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Study of the Effect of Vibration Characteristics on the Stability of RC Structures

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ABSTRACT

The strength design may be sufficient in case of regular building whereas some more design criterion needs to be considered for tall, slender and irregular building. Vibration is an important phenomenon that relates to the stability of any structure. Excessive vibration may cause unexpected displacement which may initiates cracking that is crucial for stability analysis. The time period is calculated solely depending on height in the present formula that is used in the static analysis. Logically the time period of same height building is different depending upon the varying shape and mass of the building. In this study a comparison of the story displacement would be made using 05 building models of same height and same mass with different shape using static analysis. After that modal and response spectrum analysis would be performed and check out the displacement and compare the time period values, story displacement that is obtained in the static analysis. In this study it would be demonstrated that the shape and size of the structure are also responsible for time period or frequency and the overall vibration characteristics of the building. The result of this study shows that the consequence of vibration for the same height & mass the displacement i.e. stability of structure is affected by the shape of the structure also.

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1. Introduction

1.1. Background of this study

A building's height is a primary driver of its fundamental period. The reliable and sufficient estimation of the natural period of vibration could play an essential role in the understanding of the global demands on the structure under an earthquake [1].

Some buildings have vertical irregularity which affects the period or frequency of the system. From the stiffness point of view the response of the building due to lateral force affect the building from bottom to top on the basis of its height and mass. Natural time period is also a function of number of storeys [2].

As per ACI code time period for RCC moment resisting frame can be calculated from the equation:

$$Ct= 0.0466 (h_n)^m \tag{1}$$

h_n = building height in m

m = 0.9 for RCC structure

In this formula the building height is the dominating factor which is not essentially adequate in all cases. The values of frequency or time period also changes with the change in analysis approach. The vibration period of reinforced concrete (RC) buildings is affected by many factors such as structural regularity, number of storeys and bays, dimension of member sections, infill panel properties and position, load levels etc [3].

It's a variable property and needs to be assumed an approximate value which can deliver the result nearest to a proper margin of safety. Frequency of system needs to be kept in a favorable range to attain comfort and overall safety of the building.

In this study five (05) building models would be discussed. The models are denoted as A, B, C1, C2 and C3. All the models are of same height of 62.0m. The value of time period of the three different buildings according to equation (1) is same 1.91 second which is conservative in some cases that will be illustrated in the later sections.

1.2. Frequency of structure

Stiffness is the property or tendency of a building which resists deformation in response to the applied force. The building element with more stiffness means it attracts more forces to it. During design process it can be assumed that column is stiffer than beam, beam is stiffer than slab. It is done like this to attract more forces to the column and transfer the load to the foundation. Otherwise this load will cause excessive vibration that results in more deflection to the related weaker zone in the superstructure and initiates the collapse.

The response of structural element can be kept in allowable limit by increasing the stiffness or rigidity. This can be done by strengthening its section or increasing its size, but this will generally increase its cost. Dimension of columns and beams are also controlling factor of natural frequency, because it relates to the stiffness and total mass of the structure [3].

Buildings tend to have lower natural frequencies when they are either heavier (more mass) or more flexible (that is less stiff). One of the main things that affect the stiffness of a building is its height. Taller buildings tend to be more flexible, so they tend to have lower natural frequencies compared to shorter buildings. Generally the time period or frequency of the different height building can be shown as like as the below figures.

Building a) Low height, period < 1 sec

Building b) Medium height, period ~ 1 sec

Building c) High height, period > 2 sec

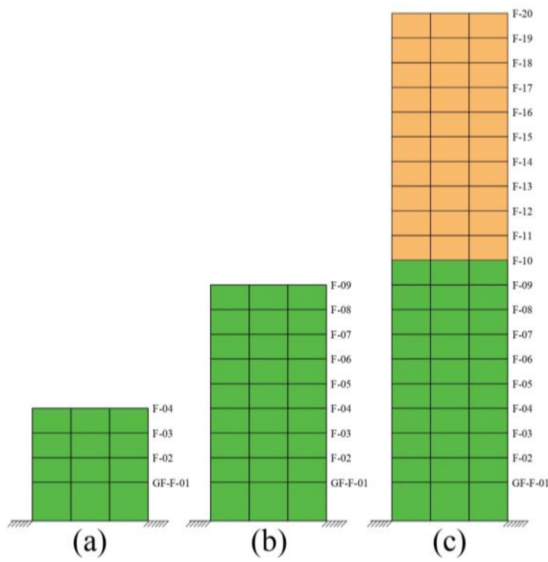
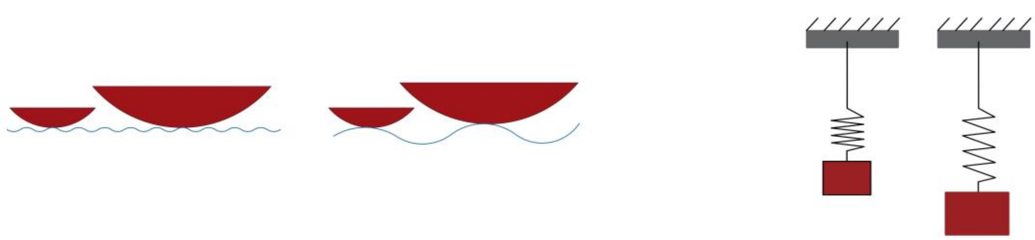


Fig. 1. General concept of time period depend on height.

1.3. Frequency of system related to mass



(a) (b)

Fig. 2. Frequency of system related to mass.

Frequency can also be understood from a simple analogy from the wave of water. A small mass or small boat experiences less vibration when the wave is small. The small wave can be considered as more frequency and lesser period. On the other hand the heavier mass or large boat experiences more vibration when the wave is big. Big wave can be considered as less frequency and larger period. Buildings that are heavy (With larger mass m) and flexible (With smaller stiffness K) have larger natural period than light and stiff buildings [4].This analogy can be helpful to design the system considering the critical situation.

There is another analogy to understand the frequency of the system. The first system contains a small mass. In this case the displacement of the spring is less and the vibration is more. That means the frequency is more and the period is less. In the second picture the displacement of the spring is more and the vibration is less due to the heavier mass.

2. Analysis approach

Different types of analysis approach are used for different types of structure. In this study following analysis approaches would be used and frequency / time period would be compared for different cases.

Analysis approach 01: Equivalent seismic load approach

Analysis approach 02: Modal Analysis

Analysis approach 03: Response Spectrum Analysis (RSA) approach

Building model A

22.5 m X 22.5 m size from bottom to 20 stories, 5X5 bay, and each bay 4.5 m.

No vertical irregularity.

Building model B

13.5 m X 13.5 m size from bottom to top, 3X3 bay, each bay 4.5 m. No vertical irregularity.

Building model C1

22.5mX22.5m size from bottom to 10 Story and 13.5 m X13.5 m size from 11 Story to 20 stories, 5X5 bay at the bottom, 3X3 bay at the middle from 11 Story to 20 stories).

Vertical irregularity exists in all sides.

