

To Cite This Article

Mr. Mahesh V. Kamthe, & Prof. Diwakar Amame. (2026). Seismic Performance Evaluation of a Diagrid Braced Dual System on Sloping Terrain Considering Soil Structure Interaction. *International Journal of Multidisciplinary Academic Studies and Research (IJMASR)*, 1(3), 94–105. <https://doi.org/10.5281/zenodo.19653289>

Article Info

Received: 22nd March 2026, Accepted: 23rd March 2026, Published: 25th March 2026.

Seismic Performance Evaluation of a Diagrid Braced Dual System on Sloping Terrain Considering Soil Structure Interaction

Mr. Mahesh V. Kamthe¹, Prof. Diwakar Amame²

¹ Research Scholar, Department of Civil Engineering, VM Institute of Engineering & Technology, Nagpur, India

² Assistant Professor, Department of Civil Engineering, VM Institute of Engineering & Technology, Nagpur, India

Corresponding Author-

Mr. Mahesh V. Kamthe

Email Id- maheshkamthe8@gmail.com

Abstract: - In recent years, rapid urbanization and scarcity of land have led to the construction of high-rise buildings, especially in challenging conditions such as sloping terrain. These structures are highly vulnerable to seismic forces due to irregular geometry, varying stiffness, and complex load distribution. Therefore, it becomes essential to study their behavior under earthquake loading conditions using advanced structural systems and realistic analysis approaches. In this study, the seismic performance of a G+10 diagrid braced dual system building on sloping terrain is evaluated by considering the effect of soil–structure interaction (SSI). The diagrid structural system is adopted due to its high efficiency in resisting lateral loads through its triangulated configuration, which enhances stiffness and reduces material consumption. The analysis is carried out using SAP2000 software by performing nonlinear time-history analysis with the El-Centro earthquake record. The building is modeled under two base conditions, namely fixed base and flexible base (with SSI). The SSI effect is incorporated using the Winkler spring model, considering different soil types such as hard soil, medium soil, and soft soil. The performance of the structure is evaluated based on key seismic parameters such as storey displacement, maximum displacement, time period, storey drift, and base shear. The results indicate that the inclusion of soil–structure interaction significantly influences the dynamic behavior of the building. It is observed that displacement and time period increase with the flexibility of soil, particularly in soft soil conditions, while base shear decreases due to the damping effect of soil. The diagrid system demonstrates improved performance in terms of load distribution and lateral resistance compared to conventional systems.

Keywords: - Diagrid Structural System, Soil–Structure Interaction (SSI), Sloping Terrain, Seismic Analysis, Time History Analysis, High-Rise Buildings, Structural Performance.

I. INTRODUCTION

In recent decades, rapid urbanization and population growth have led to a significant increase in the demand for residential, commercial, and industrial infrastructure. Due to the scarcity of land in metropolitan cities and the high cost of available land, vertical development in the form of high-rise buildings has become a necessity rather than a choice. These tall structures are subjected not only to gravity loads but also to significant lateral loads such as wind and earthquake forces. Among these lateral loads, earthquake forces are the most critical, as they are unpredictable and can cause severe damage or even collapse of structures. Therefore, proper seismic analysis and design of buildings are essential to ensure safety, serviceability, and durability. In addition to this, construction on sloping terrain has become common in hilly regions due to the unavailability of flat land. Buildings constructed on sloping ground behave differently from those on flat ground due to irregular geometry, unequal column heights, and variation in stiffness. These irregularities result in torsional effects and increased vulnerability under seismic loading. To overcome these challenges, modern structural systems such as diagrid systems and dual systems are being adopted.

These systems provide better stiffness, strength, and lateral load resistance compared to conventional systems. Furthermore, the effect of soil–structure interaction (SSI) plays a crucial role in determining the actual behavior of structures during earthquakes, as the flexibility of soil significantly affects the response of the building.

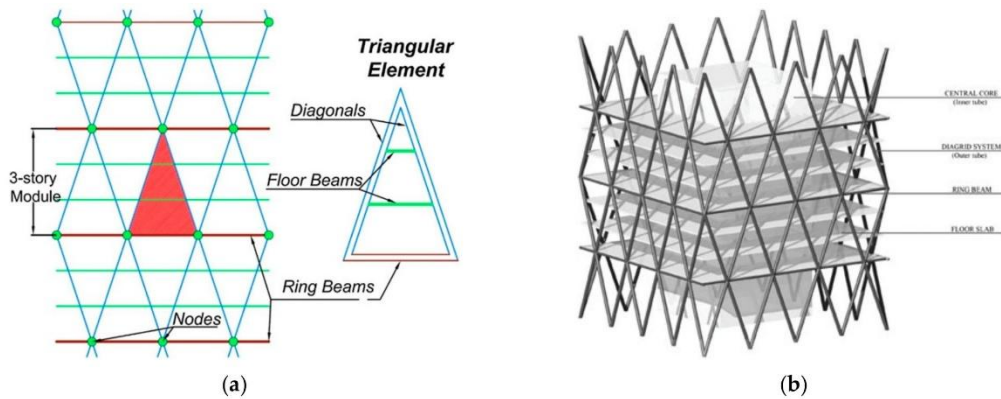


Figure 1.1: Typical Diagrid Structural System (Plan, Elevation, and 3D View)



