SEISMIC EVELUTION OF RC SPACE FRAME WITH RECTANGULAR AND EQUIVALENT SQUARE COLUMN BY PUSHOVER ANALYSIS

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Abstract

The present study is carried out to compare the seismic performance of RC frame structures of G+15 storey which consisting of rectangular shaped column as against equivalent square shaped column. The building is having 4.5m x 4.5m panels in both directions forming an overall plan dimension of 31.5m x 13.5m. All the beams are considered as 300 mm x 600 mm in size and columns with of 3 m height in each floor. In the above model all the rectangular shaped columns are oriented with longer side in global Y direction and shorter side parallel to global X direction. The M25 grade of concrete and Fe 415 grade of steel is considered for design. Pushover analysis is carried out, using commercially available software ETABS and behavior of RC frames is studied. One more factor which is studied in the current models is the material consumption variation for keeping the building in Immediate Occupancy stage. Also the comparison of normal RC frame and immediate occupancy level RC frame for both shaped columns is carried out. Quantity of concrete and quantity of steel is calculated for all the models and the overall structural cost is evaluated. Comparison for all the models in terms of quantity of materials and structural cost is also reported. It is concluded that the square cross section of columns perform better as compared to rectangular cross section of columns.

Keywords: *Performance point, Pushover analysis, RC space frame*

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1. INTRODUCTION

Recent earthquake in which many concrete structures have been severely damaged or collapsed have indicated the need for evaluating the seismic adequacy of existing buildings. About 60% of land area of India is susceptible to damaging levels of seismic hazard. We can't avoid future earthquakes, but preparedness and safe building construction practices can certainly reduce the extent of damage and loss. To have a reliable estimate of a structures, sophisticated analysis tools are necessary. Nonlinear dynamic analysis is the most accurate method available for the analysis of structures subjected to earthquake excitation. Non-linear static (Pushover) analysis is also an attractive choice because of its simplicity and ability to identify component and system-level deformation demands with accuracy comparable to dynamic analysis. By conducting pushover analysis, we can predict the weak zones in the structures and then we will decide whether the particular part is required to be retrofitted or rehabilitated according to the requirement.

Conventional limit-state design is typically a two-level design approach having concern for the service-operational and ultimate-strength limit states for a building. Performance-based design can be viewed as a multi-level design approach that additionally has explicit concern for the performance of the building at intermediate limit states related to such issues as occupancy and life-safety standards. With the emergence of the performance based approach to design, there is a need to develop corresponding analysis tools. Nonlinear static (Pushover) analysis is often an attractive choice in this regard because of its simplicity and ability to identify component and system level deformation demands with accuracy comparable to dynamic analysis.

In the present work, a series of pushover analysis is carried out by using ETABS V9.7.4. Software. The analysis is carried out on the RC space frame for G+15 storey buildings as per ATC-40 for the models having rectangular column and equivalent square columns with 31.5m x 13.5 m overall plan of building. In both the models, optimization of column sizes are done on the basis of percentage of steel not exceeding 4 percentage, as per IS 456:2000. A comparison of the influence of the shape of the column on the seismic response of a building is presented here. The scope of the present study is limited to the analysis of buildings with rectangular columns oriented in one direction only.

2. PUSHOVER ANALYSIS

Pushover analysis is an analysis method in which the structure is subjected to monotonically increasing lateral force with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. A two or three dimensional model which includes bilinear or trilinear load-deformation diagrams of all lateral force resisting elements are first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased until some members yield. The structural model is modified to account for the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable. The roof displacement is plotted against base shear to get the capacity curve.

3. THE MATHEMATICAL MODELS CONSIDERED

The problem is studied for a 31.5 m x 13.5 m plan building with 4.5 m x 4.5 m grid having rectangular columns and another model with equivalent square columns. All the rectangular columns are oriented such that longer side is parallel to the global Y direction and the shorter side is parallel to the global X direction of the building. The height of the column in global Z direction is considered as 3 m for each floor level and the columns extend for 2.5 m below plinth level up to the foundation. The sizes of the columns are selected to satisfy codal provisions in both shapes and column sizes are as shown in **Table-1**. The slab is modelled as a shell element and a rigid diaphragm action is considered for the analysis. The columns are considered to be fixed at the foundation level. All the beams are considered rectangular in cross section of size 300 mm x 600 mm deep. The M25 grade of concrete and Fe415 grade steel reinforcement is considered. The building consist of 230 mm thick brick walls on outer periphery. Typical isometric and plan view of G+15 storey frame are as shown in **Fig.1**.

