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RESEARCH ARTICLE Open Access

Numerical Investigations Of Effective Parameters On Multi-Story Building Having Inclined Supporting Foundations

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Abstract:
This study deals with the use of finite element analysis to study the response of an RC building that has inclined supporting leads in the foundations. Several RC buildings were studied to evaluate the seismic performance of these buildings under the influence of change in three parameters (the degree of inclination of the foundations (0°, 10°, 20° & 40°), the storey number (8, 10, 12, 16 & 20 storey), and the span length (4, 5 & 6 m)). All buildings were analyzed using the SAP2000 software using the time history analysis method under the influence of the EL-Centro N-S 1940 earthquake acceleration record. The results were shown the values of the base shear, time period and roof displacements decreased by 23%, 33% and 55% respectively, when the degree of foundation inclination of the building increased from 0° to 20°, while these values increased by 68%, 53.28% and 137.6% respectively, when the No. of stories increased by 50%. The increase of base shear due to increase the height of building, also the increase lateral displacements of the buildings. The increases in time period due to decrease the stiffness of RC building and it have more displacements at tip of buildings.

Keywords: *Multi-story RC Building; SAP2000; Seismic; Inclined Foundations; El-Centro 1940 Earthquake.*

1. Introduction

Any natural disaster can happen anywhere in the world. An earthquake is one of the worst and most unpredictable natural disasters. It can cause loss of life and destruction of property, so this catastrophe has the potential to destroy the economy of any country. Although earthquakes cannot be predicted or prevented, structures can be built to withstand the forces associated with them to minimize their effects. Simple and regular shape, sufficient lateral strength, stiffness, and ductility are the four main qualities that a structure must have in order to function successfully during an earthquake. In practically every nation, irregular buildings are commonly constructed due to the fast urbanization that is taking place worldwide. As a result, there is a strong and urgent need for the construction of multi-story structures near cities and on slopes. A building's behavior and stability in a sloped area depend on its structural design [1]. In many studies, finite element analysis of reinforced concrete buildings was used by time history analysis under the influence of the EL-Centro N-S 1940 earthquake acceleration record of the imperial valley earthquake using the SAP2000 program, where Ambavaram in 2021 [2] analyzed five buildings with the same plan, all with flat foundations, while Tejaswi in 2021 [3] and Gómez in 2021 [4] By analyzing reinforced concrete buildings having inclined supporting points at foundations. In addition, XIAO in 2010 [5] The dynamic response of a field mountain near the Wenchuan earthquake under the influence of slope geometry was analyzed.

In this study, a verification study was conducted for three models of reinforced concrete buildings, where the analysis was done using the SAP 2000 program, and then the obtained values were compared with previous literatures. The main objective of this study is to investigate the seismic performance of

RC buildings with flat or inclined foundation using SAP2000 software under the influence of the El-Centro N-S earthquake acceleration as shown in Figure1 [6]. Therefore, a parametric study was carried out for several reinforced concrete buildings, depending on the change in the degree of inclination of the foundation, the number of storeys, and the span length, due to know the strengths and weaknesses of these buildings, and thus obtain an appropriate analysis and design.

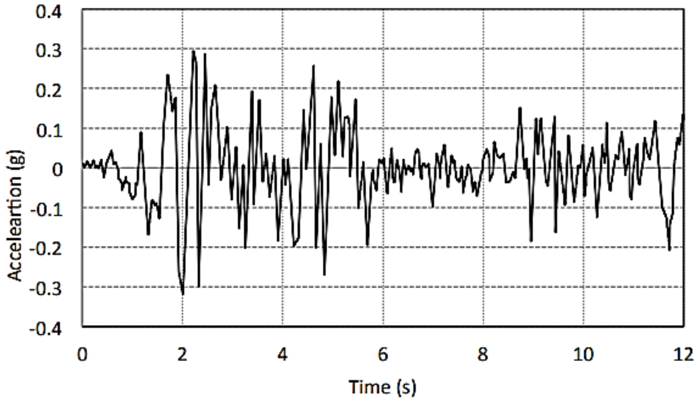

Figure 1: Time history of El Centro N-S earthquake acceleration [6]

2. Methodology

- Review of existing literature by different researchers.
- Selection of existing multistorey RC buildings.
- Modeling of the chosen structures.
- Performing dynamic analysis on selected building model and therefore the analysis results are plotted in sort of graphs.
- Column is modeled as fixed to the bottom.
- The effect of soil structure interaction was ignored.
- A 3D frame subjected to concentrated loads with un-equal supporting columns. Using SAP2000, an analysis of a multi-storey building on a sloping terrain was performed.

3. Verification Modelling of Multi Storey Building by Using Sap 2000 Software

The verification studies were performed for analyzing RC building by using SAP2000 software, where there collected from the previous literatures.

3.1 First Case Study

Verma, et al. in 2019 [7] A reinforced concrete building was studied using the SAP2000 program where the nonlinear time history method was used in the analysis under the influence of the El-Centro earthquake acceleration. The height of the building is 31 m, each floor is 3.1 m high with slab thickness (0.15 m). The beam and column size respectively are (0.45 m x 0.23 m) and (0.5 m x 0.5 m). The materials used are M25 concrete and Fe415 steel. The Number of spans in both direction (X & Y) is (4 x 3) and the Length of each span is 5 m. The value of live load is 3.5 kN/m^2 and dead load is 3.75 kN/m^2.

