RESEARCH ARTICLE OPEN ACCESS

Parametric Study of Factors Influencing Mode Shape of Oscillation

Harish A. Kadam*, Rahulkumar R. Sharma**
**M.Tech.* (Structural Engineering) *Student, M.G.M.'s C.O.E, Nanded, Maharashtra, India,*
***Assistant Professor, M.G.M.'s C.O.E, Nanded, Maharashtra, India,*

ABSTRACT
The mode shape of oscillation associated with a natural period of building is the deformed shape of the building when shaken at the natural period. Hence, a building has as many mode shapes as the number of natural periods. The deformed shape of the building associated with oscillation at the fundamental natural period is termed its first mode shape or fundamental mode shape of the building. In this study, an attempt is done to understand the various parameters which affect the fundamental mode shape of RC building. The parametric study is done as per the provision of Equivalent Static Lateral Force Method; IS1893 (Part-1): 2002. In this present work, a reinforced concrete special moment resisting frame building models are prepared and analyzed in ETAB software to evaluate the effect of stiffness of structural elements, the effect of degree of fixity at member ends, the effect of building height, and the effect of unreinforced masonry on fundamental mode shape of buildings.
Normalization-scaling technique is used in which data points are shifted and rescaled so that they end up in a range of 0 to 1. Building height and Storey Lateral Displacement are normalized in a range of 0 to 1.
To calculate the Normalized mode shape, the maximum lateral displacement of the top story is considered as 1 and the remaining story displacement is calculated in proportion to 1. Similarly, the total building height is considered as 1 from the base and the remaining floor height is calculated in proportion to 1.
Keywords – Equivalent static method, Mode Shape, Infill panel, , Flexural Stiffness

---

Date of Submission: 15-07-2022 Date of Acceptance: 29-07-2022

I. INTRODUCTION

A mode shape is a deflection pattern related to a particular natural frequency and represents the relative displacement of all parts of a structure for that particular mode. Buildings oscillate during earthquake shaking. The important dynamic characteristics of buildings are modes of oscillation and damping. Mode Shapes of Buildings depend on Overall Geometry of Building, Geometric & Material Properties of Structural Members, and Connections between the Structural Members and the Ground at the Base of the Building.

1.1 Mode Shape

Mode shape of oscillation associated with a natural period of a building is the deformed shape of the building when shaken at the natural period. Each node is free to translate in all the three Cartesian directions and rotate about the three Cartesian axes. Hence, a building has as many mode shapes as the number of natural periods. For a building, there are infinite numbers of natural period. But, in the mathematical modeling of building, usually the building is discretized into a number of elements Regular buildings have these pure mode shapes. Each node is free to translate in all the three Cartesian directions and rotate about the three Cartesian axes
Irregular buildings (i.e., buildings that have

Irregular geometry, non- uniform distribution of mass and stiffness in plan and along the height) have mode shapes that are a mixture of these pure mode shapes.

1.2 Fundamental Mode Shape of Oscillation

There are three basic modes of oscillation, namely, pure translational along **X-direction**, pure translational along **Y-direction** and pure rotation about **Z-axis (**Fig 1.1). Regular buildings have these pure mode shapes.

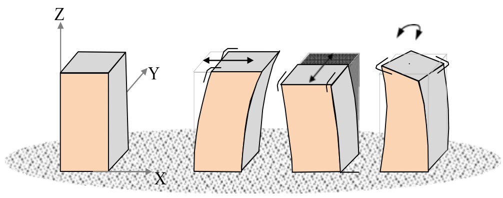


Figure 1.1: Basic modes of oscillation: Two

translational and one rotational mode shapes

Irregular buildings (i.e., buildings that have irregular geometry, non- uniform distribution of mass and stiffness in plan and along the height) have mode shapes that are a mixture of these pure mode shapes. Each of these mode shapes is independent, implying, it cannot be obtained by combining any or all of the other mode shapes.

The overall response of a building is the sum of the responses of all of its modes. The contributions of different modes of oscillation vary; usually, contributions of some modes dominate. It is important to endeavor to make buildings regular to the extent possible. But, in regular buildings too, care should be taken to locate and size the structural elements such that torsional and mixed modes of oscillation do not participate much in the overall oscillatory motion of the building.

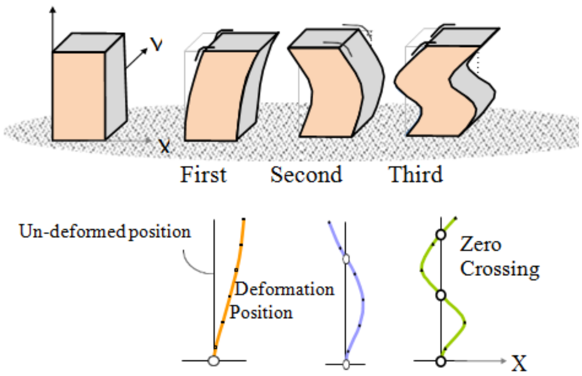


Figure 1.2: Fundamental and two higher translational modes of oscillation along X-direction: First modes shape has one zero crossing of the un-deformed position, second two, and third three

One way of avoiding torsional modes to be the early modes of oscillation in buildings is increasing the torsional stiffness of building. This is achieved by adding in-plane stiffness in the vertical plane in select bays along the perimeter of the building; this addition of stiffness should be done along both plan directions of the building, such that the building has no stiffness eccentricity. Adding braces or introducing structural walls in select bays are some common ways in which this is done.

