International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Seismic Response Evaluation of RC frame building with Floating Column considering different Soil Conditions

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Accepted 12 January 2014, Available online 01 February 2014, **Vol.4, No.1 (February 2014)**

Abstract

In present scenario buildings with floating column is a typical feature in the modern multi-storey construction in urban India. Such features are highly undesirable in a building built in seismically active areas .This paper aims to investigate the effect of a floating column under earthquake excitation for various soil conditions and as there is no provision or magnification factor specified in I.S. Code, hence the determination of such factors for safe and economical design of a building having floating column. Linear Dynamic Analysis is done for 2D multi storey frame with and without floating column to achieve the above aim i.e. the responses (effect) and factors for safe and economical design of the structure under different earthquake excitation.

Keywords: *Floating Column, Linear Analysis, Response Spectrum Analysis, Magnification Factor.*

1. Introduction

Many urban multi-storey buildings in India today have an open storey as an unavoidable feature. This is primarily being adapted to accommodate parking or reception lobbies in the first storey. The behaviour of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path; any deviation or discontinuity in this load transfer path results in poor performance of the building. Buildings with vertical setbacks (like the hotel buildings with a few storeys wider than the rest) cause a sudden jump in earthquake forces at the level of discontinuity. Buildings that have fewer columns or walls in a particular storey or with unusually tall storey tend to damage or collapse which is initiated in that storey. Many buildings with an open ground storey intended for parking collapsed or were severely damaged in Gujarat during the 2001 Bhuj earthquake. Buildings with columns that hang or float on beams at an intermediate storey and do not go all the way to the foundation, have discontinuities in the load transfer path.

Most of the buildings in Ahmedabad & Gandhidham are covering the maximum possible area on a plot within the available bylaws. Since balconies are not counted in the Floor space index (FSI) , building having balconies overhanging in the upper stories beyond the footprint area at the ground storey , overhangs up to 1.2m to 1.5 m in plan are usually provided on each side of the building. In the upper storey, the perimeter columns of the ground storey are discontinued, and floating columns are provided along the overhanging perimeter of the building. This floating rest at of the taper overhanging beams without considering the increased vulnerability of the lateral load resisting system due to vertical discontinuity.

Fig. 1: Failure of R.C. Building with floating columns

This type of construction does not create any problem under vertical loading condition. But during an earthquake a clear load path is not available for transferring the lateral forces to the foundation. Lateral forces accumulated in upper floors during the earthquake have to be transmitted by the projected cantilever beams. Overturning forces thus developed overwhelm the columns of the ground floor. Under this situation the columns begin to deform &

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buckle, resulting in total collapse. This is because of primary deficiency in the strength of ground floor columns, projected cantilever beams & ductility of beam-column joints. The ductile connection at the exterior beam-columns joints is indispensible for transferring these forces. Fig shows damage in residential concrete building due to floating columns. This is the second most notable & sepectular causes of failure in buildings. The 15th August Apartment and Nilima park apartment's buildings in Ahmedabad are the typical example of failure in which, infill walls present walls in the upper floors are discontinued in the lower floors. In this study, two cases of building model G+3 and G+5 were used for whole analysis.

2. Floating Column

A column is supposed to be a vertical member starting from foundation level and transferring the load to the ground. The term floating column is also a vertical element which ends (due to architectural design/ site situation) at its lower level (termination Level) rests on a beam which is a horizontal member. The beams in turn transfer the load to other columns below it. Such columns where the load was considered as a point load. Theoretically such structures can be analyzed and designed. In practice, the true columns below the termination level [usually the stilt level] are not constructed with care and more liable to failure. Hypothetically, there is no need for such floating columns – the spans of all beams need not be nearly the same and some spans can be larger than others. This way, the columns supporting beams with larger spans would be designed and constructed with greater care.

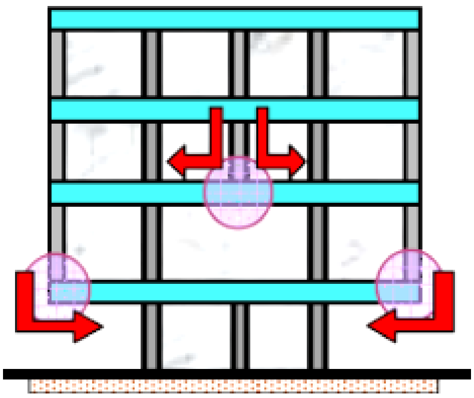


Fig. 1: Building with floating columns.

