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Seismic Analysis of Earthquake Resistant Multi Bay Multi Storeyed 3D - RC Frame

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Abstract

Earthquakes in different parts of the world demonstrated the disastrous consequences and vulnerability of inadequate structures. Many reinforced concrete (RC) framed structures located in zones of high seismicity in India are constructed without considering the seismic codal provisions. The vulnerability of inadequately designed structures represents seismic risk to occupants. The main cause of failure of multi-storey multi-bay reinforced concrete frames during seismic motion is the soft storey sway mechanism or column sway mechanism. The seismic inertia forces generated at its floor levels are transferred through the various beams and columns to the ground. The failure of a column can affect the stability of the whole building, but the failure of a beam causes localized effect. Therefore, it is better to make beams to be the ductile weak links than columns. This method of designing RC buildings is called the strong -column weak-beam design method. In the present work stress is given on structural behaviour of RC building with and without infill walls and shear walls and also behaviour of building on levelled and sloped ground. The results were obtained in forms of storey displacements and base shear. The analysis is carried base on Indian standards using equivalent static, response spectrum and pushover analysis.

1. Introduction

Civil engineering structures are mainly designed to resist static loads. Generally the effects of dynamic loads acting on the structure are not considered. This feature of neglecting the dynamic forces sometimes becomes the cause of disaster, particularly in case of earthquake. The resent example of this category is Bhuj earthquake occurred on Jan.26, 2001. This has created a growing interest and need for earthquake resistant design of structures.

Conventional Civil Engineering structures are designed on the basis of strength and stiffness criteria. The strength is related to ultimate limit state which assures that the forces developed in the structure remain in elastic range. The stiffness is related to serviceability limit state which assures that the structural displacements remains within the permissible limits. In case of earthquake forces the demand is for ductility. Ductility is an essential attribute of a structure that must respond to strong ground motions. Ductility is the ability of the structure to undergo distortion or deformation without damage or failure which results in dissipation of energy. Larger is the capacity of the structure to deform plastically without collapse, more is the resulting ductility and the energy dissipation. This causes reduction in effective earthquake forces.

Simplified approaches for the seismic evaluation of structures, which account for the in-elastic behavior, generally use the results of static collapse analysis to define the global inelastic performance of the structure. Currently, for this purpose, the nonlinear static procedure (NSP) which is described in FEMA-273/356 and ATC-40 (Applied Technology Council, 1996) documents are used. Seismic demands are computed by nonlinear static analysis of the structure subjected to monotonically increasing lateral forces with in-variant height-wise distribution until a predetermined target displacement is reached.

ETABS V9.7 Nonlinear has been chosen, a linear and non-linear static and dynamic analysis and design program for three dimensional structures. The application has many features for solving a wide range of problems from simple 2 - D trusses to complex 3-D structures. Creation and modification of the model, execution of the analysis, and checking and optimization of the design are all done through this single interface. Graphical displays of the results, including real-time animations of time-history displacements are easily produced.

2. Historical Review

2.1. S. M. Nagargoje and K. S. Sable, "Seismic performance of multi-storeyed building on sloping ground" [1]. The buildings situated on hill slopes in earthquake prone areas are generally irregular, torsionally coupled and hence susceptible to serve damage when affected by earthquake ground motion. Such buildings have mass and stiffness varying along the vertical and horizontal planes which results in the center of mass and center of rigidity not coinciding on various floors. Hence they demand torsional analysis in addition to lateral forces under the action of earthquakes. These unsymmetrical buildings require great attention in the analysis and design. Analysis of hill buildings is somewhat different than the buildings on levelled ground since the column of hill building rests at different levels on the slope. The shorter column attracts more forces and undergoes damage when subjected to earthquakes.

