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Research Article

Dynamic Analysis of a G+13 Story RCC Building Using Shear Wall in Three Different Locations on Various Seismic Zones

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ABSTRACT

Currently, Seismic impacts are a very serious concern when designing multi-storied reinforced concrete structures. Seismic tremors have occurred in numerous parts of the globe. High-rise structures should have proper stiffness to resist lateral loads caused by Earthquakes and Winds. Consequently, Engineers are extremely concerned about finding suitable solutions that will allow structures to survive without major damage. Shear walls are structural members that are designed to carry earthquake loads and oppose lateral loads significantly. They are a good choice to increase the stiffness of high-rise structures. This paper aims to use shear walls in various locations of a G+13 multi-storied residential building and to determine the best shear wall placement in high slender buildings by analyzing story displacement, story drift, base shear, and the fundamental time period in various seismic zones according to IS 1893:2016. Three models are prepared and compared under different seismic zones. Shear walls are at the core of the building, and shear walls are at the four corners of the building, which is a combination of both. Our study's goal is to test a structure's ability to bear lateral load applied to it according to the Code and also when it exceeds the limit of allowable deformation. The prepared model for this experimentation is considered to be located on medium soil, and wind velocity is high, like 148mph. The experiment concluded that building with a shear wall combination of both core and corner will show better results in resisting lateral forces, though the combination isn't enough to help withstand the high slender structure against very powerful earthquake attacks like Zone-V.

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1. Introduction

Concrete is one of the most versatile building materials in the modern world (Aditto et al., 2023; Kabbo et al., 2023; Sobuz, Khan, et al., 2024). Earthquake is considered one of the worst types of natural disasters. In general, the design of structure for seismic load is primarily considered with structural safety during any type of major natural ground motions, but economic conditions, as well as serviceability, should also be a major concern. Earthquake can be defined as a natural catastrophic tragedy caused by a rapid release of energy beneath the earth's surface. The vibrations are caused by the energy emitted from the ground and they cause enormous damage to all the internal and external substances within the surface, resulting in loss of life and structural damage (Khan et al., 2023). Earthquakes come in a variety of sizes and intensities. Soft stories, mass irregularities, low quality building materials and improper construction procedures, uneven earthquake response, soil and foundation, and the influence of pounding of nearby structures were identified to be the main causes of the failure of structures. All over the world, there is high demand for the construction of tall buildings due to increasing urbanization and spiraling population, and earthquakes have the potential to cause the greatest damage to tall structure's durability (Sobuz, Joy, et al., 2024; Sobuz, Khan, et al., 2024). As it is seen that earthquake loads are not regular, i.e., random in nature, as well as unpredictable, so the engineering tools must have the ability to account for these actions when designing any high-rise reinforced concrete structure.

When designing any structure, all types of earthquake effects must be considered dynamic in nature. However, for simple regular structures, analysis by equivalent linear static methods is often sufficient (Mohan et al., 2011). However, when dealing with high-rise buildings, the equivalent linear static method is not enough. Then, an advanced form of analytical system, called dynamic analysis, is introduced. During an earthquake, the gravitational loads are also worked as lateral loads, which will produce sway in real time. When designing any high-rise structure, some factors must be considered regarding earthquakes.

According to E. Pavan Kumar (2014), the factors are the natural frequency of the structure, damping factor, type of foundation, importance of the building, and ductility of the structure (Kumar et al., 2014). To eliminate most of the failure caused by lateral force, using a shear wall is a good option. The thickness of the shear wall is also an important parameter for resisting lateral forces. Research shows that the thickness of the shear wall may differ from 140 mm to 500 mm and the construction method is also too quick when compared to the conventional one (Magendra et al., 2016).

For obtaining the best results as well as to compare the results between the position of shear wall in various location a G+13 storied building model is prepared in this study. The building is comparatively slender and has high torsional affect.

1.1. Importance of shear wall

A shear wall is a structural system made up of braced panels that are used to counteract the effects of lateral loads on a structure. Shear panels are a type of shear wall. Shear walls are built to withstand wind and earthquake loads. The difference between columns and shear walls are column is mainly compression elements whereas shear walls is compression as well as shear-resisting elements (Pavani et al., 2015). These are provided in addition to slabs, beams, and columns in a structure and it provide the required stiffness, especially for residential constructions in general it form as a case in a structure (Ahamad & Pratap, 2021).

