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Geotechnical and Model-Based Analysis of Seismic Performance in Embankments: A review

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Abstract

This study presents an analysis of shaking table tests performed on wrap-faced embankments constructed on soft clay foundations. The experiments involved a model embankment placed within a laminar box mounted on a shaking table, with results validated through numerical simulations. Tests were conducted under varying surcharge loads and base acceleration levels to assess embankment performance. The influence of base acceleration and surcharge pressures on the embankment's response was evaluated, with a focus on acceleration profiles at different elevations and face deformations. The experimental setup incorporated earthquake data from the 1989 Loma Prieta event to simulate realistic seismic conditions. Findings reveal that the wrap-faced embankment exhibits considerable resistance to seismic loading, particularly under conditions comparable to the Loma Prieta earthquake. These results provide valuable insights into the seismic performance and design optimization of wrap-faced embankments on soft clay soils.

Keywords: *embankment; Model Test; Earthquake*

1. Introduction

Shaking table testing has become a cornerstone of seismic research, offering a reliable method for studying the response of soil structures under conditions that replicate actual earthquake ground motions. Over the past few decades, this technique has been extensively employed to evaluate the seismic behavior of embankments and retaining structures. Early investigations by Sakaguchi et al. (1992) and Sakaguchi (1996) explored shaking table tests on reinforced soil models of specific heights, focusing on parameters such as soil relative density, motion frequency, and amplitude.

Numerous studies have further advanced understanding of reinforced soil structures under seismic conditions. For example, Latha and Krishna (2006, 2008) investigated the seismic response of reinforced embankments, while Krishna and Latha (2007) expanded on these findings by analyzing key influencing factors. Sabermahani et al. (2009) and Latha and Nandhi Varman (2014) provided valuable insights into the seismic performance of soil-retaining walls. Similarly, Hore (2022) examined the dynamic behavior of embankments under seismic loads. Latha and Manju (2016) evaluated geocell retaining walls under varying seismic intensities, while Krishna and Bhattacharjee (2017, 2019) studied the effects of ground motion input on rigid-faced reinforced soil-retaining walls. Sahoo et al. (2019) conducted shaking table tests to analyze steep soil slopes at specific angles, highlighting critical performance metrics.

Recent studies by Chakraborty (2022) and Hore (2023) focused on shaking table tests of model sand walls constructed on local sandy soils, providing a deeper understanding of seismic response. While research on wrap-faced embankments on sandy soils is well-documented globally, studies on wrap-faced embankments on soft clay, particularly in the context of Bangladeshi soils, remain scarce.

In this research, a scaled model testing platform was developed to analyze the dynamic behavior of wrap-faced embankments on soft clay soils typical of Bangladesh. The setup features a wrapped geotextile-sand retaining wall erected on a clay foundation, subjected to cyclic loading. The study examines the effects of base accelerations and the resulting displacements of the embankment along different elevations. Figure 1 (after Hore et al., 2019) illustrates the distribution of clay soil layers across Bangladesh, highlighting the relevance of this research to the region's geotechnical challenges.

2. Method

A computer-controlled servo-hydraulic, single-degree-of-freedom shaking table facility was utilized for this experiment, as depicted in Figure 2. The shaking table platform measures 2 meters by 2 meters and has a payload capacity of 1500 kg. It is capable of generating base accelerations in the range of 0.05g to 2g, with an operational frequency range from 0.05 Hz to 50 Hz.

The laminar box used in the experiment is a large-sized shear box designed with 24 hollow aluminum layers to minimize interlayer friction, as shown in Figure 2. The dimensions of the laminar box are 915 mm × 1220 mm × 1220 mm, providing sufficient space to simulate soil-structure interaction under dynamic loading conditions accurately.