2.2. P. P. Chandurkar and Dr. P. S. Pajgade "Seismic Analysis of RCC Building with and without Shear Wall" [2]. The author says that in the seismic design of buildings, reinforced concrete structural walls or shear walls act as major earthquake resisting members. Structural walls provide an efficient bracing system and offer great potential for lateral load resistance. The properties of these seismic shear walls dominate the response of the buildings and therefore, it is important to evaluate the seismic response of the walls appropriately. In this present study, main focus is to determine the solution for shear wall location in multi-storey building. Effectiveness of shear wall has been studied with the help of four different models. Model one is bare frame structural system and other three models are dual type structural system. An earthquake load is applied to a building of ten storeys located in zone II, zone III, zone IV and zone V. Parameters like lateral displacement, storey drift and total cost required for ground floor are calculated in both the cases replacing column with shear wall. From the analysis it is observed that in a 10 storey building, constructing building with shear wall in short span at corner is economical as compared with other models. From this, it can be concluded that large dimension of shear wall is not effective in 10 storeys or below 10 storeys buildings. It is observed that the shear wall is effective in high rise building. Also, it is observed that changing the position of shear wall will affect the attraction of forces, so that wall must be in proper position. If the dimensions of shear wall are large, then major amount of horizontal forces are taken by shear wall. Providing shear walls at adequate locations substantially reduces the displacements due to earthquake.

2.3. Jaswant N. Arlekar, Sudhir K. Jain and C.V.R., A project on study the "Effect of infill patterns and soft storey" [3]. For these studies they had taken about nine different models of the building are studied. The open first storey is an important functional requirement of almost all the urban multi-storey buildings, and hence, cannot be eliminated. Alternative measures need to be adopted for this specific situation. The under-lying principle of any solution to this problem is in (a) increasing the stiffness of the first storey such that the first storey is at least 50% as stiff as the second storey. i.e., soft first storeys are to be avoided and (b) providing adequate lateral strength in the first storey.

3. Model Description

Basically model consists of four bay twelve storey building, each bay is having width of 5m. The story height is kept as 3m with beam and column sizes of 0.4mx0.6m and 0.6mx0.9m respectively also slab thickness is taken as 125mm. The models are analyzed on leveled as well as sloping ground 1:1/3. The material properties and geometry of models are described below.

3.1. Material Properties And Loading

3.1.1 Material properties:

Material properties assigned to structure are as shown below:
Concrete cube compressive strength, f_{ck} = 35000 kN/m^3 (M35)
Characteristic strength of reinforcing steel, f_y= 500000 kN/m^3 (Fe500)
Modulus of elasticity of concrete, E = 2.95803989x10^7 kN/m^3
Density of concrete = 25 kN/m^3

3.1.2 Gravity Loads:

(i) Dead loads:
Self-weight: Self weight is calculated by the software based on section properties and material constants provided.
Super imposed dead load (Floor finishes or water proofing's) =1.5kN/m^2
Wall load =11kN/m
Parapet load= 3.5kN/m

(ii) Live Loads:
Live load on floor =3.5kN/m^2
Live load on roof =1.5kN/m^2
Note: Except self-weight there is no load that is applied on ground floor.

3.1.3 Lateral loads:

(i) Equivalent Static Method as per IS1893 (Part1):2002
Z = 0.36 considering zone factor for zone V (Table 2 of code)
I = 1.0 considering residential building (Table 6 of code)
R = 5.0 considering special RC moment resistant frame (SMRF) (Table 7 of code)

(ii) Response Spectrum Method:
The response spectrum analysis is carried out using the spectra for medium soil as per IS 1893 (Part 1) 2002 for seismic zone V, medium soil and 5% damping.
The spectral acceleration coefficient (Sa/g) values are calculated as follows.
For medium soil sites,
$Sa/g = 1 + 15T$, $(0.00 \le T \le 0.10)$, (T= time period in seconds)
$= 2.50$, $(0.10 \le T \le 0.55)$
$= 1.36/T$, $(0.55 \le T \le 4.00)$

