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Seismic Analysis of Multi-Storey Frame with and Without Floating Columns

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ABSTRACT: In construction scenario of present days, floating column is growing as a new feature for the reinforced concrete framed buildings in urban regions of India. Generally, in earthquake prone areas such type of practices is undesirable. Use of floating column tends to increase the moments in columns, storeyshear and storeydrifts, etc. which ultimately decreases the strength of structures. The present study emphasizes to evaluate the presence and absence of floating column in high rise RC frames with and without infill walls for these two different cases of RC frames were studied and analysed by static analysis. In present study four models are used 'Model 1 (G+9 Bare RC frame without provision of floating column)', 'Model 2 (G+ 9 infill RC frames without provision of floating column)', 'Model 3 (G+9 Bare RC frame with floating column)', 'Model 4 (G+ 9 infill RC frames with floating column)'. Seismic analyses of all four models have been carried out using Equivalent static method (ESM) at zone (III). Further comparisons of results on the basis of parameters such as Storey Drifts, Storey Displacements, etc. for all four models are executed. This seismic analysis is executed using ETABS 2015 software as per the codal provisions of IS: 1893-2002. Recent trends to develop a structure with owner satisfaction level of occupancy and free circulation space, in this way floating column structures play a vital role for the occupancy and free circulation feature. Present study claims that the use of floating column in seismically active areas may cause a hazardous damage to the RC frame structures.

KEYWORDS: Seismic analysis, RC frame, Multi-storey, etc.

I. INTRODUCTION

GENERAL: The shortage of space is a growing issue nowadays in urban cities due to increase in population. For this there is a need of having column free space, and also for aesthetic and other functional requirements. The modern construction techniques in which main concern is given to the structural and architectural needs is shaping out, most high-rise buildings have open ground storey space for parking area, lobbies, receptions and for other aesthetic requirements. This new concept leads to interruption of columns that are floating columns, which makes the structure lateral irresistible.

FLOATING COLUMNS: In any RC frame column is a vertical member which transfers the load to the ground. However, the floating column is also a vertical member of RC frame which rests on beam at its lower level. In that case beam carries the additional loads and transfers it to the other nearby columns or the column just below it which ultimately increases the load on other remaining columns. Floating column concept is mainly used due to the architectural and aesthetic need and also to rule out the Floor Space Index regulatory. In earthquake prone regions this concept of floating column is highly disadvantageous. At the time of quakes seismic forces that are developed at different storey levels in a RC frame need to be transferred through the height to the bottom storey level by the shortest path; any discontinuity or distraction in this seismic force transfer path results in the damage of the RC frames. The structural behaviour during ground motions depends on its size, overall shape, geometry and location. This is how the seismic forces are carried to the bottom storey and then to the ground. The Base shear of any RC frame in whole

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depends on Time period and Seismic coefficients. As the Base shear is taken into account from the dead weight of each floor, these loads should be carried out through the shortest path from upper to the bottom storey and then to the foundation of RC frames. By the provision of floating column the load path gets disturbed due to which the Displacements and Storey shear may get increment and also moment in columns may get increased. This will lead to the collapse of RC frame structure with open ground storey. In common design practices the infill walls are considered as a non-structural component. Infill walls are common masonry walls made with bricks/stones/hollow blocks and mortar mix. RC frame with infill walls will have the same load carrying capacity as the RC frame alone or Bare frame, but it has been proved in previous studies that the presence of infill wall in RC frame can drastically improve the seismic response. In beam column mechanism floating column act as a point load on beams at which they are supported, so there is a need to design those beams with special care. Most popular software to design and analyse those type of structures is ETABS, STAAD-Pro, SAP, etc. These Floating columns can resist the gravity forces. Some of the methods like strengthening the ground floor columns, the stiffness of the columns can be increased by retrofitting methods like using composite materials like Bracings, Struts, Shear walls, etc.

OBJECTIVE OF STUDY: Multi-storeyed buildings in the urban region that have floating columns may not have been designed adequately for seismic forces. In this study following four models are designed and analysed:

- Model 1 (G+9 Bare RC frame without provision of floating column)
- Model 2 (G+9 infill RC frame without provision of floating column)
- Model 3 (G+9 Bare RC frame with floating column)
- Model 4 (G+9 infill RC frame with floating column)

Seismic analysis is carried out on all 4 models using ESM (Equivalent Static Method) to acquire the values of Storey Drifts, Maximum Storey Displacements and Storey Forces for all four models, and thereafter their comparison is carried out on basis of these parameters.

