SEISMIC PERFORMANCE OF COMPOSITE, RC AND STEEL FRAME-A COMPARATIVE STUDY

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ABSTRACT

Seismic events pose a significant threat to urban infrastructure worldwide, necessitating innovative engineering solutions to enhance the resilience of buildings and mitigate the potential for catastrophic damage. The rising popularity of steel-concrete composite structures can be attributed to their numerous advantages when compared to conventional concrete and steel constructions. These advantages encompass superior strength-to-weight ratios, increased ductility, effective fire resistance, and enhanced protection against corrosion. Conversely, reinforced concrete structures have become less cost-effective due to their higher dead load and potentially unsafe structural framework, while steel is less suitable for constructing frames in tall buildings due to its lower rigidity and increased ductility. As a result, steel-concrete composite structures have gained widespread approval because of their capacity to combine the advantageous characteristics of both steel and concrete.

An effort has been made in this work to assess the seismic performance of steel concrete composite structures, steel structures, and reinforced concrete structure in the context of Bangladesh in earthquake zone 2. All structures are made identically similar with the same plane area, floor height and loading condition. Reinforced concrete frame consist of concrete slab, while steel and composite frames are modeled with composite deck slabs.

In this study, different types of columns are used including concrete filled tube (CFT) column, fully encased column (FEC), w steel section column , hollow structural section (HSS) column, reinforced concrete (RCC) column to compare the seismic performance of these framing systems. Finite element based software ETABS is used to perform the static nonlinear pushover analysis and parameters like normalized base shear, drift ratio, performance point, and hinge formation pattern are evaluated. Comparative study concludes that the steel concrete composite frames perform the best in terms of seismic performance, better ductility, and load carrying capacity.

Keywords: *Composite frame, seismic performance, pushover analysis, ETABS*

1. INTRODUCTION

Bangladesh, a land of burgeoning urban landscapes and a resilient spirit, stands at a crossroads in its construction choices. As the nation strives to build taller and faster, a critical question arises: what material will form the backbone of its future structures? Steel, concrete, and the innovative hybrid – steel-concrete composite – each offer unique strengths and weaknesses, demanding a nuanced understanding within the Bangladeshi context.

Steel-concrete composite framing is a smart building system for medium to high-rises. It combines steel beams, metal decking, shear studs, and concrete to create a super-efficient structure. This clever mix leverages the strengths of each material: steel's strength and ductility, concrete's fire resistance and affordability

An effort has been made in this work to assess the seismic performance of steel concrete composite structures, steel structures, and reinforced concrete structure in the context of Bangladesh in earthquake zone 2 by static nonlinear pushover analysis in ETABS software. Linear analysis is used to design the section sizes of the members and nonlinear analysis is used to observe the designed structure’s behaviour.

To assess the seismic performance of these framing systems, various types of columns are used, including reinforced concrete (RCC) column, hollow structural section (HSS) column, fully encased column (FEC), w steel section column, and concrete filled tube (CFT) column. Composite columns exhibit synergistic behaviour due to the combination of steel and concrete. The interaction between these materials enhances the overall strength and stiffness of the column. The strength and ductility of the steel material are the main factors affecting steel columns. Plasticity is the defining feature of the behaviour, which is affected by slenderness and local/global buckling. Reinforced concrete columns combine concrete's compressive strength with the tensile strength of embedded steel reinforcement. The behaviour is influenced by factors such as axial load, confinement, and detailing of reinforcement.

1.1 Objective of the study

- To evaluate the seismic performance of steel concrete composite frame, steel only frame and RC frame for building using non linear pushover analysis
- To compare the capacity curve for the three framing systems of building
- To investigate the performance point for design level earthquake for the three framing systems of building
- To study the progressive failure behavior of the three framing systems by observing hinge formation

2. METHODOLOGY

A four-story industrial building in gazipur, bangladesh, serves as the test case for this study. Three types of framing systems are compared for this structure: (a) steel-concrete composite frame, (b) steel frame, (c) reinforced concrete frame. Figures 1 and 2 illustrate the building's 3d model and floor plan respectively. To ensure an accurate comparison, all three framing systems have the same floor area, floor height, and bay dimensions (4 bays of 6 meters each in both x and y directions). The finite element software etabs version 18.1.1 is used to analyze and design these different building frames. Table 1 details the buildings' key features, including geometry, material properties, and loading considerations.