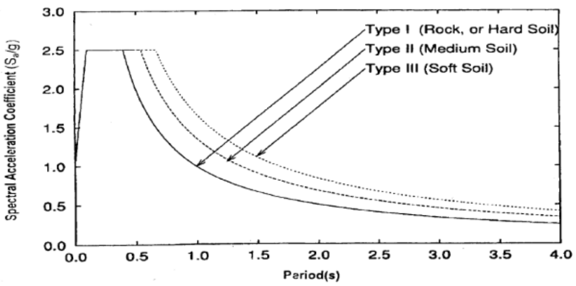

Figure 1: Response spectra for rock and soil sites for 5% damping as per IS1893 (Part1):2002 (Fig.2 of code)

3.2. Model Under Study

Set 1: Normal ground:

Model 1: Building modeled as a bare frame however masses of the walls are included in the model (Figure 2)

Model 2: Building has no walls in the first storey and has brick infill masonry walls in the upper storeys (Figure 3)

Model 3: Building has no walls in the first storey and has brick infill masonry walls in the upper storeys further shear wall is provided at corners (Figure 4)

Set 2: Sloping ground:

Model 4: Building modeled as a bare frame on a sloping ground however masses of the walls are included in the model (Figure 5)

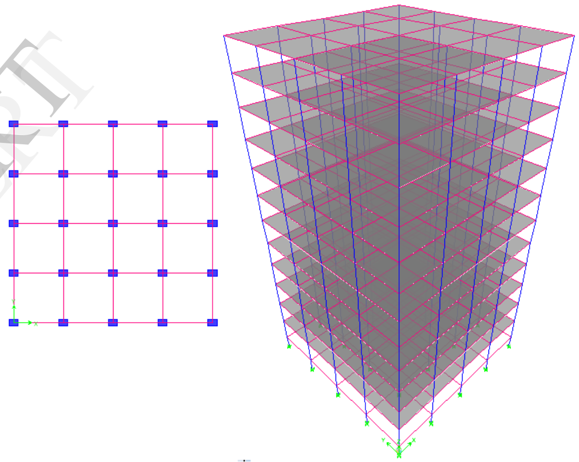

Figure 2. Plan and elevation of Model 1

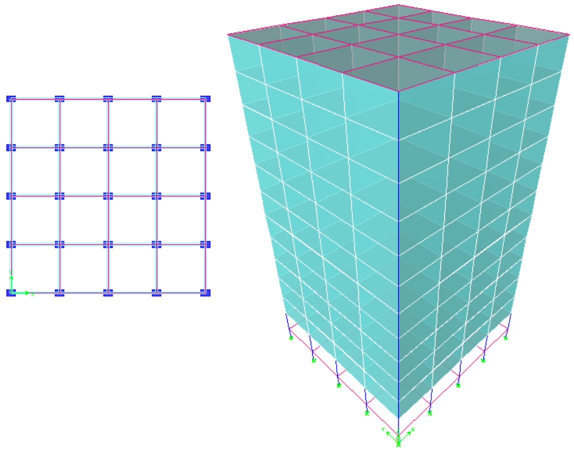

Figure 3. Plan and elevation of Model 2

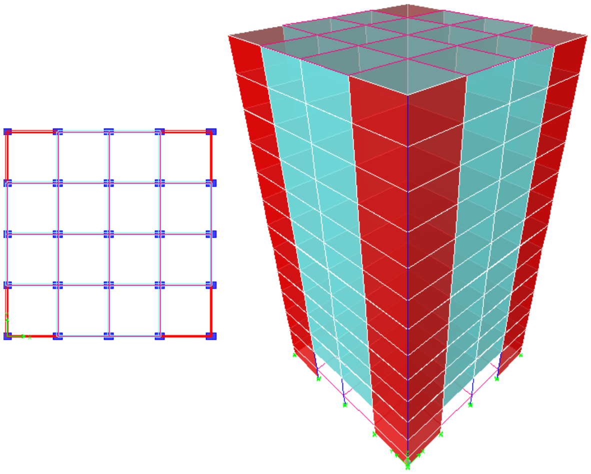

Figure 4. Plan and elevation of Model 3

Model 5: Building has no walls in the first storey and has brick infill masonry walls in the upper storeys on a sloping ground (Figure 6)