4. LOADS CONSIDERED

Load Type	**Typical Floor Level**	**Terrace Floor Level**
Dead Load	4 kN/sq.m	5 kN/sq.m
Live Load	2 kN/sq.m	1.5 kN/sq.m

Wall Load on All Periphery Beams:-

Load type	**Typical floor (Wall Load)**	**Terrace floor (Parapet Wall Load)**
Dead load	11.63 kN/m	5.10 kN/m

Table 1: Sizes of Rectangular Column and Equivalent Square Column

Storey No.	**Rectangular Column Sections (mm)**	**Equivalent Square Column Sections (mm)**	**Column No.**
9 To Roof	300 X 500	387 X 387	C1 TO C32
7,8	300 X 650	442 X 442	C1 TO C32
4,5,6	300 X 750	474 X 474	C1 TO C32
3	300 X 900	520 X 520	C6, C7, C10,C11, C14 TO C16, C18, C19, C22, C23, C26, C27
	300 X 750	474 X 474	C1 TO C5, C8, C9, C12, C13, C17, C20, C21, C24, C25, C28, C32
2	300 X 900	520 X 520	C5 TO C28
	300 X 750	474 X 474	C1 TO C4, C29 TO C32
G,1	300 X 1100	574 X 574	C2, C3, C5 TO C28, C30, C31
	300 X 750	474 X 474	C1, C4, C29, C32

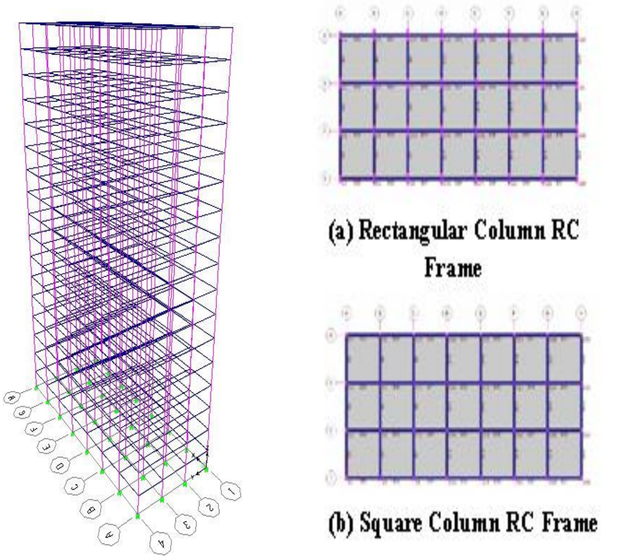


Fig 1 Typical Isometric and Plan View of G+15 Storey RC Frame

Earthquake Load EQ X and EQ Y:

This load case is static load calculated as per the Indian code IS: 1893(2002) for 5% damping with seismic zone factor Z=0.16 and medium soil with importance factor 1 and response reduction factor 5. The loading direction considered as global X and global Y. The mass considered for generating the lateral load is total dead load + 25 % of the live load lumped at diaphragm Centre.

5. PUSHOVER ANALYSIS CASES

The mathematical models developed are subjected to pushover analysis as per ATC-40 provisions using ETABS software. Default plastic hinges of four types are available in the software. Out of them, P-M-M type of hinges are defined at 5% and 95% of the span for all beam and column elements. Moreover, flexural plastic hinges M3 are defined at mid span of beam to capture the possible development of stresses beyond yield point due to gravity loads.

There are three pushover cases specified for each model.