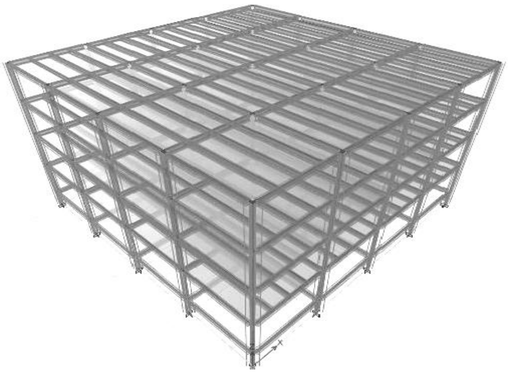

Figure 1: Typical 3-D view of steel concrete composite building

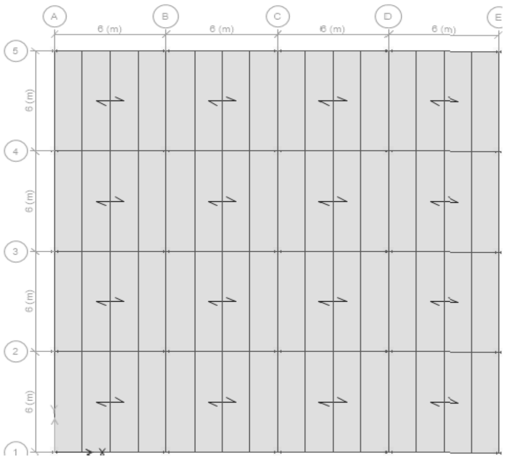

Figure 2: Typical floor plan of steel concrete composite building

Table 1. Basic features of the building

Geometric property	
Type of building	Industrial
No. of storey	4
Height of the building	16.46 m
Typical storey height	3.66 m
Length of the building	24 m
Width of the building	24 m
Material property	
Concrete strength	27.58 MPa
Yield strength of steel section	345 MPa
Yield strength of reinforcement	413.7 MPa
Loading Condition	
Live load	6 KN/m2
Floor finish	1.436 KN/m2
Partition wall	2.394 KN/m2
Cladding	7.297 KN/m2
Wind load (according to BNBC 2020)	
Site location	Gazipur
Basic wind speed	66.5 m/s
Exposure	A
Structure importance coefficient	1.15
Topographic factor, Kzt	1
Directionality factor, Kd	0.85
Gust factor	0.841

Earthquake load (according to BNBC 2020)	
Seismic modification factor, R	5 (concrete) and 4.5 (steel)
Seismic zone coefficient, Z	.2 for zone 2 (Gazipur)
Structure importance coefficient, I	1.25
Building category	III
Site class	SC
Seismic design category	C
Spectral acceleration, Sa	0.09393
K	1.0905

2.1Steel-concrete Composite Frame

In this research, two types of steel concrete composite frames are used. They are steel-concrete composite frame using fully encased column (FEC) and another one is used concrete filled tube (CFT). Both of these two models are kept same floor type composite floor with metal deck.

In this modelling, two sizes of FEC are used. One type of size is used in only corner position which is called FEC corner and another one is used rest of the column position of the building which is called FEC inner. The section type of these two fully encased columns is concrete encasement rectangular. Both of these section dimensions, depth is 500 mm and width is 500 mm. But the embedded I section is different. In FEC corner is used W10X17 and in FEC inner is used W12X40.

Also, two sizes of concrete filled tube column are used in another model. One type of size C250X19 is used in exterior position and another type of size C300X20 is used rest of the column position of the interior building. The section shape of these two concrete filled tubes is filled steel tube. The section dimensions of these columns are shown in table 2.

Table 2. Section dimension of circular filled tube

Property name	C250X19	C300X20
Total depth	250 mm	300 mm
Total width	250 mm	300 mm
Flange thickness	19 mm	20 mm
Web thickness	19 mm	20 mm
Corner radius	0 mm	0 mm

Due to pushover analysis, composite column are transformed into equivalent steel section with respect to area and moment of inertia. As pushover analysis of composite section in ETABS software is not easily done, so transform sections are used in this case. Fully encased column is transformed into equivalent W steel column and circular filled tube column is transformed into equivalent hollow structural section (HSS) steel column. Another two steel frame models are drawn using W steel column and HSS steel column with respect to economical conditions. Here composite section using an equivalent steel section with adjusted properties (area, moment of inertia) has achieved the same load-carrying capacity. However, this equivalence may ignore the individual material behaviours and their interaction in non-linear behaviour.

