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Research Article

Assessment and Mitigation of Liquefaction Vulnerability for Selected Zones of Bogura Sadar, Bangladesh

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Keywords

N-value,
Surcharge,
Earthquake,
Liquefaction,
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Abstract

The main aim of the present research is to assess the potential for soil liquefaction in the subsoil in twelve selected locations belonging to the Bogura Sadar area, using field-sponsored geotechnical data. This assessment utilizes the well-known, semi-empirical method developed by Seed and Idriss that considers earthquake magnitude, overburden pressure, the corrected value of SPT-N, peak ground acceleration (PGA), soil unit weight and depth of water table. The outcome is that, for a 6.5 MW earthquake, two zones have very high and seven zones have moderate susceptibility to liquefaction, and the remaining areas are less susceptible. The profiles of the factor of safety (FS) show that these values are greater than 1.0 at depths of 1.5 and 12 m for all the zones. However, at depths from 3 m to 9 m, most layers have FS values of less than or equal to 1.0, suggesting that the same seismic event may cause a liquefaction risk. In order to prevent or reduce this risk, surcharge loading is used as an efficient defensive action. The findings confirm that 400 kPa of surcharge guarantees to be on the safe side with respect to liquefaction in all considered zones. In general, the results contribute useful information for mitigating geotechnical hazards and realizing seismic resilience in the study region.

1. Introduction

Due to its geographical location and various geological conditions, Bangladesh is one of the most vulnerable countries in the world, where not only earthquakes but also other natural disasters occur [1]. As the situation in the Bogura district of the country's northern region continues to become urbanized and industrialized at an accelerated pace [2]. This expansion resulted in the construction of several infrastructures, thereby enhancing the susceptibility to geotechnical disasters that can greatly affect structural stability. Soil liquefaction caused by earthquakes is one of the most dangerous hazards, especially in regions underlain with loose to medium-dense granular soils [3]. This excess of pore water pressure increases with the number of seismic loadings and then decreases, there being liquefaction; it eliminates effective stress (soil-fluid-like behavior) [4]. From the historical record of great earthquakes around the world, it is known that liquefaction can cause drastic ground deformation, foundation and lifeline damage. The SPT-based deterministic method is among the most frequently used and well-established methods for liquefaction evaluation, due to its practical simplicity and international use [5]. A number of works have been conducted on mapping and quantification of liquefaction hazard using SPT-based methodologies in Bangladesh as well as neighboring areas. Rahman et al. (2015) [6] estimated the liquefaction potential with 53 in-situ SPT logs and developed hazard maps for the study site based on the GIS method. Similarly, Das et al. (2019) [7] carried out the liquefaction potential assessment within the entire city of Agartala with 97 SPT boreholes and concluded that the central parts have a Liquefaction Potential Index (LPI) ranging from moderate to high vulnerability, the northern part is characterized by moderate to low vulnerability, while the majority of the southern area towards the city periphery is represented by a low susceptibility level. Further studies of the northwestern Dinajpur region used deterministic, probabilistic and machine-learning methods that showed the northern sections to be more vulnerable to liquefaction in an MW 6.5 [1, 8-10]. Hossain et al. (2019) [11] used SPT data in Rajshahi to estimate liquefaction potential for various magnitudes of earthquakes, and the results showed differences in susceptibility level, and Sana and Nath (2016) [12] analyzed 64 SPT profiles in Kashmir Valley for an Mw 7.6 event in which significant spatial variations of susceptibility within the region were highlighted.