N. Karthiga researched structures with and without shear walls and stated that the location of the shear wall will affect the attraction of forces so that the wall must be placed in the proper position (Shenbagam & Swathika, 2019). Many researchers carried out their research work to find the optimum location and position of the shear wall in any high-rise structure. In practice, shear walls are provided in the core section of the building as a lift or elevator core, which also acts as an HVAC transmission system. In this study, three models have been prepared with shear walls located accordingly in the core, edge portion, and both the core and edge portion.

1.2. Dynamic analysis

There are two methods of analysis for determining earthquake effects on structures, static method and dynamic method (Chandiwala & Engineering, 2012). When subjected to loads or displacements, all real physical structures behave dynamically. In general, dynamic analysis is merely a natural extension of static analysis. Response spectrum analysis and Time History analysis are both used in dynamic analysis. Besides these two major types of analysis, there are many other types of earthquake analysis methods such as-

A. Equivalent Static Analysis
B. Non-Linear Static Analysis
C. Linear Dynamic Analysis
D. Non-Linear Dynamic Analysis

The initial stage in dynamic analysis is to create a mathematical model of the structure, which will be used to provide estimations of strength, stiffness, mass, and inelastic member properties. According to I. Hari Krishna (2016), Dynamic analysis is also related to resistance forces developed by the structure when the structure is excited by sudden dynamic loads (KRISHNA & VENKATESWARLU, 2016). In this study, a G+13 RCC multi-storied residential building is modeled and analyzed using ETABS v17 software.

1.2.1 Response Spectrum Method

Among all the methods of dynamic analysis, Response spectrum analysis method is one of the most effective one. According to Bahador Bagheri (2012), the response spectrum method is the representation of the maximum response of idealized single-degree freedom system having a certain period and damping, during earthquake ground motions (Bagheri et al., 2012). Unless it can be demonstrated qualitatively that the second or third mode gives the least response, at least three response modes of the structure should be examined. The response spectrum approach of seismic/earthquake analysis has computational advantages for predicting displacements and member forces in structural systems. From a case study, Nair et al. (2017) stated that the main constraint of the Response spectrum analysis is that they are globally suitable to linear systems only (Nair et al., 2017). In this experiment, the response spectrum analysis is carried out according to the code IS 1893: 2016.

2. Literature review

Chandurkar and Pajgade (2013) have performed a dynamic analysis of G + 14 storied RCC building with shear wall used in core and edge portion of the structure and then compare the results under different Earthquake zones. The study showed that the displacement is reduced when using the shear wall in all seismic zones. Similarly, the same amount of shear wall will resist more lateral load when they are used in the core portion comparing the edge portion.

Sumit and Gupta (2019) have performed a test on a G+20 storied RCC building and compared the output of the model using shear walls at two ends of the structure and both the four ends of the structure. From their research, it is observed that the shear wall at the four ends of the building is more effective rather than only the two edges of the building. Similarly, for high-rise structures, a shear wall is strongly recommended to avoid torsional irregularities.

Oni and Vanakudre (2013) have studied and published research output of seismic response analysis in RC framed structures using shear walls and no shear walls by ETABS. From their study, we obtained that the shear wall plays a vital role in resisting later load as well as any type of seismic effects. The study showed that story drift and lateral displacement of the story are significantly reduced when using the shear walls. It is also concluded that the position of the shear wall plays a vital role in high-rise structures.

Shaha and Banhatti (2016) have performed a shear wall analysis and design optimization research where it is seen that in the case of tall buildings, if the shear wall can be provided in a possible deflection position of the structure, then it can control the damages that occurred due to wind and earthquake forces, i.e., lateral and seismic forces. The study was carried out for a G+44 storied high-rise building and obtained the best result by using shear walls at two core portions of the structure.

3. Significance of this study

1. To analyze the model structure by means of Storey displacement, Storey drift, Storey shear/ Base shear, and Fundamental time period in different earthquake zones by dynamic analysis.