2.1Steel Frame

Two types of steel frame structures are used in this research. Also two types of transformed steel sections are used in pushover analysis instead of composite columns. Material and geometric properties are kept same in these models. We only used different types and sizes of steel columns in these models.

Table 3. Section dimension of transform W steel column

Property name	**Transform W steel corner**	**Transform W steel inner**
Total depth	400 mm	400 mm
Top flange width	400 mm	400 mm
Top flange thickness	50 mm	75 mm
Web thickness	76 mm	85 mm
Bottom flange width	400 mm	400 mm
Bottom flange thickness	50 mm	75 mm
Fillet radius	20 mm	28 mm

Table 4. Section dimension of transform HSS column

Property name	**Exterior HSS column**	**Interior HSS column**
Total depth	250 mm	300 mm
Total width	250 mm	300 mm
Flange thickness	25.6 mm	28.1 mm
Web thickness	24.6 mm	27 mm
Corner radius	0 mm	0 mm

Table 5. Section dimension of W steel column

Property name	**W steel corner**	**W steel inner**
Total depth	275 mm	325 mm
Top flange width	250 mm	325 mm
Top flange thickness	25 mm	25 mm
Web thickness	25 mm	25 mm
Bottom flange width	250 mm	325 mm
Bottom flange thickness	25 mm	25 mm
Fillet radius	0 mm	0 mm

Table 6. Section dimension of HSS column

Property name	**Exterior HSS column**	**Interior HSS column**
Total depth	250 mm	300 mm
Total width	250 mm	300 mm
Flange thickness	20 mm	25 mm
Web thickness	20 mm	25 mm
Corner radius	0 mm	0mm

2.2 Reinforced Concrete Frame

Two different sizes of square column are used in this reinforced concrete frame structure. One type of size is used in only corner position which is named RCC corner column and another one is used rest of the column position of the building which is named RCC inner column. The section dimension of these columns is shown in Table 7.

Table 7. Section dimension of transform HSS column

Property name	**RCC column (corner)**	**RCC column (inner)**
Depth	850 mm	950 mm
Width	850 mm	950 mm

2.2 Modelling in ETABS

For this research, five building models are drawn in ETABS version 18.1.1 software. Steel concrete composite frame, steel frame and reinforced concrete frame are used in these buildings. Loading conditions are kept same in these buildings. Floor type is composite floor system with steel deck which is used both in steel concrete composite frame and steel frame.

New model is created selecting steel section database code AISC14M, steel design code AISC 360-10 and concrete design code ACI 318-14. Then define material properties and frame sections. Deck section is used in both steel concrete composite floor system and steel frame building. Slab section is used in reinforced concrete frame building. Beam, Column and slab or deck sections are drawn.

Load cases of the building models are defined for this study. In this study define load cases are dead load, live load, floor finish, partition wall, earthquake load, wind load, cladding, push x, push y. These load cases are classified as linear or nonlinear depending on the analysis method used. Assigning the structural loads, static analysis is run using linear static load cases. Then the structure is designed. The ETABS 18.1.1 designed steel frame, concrete frame, composite beam, and composite column in the five structures.

2.3 Pushover Analysis

Nonlinear static pushover analysis is used to analyze building models performance beyond elastic limit. Nonlinear static analysis of these models is carried out to study the comparative behaviour of steel concrete composite frame, steel frame and reinforced concrete frame. Pushover analysis can determine the behaviour of a building including the ultimate load and the maximum inelastic deflection. Local nonlinear effects are modelled and the structure is pushed until a collapse mechanism gets developed. At each step, the base shear and the roof displacement is plotted to generate the pushover curve. It gives an idea of the maximum base shear that the structure was capable of resisting at the time of the earthquake. As the buildings are regular shape, so it also gives a rough idea about the global stiffness of the building.

After the structural members are designed push displacement value up to which we want to observe the behaviour of structure are decided. Push displacement value 800 mm are used in this study. The corner joint point is considered for that displacement. In this study, new load case is defined for pushover analysis named gravity load. The gravity load is included the dead load, live load, floor finish, partition wall and cladding load. Gravity load is converted to nonlinear static load case so that the program can use this case as the starting point for the pushover. Push X and Push Y load cases are also defined. The load cases are set to run analysis. Transformed sections of the designed composite columns are used here. Nonlinear static analysis is run to observe proper structural behaviour for defined push displacement. After running analysis deformed shapes are shown for push along X direction & Y direction.

