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Seismic performance of foundation with GEOGRID

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This study investigates seismic performance analysis of geogrid stabilized foundations under numerical modeling using a Geotechnical Engineering Software, PLAXIS 2D. The research focuses on consecutive acceleration differences between floors to assess the effectiveness of geogrid in improving structural stability. The results of the study show that geogrid is effective in mitigating sudden change in acceleration from a floor to another, which leads to a homogeneous seismic response. Without geogrid, differences between consecutive floors were 0.049g (Basement–1st), 0.059g (1st–2nd), 0.032g (2nd–3rd), -0.023g (3rd–4th), and 0.053g (4th–5th). But with the addition of geogrid (1.8B width and 2m spacing case), corresponding differences were 0.017g, 0.025g, 0.034g, -0.007g, and 0.087g, respectively. The results indicate that the foundation stabilized by the geogrid experiences less abrupt change in acceleration floor to floor and thus performs less abrupt jumps that tend to cause more structural damage. For example, the basement-first-floor difference reduced by 65.3% and first-second-floor difference reduced by 57.6%, which is more smoothed seismic response. The study shows the benefits of inter-floor acceleration difference reduction, and general foundation stability enhancement by geogrid reinforcement. The study highlights the importance of geogrid-reinforced foundations in seismically active areas, and its findings helps in future structural design.

Keywords: Seismic response; Geogrid; Slope stabilization; SSI

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INTRODUCTION

Nepal lies in seismic prone region where two big tectonic plates makes deformation intense. The structure in the urban region are located on various subsoil ranging from soft to dene clay and sand. Every types of soil responds different to different seismic loading. It leads to site specific mitigation measures to be adopted. In the past practises, dynamc interaction between soil and structure used to be ignored. During seismic activity many nonlinear changes occurs in the site that leads to change behavior of the foundation of the structure. So we need to understand the difference in performance of unreinforced foundation and reinforced foundation. After exploring many literatures, the use of geogrid in the foundation is absent whereas the studies suggests that the use of geogrid helps to increase the load bearing capacity but few have studies and explored on dynamic behavior of the real earthquake loading. In Nepal, the integration of geogrid is completely absent both in practice as well as code based design. Nowadays, the use of geogrid in construction works like roads and retaining walls is very high.

Geogrid are the polymer materials that are used to stabilize the soil. Geogrids stabilize the soil by increasing the stiffness and improving its stabilizing property of soil. Geogrids are the mesh structure having high strength characteristics that provides lateral confinement and settlement. The use of geogrid helps in dissipating seismic energy and enhancing the structural integrity. In the past, it is seen that the seismic designs were focused on the super structure whereas neglecting the soil and foundation interaction as well as soil and structure interaction. Here, the research conducts soil and geogrid interaction. The use of geogrid has been an effective method for increasing the seismic stability and reduction in differential settlement.

The use of geosynthetics for soil reinforcement purposes have been widely used in various geotechnical engineering applications, including bridge approach slabs, bridge abutment, building footings, and embankments. Literature suggests that the inclusion of reinforcement in soil foundations is a cost-effective solution to increase the bearing capacity and to decrease the settlement of footings compared to the conventional methods such as replacing natural soils or increasing the dimensions of the footings. Geogrids are the most commonly used geosynthetic materials to reinforce the foundation soil. By definition, geosynthetics are synthetic materials that are commonly used to solve civil and geotechnical engineering problems. It is well known that geosynthetics are capable of absorbing dynamic forces and transmitting less dynamic forces to which engineering structure it is implemented. More specifically, the use of geosynthetics under foundations can absorb seismic energy and mitigate excitations transmitting to upper layers of soils and foundation of overlying structures. In addition, tensile strength of the material and the interface between soil and geosynthetic material increases the shear resistance of soil under dynamic conditions. Other important parameters that play an important role in bearing capacity under static and dynamic conditions include the depth to the first layer of reinforcement, vertical spacing of reinforcement layers, and number of reinforcement layers and the properties of the reinforcement.