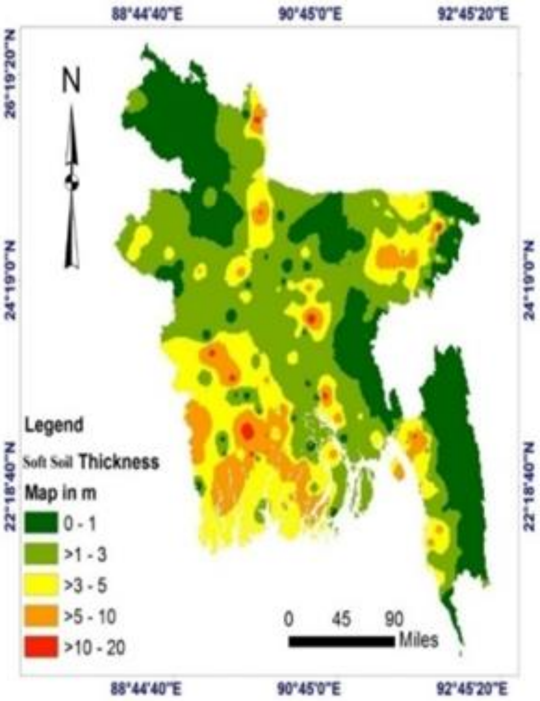

Figure 1: Thickness map

Figure 2: shaking table facility (Chakraborti, 2021)

The soil is found from BUET area indicated as Dhaka soil. The model soil has a unit weight of 14.8 kN/m3. A specific gravity is 2.64. The undrained shear strength is 28 kPa. The ultimate bearing capacity is 17.20 kPa. The sand is classified as poorly graded sand (SP) according to the Unified Soil Classification System. General geotechnical properties of the sands are presented in Table 1 (Hore 2021). A woven polypropylene multifilament geotextile (D50) was used for reinforcing the sand in the tests.

Table 1. Geotechnical properties of Sylhet Sand

Physical properties	Sylhet sand
Effective size, D10 (mm)	0.38
Average size, D50 (mm)	0.67
Coefficient of uniformity (Cu)	2.00
Coefficient of curvature (Cc)	0.92
Friction angle (°)	29
Specific gravity (Gs)	2.64

The present study was conducted with a height of 300 mm clayey soil layer foundation above which a 50 mm sand blanket was provided as shown in Figure 3 with approximately 1 m^2 geotextile was placed between the clayey soil foundation and sand blanket. The model scale is N=10 and scale factor 1/N. Accelerometers were used to monitor the accelerations of the shaking table. The Linear Vertical Displacement Transducers (LVDT) were placed. The Loma Preita earthquake was fixed for each shaking. Exactly Twelve (12) numbers of earthquake shaking were applied for this research. Embankment model was subjected to several different excitations from 0.05g (low amplitude) to 0.2g (high amplitude) peak base accelerations. The surcharge pressures are 0.70, 1.12, and 1.72 kPa.

3. PLAXIS 3D

The PLAXIS 3D software version is employed for performing the analyses. PLAXIS is a finite element package that is developed the specific purpose such as i) analysis of deformation ii) stability, and iii) flow in geotechnical engineering. Definition of soil stratigraphy embankment and retaining wall, Mesh generation are performed to calculate. The initial step for analyzing the model is to create the geometry of the model and the geometry characteristics such as embankment height slope and crest width with the second step is to provide the material properties of the embankment and the under-laying soil.

Numerical analysis of wrap faced embankment as shown in Figure 4. As the demonstrated model is symmetric in this research, only half of the whole setup is modeled (in this case the right half is chosen). A representative section of 2 m width is taken for the research with the boundary of the model are $x_{min} = 0$, $x_{max} = 6$, $y_{min} = 0$ and $y_{max} = 2$. A model embankment is four layers of sand. The slice wrapped with geotextile is modeled and the under laying soft layer are inserted. In this model the ultimate tensile strength is 16 kN/m. The normal elastic stiffness of the geotextile was considered as and 2500 kN/m.

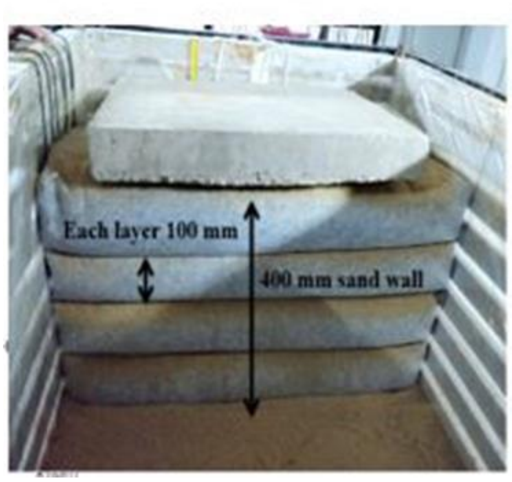

Figure 3: Experimental Model (Hore, 2022)