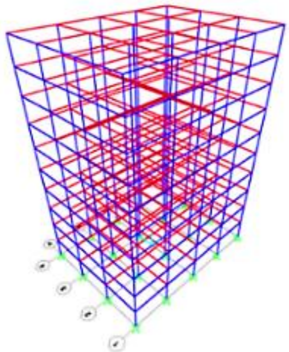

Figure 2: 3D Model of the 10-storey building

Figure.3, shown the verified results of base shear values with the previous articles of (Arjit Verma & Alhamd Farqaleet) [7].

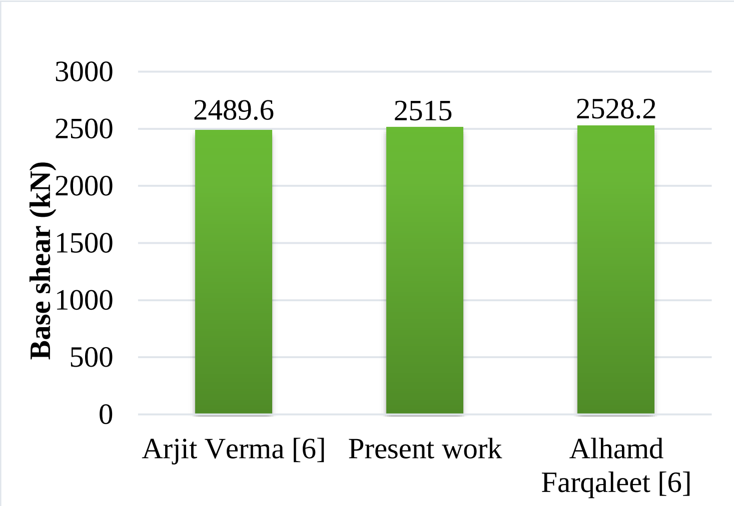

Figure 3: Maximum base shear (kN)

3.2 Second Case Study

Nitya and Arathi in 2016 [8] A seven storey RC building was studied and the plan of this building was in a plus shape. SAP2000 software was used to analyze the building. The building was analyzed using the time history analysis method (the building exposed to the El Centro 1940 earthquake). The height of the building is 21 m, each floor is 3 m high with slab thickness (0.16 m). The beam and column size respectively are (0.45 m x 0.23 m) and (0.5 m x 0.3 m). The materials used are M30 concrete and Fe415 steel. The number of spans in both direction (X & Y) is (4 x 4) and the Length of each span is 4 m. 3D Model of the building shown in the Figure 4.

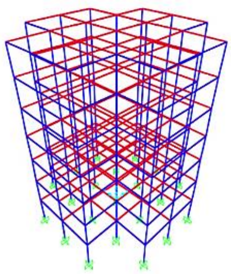

Figure 4: 3D Model of G+6 storey building

Table 1, shown the verified results of displacements values with the previous articles of (Nitya and Arathi) [8].

Table 1: The verified results of displacements values with the previous rticles of (nitya and arathi) [8]

Storey No.	Present work (m)	Nitya and Arathi work [8] (m)	(D_{Pres}/D_{ref})
7	0.066466	0.064	1.04
6	0.063232	0.061	1.04
5	0.057434	0.058	0.99
4	0.04887	0.048	1.02
3	0.037869	0.038	1.00
2	0.024545	0.024	1.02
1	0.010075	0.01	1.01
Mean			1.02
Variance			0.00035
Standard Division			0.017

3.3 Third Case Study

Kakde and Kasheef in 2021 [9] Using Altadena ground motions in SAP2000, evaluated the constructions that were resting on sloping ground that was extra exposed to heavy winds. Used SAP-2000 to run all the simulations. Based on the structure's Time period and other characteristics, the structural performance was assessed. The parametric analysis has considered fundamental Time period, which is a crucial factor to explain performance of any construction during seismically activated conditions. The findings of the Time period comprised by the constructions without shear walls located at various slopes (i.e., 20^{O}, 30^{O}, 40^{O}). The building resting upon the ground that is 40 degrees inclined has the lowest magnitude of time taken for oscillations of the structure during an earthquake compared to the other constructions, which have a considerably bigger value. The height of the building is 48 m, each floor is 3 m high with slab thickness (0.15 m). The beam and column size respectively are (0.53 m x 0.3 m) and (0.3 m x 0.6 m). The materials used are M30 concrete and Fe415 steel. The Number of spans in both direction (X & Y) is (6 x 6) and the Length of each span is 3 m. The value of slab dead load is 3.75 kN/m2 and super imposed load is 3 kN/m2. The value of External and Internal wall load 15 kN/m.

Figure 5 and Figure 6, shown the verified results of time period values with the previous articles of (Kakde and Kasheef) [9].