There are many projects in which floating columns are adopted, especially above the ground floor, where transfer girders are employed, so that more open space is available in the ground floor. These open spaces may be required for assembly hall or parking purpose. The transfer girders have to be designed and detailed properly, especially in earthquake zones. The column is a concentrated load on the beam which supports it. As far as analysis is concerned, the column is often assumed pinned at the base and is therefore taken as a point load on the transfer beam.

3. Objectives of the present study

1) To study the effect of a floating column under earthquake excitation for various soil conditions.
2) As there is no provision or the magnification factor specified in I.S. Code, hence the determination of such factors for safe and economical design of a building having floating column.

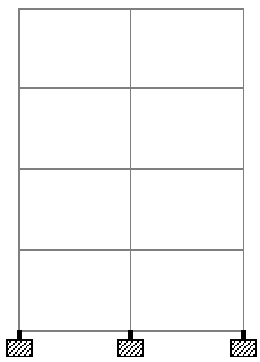
Example Building Frame

For the analysis purpose two models have been considered namely as:

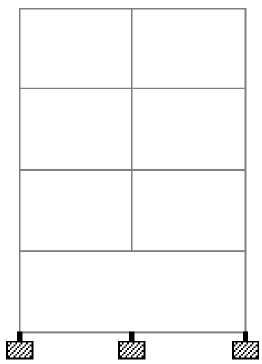
Model A: Four storied (G+3) special Moment Resisting Frame (Case 1).
Model B: Six storied (G+5) special Moment Resisting Frame (Case 2).

Model A- Model A is two bays, four storey model. Following models have been considered for Case 1.

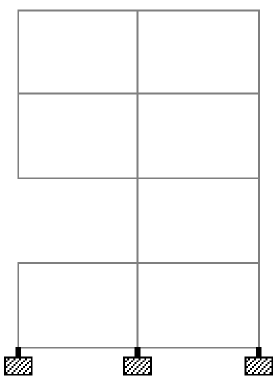
Model A-1- Building in which there are usual columns.
Model A-2- Building in which there is floating column located at ground floor.
Model A-3-Building in which there is floating column located at first floor.
Model A-4- Building in which there is floating column located at second floor.
Model A-5-Building in which there is floating column located at third floor.



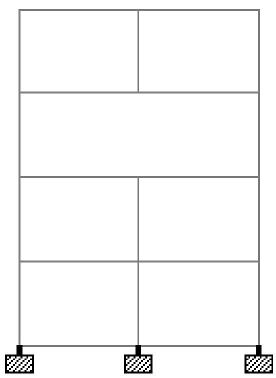
(Model A-1)



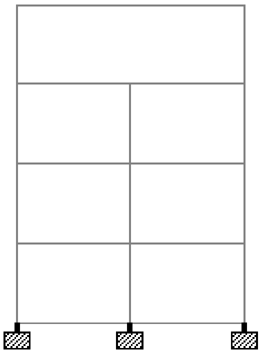
(Model A-2)



(Model A-3)



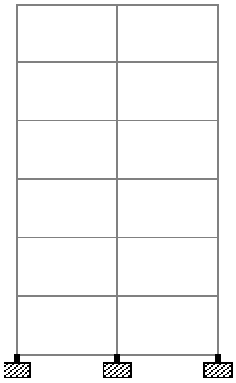
(Model A-4).



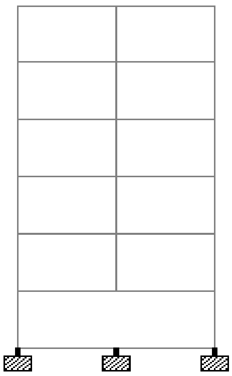
(Model A-5)

Model B- Model B is two bays, six storey model. Following models have been considered for Case 2.

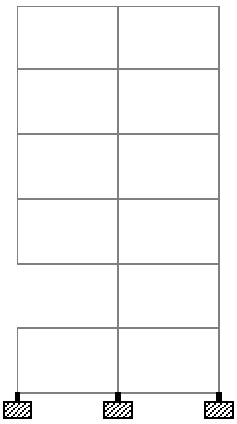
Model B-1- Building in which there are usual columns.
Model B-2- Building in which there is floating column located at ground floor.
Model B-3- Building in which there is floating column located at first floor.
Model B-4- Building in which there is floating column located at third floor.
Model B-5- Building in which there is floating column located at fourth floor.
Model B-6- Building in which there is floating column located at fifth floor.