Figure 1.2: Famous Diagrid Buildings Around the World

Advancing **II. METHODOLOGY** Disciplines

The methodology followed in this study includes the following major steps:

1. Modelling of diagrid building with different parameters considered
2. Fixing of soil properties for different soil conditions
3. Collection of earthquake ground motion data
4. Incorporation of soil–structure interaction at the base of the structure
5. Performing analysis using nonlinear dynamic (time-history) method

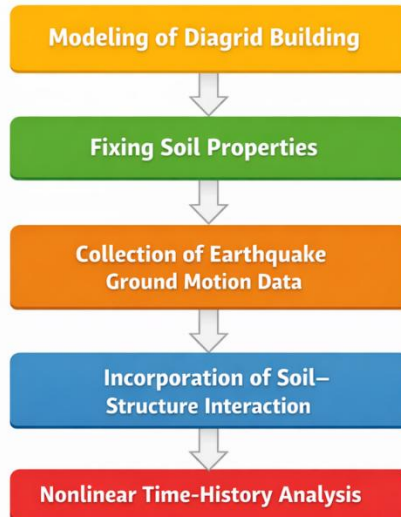


Figure 3.1: Methodology Flowchart

VALIDATION OF MODEL:

Before performing the main analysis, the developed model is validated by comparing the results with a reference research paper. A G+10 storey symmetrical building is considered for validation. The analysis is carried out using SAP2000 software under both:

- Fixed base condition
- Flexible base condition (with SSI)

Table 3.1: Model Period from SAP2000

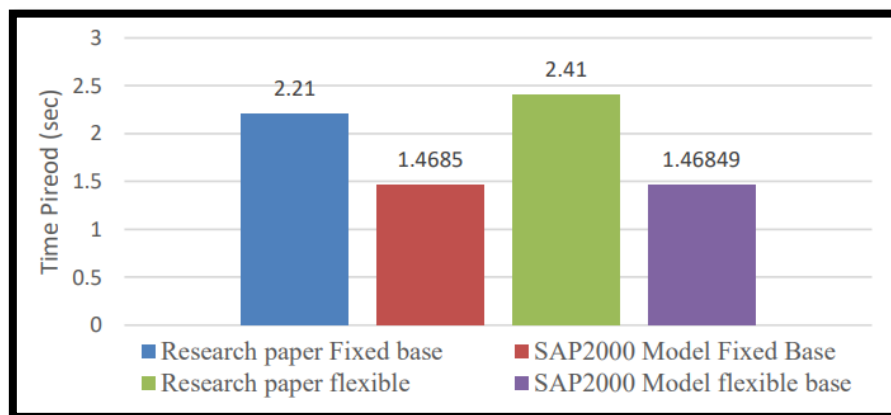
Condition	Time Period (sec)
With SSI (Flexible Base)	1.46849
Without SSI (Fixed Base)	1.69603

The obtained results are compared with reference values, and it is observed that the values are nearly similar, confirming the accuracy of the model.

Validation Observation:

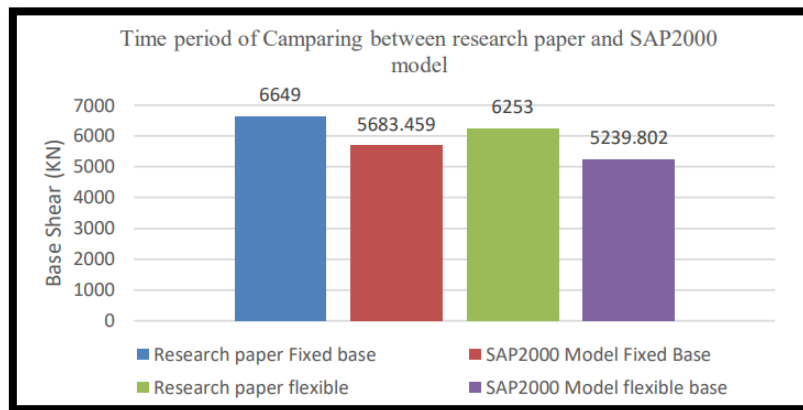
- Time period variation: 20–30%
- Base shear variation: 10–15%

This confirms that SSI significantly affects structural response.



