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Seismic Performance Assessment of RCS Building by Response Spectrum and Pushover Analysis

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ABSTRACT

Hybrid RCS frame system integrates reinforced concrete (RC) columns with structural steel (S) beams, combining the advantages of concrete and structural steel. Past studies have shown better performance of RCS structure in comparison to pure steel and conventional concrete system. Despite the past research, the use of steel in construction industry in India is very low as compared to many developing countries. The RCC Structure is no longer suitable because of increased dead load and stiffness. There is great potential for increasing volume of steel in construction. The main aim of the present work is to evaluate the performance of RCS system in severe seismic zone and facilitate the greater acceptance and use of RCS systems as an alternative to conventional lateral resisting systems in comparison with ordinary RCC building. Fifteen story regular and irregular RCS and RCC frame buildings are designed according to IS Codes of practice and analysed using - SAP2000. Response spectrum and pushover analysis are carried out to assess the seismic performance of RCS building and compared with equivalent RCC structure.

Keyword: Seismic Performance Assessment, RCS Structure, RCC Structure, Response Spectrum, Pushover Analysis

INTRODUCTION

Steel and concrete are widely used construction materials. Use of steel in structure permits slender sections with good tensile strength, increased ductility and reduced buckling. Concrete, on the other hand, possess good compressive strength, corrosion protection and thermal insulation. In order to derive the optimum benefits from both materials composite construction is preferred.

In RCS system structural steel beam generally I section, is connected to the RC columns and slabs through shear connectors, which enables flow of stresses through the members thereby improving overall rigidity and load capacity of the structure.

In spite of the various advantages of hybrid systems, their use has been constrained mainly due to the insufficient knowledge about the behaviour and design of composite members and their connections. This is significant particularly for moderate to high seismicity regions with concern about structural performance in the inelastic range.

OBJECTIVE

The main objective of the present work is to-

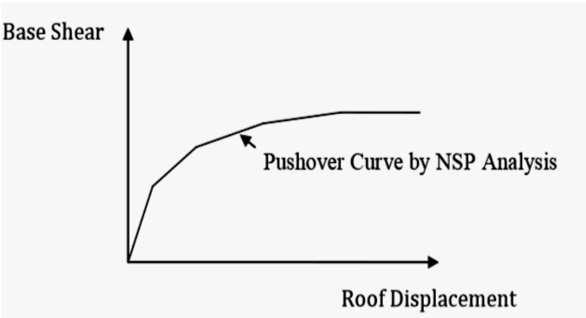
- Analyse and designRCS building using Indian Standard codes.
- Study the seismic response of tall regular and irregularRCS buildingby response spectrum analysis.
- Study the effect of joint deformations on the overall behaviour of tall regular and irregular RCS frames through pushover analysis.
- Compare the earthquake response of tall regular and irregular RCS building with an equivalent RCC building.

Response Spectrum Analysis: The peak response of the structure such as displacement, velocity, acceleration is obtained directly from response spectrum which is a plot of maximum structural response vs. frequency or natural period. The IS-1893:2002[1] gives an average Response spectrum and can be employed in seismic design of structures.

Pushover Analysis: A static non-linear procedure in which the structure is subjected to incremental lateral forces with a certain pattern until a target displacement is reached. It gives information about the seismic performance of the structure such as member ductility, development of hinges in the structure, structural behaviour beyond elastic range.

The intersection of capacity spectrum and demand spectrum marks the performance point of the structure.

Building Performance has been classified into 5 levels-Operational (OP), Immediate Occupancy (IO), Damage Control (DC), Life Safety (LS) and Collapse Prevention (CP).The lateral force is applied at the deformed state from point A. Before point B the structure will show linear behaviour. Beyond point B, hinges will start to form.