II. RELATED WORK

Malaviya et al. 2014 has analysed the RC frame of 15m X 20m, G+1 symmetrical frame with and without floating column to study the effect of cost on RC frames of floating columns. Conclusion of this study is found in favour of RC frame without floating column explaining that the cost is being reduced because in RC frame with floating column heavier weight of concrete and steel is provided in columns and beams; however, it is also concluded that after changing the position of floating columns, the quantity of steel and concrete is also getting changed.

Mundada et al. 2014 has studied the drawing of existing G+7 RC frame using STADD Pro software. ESM (equivalent static method) has been carried out on three models, RC frame with floating column, RC frame without floating column, RC frame with floating column with provision of struts. The author confirms that the failure in RC frame with floating column is more than in RC frame floating column with struts, and deflection of RC frame with only floating column is larger than the deflection of RC frame floating column with struts.

Shrikanth M.K. et al. 2014 has done a comparative study on RC frame having only floating columns and having floating columns with some kind of irregularities or complexities. High Rise RC frames were analysed for seismic forces. Author considered medium soil conditions and lower and higher seismic zones for that purpose. ETABS version 9.7.4 is used for 3D analysis of RC frames. Author concluded that frames having floating columns with irregularities are showing larger deflections than that on frames with only having floating columns in both lower and higher seismic zones.

Sreekanth Gandla et al. 2014 has analysed whether RC frames are safe or unsafe in earthquake prone areas when they are built up with the provision of floating columns and also studied the effect of floating column on economy. With respect to that, analysis of G+5 RC frame without floating column and with floating column are done for external lateral

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forces; this analysis is conducted by using SAP 2000 and external loads are calculated manually using equivalent static method (ESM). For this, three 2D models, namely model 1, model 2, model 3, are modelled in SAP 2000. Model 1 is a normal RC frame. Model 2 is RC frame with floating columns and dimensions are same as of model 1. Model 3 is RC frame with floating columns and dimensions are changed. The author concluded that displacements are found larger in RC frames with floating column rather than that are in normal building.

Isha Rohilla et al. 2015 has analysed the behaviour and need of floating column in urban regions where population index is getting high day by day. In this study behaviour and advantageous application of floating column is discussed. However, it is highly recommended to not use floating column in seismically active areas and also these columns are not suitable as path for seismic forces to go down in ground may get distributed due to their provision. In present study RC frames of G+5 and G+7 for zone II and zone V having complex and irregular shape is analysed. Software used for this analysis is ETABS to calculate the seismic parameters like storey shear, storey displacements and storey drift. Author came to the conclusion after this study that provision of floating columns in zone V that is highly seismic region must be avoided as it may cause huge damage to building and lives due to the incremental behaviour of storey displacements.

Pauley et al. 1992 investigated the RC frame performance during seismic actions which were collapsed or were damaged when they were provided with some structural modifications to the normal design system of RC frame induced by non-structural masonry walls. These partition walls found to be very weak; the provision of this masonry infill can change drastically the required response of structure and could attract forces to the part of RC frames that are not actually designed to resist them.

Kulkarni et al. 2013 found the RC frame performances that were framed with infill walls, having opening of different percentages. Author concluded lateral stiffness found to be decreasing while increasing the opening percentage in RC frame infill.

Jamnekar et al. 2013 studied the response of RC frame under the provision of masonry infill walls. Authors concluded that provision of infill wall significantly affected the dynamic characteristics, strength, stiffness and seismic performance of RC frames.

Decanini et al. 2004 has analysed the behaviour of RC frames with infill walls for seismic analysis; authors reach to a conclusion by the study that displacements in top storeys are decreasing and this is due to infill walls are providing more stiffness to the RC frames which results to the natural consequence of the stiffness of RC frames.

Rodrigues et al. 2005 has studied RC frame response analogy at the time of seismic activity. Author found that infill walls may result to increase in global stiffness of the RC frames. By the study they concluded that at the edges of the RC frames its natural period will tend to decrease and depends upon the seismic spectrum values of bare frames natural time period; hence earthquake forces might get increased.

III. METHODOLOGY

Building description

The present work is to study the importance of explicitly recognizing the presence of with and without floating column in Bare and Infill Frame in the analysis of building; and also along with floating column some complexities were considered for G+10 storey building at different alternative location, for ZONE V by using equivalent static load method.

