayed local buckling of tube than corresponding concrete which is not confined.
- Finite element analysis results were found to be in good agreement with the experimental results, thus it can be used to predict the moment capacity of the composite beam
- For increase in grade of cubic concrete by 10 MPa, maximum percentage increase in flexural capacity was 0.33%.
- For increase in grade of steel by 10 MPa, maximum percentage increase in flexural capacity was 9.58%.
- The dynamic flexural capacity increases as the strength of steel that is its yield stress.

- The participation of outer steel core in resisting the moment is more as compared to the inner concrete core.
- The cube strength has very little effect on the dynamic flexural resistance which can be attributed to the fact that most of the section moment is being resisted by the outer steel tube and the remaining moment to be resisted by concrete is relatively low.
- The dynamic flexural resistance is found to increase sharply on increase the impactor velocity at the beginning, but it becomes stagnant after sometime.
- The sectional diameter increases the dynamic impact flexural resistance of the specimen because if diameter is increased keeping the thickness constant the concrete core inside increases providing it the additional resistance.

5.3 Recommendations

The following recommendations can be drawn based on this dissertation work.

- Study of effect of change of height to width ratio with different material properties can help optimizing the CFST members.
- CFST members can be usefulin high seismic region due to there high ductility.
- More research work should be carried on CFST beams as very little research has been done on it.

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