2. To locate the best position of the shear wall in a multi-storied RCC structure so that the structure can minimize the effects of lateral loads.

3. To compare the effects of lateral load on model structure when applying shear wall on three different locations as well as four different seismic zones.

4. Model specification

The technical details and information are tabulated below. The 3D model diagram with the plan and dimensions is also shown in this section. Table 1, 2, 3 and 4 represent the basic specifications for the model.

Table 1. Location of Shear Wall

Identity	Position
Case A	Elevator core
Case B	Four Corners
Case C	Core + Four Corners

Table 2. Specifications of the Model

Description	Value
Type of the Building	Residential
Type of Structure	Reinforced Concrete Framed Multi-Storied
Storey	G + 13
Floor to Floor Height	12ft
Soil Type	Type-II (SD)
Damping	Constant 5%
Importance Factor	1
Response reduction factor, R	5
Overstrength factor	5.5
Exposure Type	B
Seismic Zones	Zone II, III, IV and V

Table 3. Properties of Structural Member

Description	Value
Total Building Height	184ft
Size of Columns	12X18 inch and 12X20 inch
Size of Beams	10X17 inch and 10X20 inch
Slab Thickness	5.5 inch
Strength of Concrete	4000psi
Strength of Steel	Grade-60
Support Condition	Fixed

Table 4. Load Details

Live Load	40psf
Floor finish	25pdf
Partition wall load on Beam	425 lb/ft
Code for Earthquake Load	UBC 97
Code used in RSA	IS 1893:2016

5. Research methodology

The full process of this study is shown in a flow diagram below in Fig. 1:

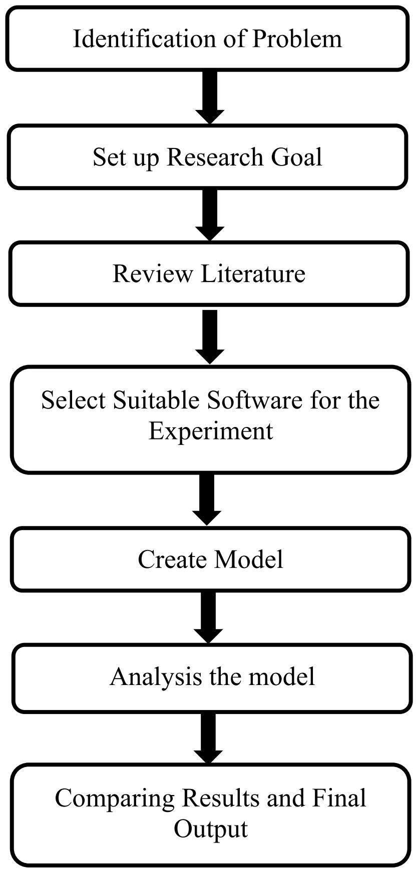


Fig. 1 Flow diagram of the process of analysis

6. Results and discussion

6.1. Floor Plan of the Model

The ground floor plan (Fig. 2) and floor plan of 1F to 13F (Fig. 3) are shown below.

