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Research Article

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Comparative Study of Regular and Irregular RC Structure in Different Seismic Zones and Soil Types

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Abstract

The resistivity of lateral forces (Wind and Seismic loading) by any structure is very much challenging. It is also one of the reasons for the failure of the reinforced concrete (RC) structure due to its asymmetric distribution of mass, strength, stiffness, and non-uniform geometrical configurations. Knowing the effect of various soils in the construction of RC structures is essential to determine the structural performance in the presence of seismic load ahead of construction. This research aims to compare regular and irregular RC structures in different seismic zones, and soil types with the provisions suggested in IS code 1893(part1):2016 and IS 875(part3):2015 using STAAD Pro V8i. Research work calculated the critical design loading for multi-story buildings put through basic wind speeds of 50 m/s and seismic zones (II, III, IV, V). The response of a G+20 storeyed RC framed building to seismic loads is examined using Indian Standard code IS 1893(part1):2016 and wind loads using Indian Standard code IS 875(part3):2015.

Keywords: Regular and Irregular Structure, Soil Types, Storey Displacement

Introduction

It is impossible to avoid irregularities during building construction. However, it's crucial to study how these atypical constructions respond to earthquakes [1]. The primary goal of earthquake engineering is to develop and build the structures so that damage to the structure and its components are minimal during an earthquake by taking the necessary steps during design and construction [2]. Regardless of whether the same structural configuration when the earthquake occurred, the damage to the structures is not proportional. Several factors define the seismic behaviour of the structure, its structural system, earthquake characteristics, construction and material quality, site soil location, repair, and maintenance [3]. However, based on knowledge from previous and current earthquakes, most damages are interconnected to structural and architectural arrangements in both plan and elevation of the structures. The infrastructure of existing urban areas is primarily made up of irregular structures[4-5]. Since earthquakes create inertia forces that are proportional to the mass of the building, the mass of the structure being built determines the structure's stiffness and seismic design [6]. Buildings designed to respond elastically to earthquakes without damage make the project economical [7]. Therefore, it could be required for the building to sustain damage to release the energy applied to it during the earthquake [8]. As a result, the conventional idea of earthquake-resistant design recommends that regular buildings should be strong enough to withstand: (1) Small shaking that causes no harm to the structure's components, (ii) Moderate shaking with minor structural damage to components, and (i) Severe shaking with structural components damaged but no collapse. Buildings are, therefore, only built to withstand between 8-14 % of the force they would have to encounter if they were constructed to remain elastic throughout the probable future intense ground shaking, allowing damage [6-9]. However, it is necessary to ensure sufficient initial stiffness to prevent structural damage during small shaking. Thus, seismic design maintains a balance between acceptable damage and greater efficiency to ensure the project's performance [10-11]. Therefore this balance was reached due to considerable research in post-earthquake damage assessment investigations [12]. A more comprehensive range of this knowledge is turned into accurate earthquake design provisions. However, structural damage is unacceptable when subjected to design wind forces. Because of this, designing against the effects of earthquakes is referred to as earthquake-resistant rather than earthquake-proof design [13]. Hence, the present study was undertaken with the prime objective of (i) to model regular and irregular buildings under different seismic zones, wind load and soil types using STAAD Pro software, and (ii) to compare the results of Shear force, Bending moment, Storey displacement.

Methodology

Earthquake

Seismic analysis is a part of structural analysis and structural design in an area prone to earthquakes (Fig.1). Various earthquake analysis methods are available for analysing structures for dynamic loading conditions.

I. Equivalent Static Lateral Force Method
II. Dynamic analysis.
a. Response spectrum method.
b. Time history method.

The IS code 1893 (Part-1):2016 equivalent lateral force method is used in this study.

Equivalent static method

The equivalent static method is also known as the seismic coefficient method. This simplest method requires fewer mathematical computations for simple and regular structures. The dynamic load must be considered during the analysis against seismic forces [14]. Formulas are given in most of the codes of practice for low or medium-rise structures. The following steps are required for the computation of structure by the equivalent static method:

I. First of all, for complete structure, base shear is calculated.
II. Base shear is distributed throughout the building's height.
III. The resultant lateral forces are distributed to specific lateral load resisting devices at each floor level [15].

Design seismic base (Vb) can be expressed as:

$V_b = A_h \times W$

Where,
A_h = Basic horizontal seismic coefficient
V_b = Base shear
W = seismic weight of the building
$A_h = (Z\ I\ S_A)/(2\ R\ g)$

Where,
R= Response Reduction Factor
I= Importance Factor
SA/g = Spectral Acceleration
A = Acceleration of earthquake at the base of the structure
g = Acceleration due to gravity
Z=Zone Factor

Distribution of Base Shear:

$Q_i = (V_b * W_j * h_j^2) / (\sum W_j * h_j^2)$

Where,
W_j= seismic weight of the jth floor
V_b =base shear
h_j =height of jth floor from the base
n =number of storey