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Structural Details

- Unit weight of Reinforced Concrete = 25 kN/m³
- Unit weight of Brick = 19 kN/m³
- Zone factor = 0.36 (zone V)
- Importance factor = 1.0
- Soil condition = Medium soil
- Damping = 5%

Parameters to find the equivalent diagonal strut

- Size of beam = 400mm*400mm
- Size of column = 500mm*500mm
- Thickness of masonry infill, $t = 0.230$ m
- Moment of Inertia of Beam / Column = 1.08×10^{-08} m²
- Modulus of elasticity of concrete = 2.5×10^7 kN/m²
- Modulus of elasticity of masonry infill = 1.38×10^7 kN/m²

Modelling and Analysis Using E-TABS

For the present study, a Reinforced Concrete Structure is selected. The same layout has adopted in construction of Alaknanda Apartment at Najafgarh, Delhi. It has symmetrical layout and consists of twenty stories with each storey height of 3.5 m. Floor plan of all stories is rectangular with length of 16 m in x-direction and length of 16 m in z-direction. The number of bays in x-direction is 5 and number of bays in y-direction is 5. The width of each bay is 4 m in both x-direction and y-direction. All the columns of the building are located at the axes intersections.

Building details are as follows:

- Building frame type is Special Moment Resisting Frame (SMRF) which is fixed at base.
- Building is located in Seismic Zone III.
- Number of storey is G+9.
- Spacing between bays is 5 m in both x and z-directions.
- Number of bays in x and z-directions are 5 and 5 respectively.
- Grade of concrete used is M 25 and grade of steel used is Fe 415.
- Floor to floor height is 3.5 m.
- Slab depth is 160 mm.
- Thickness of wall is 230 mm.
- Size of columns is 500 mm × 500 mm.
- Size of beams is 400 mm × 400 mm.
- Live load on floors is 3 kN/m².
- Live roof load is 2 kN/m².
- Building is resting on medium type soil.
- Importance factor is taken as 1.
- Unit weight of RCC is 25 KN/m³.
- Unit weight of masonry wall is taken as 12.23 kN/m³.
- Thickness of infill walls is 230 mm.
- Elastic modulus of brick infill wall is 4500 MPa.
- Elastic modulus of concrete is 25000 MPa.
- Damping of structure is taken as 5%

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IV. EXPERIMENTAL SETUPS

Assumption: In E-TABS, while creating 3-D models, some basic assumptions were taken into consideration to decrease the complexity of the program and analysis run time. Also, it is known that there are lots of parameters that affect the behaviour of the building system under loading, especially lateral loading. Material properties of the concrete and masonry are fixed for all the cases.

Structural Analysis Procedure (USING E-TABS)

The modelling of the building using E-TABS can be described in the following steps:

- Pre-processing
- Post-processing
- Analysis and design of the model
- Results

V. RESULTS AND DISCUSSION

GENERAL: The analysis results can be easily obtained. Equivalent Static Method (ESM) is adopted for linear analysis of the structure. This chapter discusses the results obtained in the present work. This chapter presents the significance of floating and non-floating building parameters in application to general engineering practices.

In this study, a G+9 Storey Building is taken with each storey of height 3.5 m. Static analysis has been done for bare frame model and bare frame model with floating column with and without infill. Comparison has been done on the basis of top floor displacement, Storey drift, Storey forces.

The obtained results are discussed below in tabular scenario.

Comparison of displacement of Bare frame and Floating column bare frame

Table 1: Displacement of Bare frame and Floating column bare frame

Storey	Height (m)	Floating column bare frame			
		Displacement (x)	Displacement (y)	Displacement (x)	Displacement (y)
10					
9					
8					
7					
6					
5					
4					
3					
2					
1					

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Above result shows that the maximum displacement obtained at top floor is **24.3 mm** in Y direction for bare frame and **25.4 mm** for floating column frame.

Above result shows that the floors displacements increase in both the directions when columns obsolete at first floor. The top floor displacement in X and Y direction are approximately equal. Top floor displacement increases 5% approximately. So we can say that floating column increase over all displacement of the structure at each floor

Comparison of storey drift of Bare frame and Floating column bare frame

Table 2: Storey Drift of Bare frame and Floating column bare frame

Storey	Height (in m)	Floating column bare frame			
		(x)	(y)	(x)	(y)
10	26.9	0.283	0.307	0.307	0.322
9	24.29	0.455	0.459	0.459	0.484
8	21.574	0.609	0.597	0.597	0.63
7	18.868	0.73	0.705	0.705	0.746
6	16.177	1.018	0.784	0.784	0.83
5	13.482	1.678	0.837	0.837	0.888
4	10.785	2.091	0.867	0.867	0.921
3	8.086	2.091	0.873	0.873	0.927
2	5.38	2.085	0.828	0.828	0.881
1	2.674	2.050	0.596	0.596	0.642

Above results show that the maximum storey drift obtained at Third floor is **0.000915 mm** in Y direction for bare frame and **0.000927mm** for floating column frame in Y direction.

