Design of Resilient Flood Resistant RC Structure in Sloped Areas

B Naveen Kumar[1], Mr. Eshwar Reddy H N[2]

[1]Postgraduate Student, Dept of civil Engineering, M S Ramaiah University of Applied Sciences, Bangalore, Karnataka, India- 560058.
[2]Associate Professor, Dept of civil Engineering, M S Ramaiah University of Applied Sciences, Bangalore, Karnataka, India- 560058.

Abstract:
Flooding, worsened by urban development in vulnerable areas, requires both structural and non-structural measures to manage risks. Current RC building codes like IS 456:2000 and ASCE 07-2002 address seismic and wind loads but often overlook flood-specific impacts. This project integrates flood loads into RC building analysis using CSI-ETABS, simulating flood conditions with a 3-meter depth and 3 m/s flow velocity across RC buildings on both flat and 20-degree slope surfaces with fixed-base and pile foundations. Key findings reveal that base shear increases by 51.9% in pile versus fixed foundations. Displacement rises by up to 8.26% in regular models on flat surfaces, while story acceleration increases by 12.34%, indicating heightened sensitivity to flood loads in certain configurations.
Further analysis highlights that bending moments are highest in 0-degree irregular models with pile foundations but decrease by 4.26% when comparing flood to earthquake loads. Vertical irregularities raise seismic risk by 25%, while regular models on a 20-degree slope with either fixed or pile foundations demonstrate greater stability. To ensure safety under flood and seismic loads, recommended structural dimensions include beams of 230 x 600 mm, columns of 500 x 500 mm, and a slab thickness of 150 mm. These results underscore the need to include flood load considerations in building codes to enhance urban resilience against severe flood events.

Keywords: Flood Resistant, IS456:2000, ASCE 07 2002, ETABS.

1. INTRODUCTION:

Severe flooding across India has highlighted critical gaps in flood management, particularly in rural areas where structural vulnerabilities are widespread. From 1953 to 2023, an average of 1.3 million homes sustained flood damage each year, emphasizing the urgent need for resilient housing solutions. Addressing these vulnerabilities requires the integration of robust foundations, flood-resistant materials, and advanced early warning systems. Flood-resilient design becomes even more complex for stepback buildings, which feature setbacks creating terraced shapes that pose structural challenges under lateral loads like floods and earthquakes. Such structures often struggle with torsional irregularity, uneven mass distribution, and lateral force resistance, making flood and seismic design more challenging. Key solutions include the use of shear walls, moment-resisting frames, and advanced structural analysis tools like ETABS, SAP2000, and STAAD Pro, which help maintain the integrity of these buildings in high-risk flood areas.

In this study, we analysed a G+10 stepback building on both flat and 20-degree sloped surfaces with various foundation types. Structural dimensions included beams of 250 x 300 mm, columns of 600 x 600 mm, and slabs with a thickness of 150 mm. Loads considered were dead, live, super dead, earthquake, and flood loads, in accordance with IS 875 Parts 1 and 3, IS 1893 Part 1, and ASCE 7-2000 for flood loads. Using Response Spectrum and Time History analyses based on the Bhuj Earthquake, we evaluated the structural performance of both flat and sloped configurations to determine their effectiveness in flood and seismic resilience.

2. OBJECTIVES:

The major objectives of the present work are:

- To study flood load and evaluate flood load on the structure.
- To perform an analysis and design a flood-resilient structure with various foundation types.
- To Compare of results on Flat surface and stepback buildings under the sloped area condition along with Soil structure Interaction.

3. PROBLEM STATEMENT:

The building configuration used for the study, with plan dimensions 25m×35m the data associated with G + 10 storey reinforced concrete building on flat and slope surface. Considered for the analysis, while the plan of the building is shown in Fig.1, in Fig.2, the direction of interest refers the perpendicular direction of flood.

