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Cyclic Behavior of Concrete Filled Steel Column and Steel Beam of Different Sections

Er. Nimmy Abraham [1]

[1] PG Scholar, Kerala Technological University India.

Er. Gopika Moorthy [2]

[2] Assistant Professor, Kerala Technological University, India.

Er. Saiprashanth Krishnan [3]

[3] Project Engineer, Noel Apartments, India.

Abstract –

A beam-column is a structural member that is subjected to transverse bending and axial compression at the same time. H Steel beams are beams that are composed of an H-steel core within a precast concrete beam. Advantage of H steel beam is its high bearing capacity compared to RC columns. Concrete Filled Steel Tubular (CFST) structure consists of hollow steel tube filled with plain or reinforced concrete. They are lighter than RC columns and are safer and dependable in seismic regions. The study is to find the seismic analysis of developed joints between H steel beam and CFST column under cyclic and monotonic loading with some key design recommendations and to compare the behavior of those joints of CFST tubes with normal beams and Reduced Beam Sections (RBS). The result aims to show a significant seismic behavior in RBS section than the normal beam section in terms of load- displacement curve, ductility, stiffness and energy dissipation.

Index Terms : *Concrete Filled Steel Tubular section, Reduced Beam Sections.*

INTRODUCTION

In comparison to standard steel, reinforced concrete (RC), and steel-reinforced concrete (SRC) columns, concrete-filled steel tube (CFST) columns offer superior seismic qualities, such as high energy dissipation and ductility. A CFST column's concrete core performs admirably in terms of compression, which helps to improve the confinement effect of the steel tube on the internal concrete and prevent localized buckling of the steel tube. The steel tube can also significantly speed up construction by acting as the concrete core's formwork. Studies have been done to optimize the CFST columns' configuration factors that are important for composite constructions, like the tube thickness and the ratio of steel to concrete. A variety of connection structures have also been created to join CFST columns and beams. There are various sorts of connecting structures. With the development of the construction industry, the joints assembled by CFST columns and RC beams are required in precast composite structures. However, the use of CFST columns in composite frame joints has been limited owing to the difficulty in arranging the longitudinal reinforcements in RC beams. A through-beam connection was developed for the prefabricated CFST column to RC beam frame joints, in which the steel tube was cut off entirely, and continuous longitudinal rebar was adopted in the floor of the RC beam.

In order to join the precast HSRC beams and CFST columns, cantilever H-steel beams are connected with the steel tube through diaphragms. The welded parts of a connection are crucial, and most of the specimens failed due to weld fracture, according to experimental findings of a prior examination. Reduced beam sections (RBS), which can be produced by cutting out pieces of the H-steel flanges and web, respectively, have therefore been suggested as a way to avoid brittle fracture failure. RBS cantilever H-steel beams have also been used as an alternative to the untreated cantilever to obtain improved seismic performance and prevent premature brittle-welding fracture of the junction.

The analysis is done in ANSYS R1 2021 workbench. CFST column was chosen as the only column and Normal beam and Reduced beam sections of different radius was used for comparison. Codes of design used for the project is Eurocode 4. The objective of the project is to find the seismic analysis of joint between H-steel beam and CFST column. It also aims to compare the behavior of those joints of CFST tubes with H – steel beam of reduced beam sections. Behavior was analyzed on the basis of load- displacement curve, hysteresis, ductility, energy dissipation and stiffness.

LITERATURE REVIEW

Various journals were referred for the thesis work. Literature works that helped to improve this thesis are briefed here.

Feng et al., (2021) applied cyclic loading test on normal, RBS and OBW beams with CFST columns. It was seen that RBS regions exhibited more favorable ductility and energy dissipation capability with a slightly reduced bearing capacity. Precast column and H- steel beam was used for the beam – column joint.

Cao et al., (2021) explored the torsional behavior of circular CFST under pure torsion. They provide good properties than normal column. CFST column showed higher values in torsional behavior which is about 0.25% higher than RC column.