Building model C2

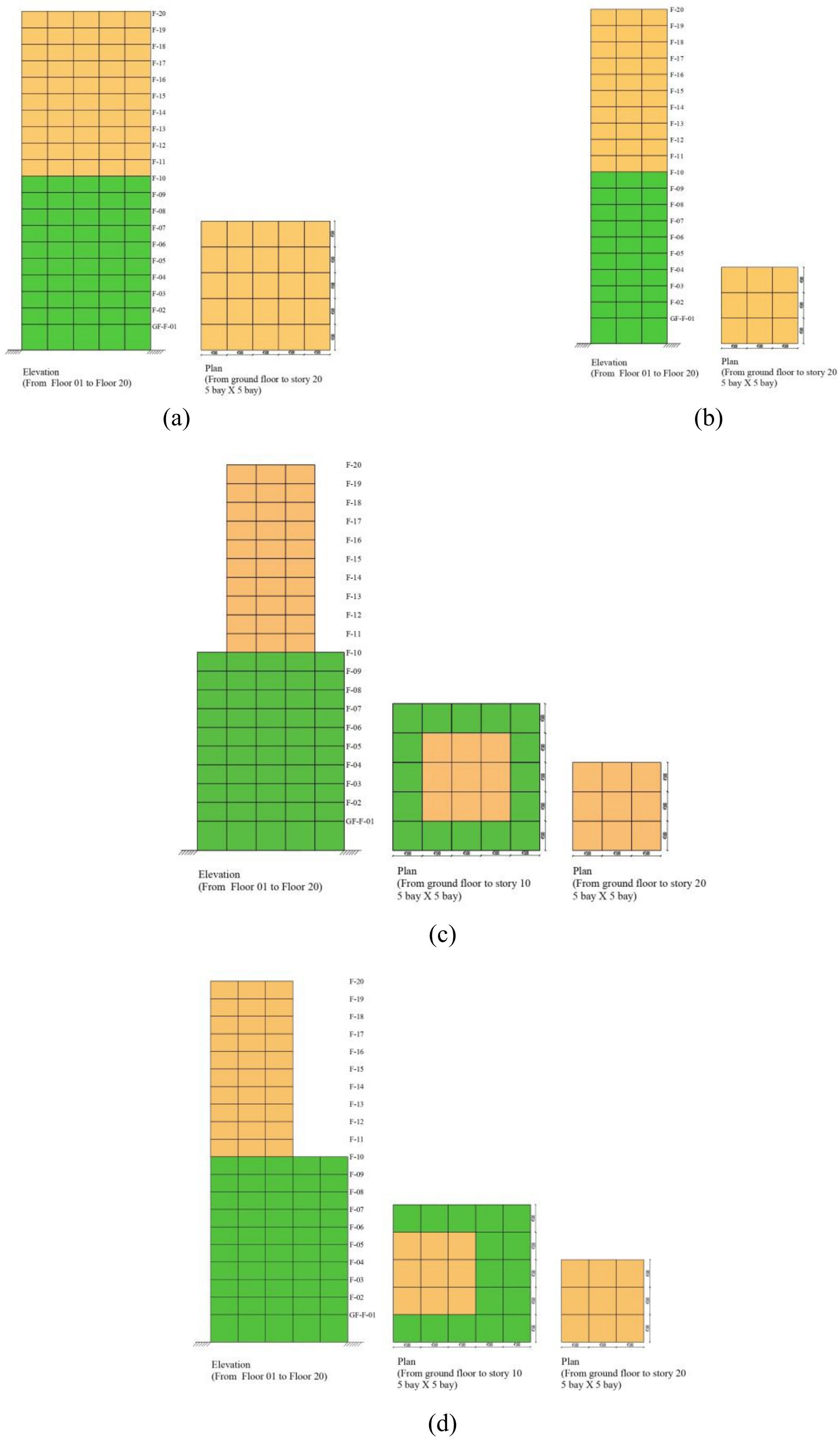
22.5mX22.5m size from bottom to 10 Story and 13.5 m X13.5 m size from 11 Story to 20 stories, 5X5 bay at the bottom, 3X3 bay at the left side (Exterior) from 11 Story to 20 stories. Vertical irregularity exists in all sides.

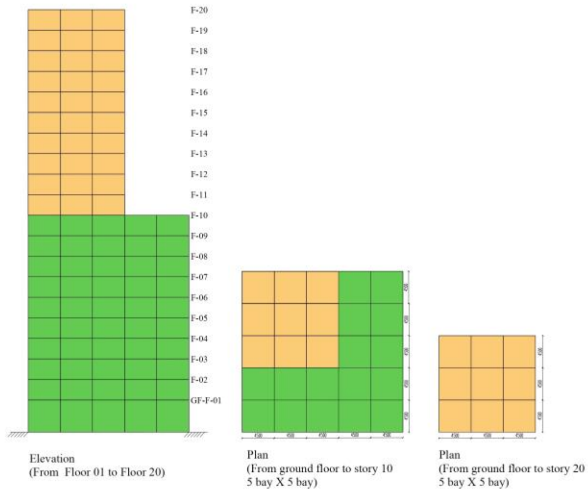
Building model C3

22.5mX22.5m size from bottom to 10 Story and 13.5 m X13.5 m size from 11 Story to 20 stories, 5X5 bay at the bottom, 3X3 bay at the corner side from 11 Story to 20 stories. Vertical irregularity exists in all sides.

Over all building height for A, B and C model= 62000 mm

Analysis is done by using a finite element analysis software ETABS.


Elevation
(From Floor 01 to Floor 20)
Plan
(From ground floor to story 20
5 bay X 5 bay)
(a)
Elevation
(From Floor 01 to Floor 20)
Plan
(From ground floor to story 20
5 bay X 5 bay)
(b)
Elevation
(From Floor 01 to Floor 20)
Plan
(From ground floor to story 10
5 bay X 5 bay)
Plan
(From ground floor to story 20
5 bay X 5 bay)
(c)
Elevation
(From Floor 01 to Floor 20)
Plan
(From ground floor to story 10
5 bay X 5 bay)
Plan
(From ground floor to story 20
5 bay X 5 bay)
(d)



(e)

Fig. 3. Plan and elevation of the 5 types of buildings.

4. Static analysis results

Some analysis results are needed to be listed out to go through the comparison and discussion study. The specification of column, beam and materials are described in Appendix A. The analysis results from ETABS analysis are given below.