The current research is conducted through numerical modelling using PLAXIS 2D to investigate the seismic performance of geogrid stabilized foundation. Our study focuses on the part where physical testing of the large model is difficult to carry out. Studies (Kassem et al., 2019) have demonstrated the effectiveness of geogrid-reinforced foundations in minimizing settlement and increasing uniformity in structural response. (Demiröz and Tan 2010**)** found that the optimal depth of geogrid reinforcement was found to be 0.5 times the foundation width (u = 0.5B), (Jawad and Shakir, 2021), highlights that geogrids can significantly increase bearing capacity, there is a need for more research on their application in clay soils. (Nielson and Cleary, 2000) found that geogrids help to dissipate seismic energy by improving the soil stiffness and preventing excessive movement during an earthquake, which reduces the overall damage to the building's foundation. (Gorib and Hussain 2020) increased the load-bearing capacity but also enhanced the overall performance of the foundation in terms of settlement control and structural stability. (Shin, E. C. et.al. 2002) The experimental results demonstrate that geogrid reinforcement can enhance the bearing capacity of clay foundations, though the improvement is less pronounced compared to sandy soils. After the devastating Gorkha earthquake 2015, the use of strong foundation has been marked as necessity in structure. The transfer of stresses from the embedded foundation to the underlying soil should more properly be understood through the detailed soil-structure interface, which can be done through the finite element analysis.

The study mainly focuses on numerically modelling as well as analysis of a five-story building model founded on geogrid-reinforced soil using PLAXIS 2D. The response of geogrids to past earthquake loading data and their influence on the foundation were subjected to finite element analysis. The study brings out the mechanism of reinforced and unreinforced foundations for the considered peak ground accelerations. Under this study: Boundary conditions, mesh refinement, and material properties can be very finely represented in PLAXIS 2D. This study intends to cover the knowledge gap and research voids with respect to soil behavior, geogrid behavior, and structural response during dynamic loading. Currently, this study is expected to yield pragmatic recommendations for the application of geogrid in foundation systems to enhance seismic resilience and highly recommended particularly for Nepal and other tectonically active regions facing similar seismic hazards.

METHODOLOGY

Numerical modelling

The study is related with the numerical analysis of the foundation and the structure of five storey. PLAXIS 2D was chosen for numerical modelling due to its ability to model advanced soil behavior. It can simulate construction phases and analyze soil-structure interaction. It has higher accuracy in simulating the behavior of real world soil and structure condition. The main aim was to investigate the seismic response of geogrid stabilized foundation. The finite element method (FEM) addressed the soil structure interaction that makes more practical results.

The model dimensions were 50m*100m boundary. This size can propagate the seismic wave that would have sufficient room without reflecting off model boundaries artificially. Two layers of soil were taken in the model i.e. upper clay layer and lower sandy soil. Four layer of geogrids were placed beneath the foundation. The building was modelled of five storey with storey height of 3m each whereas basement of 2m. The width of foundation was 10m. The structure was made uniform on each storey and also assumed to be symmetrical mass distribution. The analysis was done using uniaxial geogrid elements. Structural elements were modelled using plate and anchor elements.

Material properties

Soil sample were taken from Terai region of Nepal and soil test were conducted in Advanced College of engineering laboratory. Geogrid property was taken from design code for geogrid. Structural properties were taken with reference to construction site. The upper clay layer works on a weak surface stratum whereas the lower sandy soil serves for the bearing layer. The Hardening Soil Model (HS) was taken for simulating the non-linear behavior. The interface elements between soil and geogrid were introduced to prevent sliding and bonding. The reduction factor for the clay soil was 0.67 and for the sandy soil was 1.0. All the required parameter for modelling were presented in the Table 1.

