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SEISMIC RESPONSE OF A VERY HIGH GRS WALL: SCENARIO BASED UNCERTAINTY ANALYSES

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A very high 35 m geosynthetic reinforced soil (GRS) wall was constructed along the Teesta River at Mamring, Sikkim. Failure of this wall during a minor earthquake presents a critical case study in understanding the seismic response and role of uncertainty in earthquake geotechnical engineering. Despite multiple reinforcing elements, the wall collapsed during the seismic event, leaving only the anchored in-situ material. The ground motion responsible for the failure was of sufficiently low intensity and, accordingly, no earthquake recording was present, thereby making it impossible to directly analyze the event based on empirical data. Given the absence of recorded seismic data, synthetic ground motions are generated based on the possible seismic scenarios. Seven representative motions are then selected to study the seismic response of the reinforced structure and to investigate the potential mechanisms that possibly led to its collapse. However, the use of synthetic ground motions introduces uncertainties, particularly regarding the range of possible strong motion characteristics that could realistically occur. To address this, uncertainty analysis is conducted, incorporating randomness in the various relevant ground motion parameters obtained from the considered seismic scenarios. The uncertainty analysis is essential in this context as it allows for the exploration of a broad spectrum of potential earthquake scenarios. Hence, based on the PGA of the generated synthetic motions, the structural response of the reinforced soil structure is investigated in the form of peak tensile forces developed along the geogrid layers of all three tiers. This study discloses the significant variation of the peak tensile forces across the tiers and also picturize non-linearity induced in structure due to varying seismic scenarios.

Keywords: Geosynthetic reinforced soil (GRS) wall, Seismic scenarios, Seismic response, Uncertainty analysis.

1. Introduction

The construction of geosynthetic-reinforced soil (GRS) walls has become increasingly popular due to their cost-effectiveness and versatility in challenging geotechnical conditions. These structures are designed to withstand significant loads, including those induced by seismic events. However, their performance under seismic loading, particularly in regions with high seismicity, remains a critical area of investigation. In general, seismic response analyses of any structure comprises studying the response parameters in relation to one or a few specific input motions. However, during its lifespan, a constructed structure can be subjected to multiple seismic events. Therefore, in this case, an ensemble of ground motions accounting for the possible seismic event should be utilized to study as well as design a structure for different seismic zones. In the seismic performance assessment, it is necessary to account for the variance in the seismic response distributed parameters (Bradley 2013). In addition, the required site-specific motions are not always readily available for the analysis. This is where synthetic ground motions become valuable, as they can be generated to reflect a range of seismic scenarios specific to the area in question. In the Indian construction sector, the design and analyses of GRS walls are conducted mostly on a deterministic level, wherein the intrinsic and extrinsic parameter influencing the design are assumed constant. However, such deterministic design requirement can be superseded when subjected to different seismic scenarios. Hence, considering scenario-based uncertainty provides an avenue to understand any such exceedance and on the extent of needful action to be taken from mitigation or re-designing perspectives. In this paper, synthetic ground motions are generated to study the seismic response of a 35 m high GRS wall as the actual recording of the seismic event that caused its failure is readily unavailable. In continuation, the peak tensile forces generated along the geogrid reinforcements are examined to explore the uncertainty in the behavioral responses of a structure during the seismic event. This analysis helps in understanding how various factors influence the structural integrity of GRS walls under seismic conditions.

2. Description of the Numerical Model

A 35 m high GRS wall resting on a rocky slope, constructed to retain a backfill of weathered rock mass, is modelled in a two-dimensional (2D) finite element (FE) framework with the aid of RS2 module of Rocscience commercial software. The model is bounded by a compliant base with absorbing boundary and accompanied by transmitting lateral boundaries to avoid the seismic wave reflections. The reinforcing elements utilized in the GRS wall include geocell layers acting as fascia and geogrids as reinforcements, along with rock anchors to withhold the weathered in-situ rock mass. Plum concrete is laid to provide a base to support the three-tiered GRS wall. The mesh elements are provided in such a way that the wave propagation problem is simulated appropriately (Lysmer and Kuhlemeyer 1973). The material properties adopted in the numerical model are given in the Table 1, wherein the strength of the concrete is calculated from its grade utilized for the construction. Further parameters are obtained from the borelog data and laboratory tests conducted on the corresponding samples. Soil-infilled geocell layers are modelled as equivalent composite material (Sureka *et al.* 2024) with improved strength and stiffness properties. Geogrid reinforcements of high tensile strength is employed at the bottommost tier, with the tensile strength progressively decreasing towards the crest. The layout of the structure is as shown in the Figure 1. Non-linear time-history analyses are performed by subjecting the model to 7 different synthetic acceleration time histories applied horizontally to the base of the model. Apart from that, an external distributed load of 15 kN/m^2 is applied at the top of the GRS wall that represents some existing site constructions. The natural frequency range of the structure is obtained from the power spectrum analysis and Rayleigh damping is then determined for a defined natural frequency range.