Analysis approach (Equivalent seismic load system)

Time period = 1.91 sec (Following the formula $T = 0.0466h^{0.9}$)

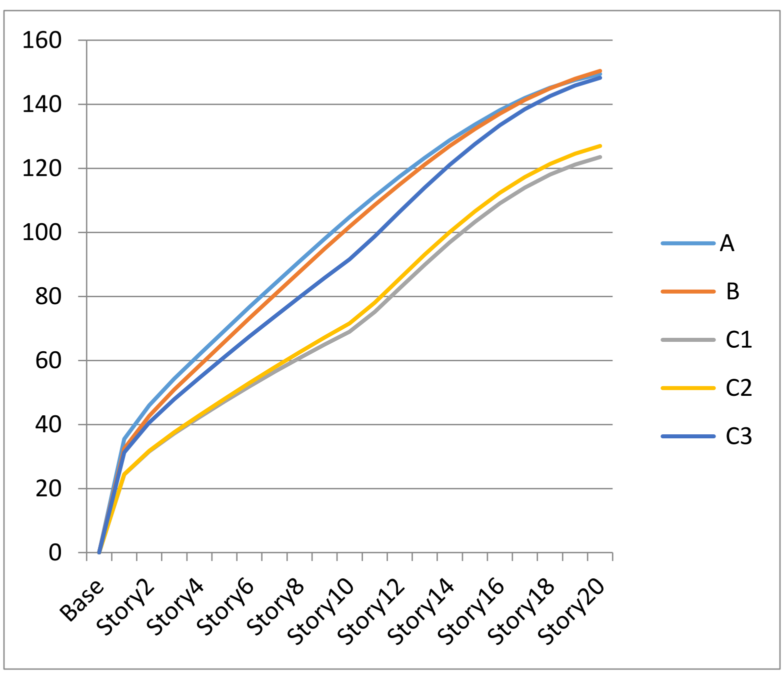


Fig. 4. Story displacement curve.

Table 1
Story displacement from ETABS result (Analysis aproach 01).

Story Displacement Result in mm					
Considered load combination = 0.9DL-1.43Ex					
Story Name	**A**	**B**	**C1**	**C2**	**C3**
Base	0	0	0	0	0
Story1	35.5	32.4	24.3	24.5	31.3
Story2	46.0	42.7	31.6	31.8	40.6
Story3	54.3	50.8	37.1	37.5	47.9
Story4	61.9	58.4	42.2	42.8	54.6
Story5	69.3	65.8	47.1	47.9	61.0
Story6	76.6	73.2	51.9	53.0	67.4
Story7	83.9	80.5	56.4	57.8	73.7
Story8	91.0	87.7	60.8	62.6	79.8
Story9	98.0	94.8	65.0	67.1	85.7
Story10	104.7	101.8	69.0	71.6	91.6
Story11	111.3	108.5	75.2	78.1	98.7
Story12	117.5	115.0	82.5	85.6	106.4
Story13	123.3	121.2	89.9	93.0	114.0
Story14	128.7	126.9	96.9	100.1	121.1
Story15	133.7	132.3	103.3	106.6	127.6
Story16	138.1	137.1	109.0	112.3	133.4
Story17	142.0	141.4	114.0	117.3	138.4
Story18	145.1	145.0	118.0	121.4	142.6
Story19	147.6	148.0	121.2	124.6	145.9
Story20	149.4	150.4	123.5	127.0	148.3

Table 2
Story stiffness considering earthquake load (Ex).

Story Name	**A**	**B**	**C1**	**C2**	**C3**
	For EX	**For EX**	**For EX**	**For EX**	**For EX**
	X-Dir	**X-Dir**	**X-Dir**	**X-Dir**	**X-Dir**
	kN/m	kN/m	kN/m	kN/m	kN/m
Base	0	0	0	0	0
Story1	88009.17	36730.08	88275.22	88146.55	88150.54
Story2	340297.9	132904.5	342774.6	341403	341446.5
Story3	439603.1	168815.4	445307.3	442155.3	442256.9
Story4	467476.8	178437.2	476021.1	471235.3	471389.4
Story5	470720.4	178595.9	481490.4	475231.5	475433.3
Story6	467720.7	176269.5	480338.3	472559.4	472812.1
Story7	463447.1	173457.9	477519.8	468044.6	468366.4
Story8	458974.7	170604.7	473645.8	462037.5	462480
Story9	454471.1	167766.9	465527	451678.2	452518.5
Story10	449868.4	164895.5	444342.3	425202.3	427029.4
Story11	445021.9	161904.7	322223.4	233298.3	225283
Story12	439730.1	158681.4	195729.8	188322.2	186462.5
Story13	433715	155075.5	183258.2	176718.4	175879.3
Story14	426574.2	150878.5	177672.9	171109.8	170493.8
Story15	417686	145781.7	173335.8	166431.4	165848.6
Story16	406009.6	139295.6	168519	161071.4	160464.1
Story17	389613.8	130573.8	162128.1	153921.4	153263
Story18	364289.1	117961.9	152353.9	143143.7	142415.4
Story19	319021.2	97785.72	134446.7	124172.2	123375.6
Story20	217388.2	60832.63	92279.67	82829.11	82118.2

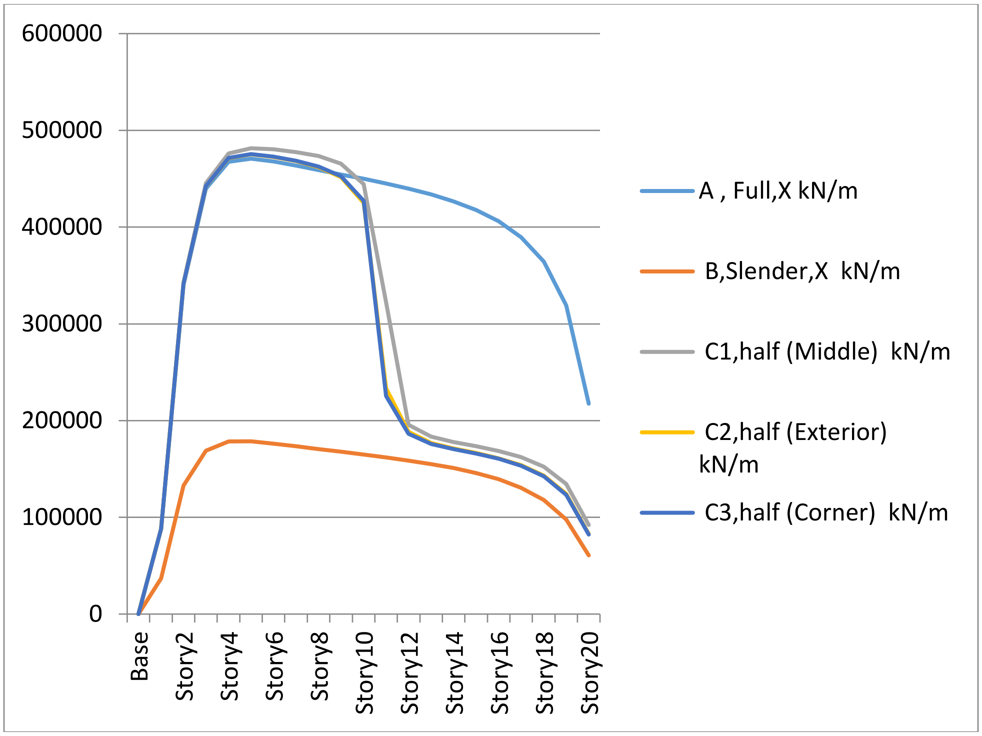


Fig. 5. Story stiffness considering earthquake load (Ex).

Table 3
Base shear of the building.