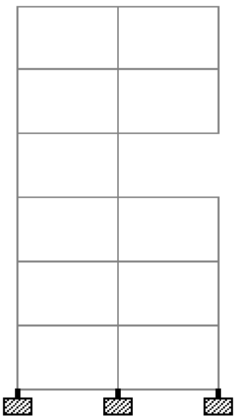
(Model B-1)



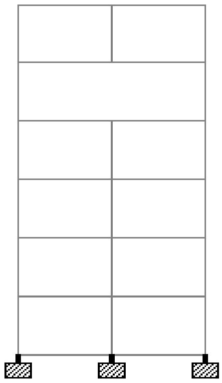
(Model B-2)



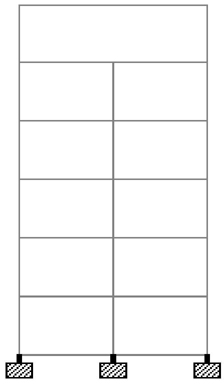
(Model B-3)



(Model B-4)



(Model B-5)



(Model B-6)

Table No.1 Details of Building Models

1	Type of Structure	Multi-storey rigid jointed plane frame (SMRF)
2	Seismic Zone	V
3	Number of stories	Four (G+3), Six (G+5)
4	Floors Height	3.5 m
5	Infill wall	230mm thick brick masonry wall along X direction and Y direction
6	Type of soil	Medium and Hard
7	Size of column	350 mm X 400mm
8	Size of Beam	300 mm X 450mm
9	Depth of Slab	120 mm
10	Live load	a) On roof = 1.5 KN/ m^2 b) On floor = 3.5 KN/ m^2
11	Floor Finishes	6 mm thick
12	Material	M 20 Grade concrete & Fe 415 Reinforcement
13	Unit weights	a) Concrete = 25KN/Cum b) Masonry = 20KN/Cum
14	Total Height of Building	14 m for G+3 And 21 m for G+5
15	Clear Cover of Beam	25 mm
16	Clear Cover of Column	40 mm
17	Damping in Structure	5%
18	Importance factor	1.0

4. Linear Analyses

Seismic analysis is a subset of structural analysis and is the calculation of the response of the building structure to earthquake and is a relevant part of structural design where earthquakes are prevalent. The seismic analysis of a structure involves evaluation of the earthquake forces acting at various levels of the structure during an earthquake and the effectiveness of such forces on the behavior of the overall structure. The analysis may be static or dynamic in approach as per the code provisions.

5. Response Spectrum Analysis (RSA)

It is the linear dynamic analysis. This method is applicable for those structures where modes other than the fundamental one affect significantly the response of the structure .In this method the response of Multi- Degreeof–Freedom (MDOF) system is expressed as the superposition of modal response, each modal response being determined from the spectral analysis of Single - Degree- of – Freedom (SDOF) system, which are then combined to compute the total response. Modal analysis leads to the response history of the structure to a specified ground motion; however, the method is usually used in conjunction with a response spectrum.

Response spectrum analysis of the all building models is carried out in Staad Pro to find out the effect of soil on the seismic performance of building for the first object and to evaluate the Max. Magnification factor for bending moment for the second object.

RSA for Object 1

A) The variation in Base shear and Moments for various soil conditions to achieve the first object have been studied. RSA is done for the response spectrum corresponding to Zone V, hard soil and medium soil and 5% damping as per IS 1893 (2002), for all the frames. To represent the extreme cases floating column is provided at various floor level and at various positions.

B) The Base shears and Max. BM. from the RSA for hard soil condition and medium soil for the various models of Case 1 (A-2,A-3, A-4, A-5) are given in Table 2. And the Base shears and Max. BM. From the RSA for hard soil and medium soil condition of the various models of Case 2 (B-2, B-3, B-4, B-5 and B-6) are given in Table 3. The percentage variation in each case are also listed (shown in parenthesis).

Table No.2 Base shear and Max. B.M. on each floor

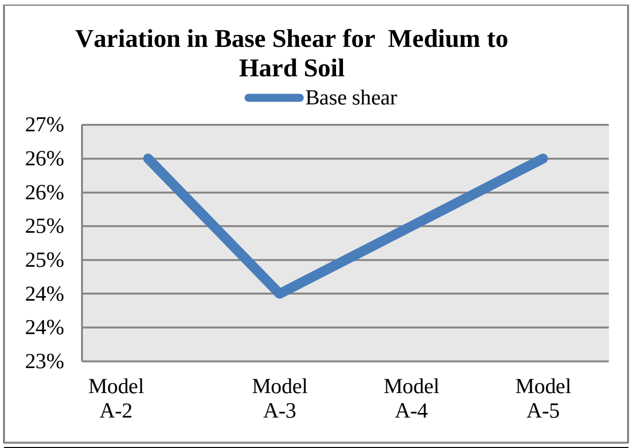
a) For Zone V and Hard Soil condition for Case 1.