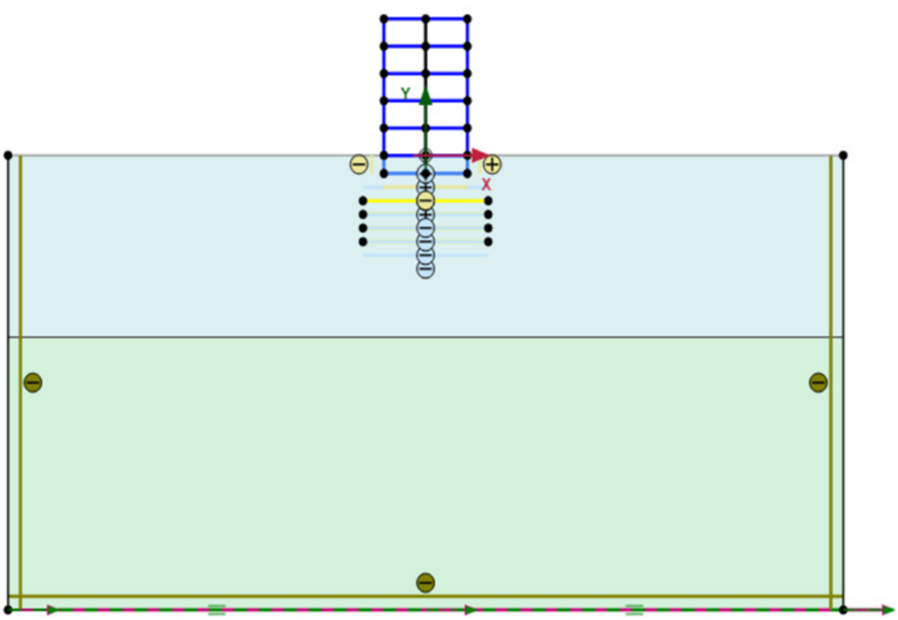

Fig. 1: 2D Finite element model

Table 1: Soil properties

Parameters	Upper Layer Clay Soil	Lower Layer Sandy Soil
Material Model	HS...	HS...
Drainage Type	Drained	Drained
Unsaturated Unit Weight (γ) (KN/m³)	16	20
Saturated Unit Weight (γ) (KN/m³)	20	20
$Eref^{50}$ (Pref =100kPa) (KN/m²)	20000	30000
$Eref^{od}$ (Pref =100kPa) (KN/m²)	25610	36010
$Eref^{ur}$ (Pref =100kPa) (KN/m²)	94840	110800
m, Power	0.5	0.5
Cohesion, C (KN/m²)	10	5
Friction Angle ϕ (°)	18	28
ψ (°)	0	0
Poisson's Ratio (ν)	0.2	0.3
Shear Strain, Go = 0.722 (γ)	$1.2*10^4$	$1.5*10^4$
Shear Modulus at Very Small Strains, Go*	$2.7*10^5$	$1.0*10^5$
Interface	0.67	1.0

Component of the structure were modelled using the plate element that can resist bending moments as well as axial moments. The material was taken to be elastic and isotropic. Based on typical reinforcing concrete value the modulus of elasticity and flexural rigidity were taken.

Table 2: Structural properties

Parameter	Name	Rest of building	Basement	Unit
Material Type	Type	Elastic; Isotropic	Elastic; Isotropic	-
Normal Stiffness	EA	$9.0*10^6$	$1.2*10^7$	kN/m²/m
Flexural Rigidity	EI	$6.75*10^4$	$1.5*10^5$	kN/m
Weight	w	10	20	kN/m/m
Poisson's Ratio	ν	0.0	0.0	-
Rayleigh damping	α	0.2320	0.2320	-
	β	$8.0*10^{-3}$	$8.0*10^{-3}$	-

To model the connection, Anchor elements were used to provide the passage for the load in the structure. It was used as a column member in the structure.