Also, there are a number of possibilities in which buildings can oscillate along each direction of oscillation. Consider a building oscillating along the X-axis. It offers least resistance to motion while oscillating in its fundamental mode, and increased resistance to oscillation in the higher modes (second, third, and so on). A special situation arises in buildings that are perfectly symmetric in mass and stiffness distribution in both plan and elevation, say square in plan. Some fundamental or early modes of oscillation are along the diagonal direction (Figure:1.2)and not along the sides of the building (i.e., along X- or Y-directions).

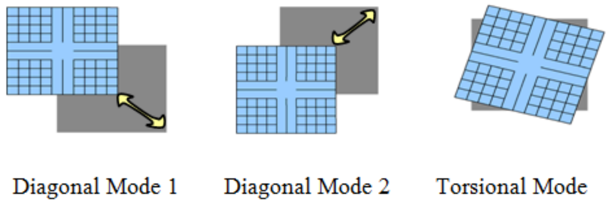


Figure 1.3: Diagonal modes of oscillation: First three modes of oscillation of a building symmetric in both directions in plan; first and second are diagonal translational modes and third rotational

Generally, in such cases, the torsional mode is also an early mode of oscillation. In such buildings, columns undergo bending about axes oriented along their diagonal. But rectangular columns have least resistance along their diagonal directions. Hence, their corners of the columns are severely damaged under this type of oscillation of buildings (Figure 1.4) This situation can be avoided by ensuring that the building (1) does not having the same structural configuration about BOTH plan axes (X and Y) passing through the center of mass, AND (2) is symmetric about each of the two plan axes (X and Y) individually passingthrough the center of mass

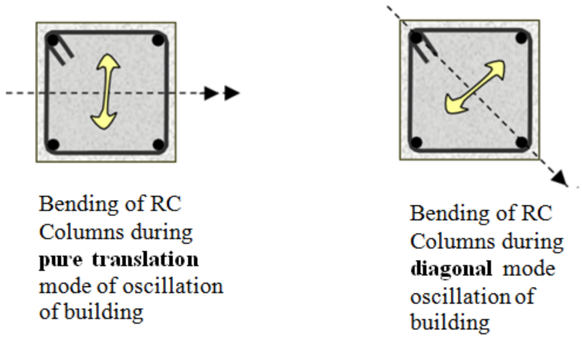


Figure 1.4.: Effect of modes of oscillation on column bending: Columns are severely damaged whilebending about their diagonal direction.

1.3 Objectives of this work:

The objective of parametric study is to examine the factors affecting the fundamental Mode shape.

- Evaluate Effect of Degree of Fixity at Member Ends
- Evaluate of effect of Flexural Stiffness of Structural Elements

- Evaluate effect of Building Height
- Evaluate effect of Unreinforced Masonry infill walls in RC frames

II. METHODOLOGY

The equivalent static lateral load method is used to determine earthquake load on building along X-direction and Y-direction. The base shear is the horizontal force acting on the structure and is calculated on the basis of structure mass (seismic weight), fundamental period of vibration and types of soil, importance factor and response reduction factor. The following steps involved in calculating base shear i.e. lateral force acting on building.
Step 1: calculation of lumped masses to various floor level
Step 2: Determination of fundamental natural period.
Step 3: Determination of Base Shear
Step 4: Vertical Distribution of Base Shear

III. PROBLEM FORMULATION

The Special RC moment resistant frame building models used to illustrate the different factors affecting the fundamental Mode shape of building. The following parameters were considered to analyze the special RC moment resistant frame building models. One of these building, namely a five storey building, is chosen basis, and is hereinafter called Benchmark Building. It bare frame with a plinth beam (and on slab) at ground floor level. The details of this benchmark building (Figure3.1) are as follows:

➢ **Thickness of slab**:
- 150mm thick

➢ **Material properties**:
- Grade of Concrete: M25
- Grade of steel Reinforcement bars: HYSD 500

➢ **Loading:**
- Dead load on beams from infill wall: 12 kN/m

(Density of Masonry block, $\rho =$ 19 kN/m^2)
- Floor finish load on floor = 1.5 kN/m^2
- Live load on Floors: 2 kN/m^2

➢ **Seismic Consideration:**
- Seismic Zone –V (Zone Factor, Z=0.36)
- Soil Type –II (Medium Soil)
- Importance Factor -1 (Residential Building)
- Response reduction Factor = 5 (special RC moment resistance frame)

➢ **Load Combinations**

In the limit state design of reinforced concrete structures the following load Combinations shall be accounted for:

Table 3.1: Load Combinations
(Clause 6.3.1.2, IS: 1893-2002, part 1)

Load Case No:	Load Combination
1	0.9DL ± 1.5EQX
2	0.9DL ± 1.5EQY
3	1.2(DL+LL±EQX)
4	1.2(DL+LL±EQY)
5	1.5 (DL+LL)
6	1.5 (DL ± EQX)
7	1.5 (DL ± EQY)