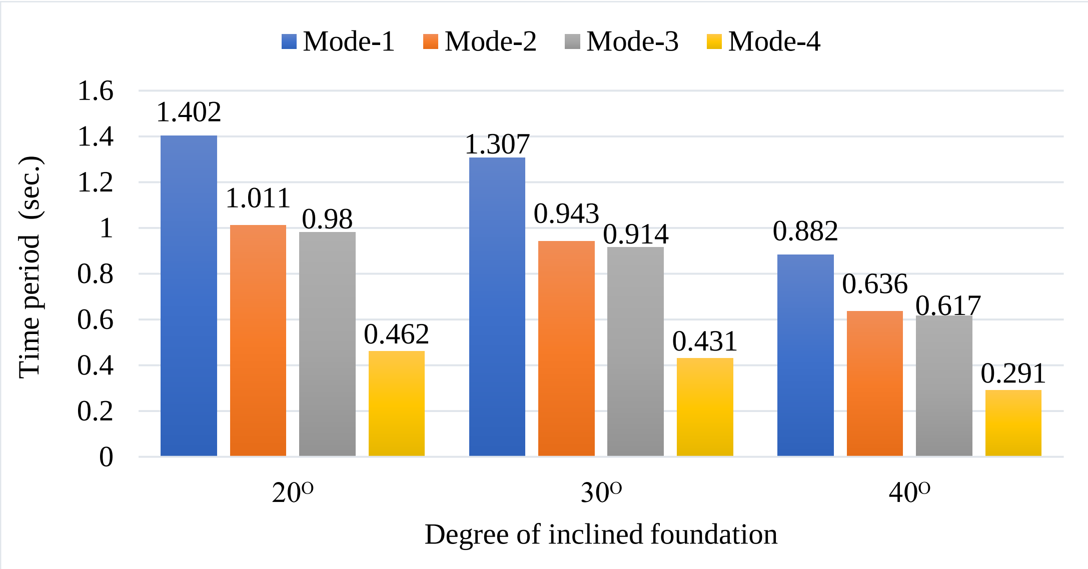

Figure 5: Time period values based on the degree of foundations inclination by (Kakde and Kasheef) [9]

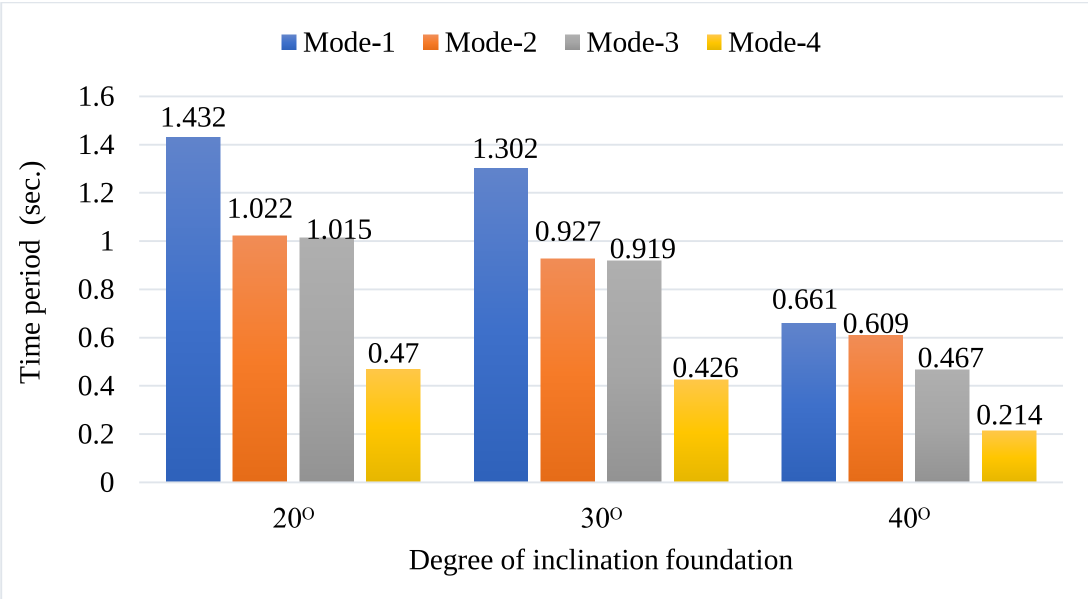

Figure 6: Time period values based on the degree of foundations inclination by the present work

3.4 Result and Discussion of Verification Study

Reached some conclusions based on conducted the case studies.:

- After modeling and analyzing all models, all results obtained in the current work were close to the results of previous literature. The results showed the values of base shear, displacements, and time period.
- For example, in the first study case, the maximum base shear value in the present work was 2515 kN, while their values were 2528.2 kN and 2489.6 according to the results of (Arjit Verma) & (Alhamd Farqaleet) respectively.

- The verification modeling process was useful because it gave a perception of the results obtained by previous researchers, as well as developed the skill of using the SAP2000 software and gave confidence in the results obtained in the present work.

4. Parametric Study Modelling Of Rc Building By Using Sap 2000 Software

Several RC buildings were studied to evaluate the seismic performance of these buildings under the influence of change in three parameters. These parameters are the degree of inclination of the foundations (0°, 10°, 20° & 40°), the number of storey (8, 10, 12, 16 & 20 storey), and the span length (4, 5 & 6 m). All buildings were analyzed using the SAP2000 software using the time history analysis method under the influence of the EL-Centro earthquake acceleration. The results were shown based on the value of base shear, time period and displacements. The building information shown in the Table 2.