- PUSHDOWN – Push given in the gravity direction up to the full magnitude of dead load and live load starting from zero stress
- PUSHX – Applying lateral loads in the X direction starting from stress due to pushdown
- PUSHY – Applying lateral loads in the Y direction starting from stress due to pushdown

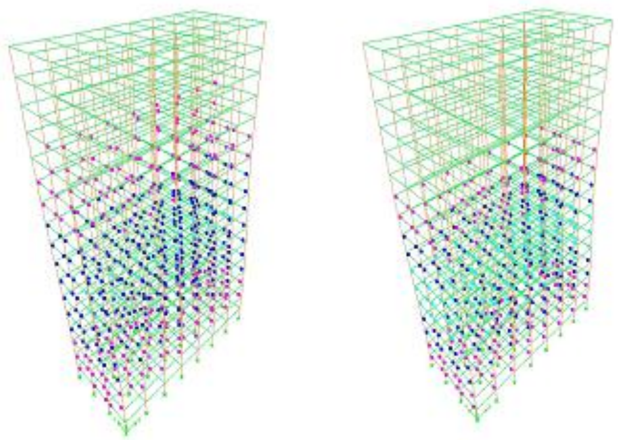
PUSH X and PUSH Y are displacement controlled in which a designated roof level node is monitored up to the initial target displacement of 0.004 times the height of the building. The other parameters are considered for pushover analyses by ETABS are P-delta effects for incorporating the geometric non linearity. These effects start governing when a few plastic hinges are fully developed and they deform the structure considerably. Apply local redistribution is used as member unloading method. The storey drift at performance point is taken as output to plot the drift parameters as an indicator of the seismic performance of a particular frame.

6. RESULTS OF PUSHOVER ANALYSIS AT PERFORMANCE POINT

The results of the analysis for rectangular column and equivalent square column for PUSH X and PUSH Y cases are represented in the form of deformed shapes as shown in **Fig.2** and **Fig.3**. The corresponding demand/capacity curve of PUSH X and PUSH Y for rectangular column and square column are as shown in **Fig.4** and **Fig.5** respectively.

Table:-2 shows the number of hinges developed at performance point for rectangular column (R) and square column(S).

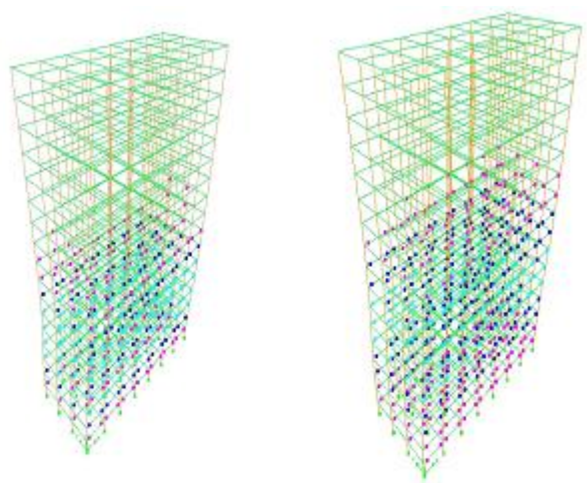
To achieve the target of keeping the building in immediate occupancy level, all IO-LS and LS-CP hinges should be eliminated. From the observation, it is said that all the hinges of IO-LS and LS-CP level are formed in beam elements. Therefore, to keep the building in immediate occupancy level, it is necessary to increase stiffness of those beams in which plastic hinges of IO-LS and LS-CP are formed. The corresponding demand/capacity curve of PUSH X and PUSH Y case at performance point for rectangular column and square column are as shown in **Fig.6** and **Fig.7**. , respectively. **Table:-3** shows the number of hinges developed at immediate occupancy level for rectangular column (R) and square column(S). The results of storey drift for normal building at performance point are as shown in **Fig.8** and **Fig.9**. Here, the results of storey drift that is DRIFT X and DRIFT Y at performance point are presented as shown in **Fig.10** and **Fig.11**, respectively.**Fig.12** and **Fig.13** shows the quantity of concrete and steel for both rectangular column and equivalent square column. **Fig.14** shows the structural cost of all the models. The cost of concrete is considered as 4500 Rs/cum and for steel it is taken as 50 Rs/Kg.