Condition of floating column	Model A-2	Model A-3	Model A-4	Model A-5
1) Base shear(kN)	441.3	346.16	421.08	438.74
2) Max. BM(kNm) Ground Floor	512.702	303.494	349.314	377.341
First Floor	446.243	374.072	417.448	307.604
Second Floor	233.941	321.021	269.622	316.081
Third Floor	134.426	232.436	223.1	125.461

b) For Zone V and Medium Soil condition for Case 1.

Condition of floating column	Model A-2	Model A-3	Model A-4	Model A-5
1) Base shear (kN)	595.43 (26%)[a]	453.07 (24%)	559.3 (25%)	590.41 (26%)
2) Max. BM (kNm) Ground Floor	693.01 (26%)	401.71 (24%)	465.29 (25%)	509.10 (26%)
First Floor	606.76 (26%)	507.86 (26%)	567.72 (26%)	418.03 (26%)
Second Floor	313.78 (25%)	424.25 (24%)	361.84 (25%)	424.48 (26%)
Third Floor	174.79 (23%)	302.07 (23%)	293.38 (24%)	160.95 (22%)

[a]percentage variation values (Base shear/BM etc) between Medium and Hard soil conditions.



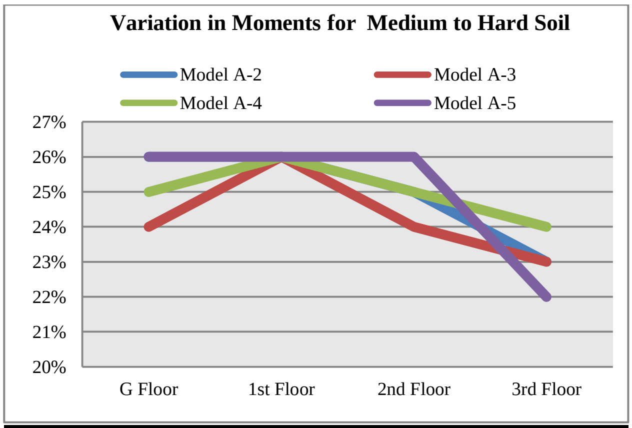


Table No.3 Base shear and Max. B.M. on each floor

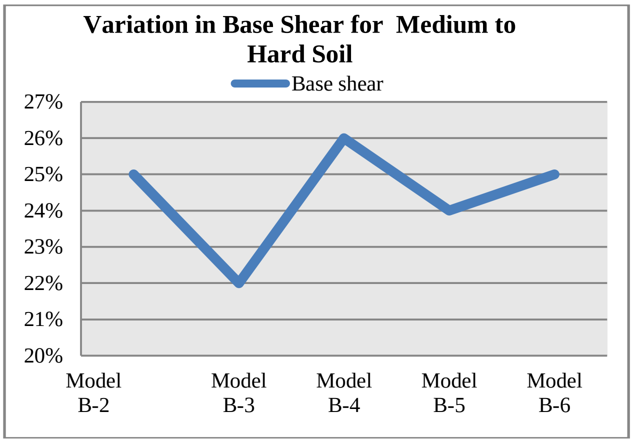
a) Zone V and Hard Soil Condition for Case 2

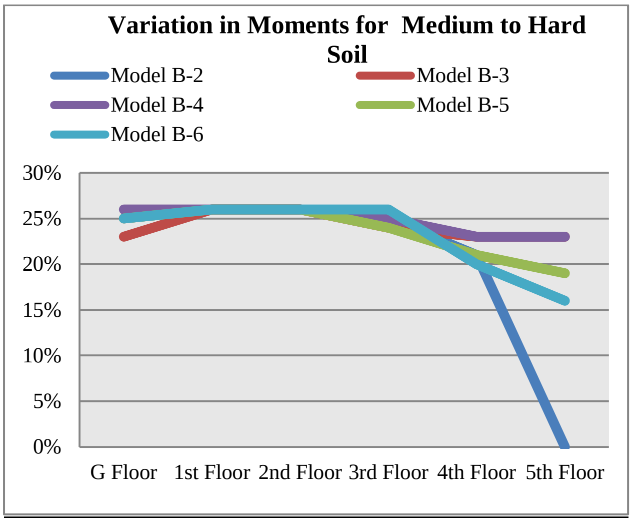
Condition of floating column	Model B-2	Model B-3	Model B-4	Model B-5	Model B-6
1) Base shear (kN)	451.16	383.08	401.28	446.58	452.5
2) Max. B.M. (kNm) Ground Floor	530.01	337.95	350.4	388.35	394.2
First Floor	488.62	412.57	324.58	345.81	351.6
Second Floor	293.54	386.79	302.6	287.09	310.8
Third Floor	260.8	347.44	344.25	359.64	251.6
Fourth Floor	197.5	293.87	289.47	228.22	256.4
Fifth Floor	131.5	211.62	207.17	185.82	99.44