Above result shows that the storey drifts increase in both the directions when columns were obsolete at first floor. The storey drift in X and Y direction are approximately equal. Storey drift at the third floor is obtained maximum in both cases. Maximum storey drift increases 1.5% approximately. So we can say that floating column increase over all drift of the structure at each storey.

Comparison of storey forces of Bare frame and Floating column bare frame

Table 3: Storey Forces of Bare frame and Floating column bare frame

Storey	Height	Floating column bare frame			
		Storey force(x)	Storey force (y)	Storey force(x)	Storey force(y)
10	27.2	7	286	286	362
9	24.6	852	129	129	905
8	21.5	562	833	833	728

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Storey7	5419	59	824	858
Storey6	5519	426	532	322
Storey5	3393	563	385	143
Storey4	9993	9	811	349
Storey3	2268	699	238	965
Storey2	3168	681	094	016
Storey1	2643	927	433	16

Above results show that the maximum storey forces obtained at first floor is **534.2643kN** in X direction for bare frame and **506.1433kN** for floating column frame in X direction.

Analysis shows that the storey forces decrease in both the directions when columns were obsolete (float) at first floor. The storey forces in X and Y direction are approximately equal. Storey force at the first floor is obtained maximum in both cases. Maximum storey force decreases 5.2% approximately. So we can say that floating column decrease lateral forces at each storey of the structure.

Comparison of displacement of Infill frame and Floating column with infill frame

Table 4: Storey displacement of infill frame and Floating column with infill frame

Storey	infill floating frame (in mm)	infill bare frame (in mm)
Storey10		
Storey9		
Storey8		
Storey7		
Storey6		
Storey5		
Storey4		
Storey3		
Storey2		
Storey1		

Above results show that the maximum storey displacement obtained at top floor is **42.6433 mm** for bare frame and **40.5 mm** for floating column frame in both directions.

This analysis results show that the displacement increases when height of floor increases. Displacements of all storeys are increasing when floating columns are provided. The storey displacement in X and Y direction are equal. These results show that the maximum increase in displacement at top floor is **5.29%** approximately. Analysis shows that the presence of floating columns increases the storey displacement at each storey.

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Comparison of drift of Infill frame and Floating column with infill frame

Table 5: Storey drift of infill frame and Floating column with infill frame

floating frame

Above results show that the maximum storey drift obtained at third floor is **0.001538mm** for bare frame and **0.001518mm** for floating column frame in both directions. These results show that the drift increases when height of floor increases at third floor, after that drift continues to decrease till top floor. Drift of all storey are increasing when floating columns are provided. The storey drift in both direction are equal. These results show that the maximum increase in drift at first floor is **35%** approximately. Analysis shows that the presence of floating columns increases the storey drift at each storey.

Comparison of storey forces of Infill frame and Floating column with infill frame

Table 6: Storey forces of infill frame and Floating column with infill frame

infill floating frame (in kN)	infill frame (in kN)
	1
	4
	5
	3
	4
	5
	7
	3
	3
	4

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Above results show that the maximum storey forces obtained at first floor is **942.3764kN** in for infill frame and **890.0473kN** for floating column infill frame in both directions.

Analysis shows that the storey forces decrease in both the directions when columns were obsolete at first floor. The storey forces in both directions are equal. Storey force at the first floor is obtained maximum in both cases. Maximum storey force decreases **5.5%** approximately. So we can say that floating column decrease strength of the structure.

VI. CONCLUSION

From the present study between the bare frame and alternative floating column with or without infill the following conclusion is to be driven. Mainly this conclusion is based on the comparison between storey displacement, storey drift and lateral forces of bare frame and floating column frame with or without infill.

A. LATERAL DISPLACEMENT

Comparison between bare frame and floating frame without infill: The lateral displacements of alternative floating column frame increases as compared to bare frame at each storey. This is because when going through a floating case the alternative column floats from first storey to last storey so the stiffness at first storey decreases as compared to bare frame. That's why the displacement at first storey for floating frame is more than the first storey displacement of bare frame. Now, the more displacement of this first storey of floating column cumulatively adds till last storey. So the overall displacement of floating frame is more than the bare frame case. The stiffness from second storey to last storey is equal in both cases because the columns cut down at base storey. So, the stiffness at first storey is less than second storey; hence the lateral displacement at first storey is greater than the second storey.