Table 2: The building information

Dimension of beam	0.23 m x 0.4 m
Column size	0.45 m x 0.45 m
Thickness of slab	0.15 m
Number of spans in both direction (X & Y)	4 x 4
Live load on floors	3 kN/m^2
Live load on roof	1.5 kN/m^2
Floor finish	1 kN/m^2
Roof treatment	1.5 kN/m^2
$\acute{f}_c$ (Grade of concrete)	25 N/mm^2
Steel type	Fe 415 N/mm^2

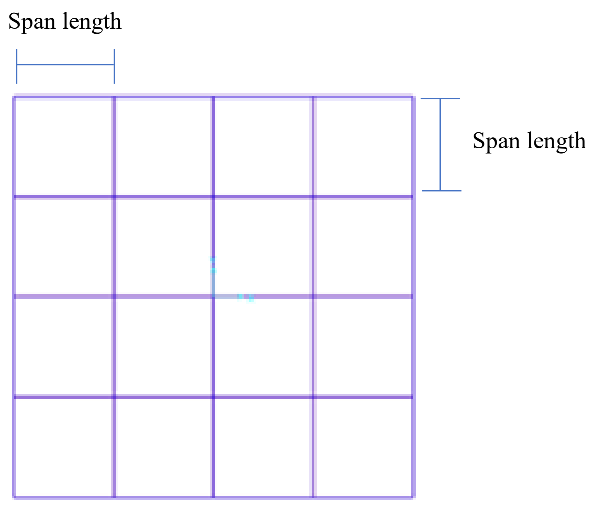

Figure 7: Plan of the building

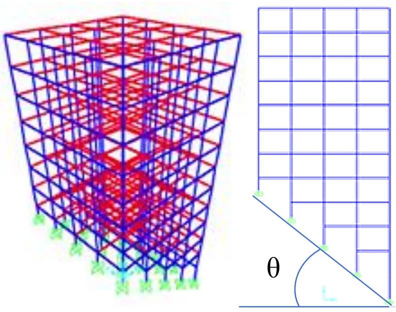

Figure 8: 3D & 2D Model of 12 storey stepback building inclined with an angle of 40°

4.1 Results of Modelling Buildings When the Storey Height (3 m) and Span Length (4 m)

The base shear values increased with the increase in the number of storeys, as it increased by 68.8% when increased the number of storeys from 8 to 12, while the increase was 190% at the 20 storey when the angle of foundation inclination was 0°, while it increased by 53.8% when increased the number of storeys from 8 to 12, while the increase was 167.45% at the 20 storey when the angle of foundation inclination was 40°. The values of the base shear decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 9. The increase of base shear due to increase the height of building, also the increase lateral displacements of the buildings.

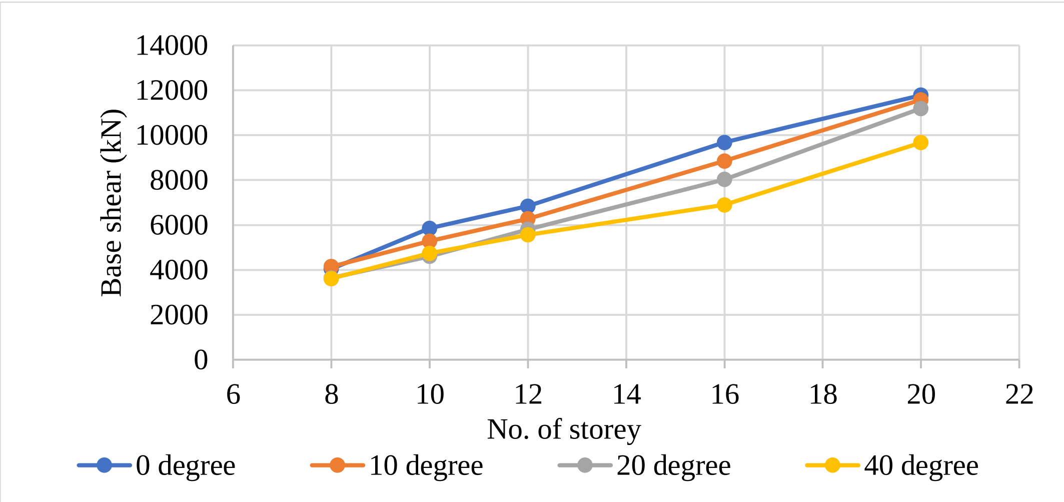

Figure 9: Maximum base shear based on the No. of storey and the degree of inclined foundation

The time period values increased with the increase in the number of storeys, as it increased by 53.28% when increased the number of storeys from 8 to 12, while the increase was 167.54% at the 20 storey when the angle of foundation inclination was 0°, while it increased by 93.07% when increased the number of storeys from 8 to 12, while the increase was 294.35% at the 20 storey when the angle of foundation inclination was 40°. The values of the Time period decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 10. This increases in time period due to decrease the stiffness of RC building and it have more displacements at tip of buildings.

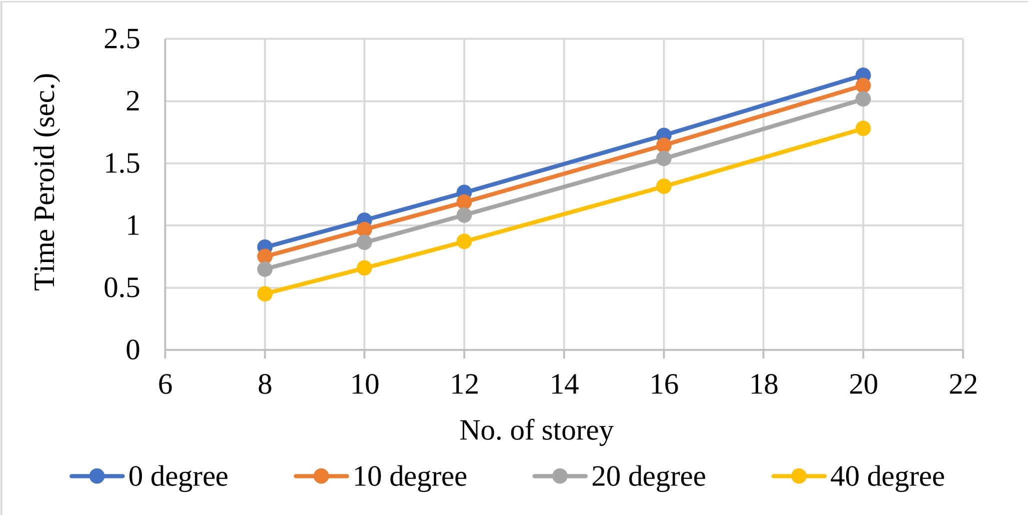

Figure 10: Time period based on the No. of storey and the degree of inclined foundation