b) Zone V and Medium Soil Condition for Case 2

Condition of floating column	Model B-2	Model B-3	Model B-4	Model B-5	Model B-6
1) Base shear (kN)	600.5 (25%)	489.41 (23%)	538.78 (25%)	590.11 (24%)	602.2 (25%)
2) Max. B.M. (kNm) Ground Floor	707.3 (25%)[a]	437.84 (23%)	470.96 (25%)	515.04 (24%)	526.2 (25%)
First Floor	659.6 (25%)	560.57 (26%)	440.18 (26%)	465.61 (26%)	474.9 (26%)
Second Floor	399 (26%)	521.84 (26%)	411.53 (26%)	389.16 (26%)	422.6 (26%)
Third Floor	346.0 (25%)	459.97 (24%)	459.69 (25%)	473.85 (24%)	338.4 (26%
Fourth Floor	249.8 (21%)	382.58 (23%)	377.56 (23%)	287.42 (20%)	322.1 (20%)
Fifth Floor	131.5 (0%)	274.69 (23%)	268.22 (23%)	228.99 (19%)	118.6 (16%)

[a]percentage variation values (Base shear/BM etc) between Medium and Hard soil conditions.





RSA for Object 2

The Max. Magnification factors for base shear and bending moment has been evaluated to achieve the second object. Response Spectrum Analysis is done for the response spectrum corresponding to Zone V, medium soil and 5% damping as per IS 1893 (2002), for all the frames.To represent the extreme, cases floating column is provided at various floor level and at various positions. The Magnification factors from the RSA for the two building frames cases for various models are given in Table 4 & Table 6.

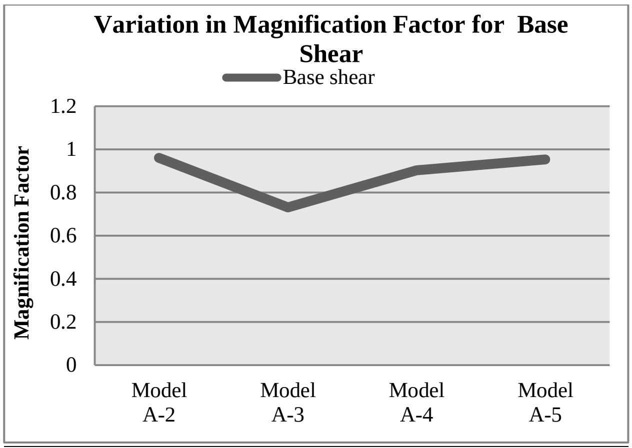
The base shear demands from RSA for both Case 1 (A-1) and Case 2 (B-1) without floating column frames are found to be higher than that of other models having a floating column, in both the cases. The magnification factors in each case are also listed (shown in parenthesis)

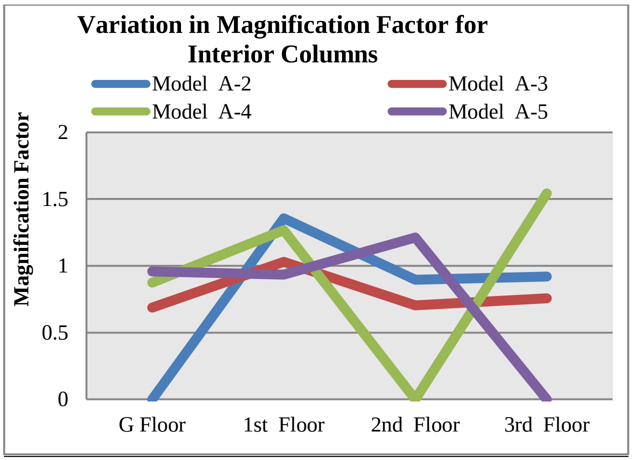
Table No.4 Magnification factors from RSA for Case 1