Item	Building				
	A	B	C1	C2	C3
Base shear (KN)	2653	1005	1828	1828	1828

Table 4
Base shear percentage of total load of the building.

Base shear percentage of total load					
Dead Load	69607.111	27252.87	48599.65	48599.65	48599.65
Live Load	19338.75	6961.95	13150.35	13150.35	13150.35
FF Load	9618.75	3462.75	6540.75	6540.75	6540.75
PW Load	29058.75	10461.15	19759.95	19759.95	19759.95
Total load	127623.36	48138.72	88050.7	88050.7	88050.7
Base shear percentage	2.08 %	2.09 %	2.08 %	2.08 %	2.08 %

Table 5
Floor wise displacement of building.

Building Name	Ground Floor	From floor 02 to floor 10	From floor 11 to top floor	Total displacement
A	35.5	113.9	44.7	149.4
B	32.4	118	48.6	150.4
C1	24.3	99.2	54.5	123.5
C2	24.5	102.5	55.4	127
C3	31.3	117	56.7	148.3

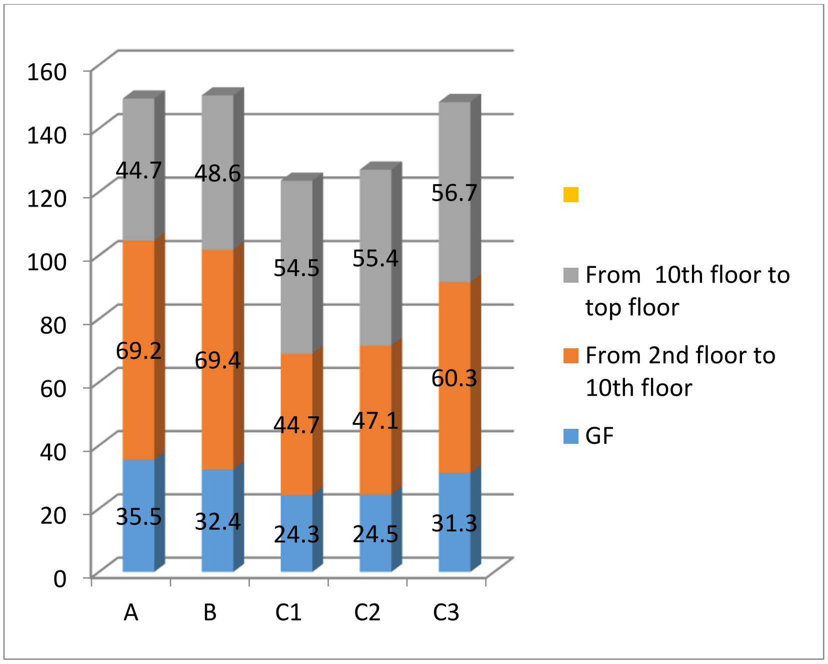


Fig. 6. Floor wise displacement of building.

5. Modal analysis results

Modal analysis is the study of structural dynamic characteristics to calculate natural frequency and vibration mode. Natural frequency can represent the overall stiffness. Lower natural frequency represents that the structure stiffness is less and structure is very soft, higher natural frequency represents structure stiffness is more and structure is very hard. From modal analysis the deformation trend of the structure under a certain natural frequency can be obtained [5]. Modal analysis can be performed based on Eigen or Ritz analysis.

For a building with a square floor plan, a central core, columns or walls along the perimeter, it is expected to get the first 02 modes as translational mode and 3rd mode is rotational mode [6].

Modal analysis result indicates the structural weakness and from this result the corrective measures can be taken accordingly. In some cases the first mode can be torsional modes due to some irregularity of the structural system that must be revised by the structural designer.

In this study the modal analysis is performed using Ritz analysis type. The mass participation ratios are attached in the Table 1.1B, 1.2B, 1.3B, 1.4B and 1.5B in the Appendix B. To attain equal to or more than 90% mass participation ratio the C2 type building requires 47 modes and B type building requires lowest 5 modes.

From the Table 07 it is figuring out that the first two modes are translational mode and the 3rd mode is rotational mode for all the building type. There is no dominating torsional mode in the 1st mode and hence the approach of the structural system involved is reasonable. For the building type C3 there is a notable amount of rotational contribution in the first mode for a time period value 2.74 sec.To avoid or limit rotational contribution in the first mode some structural system needs to be revised for a safer condition.

Table 6
First Time period obtained from modal analysis (Analysis approach 02).

Item Name	Building A	B	C1	C2	C3
Time period from modal analysis	3.478	3.429	2.651	2.744	2.852

Table 7
Modal Analysis Result for first 03 modes of the building.

Building	Time Period	Major Mass participation in the direction					Remarks
		Translational		Rotational			
		X	Y	X	Y	Z	
A	3.48	91%			8%		
	3.48		91%	8%			
	3.01					92%	
B	2.74	30%	61%	6%	3%		
	2.85	61%	30%	3%	6%		
	2.85			52%	30%		
C1	3.43	87%			10%		
	3.43		87%	10%			
	1.04					91%	
C2	2.65		80%	12%		9%	
	2.65	88%			10%		
	1.98					82%	
C3	2.74	36%	36%	7%	7%	17%	Its needs to strengthens some structural components to avoid rotation in the first mode
	2.67	44%	44%	5%	5%		
	1.97	8%	8%			74%	

6. Response spectrum analysis result

Response spectrum analysis is a method to estimate the structural response to short, nondeterministic, transient dynamic events. Examples of such events are earthquakes and shocks. Consider RSx and RSy as response spectrum load cases. Response spectrum analysis load combination is considered for this study is **0.9DL-1.43 (RSA x)**

In the response spectrum analysis result the building displacement is also lower for building C1.In the above Table 08 the story displacement both in the X and Y direction is obtained in the same time in response spectrum analysis. The static analysis gives higher values for maximum displacement especially in higher stories [7] which is also obtained in this study.

For building C3 the displacement in the orthogonal direction is around 60% of the principal direction. Generally less than or around one third (33%) is considered as the stable structural system. The building system of C3 is needed to be revised to attain a more stable condition. The displacement in the orthogonal direction in C1 building is less than 40% of the principal direction. In this point of view the building C1 is more stable than that of the other building model.

Table 8
Story displacement from Response spectrum analysis (Linear Dynamic analysis system,Analysis approach 03).