The roof displacements in X direction values increased with the increase in the number of storeys, as it increased by 137.6% when increased the number of storeys from 8 to 12, while the increase was 711.2% at the 20 storey when the angle of foundation inclination was 0°, while it increased by 257.3% when increased the number of storeys from 8 to 12, while the increase was 1594.9% at the 20 storey when the angle of foundation inclination was 40°. The values of the roof displacements in X direction decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 11.

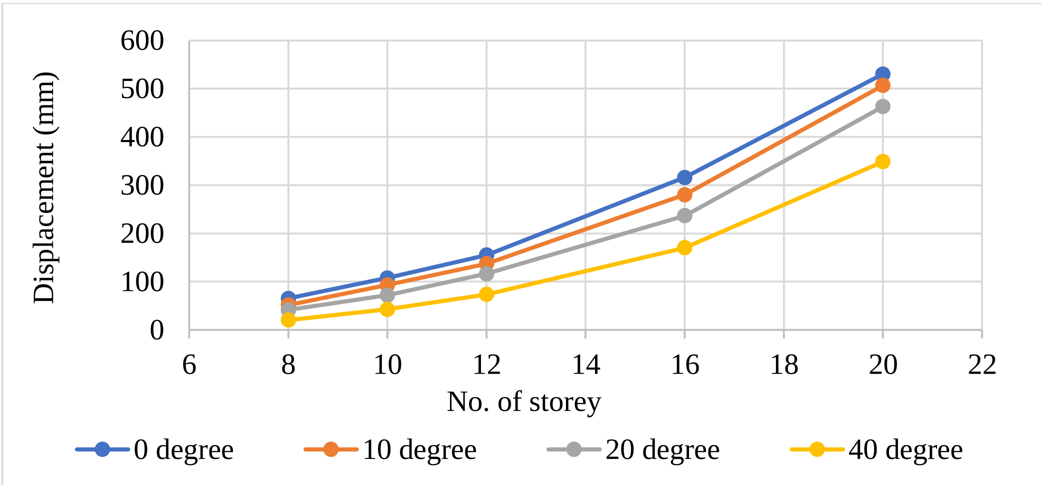

Figure 11: Roof displacements in X direction based on the No. of storey and the degree of inclined foundation

4.2 Results of Modelling Buildings When the Storey Height (3 m) and Span Length (5 m)

The base shear values increased with the increase in the number of storeys, where it increased from (6470 kN) to (13480 kN) when increased the number of storeys from 8 to 16, while it increased to (13770 kN) at the 20 storey when the degree of foundation inclination was 0°, while it increased from (3748 kN) to (8446 kN) when increased the number of storeys from 8 to 16, while it increased to (12490 kN) at the 20 storey when the degree of foundation inclination was 40°. The values of the base shear decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 12.

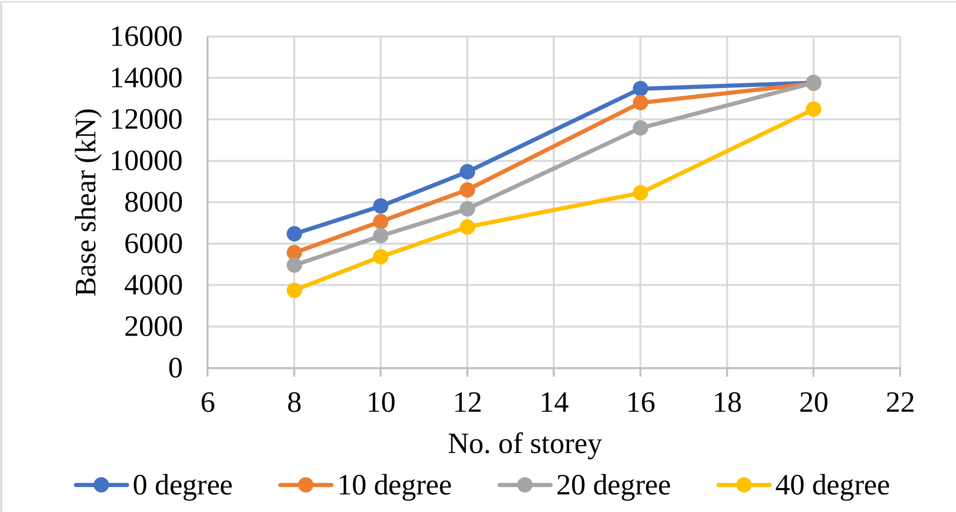

Figure 12: Maximum base shear based on the No. of storey and the degree of inclined foundation

The time period values increased with the increase in the number of storeys, where it increased from (0.999 sec.) to (1.52 sec.) when increased the number of storeys from 8 to 12, while it increased to (2.62 sec.) at the 20 storey when the degree of foundation inclination was 0°, while it increased from (0.389 sec.) to (0.888 sec.) when increased the number of storeys from 8 to 12, while it increased to (1.95 sec.) at the 20 storey when the degree of foundation inclination was 40°. The values of the Time period decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 13.