Model 6: Building has no walls in the first storey and has brick infill masonry walls in the upper storeys further shear wall is provided at corners on sloping ground (Figure 7)

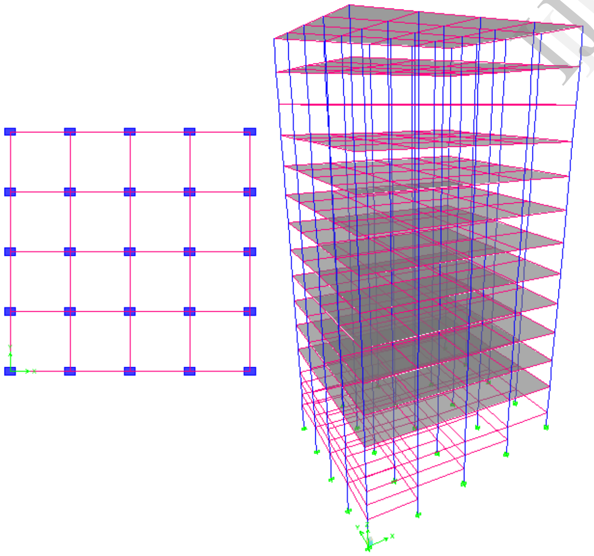

Figure 5. Plan and elevation of Model 4

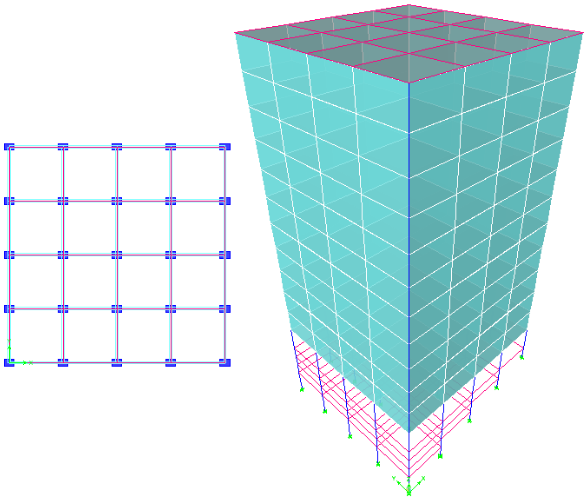

Figure 6. Plan and elevation of Model 5

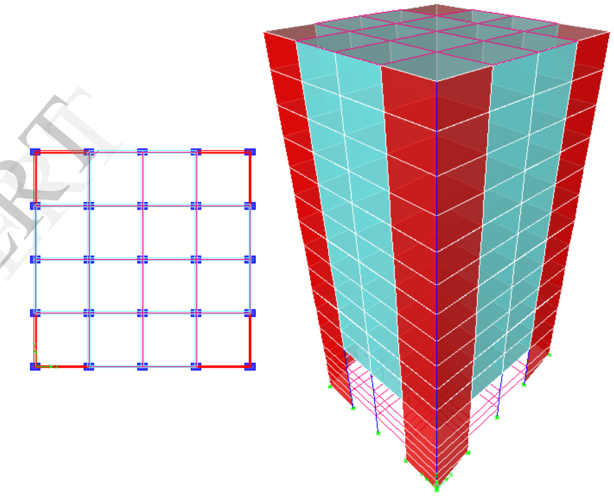

Figure 7. Plan and elevation of Model 6

3.3. Results and Discussions

3.4. Lateral Displacements

The maximum displacements are presented in Table 1 for SET1 and SET2 for Equivalent Static, Response Spectrum and Pushover Analysis. For better comparability the maximum displacement for each model along the two directions of ground motion are plotted in graphs as shown in figure 8. In the three dimensional model, however, there are six degrees of freedom with the two translational degree of freedom along X, Y-axes and rotation degree of freedom about Z (vertical)-axis playing significant role in the deformation of the structure. Apart from the translation motion in a particular direction, there is always an additional displacement due to the rotation of floor. Due to this the maximum displacement at floor levels obtained by three-dimensional analysis are always greater than the corresponding values obtained by one-dimensional analysis.