(a)Rectangular Column (b) Square Column

Fig.2 Deformed Shape for Rectangular and Square Column (PUSH X)

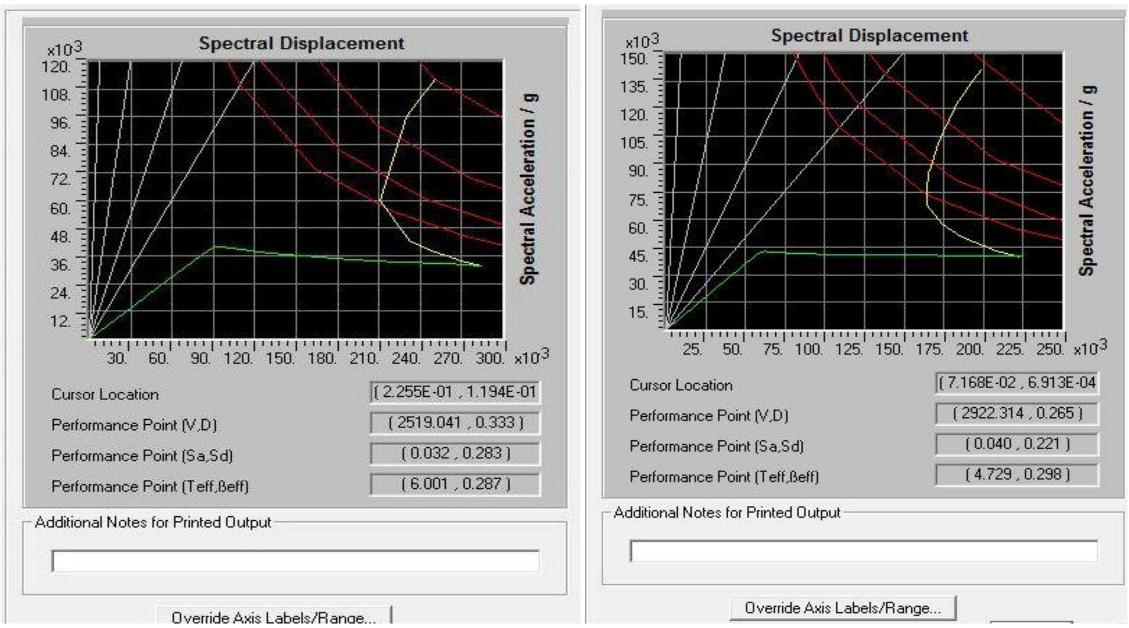
IO = Immediate Occupancy, LS = Life Safety, CP = Collapse Prevention



(a)Rectangular Column (b) Square Column

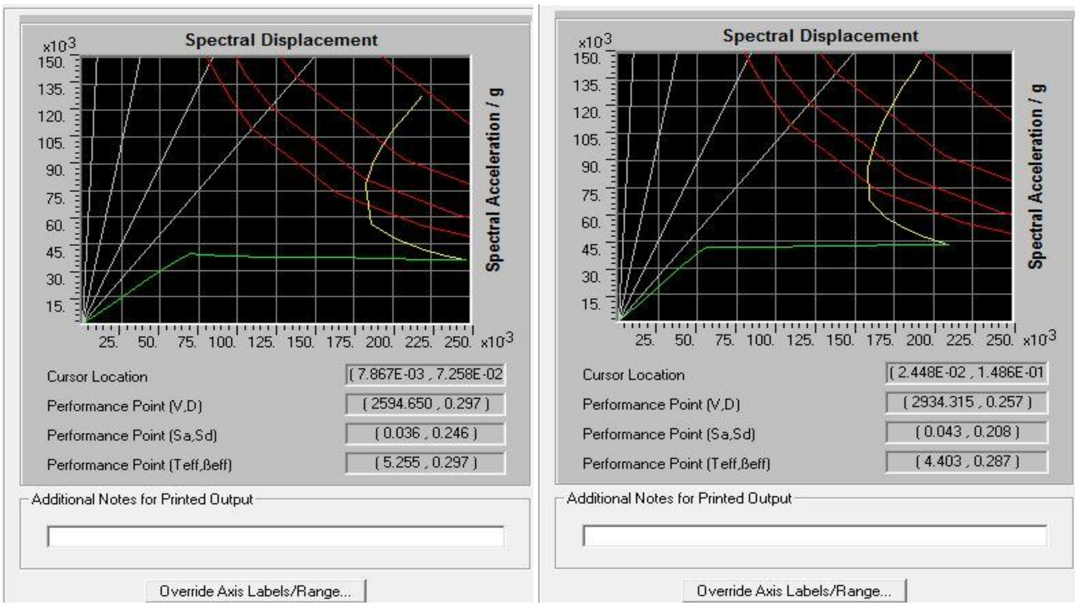
Fig.3 Deformed Shape for Rectangular and Square Column (PUSH Y)