A building's seismic behaviour is assessed using force-deformation criteria to identify possible plastic hinge points, or aggregated inelastic behaviour. Performance limit values serve as the foundation for the acceptance criterion. Three locations labelled IO (Immediate Occupancy), LS (Life Safety), and CP (Collapse Prevention) are referred to as limit states or the hinge's acceptance criteria. Five points labelled A, B, C, D, and E are utilized to characterize the force deformation behaviour of the plastic hinge in Figure 3.

At the IO level, small cracks might be seen in non-structural members but no damage is inflicted on structural members. At the LS level, low damage in the structure and small reduction on lateral stiffness and strength occurs but the structure remains stable as life safety is provided At the CP level, some walls may collapse, and permanent displacements can be observed in the structure. However, the total collapse is prevented. But after this point the structure becomes unstable and on the verge of collapse. The range D-E allows the frame elements to sustain gravity loads only. After point E the structure totally collapses.

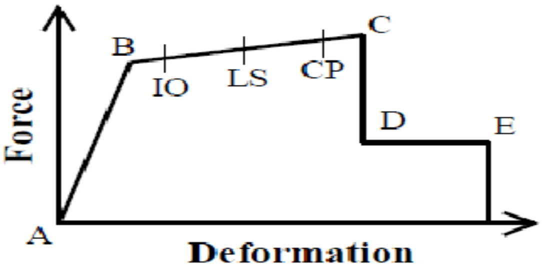

Figure 3: Level of performance

3.RESULT AND DISCUSSION

In this study, after modeling five types of frame structure which are RCC building, CFT column building, FEC column building, HSS column building, W shaped column building, a nonlinear pushover analysis is carried out for evaluating the structural seismic response among them in the form of tables and graphs. Response parameters like pushover curve in the form of normalized base shear vs drift ratio, performance point and plastic hinge formation pattern are discussed to evaluate which type of building frame is most effective during earthquake loading and performs better with least damage to the life and structure. Comparative study among composite structures and steel structures along with RCC structures is also done. In all capacity curves abscissa represents ratio of displacement and story height and ordinate represents ratio of base shear and total dead load. The point where the capacity and demand curve intersect that is performance point. The performance point obtained from plot type FEMA 440 EL. Formation of plastic hinge pattern among the five buildings is also discussed.