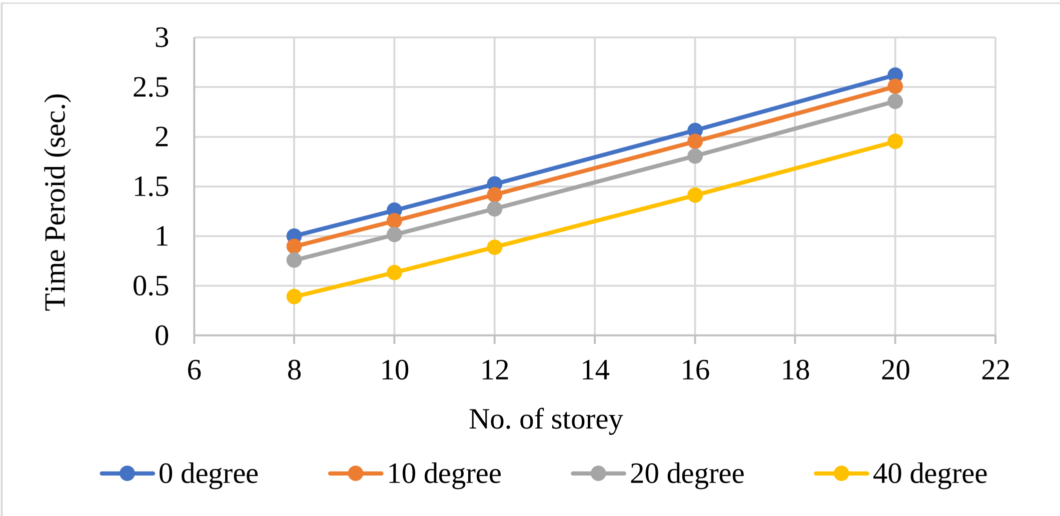

Figure 13: Time period based on the No. of storey and the degree of inclined foundation

The roof displacements in X direction values increased with the increase in the number of storeys, where it increased from (98.789 mm) to (228.177 mm) when increased the number of storeys from 8 to 12, while it increased to (616.33 mm) at the 20 storey when the degree of foundation inclination was 0°, while it increased from (15.173 mm) to (75.085 mm) when increased the number of storeys from 8 to 12, while it increased to (430.911 mm) at the 20 storey when the degree of foundation inclination was 40°. The values of the roof displacements in X direction decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 14.

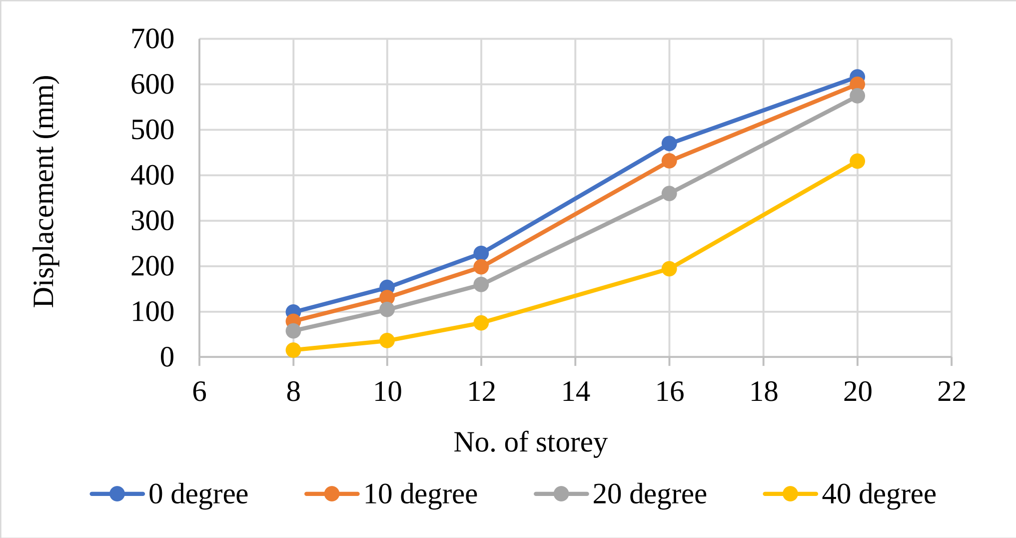

Figure 14: Roof displacements in X direction based on the No. of storey and the degree of inclined foundation

4.3 Results of Modelling Buildings When the Storey Height (3 m) and Span Length (6 m)

The base shear values increased with the increase in the number of storeys, where it increased from (8298 kN) to (13370 kN) when increased the number of storeys from 8 to 16, while it increased to (17600 kN) at the 20 storey when the degree of foundation inclination was 0°, while it increased from (4595 kN) to (8115 kN) when increased the number of storeys from 8 to 16, while it increased to (14880 kN) at the 20 storey when the degree of foundation inclination was 40°. The values of the base shear decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 15.

