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Comparison and Seismic analysis of a seven-storeyed RC Building resting on plain and sloping ground

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Abstract

An earthquake is a phenomenon of ground motion caused by the sudden breaking and movement of large sections (tectonic plates) of the earth's rocky outermost crust. If an earthquake occurs in a populated area, it may cause many deaths and injuries and extensive property damage. Although there are no guarantees of safety during an earthquake, it is difficult identifying the potential hazards ahead of time and advance planning to save lives and significantly reduce injuries and property damage. Hence it is mandatory to do seismic analysis to the structure against collapse. In this paper an attempt is made to understand the performance of R.C building frame structure in plain and sloping ground when subjected to gravity and earthquake load. To understand this four three dimensional seven-storied (G+6) reinforced concrete building are consider in which the first frame is positioned at zero degree with respect to the horizontal ground and remaining three frames are placed at 10, 20 and 30 degrees respectively. All the four frames are modelled and analyzed using SAP2000 software. The Equivalent Static Method as per IS:1893-2002 is used to analyze all the modelled manually. The performance of the structure is assessed by comparing the Shear Force, Bending Moment and deflection in different frames. Also, the base shear of different frames obtained manually is compared with the SAP 2000 results.

Keywords: *Earthquake, Seismic analysis, Equivalent static method, SAP 2000.*

1. Introduction

Earthquake is considered as a catastrophic natural disaster. Many people die every year due to collapse of buildings due to earthquakes. The most recent example is the Ecuador earthquake of 7.8 magnitude on richer scale which struck on 16th April 2016. It killed more than 650 people with buildings collapsing hundreds of kilometers from the epi-center of earthquake. The damage to structures can be reduced by adopting principles of earthquake resistant designs.

This project shows an analysis of G+6 storey residential building by seismic analysis (with dead, live and earthquake loads). Seismic response of a structure can be obtained by using linear, non-linear analysis. Various methods of seismic analysis include (i) Equivalent Static Analysis, (ii) Response Spectrum Analysis, (iii) Linear Dynamic Analysis, (iv) Non-linear Dynamic Analysis.

This project employs Equivalent Static Analysis to obtain seismic response of G+6 storey residential building. All these G+6 storey residential building are od zero degree, 10 degree, 20 degree and 30 degree.

As per IS 1893 (2002) code, five types of irregularities for buildings are stiffness irregularity, Weight (Mass) Irregularity, Vertical geometric irregularity, In-plane Discontinuity in capacity.

a) Stiffness Irregularity- Soft Storey: is defined to exist when there is a storey in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.

b) Stiffness Irregularity – Extreme Soft Storey: is defined to exist where there is a storey in which the lateral stiffness is less than 60% of that in the storey above or less than 70% of the average stiffness of the three stories above.

Weight (Mass) Irregularity- It is considered to exist where the effective mass of any storey is more than 150% of the effective mass of an adjacent storey.

Vertical geometric irregularity – It shall be considered to exist where the horizontal dimension of the lateral force- resisting system in any storey in any storey is more than 130% of that in an adjacent storey.

In-plane Discontinuity – In Vertical Lateral-Force-Resisting Elements is defined to exist where an in-plane offset of the lateral-force-resisting elements is greater than the length of those elements or where there is a reduction in stiffness of the resisting element in the storey below.

Discontinuity in Capacity – The weak storey is one in which the storey lateral strength is less than 80% of the in the above storey. The storey lateral strength is the total lateral strength of all seismic-resisting elements sharing the storey shear in the consideration direction.

2. Structural Modelling

2.1 GENERAL

The study in this thesis is based on linear analysis of a structural model subjected to gravity and earthquake load. The buildings are designed according to IS: 1893(part I): 2002and analysis by SAP2000 v21, which is a structural analysis program for static and dynamic analysis of structures.