Story Displacement Result, Unit mm										
Considered load combination = 0.9DL-1.43 RSAx										
Story Name	A		B		C1		C2		C3	
	X	Y	X	Y	X	Y	X	Y	X	Y
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Story1	38.7	15.4	37.2	14.5	28.2	11.0	28.5	12.8	33.3	22.6
Story2	49.9	19.9	48.1	18.8	36.3	14.2	36.6	16.5	42.8	29.1
Story3	58.3	23.2	56.1	21.9	42.2	16.5	42.4	19.1	49.8	33.9
Story4	65.6	26.1	62.8	24.5	47.2	18.4	47.4	21.4	55.7	37.9
Story5	72.3	28.8	69.0	27.0	51.8	20.2	51.8	23.5	61.0	41.6
Story6	78.6	31.3	74.9	29.2	55.9	21.8	55.8	25.4	65.9	45.0
Story7	84.7	33.8	80.5	31.5	59.7	23.2	59.4	27.2	70.3	48.0
Story8	90.4	36.1	86.0	33.6	63.1	24.6	62.7	28.8	74.4	50.7
Story9	95.8	38.3	91.3	35.7	66.2	25.7	65.5	30.3	78.1	53.0
Story10	101.0	40.4	96.4	37.7	69.0	26.8	68.1	31.6	81.5	55.1
Story11	105.9	42.4	101.4	39.6	70.7	26.1	69.4	33.4	86.1	53.9
Story12	110.6	44.3	106.1	41.5	75.4	27.9	74.5	35.4	91.4	56.8
Story13	115.1	46.1	110.6	43.2	80.3	29.8	79.8	37.4	96.6	59.7
Story14	119.2	47.8	114.8	44.8	84.9	31.7	84.8	39.2	101.5	62.3
Story15	123.0	49.4	118.7	46.3	89.1	33.3	89.5	40.8	106.0	64.6
Story16	126.3	50.7	122.2	47.7	93.0	34.8	93.8	42.3	110.0	66.7
Story17	129.2	51.9	125.3	48.8	96.3	36.2	97.6	43.5	113.5	68.4
Story18	131.7	52.9	127.9	49.8	99.1	37.2	100.7	44.5	116.5	69.8
Story19	133.5	53.6	130.0	50.6	101.2	38.0	103.3	45.3	118.8	70.8
Story20	134.9	54.2	131.8	51.2	102.8	38.6	105.2	45.8	120.7	71.5

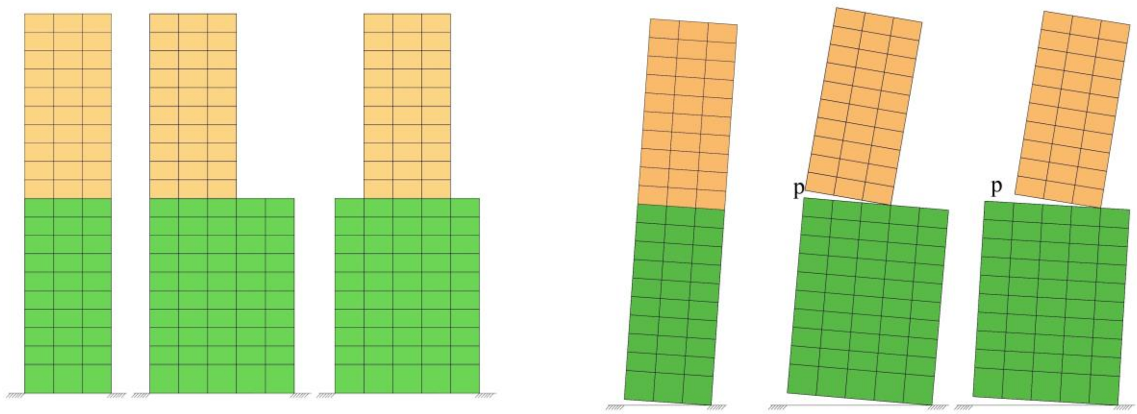
7. Result analyses and Comparison study

In the above Fig. 4 it can be seen that the story displacement pattern of the building A and B is quite same. The maximum displacement value is also nearest to each other.

For building C1 the overall story displacement is lower in every point. The building C1 shows comparatively more stable than that of the other two buildings C2 and C3. From the frequency point of view it can be obtained that the frequency of this building is more and the period is low. For his reason the displacement is low.

From the stiffness curve in Fig. 5 it is seen that there is a sudden drop in the stiffness values after 10 story for C type building. Sudden drop or sudden increase in the stiffness value means one part is weaker compared to other. In this case there is a possibility of tension crack in the exterior side of the column or shear failure in the vertical element (Here in column) may create a thrust in that area (The structural design of this area should be taken special care). There is also a lateral force develops due to the mass of the upper block with the as usual lateral force.

It can be assumed in another concept that the orange portion is worked as one single block and bottom portion is worked as another single block as like as below picture.



(a) (b)

Fig. 7. Probable displacement pattern of building.

The point P in Figure 07 (b) is the critical point in the view of vibration associated system. This is the point where there is a change of stiffness and displacement pattern and in the same time change of vibration characteristics. As consequences the frequency of lower part and upper part is different. That can be termed as local mode. The response of green portion and the response of orange portion is not same that is shown in the Figure 07 .

Differently it can be said that the mass is a dominating factor against side sway or any other displacement. The displacement of the building A is expected to a lower value than that of building B and C as the mass is increased and the height is constant. But from the analysis result the displacement is nearest to building B. The probable reason behind it is the frequency of the system which is related to stiffness of the building. There is a further scope of research work in these issues.

Actually in those cases for A building it would be expected the deflection can be small compared to the slender building B as the mass is increased and the stiffness is also increased. But in the real analysis we can see that the result is not same.

a) All the buildings are of same height but the displacement values are different. In this static analysis procedure the period is same for all the buildings. But practically structures of shorter period experience greater acceleration, whereas those of longer period experience greater displacement. For this criterion the time period used 1.91 sec is not applicable for all the cases. Dynamic analysis needs to be performed for more accurate results.

8. Research Output / application of this study

This study helps the structural engineer to observe the variation of displacement values for same height building depending on the size and shape of the building. The building model of C1 is more stable than that of other model as the energy distribution and load distribution is as like as pyramid shape. From the load transmission criterion it is known that the load distributes in a triangular shape as the load gradually coincides to the middle of the structure from the outer side of the structure from bottom to top. And for this reason the pyramid shaped loading arrangement adds some more stiffness of the building and for this reason the displacement value is lower and more stable arrangement. This concept is followed in most of the high-rise buildings to minimize the sway of the structure against any lateral loading. For a same height building if the width of top and bottom is equal then the stability of the building is less compared to the width less in the top. For this reason the displacement of the building C1 is lower than that of other two buildings. Generally the width of the base of the building is necessary to kept wider than that of top portion for high-rise structures.

This study demonstrates that the frequency of building does not related to height only. It is also related with the mass and stiffness of the system. The building architectural plan in the C1 type model where the floor area in the upper floors is less compared to the lower story shows significant changes in the displacement values which is related to the change in frequency and time period as well.

Theoretically the time period is more when the height is more. The displacement is more when the time period is more (Frequency is less). Building height is not the only factor for these characteristics. In this study shear wall system is not used as the scope is limited here. The authors have an intend to work for another study related to shear wall contribution to the frequency characteristics.

9. Conclusions

a) The mass and height of C1, C2 and C3 building is same. The section properties are also same (Column and beam dimensions).But the displacement is different. Form this study it is illustrated that the location of the upper ten stories is one of the factors for varying time period and varying displacement as a consequence. The building shape is also responsible for vibration characteristics of the building. The C1 building is more stable arrangement that is evaluated in this study.

b) The height of A and B building is same. The mass and base dimension of A is more than B.