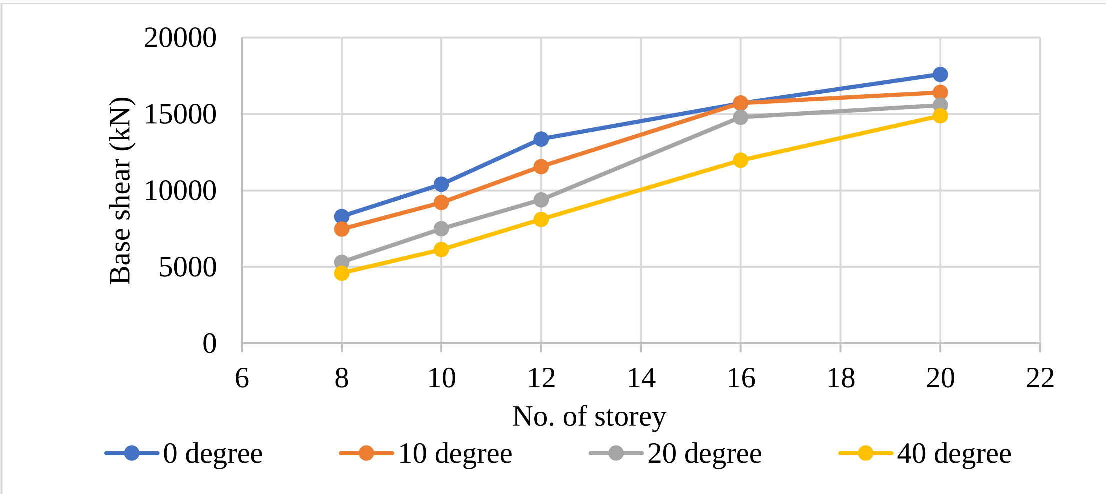

Figure 15: Maximum base shear based on the No. of storey and the degree of inclined foundation

The time period values increased with the increase in the number of storeys, where it increased from (1.181 sec.) to (1.796 sec.) when increased the number of storeys from 8 to 12, while it increased to (3.065 sec.) at the 20 storey when the degree of foundation inclination was 0°, while it increased from (0.287 sec.) to (0.857 sec.) when increased the number of storeys from 8 to 12, while it increased to (2.133 sec.) at the 20 storey when the degree of foundation inclination was 40°. The values of the Time period decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 16.

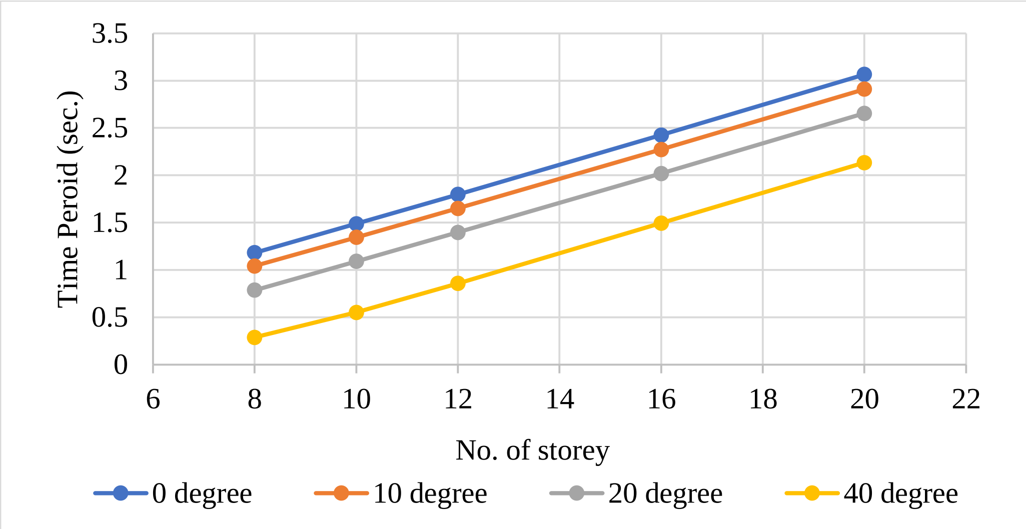

Figure 16: Time period based on the No. of storey and the degree of inclined foundation

The roof displacements in X direction values increased with the increase in the number of storeys, where it increased from (133.864 mm) to (345.129 mm) when increased the number of storeys from 8 to 12, while it increased to (768.543 mm) at the 20 storey when the degree of foundation inclination was 0°, while it increased from (5.99 mm) to (62.078 mm) when increased the number of storeys from 8 to 12, while it increased to (456.716 mm) at the 20 storey when the degree of foundation inclination was 40°. The values of the roof displacements in X direction decreased with the increase in the degree of foundation inclination of the building, as shown in Figure 17.

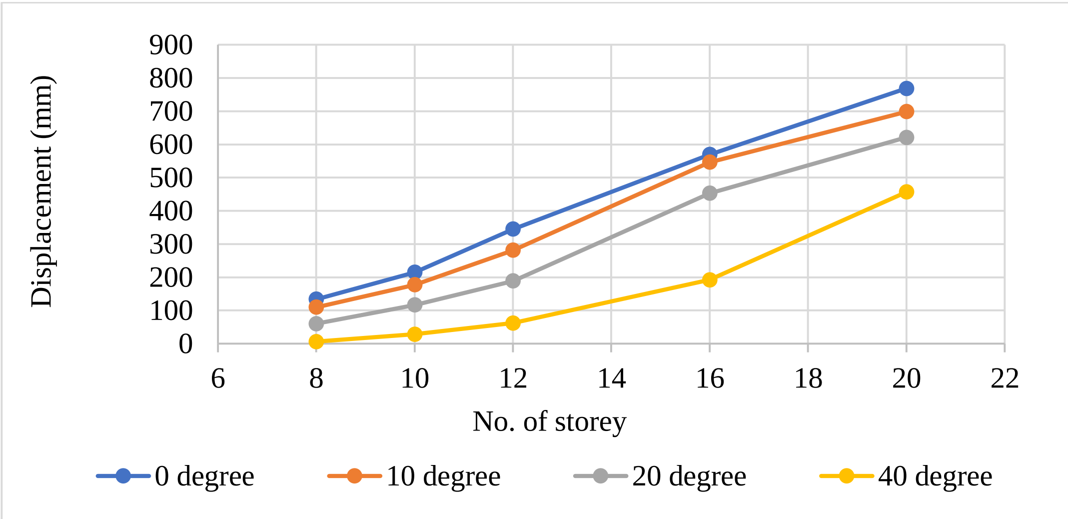

Figure 17 Roof displacements in X direction based on the No. of storey and the degree of inclined foundation

4.4 Effect of The Span Length on The Results

The value of the base shear, time period and displacements increased when the span length increased.