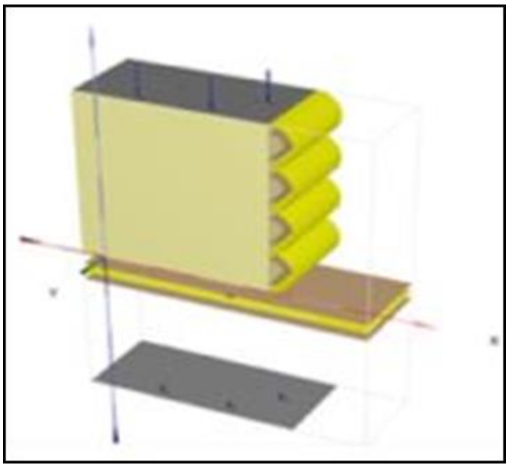

Figure 4: PLAXIS model (Hore, 2022)

4. Analysis and Discussion

The soil layer in equal lifts is 100 mm. To achieve a total wall height (H) of 400 mm the equal lifts (each 100 mm) are inserted. A series of twelve shaking table tests were performed were performed for this research. The variation of the different soil parameters like acceleration amplification, displacement, pore water pressure and strain (LST1, LST2, LST3, LST4, LST5 and LST9) with respect to height for various Loma Prieta earthquakes are presented in this section.

3.1 Acceleration amplification profile

The different base accelerations are 0.05g, 0.10g, 0.15g, and 0.2g. The test pattern are LST1, LST2, LST3 and LST4 tests, respectively, which was conducted at 1.72 kPa surcharge pressure. Acceleration amplifications were increased with increased base accelerations. From the Figure 5, it is observed that the maximum acceleration amplification was 1.52 at an acceleration of 0.2g, whereas it decreased to 1.28 at an acceleration of 0.05g. Results from By PLAXIS 3D analysis showed that acceleration amplification [Profile for tests LST1(P), LST2 (P), LST3(P), and LST4(P)] also at all elevations increased with an increase in Acceleration. The maximum and minimum acceleration amplification from PLAXIS 3D was 11.18% and 12.50% higher than the shake table model test respectively. Acceleration response against different surcharge pressures was presented from tests LST1, LST5 and LST9 are depicted in Figure 6. These tests were conducted with 1.72 kPa, 1.12 kPa and 0.7 kPa surcharge pressures at 0.05g base acceleration. Accelerations at the top of the wall were inversely proportional to the surcharge pressures from the range of tests that were conducted. Results from By PLAXIS 3D analysis showed that acceleration amplification [Profile for tests LST1(P), LST5(P) and LST9(P)] also at all elevations decreased with an increase in surcharge as can be seen from Figure 6. The maximum and minimum acceleration amplification from PLAXIS 3D was 4.27% and 12.50% higher than the shake table model test respectively.

3.2 Displacement Profile

Figure 7 depicts the normalized displacement profile for different base accelerations of 0.05g, 0.10g, 0.15g and 0.20g. The tests are LST1, LST2, LST3 and LST4. By PLAXIS 3D analysis showed that displacement [Profile for tests LST1(P), LST2(P), LST3(P), and LST4(P)] also at all elevations acceleration variation was directly proportional as can be seen from Figure 7. From the same figure, it can also be observed that the maximum displacement was 0.280 mm at an acceleration of 0.20 g, whereas it decreased to 0.088 mm at an acceleration of 0.05 g. The maximum and minimum displacements from PLAXIS 3D were 12.00% and 10.00% higher than the shake table model test respectively.