Moreover, the floor rotation is maximum at the top floor, gradually reducing down the height of the building to an almost negligible rotation at the lowest basement floor.

In Equivalent Static Method it can be seen that the reduction in displacements for SET1 of model 2 and model 3 w.r.t model 1 are respectively 82% and 90.36%. For SET2 of model 5 and model 6 w.r.t model 4 are 79.15% and 89.27% in longitudinal direction and in transverse direction for SET1: 82.1% and 91.35% and for SET2 of model 5 and model 6 w.r.t model 4 are 76.92% and 90.31% along transverse direction. So we can say that bare frame deflects more and hence seismically critical.

In Response Spectrum Method it can be seen that the reduction in displacements for SET1 of model 2 and model 3 w.r.t model 1 are respectively 69.11% and 84.30% and for SET2 of model 5 and model 6 w.r.t model 4 are 50.95% and 73.97% in longitudinal direction and in transverse direction for SET1 are 67.80% and 84.73% and for SET2 of model5 and model 6 w.r.t model 4 51.42% and 74.29% along transverse direction. So we can say that bare frame deflects more and hence seismically critical.

From above conclusion it is clear that presence of brick infill and concrete shear wall reduces the lateral displacement considerable by both equivalent static and response spectrum analysis.

Table 1. Lateral displacement in longitudinal and transverse direction

Model	Esa		Rsa		Pushover	
No	Ux	Uy	Ux	Uy	Ux	Uy
1	0.0367	0.0419	0.0291	0.0308	0.065	0.0736
2	0.0064	0.0075	0.009	0.0099	0.0174	0.0133
3	0.0035	0.0036	0.0046	0.0047	0.0158	0.0176
4	0.0379	0.0442	0.0211	0.0226	0.0646	0.0783
5	0.0079	0.0102	0.0103	0.011	0.012	0.0179
6	0.0041	0.0043	0.0055	0.0058	0.0202	0.0147

3.5. Base Shear (kN)

Base shear and displacement for twelve storey different building models along longitudinal and transverse directions are shown in Table 2.

Table 2. Base shear and displacements along longitudinal direction

Model	Esa		Rsa		Pushover	
No	SF-X	SF-Y	SF-X	SF-Y	SF-X	SF-Y
1	3931.6	3931.6	2621.7	2468.3	3831.5	1395.7
2	4233.2	4233.2	6994	6639.7	19750	7480.7
3	4214.1	4214.1	6356.2	6390.4	290803	304284
4	4069.3	4069.3	2601.1	2415.5	3602.8	6711.5
5	4371.1	4371.1	6508.9	5215.7	4424.7	2263.9
6	4376.9	4376.9	6617.8	6655.5	76836	256846

For SET1: From the above table it can be observed that amongst the all model the bare frame has shear force least. The maximum shear force has appeared in model 2 in case of equivalent method and response spectrum method and in case of pushover analysis shear wall model has maximum shear force. So it can be said that addition of shear wall will increase the base shear.

For SET2: From the above table it can be observed that amongst the all model the bare frame has shear force least. The maximum shear force has appeared in model 3 in all cases of analysis i.e. equivalent method and response spectrum method and pushover analysis. So it can be said that addition of shear wall will increase the base shear.

3.6 Storey Drifts

The permissible inter storey drift is limited to 0.004 times the storey height, so that minimum damage would take place during earthquake and pose less psychological fear in the minds of people. The maximum storey drifts of different models along longitudinal and transverse directions are shown in Table 3. For buildings on normal ground and on sloped ground the maximum drift allowed is = 0.004*3= 0.012m. Hence it can be said that all buildings are within permissible drifts.