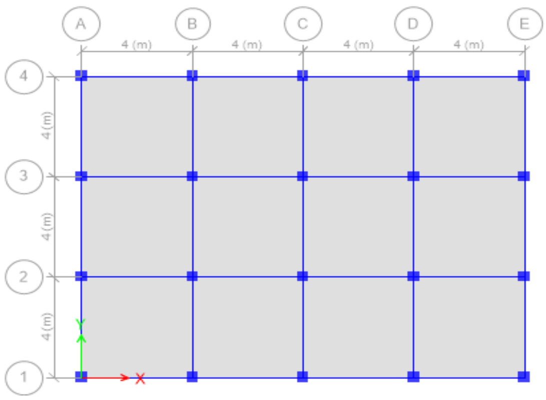


Fig. 3.1 Plan of building

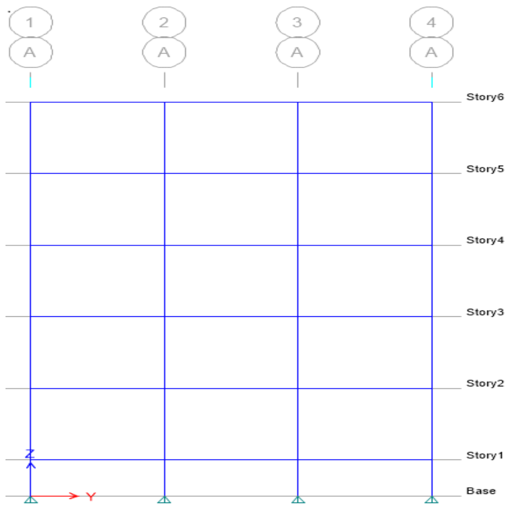


Fig 3.2 Elevation

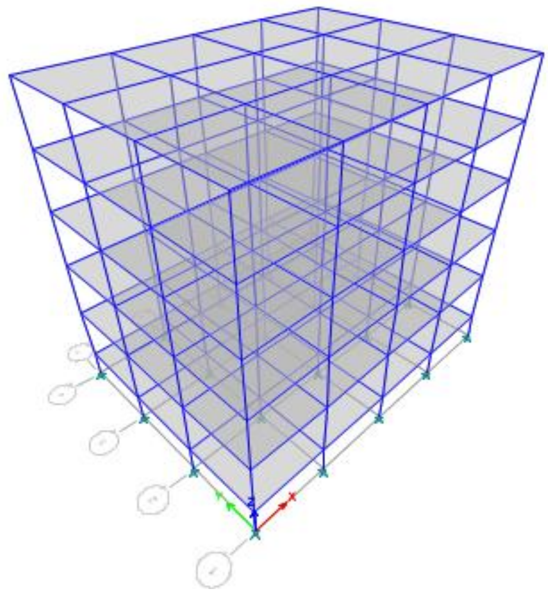


Fig. 3D Model

Table 3.2: Buildings Models considered

Building Model /Frame No:	**Factors affecting Fundamental Mode Shape of Building**	**No.of Storeys**	**Number ofBays**		**Column Dimension in (mm×mm)**	**Changed parameter**
			X- Direction	Y- Direction		
A	**Flexural Stiffness**	5	4	3	550x 600	Beam 230x230
B		5	4	3	400x400	Beam 300x400
C		5	4	3	230x230	Beam 450x550
D	**Degree of fixity**	5	4	3	400x400	Fixed Column Base,
E		5	4	3	400x400	Hinged Column Base
F	**Building Height**	5	4	3	400x400	5-Storey Building
G		25	4	3	800x800	25- Storey Building
H		40	4	3	1000x1000	40-Storey Building

I	**Unreinforced masonry infill wall**	5	4	3	400x400	without URM Infill
J		5	4	3	400x400	with Soft storey URM Infill
K		5	4	3	400x400	All URM Infill

1. Bay length in each plan direction is 4m (Centre toCentre).
2. All columns at each storey are of the same size.
3. As per this above table, these are the 11 types ofbuildings.
4. In above table, wherever beam size is not mentioned assume it as (300 mm x400 mm)

IV. RESULT ANALYSIS

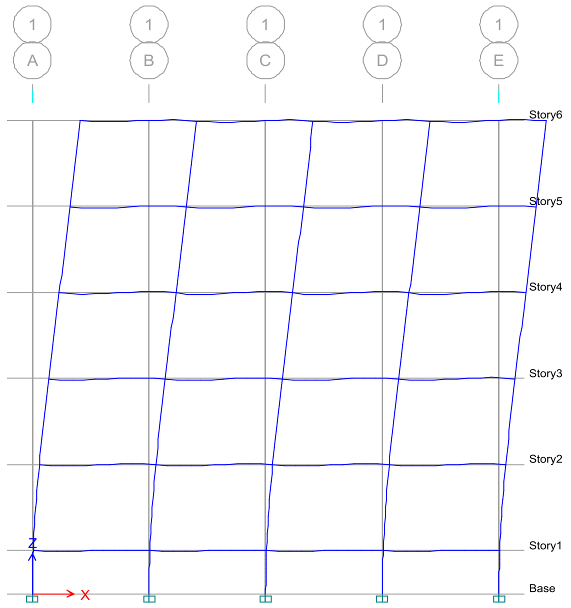
4.1. Effect of Flexural Stiffness of Structural Elements.

The overall lateral translational mode shapes depend on flexural stiffness of beams relative to that of adjoining columns. The fundamental mode shape of buildings changes from flexural-type to shear-type as beam flexural stiffness increases relative to that of column (Figure 4.1). On one hand, in pure flexural response (when flexural stiffness of beams is small compared to that of the adjoining columns), column deformation is predominantly in single curvature bending leading to overall flexure-type deformation behaviour of (the cantilever) building (Model A). And, on the other hand, in pure shear-type deformation behaviour (when flexural stiffness of beams is large compared to that of the adjoining columns), column deformation is predominantly in double curvature bending within in each storey leading to overall shear-type deformation behaviour of building (Model B). But, increasing the flexural stiffness of a beam also increases its strength; this is not desirable when strengths of beams exceed that of columns into which they frame in, especially when beam strengths exceed those of the columns adjoining.