2.2 GEOMETRY OF BUILDING:

Table 1 Geometry of zero-degree structure

TYPE OF BUIDING	MEMBER	FLOOR	WIDTH (mm)	DEPTH (mm)	REINFORCEMENT
Zero-degree structure	Column	1 to3	450	450	#8-28d
		4 to 6	350	350	#8-20d
		7	300	300	#8-16d
	Beam	1 to 7	300	300	#8-16d

Table 2 Geometry of 10-degree structure

TYPE OF BUIDING	MEMBER	FLOOR	WIDTH (mm)	DEPTH (mm)	REINFORCEMENT
10-degree structure	Column	1 to 3	500	500	#12-28d
		4 to 6	450	450	#8-20d
		7	400	400	#8-16d
	Beam	1 to 7	300	300	#8-16d

Table 3 Geometry of 20-degree structure

TYPE OF BUIDING	MEMBER	FLOOR	WIDTH (mm)	DEPTH (mm)	REINFORCEMENT
20-degree structure	Column	1 to 3	500	500	#12-28d
		4 to 6	450	450	#8-20d
		7	400	400	#8-16d
	Beam	1 to 7	300	300	#8-16d

Table 4 Geometry of 30-degree structure

TYPE OF BUIDING	MEMBER	FLOOR	WIDTH (mm)	DEPTH (mm)	REINFORCEMENT
30-degree structure	Column	1 o 5	550	550	#12-36d
		6 to 7	500	500	#8-28d
	Beam	1 to 7	300	300	#8-16d

2.3 MATERIAL PROPERIES:

Material properties are assumed as 25MPa for concrete compressive strength and 415Mpa for yield strength of reinforcing steel for all the models used in the study. Elastic properties of these materials are taken as per Indian standard IS: 456- 2000.

The short-term modulus of elasticity (E_c) of concrete is taken as:

$$\mathbf{E_C = 5000\sqrt{fck}\ MPa}$$

Where, f_{ck} is the characteristic compressive strength of concrete cube in MPa at 28th day. For the steel rebar, yield stress(f_y) and modulus of elasticity (E_s) are taken as per IS: 456-2000.

2.4 STRUCTURAL ELEMENTS:

The structural system of the building is considered as space frames having 3- dimensional frame elements representing beams and columns and shell elements are used for slabs. The columns are fixed at the base of the foundation level and floor slabs are assumed to act as diaphragm. The beam-column joints are assumed to be rigid and hence modelled by giving end-offsets to the frame elements with rigid zone factor 1, so as to obtain the bending moments and forces at the beam and column faces. Soil- structure interaction and P-delta effects are not considered for the analysis. The buildings are considered as ordinary moment resistant frame (OMRF) buildings situated in seismic zone V and medium type of soil is considered with 5% damping. The floor diaphragms are considered as rigid in their plane and each nodal point in the frame has six degrees of freedom, three translations and three rotations the material properties and structural components are tabularized on Table 5.

Table 5 Material properties and structural components of the structures

Property / Structural component	Value
Yield strength of steel, f_y	500 Mpa
Compressive strength of concrete, f_{ck}	45 Mpa
Modulus of elasticity of steel. E_s	200000 Mpa
Modulus of elasticity of concrete, E_c	22360.67 Mpa
Unit weight of concrete	25 KN/m^3
Slab Thickness	125 mm

3. SAP2000

SAP2000 is general-purpose civil-engineering software ideal for the analysis and design of any type of structural system. Basic and advanced systems, ranging from 2D to 3D, of simple geometry to complex, may be modelled, analyzed, designed, and optimized using a practical and intuitive object-based modelling environment that simplifies and streamlines the engineering process. The SAP Fire ® Analysis Engine integral to SAP2000 drives a sophisticated finite-element analysis procedure. An additional suite of advanced analysis features is available to users engaging state-of-the-art practice with nonlinear and dynamic consideration. Created by engineers for effective engineering, SAP2000 is the ideal software tool for users of any experience level, designing any structural system.

First the layout of the frame was established in SAP 2000 followed by the defining the materials and material properties and construction of te members in the structure. After this the loads are assigned in the respective members and areas and all the joints are constrains in z- direction. After this all the members, beam and column are rigidly fixed with rigidity zone factor 1. The floor diaphragms are considered as rigid in their plane and each nodal point in the frame has six degrees of freedom. Three translations and three rotations. After assigning all the factors mentioned above the frame is ready for the analysis.

3.1 Loading in SAP2000:

The dead load of the structure in SAP2000 is calculated automatically when there is assigning of any member of the structure. To add live load of the structure, one has to calculate the live load coming in the structure and has to enter the load values manually corresponding to its load type and assign to the member. For the present study total eleven different loads are chosen which is given in the table 7. The entire load chosen has to assign one by one in the structure.