More recent worldwide investigations highlight the importance of including updated semi-empirical models, new seismic hazard parameters, and refined soil behavior descriptions in liquefaction evaluations [13–24]. These findings indicate the increasing demand for site-specific evaluation of liquefaction, particularly in rapidly expanding cities like Bogura. The work of Lai et al. (2019) [13] aimed at enhancing the quality of liquefaction susceptibility mapping through employing advanced geospatial tools and probabilistic analyses. They hoped to address the limitations of traditional mapping methods, which often did not have sufficiently high spatial resolution and were unable to quantify uncertainty. It showed that using the GIS-based techniques and probabilistic approach can result in more accurate and spatial surface hazard maps, which are used for the decision-making process, land-use planning, and risk of seismic activity. Ilgac et al. (2019) [14] aimed at reassessment of liquefaction resistance by revising the SPT-based models with a global record of field performance information. They were trying to improve the empirical correlations that engineers often use when they design buildings and structures for earthquakes. Their contributions led to improved resistance curves for soils in cyclic loading that better characterize soil response and thus increase the applicability of liquefaction evaluations in varied geologic environments. Özener et al. (2020) [15] conducted a detailed review on the recent developments in seismic soil liquefaction assessment, aiming to summarize the recent progress in cyclic stress analysis, seismic demand estimation, and characterization of soil behavior. The advancements in analytical modelling as well as the new empirical models were summarized with respect to enhancing realistic and reliable liquefaction predictions. The results highlighted the increasingly accurate modern assessment techniques, capable of adequately reproducing soil behavior under strong ground motion. Geyin et al. (2020) [16] intended to develop

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a comprehensive high-quality global dataset of dynamic liquefaction case histories in order to facilitate the development and application of empirical models. Their goal was to improve the confidence of liquefaction prediction procedures by means of large and well-recorded databases. The investigation has developed a strong database that has now enabled calibrating several triggering models to it and which added geometrical complexity as none of the previous data-driven assessments have had access to. Green et al. (2019) [17] studied seismic demand and liquefaction signs resulting from the last big earthquakes in order to calibrate the empirical models. They had evidence of ground deformations, pore pressure response and site-specific failure modes in a real-world situation that can be used to provide crucial information for how well the model is performing. The results of the study provided guidance on the situations in which state-of-the-art predictive capabilities are well aligned with observations and where there is still room for improvement. The objective of Rawat et al. (2022) [18] aimed to evaluate liquefaction potential in fast-urbanizing areas with the aid of analysis tools based on GIS. The study was designed to work out risk mapping effectively using spatial, seismic and geotechnical data. The findings showed the ability of GIS tools to effectively represent spatial variability of soil properties and seismic demand by generating high-resolution maps useful for urban planning and risk reduction measures in all scenarios. Juang et al. (2010) [19] proposed a probability-based framework for liquefaction susceptibility in seismically active regions. Their aim was to estimate uncertainties of soil parameters, seismic loading and model assumptions. Results of the study demonstrated that the probabilistic analysis reveals a more detailed picture of liquefaction risk compared to deterministic analysis and, therefore, better input in geotechnical design. Rahman et al. (2024) [20] developed a predictive model to assess the potential of liquefaction using machine learning models based on extensive geotechnical data. They wanted to see if data-driven models had anything over conventional empirical ones. It was observed that all machine learning models had better predictive performance and more stability, indicating their high application value in the assessment of liquefaction. Beyzaei et al. (2020) studied subsurface and liquefaction with SPT-based correlations to enhance the accuracy of site-specific seismic risk assessment. Their findings led to detailed characterization of soil stratigraphy and resistance parameters, which enabled the authors to identify areas that were generally more vulnerable to liquefaction. The results can provide the instruction of infrastructure planning and seismic design. This study attempts to assess liquefaction susceptibility of twelve zones of Sadar Upazilla of Bogura using extensive field test data in this perspective. The study is based on the well-established semi-empirical correlation method of Seed and Idriss, which incorporates important factors such as magnitude of earthquake, overburden stress, corrected SPT-N value, peak ground acceleration (PGA), soil unit weight and depth of ground water. In addition, this study also investigates which level of surcharge will be effective as a liquefaction mitigator occurring under an earthquake of magnitude 6.5. It is hoped that the results will assist engineers and planners in obtaining useful information for locating potential risk areas, as well as downscaling long-term hazard mitigation measures.

2. Study Area

Bogura District is located in the north of Bangladesh under Rajshahi Division. At the center of the district (Figure 1) is located Bogura Sadar Upazila, covering an area of 176.58 km² and situated at around latitude 24°51′ N and longitude 89°22′ E. For the vulnerability analysis, 12 specific locations were chosen: Bhabanigonj, Shakharia Namabala, Jamil Nagar Nishindra Shahpara, Thanthania Natunpara, Naruly West Para, Hajradighi, Shakharia, Baruipara, Banani, Mothura, Chokrampur and Chok-Alom.