Often in low-rise and mid-rise buildings that are designed as per codes, the relative stiffness of frame members lies in between the above two extreme cases. With the usual finite ratio of beam to column flexural stiffness, both beams and columns bend in double curvature and the response is almost of shear type (Model C). Thus, often, real buildings are idealized as shear buildings in structural analysis.

Table 4.1: Effect of Flexural Stiffness on Story Displacement

Max Lateral Displacement of Building and Natural Time period in X-direction					
Model-A		Model-B		Model-C	
Displace-ment (mm)	Time period (s)	Displace-ment (mm)	Time period (s)	Displaceme nt (mm)	Time period (s)
40.60	0.97	28.39	0.79	46.07	1.311



A)
Fig 4.1 (a) Elevation of Building Model-A
Column Size:-**550x600**, Beam Size:- **230x230**

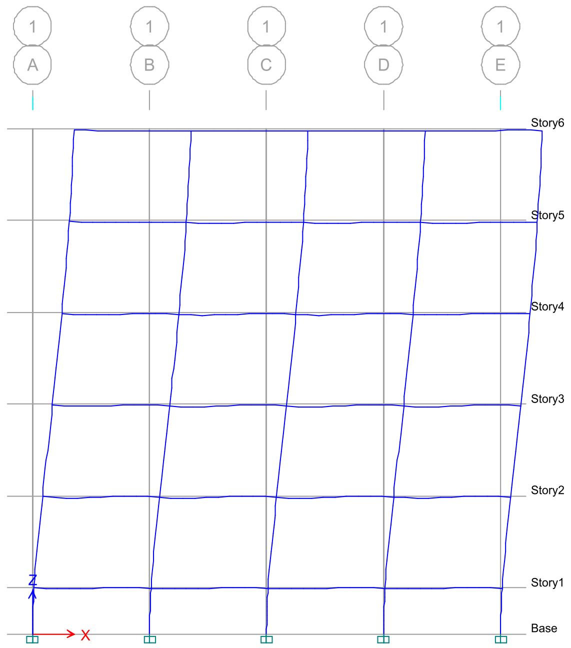


Fig 4.1 (b) Elevation of building Model-B
(Column Size:-**400x400**, Beam Size:- **300x400**)

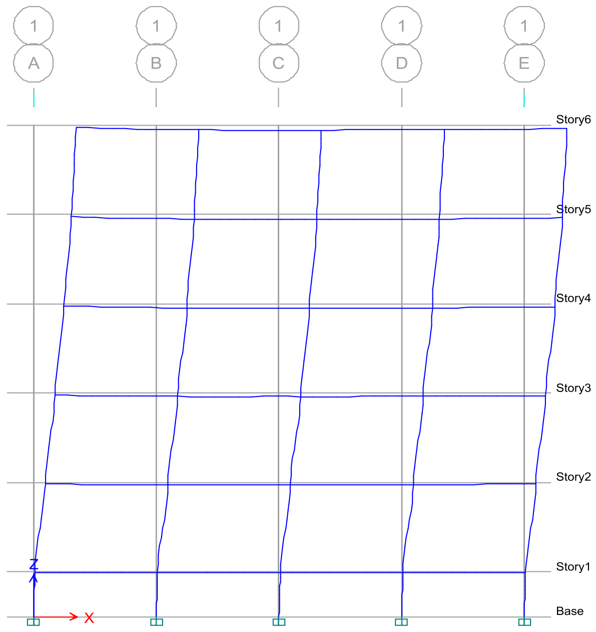


Fig 4.1 (c) Elevation of Building Model
(Column Size:-**230x230**, Beam Size:- **450x550)**

From Figure 4.1 (a, b, c), it is observed that the Fundamental translational mode shape changes from flexural-type to shear-type with increase in beam flexural stiffness relativeto that of column

4.2 Effect of Degree of Fixity at member Ends

Two conditions determine the rotational flexibility of columns at the base of the building. The first condition is when the structural design and detailing deliberately creates rotational flexibility at those locations. And, the second is when the flexibility of soil underneath the footings of columns allows rotation of the columns; this happens when individual footings are used.

Highly flexible soils make column bases as good as hinged, and rocky layers below as good as fixed. The extent of fixity at column bases controls overall behaviour of buildings (Figure 4.2). Lack of rotational fixity at column base (hinged condition) increases the lateral sway in the lower storeys than in higher storeys, and the overall response of the building is more of shear-type (Model D). On the other hand, full rotational fixity at column base restricts the lateral sway at the first storey and thus, induces initial flexural behaviour near the base (Model E). The overall response of the building is still of shear-type due to flexural stiffness of beams (Graph: 4.2).

Table 4.2: Effect of Degree of Fixity on Story Displacement

Sr.no	**Storey Height from base**	**Building Model-D, with Fixed column base Support**	**Building Model-E, with Hinged column base Support**
		Story Displacement in X-Direction (mm)	**Story Displacement in X-Direction (mm)**
1	0	0	0
2	1.5	1.01	3.39
3	4.5	6.8	10.11
4	7.5	13.66	16.55
5	10.5	20.056	22.314
6	13.5	25.154	26.87
7	16.5	28.39	29.758

Story displacement and building height mentioned in table 4.2 is normalized in scale of 0 to 1 and top story displacement is considered as 1 and in proportion to those remaining storey displacements is calculated.