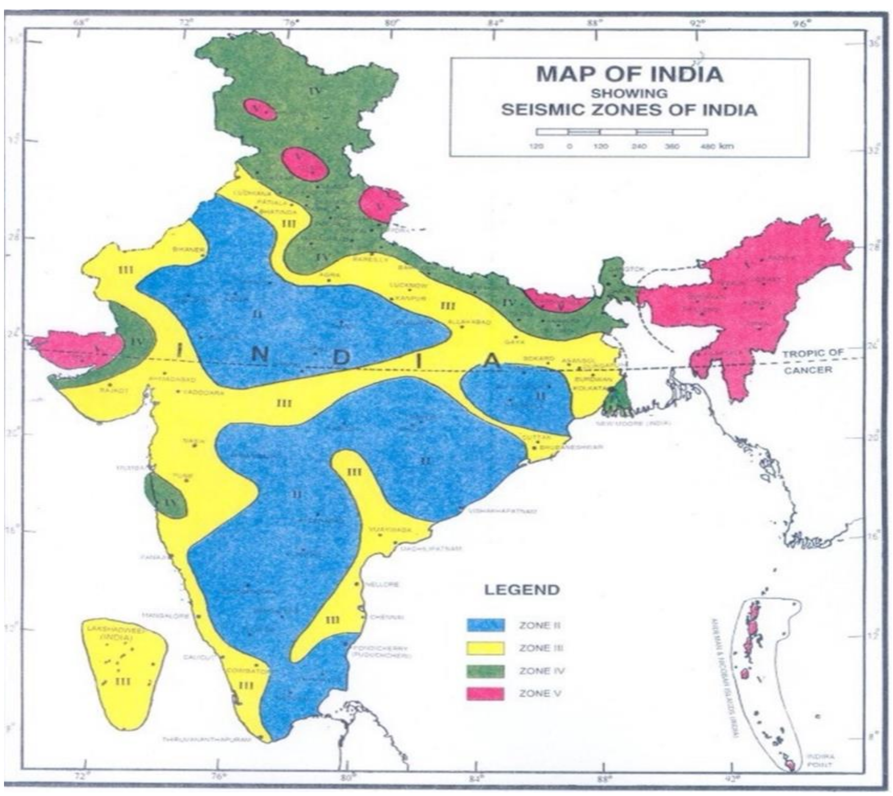


Figure 1: Seismic zoning map of India

Response Spectrum Method

In engineering, the term spectrum signifies the concept that the response of structures over a wide range of time is represented in a single graph. The procedure must be carried out using the design spectrum given in the code for a structure created at a project site. For dynamic analysis of steel and reinforced concrete buildings, the damping values for buildings may be regarded as 5 % of the critical value [16-18]. An inelastic analysis is more appropriate for design because it can be anticipated that an inelastic response will happen during a big earthquake for most buildings. Despite the availability of nonlinear inelastic programmes, they are not used in common design practice for the following reasons:

i. Understanding their fundamental workings and theories is essential for unlimited usage.

ii. The created design and results are challenging to evaluate and apply to conventional design criteria

iii. The calculations required are expensive [19-22].

As a result, analysis in practical situations often uses linear elastic techniques based on the response spectrum method. The suggested method is response spectrum analysis as it is simpler to use.

Time History Method

The application of this method must be performed using recommended dynamics concepts and on a suitable ground motion. In this technique, accelerations from earthquake ground motions that simulate the anticipated earthquake at the base of the structure are evaluated to the mathematical model of the structure [23-25].

Wind load

The Indian standard code IS: 875 (Part 3) is used to check and design loads for structures.

Design wind velocity is calculated from,

$Vz = Vb\times k1\times k2\times k3$

Where,

K1 = risk coefficient (clause 5.3.1)

K2 = topography, structure dimension factor and height factor (clause 5.3.2)

K3 = topography factor (clause 5.3.3)

Vz = designed wind velocity at any elevation z in m/s

Vb = basic wind velocity in m/s

The relationship between wind pressure and wind speed can be used to calculate the design wind pressure at any elevation above mean ground level.

$Pz = 0.60Vz2$

Where,

Pz = designed wind pressure at elevation z in N/m2

Vz = designed wind velocity at elevation z in m/s

Modelling

Modelling of structure

In the present study, a total of 24 RC frame structures (Fig. 2a-b) of 20 storey are evaluated, consisting of 12 models in regular frame building and 12 models in irregular frame building. In 12-storey, 3 RC frame structures (Fig. 3a-b) in each seismic zone and wind speed of 50m/s with different types of soil such as hard, medium, and soft soil with topography category II, response reduction factor 5, effective damping 5%, and importance factor 1. The 3D model (Fig. 4a-b) has been analyzed and designed by software STAAD Pro by applying loads per Indian norms. IS 456:2000, IS 1893(part1):2016 and IS 875(part3):2015.