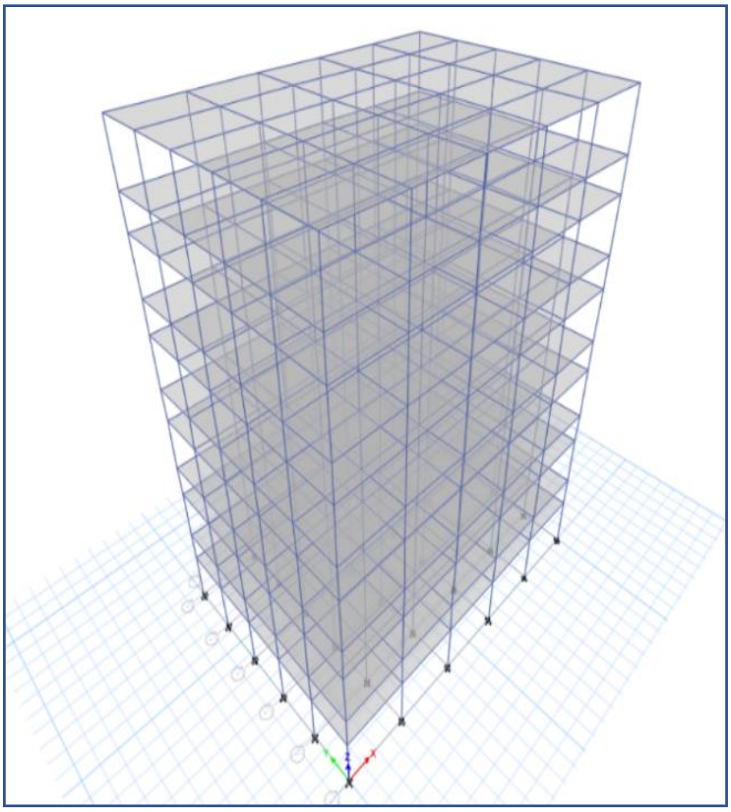


Figure 1 : Typical 3D plan of G+10 RC Flat Surface Building.

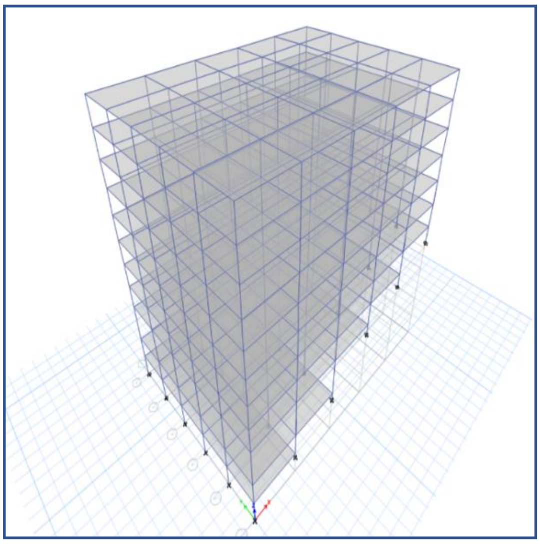


Figure 2: Typical 3D plan of G+10 RC 20° slope Surface Building.

The building has a total height of 33 meters above ground level, with each floor having a height of 3 meters. It consists of 5 bays in both the X and Y directions, with a bay width of 7 meters in the X direction and 5 meters in the Y direction. The columns are sized at 600 mm x 600 mm, while the beams are 230 mm x 500 mm. The slab thickness is 150 mm, with a total of 11 slabs throughout the structure.
The design parameters for the building include a live load of 3.0 kN/m² on typical floors and 1.5 kN/m² on the terrace, as per IS:875 (Part 2) - 1987. The floor finish load is 1.5 kN/m² on the terrace, in line with IS:875 (Part 2) - 1987, and waterproofing on the terrace is also considered at 1.5 kN/m² as per the same standard. Earthquake loads are accounted for according to IS:1893 (Part 1) - 2016, with the site located on Type II medium soil, as specified in clause 6.4.2.1 of IS 1893. The building is in Seismic Zone V, as per IS:1893 (Part 1) - 2016, with a damping ratio of 5%.

4. DYNAMIC LOADS:

4.1 TIME HISTORY METHOD:

The Bhuj Earthquake on January 26, 2001, at 08:46:42.9 IST, registered a magnitude of 7.0 (mb) and 7.6 (Ms). Data from the Ahmedabad station (latitude 23°02' N, longitude 72°38' E) was recorded on a N78E component accelerogram, filtered between 0.07 Hz and 27.0 Hz. Initial conditions included a velocity of -0.001411 m/s and a displacement of 3.97 mm. The peak acceleration recorded was -1.0382 m/s², occurring at 46.94 seconds, with a total of 26,706 acceleration data points (in m/s²) sampled at intervals of 0.005 seconds.

4.2 NEED FOR THE RESEARCH:

The purpose of this study is to evaluate the resistance and strength of high-rise building structures against flood conditions. A key focus is to compare the structural analysis for earthquake resistance with the analysis of flood-induced loads. Architects and engineers must understand how building design and structural features influence a building's response to hazards, particularly those associated with floodwaters.

5. MODELLING:

To compute the critical effect, the flood load was assumed to act along the 25-meter side of the building.

Eight different models were created for this analysis, as follows:

- DL+LL+SDL+ EQ – X, EQ – Y
- DL+LL+SDL + FL (1M).
- DL+LL+SDL + FL (2M).
- DL+LL+SDL + FL (3M).

6. CALCULATION OF HYDRODYNAMIC FORCES:[1]

Flood water velocities in the area of the house = 3 m/sec.