Table 4.3: Effect of Degree of Fixity on Normalised Mode Shape

Story No.	story height from base	Normalized mode shape (fixed column base)	Normalized mode shape (hinged column base)	Normalized building height
base	0	0	0	0
1	1.5	0.04	0.11	0.09
2	4.5	0.24	0.34	0.272
3	7.5	0.48	0.56	0.454
4	10.5	0.71	0.75	0.636
5	13.5	0.89	0.90	0.818
6	16.5	1.00	1.00	1

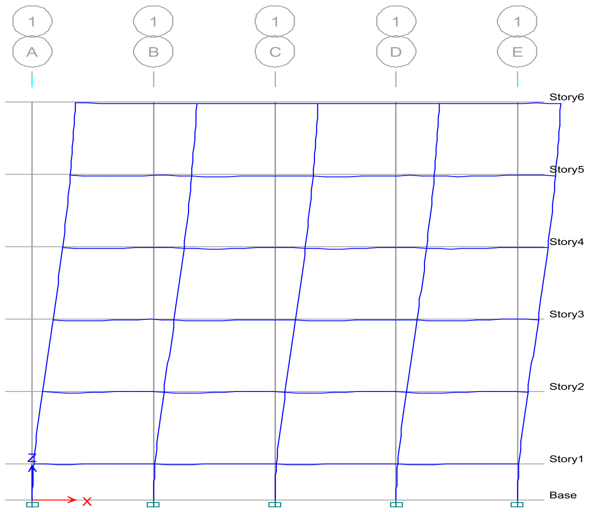


Fig 4.2 (a) Elevation of Building Model-D

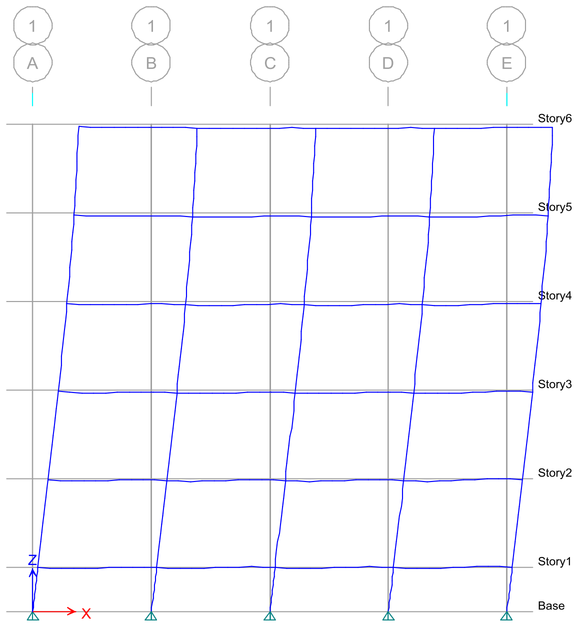
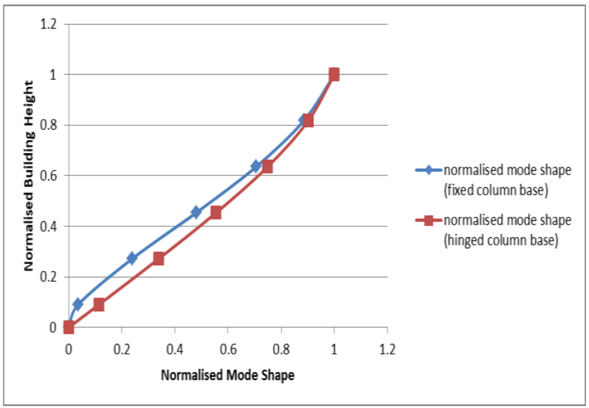


Fig 4.2 (b) Elevation of Building Model-E

Table 4.3 and Fig 4.2 (a & b) illustrates that the lack of fixity at beam ends induces flexural-type behaviour, while the same at column bases induces shear-type behaviour to the fundamental translational mode of oscillation.



Graph 4.1: Effect of Degree of Fixity at member ends

Graph 4.1 illustrates that the Normalized modal displacement at lower part of building is less for fixed column base as compared to the hinged column base.

4.3 Effect of Building Height

In well-designed low height moment frame buildings, the fundamental translational mode of oscillation is of shear-type. Buildings become laterally flexible as their height increases. As a result, the natural period of buildings increase with increase in height. However, the fundamental mode shape does not change significantly (from shear type to flexure type).

Flexural type behavior is exhibited only near the lower storeys where the axial deformation in the columns could be significant, particularly in tall buildings. However at higher floor levels, the response changes to shear type as the axial load level lowers. The shapes of fundamental mode of a **5-storey, 15-storey** and **25-storey** building show the same trend, although the fundamental periods are significantly different (Figure 4.3); the fundamental translational natural periods of these three buildings are 0.583s, 2.21s, and 3.96s, respectively

Table 4.4 Effect of Building Height on Normalized mode shape.

Building Model-F (5- storey)				
Sr.no	Storey Height from base	Story Displacement (mm)	Normalized Mode Shape	Normalized Building Height
1	0	0	0.00	0.00
2	1.5	0.828	0.04	0.11
4	4.5	5.644	0.27	0.33
3	7.5	11.72	0.55	0.56
5	10.5	17.17	0.81	0.78
6	13.5	21.13	1.00	1.00

Building Model-G (15 Story)				
Sr.No	Storey Height from base	Story Displace-ment (mm)	Normalised Mode Shape	Normalised Building Height
1	0	0	0.00	0.00
2	1.5	0.538	0.01	0.03
4	4.5	4.045	0.05	0.10
3	7.5	9.563	0.12	0.17
5	10.5	16.182	0.21	0.24
6	13.5	23.352	0.30	0.31
7	16.5	30.726	0.39	0.38
8	19.5	38.064	0.48	0.45
9	22.5	45.182	0.58	0.52
10	25.5	51.926	0.66	0.59