2.4 Pushover Capacity Curve

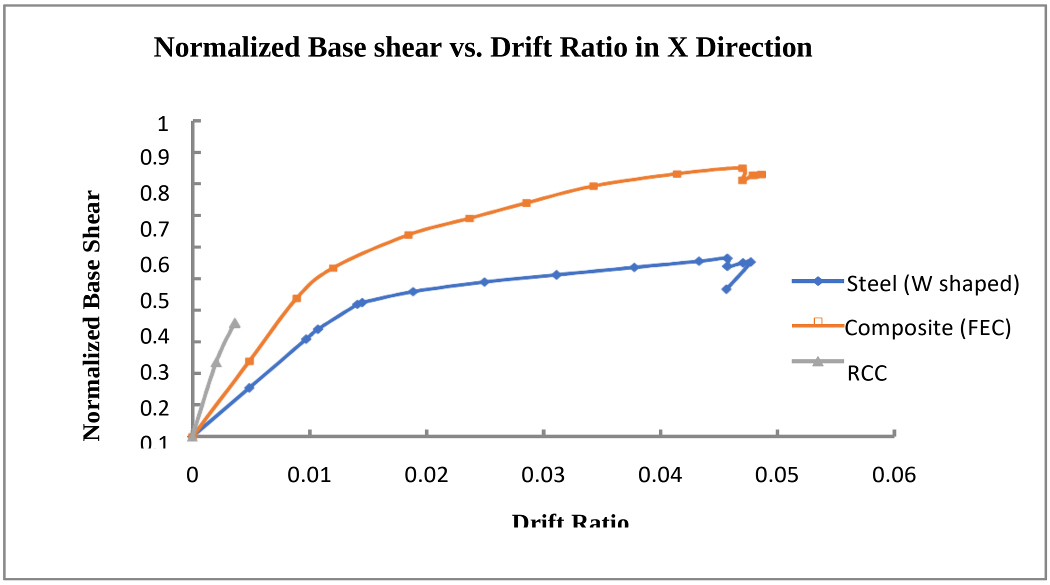

Figure 4: Normalized base shear vs drift ratio in X direction

Figure 4 shows capacity curves obtained in X direction for RCC building, FEC column building and W shaped column building in the form of normalized base shear vs drift ratio. The behaviour of three curves is similar up to yield point which is linear behaviour. Beyond yield point, drift ratio is increasing at a higher rate with little increase in the normalized base shear. It represents the yielding of the structure and starting of inelastic action of building components. W shaped column building shows more linear behaviour than FEC column building and FEC column building shows more linear behaviour than RCC building as FEC column building, W shaped column building and RCC building behave linearly up to normalized base shear of 0.436, 0.339 and 0.235 with drift ratio of 0.0089, 0.0107 and 0.0020 respectively. But FEC column building shows more ductile behaviour and stiffness than W shaped column building and RCC building shows brittle behaviour. Here base shear capacity of FEC column building is almost 50% and 135% higher than W shaped column building and RCC building respectively. So, FEC column building performs better in seismic loading over both RCC building and W shaped column building.

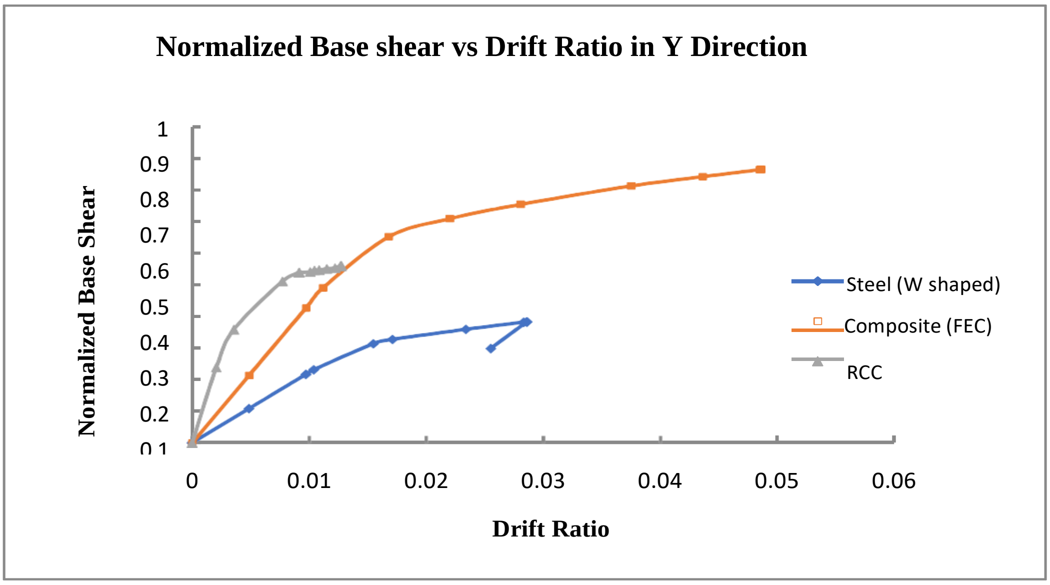

Figure 5: Normalized base shear vs drift ratio in Y direction

Figure 5 shows capacity curves obtained in Y direction for RCC building, FEC column building and W shaped column building in the form of normalized base shear vs drift ratio. It shows similar result like Figure 4.