$dh = \frac{Cd}{2g} v^2$ → ASCE 7.2002 (pg. no: 18).

dh = Equivalent head due to low velocity flood flows (m).

C_d = Drag coefficient (from table).

V = Velocity of flood water (m/sec).

g = Acceleration of gravity (9.8 m/sec^2).

Drag coefficient C_d by calculating b/H.

b = 25m (Width of the Building)

H = 1.3 (Flood proofing design depth)

$\frac{b}{H} = \frac{25}{1.3} = 19.23$

$C_d = 1.3$

Table 1: Drag coefficient.

Width to height ratio (b/H)	Drag coefficient (C_d)
1 – 12	1.25
13 – 20	1.3
21 – 32	1.4
33 – 40	1.5
41 – 80	1.75
81 – 120	1.8
>120	2.0

$dh = \frac{1.3}{2x9.81} x\ 32 = 0.596.$

$f_{dh} = \gamma_W$ x dh x H x W

f_{dh} = Equivalent hydrostatic force due to low velocity flood flows (KN/m).

γ_W= Specific weight of water (9.8 KN/m^3).

dh = Equivalent head.

H = Flood proofing design depth (m).

W = width of the column.

f_{dh} = 9.8 x 0.596 x 1.3 x 0.6

= 4.56 KN/m.

Table 2: Calculations of Force due to low velocity flood flows.

Sl. No	H = Flood proofing design depth (m).	dh	$f_{dh} = \gamma_W$ x dh x H x W	f_{dh} acting at H/2
1	1.3	0.596	4.56	0.65
2	2.3	0.573	7.75	1.15
3	3.3	0.573	11.12	1.65

6.1 Calculation of wave load: [1]

$H_b = 0.78\ d_S$ → ASCE 7.2002 (pg. no: 19).
H_b = Breaking wave height.
d_S = Still water depth.
$F_D = 0.5 \times \gamma_W \times CD \times D \times Hb2$ → ASCE 7.2002 (pg. no: 19).
F_D = Net wave force (KN).
γ_W = Specific weight of water (9.8 KN/m^3).
C_D = Coefficient of drag for breaking waves.

$$\begin{pmatrix} \text{1.75 for round piles of columns} \\ \text{2.25 for square piles of columns} \end{pmatrix}$$

D = Column diameter for circular section.
(For square sections 1.4 times of width of column).
H_b = Breaking wave height (m).
$H_b = 0.78(dS)$ ∴ dS = 1m.
= 0.78(1)
= 0.78m.
$F_D = 0.5 \times 9.8 \times 2.25 \times (1.4\times0.6) \times (0.78)^2$
= 5.64

Table 3: Calculations of Breaking Wave Load on Columns.

Sl. No	$H_b = 0.78(d_S)$	$F_D = 0.5\gamma_W \times C_D \times D \times Hb^2$	Still water depth from GL (m)
1	0.78	5.64	1
2	1.56	22.56	2
3	2.34	50.76	3

6.2 Calculation of Impact Load: [1]

$F_i = W \times V \times C_D \times C_B \times C_{Str}$
F_i = Impact force (KN)
W = Weight of object (KN) = 5KN.
V = Velocity of water = 3m/sec.

C_D =Depth coefficient.
C_B = Block coefficient.
C_{Str} = Building structure coefficient.
=0.2 for timber pile and masonry column supported structures 3 stories or less in height above grade.
= 0.4 for concrete pile or concrete or steel moment resisting frames 3 stories or less in height above grade.
= 0.8 for reinforced concrete (including insulated concrete) and reinforced masonry foundation walls.

Table 4: Depth Coefficient (C_D) by Flood Hazard Zone and Water Depth.

Flood Hazard Zone and Water Depth	C_D
Floodway or Zone V	1.0
Zone A, Stillwater flood depth > 5ft	1.0
Zone A, Stillwater flood depth = 4ft	0.75
Zone A, Stillwater flood depth = 3ft	0.5
Zone A, Stillwater flood depth = 2ft	0.25
Zone A, Stillwater flood depth < 1ft	0.0

Table 5: Values of Blockage Coefficient (CB).

Degree of Screening or Sheltering with 100ft upstream	C_B
No upstream screening, flow path wider than 30ft	1.0
Limited upstream screening, flow path 20ft wide	0.6
Moderate upstream screening, flow path 10ft wide	0.2
Dense upstream screening, flow path less than 5ft wide	0.0

F_i = 5 x 3 x 1.0 x 1.0 x 0.8
= 12.
F_R = Resultant force.
F_D = Net wave force.
F_i = Impact force.

Table 6: Calculations of Resultant Force at Still Water Depth.