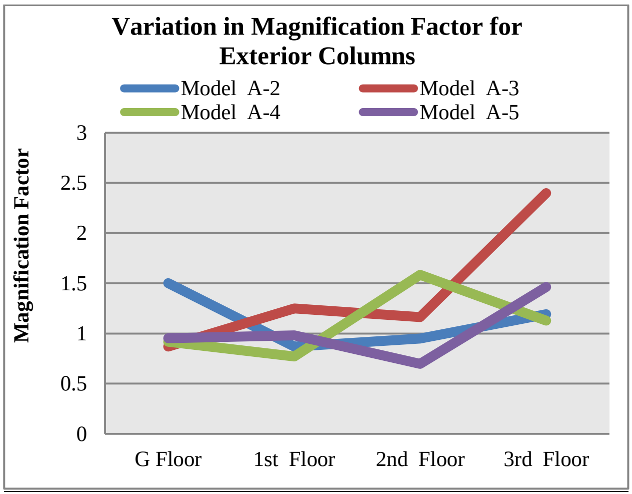
a) Base shear and Max. Moment in columns.

Model		Model A-1	Model A-2	Model A-3	Model A-4	Model A-5
Base shear (kN)		619.46	595.43 (0.96)[b]	453.07 (0.73)	559.3 (0.90)	590.41 (0.95)
Max. BM in GF (kNm)	Int Col	531.61	0	365.57 (0.69)	465.3 (0.88)	509.1 (0.96)
	Ext Col	461.3	693.01 (1.5)	401.71 (0.87)	423.91 (0.92)	439.68 (0.95)
Max. BM in 1ST Floor (kNm)	Int Col	447.75	606.76 (1.36)	460.89 (1.03)	567.72 (1.27)	418.03 (0.93)
	Ext Col	266.49	232.02 (0.87)	332.78 (1.25)	205.71 (0.77)	261.96 (0.98)
Max. BM in 2ND Floor (kNm)	Int Col	350.35	313.78 (0.9)	246.91 (0.7)	0	424.48 (1.21)
	Ext Col	228.6	216.89 (0.95)	265.77 (1.16)	361.84 (1.58)	159.65 (0.7)
Max. BM in 3RD Floor (kNm)	Int Col	190.2	174.8 (0.92)	144.1 (0.76)	293.38 (1.54)	0
	Ext Col	110.12	131.36 (1.19)	263.94 (2.4)	124.13 (1.13)	160.95 (1.46)

[b] magnification factor, value (Base shear/BM at columns etc) divided by the corresponding value for the frame with usual columns.







b) Max. Moment in Beams

Model		Model A-1	Model A-2	Model A-3	Model A-4	Model A-5
Max. BM in Beams (kNm)	G Floor	430.82	454.96 (1.06)	386.58 (0.89)	389.54 (0.9)	413.07 (0.96)
	1st Floor	398.57	371.98 (0.93)	507.85 (1.27)	410.47 (1.03)	384.61 (0.96)
	2nd Floor	252.54	233.84 (0.93)	424.25 (1.68)	275.30 (1.09)	285.87 (1.13)
	3rd Floor	110.12	131.36 (1.19)	302.07 (2.74)	124.13 (1.13)	160.95 (1.46)

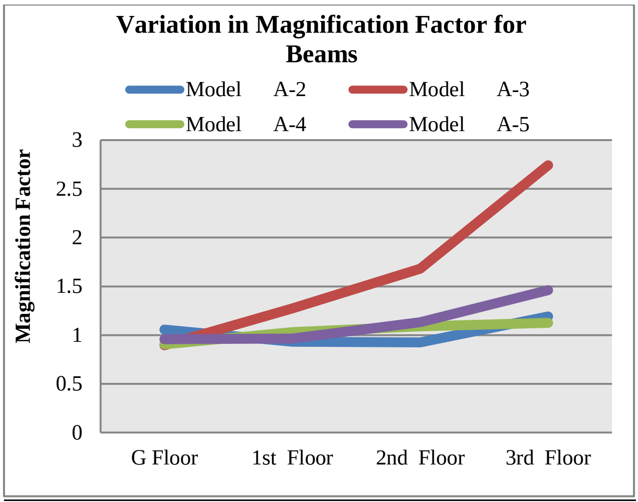
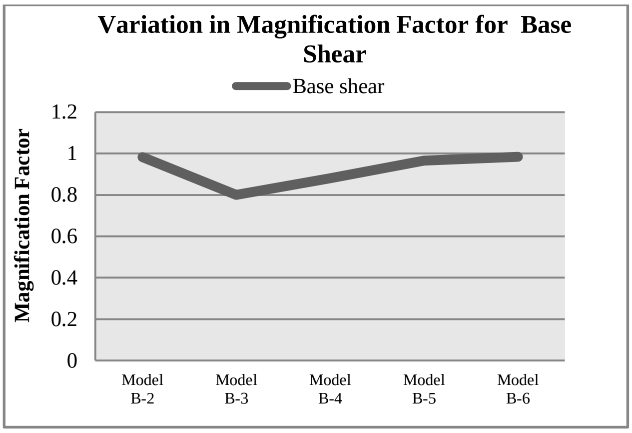