Graph 3.1: Time Period

Graph 3.1 shows the comparison of the time period of the building under fixed base and flexible base conditions for both research paper results and SAP2000 model results. It is observed from the graph that the time period is higher in the flexible base condition (with SSI) as compared to the fixed base condition. This increase in time period is due to the flexibility of soil, which makes the structure more flexible and allows more movement during seismic excitation. The research paper shows a time period of about 2.41 sec in flexible base and 2.21 sec in fixed base, while the SAP2000 model shows approximately 1.468 sec in flexible base and 1.468 sec in fixed base with slight variation. The comparison indicates that the values obtained from the present analysis are in close agreement with the reference study, validating the model accuracy.



Graph 3.2: Base Shear

Graph 3.2 represents the comparison of base shear values under fixed base and flexible base conditions. From the graph, it is observed that the base shear is higher in the fixed base condition and reduces when soil flexibility (SSI) is considered. This reduction in base shear occurs because the soil absorbs a portion of the seismic energy, acting as a damping medium. As a result, the force transmitted to the structure is reduced. The variation between fixed and flexible base conditions is found to be approximately 10% to 15%, which is consistent with previous research findings. The graph also shows that the SAP2000 model results are in good agreement with the research paper values, confirming the reliability of the analysis.

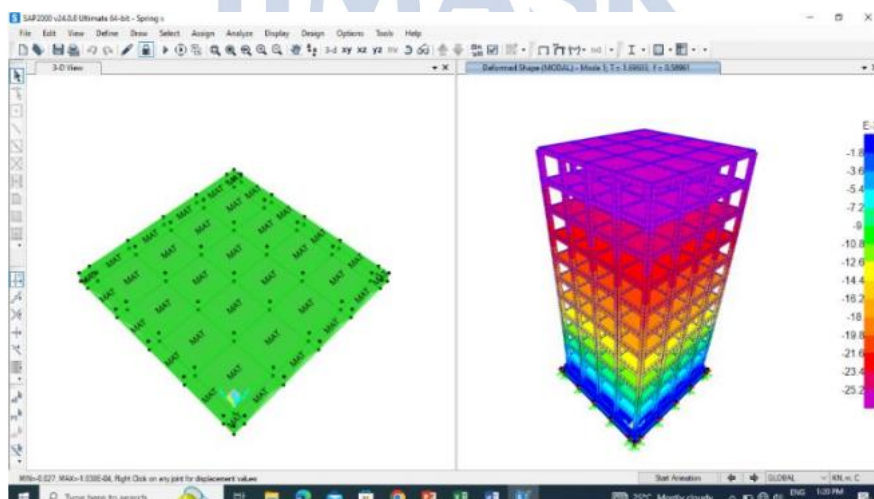


Figure 3.2: View of SAP2000 for model period

Figure 3.2 shows the output view obtained from SAP2000 software, representing the model period (natural time period) of the analyzed building. The model period is one of the most important dynamic properties of a structure, which indicates the time taken by the structure to complete one full cycle of vibration during seismic excitation. In this figure, the SAP2000 model displays the calculated time period values for the G+10 diagrid building under the considered loading and boundary conditions. The model period is obtained after performing modal or time-history analysis, where the structure's stiffness, mass distribution, and support conditions are taken into account. From the SAP2000 output, it is observed that the time period varies depending on the base condition of the structure.

When the structure is considered as a fixed base, the stiffness is higher, resulting in a lower time period. On the other hand, when soil–structure interaction (SSI) is considered, the base becomes flexible due to soil springs, which reduces the overall stiffness of the structure and leads to an increase in the natural time period. This figure is important as it visually confirms the analytical results obtained in the study and helps in validating the model. The close agreement between SAP2000 results and reference values indicates that the modeling and analysis procedures adopted in this study are accurate and reliable.

BUILDING MODEL DESCRIPTION:

A G+10 storey RCC diagrid building is considered for analysis. The building is symmetric in plan and modeled using SAP2000 software.

Table 3.2: Building Dimensions

Parameter	Value
Plan Size	16 m × 16 m
Number of Storeys	11
Storey Height	3.2 m
Slab Thickness	150 mm
Beam Size	300 mm × 500 mm
Column Size	450 mm × 600 mm

The model of building is G+10 storey RCC structure considered for the analysis. The building is symmetric in plan as shown in figure 3.3. The building has bay width of 4m in X and Y direction with 3.2m storey height. Slab is 150mm thick. Diagrid system Building of structure. Non-linear time history analysis is carried out in SAP2000 software using EL Centro.