Sl. No	Resultant force (F_R) = F_D+F_i (KN)	Still water depth from GL (m)
1	5.64 + 12 = 17.64	1
2	22.56 + 12 = 34.56	2
3	50.76 + 12= 62.76	3

7. ANALYSIS OF MODEL:

The procedure includes both linear static and linear dynamic analysis. For seismic evaluation, these methods determine the design seismic forces, load distribution across the building height, and corresponding displacements through linearly elastic analysis. The steps for performing the analysis in CSI ETABS are as follows:

- **Frame Section Modelling:** Develop the structural model with frame sections.
- **Defining Material and Section Properties:** Specify materials and cross-sectional properties.
- **Assigning Support Conditions:** Define support conditions for the model.
- **Defining Load Patterns and Cases:** Establish relevant load patterns and load cases.
- **Assigning Load Combinations:** Apply necessary load combinations for accurate analysis.
- **Configuring Analysis Settings:** Set up analysis options in ETABS.
- **Running the Analysis:** Execute the analysis process.
- **Interpreting Results:** Analyse and interpret the resulting data.

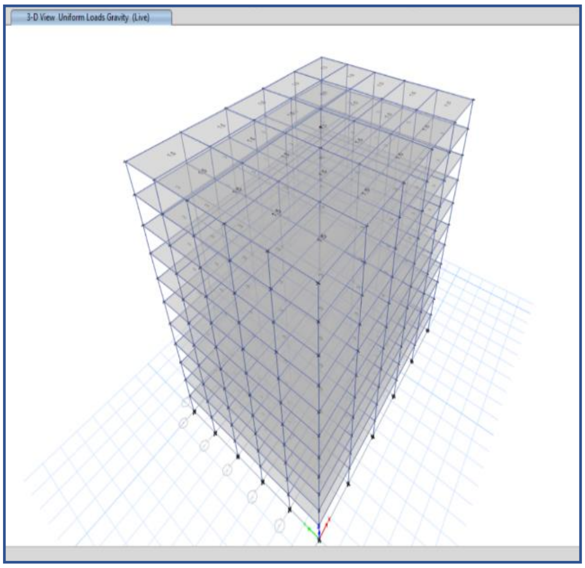


Figure 3: Assigning live load on slabs

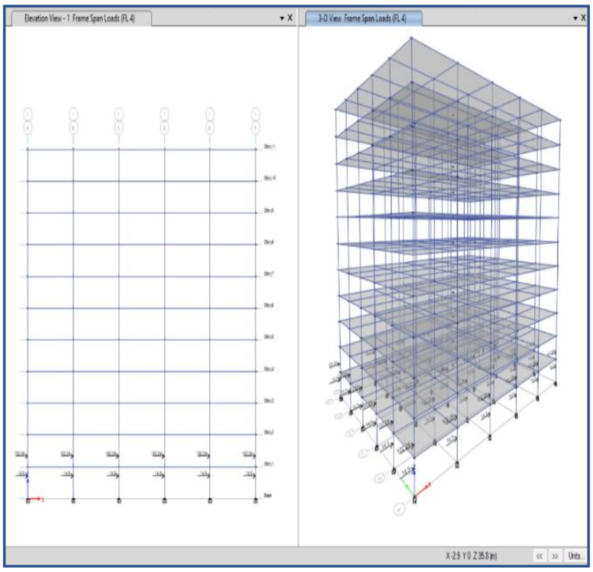


Figure 4: Applying flood load on structure along x direction of flood flow for flat.

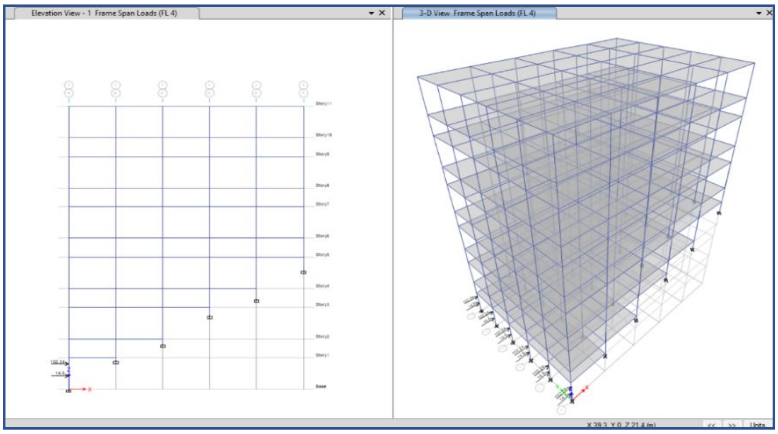


Figure 5: Applying flood load on structure along X direction of flood flow for 20 degree.