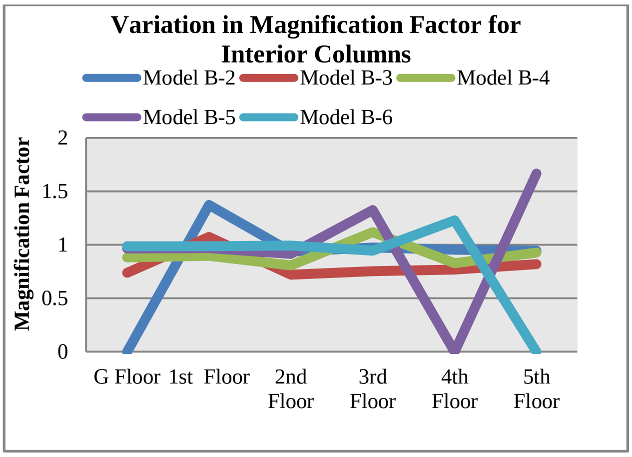
Table No.5 Magnification factors from RSA for Case 1

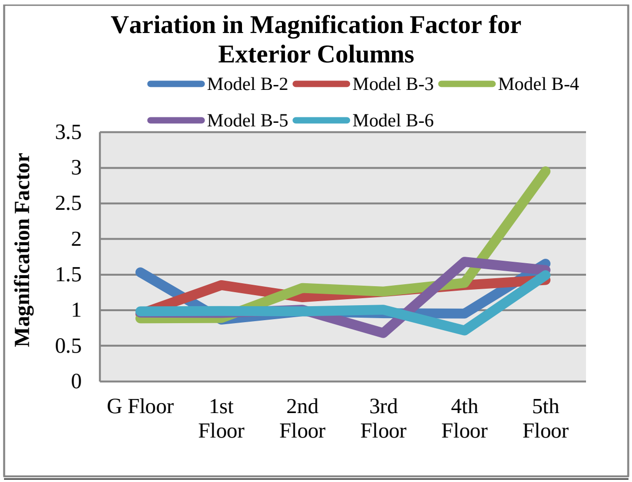
a) Base shear and Max. Moment in columns.

Model		Model B-1	Model B-2	Model B-3	Model B-4	Model B-5	Model B-6
Base shear (kN)		611.7	600.5 (0.98)[a]	489.4 (0.8)	538.8 (0.88)	590.1 (0.96)	602.1 (0.98)
Max. BM in GS (kNm)	Int Col	534.1	0	394.3 (0.74)	471 (0.88)	515.0 (0.96)	526.2 (0.99)
	Ext Col	462.1	707.3 (1.53)	437.8 (0.95)	410 (0.89)	446 (0.97)	455.1 (0.99)
Max. BM in 1ST Floor (kNm)	Int Col	480.9	659.6 (1.37)	515.6 (1.07)	431.7 (0.9)	465.6 (0.97)	474.9 (0.96)
	Ext Col	272	235.4 (0.87)	367.7 (1.35)	242.1 (0.89)	262.1 (0.96)	268.7 (0.99)
Max. BM in 2ND Floor (kNm)	Int Col	426.2	399 (0.94)	307.2 (0.72)	344.3 (0.81)	389.7 (0.91)	422.6 (0.99)
	Ext Col	250.9	246.5 (0.98)	295.9 (1.18)	329.1 (1.31)	252.5 (1.01)	246.8 (0.98)
Max. BM in 3RD Floor (kNm)	Int Col	358	349.0 (0.97)	269.1 (0.75)	400.6 (1.12)	473.8 (1.32)	338.4 (0.95)
	Ext Col	216.2	207.1 (0.96)	272.5 (1.26)	272.8 (1.26)	146.8 (0.68)	217.3 (0.99)
Max. BM in 4TH Floor (kNm)	Int Col	262.3	249.8 (0.95)	201.3 (0.77)	216.9 (0.83)	0	322.0 (1.23)
	Ext Col	171	163.2 (0.95)	231.5 (1.35)	236.7 (1.38)	287.4 (1.68)	121.9 (0.71)
Max. BM in 5TH Floor (kNm)	Int Col	137.4	129.7 (0.95)	112.5 (0.82)	127.4 (0.93)	229 (1.67)	0
	Ext Col	79.5	131.6 (1.65)	113.2 (1.42)	234.6 (2.95)	124.1 (1.56)	118.5 (1.49)

[b]magnification factor, value (Base shear/Max.BM in columns etc) divided by the corresponding value of the frame without floating column.