Table 3: Column properties

Parameter	Name	Column	Unit
Material Type	Type	Elastic	-
Normal Stiffness	EA	$2.5*10^6$	KN
Spacing out of plane	Lspacing	3.0	m

The geogrid data were taken from the design code of geogrid. We assumed the grogrid to be uniaxial for 2D model. The geogrids were placed in four layers in which the first layer of geogrid is placed just 3m below the foundation. It can transmit the axial forces which is specified in accordance with IS 16352:2015 for soil reinforcement applications.

Table 4: Geogrid properties

Stiffness	500.0E3	KN/m

Dynamic excitations

Gorkha Earthquake 2015 (Mw = 7.8, PGA = 0.248g) records were obtained from United State Geological Survey (USGS) which have been used for the dynamic response analysis. The input was provided at the bottom to make it realistic shaking.

Fig.2 is refined and filtered data of earthquake after cancel out the noise. The acceleration of the seismic load was provided at the bottom of the model. The resultant acceleration were taken in consideration whereas the vertical motion was neglected. We focused only in horizontal direction.

Modelling

Material defining was done for the model where two layers of soil are used. Upper layer is clay soil and lower layer is sandy soil. Boundary conditions were applied on the model and the interface between soil and the structure was addressed. Geogrid was introduced into the model and applied as structural element having high tensile stiffness of uniaxial type. It helps in load distribution. Mesh generation

consists of finite element mesh which is refined near the foundation for better accuracy. A structured mesh consists of a triangular mesh elements. In the foundation and geogrid zone, refinement was done to increase the accuracy in the mesh generation. A structured mesh was then used to address the interaction between the soil and geogrid interaction. The boundary condition for the fixation of the movement in the x-direction as well as y-direction were restricted. To prevent wave reflection, absorbing boundaries were taken in the model.

Stage construction consists of four phases. In the initial phase, only the soil was activated the in geogrid phase, soil and geogrid were activated, in building phase , structural elements like anchor, plate were activated whereas the basement soil was deactivated. In the earthquake phase, all the elements were activated along with dynamic loads are also activated. The analysis of the model was done between reinforced and unreinforced case to analyze the inter-floor acceleration difference between the levels. The methodology provides a framework for analyzing the effectiveness of geogrid in seismic design of foundation in earthquake prone regions. Every phases of the modelling were done in the drained condition to find out more realistic output and results.

RESULTS

The output of the model after the finite element analysis were simulated numerically that was conducted in PLAXIS 2D. The result is focused on the influence of the geogrid reinforcement. It is focused in terms of acceleration differenced, settlement and deformation pattern of the structure after the application of the seismic loads. The results of the study show that geogrid is effective in mitigating sudden change in acceleration from a floor to another, which leads to a homogeneous seismic response. Without geogrid, differences between consecutive floors were 0.049g (Basement–1st), 0.059g (1st–2nd), 0.032g (2nd–3rd), -0.023g (3rd–4th), and 0.053g (4th–5th). But with the addition of geogrid (1.8B width and 2m spacing case), corresponding differences were 0.017g, 0.025g, 0.034g, -0.007g, and 0.087g respectively. This shows the transmission and the intensity of the seismic energy form the foundation to the upper structure.