Comparison between bare frame and floating frame with infill: The lateral displacements of alternative floating column infill frame increases as compared to infill bare frame at each storey. This is because when going through a floating case the alternative column floats from first storey to last storey so the stiffness at first storey decreases as compared to infill bare frame. Infill frame increase the stiffness of overall structure but less than the mass of the structure. So the seismic weight of the structure increases as compared to stiffness of the structure. That's why the displacement at first storey for floating infill frame is more than the first storey displacement of infill bare frame. Now the more displacement of this first storey of floating column cumulatively adds till last storey. So the overall displacement of floating frame is more than the bare frame case. The stiffness from second storey to last storey is equal in both cases because the columns cut down at base storey. So the stiffness at first storey is less than to second storey so the lateral displacement at first storey is greater than the second storey.

Comparison between floating frame with and without infill: The lateral displacements of alternative floating column infill frame increases as compared to floating column without infill frame at each storey. This is due to the weight of building predominant as compared to stiffness increment. So the displacement of first storey is more; that is main cause of increment in all storey displacement.

B. STOREY DRIFT

Comparison between bare frame and floating frame without infill: The storey drift of floating frame observed more than the bare frame. This phenomenon occurred because when the alternate columns cut down then the stiffness of the structure decrease, the storey displacement increases at each floor and the drift noted as the relative displacement of a storey as compared to the other storey. Storey drift max at the third-floor floating frame case as compared to the bare frame case. This is because the stiffness at a particular storey is the cumulative addition of the lower storey's stiffness but the weight of the structure is taking overall mass of the structure. Till third floor the mass is effective rather than the stiffness of the structure. That's why the drift at the third floor is more than the upper floors.

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Comparison between bare frame and floating frame with infill: Floating column infill frame observed more than the infill bare frame. This phenomenon occurred because when the alternate columns cut down then the stiffness of the structure decrease, the storey displacement increases at each floor and the drift noted as the relative displacement of a storey as compared to the other storey. Infill wall also provide some stiffness but the weight of the infill wall is more predominant as compared to the stiffness of the infill wall. So the drift in case of floating column infill frame is more than the simple without infill floating column frame. Storey drift max at the third-floor floating infill frame case as compared to the infill bare frame case. This is because the stiffness at a particular storey is the cumulative addition of the lower storey's stiffness but the weight of the structure is taking overall mass of the structure. Till third floor the mass is effective rather than the stiffness of the structure. That's why the drift at the third floor is more than the upper floors.

Comparison between floating frame with and without infill: The storey drift of alternative floating column infill frame increases as compare to floating column without infill frame at each storey. Maximum storey drift is measured at third storey. This is due to the weight of structure is increased more as compared to stiffness. So the storey drift is higher at each floor in with infill frame.

C. STOREY FORCES (STOREY SHEAR):

Comparison between bare frame and floating frame without infill: The Storey forces of alternative floating column frame decreases as compared to bare frame at each storey. This is because when going through a floating case the alternative column floats from first storey to last storey so the stiffness at first storey is decreased as compared to bare frame. That's why the storey forces at first storey for floating frame is less than the first storey forces of bare frame. Now the less lateral forces of this first storey of floating column cumulatively adds (base shear) till last storey. So, the overall storey force (base shear) of floating frame is less than the bare frame case.

Comparison between bare frame and floating frame with infill: The Storey forces of alternative floating column infill frame decreases as compared to infill bare frame at each storey. This is because when going through a floating case the alternative column floats from first storey to last storey so the stiffness at first storey is decreased as compared to infill bare frame. Infill frame increase the stiffness of overall structure but less than the mass of the structure. So, the seismic weight of the structure increases as compared to stiffness of the structure. That's why Storey forces at first storey for floating infill frame is less than the first storey forces of infill bare frame. Now the less lateral forces of this first storey of floating column infill frame cumulatively adds (Base shear) till last storey. So, the overall storey force (base shear) of floating infill frame is less than the infill bare frame case.

Comparison between floating frame with and without infill: The storey force of alternative floating column infill frame increases as compared to floating column without infill frame at each storey. Maximum storey shear is measured at first storey. This is due to the weight of structure is increased due to infill. So the storey force increases at each floor in infill frame.

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