11	28.5	58.16	0.74	0.66
12	31.5	63.757	0.81	0.72
13	34.5	68.615	0.87	0.79
14	37.5	72.667	0.93	0.86
15	40.5	75.922	0.97	0.93
16	43.5	78.528	1.00	1.00

Building Model-H (25- storey)				
Sr.no	Storey Height from base	Story Displacement (mm)	Normalised Mode Shape	Normalised Building Height
1	0	0	0.00	0.00
2	1.5	0.511	0.00	0.02
4	4.5	3.85	0.03	0.06
3	7.5	9.168	0.06	0.10
5	10.5	15.611	0.11	0.14
6	13.5	22.707	0.16	0.18
7	16.5	30.176	0.21	0.22
8	19.5	37.847	0.27	0.27
9	22.5	45.612	0.32	0.31
10	25.5	53.396	0.37	0.35
11	28.5	61.142	0.43	0.39
12	31.5	68.803	0.48	0.43
13	34.5	76.334	0.54	0.47
14	37.5	83.693	0.59	0.51
15	40.5	90.836	0.64	0.55
16	43.5	97.718	0.68	0.59
17	46.5	104.293	0.73	0.63
18	49.5	110.512	0.77	0.67
19	52.5	116.327	0.82	0.71
20	55.5	121.688	0.85	0.76
21	58.5	126.549	0.89	0.80
22	61.5	130.868	0.92	0.84
23	64.5	134.618	0.94	0.88
24	67.5	137.794	0.97	0.92
25	70.5	140.436	0.98	0.96
26	73.5	142.66	1.00	1.00

ISSN: 2248-9622, Vol. 12, Issue 7, (Series-I) July 2022, pp. 153-165

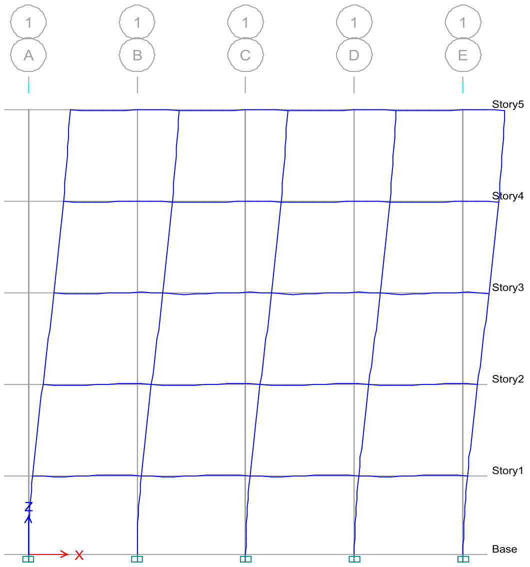
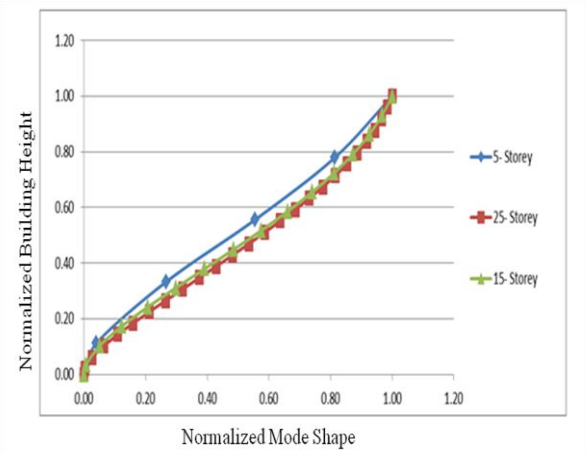


Fig 4.3 (a) Elevation of Model-F (First Mode shape)



Graph 4.2 Effect of Building Height on Normalized Mode Shape

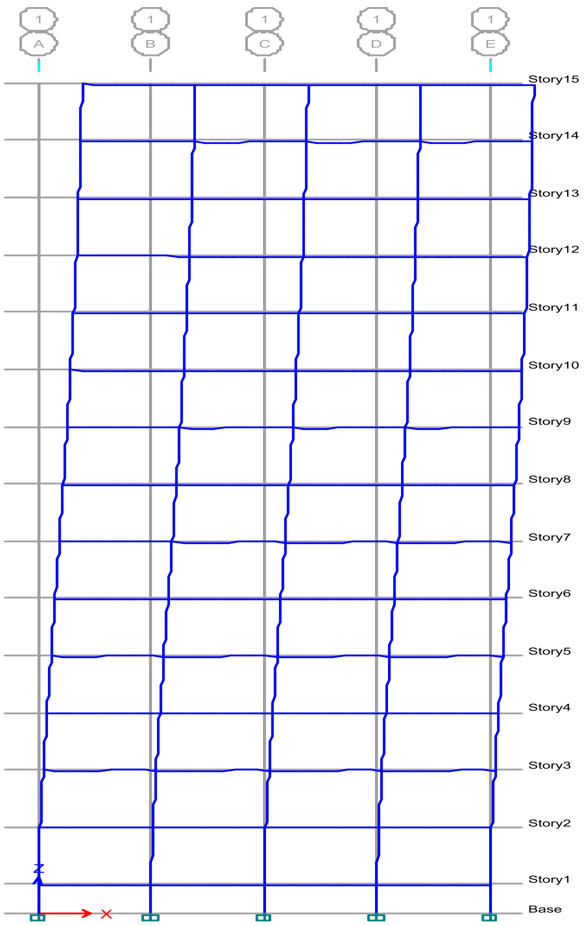


Fig 4.3 (b) Elevation of Model-G (First Mode shape)