- (Fig.9, Fig.12 & Fig.15) showed that the value of base shear increased by (29% & 54%) when the span length increased from 4 m to (5 & 6) m respectively, when the degree of the foundation inclination 40° and storey number 20. While its value increased by (17% & 82%) when the span length increased from 4 m to (5 & 6) m respectively, when the degree of the foundation inclination 0° and storey number 20. This phenomenon can be accrued because the increasing of span length leads to decreasing the lateral stiffness of beams of studied RC building.

- (Fig.10, Fig.13 & Fig.16) showed the value of time period increased by (10% & 20%) when the span length increased from 4 m to (5 & 6) m respectively, when the degree of the foundation inclination 40° and storey number 20. While its value increased by (19% & 39%) when the span length increased from 4 m to (5 & 6) m respectively, when the degree of the foundation inclination 0° and storey number 20.

- (Fig.11, Fig.14 & Fig.17) showed that the value of displacements in X direction increased by (24% & 31%) when the span length increased from 4 m to (5 & 6) m respectively, when the degree of the foundation inclination 40° and storey number 20. While its value increased by (16% & 45%) when the span length increased from 4 m to (5 & 6) m respectively, when the degree of the foundation inclination 0° and storey number 20.

Conclusions

- This study aimed to verify the stability of multi-storey structures with sloping foundations under the influence of seismic load. All case studies were based on the time history analysis of buildings, where evaluated the performance of buildings under the influence of the El Centro N-S 1940 earthquake acceleration record of the imperial valley earthquake using SAP2000 software.
- The percentage of error in the results obtained from the applied models didn't exceed 4%.
- The values of the base shear, time period and roof displacements decreased by 23%, 33% and 55% respectively, when the degree of foundation inclination of the building increased from 0° to 20°, while these values increased by 68%, 53.28% and 137.6% respectively, when the No. of storeys increased by 50%.
- The increase of base shear due to increase the height of building, also the increase lateral displacements of the buildings.
- The increases in time period due to decrease the stiffness of RC building and it have more displacements at tip of buildings.
- The base shear, time period and roof displacements values increased when the span length increased. However, it may lead to made to redistribution the internals forces and re-arranged the location of plastic hinges. This phenomenon can be accrued because the increasing of span length leads to decreasing the lateral stiffness of beams of studied RC building.

References

[1] R. M. Thejaswini, L. Govindarajuand, and V. Devaraj, "A numerical study on seismic characteristics of stepback buildings considering SSI effect American Journal of Engineering Research (AJER)," no. 12, pp. 9–15, 2020.

[2] V. S. Ambavaram, A. Muddarangappagari, A. Mekala, and R. Chenna, "Dynamic performance of multi-storey buildings under surface blast: A case study," *Innov. Infrastruct. Solut.*, vol. 6, no. 4, pp. 1–20, 2021, https://doi.org/10.1007/s41062-021-00585-y.

[3] P. S. Tejaswi, P. Jha, and S. Sutar, "Comparison and Seismic analysis of a seven-storeyed RC Building resting on plain and sloping ground," vol. 9, no. 9, pp. 78–83, 2021.

[4] M. A. Gómez, E. G. Díaz-Segura, and J. C. Vielma, "Nonlinear numerical assessment of the seismic response of hillside RC buildings," *Earthq. Eng. Eng. Vib.*, vol. 20, no. 2, pp. 423–440, 2021, https://doi.org/10.1007/s11803-021-2029-4.

[5] S. Xiao, W. Feng, and J. Zhang, "Analysis of the effects of slope geometry on the dynamic response of a near-field mountain from the Wenchuan Earthquake," *J. Mt. Sci.*, vol. 7, no. 4, pp. 353–360, 2010, https://doi.org/10.1007/s11629-010-2055-6.

[6] M. Jameel, A. B. M. Saiful Islam, R. R. Hussain, S. D. Hasan, and M. Khaleel, "Non-linear FEM analysis of seismic induced pounding between neighbouring Multi-storey Structures," *Lat. Am. J. Solids Struct.*, vol. 10, no. 5, pp. 921–939, 2013, https://doi.org/10.1590/S1679-78252013000500004.

[7] A. Verma, P. Pal, and Y. K. Gupta, "Non-linear Dynamic Analysis of a Multi-storey Building Subjected to Earthquakes," in *Recent Trends in Civil Engineering*, Springer, 2021, pp. 231–242.

[8] M. Nitya and S. Arathi, "Study on the earthquake response of a RC building with base isolation," *Int. J. Sci. Res*, vol. 5, pp. 1002–1005, 2016.

[9] S. M. K. D.N. Kakde, "Influence of slope angle variation on the structures resting on Sloping ground subjected to heavy winds," vol. 63, no. 1, 2021.