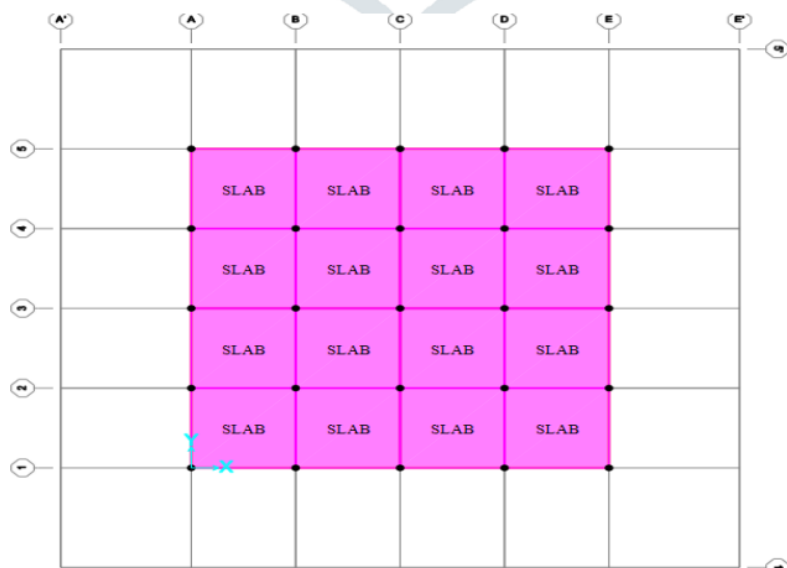


Figure 3.3: Plan view of symmetrical building

SPRING CONSTANTS FOR SSI:

Table 3.3: Spring Constants

Parameter	Hard Soil	Medium Soil	Soft Soil
Kx (kN/m)	1380000	946285	487058
Ky (kN/m)	1380000	946285	487058
Kz (kN/m)	1586250	1128000	604228
Kxx (kN-m/rad)	63281250	77760000	41657142
Kyy (kN-m/rad)	110224800	78382080	41990400
Kzz (kN-m/rad)	181958400	121305600	60658280

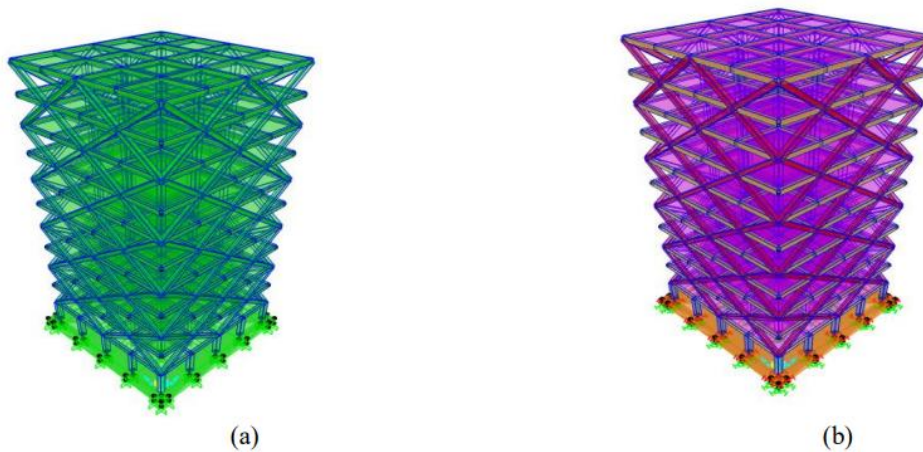


Figure 3.4: (a) Diagrid Building without SSI and (b) Diagrid Building with SSI.

Figure 3.4 illustrates the comparison between the SAP2000 models of the diagrid building without soil–structure interaction (SSI) and with SSI effect. In Figure 3.4(a), the building is modeled with a fixed base condition, where the foundation is assumed to be perfectly rigid. In this case, the base of the structure does not undergo any deformation, and all the seismic forces are directly transferred to the structure. This assumption increases the overall stiffness of the building and generally results in lower displacement and lower time period, but it does not represent actual field conditions. On the other hand, Figure 3.4(b) shows the building model with soil–structure interaction incorporated using spring elements at the base. In this model, the soil flexibility is considered by providing translational and rotational springs, which simulate the real behavior of the soil supporting the structure. Due to the presence of these springs, the base of the structure becomes flexible, allowing slight movement and deformation under seismic loading. The comparison between the two models clearly shows that SSI significantly affects the structural response. In the model with SSI, the overall stiffness of the structure reduces, which leads to an increase in time period and displacement, while the base shear generally reduces due to energy absorption by the soil. This demonstrates that the flexible base condition provides a more realistic representation of structural behavior compared to the fixed base assumption.