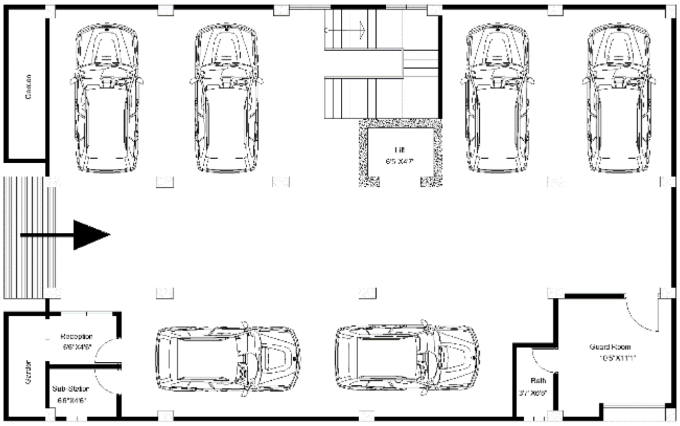


Fig. 2. Ground Floor plan of the Model

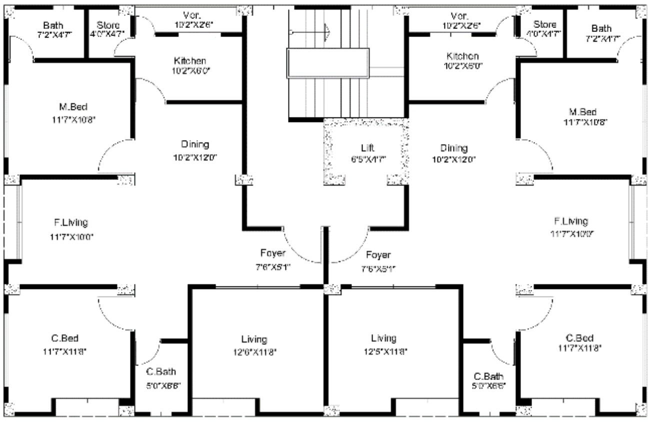
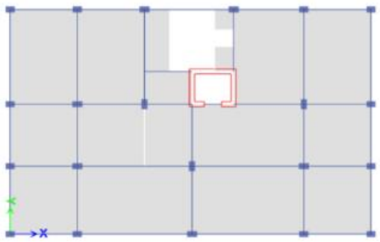
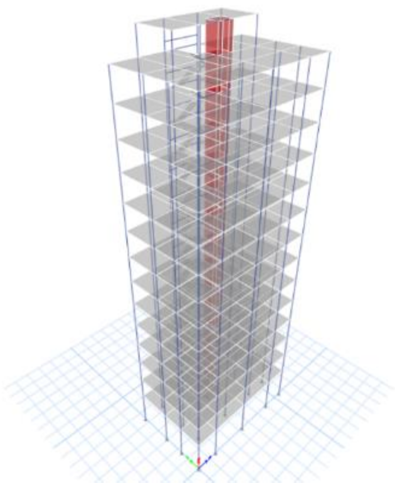


Fig. 3. First Floor plan of the Model

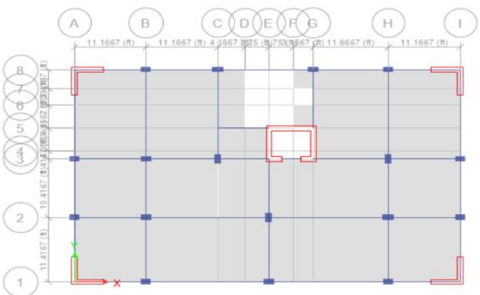
6.2. Detailing of 3D model

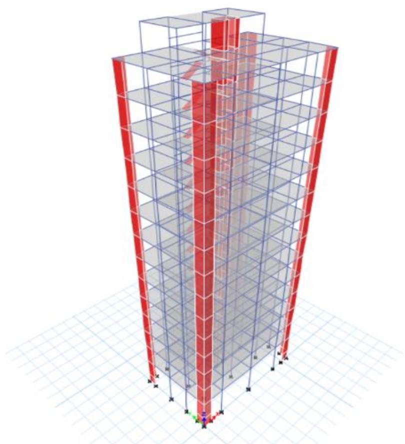
Figs. 4 and 5 represent the plan and corresponding 3D model and contour view of the building structures.