Table 3. Inter storey drift x and y in meters

Model	Esa		Rsa		Pushover	
No	DRIFT-X	DRIFT-Y	DRIFT-X	DRIFT-Y	DRIFT-X	DRIFT-Y
1	0.00133	0.001501	0.00105	0.0011	0.00236	0.00265
2	0.00044	0.000687	0.00071	0.00107	0.00119	0.00123
3	0.00013	0.000141	0.00019	0.00021	0.00057	0.00069
4	0.00135	0.001545	0.0008	0.00086	0.00232	0.00276
5	0.00064	0.000788	0.00094	0.00096	0.00112	0.00141
6	0.00019	0.00016	0.00028	0.00024	0.00096	0.00056

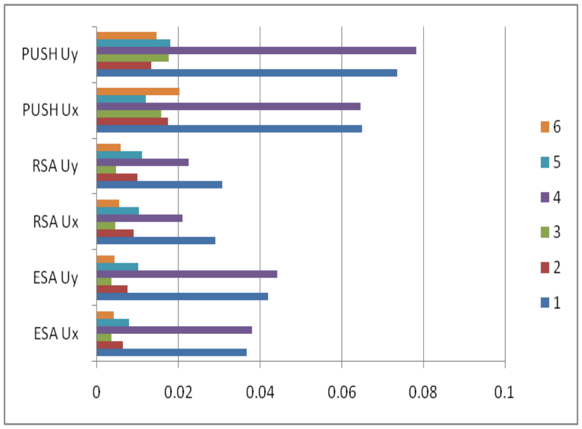

Figure 8. Maximum lateral displacements

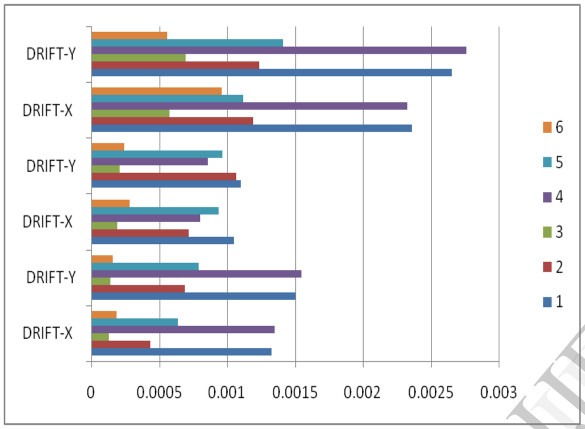

Figure 9. Maximum drifts

3.7 Performance Point

The performance point of the building models in longitudinal and transverse directions are tabulated in Table 5 to Table 8 as obtained from ETABS. The values of seismic coefficients Ca and Cv for zone-V are taken from Table 4.

Table 4. Interpolated values of Seismic coefficient (Ca and Cv) for the soil type.

Seismic Coefficients: Ca				
Soil	Zone II (0.1)	Zone III (0.16)	Zone IV (0.24)	Zone V (0.36)
Type I	0.12	0.19	0.28	0.37
Type II	0.15	0.23	0.31	**0.41**
Type III	0.23	0.31	0.35	0.36
Seismic Coefficients: Cv				
Type I	0.17	0.26	0.37	0.52
Type II	0.23	0.34	0.46	**0.6**
Type III	0.34	0.3	0.72	0.91

Table 5. Performance point: Push 2 Set 1

Model	Sa	Sd	V	D
1	0.14	0.21	8251.2	0.3
2	--	--	--	--
3	0.96	0.04	65725	0.06

Table 6. Performance point: Push 3 Set 1

Model	Sa	Sd	V	D
1	0.13	0.23	7884.6	0.3
2	--	--	--	--
3	0.96	0.04	66110	0.1

Table 7. Performance point: Push 2 Set 2

Model	Sa	Sd	V	D
4	0.14	0.22	8454.4	0.3
5	--	--	--	--
6	0.93	0.05	67191	0.1

Table 8. Performance point: Push 3 Set 2

Model	Sa	Sd	V	D
4	0.13	0.23	7996.9	0.3
5	--	--	--	--
6	0.91	0.05	62767	0.1

From above tables it can be seen that for buildings on leveled ground the spectral acceleration (Sa) and base shear (V) is maximum in Model 3 and minimum in model 1 whereas Spectral displacement (Sd) and Roof Displacement (D) is maximum in Model 1 and minimum in model 3 when pushover analysis is performed in longitudinal direction. Same is observed in transverse direction.