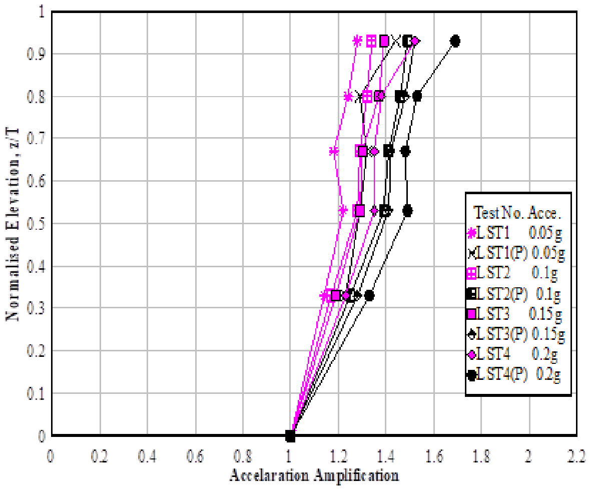

Figure 5: Effect of base acceleration

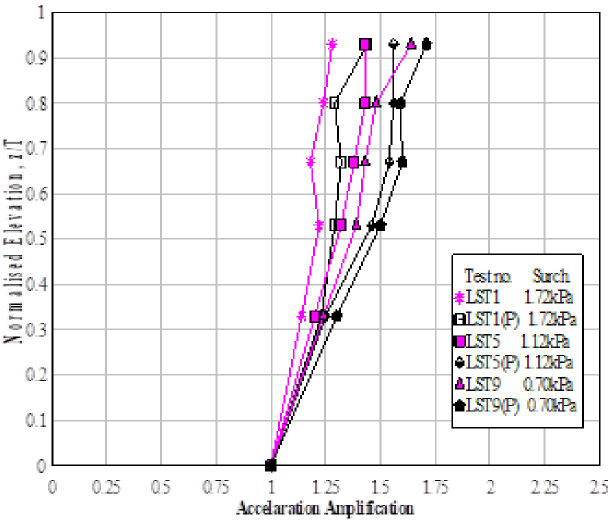

Figure 6: Effect of surcharge

The normalized displacement profile for tests LST1, LST5 and LST9 which were conducted at 0.05g base acceleration were providing an insight into the effect of different surcharge loadings of 1.72 kPa, 1.12kPa and 0.7kPa as shown in Figure 8. It was observed that the displacement response against surcharge variation was inversely proportional at all elevations. The maximum and minimum displacements from PLAXIS 3D were 9.68% and 10.00% higher than the shake table model test respectively. Figure 9 shows the PLAXIS output result.

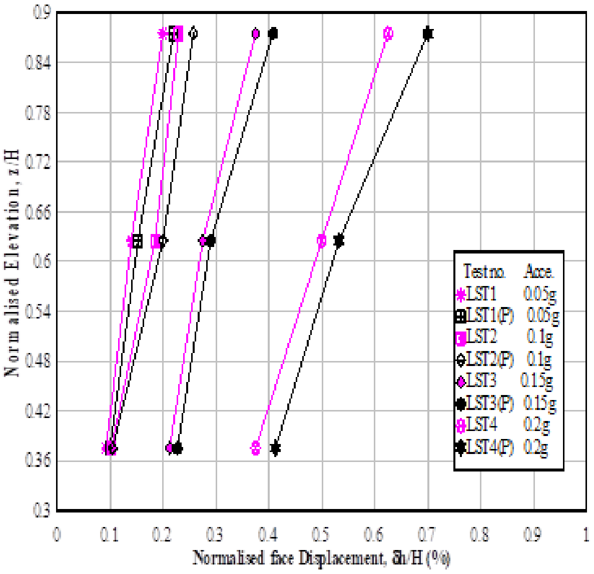

Figure 7: Effect of base acceleration (Disp.)

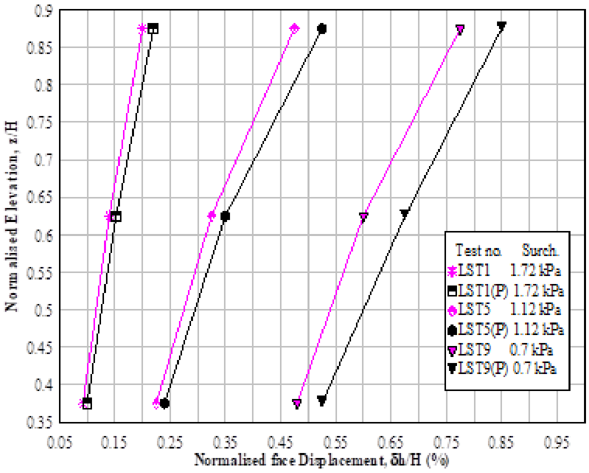

Figure 8: Effect of surcharge (Disp.)

5. Conclusion

This paper presents an analysis of the behavior of wrap-faced embankments constructed on soft clayey soil. The experimental tests revealed that acceleration amplification increased with higher base accelerations, while accelerations at the top of the wall were inversely proportional to the applied surcharge pressures. Displacements at all elevations were observed to vary directly with acceleration levels.

Comparisons between experimental and numerical results, obtained using PLAXIS 3D, showed deviations of less than 5% in all cases, with experimental values being consistently lower. These findings are significant for designing and planning large-scale wrap-faced embankments on soft soils. A 200-meter pilot project provides a basis for refining construction techniques and validating these results.