Types of models

1. Seismic Zone II:

Regular and Irregular structures in Soft soil

Regular and Irregular structures in Medium soil

Regular and Irregular structures in Hard Soil

2. Seismic Zone III:

Regular and Irregular structures in Soft soil

Regular and Irregular structures in Medium soil

Regular and Irregular structures in Hard Soil

3. Seismic Zone IV:

Regular and Irregular structures in Soft soil

Regular and Irregular structures in Medium soil

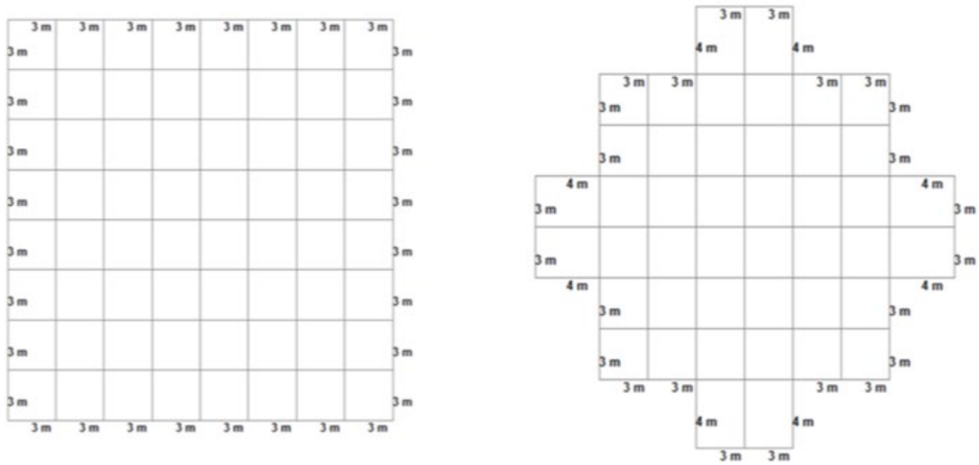
Regular and Irregular structures in Hard Soil

4. Seismic Zone V:

Regular and Irregular structures in Soft soil

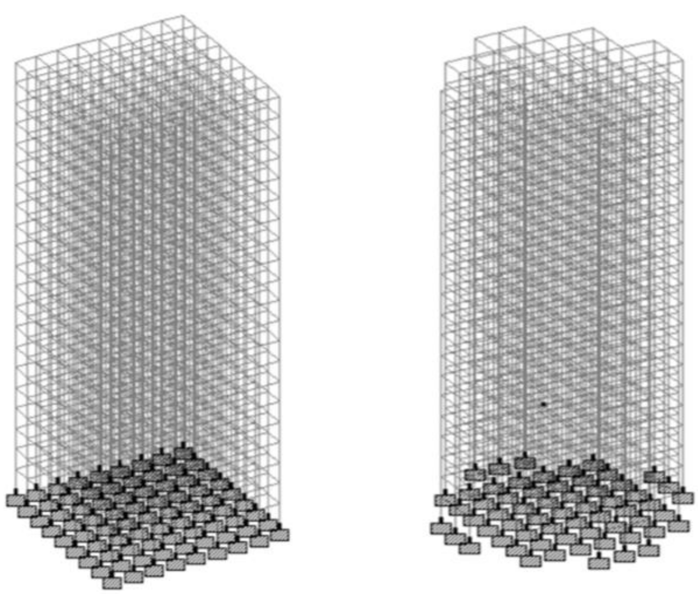
Regular and Irregular structures in Medium soil

Regular and Irregular structures in Hard Soil



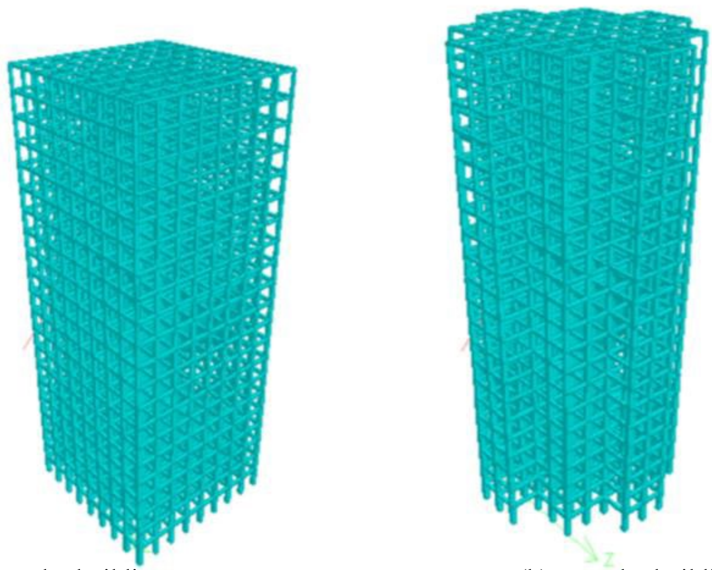
(a) Regular building (b) Irregular building

Figure 2: Plan of (a) regular building and (b) irregular building



(a) Regular building (b) Irregular building

Figure 3: Isometric View of (a) regular building and (b) irregular Building



(a) Regular building (b) Irregular building

Figure 4: 3D Frame of (a) regular building and (b) irregular building

The complete description of the parameters uesd i.e., type of structure, zones, soil type, building dimensions, grade of concrete & steel and type of loading is given below in tabular form (Table 1).

Table 1: Design Data Used In Regular and Irregular Building Design

S.NO	PARAMETERS	DESCRIPTION			
1	Model	G+20			
2	Type of Structure	Regular and Irregular			
3	Seismic Zone	II	III	IV	V
4	Terrain Category	II			
5	Wind Velocity	50 m/s			
6	Soil Type	Hard	Medium	Soft	
7	Length x Width x Height	Regular		24x24x63 m	
		Irregular		26x26x63 m	
8	Floor to Floor Height	3 m			
9	Column Size	600x600 mm		G to 5th	
		500x500 mm		6th to 11th	
		400x400 mm		12th to 16th	
		300x300 mm		17th to 20th	
10	Beam Size	600x300 mm		G to 5th	
		500x300 mm		6th to 11th	
		400x300 mm		12th to 16th	
		300x300 mm		17th to 20th	
11	Wall Thickness	Main wall		250 mm	
		Partition wall		125 mm	
12	Slab Thickness	125 mm			
13	Depth of Foundation	3m			
14	Grade of Concrete and Steel	M30 & Fe 550			
15	Loading	DL		16.5KN/m2	
		LL		2KN/m2	
		Floor Weight		5KN/m2	