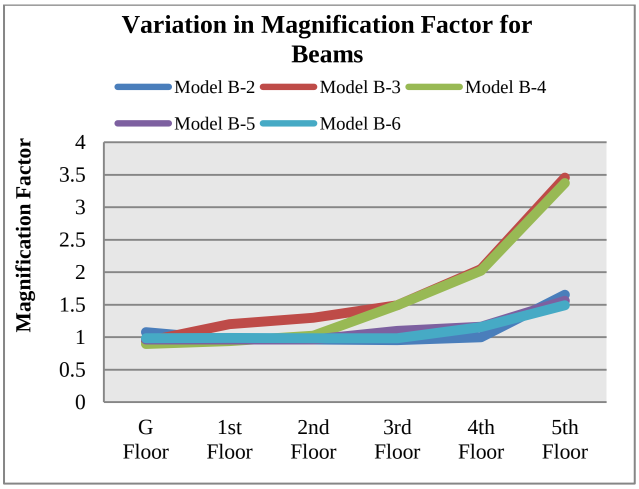




b) Base shear and Max. Moment in beams

Model		Model B-1	Model B-2	Model B-3	Model B-4	Model B-5	Model B-6
Max. BM in Beams (kNm)	G Floor	448.3	484.3 (1.08)	420.5 (0.94)	401.3 (0.9)	432.8 (0.97)	442.4 (0.99)
	1st Floor	466.9	450.5 (0.96)	560.6 (1.2)	440.2 (0.94)	451.3 (0.97)	461.3 (0.99)
	2nd Floor	401.7	387.5 (0.96)	521.8 (1.3)	411.5 (1.02)	388 (0.97)	395.6 (0.99)
	3rd Floor	307.9	294.7 (0.96)	460 (1.49)	459.7 (1.49)	337.7 (1.1)	302.8 (0.98)
	4th Floor	186.6	187 (1)	382.6 (2.05)	377.6 (2.02)	216.5 (1.16)	215.5 (1.15)
	5th Floor	79.48	131.5 (1.65)	274.7 (3.46)	268.2 (3.37)	124.1 (1.56)	118.6 (1.49)

[b]magnification factor, value (Base shear/Max.BM in columns etc) divided by the corresponding value for the frame with usual columns



6. Results and discussions

In the present study, result of RSA for varying soil conditions has shown that the base shear demands for medium soil is found higher than that of the hard soil in both cases.

The variation of base shear for Case 1 is from 24% to 26% and for Case 2 it is from 23% to 25%. The variation in moments is in the range of 22% to 26% for Case 1 and 16% to 26 % for Case 2.

The magnification factor which is evaluated for base shear and moments for object two in case of G+3 building model has been found in the range of 0.73 – 0.96 for base shear, 0.69 to 2.4 for moments in interior and exterior columns and 0.89 – 2.74 for moments in beams.

The magnification factor in the case of G+6 has been found in the range of 0.8-0.98 for base shear, 0.71 to 2.95 for moments in interior and exterior columns and 0.9 – 3.6 for moments in beams.

7. Conclusion

From the present study it is concluded that-

In Object 1: The base shear demands for medium soil are found higher than that of the hard soil in both cases (i.e. G+3 and G+6 model). As the height of the building increases, variation in base shear from medium to hard soil condition decreases. For different soil conditions (medium to hard) the max. moments vary from 22- 26% for four storied building model and 16-26% for six storied building model. It has been found that max. variation in values of max. moments comes at the ground floor (26%) for both the cases whereas the min. variation comes at the top floor (22% for case 1 and 16% for case 2). It can further been concluded that as the height of the building increases the variation of max. moments gets reduced for different soil conditions.

In Object 2: The Max. Magnification Factor for the moment based on linear analysis for G+3 is in the range of 0.87 – 1.5 for A-2 model, 0.69 – 2.74 for A-3 model, 0.77-1.58 for A-4 model , 0.7 – 1.46 for A-5 model and for G+5 is in the range of 0.94-1.65 for B-2 model, 0.74-3.46 for B-3 model, 0.81- 3.37 for B-4 model, 0.9- 1.67 for B-5 model, 0.71 – 1.49 for B-6 model.

Results from RSA shows that the location of floating column at corners as in the model A-3,B-3 and B-4 is more critical than others.

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