Although the base dimension and mass of A building can limit the displacement criteria compared to building B but the displacement is quite same as per analysis. From the analysis it is shown that the more mass contribute more base shear. And for this reason the effect of mass cancel out each other and experiences approximately same displacement values.

c) From comparison study it is revealed that the displacement of C type building can be divided into three (03) parts. From base to Story 01 (Ground floor), story 02 to story 10 and story 11 to top. The first one is related to soft story mechanism that is not included in this study.

The other two types of displacement comparison evaluated that for the structure with vertical irregularity (C type building) the displacement can be occurred in a localized block. The displacement curve for C type building (Vertically irregular) is more steep after story 10 than that of the building A and B.

d) From the modal analysis result it is seen that the building C3 associated with time period 2.74 is the critical situation with coupled translational and rotational mode in the first mode. The structural system must be revised from the stability point of view. The time period of 1.91 second is not providing sufficient result in all cases.

e) From the Response spectrum analysis it is seen that every displacement is not purely occurs in one direction. The displacements have some contribution to the orthogonal direction as well. From the response spectrum analysis it is also shown that the orthogonal displacement of C3 building is the highest 60% of its displacement in the principle direction. The lowest 38% displacement is for orthogonal direction in case of C1 building. That means the stability of C1 building is better than the other building system which is the major target and findings of this study.

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Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Eleftheriadou AK, Karabinis AI, Baltzopoulou AD. Fundamental period versus seismic damage for reinforced concrete buildings. Proc. 15th World Conf. Earthq. Eng. Lisboa, 2012.

[2] Patel SK, Desai AN, Patel VB. Effect of Number of Storeys To Natural Time Period of Building. Natl. Conf. Recent Trends Eng. Technol., 2011, p. 13–5.

[3] Siddika A, Awall M, Mamun M, Al A, Humyra T. Study on natural frequency of frame structures. Comput Eng Phys Model 2019;2:36–48.

[4] Bhuskade SR, Sagane SC. Effects of various parameters of building on natural time period. Int J Eng Res Technol 2017;6:181–2278.

[5] Ji D, Li L. Modal analysis of frame structure teaching building. 2014 Int. Conf. Mechatronics, Electron. Ind. Control Eng., Atlantis Press; 2014, p. 1724–7.

[6] Edskär I. Modal analysis, dynamic properties and horizontal stabilisation of timber buildings 2019.

[7] Alghuff AY, Shihada SM, Tayeh BA. Comparative study of static and response spectrum methods for seismic analysis of regular RC buildings. J Appl Sci 2019;19.

Appendix A

Column size = 600 X 600 mm
Beam size = 350 X 450 mm
Slab thickness = 150 mm
Bottom story = 5000 mm, other story = 3000 mm
28 day Concrete compressive strength, f'_c = 20 Mpa
Yield strength of steel, f_y= 415 Mpa
Live Load, LL= 1.9 KN/m^2
Floor Finish, FF = 0.95 KN/m^2
Partition Wall, PW = 2.87 KN/m^2

Appendix B

A Building

TABLE 1.1B: Modal Participating Mass Ratios (Case-Modal)

Mode	Period	UX	UY	UZ	Sum UX	Sum UY	Sum UZ	RX	RY	RZ	SumRX	SumRY	SumRZ
	sec												
1	3.478	0.91	0.00	0.00	0.91	0.00	0.00	0.00	0.08	0.00	0.00	0.08	0.00
2	3.478	0.00	0.91	0.00	0.92	0.92	0.00	0.08	0.00	0.00	0.08	0.08	0.00
3	3.006	0.00	0.00	0.00	0.92	0.92	0.00	0.00	0.00	0.92	0.08	0.08	0.92
4	1.075	0.06	0.00	0.00	0.98	0.92	0.00	0.00	0.73	0.00	0.08	0.81	0.92
5	1.075	0.00	0.06	0.00	0.98	0.98	0.00	0.73	0.00	0.00	0.81	0.81	0.92
6	0.925	0.00	0.00	0.00	0.98	0.98	0.00	0.00	0.00	0.06	0.81	0.81	0.98
7	0.583	0.01	0.00	0.00	0.99	0.98	0.00	0.00	0.03	0.00	0.81	0.84	0.98
8	0.583	0.00	0.01	0.00	0.99	0.99	0.00	0.03	0.00	0.00	0.84	0.84	0.98
9	0.39	0.00	0.00	0.00	1.00	0.99	0.00	0.00	0.03	0.00	0.84	0.87	0.98
10	0.39	0.00	0.00	0.00	1.00	1.00	0.00	0.03	0.00	0.00	0.87	0.87	0.98
11	0.284	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.87	0.87	0.98
12	0.284	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.87	0.87	0.98
13	0.219	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.01	0.00	0.87	0.88	0.98
14	0.219	0.00	0.00	0.00	1.00	1.00	0.00	0.01	0.00	0.00	0.88	0.88	0.98
15	0.209	0.00	0.00	0.78	1.00	1.00	0.78	0.00	0.00	0.00	0.88	0.88	0.98
16	0.174	0.00	0.00	0.00	1.00	1.00	0.78	0.00	0.00	0.00	0.88	0.88	0.98
17	0.174	0.00	0.00	0.00	1.00	1.00	0.78	0.00	0.00	0.00	0.88	0.88	0.98
18	0.15	0.00	0.00	0.06	1.00	1.00	0.84	0.00	0.00	0.00	0.88	0.88	0.98
19	0.14	0.00	0.00	0.00	1.00	1.00	0.84	0.00	0.01	0.00	0.88	0.90	0.98
20	0.14	0.00	0.00	0.00	1.00	1.00	0.84	0.01	0.00	0.00	0.90	0.90	0.98
21	0.116	0.00	0.00	0.00	1.00	1.00	0.84	0.00	0.00	0.00	0.90	0.90	0.98
22	0.104	0.00	0.00	0.00	1.00	1.00	0.84	0.00	0.00	0.00	0.90	0.90	0.98
23	0.104	0.00	0.00	0.00	1.00	1.00	0.84	0.00	0.00	0.00	0.90	0.90	0.98
24	0.1	0.00	0.00	0.01	1.00	1.00	0.85	0.00	0.00	0.00	0.90	0.90	0.98
25	0.083	0.00	0.00	0.07	1.00	1.00	0.92	0.00	0.00	0.00	0.90	0.90	0.98
26	0.065	0.00	0.00	0.00	1.00	1.00	0.92	0.01	0.00	0.00	0.90	0.90	0.98
27	0.065	0.00	0.00	0.00	1.00	1.00	0.92	0.00	0.01	0.00	0.90	0.90	0.98
28	0.064	0.00	0.00	0.04	1.00	1.00	0.96	0.00	0.00	0.00	0.90	0.90	0.98
29	0.05	0.00	0.00	0.02	1.00	1.00	0.97	0.00	0.00	0.00	0.90	0.90	0.98
30	0.025	0.00	0.00	0.02	1.00	1.00	1.00	0.00	0.00	0.00	0.90	0.90	0.98