8. RESULT AND DISCUSSION:

8.1 BENDING MOMENT:

Comparing the maximum bending for the flat and 20-degree slope surface with fixed base & pile for regularity and irregularity buildings.

Maximum Bending moment was observed to be highest in the 0-degree irregular model with a pile foundation, while it was significantly lower in the 20-degree regular model with a fixed base. Maximum Bending moment was found to be decrease by up to 4.26% when comparing the Earthquake loads and Flood loads.

Table 7: Comparing the maximum Bending moments.

Maximum Bending Moment KN-mm		
Model	**Earthquake load**	**Flood loads**
0° with Fixed base for regular Structure	1355904.45	1279707.54
0°with Pile Foundation for Regular Structure	1352527.55	1279707.54
0° with Fixed base for irregular Structure	1512098.75	1481133.44
0° with Pile foundation for irregular Structure	1510156.46	1417424.17
20° with Fixed base for regular Structure	635944.50	599016.82
20°with Pile Foundation for Regular Structure	638397.88	596817.42
20° with Fixed base for irregular Structure	716721.78	677119.40
20° with Pile Foundation for irregular Structure	720744.81	673981.39

8.2 TIME HISTORY ANALYSIS:

8.2.1 BASE SHEAR:

Table 8: Comparing Base Shear values.

Base Shear, KN								
Model	**Regular Structure**				**Irregular Structure**			
	Fixed base		**Pile Foundation**		**Fixed base**		**Pile Foundation**	
	X direction	**Y direction**	**X direction**	**Y direction**	**X direction**	**Y direction**	**X direction**	**Y direction**
0°	4452.4	8454.7	11083.6	11065.6	4543.9	3904.7	5511.7	6170.9

20°	9684.5	8598.7	16470.9	12138.3	7544.1	6248.9	12045.3	6846.1

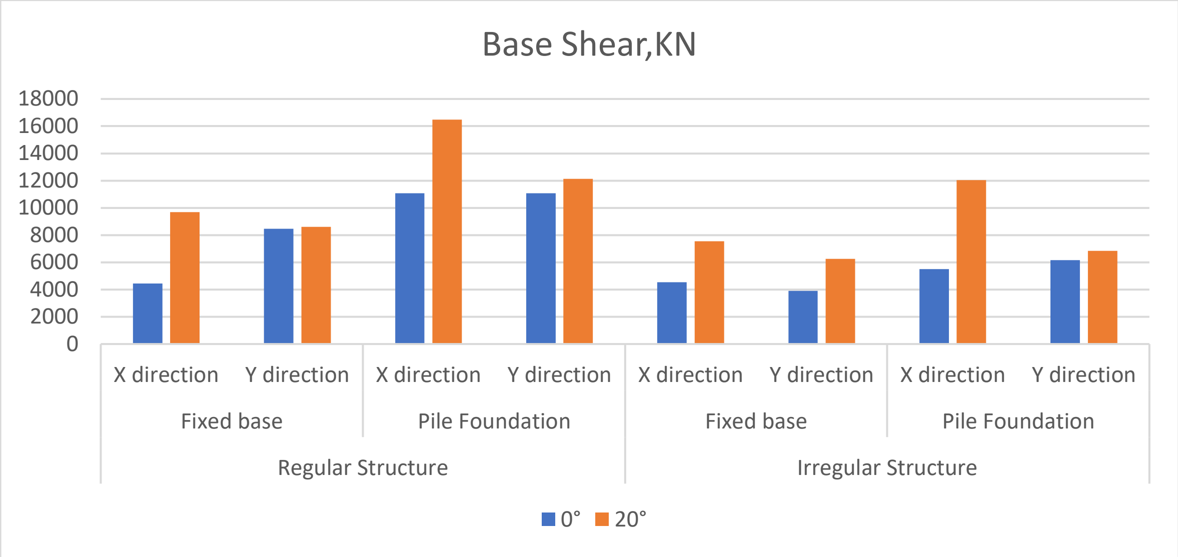


Figure 6: Comparing the Base Shear values.

The base shear was observed to be highest in the 20-degree regular model with a pile foundation, while it was significantly lower in the 0-degree irregular model with a fixed base. The overall average percentage difference between fixed base and pile foundation across both regular and irregular structures is approximately 51.9**%**.