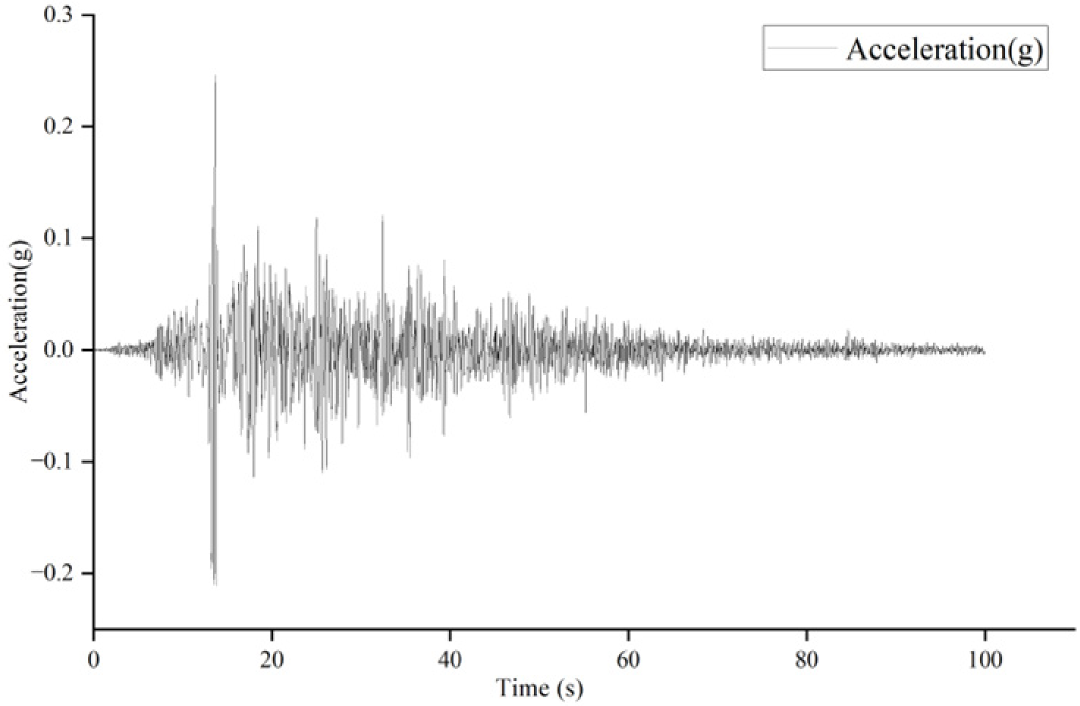

Fig. 2: Gorkha earthquake 2015.

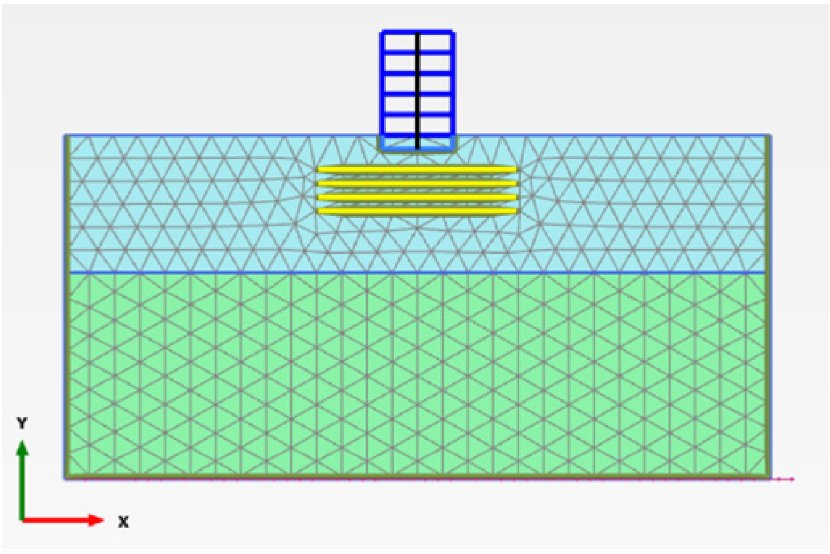

Fig. 3: Mesh generation.