B building

TABLE 1.2 B : Modal Participating Mass Ratios(Case-Modal)

Mode	Period	UX	UY	UZ	Sum UX	Sum UY	Sum UZ	RX	RY	RZ	SumRX	SumRY	SumRZ
	sec												
1	3.429	0.30	0.61	0.00	0.30	0.61	0.00	0.06	0.03	0.00	0.06	0.03	0.00
2	3.429	0.61	0.30	0.00	0.91	0.91	0.00	0.03	0.06	0.00	0.10	0.10	0.00
3	1.044	0.03	0.05	0.00	0.93	0.96	0.00	0.52	0.30	0.00	0.62	0.39	0.00
4	1.044	0.05	0.03	0.00	0.99	0.99	0.00	0.30	0.52	0.00	0.91	0.91	0.00
5	0.19	0.00	0.00	0.86	0.99	0.99	0.86	0.00	0.00	0.00	0.91	0.91	0.00

C1 building

TABLE 1.3 B : Modal Participating Mass Ratios(Case-Modal)

Mode	Period	UX	UY	UZ	Sum UX	Sum UY	Sum UZ	RX	RY	RZ	SumRX	SumRY	SumRZ
	sec												
1	2.651	0.88	0.02	0.00	0.88	0.02	0.00	0.00	0.10	0.00	0.00	0.10	0.00
2	2.651	0.02	0.88	0.00	0.89	0.89	0.00	0.10	0.00	0.00	0.10	0.10	0.00
3	1.977	0.00	0.00	0.00	0.89	0.89	0.00	0.00	0.00	0.92	0.10	0.10	0.92
4	1.151	0.08	0.00	0.00	0.97	0.89	0.00	0.01	0.61	0.00	0.11	0.71	0.92
5	1.151	0.00	0.08	0.00	0.97	0.97	0.00	0.61	0.01	0.00	0.72	0.72	0.92
6	0.975	0.00	0.00	0.00	0.97	0.97	0.00	0.00	0.00	0.05	0.72	0.72	0.96
7	0.569	0.02	0.00	0.00	0.99	0.97	0.00	0.00	0.11	0.00	0.72	0.83	0.96
8	0.569	0.00	0.02	0.00	0.99	0.99	0.00	0.11	0.00	0.00	0.83	0.83	0.96
9	0.391	0.00	0.00	0.00	0.99	0.99	0.00	0.00	0.03	0.00	0.83	0.86	0.96
10	0.391	0.00	0.00	0.00	0.99	0.99	0.00	0.03	0.00	0.00	0.86	0.86	0.96
11	0.278	0.00	0.00	0.00	1.00	0.99	0.00	0.00	0.00	0.00	0.87	0.87	0.96
12	0.278	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.87	0.87	0.96
13	0.216	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.01	0.00	0.87	0.87	0.96
14	0.216	0.00	0.00	0.00	1.00	1.00	0.00	0.01	0.00	0.00	0.88	0.88	0.96
15	0.193	0.00	0.00	0.59	1.00	1.00	0.59	0.00	0.00	0.00	0.88	0.88	0.96
16	0.172	0.00	0.00	0.00	1.00	1.00	0.59	0.00	0.00	0.00	0.88	0.88	0.96
17	0.172	0.00	0.00	0.00	1.00	1.00	0.59	0.00	0.00	0.00	0.88	0.88	0.96
18	0.143	0.00	0.00	0.00	1.00	1.00	0.59	0.00	0.01	0.00	0.88	0.89	0.96
19	0.142	0.00	0.00	0.00	1.00	1.00	0.59	0.01	0.00	0.00	0.89	0.89	0.96
20	0.117	0.00	0.00	0.13	1.00	1.00	0.72	0.00	0.00	0.00	0.89	0.89	0.96
21	0.117	0.00	0.00	0.00	1.00	1.00	0.72	0.00	0.00	0.00	0.89	0.89	0.96
22	0.117	0.00	0.00	0.00	1.00	1.00	0.72	0.00	0.00	0.00	0.89	0.89	0.96
23	0.088	0.00	0.00	0.06	1.00	1.00	0.78	0.00	0.00	0.00	0.89	0.89	0.96
24	0.086	0.00	0.00	0.00	1.00	1.00	0.78	0.01	0.00	0.00	0.90	0.89	0.96
25	0.086	0.00	0.00	0.00	1.00	1.00	0.78	0.00	0.01	0.00	0.90	0.90	0.96
26	0.084	0.00	0.00	0.12	1.00	1.00	0.90	0.00	0.00	0.00	0.90	0.90	0.96
27	0.066	0.00	0.00	0.02	1.00	1.00	0.92	0.00	0.00	0.00	0.90	0.90	0.96
28	0.057	0.00	0.00	0.04	1.00	1.00	0.96	0.00	0.00	0.00	0.90	0.90	0.96
29	0.056	0.00	0.00	0.00	1.00	1.00	0.96	0.00	0.00	0.00	0.90	0.90	0.96
30	0.056	0.00	0.00	0.00	1.00	1.00	0.96	0.00	0.00	0.00	0.90	0.90	0.96
31	0.037	0.00	0.00	0.01	1.00	1.00	0.97	0.00	0.00	0.00	0.90	0.90	0.96
32	0.021	0.00	0.00	0.02	1.00	1.00	1.00	0.00	0.00	0.00	0.90	0.90	0.96

C2 building

TABLE 1.4 B : Modal Participating Mass Ratios(Case-Modal)

Mode	Period	UX	UY	UZ	Sum UX	Sum UY	Sum UZ	RX	RY	RZ	SumRX	SumRY	SumRZ
	sec												
1	2.744	0.00	0.80	0.00	0.00	0.80	0.00	0.13	0.00	0.10	0.13	0.00	0.10
2	2.666	0.89	0.00	0.00	0.89	0.80	0.00	0.00	0.11	0.00	0.13	0.11	0.10
3	1.974	0.00	0.10	0.00	0.89	0.90	0.00	0.01	0.00	0.82	0.14	0.11	0.92
4	1.16	0.08	0.00	0.00	0.97	0.90	0.00	0.00	0.60	0.00	0.14	0.71	0.92
5	1.14	0.00	0.07	0.00	0.97	0.97	0.00	0.57	0.00	0.00	0.70	0.71	0.92
6	0.973	0.00	0.00	0.00	0.97	0.97	0.00	0.01	0.00	0.05	0.72	0.71	0.97
7	0.571	0.00	0.02	0.00	0.97	0.99	0.00	0.11	0.00	0.00	0.82	0.71	0.97
8	0.565	0.02	0.00	0.00	0.99	0.99	0.00	0.00	0.11	0.00	0.82	0.82	0.97
9	0.486	0.00	0.00	0.00	0.99	0.99	0.00	0.01	0.00	0.02	0.84	0.82	0.99
10	0.392	0.00	0.00	0.00	0.99	0.99	0.00	0.00	0.03	0.00	0.84	0.85	0.99
11	0.388	0.00	0.00	0.00	0.99	0.99	0.00	0.03	0.00	0.00	0.86	0.85	0.99
12	0.328	0.00	0.00	0.00	0.99	0.99	0.00	0.00	0.00	0.00	0.86	0.85	0.99
13	0.278	0.00	0.00	0.00	0.99	1.00	0.00	0.01	0.00	0.00	0.87	0.85	0.99
14	0.278	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.87	0.86	0.99
15	0.245	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.87	0.86	1.00
16	0.217	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.01	0.00	0.87	0.86	1.00