Brinda et al., (2020) compared Normal concrete beam and SFRC beam and observed an increase in torsional strength and decrease in angle of twist. SFRC beam of 0.75% fiber fractions was having the highest torsional moment of 2.698 kNm. Angle of twist of SFRC beam (0.75% fiber) was 0.0616**.**

Radzi et al., (2020) discussed the fire effect in beam- column connections. They concluded that high-strength bolt connections had a strong influence on the dynamic response of a structure. So, for a good fire performance, we can opt for high – strength bolt connections in beam -column connections.

Ilanthalir et al., (2020) studied different cross sections of CFST columns under axial compression. It could be concluded that small circular CFST columns have stronger confinement to the concrete core which is less prone to local buckling loads. Higher grade concretes can be used in CFST columns, mainly for M40 concrete.

Wang et al., (2020) researched on the ductility and energy dissipation in beam- column joints. It showed a relation between ductility and loss of energy with that of hysteresis curve. Also, it solved some equations to find these properties from hysteresis curve.

Liu et al., (2019) conducted a low – cycle reversed loading test on CFST – RC beam joint. From the study it could be understood that loading has less effect on CFST columns but damaged RC beams had larger impact at failure mode. The parameters of loading and unloading were considered for the CFST – RC beam joint.

Zhang et al., (2018) did an experimental study of CFST columns with and without foundations. They found that CFST columns have high bearing capacity and effective plastic behavior. CFST column proved to have good properties in ductility and fire resistance with foundations than that of without foundations.

Yang et al., (2017) studied about the seismic behavior in plates connecting beam – column joint. From the results, it showed more bending effect than twisting effect. Maximum load was attained by the plates in order to provide minimum load in beam and column.

Shi et al., (2014) compared ductility behavior of hybrid beams and high strength beams. From comparison, High strength beams provide less ductility which shows more yielding nature than brittle nature. Hybrid beams showed more ductility as it expands with increase in load.

CFST columns have high bearing capacity than normal columns and provides stronger confinement with the concrete. High bolt connections possess high fire dynamic resistance. RC beams containing steel have highest torsional moment and lowest angle of twist. A H – beam have high bearing capacity and stronger cross sections than any other beams. RBS H-beam possess significant seismic behavior than normal H beam. It showed excellent results for monotonic and cyclic load behavior which is better than normal beam.

CYCLIC LOADING

The model consists of beam- column joint. Hollow square CFST column and H-beam joined by welded connection is considered here. The cross-sectional dimensions of the square hollow CFST column were 250 mm × 250 mm x 6mm, and the column length was 1000 mm. M40 grade concrete was used and the structural steel was Q345. The bolt was 10.9 M20 grade. The geometry diagram is shown in Fig.1.

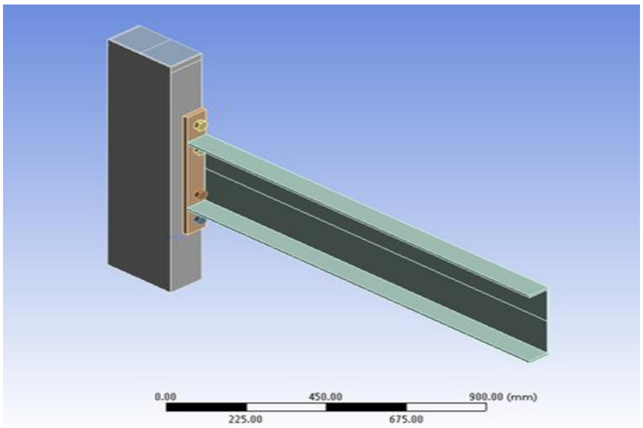

Fig. 1 Square CFST column- Normal H steel beam

The sectional dimensions of the H-steel beam were 300 mm × 150 mm × 6.5 mm × 9 mm (height × width × web-thickness × flange-thickness), and its total length was 1360 mm. The software feature of ANSYS "model symmetry" was chosen for easy evaluation. A mesh size of 35mm was chosen as it showed the highest deformation and have a highest peak value.