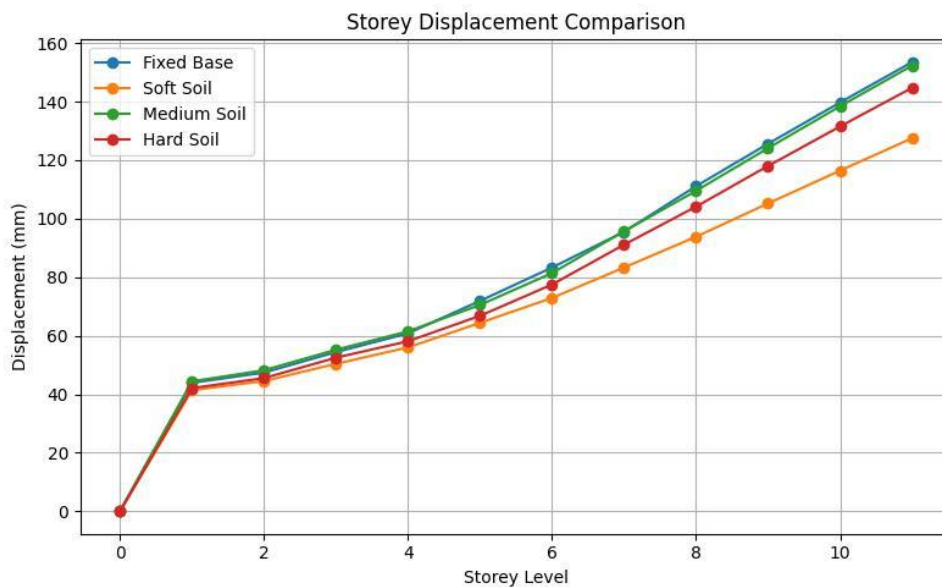
III. RESULTS AND DISCUSSION

STOREY DISPLACEMENT:

The displacement values for the G+10 diagrid building under different conditions are presented in Table 4.1.

Table 4.1: Storey Displacement (mm)

Storey	Fixed Base	Soft Soil	Medium Soil	Hard Soil
11	153.5	127.5	152.3	144.7
10	139.7	116.4	138.4	131.5
9	125.6	105.2	124.1	118
8	111.1	93.8	109.5	104.1
7	95.5	83.3	95.7	91.1
6	83.3	72.9	81.4	77.5
5	71.9	64.4	70.5	66.8
4	60.8	56.0	61.5	58.1
3	54.4	50.4	55.2	52.5
2	47.4	44.5	48.2	45.5
1	43.9	41.4	44.4	42.1
0	0	0	0	0



Graph 4.1: Storey Displacement (mm)

Discussion:

From the results, it is observed that the maximum displacement occurs at the top storey (11th floor). The displacement is highest in the fixed base condition, while comparatively lower values are observed when SSI is considered.

Among soil types:

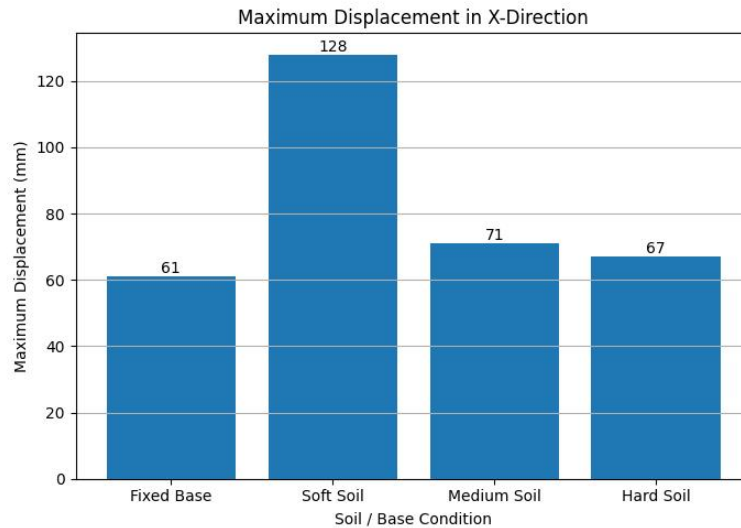
- Soft soil shows higher displacement due to low stiffness
- Hard soil shows lower displacement due to higher stiffness

This indicates that soil flexibility plays an important role in controlling structural response.