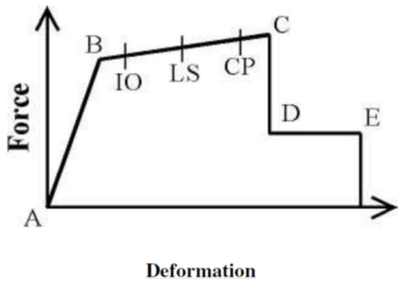


Fig.1 Base Shear vs. Roof Displacement Fig.2Risk Indicator Curve

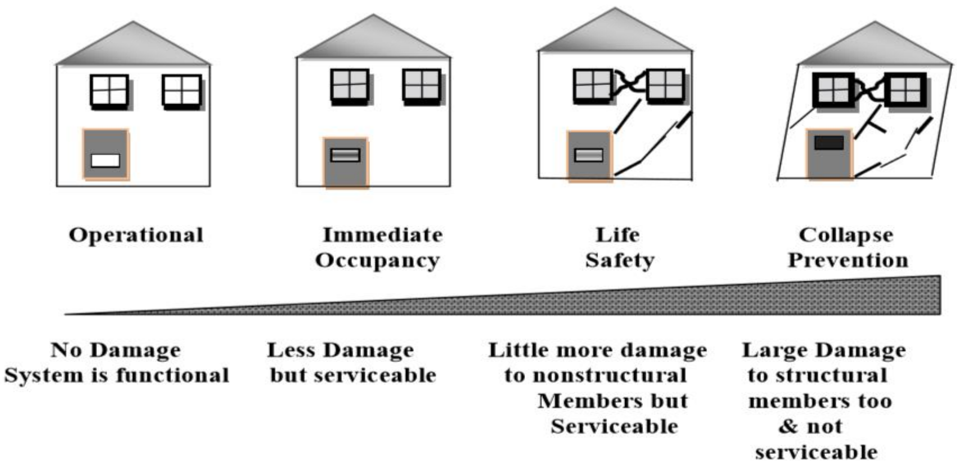


Fig.3 Performance Levels and Damage Functions

MODEL DESCRIPTION.

Three types of tall symmetrical buildings i.e. building with regular plan, plan irregularity and vertical irregularity, located in seismic zone IV have been considered. The modelling of the buildings and earthquake loads are in accordance with IS: 1893-2002[1] and IS: 456-2000[2].The plan dimension of regular model and H-shape model is 24x36 and that of L-shape model is 42x42 m on the outer periphery and 24x24m on the inner periphery in both perpendicular directions. The columns are placed at 6m centre to centre along both the axes for all the three building models. For comparison purpose same building plan is considered for RCS and RCC frame model. The frame sections have been chosen in relevance to practical application.The material properties, section and load details are given in table 1.