Dead load calculation

As per IS 875 (Part-1), 2016
Unit weight of Bricks = 19.2 kN/m3
Unit Weight of Plaster = 20 kN/m3
Height of each floor = 3m
The thickness of the wall = 250 mm
Thickness of Plaster (Inside+Outside)=(20+15)=35mm

Dead load due to Walls = 0.25x3x1x19.2 = 14.4 kN/m
Dead Load due to Plaster = 3x0.035x20 = 2.1 kN/m

Total Dead Load = 14.4+2.1 = 16.5 kN/m

Live load calculation

As Per IS 875 (Part 2)
Live Load = 2 kN/m

Seismic load calculation

As Per IS 1893(Part 1)

Wind load calculation

As per IS 875 (Part-3) 2016
Terrain Category = II
Basic Wind Speed, Vb = 50 m/s
K1 = probability/Risk coefficient or factor
K2 = topography, structure dimension factor and height factor
K3 = topography (terrain) factor
Design Wind Speed, Vz = Vb K1 K2 K3
Design Wind Pressure, Pz = 0.6 Vz2

The calculation of wind velocity and wind pressure used in the regular and irregular structure is given below in tabular form (Table 2).

Table 2: Wind pressure used in Regular and Irregular Structures

S No.	Height (m)	Vb (m/s)	K1	K2	K3	Vz (m/s)	Pz (kN/m2)
1	3	50	1	1	1	50	1.5
2	15	50	1	1.05	1	52.5	1.6537
3	30	50	1	1.12	1	56	1.8816
4	45	50	1	1.1575	1	57.875	2.0097
5	63	50	1	1.1882	1	59.41	2.1177

Result and Discussion

This chapter deals with results and discussion of RC building with Regular and Irregular configurations in each zone and soil type. Discussions are made based on the following parameters:

I. Shear force
II. Bending moment
III. Storey displacement

Axial force, shear force and bending moment

The result obtained by the analysis regarding the structural behaviour of regular and irregular buildings in Zone V with soft, medium and hard soil are tabulated below (Table 3):

Table 3: Comparison of SF and BM of Regular and Irregular structure in Zone V

Soft Soil		
Parameter	**Irregular**	**Regular**
Max Fx	6147.842 KN	6177.583 KN
Max Fy	206.589 KN	180.968 KN
Max Fz	140.762 KN	115.855 KN
Max Mx	5.250 KNm	1.085 KNm
Max My	212.434 KNm	194.458 KNm
Max Mz	272.448 KNm	216.307 KNm
Medium Soil		
Parameter	Irregular	Regular
Max Fx	6147.842 KN	6177.583 KN
Max Fy	184.755 KN	165.193 KN
Max Fz	119.707 KN	97.070 KN
Max Mx	4.976 KNm	1.085 KNm
Max My	181.210 KNm	159.298 KNm
Max Mz	244.550 KNm	192.814 KNm

Hard Soil		
Parameter	Irregular	Regular
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	148.325 KN
Max Fz	106.846 KN	78.479 KN
Max Mx	4.658 KNm	1.085 KNm
Max My	196.918 KNm	118.559 KNm
Max Mz	223.152 KNm	165.531 KNm

The result obtained by the analysis regarding the structural behaviour of regular and irregular buildings in Zone IV with soft, medium and hard soil are tabulated below (Table 4):

Table 4: Comparison of SF and BM of Regular and Irregular structure in Zone IV

Soft Soil		
Parameter	**Irregular**	**Regular**
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	153.635 KN
Max Fz	106.846 KN	84.332 KN
Max Mx	4.575 KNm	1.085 KNm
Max My	171.333 KNm	131.364 KNm
Max Mz	223.152 KNm	174.120 KNm
Medium Soil		
Parameter	Irregular	Regular
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	143.951 KN
Max Fz	106.846 KN	73.659 KN
Max Mx	4.575 KNm	1.085 KNm
Max My	171.333 KNm	115.274 KNm
Max Mz	223.152 KNm	158.458 KNm
Hard Soil		
Parameter	Irregular	Regular
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	139.547 KN
Max Fz	106.846 KN	68.681 KN
Max Mx	4.363 KNm	1.085 KNm
Max My	171.333 KNm	115.274 KNm
Max Mz	223.152 KNm	151.147 KNm

The result obtained by the analysis regarding the structural behaviour of regular and irregular buildings in Zone III with soft, medium and hard soil are tabulated below (Table 5):

Table 5: Comparison of SF and BM of Regular and Irregular structure in Zone III

Soft Soil		
Parameter	**Irregular**	**Regular**
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	139.547 KN
Max Fz	106.846 KN	68.681 KN
Max Mx	4.286 KNm	1.085 KNm
Max My	171.333 KNm	115.274 KNm
Max Mz	223.152 KNm	151.147 KNm
Medium Soil		
Parameter	Irregular	Regular
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	139.547 KN
Max Fz	106.846 KN	68.681 KN
Max Mx	4.286 KNm	1.085 KNm
Max My	171.333 KNm	115.274 KNm
Max Mz	223.152 KNm	151.147 KNm
Hard Soil		
Parameter	Irregular	Regular
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	139.547 KN
Max Fz	106.846 KN	68.681 KN
Max Mx	4.286 KNm	1.085 KNm
Max My	171.333 KNm	115.274 KNm
Max Mz	223.152 KNm	151.147 KNm