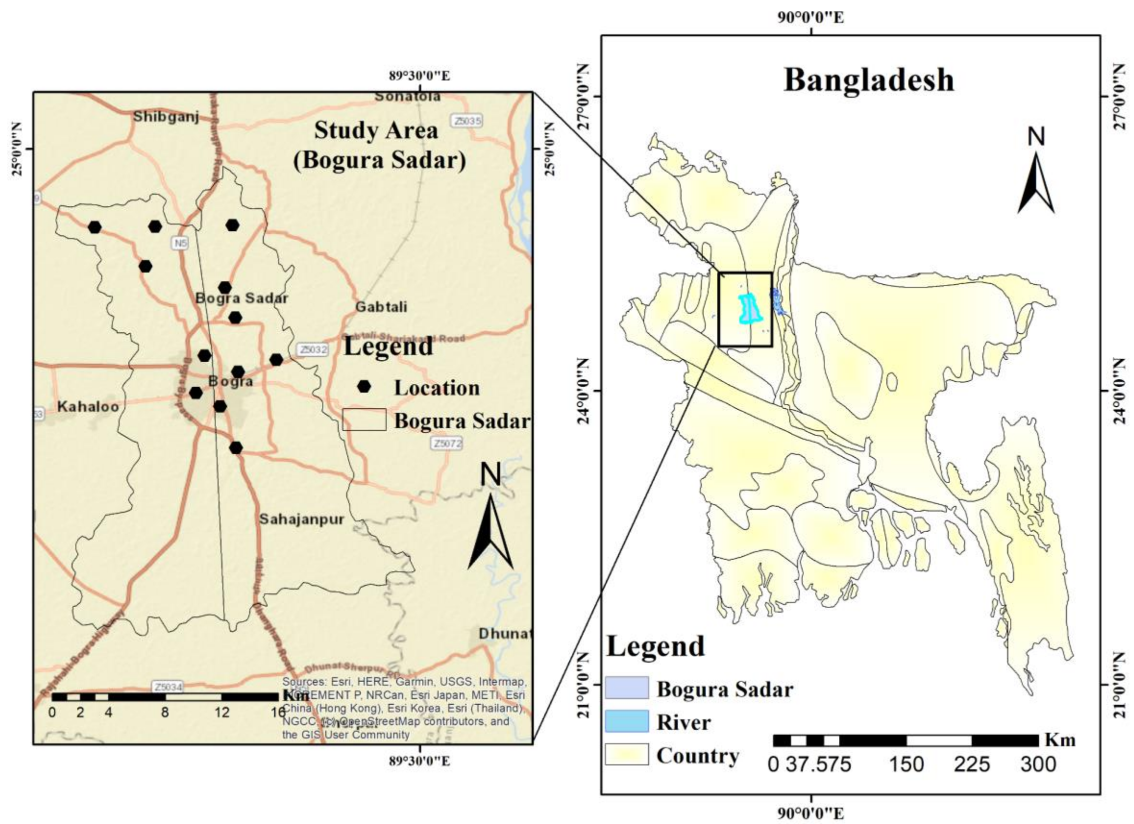

Figure 1. Map of the study area

Bangladesh lies on several geological blocks that have had massive earthquakes in the past. The regions around Bangladesh's northeast, west, and north, namely Tripura, Assam, and Calcutta, are most vulnerable to earthquakes [22]. Five larger fault segments are recognized on the basis of geological and plate tectonic studies, and they are mainly responsible for the occurrence of potentially destructive earthquakes (Table 1). The

Bogra Fault immediately near the Jamuna River and the town of Bogra is defined as a normal or gravity-sitting fault, which can mirror the flexural deformation along the western border of the basin [23]. In general, Bogura District is recognized as a geologically stable district, being located away from major tectonic plate boundaries which could experience significant earthquakes. As a result, the area has low seismicity in comparison to other earthquake areas. Bogura is located in Zone 3 of the seismic zonation map with a zone coefficient of 0.28 [24]. According to local accounts, the district has also had a few mild to moderate earthquakes ranging from 4 to 5 on the Richter scale caused by regional tectonic settings or far-field seismicity and have been of an infrequent nature.