Table 6 Loads used and their magnitude

SL. NO	TYPE OF LOAD	MAGNITUDE
1.	Dead load	Automatic calculated by SAP2000
2.	Floor Live	4 KN/m^2
3.	Roof Live	2 KN/m^2
4.	Floor Finish	0.28 KN/m^2
5.	Ceiling Finish	0.2 KN/m^2
6.	Roof Finish	0.1 KN/m^2
7.	External Partition Load	15 KN/m
8.	Internal Partition Load	7.5 KN/m
9.	Earthquake load in x-direction	IS:1893 -2002
10.	Earthquake load in y-direction	IS: 1893- 2002

Few loading patterns on the frames are shown in the below given figures done in the SAP2000 v21

Figure 3.5: **:** (a) External wall loading on the frame (b) Interior wall loading on the frame & (c) Live loading on the Floor of structure.

4. Analysis of the building

A step-by-step procedure for the analysis of the frame by equivalent static lateral force method is as follows:

4.1 Calculating using Equivalent static lateral force method:

STEP 1: Calculation of Lumped Masses to Various Floor Levels:

At every level the mass is calculated such as:

1. Mass of columns:
   I) Weight of the column in first half= No. of columns x D x W x H x Unit weight of concrete
   II) Weight of the column in second half = No. of columns x D x W x H x Unit weight of concrete
2. Mass of beams = L x D x W x Unit weight of concrete
3. Mass od slab = Slab area x D x Unit weight of concrete
4. Mass of Walls = Thickness x Height x L x Unit weight of wall
5. Floor live load = Total area x Floor live load x % of floor live load
6. Floor finish = Total area x Finish load
7. Ceiling load = Total load x ceiling finish
8. Roof Live load = Total area x Roof live load x % Roof live load
9. Roof finish = Total area x Roof finish

Total Seismic load = 1 +2 +3+ 4 +5 +6 +7 +8 +9

Height h1= 1.75m
Height h2= 5.25m
Height h3= 8.75m
Height h4= 12.25m
Height h5= 15.75m
Height h6= 19.25m
Height h7= 22.75m

STEP 2: Determination of Fundamental Natural Period: The approximate fundamental natural period of a vibration (T_a), in seconds, of a moment resisting frame building without brick infill panels may be estimated by the empirical expression

$$T_a = 0.075(h)^{0.75} = 0.075(22.75)^{0.75} = 0.7812s$$

Where h is the height of the building, in meters.

STEP 3: Determination of Design Base Shear

Design seismic base shear, $V_B = A_h W$

$$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g} = \frac{0.24}{2}\frac{1}{5}(1.740) = 0.0417$$

For $T_a = 0.7812 \Rightarrow \frac{S_a}{g} = \frac{1.36}{T_a} = 1.740$, for medium soil from ***Figure 2 of IS 1893 (Part 1): 2002***

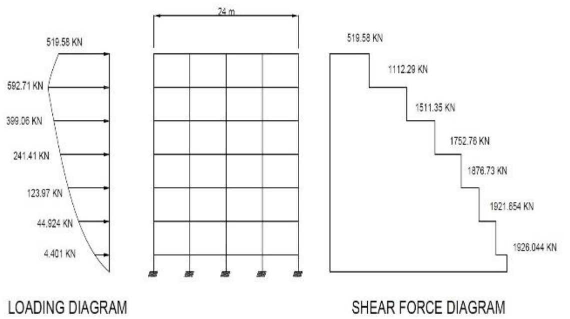
Design seismic base shear,

V_B = 0.041778 x 46101.33 = **1926.044 kN**

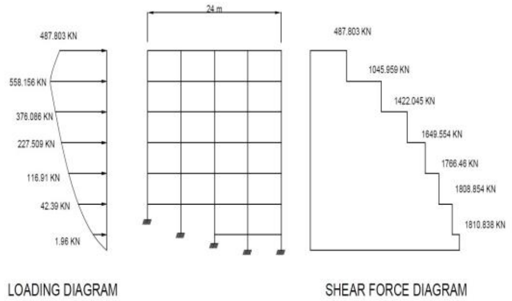
STEP 4: Vertical Distribution of Base Shear

The design base shear (V_B) computed shall be distributed along the height of the building as per the expression,

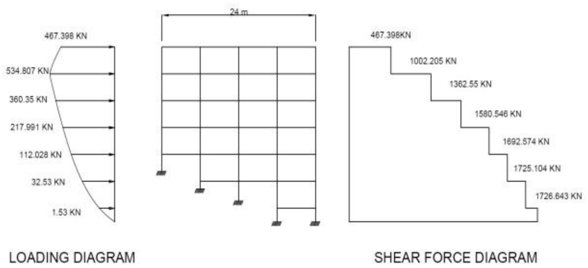
$$Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2}$$