For cyclic loading, two hinge supports were applied on both ends of the beam and a load of 3000N (in model symmetry, taken as 1500 N) was applied on top of the column. Maximum displacement value of 80mm was chosen for the time step of 32 seconds. Remote displacements were provided on top and bottom portions of the column by the keeping its rotation at X, Y and Z axis as zero. A pretension force of $1.55x10^5$N was applied on one side of bolts as load and another side as lock. Time steps up to 0.1 seconds shows the pre-tensioning force which occur at the bolts. After 0.5 seconds, cyclic loading of the structure starts up to the maximum displacement value.

RBS SECTION

RBS section stands for Reduced Beam Section. The main aim of these type of beam section is that RBS forces the plastic hinge in a beam to form away from the column face. A radius of 15mm, 30mm and 35mm was chosen for RBS section. The Fig. 3.2 shows the ANSYS geometry of Reduced beam sections of radius 15mm, 30mm and 35mm.

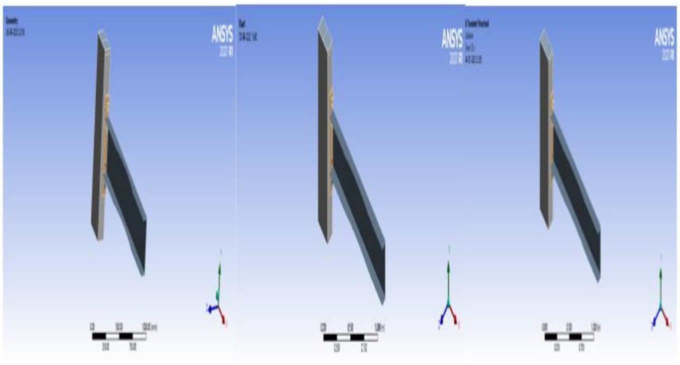

Fig.2 Geometry of RBS sections- R15, R30 and R35

MONOTONIC LOADING

A static load that increases continuously is a monotonic load. A dynamic load is applied fast such that the body is subjected to a motion, and the resistances to the load are provided by the stiffness, viscosity, and inertia of the body. Fixed support was provided on bottom end of CFST column and an axial load of 3000kN (in model symmetry, it is 1500kN).

RESULTS AND DISCUSSIONS

Seismic behavior of CFST column along with the normal and RBS beams was analyzed in ANSYS. Fig. 3 shows the hysteresis curve of normal beam. Yield stress is obtained by tangent method (frequently obtained minimum stress where the material starts to deform plastically). Ultimate stress is the maximum stress obtained in the analysis. It is the maximum stress the material withstands before failure. The ultimate stress obtained was 123.17kN. Failure stress or Failure displacement = 0.85 x (Ultimate stress or Ultimate displacement) where 0.85 is the factor of safety considering external conditions.

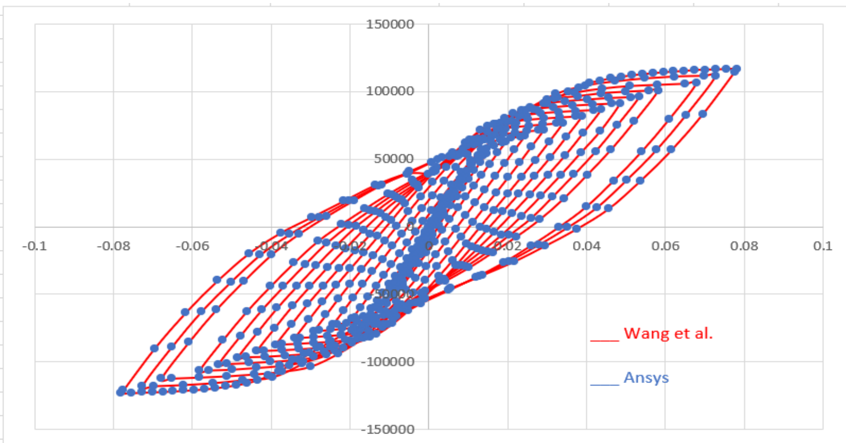

Fig .3 Hysteresis curve of normal beam

Table 1 shows the results of yield stress, ultimate stress and failure stress with their yield, ultimate and failure displacement attained by normal beam. Fig 4,5,6 shows the hysteresis curve of R15, R30 and R35 beams.