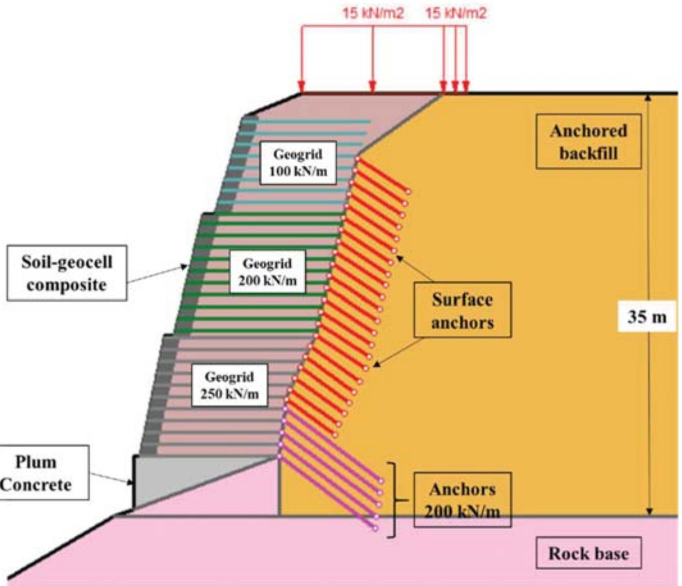

Fig. 1. Layout of the 35 m high GRS model

Table 1. Material properties adopted in the numerical model.

Soil parameters	Anchored backfill	Rock base	Reinforced fill	Soil-geocell composite	Plum concrete
Unit weight (kN/m^3)	19	20	18	18	24
Young's modulus (MPa)	192	192	312	468	1.58×10^7
Poisson's ratio	0.3	0.2	0.3	0.3	0.15
Peak friction angle (°)	33	33	32	32	45
Peak cohesion (kPa)	40	100	0	33	750

Anchor type	Diameter (mm)	Young's modulus (MPa)	Tensile capacity (kN)
Anchors 200 kN/m	19	2×10^5	200
Surface anchors	19	2×10^5	50

Geogrid type	Tensile modulus (MPa)
Geogrid 100 kN/m	56
Geogrid 200 kN/m	102
Geogrid 250 kN/m	150

3. Identification of Seismic scenarios

Ground motions recorded during a seismic event are a function of earthquake magnitude, faulting mechanism, source to site distance, source directivity effects, local site conditions, depth of sediments and other wave-focusing effects. Since the recording of the seismic event that caused the failure of the retaining wall is unavailable, in this study, a reference earthquake (M3.3) is considered that occurred around the date of the wall collapse (19th

February, 2022) with its epicentre at Darrang, Assam. The corresponding seismic scenario is employed for generating scenario-specific ensemble of unidirectional motions by varying the local magnitude using SeismoGen2 (Nithin *et al*. 2017). A total of 300 synthetic motions are generated comprising a range of ground motion parameters. Thereafter, based on the range of peak ground acceleration (PGA), seven representative motions were chosen out of those, for seismic response analyses of the GRS wall. Table 2 highlights the ground motion parameters of the chosen scenario-based representative motions.

Table 2. Ground motion parameters of the 7 representative motions chosen for seismic response analyses.

Ground motion parameters	EQ1	EQ2	EQ3	EQ4	EQ5	EQ6	EQ7
PGA (g)	0.02	0.04	0.09	0.17	0.57	0.40	0.72
Peak Displacement (cm)	0.52	1.44	5.84	17.67	65.56	43.83	127.41
Acceleration RMS (g)	0.00	0.01	0.02	0.03	0.09	0.07	0.14
Arias Intensity (m/s)	0.01	0.04	0.33	1.18	11.83	6.53	25.79
Average spectral acceleration, $S_{a,avg}$ (g)	0.02	0.04	0.14	0.28	0.99	0.77	1.34

4. Analysis of peak tensile forces across geogrid layers

Peak tensile forces recorded along the geogrid reinforcements are plotted (Figure 2) for all the seismic events taken into consideration. The geogrid layers are numbered in an increasing order from toe to crest, with the highest number indicating the topmost geogrid layer around the crest. It can be seen that the reinforcements in the bottommost tier undergo significant variation in the peak tensile forces and hence, higher tensile strength geogrids are adopted for the bottommost tier. However, this fluctuation is not existing in the top two tiers. Except for the reinforcements at the extreme locations of the tier, the magnitude of the peak tensile forces developed along the reinforcements experiences a steady variation. Motions corresponding to lesser PGA inhibits similar range of peak tensile forces in all three tiers, whereas the ones higher PGA seismic events tend to show increasing magnitude of tensile forces from crest to toe.