Table 5: Results

		Basement	1st	2nd	3rd	4th	5th
No Geogrid		0.215	0.166	0.107	0.075	0.098	0.151
B	**1.5**	0.198	0.16	0.129	0.074	0.087	0.158
	1.8	0.197	0.161	0.127	0.076	0.085	0.157
	2	0.206	0.166	0.129	0.077	0.084	0.155
1.5B	**1.5**	0.202	0.167	0.134	0.080	0.076	0.167
	1.8	0.194	0.164	0.135	0.084	0.094	0.173
	2	0.192	0.165	0.136	0.082	0.097	0.175
1.8B	**1.5**	0.193	0.168	0.140	0.102	0.073	0.182
	1.8	0.189	0.169	0.142	0.105	0.093	0.185
	2	0.184	0.167	0.142	0.108	0.101	0.188
2B	**1.5**	0.197	0.171	0.137	0.110	0.071	0.192
	1.8	0.192	0.172	0.140	0.111	0.087	0.196
	2	0.191	0.17	0.147	0.113	0.093	0.199

The results indicate that the foundation stabilized by the geogrid experiences less abrupt change in floor to floor acceleration and thus performs less abrupt jumps that tend to cause more structural damage. For example, the basement-first-floor difference reduced by 65.3% and first-second-floor difference reduced by 57.6%, which is more smoothed seismic response. This shows the increment in the uniformness of the structure motion that reduces potential structural damages and prevents from cracking and collapse of the building.

The practical implication of the geogrid stabilized foundation in Nepal can be made more efficient. The study can provide the base and the application for the revision of the design code of geogrid in the future. Fig.4 represents the case of unreinforced foundation. The deformation at the foundation is relatively high. There is very less load dispersion that cause to more deformation that makes less stable.

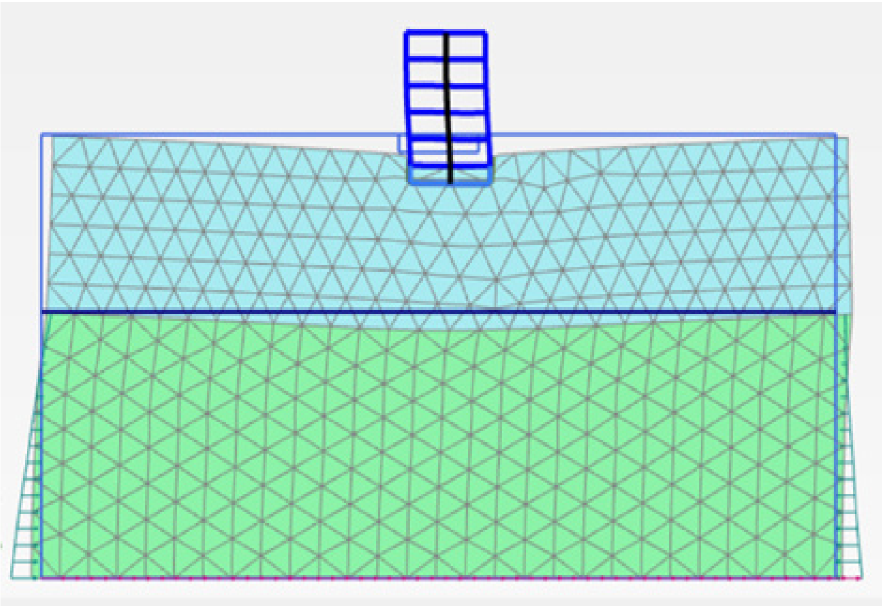

Fig. 4: Unreinforced foundation.

Fig.5 represents the case of reinforced foundation. We found that the use of geogrid shows more stable and less deformed shape.