Family of demand spectra **Single Demand Spectrum** **Constant period lines**



(a) Rectangular Column **(b) Square Column**

Fig.4 Demand/Capacity Curves for PUSH X



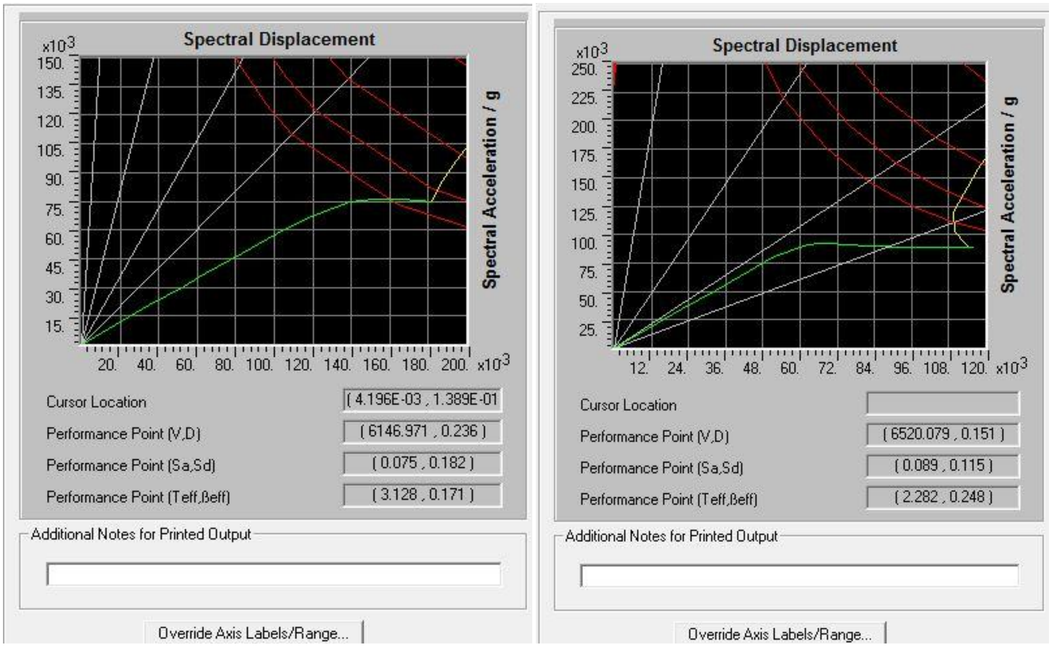
(a) Rectangular Column **(b) Square Column**