Table 1. Probable seismic events that can be resulted from different fault zones

Fault Zones	Probable peak magnitude
Bogra fault	7.0
Tripura fault	7.0
Shilong plateau	7.0
Dauki fault	7.3
Assam fault	8.5

2. Methodology

The potential for liquefaction in the study area was evaluated using the Liquefaction Potential Index (LPI) and the factor of safety (FS). These measures were computed following standard procedures as described below.

2.1. Calculation of FS

The factor of safety against liquefaction is analyzed in this study using Idriss and Boulanger chord-based method [25]. The FS is determined by Eqn. (1).

$$FS = \frac{CRR_{7.5}}{CSR} * MSF * K_\sigma \qquad (1)$$

In Eqn. 1, the $CRR_{7.5}$ is the cyclic resistance ratio at Mw = 7.5 and MSF, which is magnitude scaling factor; The factor K_σ is included to account for sustained static shear stresses. The MSF and K_σ were computed using Eqn. (2) and Eqn. (3) respectively.

$$MSF = 6.9e^{\frac{-M_w}{4}} - 0.058 \ (\leq 1.8) \qquad (2)$$

$$K_\sigma = 1 - C_\sigma \ln\left(\frac{\sigma_v'}{P_a}\right) \ (\leq 1.1) \qquad (3)$$

The $CRR_{7.5}$ is assessed using Eqn. 4.

$$CRR_{7.5} = \exp\left(\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 + \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right) \qquad (4)$$

where $(N_1)_{60cs}$ represents an equivalent clean-sand blow count. Eqns. 5 and 6 are used to calculate $(N_1)_{60cs}$:

$$(N_1)_{60cs} = (N_1)_{60} + \Delta(N_1)_{60} \qquad (5)$$

$$\Delta(N_1)_{60} = \exp\left(1.63 + \frac{9.7}{FC+0.01} - \left(\frac{15.7}{FC+0.01}\right)^2\right) \qquad (6)$$

In Eqn. 6, FC represents the fines content in the soils. The CSR is then computed using Eqn. 7.

$$CSR = 0.65 \frac{a_{max}}{g} \frac{\sigma_v}{\sigma_v'} r_d \qquad (7)$$

In Eqn. 7 a_{max} is the maximum ground acceleration; σ_v and σ_v' are the total and effective overburden stress, respectively; rd is "the ratio of effective to total stress reduction" as defined by Eqn. 8.

$$\text{For, } z \leq 34m, \ rd = \exp[\omega(z) + \mu(z)M] \qquad (8)$$

In Eqn. 8,

$$\omega(z) = -1.012 - 1.126 \sin\left[\frac{z}{11.73} + 5.133\right] \text{ and } \mu(z) = 0.106 + 0.118 \sin\left[\frac{z}{11.28} + 5.142\right]$$

Where 'z' is the soil layer depth below the ground in meters and M is the magnitude of the earthquake.

2.2. Calculation of LPI

The liquefaction potential index (LPI) at the specified locations is determined using the method presented by Iwasaki et al. (1982) [26]. The LPI is calculated at Eqn. 9 for several soil layers from the earth's surface.

$$LPI = \int_0^z F(z)W(z)dz \qquad (9)$$

Where, z = depth of layer; FS≤1 then F(z)=1; FS > 1 then F(z)=0; W(z) can be calculated by the Eqn. 10.

$$W(z) = 10 - 0.5z \qquad (10)$$

Liquefiable susceptibility can be classified into four groups according to the LPI value: very low, low, high and very high.