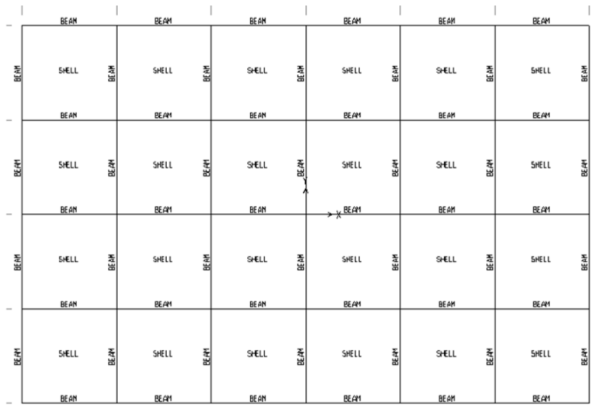


Fig.4 Regular frame plan

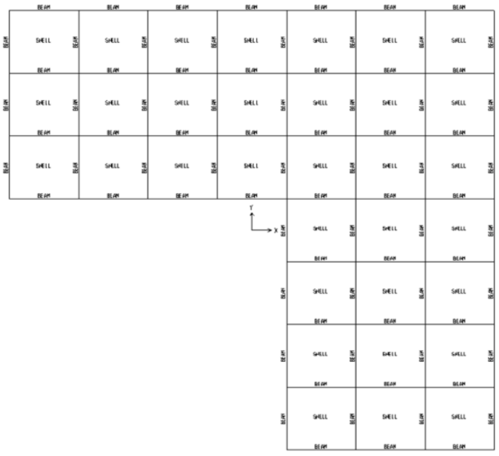


Fig.5 L Shape building plan

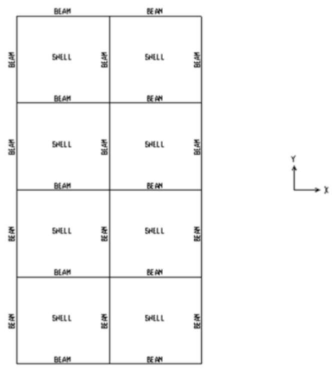


Fig.6 Horizontal section at third storey for H-Shape building plan

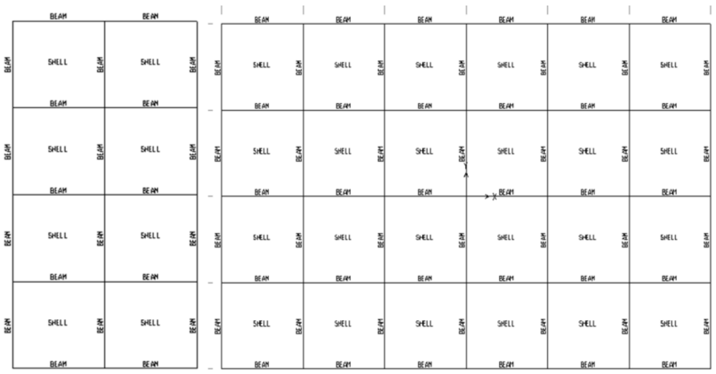
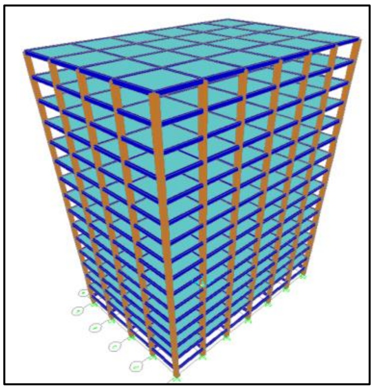
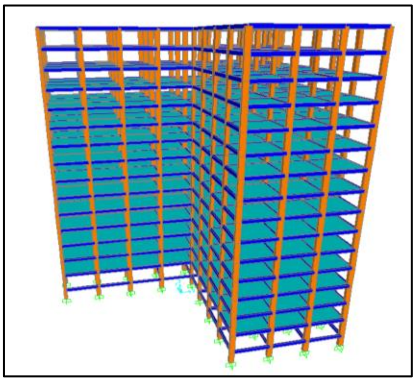


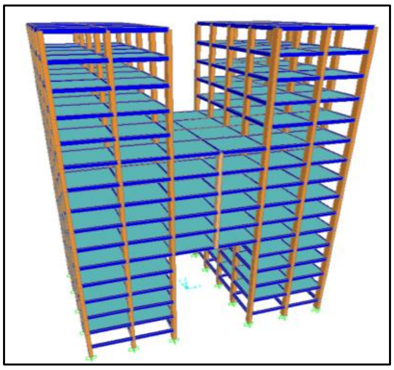
Fig.7 H-Shape building



Regular (R) frame model



L-Shape model (Horizontal Irregularity, HI)



H-Shape model (Vertical Irregularity, VI)

Fig.8 frame model 3D view

Table 1: Design Particulars

Particulars	RCS	RCC
Height Of Each Storey	3.5 m	3.5 m
Height Of Bottom Storey	2m	2m
Length of each bay for all models(along both the axes)	6m	6m
Height Of Parapet	1.5 m	1.5 m
Beam Size	ISMB450 @60.3 kg/m	300x600 mm
Column Size	C1-500x800 mm, C2-500X1000mm(VI Model)	C1-500x800 mm, C2-500X1000mm(VI Model)
Wall Thickness	200 mm	200 mm
Slab Thickness	200 mm	200 mm
Seismic Zone	IV	IV
Soil Condition	Moderate	Moderate
Response Reduction Factor	5	5
Importance Factor	1.5	1.5
Floor Finishes	2 kN/m^2	2 kN/m^2
LL At Roof Level	1.5 kN/m^2	1.5 kN/m^2
LL At All Floors	4kN/m^2	4 kN/m^2
Grade Of Concrete For Column	M45	M45
Grade Of Concrete For Beam	-	M25
Grade Of Concrete For Slab	M25	M25
Grade Of Reinforcing Steel	Fe 500	Fe 500
Grade Of Structural Steel	Fe250	-
Density Of Concrete	25 kN/m^3	25 kN/m^3
Density Of Masonry	22 kN/m^3	22 kN/m^3
Damping Ratio	5%	5%

Building modelling.