17	0.214	0.00	0.00	0.00	1.00	1.00	0.00	0.01	0.00	0.00	0.88	0.86	1.00
18	0.193	0.00	0.00	0.55	1.00	1.00	0.55	0.00	0.01	0.00	0.88	0.88	1.00
19	0.172	0.00	0.00	0.00	1.00	1.00	0.55	0.00	0.00	0.00	0.88	0.88	1.00
20	0.171	0.00	0.00	0.00	1.00	1.00	0.55	0.00	0.00	0.00	0.88	0.88	1.00
21	0.152	0.00	0.00	0.00	1.00	1.00	0.56	0.00	0.03	0.00	0.88	0.91	1.00
22	0.148	0.00	0.00	0.00	1.00	1.00	0.56	0.02	0.00	0.00	0.90	0.91	1.00
23	0.139	0.00	0.00	0.00	1.00	1.00	0.56	0.00	0.00	0.00	0.90	0.91	1.00
24	0.127	0.00	0.00	0.00	1.00	1.00	0.56	0.00	0.00	0.00	0.90	0.91	1.00
25	0.116	0.00	0.00	0.12	1.00	1.00	0.68	0.00	0.00	0.00	0.90	0.91	1.00
26	0.116	0.00	0.00	0.03	1.00	1.00	0.71	0.00	0.00	0.00	0.90	0.92	1.00
27	0.114	0.00	0.00	0.01	1.00	1.00	0.72	0.00	0.01	0.00	0.90	0.92	1.00
28	0.107	0.00	0.00	0.00	1.00	1.00	0.72	0.00	0.00	0.00	0.90	0.92	1.00
29	0.104	0.00	0.00	0.06	1.00	1.00	0.78	0.00	0.04	0.00	0.90	0.96	1.00
30	0.098	0.00	0.00	0.00	1.00	1.00	0.78	0.00	0.00	0.00	0.90	0.96	1.00
31	0.097	0.00	0.00	0.00	1.00	1.00	0.78	0.00	0.00	0.00	0.90	0.96	1.00
32	0.091	0.00	0.00	0.02	1.00	1.00	0.80	0.00	0.00	0.00	0.90	0.96	1.00
33	0.084	0.00	0.00	0.00	1.00	1.00	0.80	0.00	0.00	0.00	0.90	0.96	1.00
34	0.083	0.00	0.00	0.08	1.00	1.00	0.88	0.00	0.00	0.00	0.90	0.97	1.00
35	0.078	0.00	0.00	0.00	1.00	1.00	0.89	0.00	0.00	0.00	0.90	0.97	1.00
36	0.077	0.00	0.00	0.00	1.00	1.00	0.89	0.00	0.00	0.00	0.90	0.97	1.00
37	0.071	0.00	0.00	0.00	1.00	1.00	0.89	0.00	0.00	0.00	0.90	0.97	1.00
38	0.064	0.00	0.00	0.02	1.00	1.00	0.92	0.00	0.00	0.00	0.90	0.97	1.00
39	0.062	0.00	0.00	0.01	1.00	1.00	0.93	0.00	0.00	0.00	0.90	0.97	1.00
40	0.056	0.00	0.00	0.03	1.00	1.00	0.96	0.00	0.00	0.00	0.90	0.97	1.00
41	0.052	0.00	0.00	0.00	1.00	1.00	0.96	0.00	0.00	0.00	0.90	0.97	1.00
42	0.05	0.00	0.00	0.00	1.00	1.00	0.96	0.00	0.00	0.00	0.90	0.97	1.00
43	0.041	0.00	0.00	0.01	1.00	1.00	0.96	0.00	0.00	0.00	0.90	0.97	1.00
44	0.038	0.00	0.00	0.00	1.00	1.00	0.97	0.00	0.00	0.00	0.90	0.97	1.00
45	0.027	0.00	0.00	0.02	1.00	1.00	0.98	0.00	0.00	0.00	0.90	0.97	1.00
46	0.017	0.00	0.00	0.00	1.00	1.00	0.99	0.00	0.00	0.00	0.90	0.97	1.00
47	0.015	0.00	0.00	0.01	1.00	1.00	1.00	0.00	0.00	0.00	0.90	0.97	1.00

C3 building

TABLE 1.5 B : Modal Participating Mass Ratios(Case-Modal)

Mode	Period	UX	UY	UZ	Sum UX	Sum UY	Sum UZ	RX	RY	RZ	SumRX	SumRY	SumRZ
	sec												
1	2.852	0.36	0.36	0.00	0.36	0.36	0.00	0.08	0.08	0.17	0.08	0.08	0.17
2	2.666	0.44	0.44	0.00	0.81	0.81	0.00	0.05	0.05	0.00	0.13	0.13	0.17
3	1.972	0.09	0.09	0.00	0.90	0.90	0.00	0.01	0.01	0.75	0.14	0.14	0.92
4	1.161	0.04	0.04	0.00	0.94	0.94	0.00	0.30	0.30	0.00	0.44	0.44	0.92
5	1.138	0.03	0.03	0.00	0.97	0.97	0.00	0.26	0.26	0.00	0.70	0.70	0.92
6	0.967	0.00	0.00	0.00	0.97	0.97	0.00	0.01	0.01	0.05	0.71	0.71	0.97
7	0.566	0.01	0.01	0.00	0.98	0.98	0.00	0.06	0.06	0.00	0.76	0.76	0.97
8	0.561	0.01	0.01	0.00	0.99	0.99	0.00	0.06	0.06	0.00	0.82	0.82	0.97
9	0.392	0.00	0.00	0.00	0.99	0.99	0.00	0.02	0.02	0.00	0.84	0.84	0.97
10	0.302	0.00	0.00	0.00	1.00	1.00	0.00	0.02	0.02	0.00	0.86	0.86	0.97
11	0.277	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.86	0.86	0.97
12	0.199	0.00	0.00	0.00	1.00	1.00	0.00	0.01	0.01	0.00	0.87	0.87	0.97
13	0.193	0.00	0.00	0.52	1.00	1.00	0.52	0.01	0.01	0.00	0.88	0.88	0.97
14	0.15	0.00	0.00	0.00	1.00	1.00	0.53	0.00	0.00	0.00	0.88	0.88	0.97
15	0.117	0.00	0.00	0.20	1.00	1.00	0.73	0.02	0.02	0.00	0.90	0.90	0.97
16	0.104	0.00	0.00	0.10	1.00	1.00	0.83	0.00	0.00	0.00	0.90	0.90	0.97
17	0.068	0.00	0.00	0.14	1.00	1.00	0.97	0.00	0.00	0.00	0.90	0.90	0.97