The result obtained by the analysis regarding the structural behaviour of regular and irregular buildings in Zone II with soft, medium and hard soil are tabulated below (Table 6):

Table 6: Comparison of SF and BM of Regular and Irregular structure in Zone II

Soft Soil		
Parameter	**Irregular**	**Regular**
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	139.545 KN
Max Fz	106.846 KN	68.681 KN
Max Mx	4.286 KNm	1.085 KNm
Max My	171.333 KNm	115.267 KNm
Max Mz	223.152 KNm	151.142 KNm
Medium Soil		
Parameter	Irregular	Regular
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	139.547 KN
Max Fz	106.846 KN	68.681 KN
Max Mx	4.286 KNm	1.085 KNm
Max My	171.333 KNm	115.274 KNm
Max Mz	223.152 KNm	151.147 KNm

Hard Soil		
Parameter	Irregular	Regular
Max Fx	6147.842 KN	6177.583 KN
Max Fy	170.075 KN	139.547 KN
Max Fz	106.846 KN	68.681 KN
Max Mx	4.286 KNm	1.085 KNm
Max My	171.333 KNm	115.275 KNm
Max Mz	223.152 KNm	151.147 KNm

This graph (Fig. 5) shows the plot of maximum shear force values in y-direction for the regular and irregular model in zone II, III, IV, V with hard, medium and soft soil.

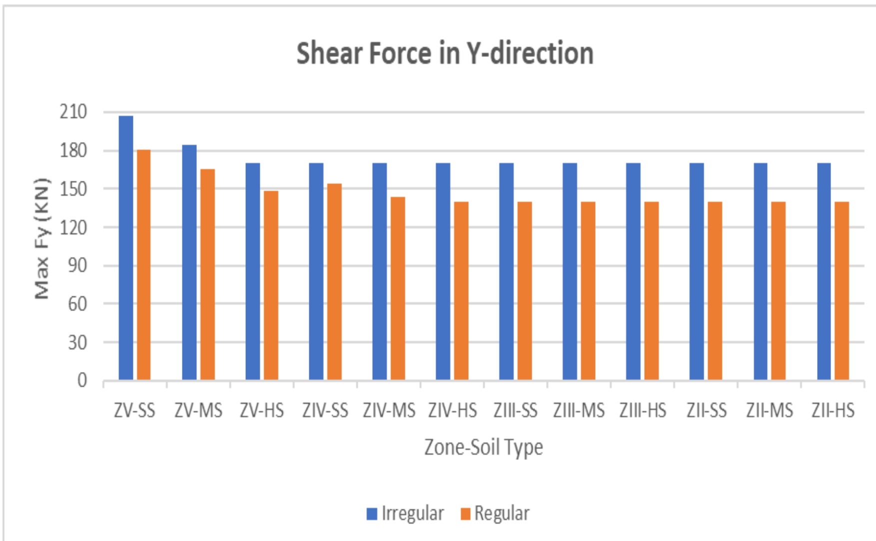


Figure 5: Shear Force in Y- direction of regular and irregular model

This graph (Fig. 6) shows the plot of maximum shear force values in z-direction for the regular and irregular model in zone II, III, IV, and V with hard, medium and soft soil.

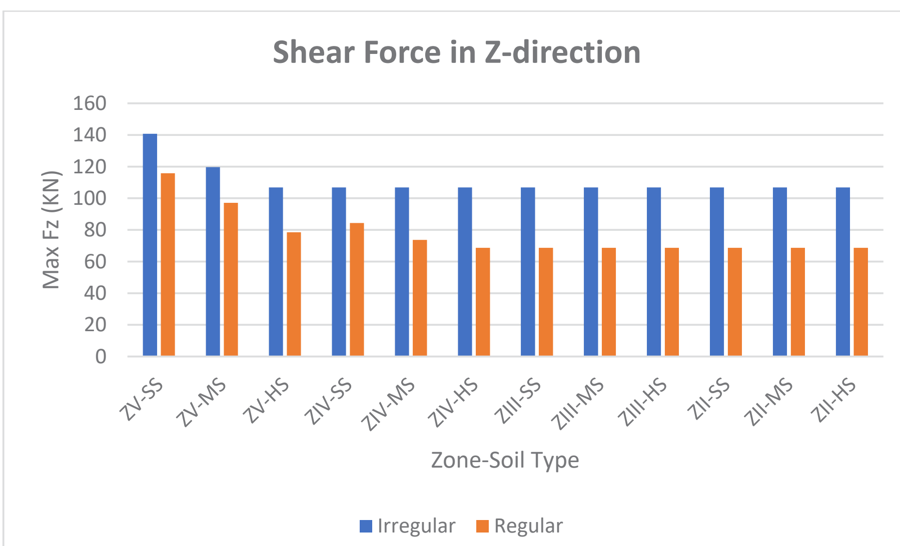


Figure 6: Shear Force in Z- direction of regular and irregular models

This graph (Fig. 7) shows the plot of maximum bending moment values in the x-direction for the regular and irregular models in zone II, III, IV, and V with hard, medium and soft soil.