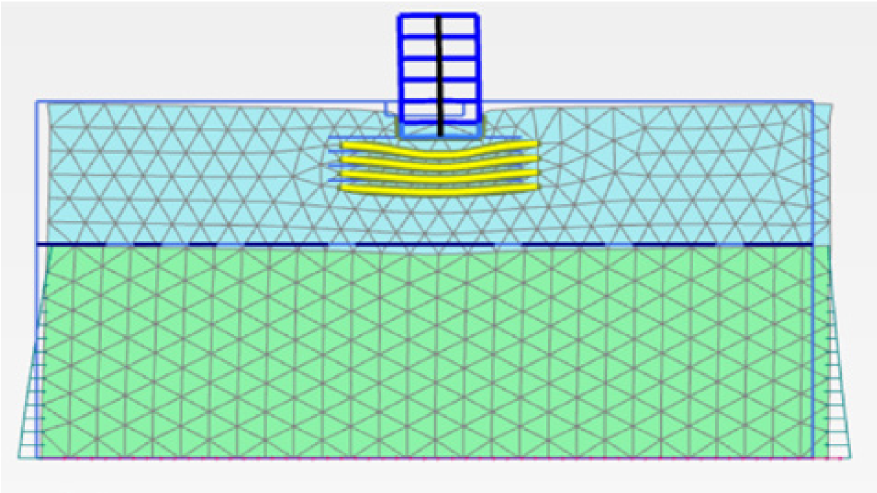

Fig. 5: Reinforced foundation.

The comparison between unreinforced and reinforced foundation shows huge difference in settlement of structure. The deformed shape of geogrid layers dissipates the energy released during earthquake that increases the bearing capacity of the foundation.

DISCUSSION

Significant advantages of employing geogrid-reinforced foundations under seismic loading have been determined through this research. Placing these in perspective requires comparing with previous work done by other researchers. The following discussion compares results and integrates knowledge from a broad spectrum of numerical and analytical investigations.

Previous Researcher Yıldız and Çolak (2016) cited that geogrid-reinforced soil improves the bearing capacity and reduces settlements, particularly in pavement construction. Our study, though concerned with foundations rather than pavements, saw the same settlement behavior and shows evidence to the geogrid's reliable performance regardless of infrastructure. Seismic Performance and Dynamic Loading Response by Kassem et al. (2019) performed experimental research on the seismic behavior of geogrid-reinforced foundation high-rise buildings and concluded that the seismic response is successfully reduced by geogrid utilization, which restricts the propagation of acceleration and enhances overall overall stability. Our results support these findings with quantitative data: inter-storey accelerations differences reduced up to 65.3% and lateral displacement reduced over 60%, validating geogrid's stiffening and damping effect for seismic loading. Gorib and Hussain (2020) focused on mid-rise building construction and stated that foundations with geogrid reinforcement provide better settlement restraint and seismic stability. Our study model is a five-storey mid-rise building and involves actual site soil conditions of Nepal, thus making our study even more site-specific. Edinçliler and Toksoy (2019) compared reinforcement of geogrid under various seismic conditions for medium-sized buildings. They concluded that geogrid systems minimize displacement greatly under various seismic conditions.Our study performance was consistent under various designs of reinforcement (1.5B, 1.8B, 2B widths; 1.5m–2.0m spacing). Chen et al. (2014) conducted experimental and numerical tests on high-rise structures and observed that the foundation movement was reduced. Similarly, our results lso found reduction in acceleration. Jiang et al. (2017) experimentally tested low-rise buildings and measured seismic isolation and foundation response increase caused by geogrids. This completes our investigation using this idea in a numerically simulated mid-rise structure, bridging the gap between low-rise laboratory specimens and urban applications. Berg and Giroud (2001) provide a detailed definition of geogrid-soil interaction modes and consider lateral restraint, membrane tension and interlocking to be performance-affecting. The modes of interaction responded easily in our simulations, particularly the shear strain contour maps showing the regions of energy dissipation and zones of reduced concentration below the foundation. Latha and Somwanshi (2009) illustrated that geogrid reinforcement increases bearing capacity and lowers footing deformation. Our modeling result adds largely static analyses in the bearing capacity. Shin et al. (2002) tested strip footings on geogrid-reinforced clay and realized satisfactory performance in relation to sandy soils. Similarly, our computation for the upper clay and lower sand layer showed that although the performance was extremely good in both the layers, improvement was greater in the sandy layer, supporting their evidence of reinforcement effects in soil-specific forms. For soil structure interaction, Jawad and Shakir (2021) went through all the literature once again and came across the reaffirmation of optimum spacings of geogrid employed in foundation design. Our research experiment for different spacings and widths (1.5B to 2B, 1.5m to 2m) validates their hypothesis by depicting optimum performance for width 1.8B and spacing 1.8m yielding optimum between effectiveness and material economy. Dhanya et al. (2013)