2.3. Calculation of surcharge as mitigation

Using a surcharge further reduces the cyclic stress ratio of the layer at a given earthquake intensity. Therefore, the safety margin for each layer is increased. The minimum surcharge load to increase the FS can be determined by relying on the updated formula of cyclic stress ratio represented as Eqn. 11.

$$CSR = 0.65 * \frac{a_{max}}{g} * \frac{(\sigma_v + S)}{(\sigma_v' + S)} * r_d \quad (11)$$

where in Eqn. 11, S is the surcharge load (kPa).

3. Results and Discussion

3.1. FS and LPI risk evaluation

The safety factor against soil liquefaction and the susceptibility to liquefaction in terms of Liquefaction Potential Index were evaluated based on site investigations in twelve considered zones. The boreholes in the study area are shown in Figure 1. Table 2 demonstrates the FS and LPI values at different depths for the Mothura zone, estimated as per the Idriss–Boulanger (2008) [25] approach. LPI values and their respective severity were also determined using the method described by Iwasaki et al. (1982) [26].

Table 2. FS and LPI calculation for Mothura zone at magnitude 6.5

Depth (m)	$(N_1)_{60}$	CSR	$CRR_{7.5}$	FS	H	w(z)	F	LPI=w(z).F.H	remark for LPI [26]
1.5	16	0.180	0.226	1.43	1.5	9.62	0	0	very low
3	7	0.175	0.136	0.88	1.5	8.87	0.113	1.511	Low
4.5	10	0.213	0.160	0.86	1.5	8.12	0.137	1.671	Low
6	11	0.235	0.169	0.82	1.5	7.37	0.174	1.931	Low
7.5	12	0.247	0.176	0.81	1.5	6.62	0.184	1.829	Low
9	14	0.252	0.197	0.89	1.5	5.87	0.107	0.947	Low
10.5	18	0.253	0.254	1.14	1.5	5.12	0	0	very low
12	19	0.250	0.273	1.24	1.5	4.37	0	0	very low
13.5	21	0.245	0.323	1.50	1.5	3.62	0	0	very low
15	25	0.238	0.502	2.40	1.5	2.87	0	0	very low

According to Iwasaki et al. (1982) [26], Table 3 summarizes the severity level of soil liquefaction for Mw = 6.5 based on the total LPI value for each location. Hajradighi, Shakharia Baruipara, Mothura and Jamil Nagar of the twelve zones are highly severely affected zones, and Bhabanigonj is found to be a very high severe zone.

Table 3. Severity level based on total LPI for all zones at magnitude 6.5

Zone Name	Total LPI	Severity level	Zone Name	Total LPI	Severity level
Bhabanigonj	18.68	Very High	Naruly west para	3.28	Low
Thanthania Natunpara	4.60	Low	Chokrampur	2.99	Low
Hajradighi	5.44	High	Chok-Alom	2.82	Low
Shakharia Baruipara	12.05	High	Shakharia Namabala	3.68	Low
Banani	3.05	Low	Jamil Nagar	8.70	High
Mothura	7.89	High	Nishindra shahpara	1.60	Low

The factor of safety (FS), the cyclic stress ratio (CSR), and the cyclic resistance ratio (CRR) were calculated for earthquakes with magnitudes 6.0, 6.5, 7.0, and 7.5, respectively. Figures 2–5 display the evolution of FS as earthquake magnitude increases in 0.5 steps.