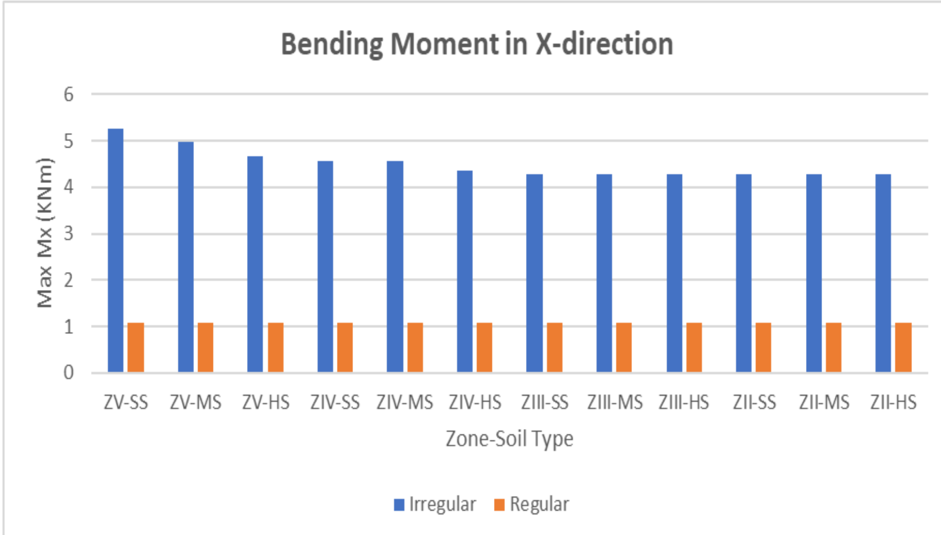


Figure 7: Bending Moment in X-direction of regular and irregular models

This graph (Fig. 8) shows the plot of maximum bending moment values in y-direction for the regular and irregular model in zone II, III, IV, and V with hard, medium and soft soil.

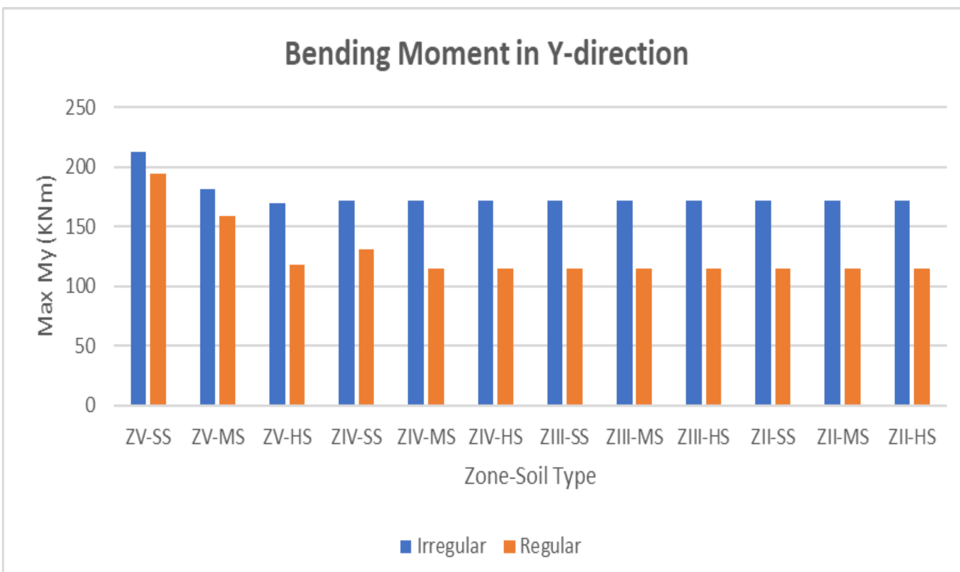


Figure 8: Bending moment in Y-direction of regular and irregular models

This graph (Fig. 9) shows the plot of maximum bending moment values in z-direction for the regular and irregular model in zone II, III, IV, and V with hard, medium and soft soil.