Table 1. Hysteresis result of yield state

Displacement(m)	**Force reaction (Yield state) N**
28.47×10^{-3}	75424

Displacement(m)	**Force reaction (Ultimate state) N**
61.605x10-3	**123171**

Displacement(m)	**Force reaction (Failure state) N**
46.5x10-3	105300

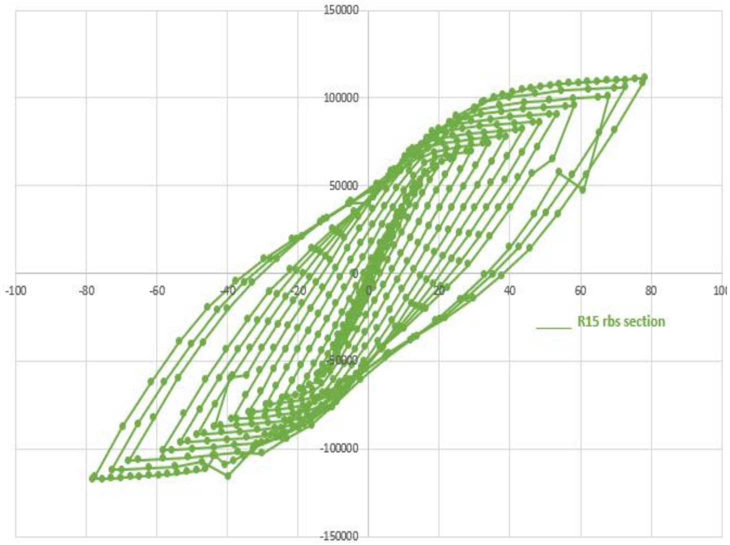

Fig 4. Hysteresis curve of R15 beam

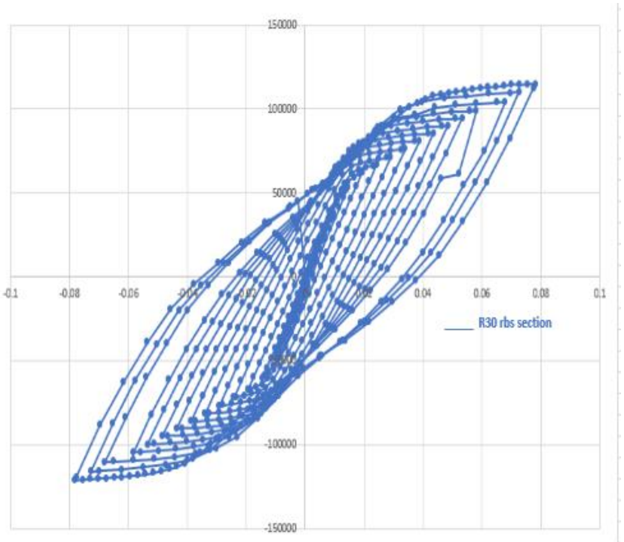

Fig 5. Hysteresis curve of R30 beam

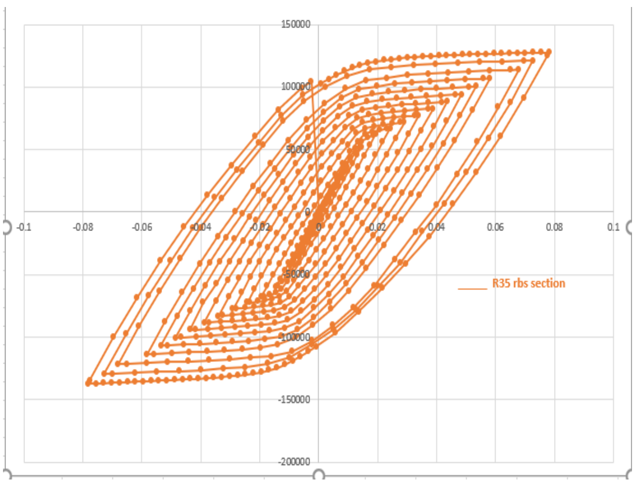

Fig 6. Hysteresis curve of R35 beam

Table 2 shows a comparison of results of different RBS cross sections. Except for R15, the values of R30 and R35 are higher than that of normal beam, hence, proving their suitability in earthquake prone regions.

Table 2. Hysteresis results of different RBS sections

	Displacement (mm)	Force Reaction (Yield state) (N)	Displacement (mm)	Force Reaction (Ultimate state) (N)	Displacement (mm)	Force Reaction (Failure state) (N)
R15	30.85	72137	61.734	117300	53.708	102051
R30	29.84	71278	53.225	121210	45.24	103028
R35	45.6	79157	70.555	137320	59.97	116722

Table 3 shows the different values of ultimate load bearing capacities of different beam sections. As per the data, normal beam possesses higher load bearing capacity and among reduced beam sections, it is R35 beam.

Table 3. Monotonic Loading Results

CFST column-	Ultimate bearing capacity (kN)
Normal beam	119.4
R15 beam	117.8
R30 beam	117.7
R35 beam	120.5

The ultimate load bearing capacity corresponding to 40mm are 119.4kN, 117.8kN, 117.7kN, and 120.5kN respectively from the ANSYS analysis. Hence, it proves better results in monotonic behavior. Fig 7,8,9,10 shows the monotonic behavior of Normal, R15, R30 and R35 beams.