The design specifications derived from this study incorporate dynamic loading considerations, making them suitable for critical infrastructure projects such as railway and roadway embankments. These results will accelerate the adoption of efficient and resilient wrap-faced embankment designs for such applications.

References

1. Hossain, M.Z., Hore, R. & Ansary, M.A. Model tests of reinforced soil retaining sand walls by shaking table test. *Arab J Geosci* **17**, 166 (2024). https://doi.org/10.1007/s12517-024-11965-w
2. Bathurst, R.J., Hatami, K. (1998). Seismic response analysis of a geosynthetic reinforced soil retaining wall. *Geosynthetics International* 5 (1–2), pp. 127–166. DOI: https://doi.org/10.1680/gein.5.0117
3. Chakraborty, S., Hore, R. Ahmed, F., Ansary, M. A., Soft ground improvement at the Rampal Coal Based Power Plant Connecting Road Project in Bangladesh, Geotechnical Engineering Journal of the SEAGS & AGSSEA, AIT December 2017.
4. Chakraborty, S., Hore, R., Shuvon, A. M., Ansary, M. A, Dynamic Responses of Reinforced Soil Model Wall on Soft Clay Foundation, Geotechnical

and Geological Engineering, January 2021. (https://doi.org/10.1007/s10706-020-01665-z)

5. Chakraborty, S., Hore, R., Shuvon, A. M., Ansary, M. A, Physical and numerical analysis of reinforced soil wall on clayey foundation under repetitive loading: effect of fineness modulus of backfill material, Arabian Journal of Geosciences, June 2021. (DOI:10.1007/s12517-021-07317-7)
6. Chakraborty, S., Hore, R., Shuvon, A.M. et al. Effect of Surcharge Pressure on Model Geotextile Wrapped-Face Wall Under Seismic Condition. Iran J Sci Technol Trans Civ Eng (2022). https://doi.org/10.1007/s40996-022-00900-2
7. El-Emam, M. M., Bathurst, R. J. (2007). Influence of reinforcement parameters on the seismic response of reduced-scale reinforced soil retaining walls. *Geotextiles and Geomembranes* 25 (1), pp. 33–49. DOI: https://doi.org/10.1016/j.geotexmem.2006.09.001
8. Guan, Y., Zhou, X., Yao, X., & Shi, Y. (2019). Seismic performance of prefabricated sheathed cold-formed thin-walled steel buildings: Shake table test and numerical analyses. *Journal of Constructional Steel Research*, p. 105837.DOI: https://doi.org/10.1016/j.jcsr.2019.105837
9. Hore, R. & Ansary M. A., SPT-CPT Correlations for Reclaimed Areas of Dhaka, Journal of Engineering Science, JES, KUET, June 2018.
10. Hore, R., M. R. Arefin, Ansary, M. A., Development of Zonation Map Based on Soft Clay for Bangladesh, Journal of Engineering Science 10(1), 2019, 13-18
11. Hore, R., Chakraborty, S., Ansary, M. A., Field Investigation to Improve Soft Soils Using Prefabricated Vertical Drain, Transportation Infrastructure Geotechnology, September 2019. (https://doi.org/10.1007/s40515-019-00093-8).
12. Hore, R., Chakraborty, S., Bari, M. F., Shuvon, A. M., Ansary, M. A., Soil Zonation and The Shaking Table Test of The Embankment on Clayey Soil, Geosfera Indonesia, August 2020 (DOI: https://doi.org/10.19184/geosi.v5i2.17873)
13. Hore, R., Chakraborty, S., Ansary, M. A., Experimental Investigation of Embankment on Soft Soil Under Cyclic Loading: Effect of Input Surcharges, Journal of Earth Engineering (JEE) Vol. 5, No. 1, (2020).
14. Hore, R., Ansary, M. A., Different Soft Soil Improvement Techniques of Dhaka Mass Rapid Transit Project, Journal of Engineering Science 11(2), 2020, 37-44. (https://doi.org/10.3329/jes.v11i2.50896)
15. Hore, R., Al-Mamun. S., Climate Change and its diverse impact on The Rural Infrastructures in Bangladesh, Disaster Advances, Vol. 13 (9) September (2020).
16. Hore, R., Chakraborty, S., Ansary, M. A., "Liquefaction Potential Analysis based on CPT and SPT" Geotechnical Engineering Journal of the SEAGS & AGSSEA, December 2020
17. Hore, R., Chakraborty, S., Ansary, M. A., Seismic Response of Embankment on Soft Clay Based on Shaking Table Test, International Journal of Geosynthetics and Ground Engineering, March 2021. (https://doi.org/10.1007/s40891-020-00246-7)
18. Hore, R., Chakraborty, S., Shuvon, A. M., Ansary, M. A., Dynamic Response of Reinforced Soil Retaining Wall Resting on Soft Clay, Transportation Infrastructure Geotechnology, February 2021. (https://doi.org/10.1007/s40515-021-00156-9).
19. Hore, R., Chakraborty, Kamrul, K. S., Shuvon, A. M. and Ansary, M. A., Numerical Verification for Seismic Response of Reinforce Soil Embankment on soft Clay foundation, Geotechnical Engineering Journal of the SEAGS & AGSSEA, 53(2), 18-28, June 2022.
20. Hore, S. Assessment of soil chemical characteristics in the context of Bangladesh: A comprehensive review, Community and Ecology, 2(1), 2024.
21. Hore, R., Hore, S. (2024). Analysis of Dynamic Soil Properties by a Systematic Approach. In: Feng, G. (eds) Proceedings of the 10th International Conference on Civil Engineering. ICCE 2023. Lecture Notes in Civil Engineering, vol 526. Springer, Singapore. https://doi.org/10.1007/978-981-97-4355-1_59
22. Hore, R., Hossain, M.Z., Hore, S. et al. A Comparative Seismic Study of Wrap-Faced Retaining Wall Embankment Using Sands of Bangladesh. Iran J Sci Technol Trans Civ Eng (2024). https://doi.org/10.1007/s40996-024-01600-9
23. Hasan, M.M., Hore, S., Al Alim, M. et al. Numerical modeling of seismic soil-pile-structure interaction (SSPSI) effects on tall buildings with pile mat foundation. Arab J Geosci 18, 10 (2025). https://doi.org/10.1007/s12517-024-12155-4
24. MS Arefin, MAR Talukder, S Hore, R Hore, A Novel Study on Present Situation of Infrastructure of Water, Sanitation and Hygiene of Rural People in Bangladesh. (2023). Western European Journal of Historical Events and Social Science, 1(1), 44-58.
25. MAR Talukder, S Hore, R Hore, A Review of Soil Chemical Properties for Bangladesh Perspective. (2023). Western European Journal of Modern Experiments and Scientific Methods, 1(1), 52-65.
26. MAR Talukder, S Hore, R Hore, Systematic Approach of Earthquake Awareness Analysis in Bangladesh. (2023). Earthquake, 1(1), 1-9.
27. Hossain, M.Z., Hore, R. & Ansary, M.A. Model tests of reinforced soil retaining sand walls by shaking table test. Arab J Geosci 17, 166 (2024). https://doi.org/10.1007/s12517-024-11965-w.
28. Khair, A., Hore, R. & Ansary, M.A. Investigation of Site Amplification for the Sedimentary Deposits of