MAXIMUM DISPLACEMENT:

Table 4.2: Maximum Displacement (mm)

Direction	Fixed Base	Soft Soil	Medium Soil	Hard Soil
X-Direction	61	128	71	67



Graph 4.2: Maximum Displacement (mm)

Discussion:

The maximum displacement is observed in soft soil condition, which is nearly double compared to fixed base. This is due to:

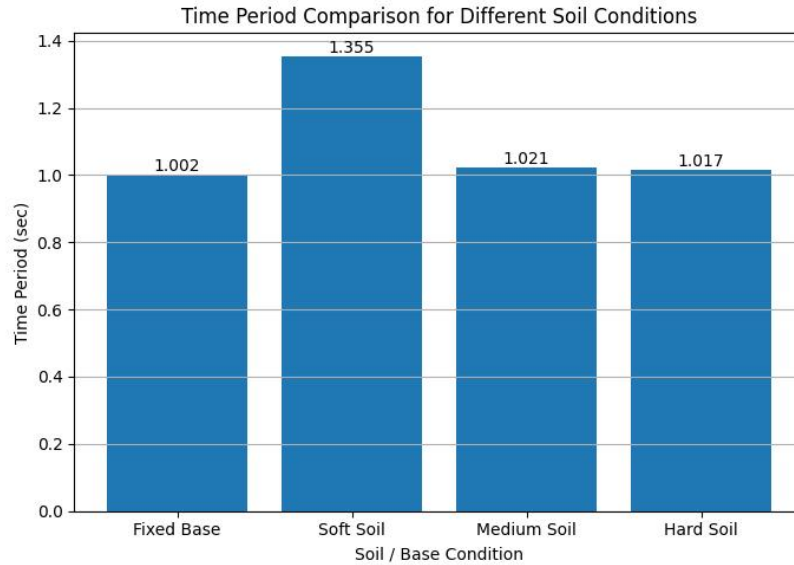
- Low stiffness of soil
- Higher flexibility of foundation

Thus, SSI increases displacement significantly, especially in soft soil.

TIME PERIOD:

Table 4.3: Time Period (sec)

Condition	Time Period
Fixed Base	1.00223
Soft Soil	1.35452
Medium Soil	1.02072
Hard Soil	1.0166



Graph 4.3: Time Period (sec)

Discussion:

It is observed that:

- Time period increases with SSI
- Maximum time period is seen in soft soil

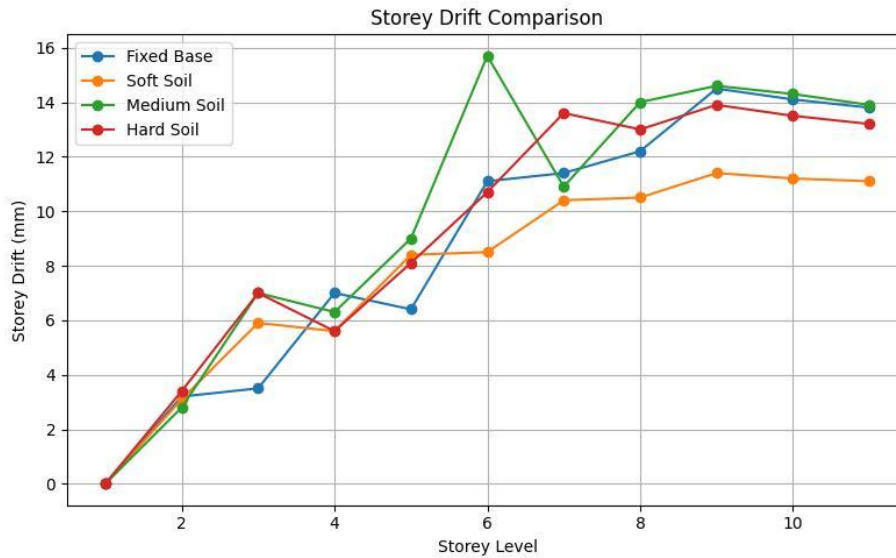
This is because soil flexibility reduces structural stiffness, leading to:

- Higher natural time period
- More dynamic response

STOREY DRIFT:

Table 4.4: Storey Drift (mm)

Storey	Fixed Base	Soft Soil	Medium Soil	Hard Soil
11	13.8	11.1	13.9	13.2
10	14.1	11.2	14.3	13.5
9	14.5	11.4	14.6	13.9
8	12.2	10.5	14.0	13.0
7	11.4	10.4	10.9	13.6
6	11.1	8.5	15.7	10.7
5	6.4	8.4	9.0	8.1
4	7.0	5.6	6.3	5.6
3	3.5	5.9	7.0	7.0
2	3.2	3.1	2.8	3.4
1	0	0	0	0



Graph 4.4: Storey Drift (mm)