Fig.5 Demand/capacity curves for PUSH Y

Table 2:- Number of Hinges Developed Up to Performance Point for Both Models

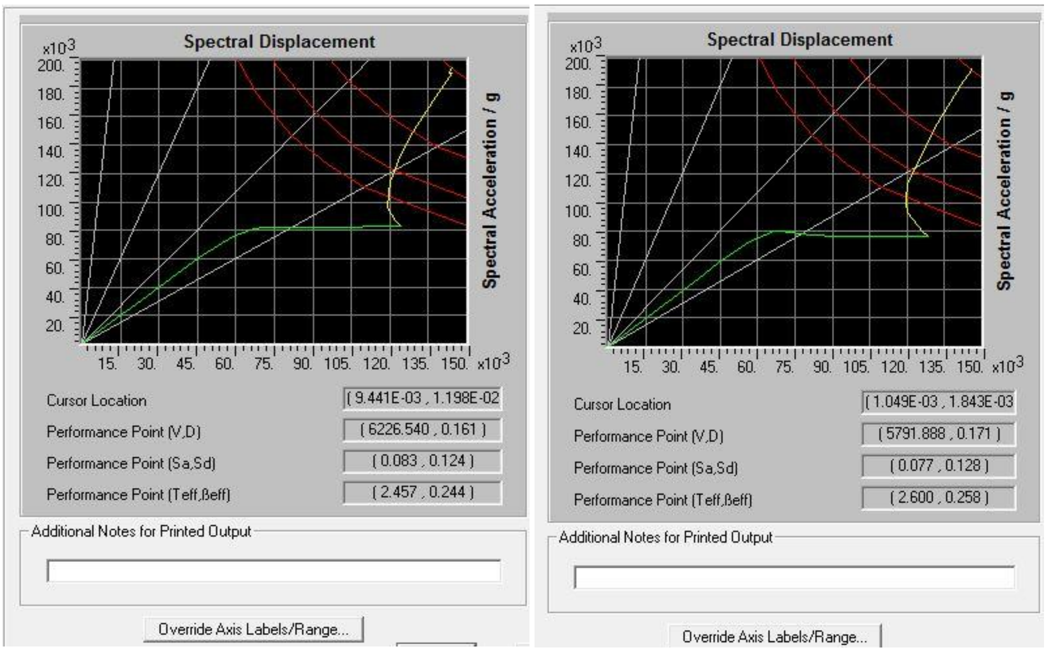
Push Dir.	Roof Displacement (mm)		Base Force (kN)		A-B		B-IO		IO-LS		LS-CP		TOTAL	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
X	333	265	2519	2922	5044	4922	128	194	112	228	224	164	5508	5508
Y	257	297	2934	2595	4932	4986	240	186	316	192	20	144	5508	5508

Family of demand spectra **Single Demand Spectrum** **Constant period lines**



(a) Rectangular column **(b) Square column**

Fig.6 Demand/Capacity Curves for PUSH X



(a) Rectangular Column **(b) Square Column**

Fig.7 Demand/capacity curves for PUSH Y

Table 3:- Summary on the Parameters of Models at Performance Point

Push Dir.	**Roof Displacement (mm)**		**Base Force (kN)**		**A-B**		**B-IO**		**IO-LS**		**LS-CP**		**TOTAL**	
	R	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**
X	236	150	6146.971	6639.508	4946	4919	562	589	0	0	0	0	5508	5508
Y	161	168	6226.54	5883.816	4980	4964	528	544	0	0	0	0	5508	5508

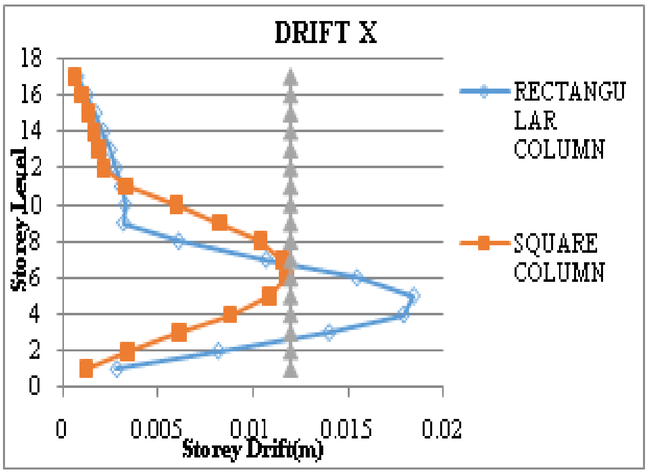


Fig.8 Storey Drift of R and S Columns in Push-X (Normal Building)

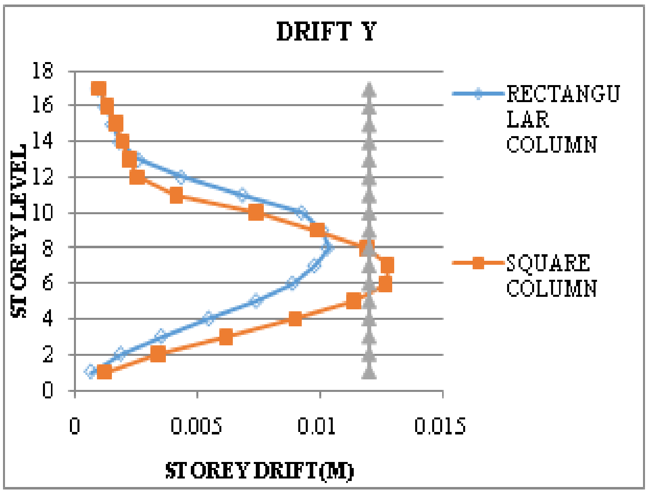


Fig.9 Storey Drift of R and S Columns in Push-Y (Normal Building)