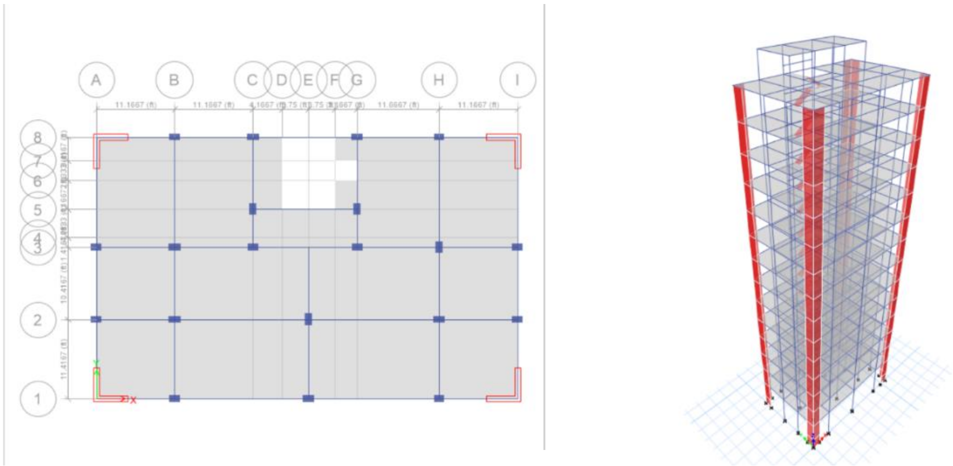


CASE A. Plan and 3D model of structure with shear wall at core.





CASE C. Plan and 3D model of structure with shear wall at core + corners.



CASE B. Plan and 3D model of structure with shear wall at four corners.

Fig. 4. Plan and 3D model of Case A, Case C and Case B.

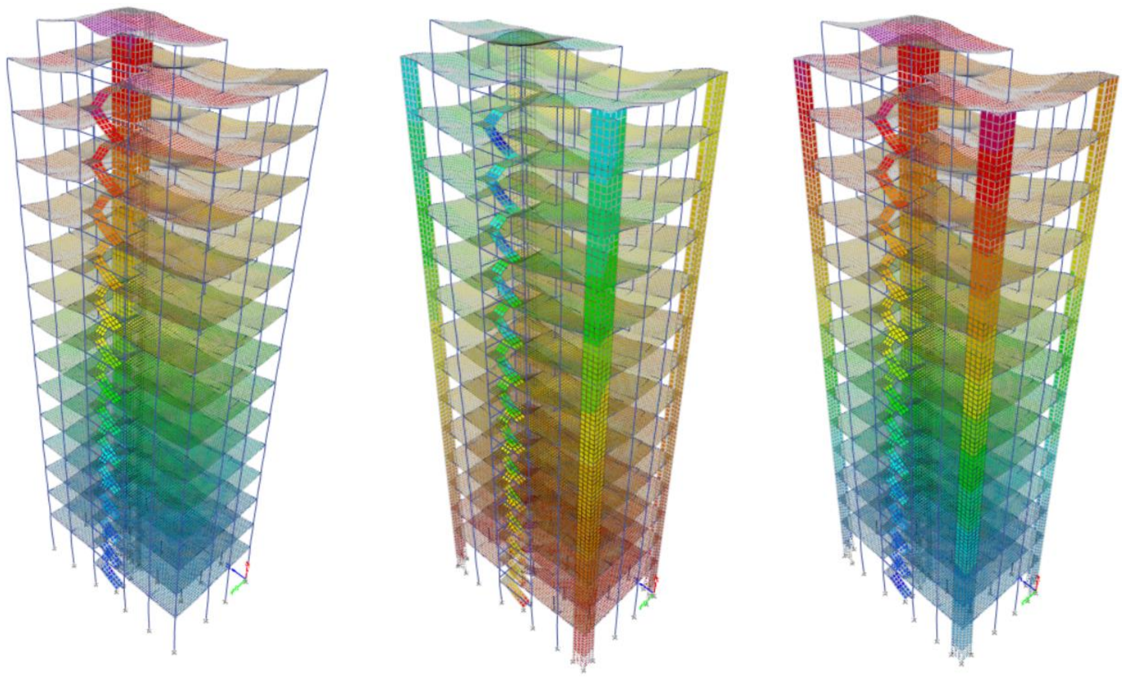


Fig. 5. Contour view of deformation due to vertical loads

6.3. ANALYSIS OF STRUCTURE

The maximum story displacement along both the global X direction and global Y direction are plotted in the graph below.