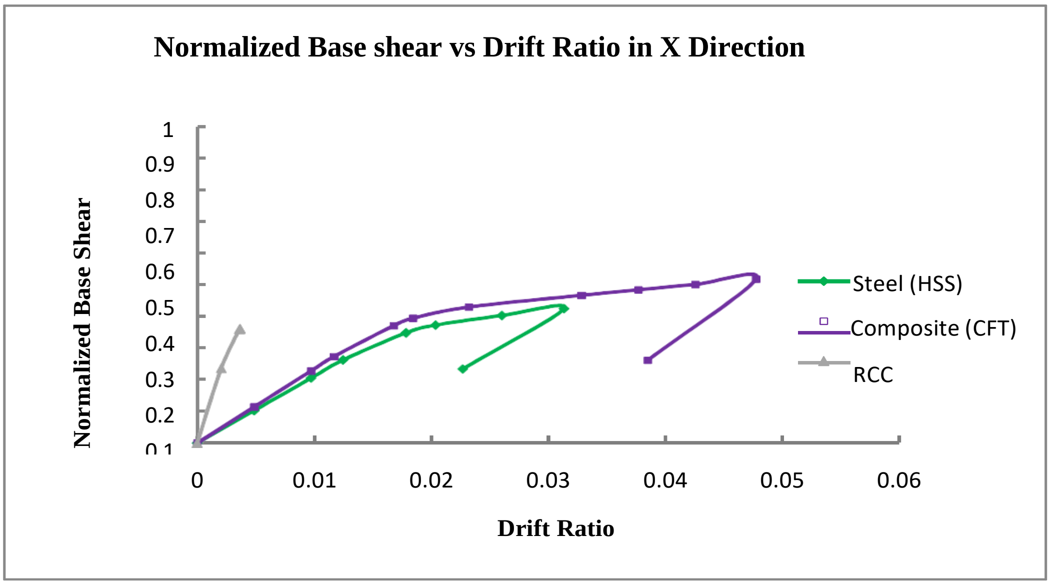

Figure 6: Normalized base shear vs drift ratio in X direction

Figure 6 shows capacity curves obtained in X direction for RCC building, CFT column building and HSS column building in the form of normalized base shear vs drift ratio. CFT column building shows more linear behaviour than HSS column building HSS column building shows more linear behaviour than RCC building as CFT column building, HSS column building and RCC building behave linearly up to normalized base shear of 0.272, 0.204 and 0.235 with drift ratio of 0.0116, 0.0097 and 0.0020 respectively.

CFT column building shows more ductile behaviour than HSS column building and RCC building shows brittle behaviour. But both CFT column building and HSS column building snap at the points (0.0477, 0.516) and (0.0313, 0.423) respectively after sufficient yielding. Here base shear capacity of CFT column building is almost 22% and 43% higher than HSS column building and RCC building respectively. CFT column building performs better in seismic loading over both RCC building and HSS column building.

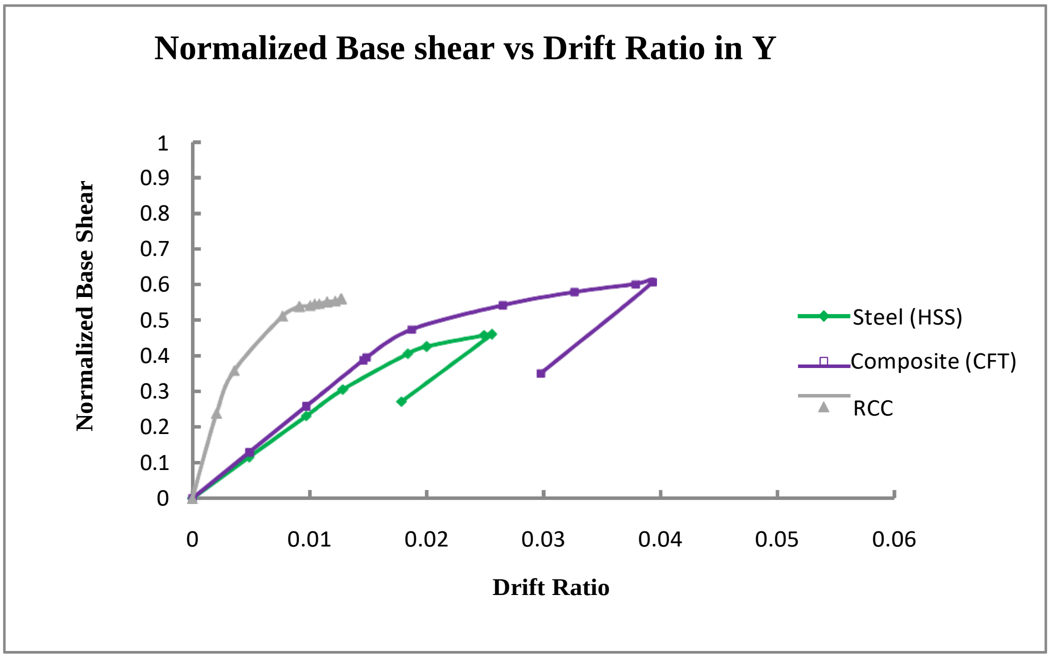

Figure 7: Normalized base shear vs drift ratio in Y direction

Figure 7 shows capacity curves obtained in Y direction for RCC building, CFT column building and HSS column building in the form of normalized base shear vs drift ratio. It shows similar result like Figure 6.