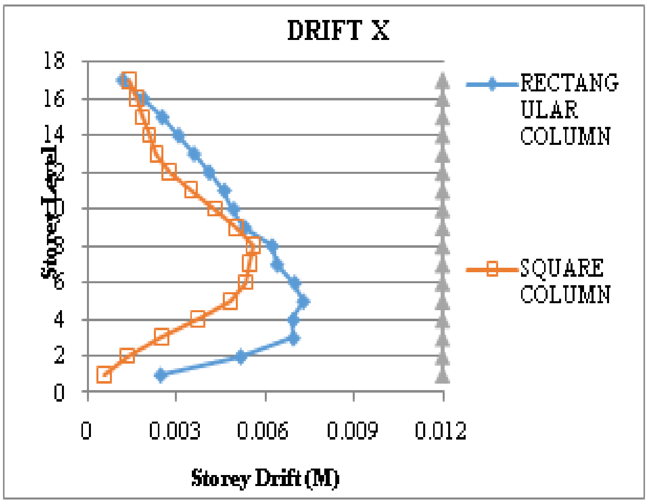


Fig.10 Storey Drift of R and S Columns in Push-X (IO Level Building)

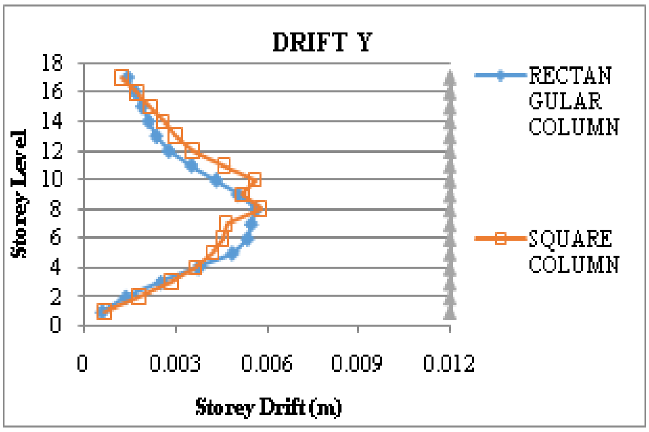


Fig.11 Storey Drift of R and S Columns in Push-Y (IO Level Building)