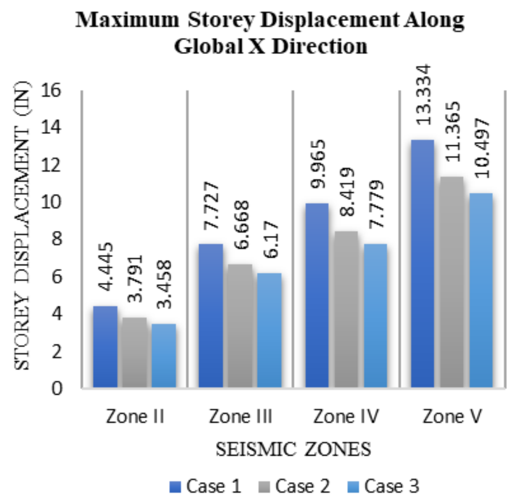


Fig. 6. Maximum story displacement along the global X direction

Along the global X direction, the maximum displacement is found when the shear wall is positioned in the core of the structure for all four zones, and the minimum displacement is found when the shear wall is placed in both the core of the structure as well as the four corners of the structure as shown in Fig. 6.

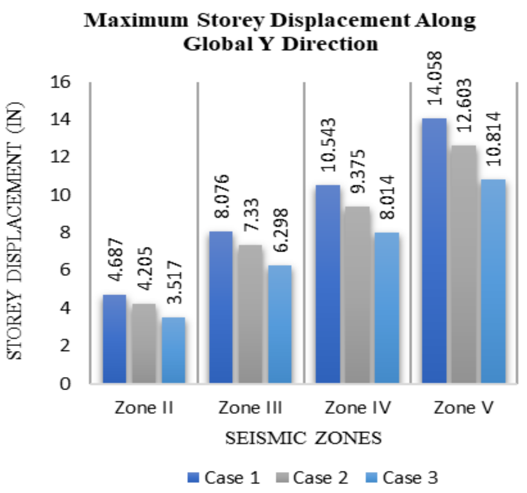


Fig. 7. Maximum story displacement along the global Y direction

The same results were found for the global Y direction also. According to the code, the maximum permissible displacement is 0.004H, i.e. 8.8inch for our structure. In this case, the modeled structure with a shear wall at the core will not survive in earthquake zones IV and V. The Same will happen for the structure having a shear wall at four corners of the structure. Only structures with shear walls at both core and corners will withstand in zone IV, but unfortunately, every model will fail in seismic zone V in terms of maximum displacement analysis as shown in Figs. 7 and 8.

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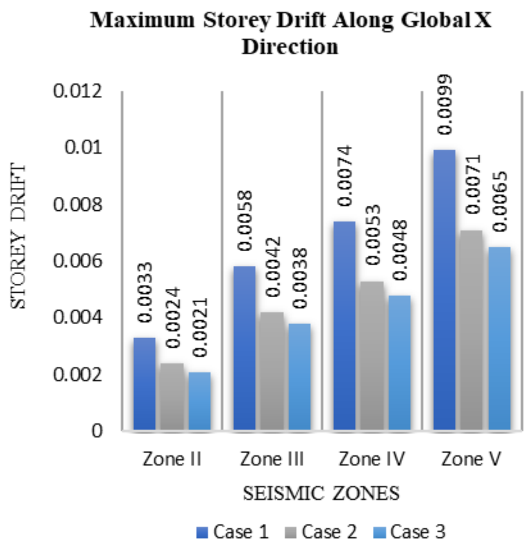

Fig. 8. Maximum story drift along the global X direction

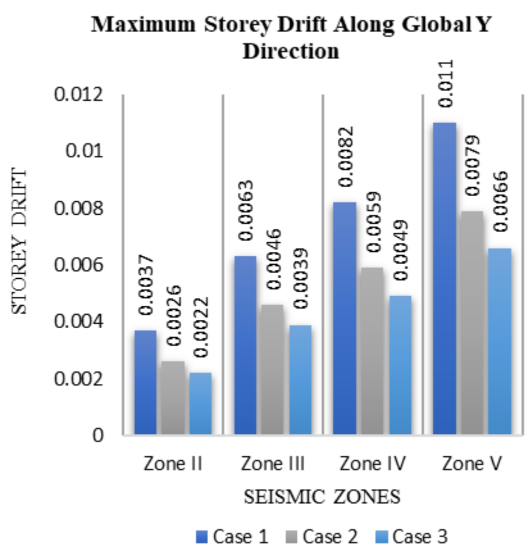

Fig. 9. Maximum story drift along global Y direction

Similar to the pattern of maximum story displacement, the maximum story drift is also the max for the shear wall center of the structure and the minimum when the shear wall is located in both the elevator core and corners of the building. The story drift in the global Y direction is comparatively higher than the global X direction. The reason can be written that our structure is narrow in the global Y direction comparing other directions. As a result, when subjected to lateral loads, the structure tends to show more deformation in the global Y direction as shown in Fig. 9.