Total twelve models representing RCS and RCC each have been modelled using FEA software SAP2000v14.The buildings have been modelled for structural elements such as beams, columns and slab. The floor wall loads and the parapet loads have been assigned as super dead load on the beam elements. In order to ensure integral action of the vertical structural members, diaphragm is provided at each storey.

MODEL ANALYSIS PROCEDURE

1. Response spectrum analysis- After generating the 3-D frame model of the building, define mass source and response spectrum function and load case i.e. specx and specy. The analysis is carried out for various load cases. The results are obtained for two load cases-

COMBO-1 =1.2 (DL+LL+SPECX)

COMBO-2 =1.2 (DL+LL+SPECY)

The responses of the building such as time period of vibration, frequency and displacement have been plotted against modes of vibration and storey level respectively.

2. Pushover Analysis-Define and assign the member properties, sections, load cases and mass source. The hinges are assigned to the beams and column members as per ATC40 [2]. Default hinge property for beam is M3 and for column member PM2M3.Define three non-linear static load cases i.e., Push-1, Push-2 and Push-3, wherein the building is subjected to gravity load, lateral loads along longitudinal direction and lateral loads along transverse direction respectively. Then linear static analysis is performed and design check is carried out to facilitate the generation of hinges. Linear pushover analysis is performed and performance point of the structure is established.

ANALYSIRESULT

1. Response spectrum results.

Time Period and Frequency- From fig.5 it is observed that time period is more for RCS structure than RCC structure. Also time period is more for regular structure and less for vertically irregular model for both RCS and RCC. From fig. 6, it can be said that the frequency of RCS is relatively lower than RCC model.

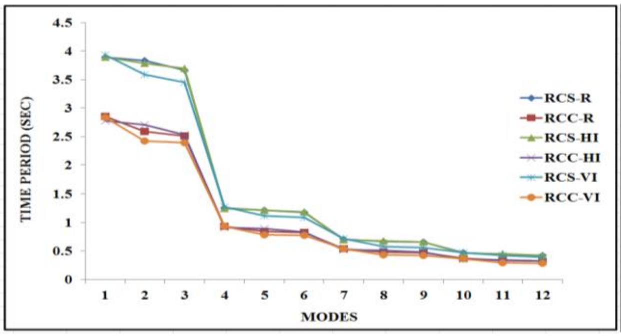


Fig.9 Comparison of Time Period vs. Modes

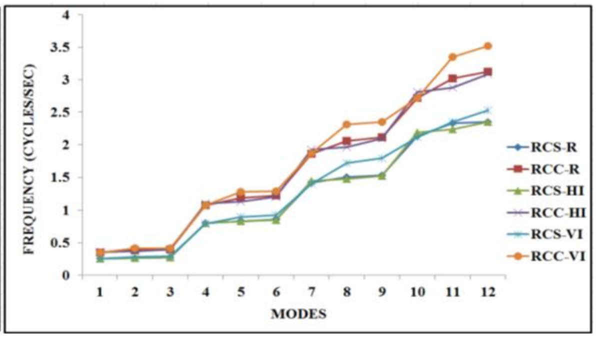


Fig.10 Comparison of Frequency vs. Modes

Base Reaction. The base reaction for RCS structure is less as compared to RCC structurefig7 and fig.8.this may be due to higher resistance offered by RCC structure.