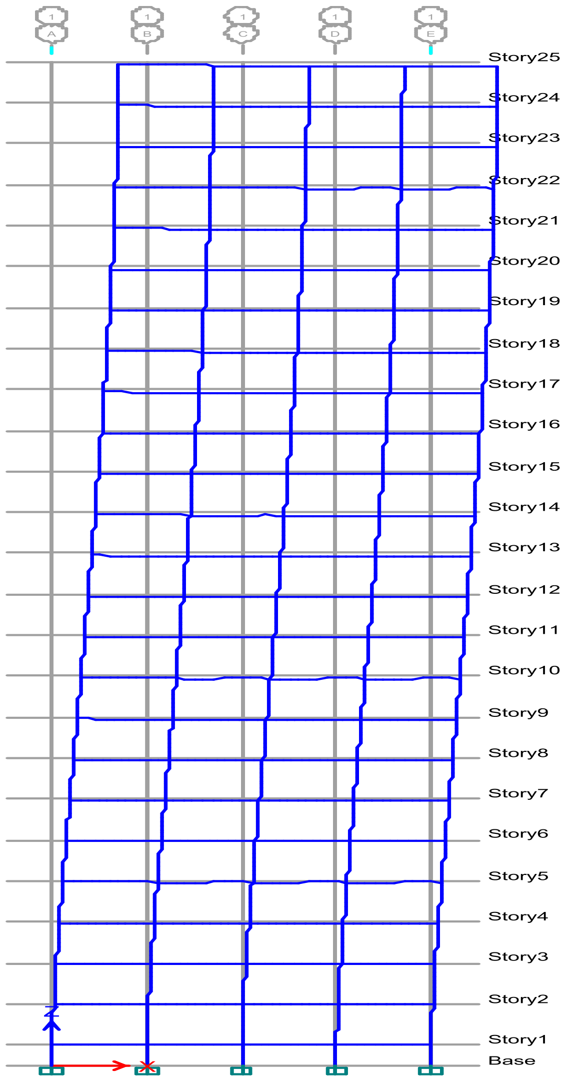


Fig 4.3 (c) Elevation of Model-H (First Mode Shape)

Figure 4.3, Table 4.4 and Graph 4.2 illustrate that the Fundamental translational mode shape of oscillation does not change significantly with increase in building height, unlike the fundamental translational natural period, which does change.

4.4 Effect of Unreinforced masonry infill walls in RC Frames.

Mode shape of a building depends on the distribution of lateral storey stiffness along the height of the building. As a consequence, it also depends on factors which may affect lateral storey stiffness. Role of URM infill walls discussed above is a major factor that influences lateral storey stiffness of a building. Enhancement of lateral storey stiffness depends on the extent and distribution of URM in each storey. Mode shape of building is affected the least when the lateral storey stiffness (after accounting for the stiffness contribution form URM infill walls) is constant throughout the height of the building; it is affected the most, when the lateral storey stiffness (after accounting for the stiffness contribution form URM infill walls) differs significantly between any two consecutive storeys.

URM infill walls are not considered in analysis and design of RC frame buildings in current design practice in many countries. They are assumed to not carry any vertical or lateral forces, and hence, declared as non-structural elements insofar as transfer of forces is concerned between structural elements (e.g., beams and columns) that are generated in the building during earthquake shaking.

Table 4.5: Effect of URM infill walls on Storey Displacement.

Sr.no	Storey Height from base	Frame with URM All Storeys	Frame with No URM All Storeys	Frame with No URM Ground Storey
		Story Displacement in X-Direction (mm)	Story Displacement in X-Direction (mm)	Story Displacement in X-Direction (mm)
1	0	0	0	0
2	3	6.585	28.578	20.932
3	6	14.5	72.93	30.144
4	9	22.338	117.553	37.88
5	12	29.529	157.253	45.092
6	15	35.316	187.76	50.882
7	18	38.89	205.633	54.46

Frame with URM All Storeys	Frame with No URM All Storeys	Frame with No URM Ground Storeys	Normalised Building Height
Normalised Mode Shape	Normalised Mode Shape	Normalised Mode Shape	
0	0	0	0
0.169	0.14	0.38	0.167
0.373	0.35	0.55	0.333
0.574	0.57	0.70	0.500
0.759	0.76	0.83	0.667
0.908	0.91	0.93	0.833
1.000	1.00	1.00	1.000

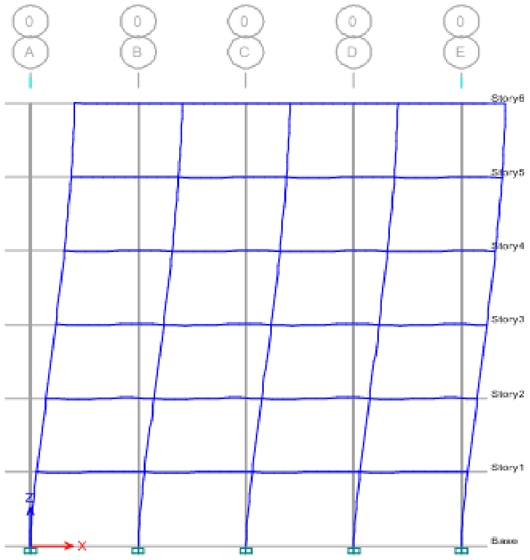


Fig 4.4 (a) Elevation of Model-I
(No URM all Storey)