From above tables it is observed that the for buildings on sloped ground the spectral acceleration (Sa) and base shear (V) is maximum in Model 6 and minimum in model 1. Whereas Spectral displacement (Sd) and Roof Displacement (D) is maximum in Model 4 and minimum in model 6, when pushover analysis is performed in longitudinal direction. Same is observed in transverse direction.

The model 2 and model 5 are modeled with infill walls with no walls in bottom storey. Due to this structural irregularity and heavy mass that is coming due to self-weight of walls, the building is undergoing a critical situation i.e., mass and stiffness irregularity at the region between first storey (storey without infill) and second storey (with infill) and lack to get the performance point. This is situation is common in today's world where the buildings are provided with an open space for parking.

4. Conclusions

1. The formation of first hinge is not early in models with shear wall as compared with bottom soft storey and bare frame even base shear is also more for shear wall models.
2. The presence of masonry infill influences the overall behavior of structures when subjected to lateral forces. Joint displacements and storey drifts are considerably reduced while contribution of infill brick wall is taken into account.
3. Provision of both external shear wall and internal shear wall effectively reduce large joint displacements found in bare frame.
4. Provision of external and internal shear walls in general results in reducing support reactions and member forces, but may give rise to additional forces such as shear force and torsion moment in columns and beams which need to be accounted for during design.
5. Results indicate that infill panels have a large effect on the behavior of frames under earthquake excitation. In general, infill panels increase stiffness of the structure.
6. From the result it is observed that infill effect stiffness of the frame, due to which comparatively less reinforcement is required as compared to reinforcement required in bare frame.
7. Storey drifts are found within the limit as specified by code (IS: 1893-2002, part-1) in both linear dynamic and nonlinear static analysis.
8. The overall results of pushover analysis in the longitudinal and transverse direction indicated that the capacity of RC building with shear walls are best.
9. The sloping ground buildings possesses relatively more maximum displacements and shear forces which may give rise to critical situations than the buildings on leveled ground.

References

1. S. M. Nagargoje and K. S. Sable, "Seismic performance of multi-storeyed building on sloping ground"
2. P. P. Chandurkar and Dr. P. S. Pajgade "Seismic Analysis of RCC Building with and without Shear Wall"
3. Jaswant N. Arlekar, Sudhir K. Jain and C.V.R "Effect of infill patterns and soft storey"
4. I.S.1893, "Criteria for Earthquake Resistant Design of Structures (part1) General Provisions and Buildings (Fifth Revision)", Bureau of Indian Standards, 2002.
5. I.S.456, "Plain and Reinforced Concrete-Code of Practice", Bureau of Indian Standards, 2000.
6. I.S13920, "Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces-Code of Practice", Bureau of Indian Standards, 1993.
7. SP16, "Design Aids for Reinforced Concrete", Bureau of Indian Standards, 1980.
8. Agarwal Pankaj and Shrikhande Manish, "Earthquake resistant design of structures", Prentice Hall of India Private Limited.
9. EERI, "Bhuj, India Earthquake of January 26, 2001: Reconnaissance Report" Earthquake spectra, supplement to Vol.18, July2002.
10. Goel, R. K., "Performance of Building during the January 26, 2001, Bhuj Earthquake", Earthquake Engineering Research Institute, California.
11. Paulay T. and Priestley M. J. N., "Seismic Design of Reinforced Concrete and Masonry Buildings"
12. Penils, G. G. and Kappors "Earthquake-Resistant concrete structures", E & FN SPON, anim print of Chapman & Hall, 1997
13. Wanga dinata W. "Capacity design, a concept to ensure seismic resistance of building structure" National conference on Earthquake Engineering, Institute Technology Bandung, Nov.4-5.1999
14. M. A. Ismaeil et. al. "Assessment Of Seismic Performance And Strengthening Of RC Existing Residual Buildings In The Sudan", International Journal of Engineering Research & Technology (IJERT), Vol. 2 Issue 6, June - 2013