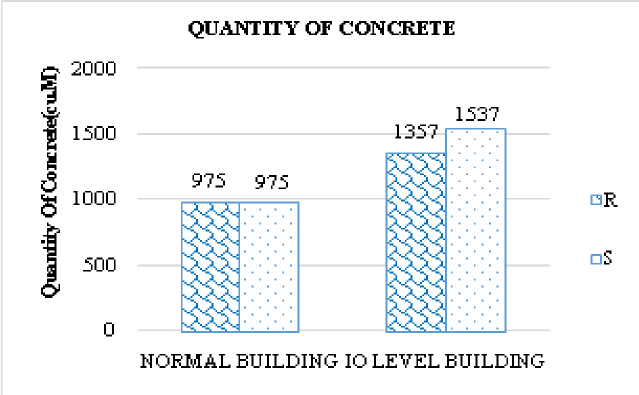


Fig.12 Quantity of Concrete in Both Models

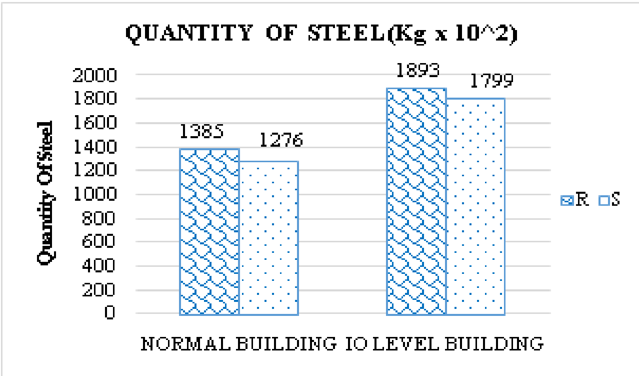


Fig.13 Quantity of Steel in Both Models

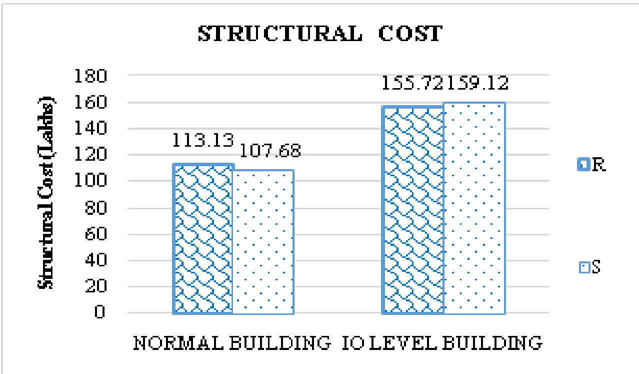


Fig.14 Structural Cost for Models

7. DISCUSSION OF RESULTS

- The **hinges** developed in rectangular column models at LS-CP level are more in numbers as compared to square columns in PUSH X case as in rectangular columns X-direction is weak direction. This is evident from **Table -1**.
- The **hinges** developed in rectangular column models at LS-CP level are very less in numbers as compared to square columns in PUSH Y case as shown in **Table-1**.
- The **deformed shape** of both the models under lateral push as shown in **Fig.1** and **Fig.2**, clearly indicates that there is more lateral deformation in the model with rectangular columns in push X case while in push Y case there is not much difference in deformed shape.
- The **storey drift** value for normal building is increased than the permissible value of storey drift as per IS:1893 (2002) in case of push-X case for rectangular column RC frame and Push-Y case square column RC frame as shown in **Fig.8** and **Fig.9**.
- From **Fig.10** it can be seen that at immediate occupancy level building, there is **excessive drift** in case of push x case in rectangular column, which indicates poor performance of rectangular column in X direction.
- **Table-2** indicates that **base shear** at performance point for frames with square column is more than the equivalent rectangular column when pushed in weak X- direction indicating superior behavior of square column.
- From the **Table-2** it can be noticed that in both lateral direction the **roof displaceme**nt at performance point is less in case of square column model than in rectangular column model.
- From **Fig.10**, it can be noticed that **consumption of concrete** at Immediate Occupancy level building compared to normal building is **28.15%** more for rectangular column and for square column it is **36.56%** more.
- From **Fig.13**, it can be noticed that the **consumption of steel** in immediate occupancy level building when compared to normal building is **24.84%** more for rectangular column and **29.07%** more for square column model.
- Also from **Fig.12**, it can be observed that in square column RC frame **quantity of concrete** used **11.71%** is more as compared to rectangular column RC frame at immediate occupancy level and **4.9%** more steel is utilized in rectangular column RC frame as compared to square column RC frame.
- From **Fig.14**, it can be observed that there is not much difference in **structural cost** between rectangular column and square column RC frame at immediate occupancy level.
- From **Fig.14**, it can be noticed that at immediate occupancy level the structural cost is **27.35%** more as compared to normal building in rectangular column RC frame while in square column RC frame at immediate occupancy level the structural cost is **32.33%** more as compared to normal building.
- From **Fig.14**, it can be noticed that at immediate occupancy level, there is only **2.1%** difference in the structural cost of rectangular column RC frame and square column RC frame building.

8. CONCLUSIONS

We conclude from the study that

- The numbers of **plastic hinges** developed in rectangular column RC frame are more as compared to square column RC frame as in rectangular column one direction is weaker direction.
- Referring the result summary for RC frames, it can be seen that the **number of plastic hinges** developed in normal building is higher than those developed in strengthen building. Moreover, the base shear resisted at performance point is higher for the buildings which are strengthen as compare to the normal building.
- **Storey drift** are found within the limit as specified by code IS: 1893-2002, part – I in nonlinear static analysis at immediate occupancy level.
- There is a little difference in **structural cost** of rectangular column RC frame and Square column RC frame at immediate occupancy level.
- The **behaviour** of square column is better than rectangular column when the comparison is in terms of storey drift, base shear and roof displacement.
- The **performance** of square column RC frame is better than the rectangular column RC frame.

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