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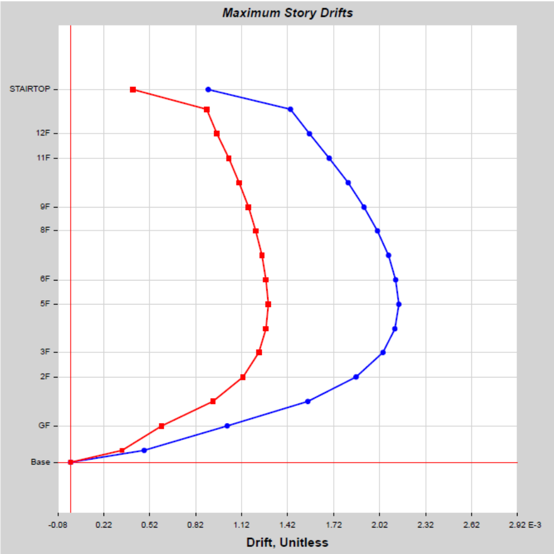

Fig. 10. Typical story drift pattern obtained from ETABS

The maximum story shear is also known as Base shear. From the graph, it is obtained that the maximum story shear tends to increase when moving from a lower earthquake to a higher risky earthquake zone. Similarly, in the same earthquake zone, story share is maximum for Case C (shear wall at both core and corners) and minimum for Case A (shear wall in core only). The Seismic zone factor for these seismic zones is accordingly- zone-II (0.10), zone-III (0.16), zone-IV (0.24) and zone-V (0.36). Figs. 10, 11 and 12 illustrated story drift, and story shear X and Y direction.