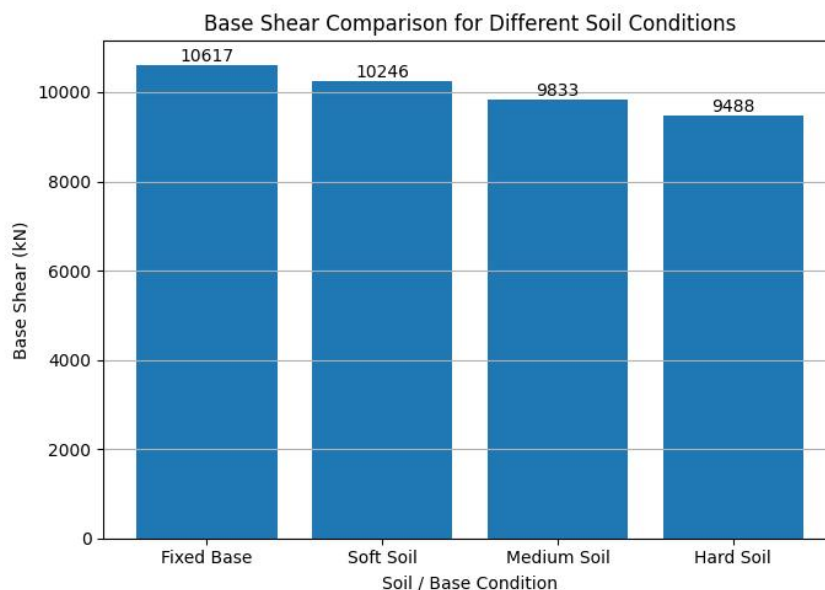
Discussion:

- Maximum drift occurs in upper storeys
- Drift is reduced when SSI is considered
- Soft soil shows controlled drift due to damping effect

BASE SHEAR:

Table 4.5: Base Shear (kN)

Condition	Base Shear
Fixed Base	10616.622
Soft Soil	10246.33
Medium Soil	9832.65
Hard Soil	9488.418



Graph 4.5: Base Shear (kN)

Discussion:

From the results:

- Base shear is maximum in fixed base condition
- Base shear reduces with SSI

Reason:

- Soil absorbs seismic energy
- Acts as damping medium

Reduction is about 10–15%, which matches literature.

CONCLUSION

The study clearly indicates that soil–structure interaction (SSI) plays a very significant role in the seismic behavior of structures. The conventional assumption of fixed base condition does not represent actual field conditions, and hence considering SSI provides more realistic and reliable results. It is observed that the storey displacement increases significantly when soil flexibility is considered, especially in the case of soft soil. The maximum displacement is found at the top storey of the building, which is expected due to the cumulative effect of lateral loads. Among all soil types, soft soil shows the highest displacement, while hard soil shows comparatively lower displacement due to its higher stiffness. The analysis of maximum displacement reveals that the structure resting on soft soil undergoes almost double the displacement compared to fixed base condition. This indicates that soil flexibility reduces the stiffness of the system and increases structural deformation during seismic loading. The results also show that the natural time period of the structure increases when SSI is considered. This increase is more prominent in soft soil due to its low stiffness. An increase in time period indicates that the structure becomes more flexible and sensitive to seismic excitation. From the storey drift analysis, it is observed that the drift values are maximum at the upper storeys. However, with the inclusion of SSI, there is a slight reduction in drift values due to the damping effect of soil. This indicates that soil can absorb some amount of seismic energy, thereby reducing relative displacement between floors. The base shear results show a decreasing trend when SSI is considered. The maximum base shear is observed in the fixed base condition, while it reduces for soft, medium, and hard soil conditions. This reduction is due to the energy dissipation capacity of soil, which acts as a natural damping medium. The reduction in base shear is approximately in the range of 10–15%, which is consistent with previous research findings.