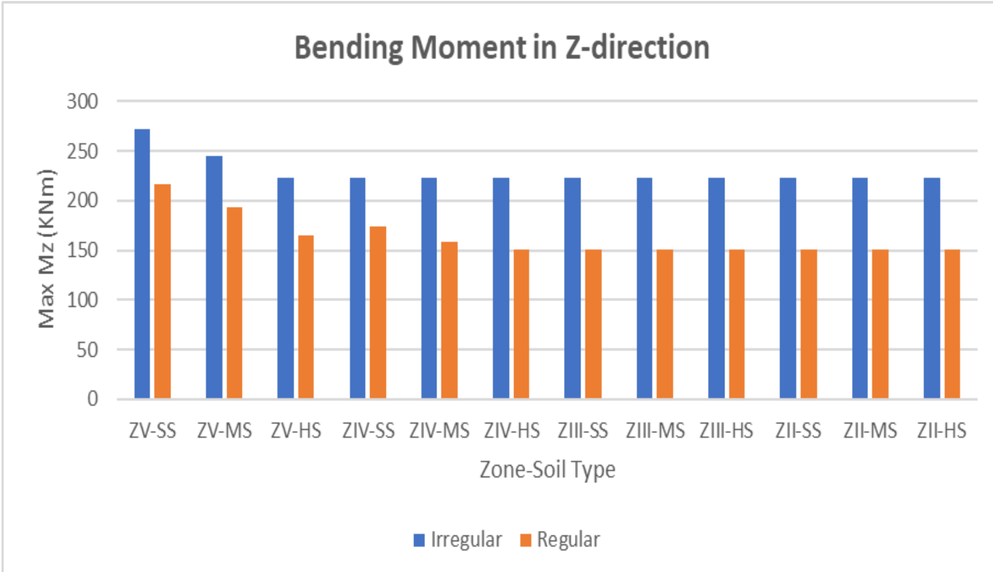


Figure 9: Bending Moment in Z-direction of regular and irregular models

Storey displacement

To study the response of lateral load on RC structure, we used RC frame 20-storey regular and irregular structures with different zones and soil conditions. The result obtained by the analysis at each storey are tabulated below (Table 7):

Table 7: Storey Displacement in Regular and Irregular structure for 20 storeys

Storey Number	Storey Displacement (mm)	
	Irregular	Regular
20th	49.330	30.122
19th	48.030	29.390
18th	46.009	28.121
17th	43.160	26.271
16th	39.955	24.187
15th	37.505	22.794
14th	34.830	21.197
13th	31.892	19.375
12th	28.738	17.364
11th	25.708	15.432
10th	23.347	14.077
9th	20.930	12.656
8th	18.420	11.143
7th	15.819	9.546
6th	13.165	7.892
5th	10.700	6.367
4th	8.743	5.245
3rd	6.795	4.120
2nd	4.839	2.970
1st	2.894	1.811

This graph (Fig. 10) shows the plot of storey displacement of the regular and irregular model in zone II, III, IV, and V with hard, medium and soft soil.

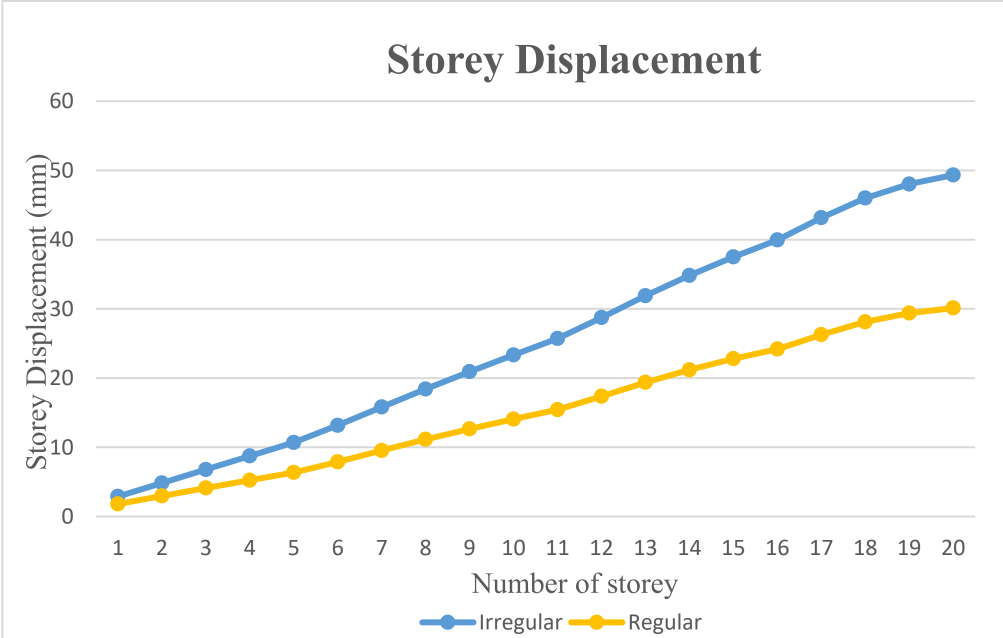


Figure 10: Graph for Storey Displacement of regular and irregular models

Conclusion

The following are the conclusions drawn from the analysis results after comparing the regular and irregular models we have observed:

1. Maximum shear force variation

1.1 In seismic zone V

In y-direction shear force was found to be 10.5-12.8% more in irregular structure regular structure

In z-direction shear force was found to be 17.7-26.5% more in irregular structure than regular structure

1.2 In seismic zone IV

In y-direction shear force was found to be 9.6-17.95% more in irregular structure than regular structure

In z-direction shear force was found to be 21-35% more in irregular structure than regular structure

1.3 In seismic zone III and II

SF in irregular structure was found to be 33 % more in both y and z direction than regular structure

Maximum torsional moment is 484% more in irregular structure than regular structure in Zone V.