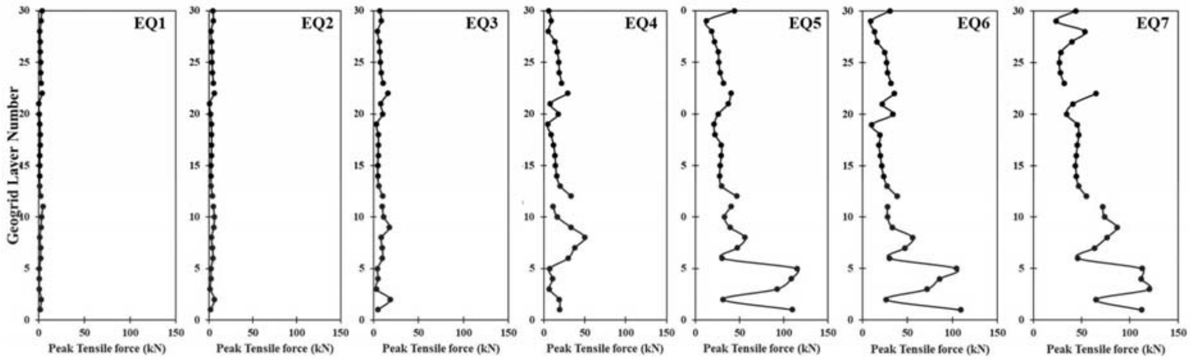

Fig. 2. Peak tensile force profile along the three tiers in the GRS wall

The uncertainty in the peak tensile forces is investigated across every geogrid layer for all chosen seismic events (Figure 3). It is observed that layers 1-5 experiences relatively high mean peak tensile force, marred with large margins of error. This indicates significant variability in tensile forces with larger scatter in the force distributions. The bottommost layer, i.e. Layer 1, exhibits the highest coefficient of variation (COV). Moving towards the crest, the geogrid layers exhibit progressively lower variability. As can be clearly noticed, the 95% confidence band is wider for the bottom tier, thereby indicating the increased uncertainty towards the more confined sections of the GRS wall. The band eventually narrows down towards the top tiers, exhibiting lesser uncertainty in the estimations. The mean peak tensile force increases significantly for each seismic scenario (Figure 4). The standard deviation indicates the variation in nonlinearity imparted in the structural response with the variation in scenario. The lower and upper bounds of confidence intervals display a wider range of peak tensile forces that is likely to be experienced under scenarios EQ5 to EQ7. It may be clearly noted that the increasing seismic magnitude increases the uncertainty in the behavioural response of the GRS wall.

5. Conclusions

The peak tensile forces recorded in the bottom tier geogrid reinforcements were found to be highly varying, thereby reflecting enhanced uncertainty. When the seismic behaviour is investigated under varying earthquake scenario, uncertainty being induced in the system was witnessed due to the increasing earthquake magnitude. Further studies on the probabilistic variation of the material properties along with additional seismic scenarios should be included to gather deeper insights into added aspects of uncertainty that would have led to the failure of the GRS wall. In addition, further aspects of seismic analysis that are crucial to ascertain the response of any structure such as displacement and acceleration should also be incorporated.