8.2.2 STOREY DISPLACEMENT:

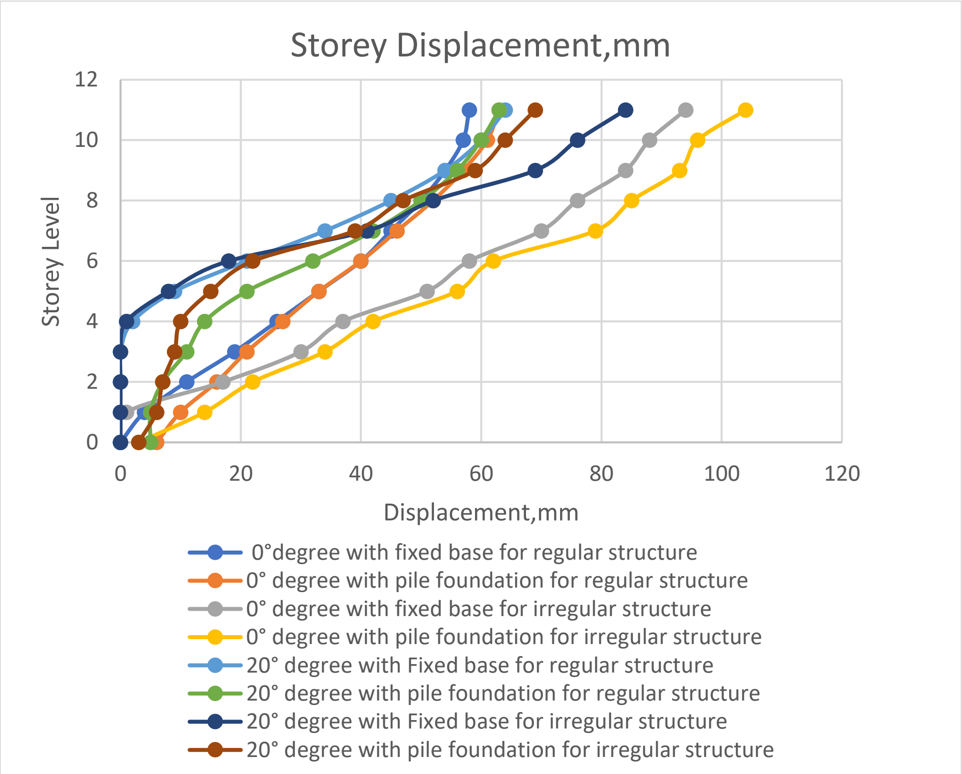


Figure 7: Comparison of Displacement values.

Storey Displacement was observed highest for 0-degree models both in regular and irregular configuration with fixed base, pile foundation. Where 20-degree models observed lower. Storey Displacement was found to be increase by up to 8.26% when comparing the fixed base to the pile foundation in regular models. Storey Displacement was found to be decrease by up to 10.1% when comparing the fixed base to the pile foundation in irregular models.