DMDP Area in Bangladesh. *Indian Geotech J* (2024). https://doi.org/10.1007/s40098-024-00931-8

29. Latha, G. M., Manju, G. S. (2016). Seismic Response of Geocell Retaining Walls Through Shaking Table Tests.*International Journal of Geosynthetics and Ground Engineering*, 2(1), p.7. DOI: https://doi.org/10.1007/s40891-016-0048-4
30. Md Monir Hossain, Md Tanvir Hasan, Shoma Hore, Ripon Hore, Stability analysis of rainfall-induced landslides: A case study of a hilly area in Bangladesh, Earthquake, vol1, no, 1, 2023.
31. Shoma Hore. (2023). Review of Phosphate Removal From Water by Various Sorbents. *Web of Technology: Multidimensional Research Journal*, *1*(1), 15–24.
32. Xiao, M., Ledezma, M., Hartman, C. (2014). Shake Table Test to Investigate Seismic Response of a Slurry Wall. In Geo-Congress 2014: *Geo-characterization and Modeling for Sustainability*, pp. 1234-1243. DOI: https://doi.org/10.1061/9780784413272.120
33. Yazdandoust, M. (2017). Investigation on the seismic performance of steel-strip reinforced-soil retaining walls using shaking table test. *Soil Dynamics and Earthquake Engineering*, *97*, pp. 216-232. DOI:https://doi.org/10.1016/j.soildyn.2017.03.011