carried out research on geotechnical seismic isolation and demonstrated that reinforcement densities could regulate floor acceleration and settlement. Even as they were working with base-isolated structures, the study demonstrates that soil reinforcement alone, without conventional base isolators, can bestow the same benefits, especially where the economic condition makes it impossible to avail themselves of state-of-the-art technology. Moghaddas et al. (2010) contrasted geocells with planar geosynthetics and reported that both have bearing capacity advantage but geocells with the additional advantage of confinement. Since geocells do not come within our study, it is apparent that planar geogrids also provide significant improvement and conclude their applicability in cases where geocells are not an option.

All of the previous research studies, e.g., Kumar and Saran (2003) and Latha and Somwanshi (2009), were based on static or monotonic load conditions. This paper includes real seismic input (Gorkha Earthquake 2015) in the problem and enhances engineering practice relevance in earthquake engineering. Venkateswarlu and Hegde (2012) studied machine foundations on geocell-strengthened soils. Numerical simulation in this research provides an excellent theoretical background, but our research takes buildings into account and accordingly deals with many practical problem and lateral loading. Base isolation studies such as Zhang et al. (2022), Patel et al. (2023) and Singh (2023) were concerned about the performance of isolators at the superstructure level. But our study proposes geogrids as an alternative for foundation level isolation, which is easily available in developing nations such as Nepal.

The main aim of this study was to analyze the maximum response of the geogrid and its effectiveness of the geogrid reinforcement on a five storey building foundation. The results after the simulation shows the effectiveness of the geogrid that has greatly enhanced its application on the load bearing capacity, vertical settlement and lateral deformation. This greatly validates that the geogrid in the foundation improves the seismic resilience by dissipating seismic wave, its energy and can control its deformation. The observation was done based on the inter storey acceleration differences leads to suggest for a more uniform pattern of the structure. The main advantage of this helps in conforming the structural safety as well as to make safe from storey failure and storey drift. Due to this, the common cause of the structural damage reduces. The study shows that the reinforced foundation experiences lower settlement compared to the unreinforced foundation. The study extends the knowledge in geotechnical field for Nepalese soil data using site specific input on gorkha earthquake. The success of the geogrid reinforced foundation has effect on the several condition that benefits engineering mechanisms. Geogrid interlocks with the soil by creating the interface and creating the effect on the tension membrane that leads to restrict the lateral spreading. The load distribution of the structure over a wide area cause to reduce the stress and settlement beneath the foundation. It improves the modulus of soil and improves the stiffness.

CONCLUSION

The study represents the numerical study of the foundation stabilized with geogrid where five storey building was analyzed and the dynamic input was taken from Gorkha Earthquake 2015. The study was conducted based on the use of geogrid on the foundation with variation on width and spacing which represented the interaction between soil and structure. The result clearly shows that the use of geogrid increases seismic performance and uniformity in structural response. From above results, the basement-first-floor difference reduced by 65.3% and first-second-floor difference reduced by 57.6%. The study shows that the use of geogrid in foundation leads to viable solution for midrise building. The study contributes to the civil engineer and geotechnical engineer for better design of foundation.

AUTHOR'S CONTRIBUTION

The concept of the research was jointly developed by Samundra Kandel, Bishal Khadka, Bijaya Dangol, Janak Bista, Jessica Karki and Bibek Bishwokarma. Samundra Kandel, Bishal Khadka and Jessica Karki worked for report writing, literature review and figures preparation. Bijaya Dangol, Janak Bista and Bibek Bishwokarma performed numerical modelling and data collection. All the authors has contributed for drafting, revision and finalizing the manuscript for submission of the report.

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