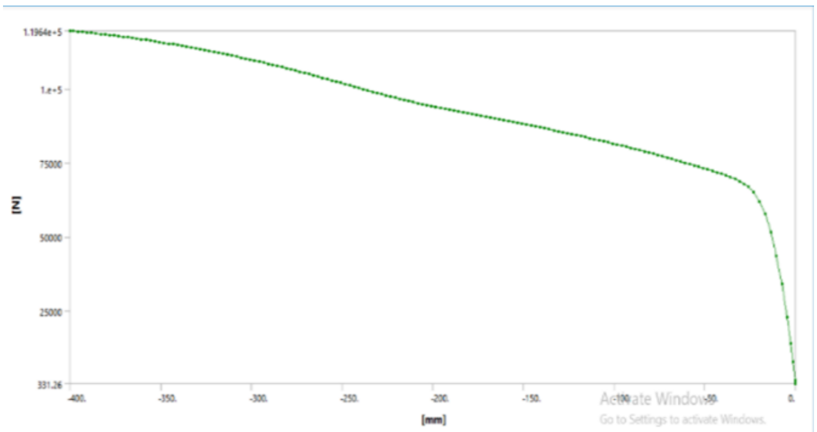

Fig 7. Monotonic curve of Normal beam

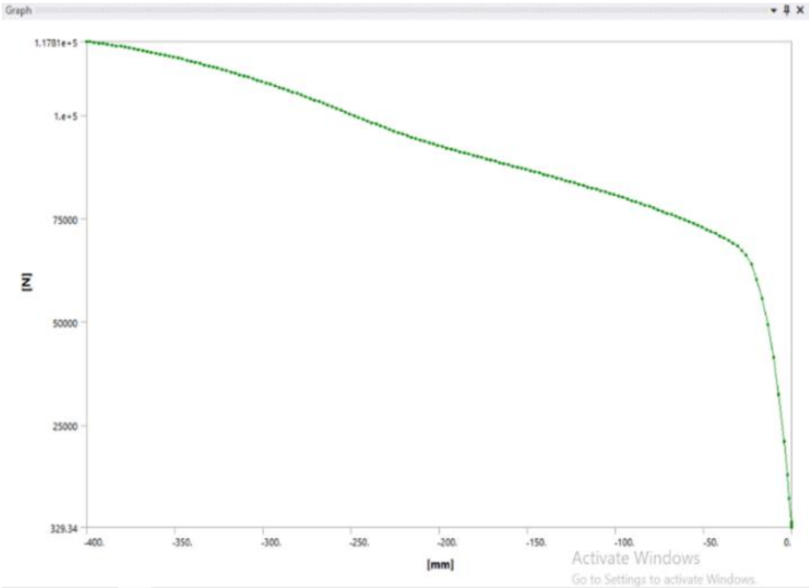

Fig 8. Monotonic curve of R15 beam

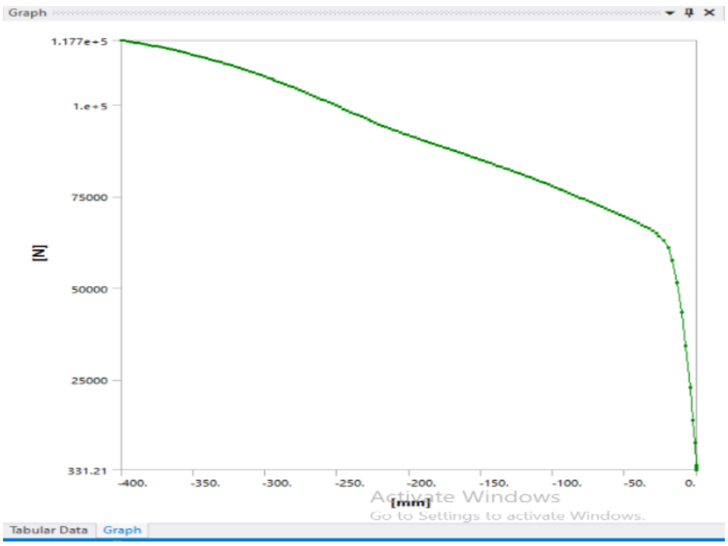

Fig 9. Monotonic curve of R30 beam

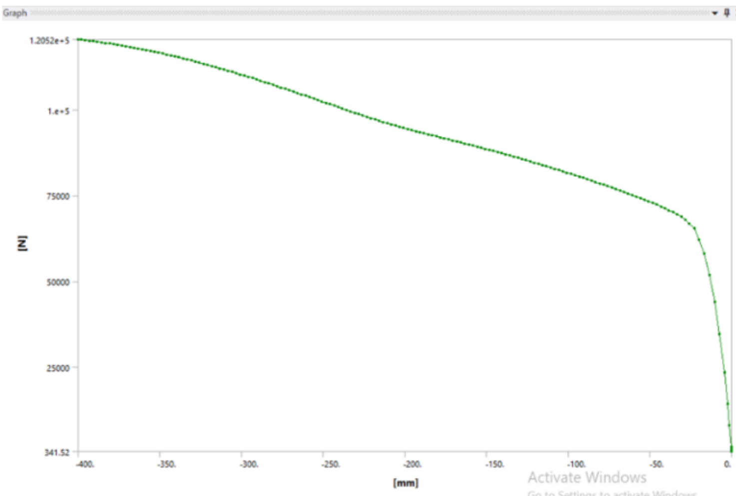

Fig 10. Monotonic curve of R35 beam

ADDITIONAL COMPONENTS IN CYCLIC LOADING

Ductility coefficient is the ratio of ultimate displacement to yield displacement. It is denoted by the symbol μ. Table 4 shows the various ductility coefficient values of normal beam and different RBS beams.