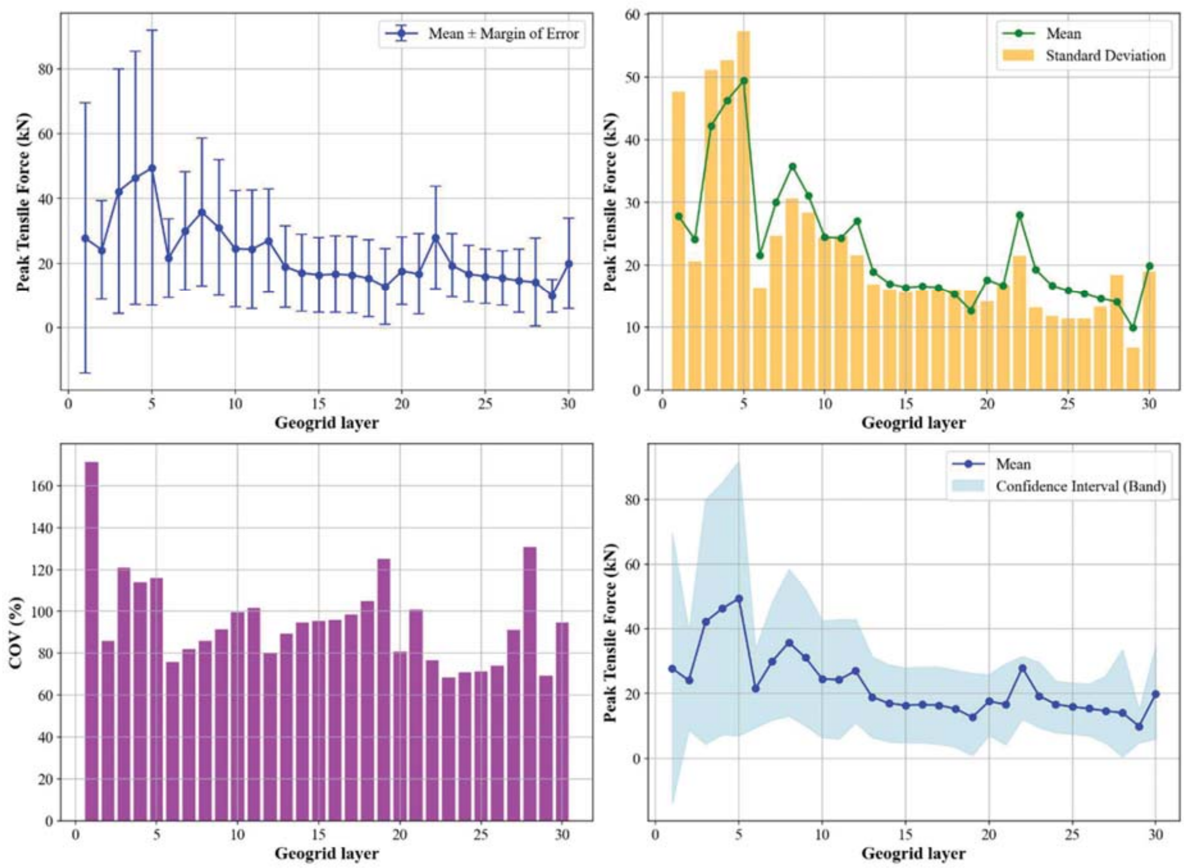

Fig. 3. Uncertainty in peak tensile forces across geogrid layers

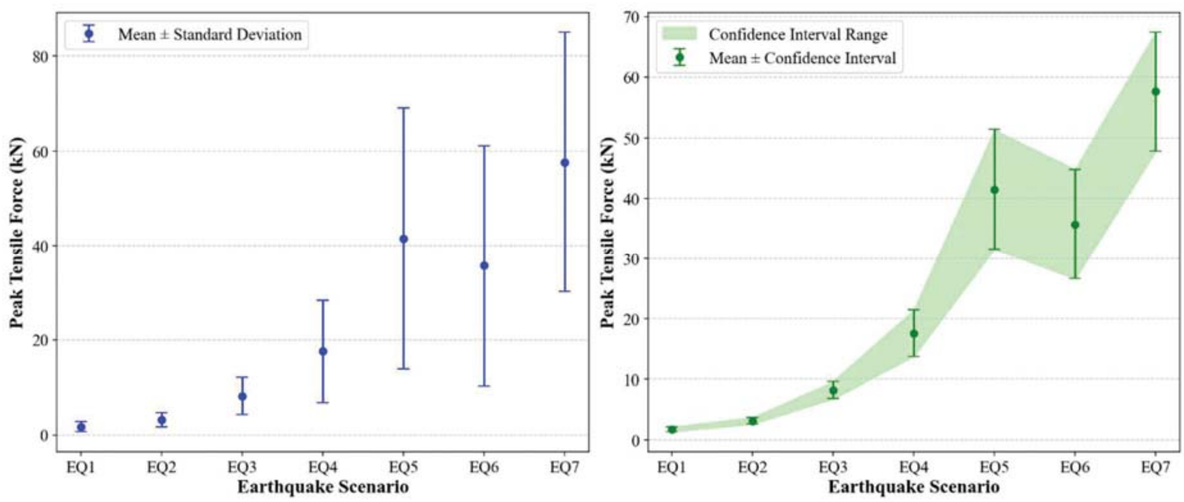

Fig. 4. Mean peak tensile force with standard deviation (left) and confidence interval (right) corresponding to the earthquake scenarios considered

References

Bradley, B. A. (2013). A critical examination of seismic response uncertainty analysis in earthquake engineering. *Earthquake Engineering & Structural Dynamics*, *42*(11), 1717-1729.

Kuhlemeyer, R. L., & Lysmer, J. (1973). Finite element method accuracy for wave propagation problems. *Journal of the Soil Mechanics and Foundations Division, ASCE*, 99(5), 421-427.

Nithin, V. L., Das, S., & Kaushik, H. B. (2017). Wavelet-based simulation of scenario-specific nonstationary accelerograms and their GMPE compatibility. *Soil Dynamics and Earthquake Engineering*, *99*, 56-67.

Sureka, S., Wable, A., Lhousa, V., Lupheng, C. and Dey, A. (2024) Stability and seismic response analysis of geocell reinforced slopes based on an equivalent composite approach. *Japanese Geotechnical Society Special Publication*: 10(25), 930-935.