REFERENCES

- [1] Bhale, S. A., & Shimpale, P. M. (2022). Analytical study on seismic performance of diagrid structural system. *Journal of Emerging Technologies and Innovative Research (JETIR)*, 9(10).
- [2] Bush, R. C., Rani, V., Suleiman, M. F., Biradar, B. B., Vyas, R., Ahmad, A., & Shirkol, A. I. (2024). Seismic performance evaluation and comparative study of reinforced concrete building on a sloped terrain with regular building by considering the effect of URM infill walls. *Buildings*, 14(1), 33. <https://doi.org/10.3390/buildings14010033>
- [3] Ganar, A. S., & Patil, S. D. (2015). Comparative analysis on cost and duration of MIVAN formwork building and conventional formwork building. *International Journal*.
- [4] Geetha, L., Valmiki, A. K. S., Shivanand, C. G., Nayana, B. S., Kallimani, K. S., & Kumar, R. (2026). Data-driven structural assessment of variable inclination diagrid systems under lateral loading. *E3S Web of Conferences*. <https://doi.org/10.1051/e3sconf/202670206012>
- [5] Hansora, A. G., Parmar, V. N., & Tarachandani, D. R. (2025). Comparative analysis of diagrid structural system with moment frame, shear wall and brace tube as inner core. *IJSRD*, 13(4).
- [6] Hassain, M., & Chithra, S. (2020). Analytical study and seismic evaluation of diagrid structural system for high rise steel building. *IRJET*, 7(6). DOI: Not Available
- [7] Ichpas, J. B. C., Sedano, F. M., & Malpartida, E. M. L. (2025). Seismic performance between the diagrid structural system and the dual structural system for important buildings. *International Journal of Civil Engineering*, 12(11), 160–170. <https://doi.org/10.14445/23488352/IJCE-V12I11P113>
- [8] Jadhav, P. (2021). Seismic evaluation of diagrid structure with performance based design. *IJSART*, 7(8).
- [9] Kewatkar, G. S., & Lande, P. S. (2023). Seismic response of diagrid system building and effect of soil-structure interaction on conventional building: A review. *IJRSET*, 12(7). <https://doi.org/10.15680/IJRSET.2023.1207091>
- [10] Kewatkar, G. S., & Lande, P. S. (2023). Seismic response of diagrid system building with soil-structure interaction. *JETIR*, 10(7).

- [11] Kim, J., & Lee, Y. H. (2012). Seismic performance evaluation of diagrid system buildings. *Structural Design of Tall and Special Buildings*, 21(10), 736–749. <https://doi.org/10.1002/tal.643>
- [12] Liu, C., Li, G., He, B., Zhou, C., & Ma, Y. (2024). Sustainable seismic performance of diagrid core-tube structure with replaceable steel coupling beam. *Sustainability*, 16(7), 2690. <https://doi.org/10.3390/su16072690>
- [13] Mehtani, D. V., & Patel, P. V. (2022). Evaluation of seismic performance factors for concrete filled steel tube diagrid structural system. <https://doi.org/10.38208/acp.v1.728>
- [14] Naik, H. A., & Suryawanshi, S. R. (2018). Diagrid structural system: Comparative study to reduce earthquake forces on high rise building. *JASRAE*, 15(2).
- [15] Nourin, N., Hazeena, R., & Basheer, A. (2021). A review on seismic performance assessment of steel diagrid structures. *AJR Proceedings*. <https://doi.org/10.21467/proceedings.112.37>
- [16] Ovi, M. M. H., Bintu, B. O., Sarkar, B., & Chowdhury, S. R. (2025). Impact of sloping ground on the seismic and wind performance of high-rise buildings with outrigger bracing systems. *IJERT*, 14(8). <https://doi.org/10.5281/zenodo.18103693>
- [17] Panchal, S., & Jayswal, K. (2024). A review on seismic analysis of irregular plan of diagrid structure on sloping ground. *IRJET*, 11(1).
- [18] Parmar, D., Ponnappan, N., Thampi, A., & Prasanth, S. (2025). Seismic performance of various structural configurations for RC building on sloped terrain considering soil–foundation–structure approach. *Frontiers in Built Environment*, 11, 1709068. <https://doi.org/10.3389/fbuil.2025.1709068>
- [19] Patel, K. G., & Chandresha, S. P. (2022). Effects of plan irregularities of multi-storeyed structure resting on sloping terrain with soil structure interaction. *IJRASET*, 10(5).
- [20] Ramírez, A. Q., Terán Gilmore, A., & Medrano, M. S. (2024). Earthquake-resistant and environmental advantages of diagrid systems in high seismicity zones. *Journal of Building Technology*, 6(1). <https://doi.org/10.32629/jbt.v6i1.2188>
- [21] Seyedkazemi, A., & Qolian Seraji, R. (2019). Evaluation of seismic performance of double-layer steel diagrid systems. *Periodica Polytechnica Civil Engineering*, 63(4), 1183–1192. <https://doi.org/10.3311/PPci.12294>
- [22] Shah, A., & Suthar, A. (2025). Seismic performance of buildings on sloping terrain: A review of structural behavior and design consideration. *IRJET*, 12(5).
- [23] Singh, R., & Grover, R. K. (2024). Comparative study and analysis of conventional and diagrid building in seismic loading. *Journal of Computational Analysis and Applications*, 33(8).
- [24] Soumya, M., Veerashaiah, H. M., Kumar, P., & Gurupadaswamy, N. (2023). Seismic behaviour of buildings on sloping ground with bracing systems using ETABS software.
- [25] Veera Babu, K., Siva Rama Krishna, S., & Malagavelli, V. (2023). Seismic analysis of multi-storey building on sloping ground and flat ground using ETABS. *IOP Conference Series: Earth and Environmental Science*, 1130, 012004. <https://doi.org/10.1088/1755-1315/1130/1/012004>