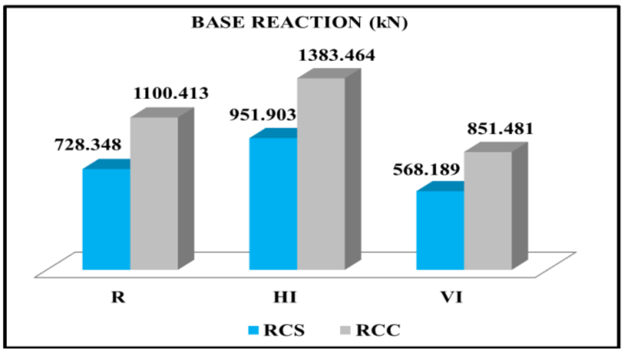


Fig.11 Base Reaction for Earthquake Force in X-Direction

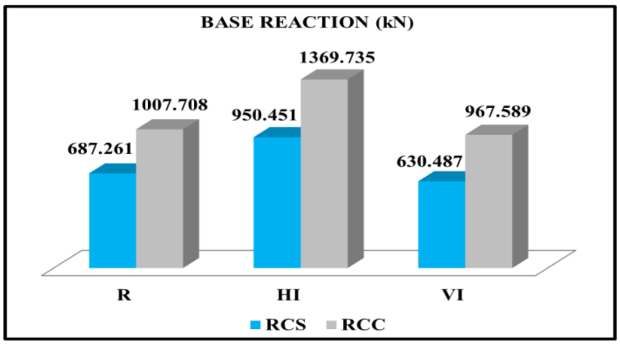


Fig.12 Base Reaction for Earthquake Force in Y-Direction

Displacement. From fig.9 and fig.10 it is observed that displacement is more for RCS structure as compared to RCC structure. For x direction force , RCS-VI model shows maximum displacement whereas for Ydirection force, RCS-R model shows maximum deflection.

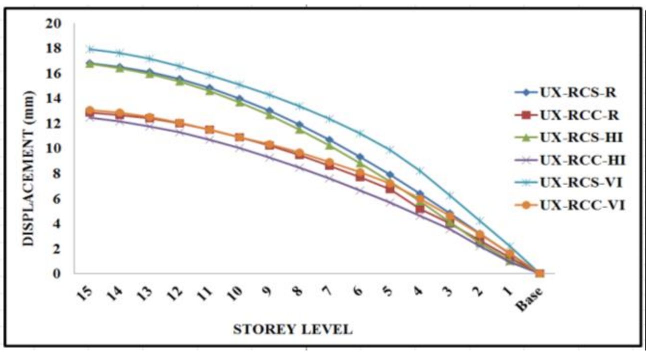


Fig.13 Displacement vs. Storey level for Earthquake Force in X-Direction

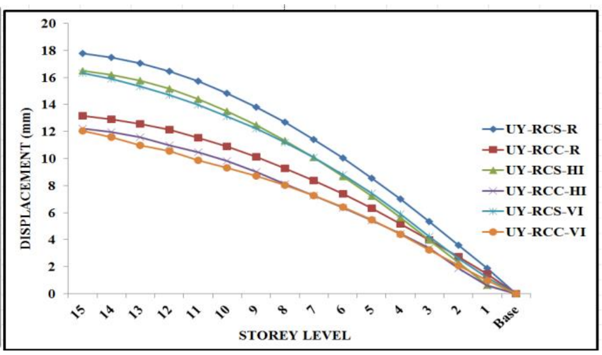


Fig.14 Displacement vs. Storey level for Earthquake Force in Y-Direction

2. Pushover Analysis Result.

The ultimate base shear and the corresponding displacement values are established from the pushover curve for all the building models and are tabulated in table 2. It is observed that the base shear and displacement values are more for RCS structure.

Table 2: Pushover curve results

Type of model	Ultimate Base Shear (kN)	Corresponding Roof Displacement(mm)
RCS-Regular	30655.21	884.0923
RCC-Regular	20746.52	492.8767
RCS-L Shape	36479.39	907.3651
RCC- L Shape	23501.7	441.5456
RCS-H Shape	20230.44	806.887
RCC-H Shape	17312.98	638.1694

Capacity Spectrum

The capacity spectrum gives the performance point of the structure. From the capacity spectrum of all the building models it is clear that RCS structure performs better than RCC structure.