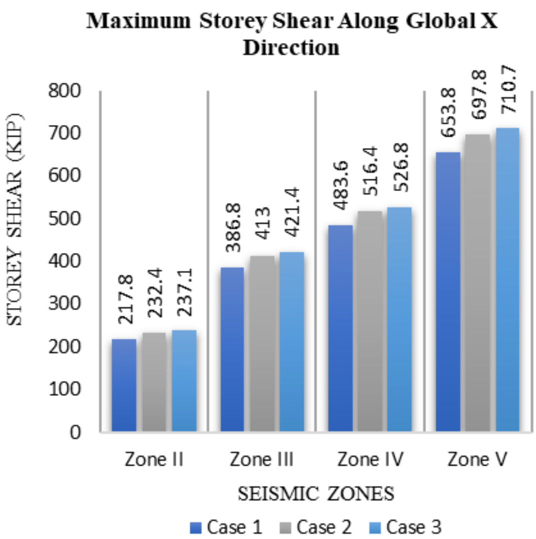

Fig. 11. Maximum story shear along global X direction

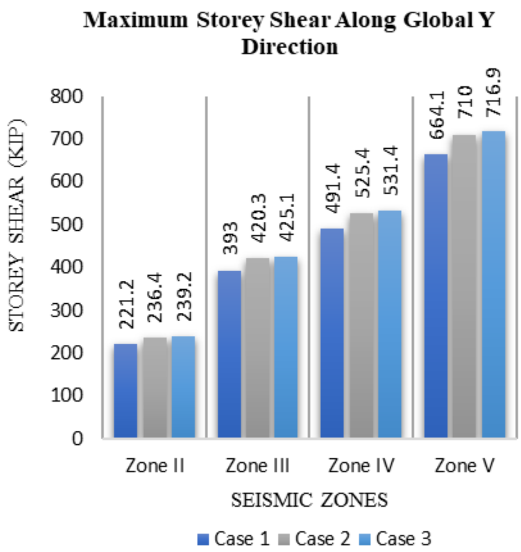

Fig. 12. Maximum story shear along global Y direction

6.4. Time period and frequency

The time period obtained from ETABS is plotted in Figs. 13 and 14 below

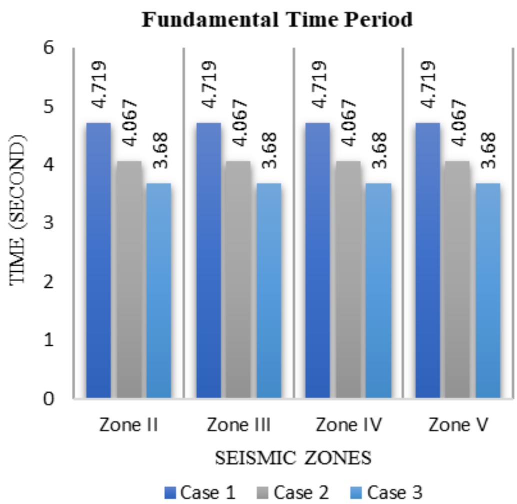

Fig. 13. The time period of the structure in different seismic zones

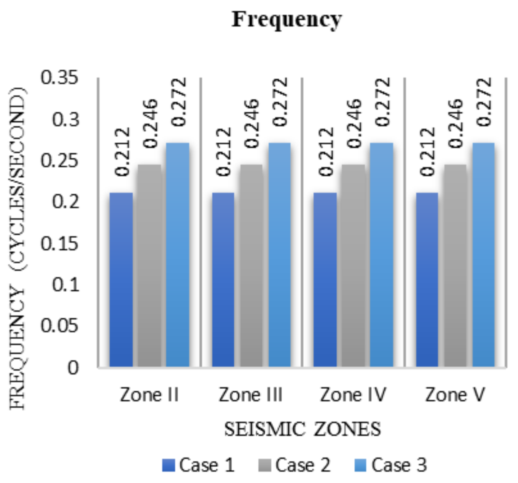

Fig. 14. Frequency of the structure in different seismic zones

The analysis is done by using Modal case type EIGEN, and to confirm the highest mass participation, 48 modes are taken. Hence, this setup confirms 99% of mass participation. In time period analysis, it is seen that the fundamental time period remains the same even changing the seismic zones for the same model. Also, the time period tends to decrease when we increase the cross-sectional area of the shear wall. The time period is minimum for the Case C model and maximum for the Case A model. Frequency can be expressed as (1/T) where T is the natural time period of the structure as depicted in Fig. 15.

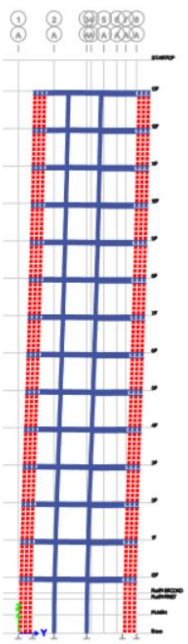

Fig. 15. Deflected shape of the structure due to earthquake load (Q_x)

4. Conclusions

After successfully performing the experiment, the results can be concluded as-

- The maximum story displacement and drift are seen to be higher in seismic zone V. In general, the higher the seismic effect, the more displacement will occur. Case C has higher Stiffness and shows low displacement and story drift comparing the other two cases.
- From the experimentation, it is seen that buildings with both shear walls at the core and corners had given better outputs considering story displacement, drifts, base shear, and other parameters.
- The designed model has a high slenderness value. As a result, the structure will fail in zone V for all cases according to the IS code. This is due to uneven stiffness as well as a low amount of provided shear wall. To make the model stiffer and to withstand it in a higher earthquake zone, more shear walls should be provided.
- Torsional irregularities are observed when moving higher seismic zones. To avoid torsional irregularity the shear wall should be provided uniformly all over the structure.
- As last, it can be concluded that the shear wall at all four corners showed better results comparing only the core of the structure. But if the shear wall is provided not only in the core but also in all four corners of the structure, then the structure will give extra stiffness to the structure and help to withstand any highly slender building in high seismic areas.

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