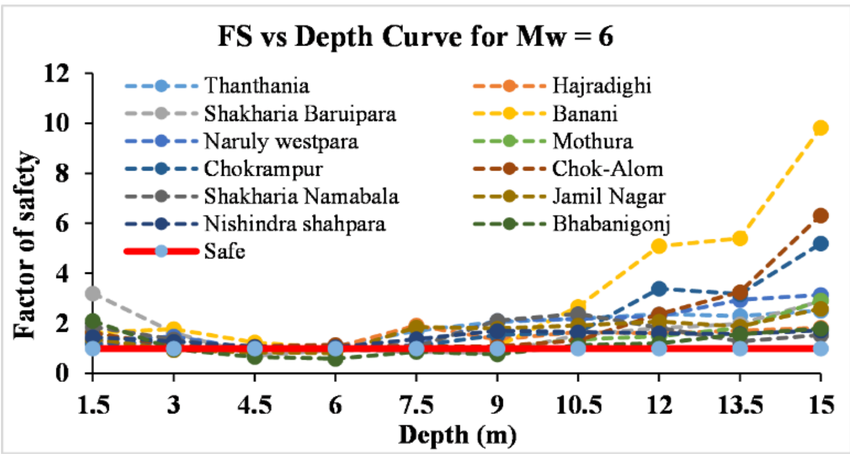

Figure 2. FS versus depth for Mw = 6.0

On a scale of 6.0 (Figure 2), only the FS values for four sites—Chok-Alom, Nishindra Shahpara, Banani, and Naruly Westpara—are greater than one, indicating that these locations are safe from liquefaction, while all other sites have FS values less than one, meaning they are considered unsafe. As a more severe level earthquake (i.e., 6.5, 7.0 and 7.5) occurs in Figures 3–5, the FS degrades further down, resulting in all the locations becoming susceptible to liquefaction situations. At a depth of 3 and 6 m, FS is consistently less than one for all locations. On the other hand, at the ground surface and at a depth of 15 m, the FS values are above unity, which corresponds to relatively stable layers.