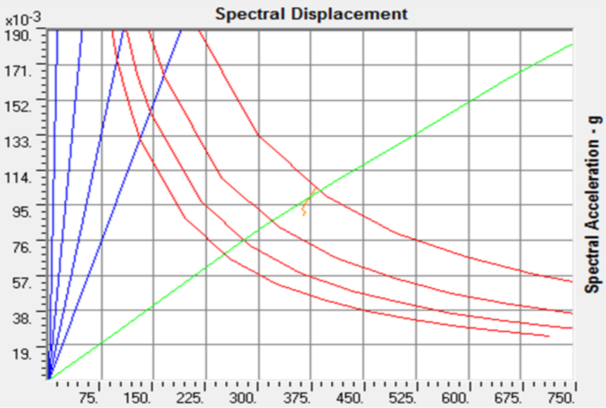


Fig.15 Capacity Spectrum for RCS-R Model in X-Direction

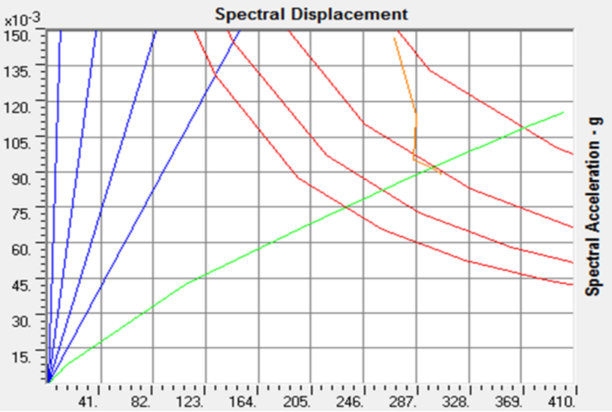


Fig.16 Capacity Spectrum for RCC-R Model in X-Direction

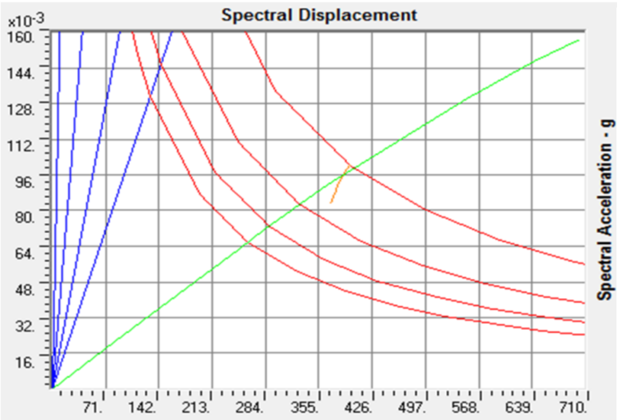


Fig.17 Capacity Spectrum for RCS-HI Modelin X-Direction

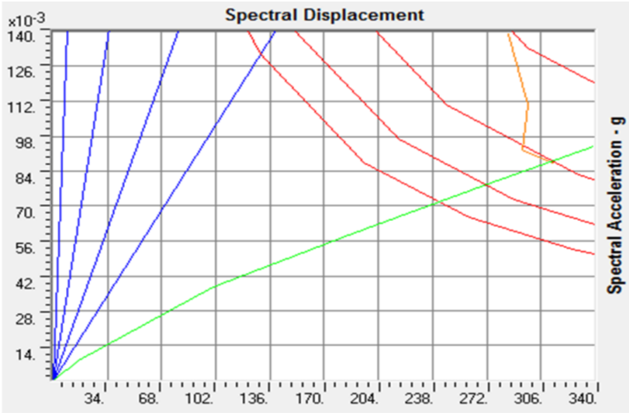


Fig.18 Capacity Spectrum for RCC-HI Model in X-Direction

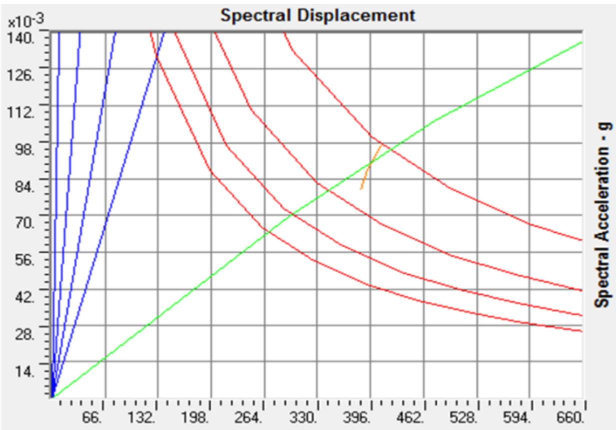


Fig.19 Capacity Spectrum for RCS-VI Model in X-Direction

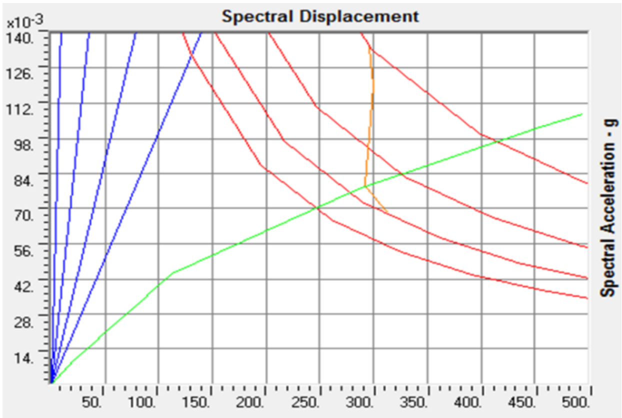


Fig.20 Capacity Spectrum for RCC-VI Model in X-Direction

Table 3: Structure Response at Performance point

Type of model	Displacement (mm)	Base Force (kN)	Performance level
RCS-Regular	371.531	13727.15	B to IO
RCC-Regular	353.0342	15946.28	IO to LS
RCS-L Shape	370.9335	16261.48	B to IO
RCC- L Shape	353.5525	19651.43	IO to LS
RCS-H Shape	371.7521	10117.28	B to IO
RCC-H Shape	368.0524	12311.86	IO to LS

Literature References

Over the past, only a few researcheshave been carried out to study the inelastic behaviour of RCS system under seismic loads. Ashraf. E. Morshed [3]performed inelastic analyses on low rise RCS frame building using FEA software

SAP2000, and compared the result with an equivalent RCC frame model. The results have shown that the base shears capacity for both the structures are almost the same, but RCS model shows linear behaviour up to the maximum shear capacity. The structure failure is accompanied by failure mechanism of soft story.

Montesinoset.al.[4] investigated the distortion behaviour of steel beam and RC column joints for structures highly vulnerable to seismic forces. Controlling the joint distortion resulted in occurrence of inelastic deformations and formation of plastic hinges at the beam ends. Also the structure dissipated significant amount of energy. This means the structure possess adequate seismic resistance.