2.5 Performance Point

The tabular representation of displacement , base shear and performance level at performance point and graphical representation of spectral displacement and spectral acceleration obtained for RCC building, CFT column building, FEC column building, HSS column building, W shaped column building using pushover analysis are shown here.

Table 8. Displacement, base shear and performance level at performance point

	X direction			Y direction		
Building type	**Displacement (mm)**	**Base shear (kN)**	**Performance level**	**Displacement (mm)**	**Base shear (kN)**	**Performance level**
FEC column	187	15062	A-IO	202	15351	IO-LS
CFT column	279	10329	IO-LS	261	11525	IO-LS
W shaped column	234	11777	IO-LS	271	9030	>CP or B-C
HSS column	290	9459	IO-LS	273	10268	IO-LS
RCC	-	-	-	128	25159892	IO-LS

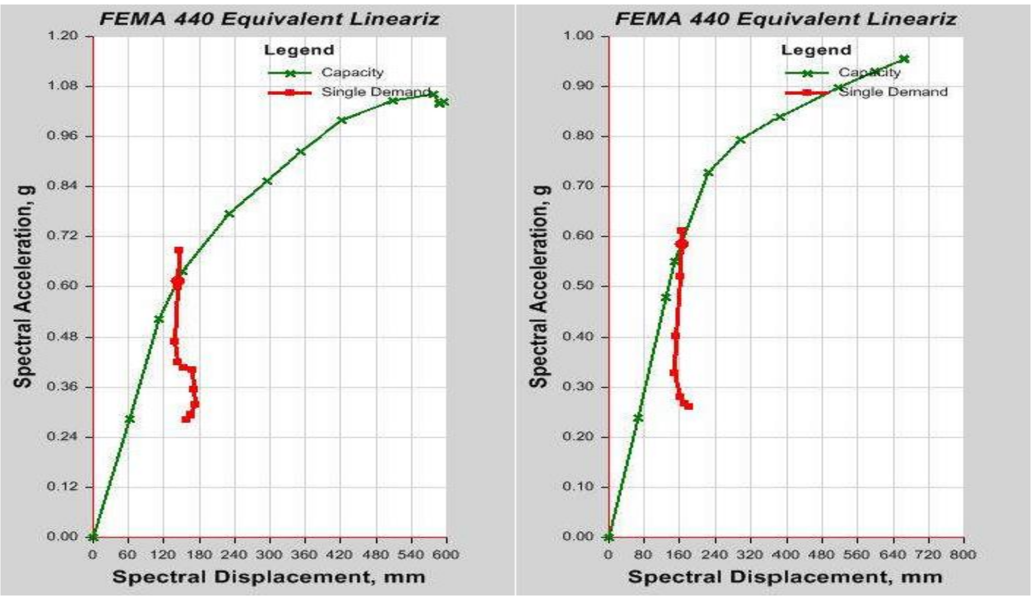

Figure 8: Performance point of FEC column building in X direction and Y direction

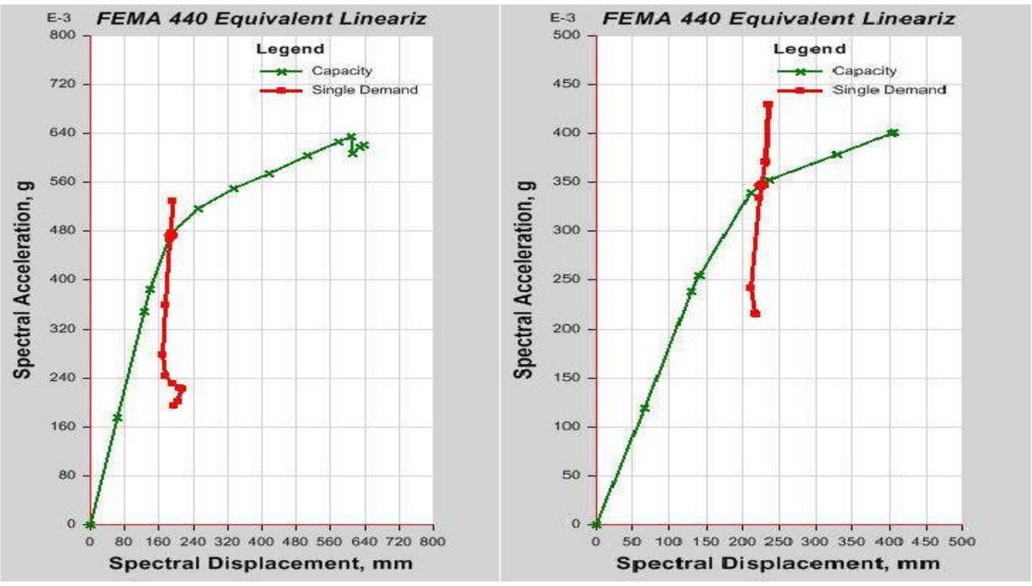

Figure 9: Performance point of W shaped column building in X direction and Y direction