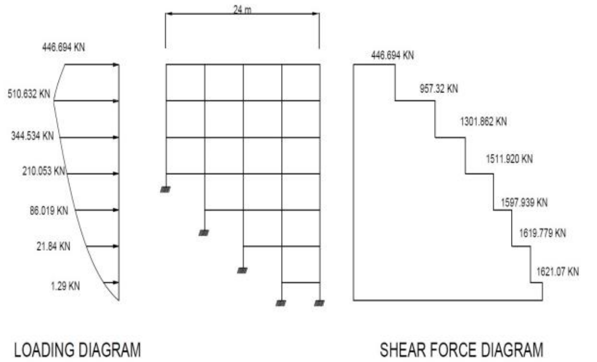
ZERO-DEGREE STRUCTURE



10-DEGREE STRUCTURE

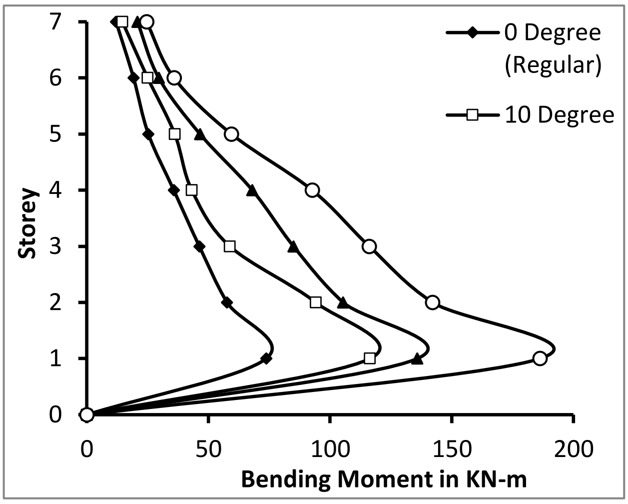


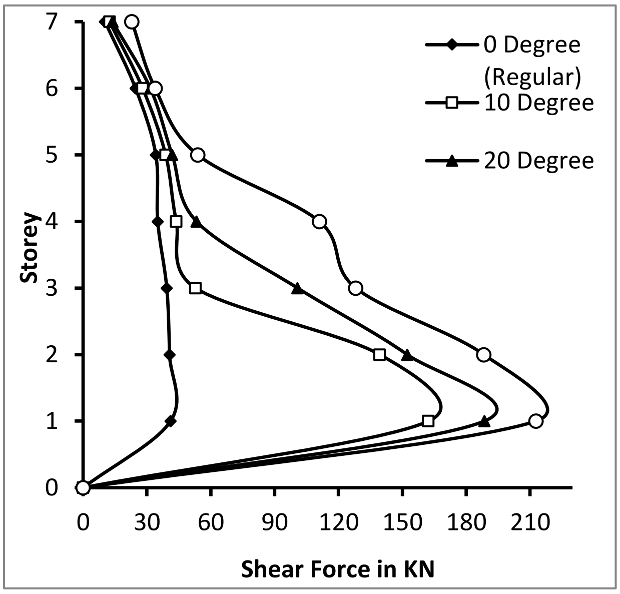
20-DEGREE STRUCTURE



30-DEGREE STRUCTURE

3.2 ANALYSIS OF FRAME IN SAP2000:



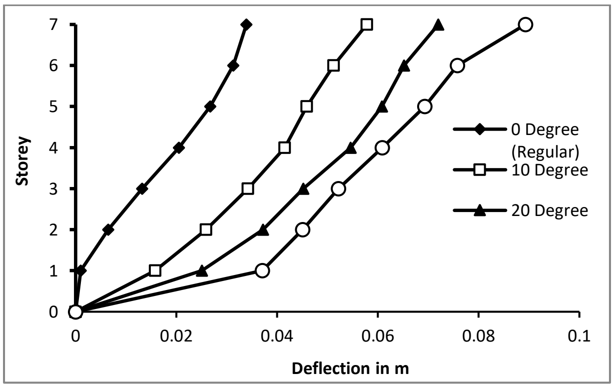


The first step is to open the SAP2000 V.20 and create a new file. To create new file, go to File > New Model. Then a popup window appears and select the suitable template such as Grid only for this case and initialize the model with units such as KN, m, C. Now another popup window appears for the grid lines specifications. After giving all the required specifications the model is created. Now the next step is to define the material properties for that go to Define > materials in that define the concrete and steel properties. Define > section properties > frame sections and define the columns and beams. Define > Area sections and define the slab. Draw > Draw Frame/cable/tendon and draw all the columns and beams. Draw > Draw quick area sections and draw the slabs. Assign > Joints > Restraints as support. Define > Load cases. Define > Load combinations. Assign > Frame loads > Distributed. Assign > Area loads > uniform to shell. Define > mass source. Now analyse the structure.