Noguchiand Uchida [5] analysed RCS frame models having different joint connections between the beam and column element, through-beam type of joints with face-bearing and cover plates. The first specimen failed through yielding of the beam element while the second failed due to shear failure at the joints. These results were not possible to obtain from experimental investigations.

CONCLUSION

1. The increase in time period and subsequent decrease in frequency of RCS in comparison to RCC structure shows that the intrusion of structural steel has increased the flexibility of the structure with reduced stiffness. The increase in period of vibration with decrease in frequency may reduce the buckling and damage to the vertical load bearing members.
2. The results of response spectrum and pushover analysis show that displacement of RCS is more as compared to RCC building. This may be due to direct transfer of loads on steel beam rather than concrete. Hence, because of the ductile nature of steel and increased flexibility, RCS structure undergoes relatively more displacement.
3. From the pushover analysis result, the performance of RCS structure is established in the range B to IO, indicating that the building can be occupied immediately post-earthquake. The building is operational with negligible damage. This means that the structure possess good strength and adequate seismic resistance whereas the performance level of RCC structure is found to be in the range IO to LS. This means that the structure has suffered some damage. Thus it can be said that the strength of RCC structure is relatively less. An important point to note here is that though the time period and displacement of RCS is more as compared to RCC structure but the damage is less in case of RCS building.
4. From table 3 it can be said that the base shear decreases with decrease in mass and increase in flexibility of the structure. A flexible structure would experience less acceleration, whereas a stiff structure such as RCC would offer higher resistance resulting in high base shear.

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