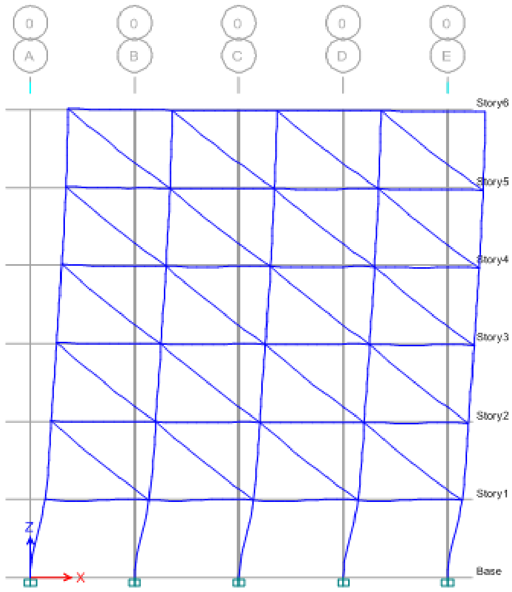


Fig 4.4 (b) Elevation of Model-I
(No URM Ground Storey)

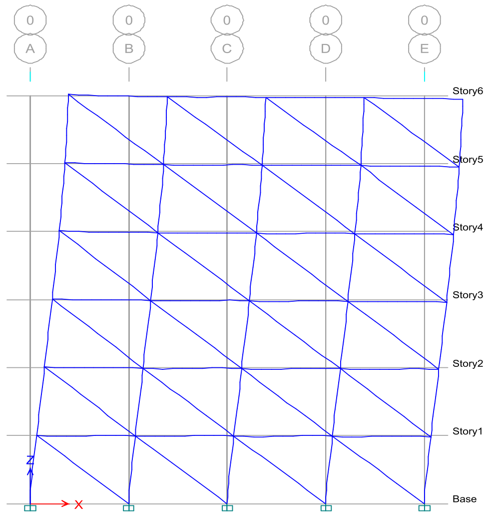
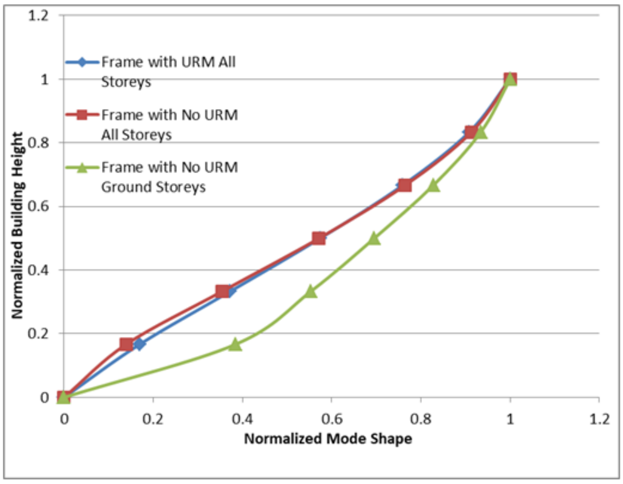


Fig 4.4 (c) Elevation of Model-I
(With URM All Storey)



Graph 4.3 Effect of URM infill walls in mode shape of RC frame building.

Table 4.5 and Figure 4.4(a,b), Graph 4.3 illustrate that the mode shape of building obtained considering stiffness contribution of URM is significantly different from that obtained without considering the same.

V. CONCLUSIONS

- The fundamental mode shape of buildings changes from flexural-type to shear-type as beam flexural stiffness increases relative to that of column
- Lack of rotational fixity at column base (hinged condition) increases the lateral sway in the lower storeys than in higher storeys, and the overall response of the building is more of shear-type.
- In well-designed low height moment frame buildings, the fundamental translational mode of oscillation is of shear-type. Buildings become laterally flexible as their height increases.

- Mode shape of building is affected the least when the lateral storey stiffness (after accounting for the stiffness contribution form URM infill walls) is constant throughout the height of the building; it is affected the most, when the lateral storey stiffness (after accounting for the stiffness contribution form URM infill walls) differs significantly between any two consecutive storeys.

REFERENCES

[1]. Kaushik,H.B. (2006), "Evaluation of strengthening options for masonry-infilled RC frames with open first- storey", *Ph.D. Thesis*, Department of Civil Engineering, Indian Institute of Technology Kanpur, India

[2]. Murty,C.V.R., Chrleson,A.W., and Sanyal,S.A., (2006), Earthquake Design Concepts, Teaching Resource Material for Teachers of Architecture Colleges, National Information Center of Earthquake Engineering, IIT Kanpur, India

[3]. Jaswant N. Arlekar, et al (1997), "Seismic Response of RC Frame Buildings with Soft First Storeys" Proceedings of the CBRI Golden Jubilee Conference on Natural Hazards in Urban Habitat, 1997, New Delhi.

[4]. C. V. R. Murty, Rupen Goswami, A. R. Vijayanarayanan and Vipul V. Mehta, "Earthquake Behaviour of Buildings".

[5]. Poncet, L. and Tremblay, R."Influence of mass irregularity on the seismic design and, January 30–February 4, 2000Performance of multi-storey braced steel frames".

[6]. Murty C.V.R. and Sudhir K.J., Beneficial influence of masonry infill walls on seismic performance of RC frame th buildings, The12 World Conference on Earthquake Engineering, Paper No. 1790, Auckland, New Zealand

[7]. IS:1893 (Part 1), (2007), Indian Standard Criteria for Earthquake Resistant Design of Structures, Bureau of Indian Standards, New Delhi

[8]. IS:456, (2000), Indian Standard Code of Practice for Plain and Reinforced Concrete, Bureau of Indian Standards, New Delhi