8.2.3 STOREY ACCELERATION:

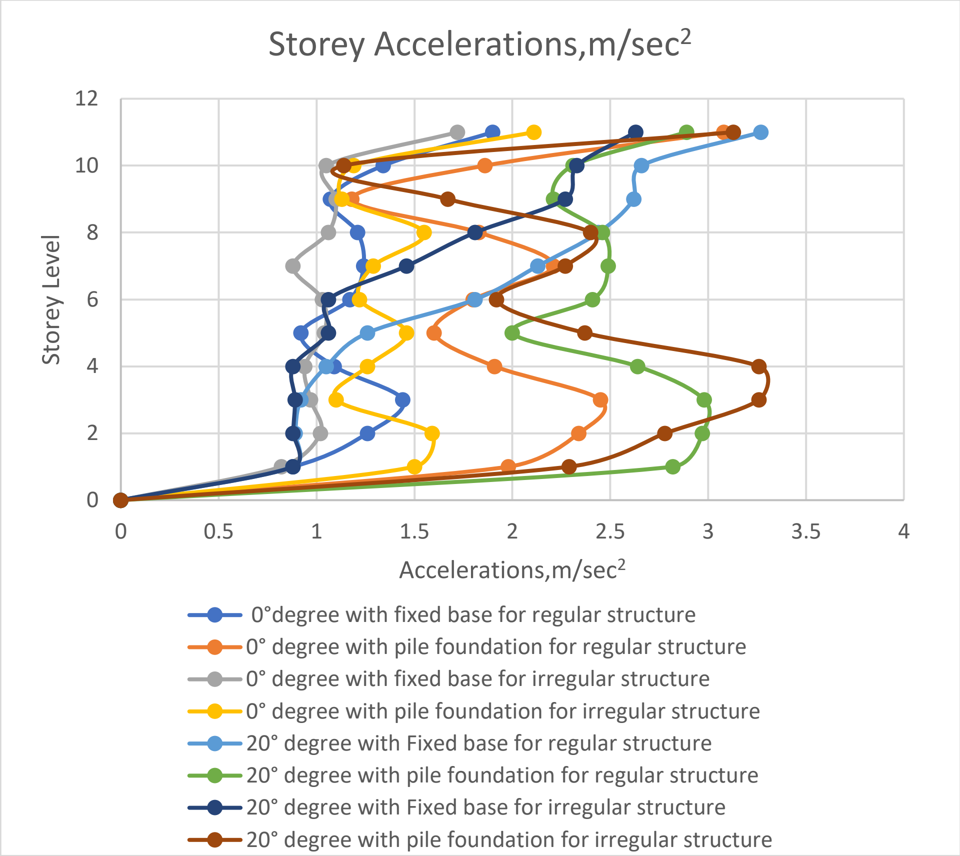
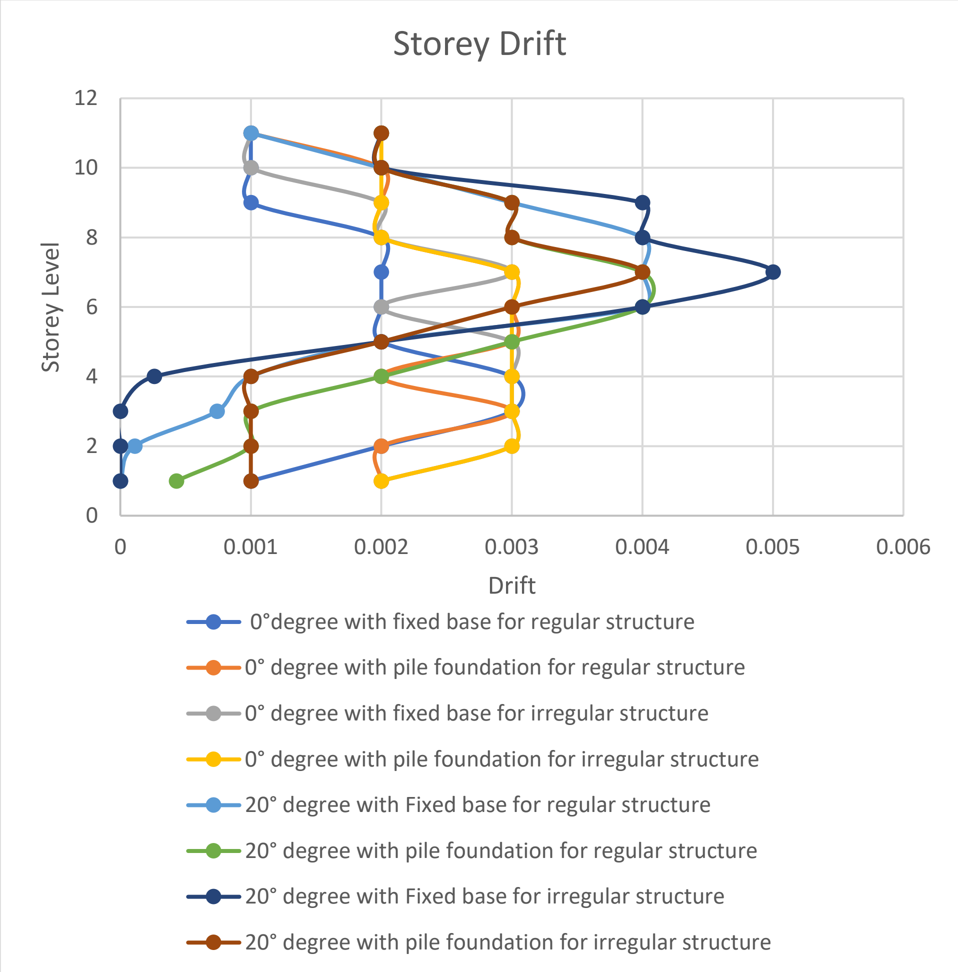


Figure 8: Comparison of Storey Acceleration values.

Storey acceleration was highest in the 20-degree irregular model with a pile foundation, while it was significantly lower in the 0-degree regular model with a Pile Foundation. Storey acceleration increased by up to 12.34% when comparing the fixed base to the pile foundation in regular models, and by up to 17.36% in irregular models.

8.2.4 STOREY DRIFT:



The highest storey drift was observed in irregular structures at a 20° angle, with a 20% reduction when using a pile foundation (from 0.005 to 0.004). In regular structures, the maximum drift remained consistent at 0.004 for both foundation types, while the lowest drift was recorded at storey 1 with a pile foundation at 0.00043. Pile foundations improved stability in irregular structures, while regular structures showed negligible variation.

9. CONCLUSION:

Accurate structural analysis is essential for designing any building. Engineers consider dead loads, live loads, earthquake loads and other applicable forces. With the revision of IS 1893: 2016, structures must now be evaluated for anticipated earthquake loads according to prescribed seismic zones. However, despite floods being a significant natural hazard like earthquakes, there is no standardized procedure for calculating flood-induced loads on structures, including those on sloped surfaces. Given climate change and the increasing frequency of floods, it is crucial to assess the capacity of both level and sloped structures to withstand flood loads, ensuring they remain resilient under such conditions.