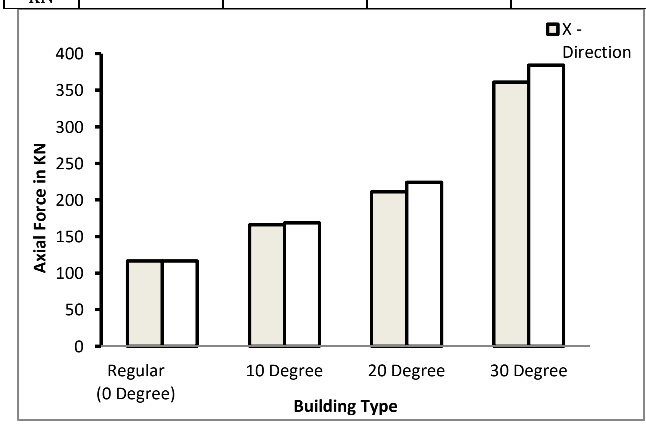
Specify the design code to be used through the Design > concrete Frame Design > View/Revise Preferences menu. Review the load combinations that will be used for design, making changes if necessary, through the Design > concrete Frame Design > Select Design Combos menu. Run the design by selecting the Design > concrete Frame Design > Start Design/Check of Structure option. Please note that analysis must be run prior to design. Review the design results either graphically, by right-clicking on a member for more detailed information, or in tabular format by selecting the Display > Show Tables > Design Data option.

4. Performance of the structure

The thesis addresses multi-storey reinforced concrete (R/C) frame buildings of regular, irregular and vertical irregular in elevation subjected to seismic and without seismic force. The buildings are designed as per IS: 1893(Part I): 2002 considering soil type-2. Analysis is performed on both the buildings and variation in response qualities such as; Shear force, bending moments, Displacement and Axial force in different structural element have been assessed.



VARIATION IN BASE SHEAR								
	Regular (0 Degree)		10 Degrees		20 Degrees		30 Degrees	
	X	Y	X	Y	X	Y	X	Y
SAP results in kN	778.46	778.46	875.35	840.10	970.91	909.75	1060.85	948.02
Manual results in kN	1926.044		1810.84		1726.643		1621.079	



Time period		
Structure	Manual calculations (in secs)	SAP2000 (in secs)
Regular (0 Degree)	0.7812	1.808
10 Degree		1.573
20 Degree		1.336
30 Degree		0.799

Conclusion

The three dimensional frame of regular zero-degree, 10-degree, 20-degree and 30-degree sloped building analyses have been performed to evaluate the performance of RC structural models with seismic loading as per the provisions of IS: 1893(part I)- 2002 and IS: 456-2000 and based on that work the following conclusions can be drawn:

The maximum shear force is experienced by the lower or bottom storey columns. As the slope of the ground is increasing the shear force of the structure is increasing. By the comparison of regular zero-degree structure with the 30-degree sloped structure it is observed that the shear force is increased by 81.513% in X direction and 78.865% in Y direction respectively.

As the slope of the ground is increasing the bending moment of the structure is increasing. By the comparison of regular zero-degree structure with the 30-degree sloped structure it is observed that the bending moment is increased by 60.401% in X direction and 59.032% in Y direction respectively.

The maximum displacement will occur at the roof level. As the slope of the ground is increasing the deflection of the structure is increasing. By the comparison of regular zero-degree structure with the 30-degree sloped structure it is observed that the deflection is increased by 62.038% in X direction and 62.154% in Y direction respectively.

The maximum axial force is at bottom storey. As the slope of the ground is increasing the axial force is increasing. By the comparison of regular zero-degree structure with the 30-degree sloped structure it is observed that the axial force is increased by 47.541% in X direction and 45.185% in Y direction respectively.

As the slope of the ground is increasing the time period of the structure is decreasing. By the comparison of regular zero-degree structure with the 30-degree sloped structure it is observed that the time period is decreased by 55.807%.

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