2. Maximum bending moment variation

2.1 In seismic zone V

In y-direction bending moment was found to be 8.5-26% more in irregular structure

In z-direction bending moment was found to be 8.5-26% more in irregular structure

2.2 Zone IV, III and II

BM in irregular structure was found to be 33% more in both in both y and z direction

3. Storey displacement

It is 63.76% more in irregular structure in all zones and soil types

It shows a max displacement of 49.330mm in irregular and 30.122mm in regular on the 20th floor

References

1. Ajay, T., Parthasarathi, N., Prakash, M., & Satyanarayanan, K. S. (2021). Effect of planar irregularity of linear static and dynamic analysis. Materials Today: Proceedings, 40, S56-S63.
2. Akyürek, O., Suksawang, N., & Go, T. H. (2019). Vibration control for torsionally irregular buildings by integrated control system. Engineering Structures, 201, 109775.
3. Al Agha, W., & Umamaheswari, N. (2021). Analytical study of irregular reinforced concrete building with shear wall and dual Framed-Shear wall system by using Equivalent Static and Response Spectrum Method. Materials Today: Proceedings, 43, 2232-2241.
4. Cluni, F., Gusella, V., Spence, S. M. J., & Bartoli, G. (2011). Wind action on regular and irregular tall buildings: Higher order moment statistical analysis by HFFB and SMPSS measurements. Journal of Wind Engineering and Industrial Aerodynamics, 99(6-7), 682-690.

5. Koçak, A., Zengin, B., & Kadioğlu, F. (2015). Performance assessment of irregular RC buildings with shear walls after Earthquake. Engineering Failure Analysis, 55, 157-168.
6. Aldeka, A. B., Tziavos, N. I., Gkantou, M., Dirar, S., & Chan, A. H. (2022). Seismic design of non-structural components mounted on irregular reinforced concrete buildings. Journal of Building Engineering, 46, 103783.
7. Cotipalli, V., Varma, V. N. K., & Kumar, U. P. (2021). Earth quake analysis of regular and irregular structures for all the soil types in seismic zone V. Materials Today: Proceedings.
8. Ishack, S., Bhattacharya, S. P., & Maity, D. (2021). Rapid Visual Screening method for vertically irregular buildings based on Seismic Vulnerability Indicator. International Journal of Disaster Risk Reduction, 54, 102037.
9. Rao, A. B., Reddy, P. S., & Shaly, C. M. (2022). Mode shape modification of irregular design of buildings. Materials Today: Proceedings.
10. Khanal, B., & Chaulagain, H. (2020, October). Seismic elastic performance of L-shaped building frames through plan irregularities. In Structures (Vol. 27, pp. 22-36). Elsevier.
11. Wang, D., Yang, Y., Zhou, T., & Yang, F. (2021). An investigation of fire evacuation performance in irregular underground commercial building affected by multiple parameters. Journal of Building Engineering, 37, 102146.
12. Divya, R., & Murali, K. (2022). Comparative analysis of behaviour of horizontal and vertical irregular buildings with and without using shear walls by ETABS software. Materials Today: Proceedings, 52, 1821-1830.
13. Dya, A. F. C., & Oretaa, A. W. C. (2015). Seismic vulnerability assessment of soft story irregular buildings using pushover analysis. Procedia Engineering, 125, 925-932.
14. Gičev, V., Trifunac, M. D., Todorovska, M. I., Kocaleva, M., Stojanova, A., & Kokalanov, V. (2021). Ambient vibration measurements in an irregular building. Soil Dynamics and Earthquake Engineering, 141, 106484.
15. Varma, V. N. K., & Kumar, U. P. (2021). Seismic response on multi-storied building having shear walls with and without openings. Materials Today: Proceedings, 37, 801-805.
16. Kumar, V. R., & Rao, R. (2017). Comparative Study on Regular & Irregular Structures Using Equivalent Static And Response Spectrum Methods. International Journal of Civil Engineering and Technology, 8(1), 615-622.
17. Lin, J. L., Chen, W. H., Hsiao, F. P., Weng, Y. T., Shen, W. C., Weng, P. W., ... & Hwang, S. J. (2021). Effects of hysteretic models on the seismic evaluation of a collapsed irregular building from bidirectional near-fault ground motions on a shake table. Engineering Structures, 247, 113087.
18. Mazza, F. (2014). Modelling and nonlinear static analysis of reinforced concrete framed buildings irregular in plan. Engineering structures, 80, 98-108.
19. Blasone, V., Basaglia, A., De Risi, R., De Luca, F., & Spacone, E. (2022). A simplified model for seismic safety assessment of reinforced concrete buildings: framework and application to a 3-storey plan-irregular moment resisting frame. Engineering Structures, 250, 113348.
20. Ishack, S., Bhattacharya, S. P., & Maity, D. (2021). Rapid Visual Screening method for vertically irregular buildings based on Seismic Vulnerability Indicator. International Journal of Disaster Risk Reduction, 54, 102037.
21. Jain, A., & Surana, M. (2022). Floor displacement-based torsional amplification factors for seismic design of acceleration-sensitive non-structural components in torsionally irregular RC buildings. Engineering Structures, 254, 113871.
22. Lin, C. C., Ueng, J. M., & Huang, T. C. (2000). Seismic response reduction of irregular buildings using passive tuned mass dampers. Engineering Structures, 22(5), 513-524.
23. Meral, E. (2021, December). Determination of seismic isolation effects on irregular RC buildings using friction pendulums. In Structures (Vol. 34, pp. 3436-3452). Elsevier.
24. Shalmaee, M. M., & Pourzeynali, S. (2022, July). A modal displacement-based design method for irregular building frames equipped with elastomeric bearings. In Structures (Vol. 41, pp. 541-552). Elsevier.
25. Mouhine, M., & Hilali, E. (2022). Seismic vulnerability for irregular reinforced concrete buildings with consideration of site effects. Materials Today: Proceedings, 58, 1039-1043.