- The maximum bending moment was highest in the 0-degree irregular model with a pile foundation and significantly lower in the 20-degree regular model with a fixed base.
- Bending moments decreased by up to 4.26% when comparing earthquake loads to flood loads.
- Storey displacement was highest for 0-degree models in both regular and irregular configurations with fixed bases and pile foundations, while 20-degree models showed lower values.

- Storey displacement increased by up to 8.26% when comparing fixed bases to pile foundations in regular models.
- Storey displacement decreased by up to 10.1% when comparing fixed bases to pile foundations in irregular models.
- Storey acceleration was highest in the 20-degree irregular model with a pile foundation and significantly lower in the 0-degree regular model with a pile foundation.
- Storey acceleration increased by up to 12.34% in regular models and 17.36% in irregular models when comparing fixed bases to pile foundations.
- The highest storey drift was observed in irregular structures at a 20° angle, with a 20% reduction when using a pile foundation. Regular structures showed a consistent maximum drift of 0.004, and the lowest drift was 0.00043 at storey 1 with a pile foundation.
- 20-degree configuration for both regular and irregular models (with either a fixed base or pile foundation) is optimal for stability and seismic performance, particularly under Time History Analysis in Zone III. Therefore, adopting a 20-degree surface structure is recommended as it ensures safety and reliability within this seismic zone.
- The assumed dimensions for structural elements: Beams: 230 mm x 600 mm, Columns: 500 mm x 500 mm, Slab: 150 mm thick. These are safe for various load combinations and fall within the safe zone based on analysis.

10. REFERENCES:

1. Shelar, V. & Sanket, S. (2023) ‘Behaviour of Flood Resistant Building and Ductile Detailing of G+7 RC Building Using IS 13920 - 2016’, World Journal of Advanced Engineering Technology and Sciences.
2. Davkare, A., Prasad, C., & Patil, L. (2023) ‘Flood Resistant Design of the RC Multi-Storey Building’, International Research Journal of Modernization in Engineering Technology and Science.
3. Singh, A., Sharma, P., Krishnaraj, L. & Kumar, V.P. (2021) ‘Design and Analysis of Flood Resisting Residential Building: A Case Study in Malappuram-KERALA’, Journal of Engineering Research, ACMM Special Issue 10.
4. Pawar, R.M. & Sohani, S.B. (2017) ‘Analysis of Setback Step-Back Building Resting on Sloping Ground’, Journal of Emerging Technologies and Innovative Research.
5. Likhitharadhya, Y.R., Praveen, J.V., Sanjith, J. & Ranjith, A. (2016) ‘Seismic Analysis of Multi-Storey Building Resting on Flat Ground and Sloping Ground’, International Journal of Innovative Research in Science, Engineering and Technology, 5(6).
6. Jarapala, R. & Biswal, K.C. (2020) ‘Dynamic Behavior of Vertically Irregular Sloping Ground Buildings’, Asian Journal of Civil Engineering.
7. Babu, K.V. (2023) ‘Seismic Analysis of Multi-storey Building on Sloping Ground and Flat Ground Using ETABS’, IOP Conference Series: Earth and Environmental Science.
8. Waiker, M.L. & Mehboob, S.S. (2021) ‘Seismic Evaluation of High-Rise Building with Vertical Irregularities by Pushover Analysis’, International Journal of Engineering Applied Sciences and Technology.
9. Kiran, K.S. & Suresh, G. (2018) ‘Seismic Analysis and Design of Vertically Irregular RC Building Frames’, International Journal of Innovative Technology and Research.

10. Bansal, H. & Gagandeep (2012) ‘Seismic Analysis and Design of Vertically Irregular RC Building Frames’, International Journal of Science and Research.
11. Bureau of Indian Standards (2000) IS 456: 2000 Plain and Reinforced Concrete Code of Practice.
12. Bureau of Indian Standards (1987) IS 875 (Part 1): Code of Practice for Design Loads for Building and Structures (Dead Loads).
13. Bureau of Indian Standards (1987) IS 875 (Part 2): Code of Practice for Design Loads for Building and Structures (Imposed Loads).
14. Bureau of Indian Standards (2002) IS 1893 (Part 1): Criteria for Earthquake Resistant Design of Structures.
15. Bureau of Indian Standards (1993) IS 13920: Ductile Detailing of RCC Structures Subjected to Earthquake Forces.
16. American Society of Civil Engineers (2016) ASCE 7-16: Minimum Design Loads and Associated Criteria for Buildings and Other Structures, Reston, VA: ASCE.