Table 4 Ductility coefficient values

CFST column and	Ductility coefficient
Normal beam	2.001
R15 RBS beam	1.78
R30 RBS beam	1.54
R35 RBS beam	2.16

Higher energy dissipation coefficient means higher ductile behavior and is helpful to avoid sudden brittle failure in earthquake regions

Viscous dissipation or equivalent viscosity coefficient is an irreversible process by means of which the work done by a fluid on adjacent layers due to the action of shear forces is transformed into heat. It is the parameter to determine the amount of energy lost by the viscous force in the turbulent flow.

Equivalent viscosity coefficient, $h_e = (1/2\pi) *(S_{\text{full upper curve}} + S_{\text{full lower curve}}) / (S_{\text{half upper curve}} + S_{\text{half lower curve}})$.

Energy dissipation coefficient, $E = 2\pi h_e$.

Table 5 Energy dissipation values

CFST column-	Equivalent viscosity coefficient, h_e	Energy dissipation coefficient, E
Normal beam	0.26	1.63
R15 RBS beam	0.21	1.31
R30 RBS beam	0.25	1.62
R35 RBS beam	0.42	2.62

As per the Table 5, R35 RBS beam has higher loss of heat energy produced from deformation of fluid. R15 RBS beam has lower energy loss than normal beam.

Stiffness is a measure of how much force is required to displace a building by a certain amount. The results show that R35 showed least percentage decrease in stiffness from the other RBS beams and normal beam. R35 showed 65.42% of decrease in stiffness whereas normal beam, R15 beam and R30 beam showed 66.31%, 70.32%, and 66.47% respectively.

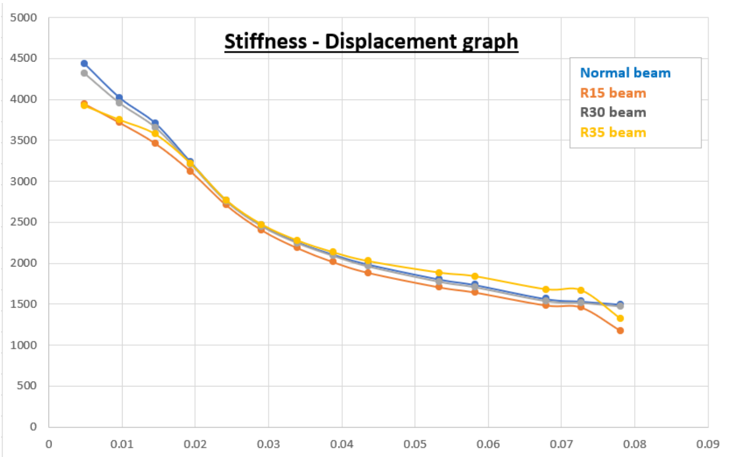

Fig 11. Stiffness v/s displacement graph

Fig. 11 showed the different stiffness versus displacement graphs obtained from normal beam, R15, R30 and R35 beam respectively. Major failure of the structure happened in the bolted areas and minimum deflection in column areas. There were small amount of bending and twisting observed in the beam area after the failure.

CONCLUSION

This work deals with the seismic behavior of CFST column along with the normal and RBS beams. Cyclic loading is the movement due to impact, waves, wind gusts and strong earthquakes. CFST column – H steel beam shows significant seismic behavior as a composite structure. The load bearing capacity of reduced beams were also studied and the results were compared to that of a normal beam. Following were the results obtained from cyclic loading of CFST column with normal and reduced beams:

- Higher radius showed higher stress capacity in reduced beam sections.
- CFST column with RBS of radius 30mm and 35mm showed higher yield stress, ultimate stress and failure stress than CFST column with normal beam sections.
- Higher ductility coefficient had higher energy dissipation, thus preventing brittle failure of the connection.
- Higher energy dissipation coefficient was for R35 beam which possessed higher area in hysteresis curve.
- Lower decrease in stiffness was also observed in R35 beam which showed a greater seismic performance.
- R35 beam also showed more load bearing capacity in case of monotonic loading than other beams.

Hence it could be concluded that reduced beam sections are applicable in high impact areas like earthquake prone regions.

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