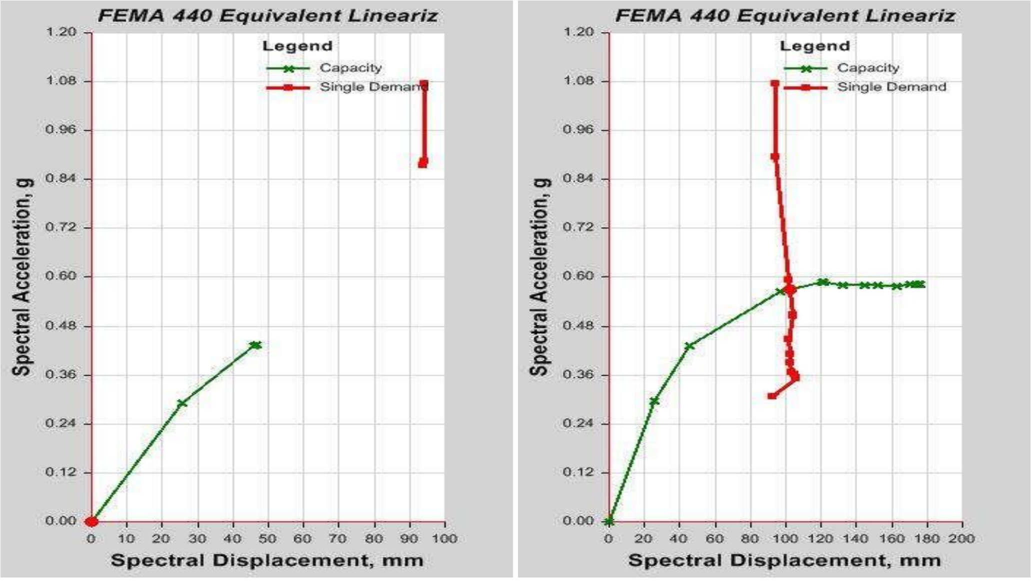

Figure 10: Performance point of RCC building in X direction and Y direction

2.6 Hinge Formation

Ultimate hinge behaviour of the five type buildings according to the hinge formation are illustrated by the tables.

Table 9. Ultimate hinge behavior at X direction

Building type	**Max. Displacement (mm)**	**Max. Base Shear (kN)**	**Type of Affected Member**	**No of affected Member**
FEC column	800	25390	-	-
CFT column	647	16807	Column	2
HSS column	303	11155	Column	2
W shaped column	255	8791	Column	10
RCC	34	11929	Column at support	16

Table 10. Ultimate hinge behavior at Y direction

Building type	**Max. Displacement (mm)**	**Max. Base Shear (kN)**	**Type of Affected Member**	**No of affected Member**
FEC column	773	24912	Beam	16
CFT column	539	12886	Column	2
HSS column	515	11650	Column	6
W shaped column	752	15800	Column	3

CONCLUSIONS

From the capacity curves it is observed FEC column building performs better in seismic loading over both RCC building and W shaped column building and CFT column building performs better in seismic loading over both RCC and HSS column buildings. Again FEC column building performs better than CFT column building under seismic loading. FEC column building is more ductile than CFT column building. From performance points of the buildings it is observed at performance point

RCC building has lowest displacement and highest base shear and steel buildings have highest displacement and lowest base shear whereas composite buildings have medium displacement and medium base shear with good level of performance compare to the RCC and steel buildings. From observation of hinge formation pattern composite buildings perform better than steel and RCC buildings. Again FEC building performs better than CFT building as ultimate plastic hinge formed in beams indicating weak beam strong column behaviour and RCC building performs the poorest as plastic hinge formed in support.

After considering all the parameter in pushover analysis seismic performance of five buildings can be presented by good to poor descending order:
FEC building > CFT building > HSS building > W shaped building > RCC building

To be certain about the performance of composite structures under seismic loads, however, more experimental research is needed.

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