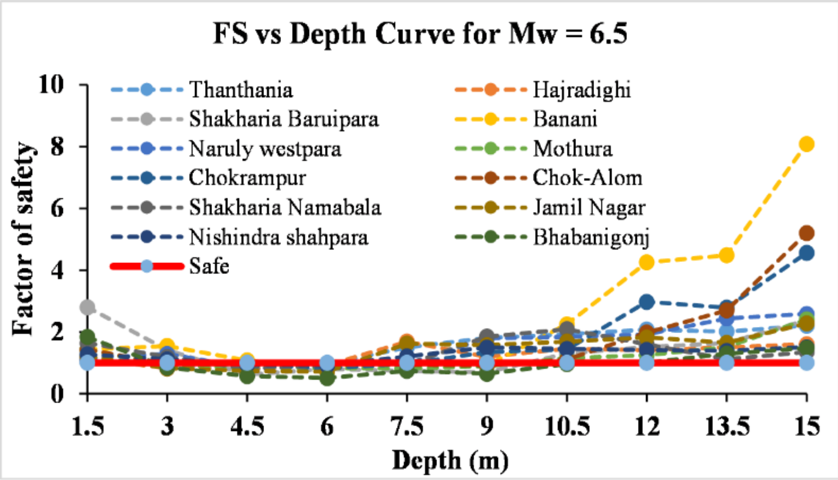

Figure 3. FS versus depth for Mw = 6.5

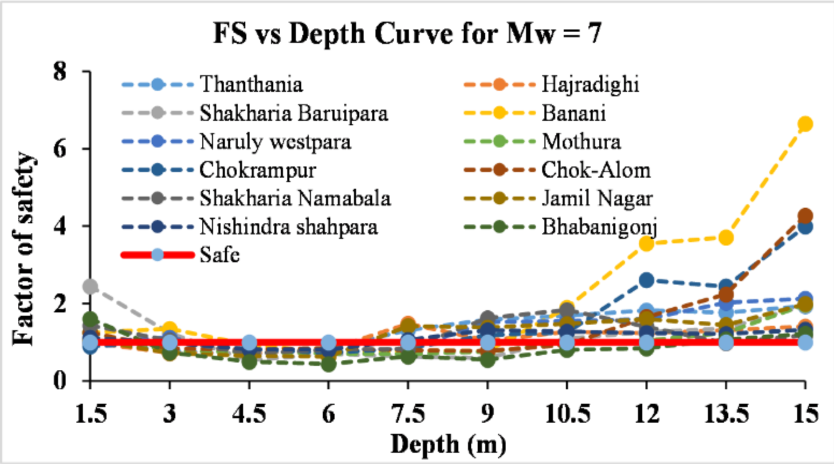

Figure 4. FS versus depth for Mw = 7.0

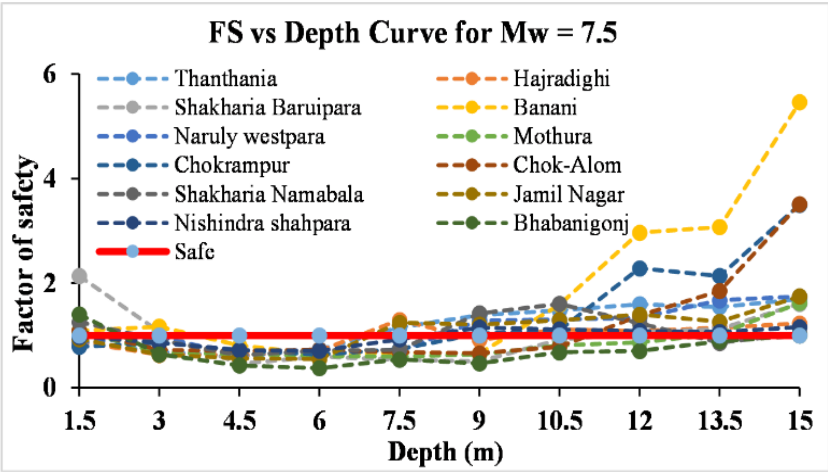

Figure 5. FS versus depth for Mw = 7.5

3.2. Surcharge effect as mitigation

Surcharge loading is one of the most effective countermeasures to prevent soil liquefaction. Based on the analysis of these twelve sites, they are all susceptible to liquefaction under the earthquake magnitudes of 6.5 to 7.5. This study estimates the surcharge pressure needed to eliminate the liquefaction hazard for the 6.5 magnitude during static and dynamic conditions. Table 4 provides the appropriate total surcharge load, measured in kPa, necessary to raise the factor of safety above one for the Bhabanigonj zone as a typical case.

Table 4. Calculation of FS for different soil layers applying different surcharge loads for the Bhabanigonj zone

Depth (m)	Unit weight (kN/m^3)	$CRR_{7.5}$	FS without surcharge	FS with surcharge			
				100 KPa	200 KPa	300 KPa	400 KPa
1.5	17.1	0.289	1.84	1.84	1.84	1.84	1.84
3	16.9	0.164	1.07	1.07	1.07	1.07	1.07
4.5	16.9	0.165	0.89	1.01	1.04	1.06	1.07
6	16.9	0.158	0.77	0.93	0.98	1.01	1.02
7.5	17.1	0.171	0.80	0.98	1.05	1.09	1.12
9	17.4	0.152	0.69	0.86	0.94	0.98	1.01
10.5	18.1	0.212	0.97	1.20	1.32	1.38	1.42
12	18.3	0.222	1.02	1.26	1.39	1.46	1.51
13.5	18.8	0.278	1.31	1.61	1.77	1.87	1.94
15	19.1	0.309	1.49	1.82	2.01	2.13	2.21

For an earthquake of magnitude 6.5, the surcharge load of 400 kPa results in the value of the factor of safety (FS) from 0.69 to 1.01 at a depth of 9 m in the Bhabanigonj zone. Elsewhere, application of a 100 kPa surcharge brings FS to 1.15 and 0.72 in Jamil Nagar, to 1.11 and 0.92 in Nishindra Shahpara, and to 1.07 and 0.78 for Thanthania and Banani, reaching about 1.04–0.86, respectively (Table 4). The surcharge load is 200 kPa for the cases related to the Shakharia Namabala and Naruly Westpara areas, which is sufficient to minimize the potential susceptibility of liquefaction. In the Mothura, Chokrampur and Chok-Alom zones, a 300 kPa surcharge raises FS from 0.82 to 1.13, 0.83 to 1.08 and 0.94 to 1.12, respectively. The Hajradighi and Shakharia Baruipara papers, too, are liquefaction-prone and require surcharge loads in the order of 120 kPa and 320 kPa, respectively, to counteract the danger. This approach could be extended to other earthquake-affected areas susceptible to future earthquakes.

4. Conclusion

The current study evaluated the soil liquefaction susceptibility to varying earthquake magnitudes in 12 Bogura zones and calculated the surcharge load needed to mitigate the geohazard. The result revealed that for 6 earthquake magnitudes over 12 localities, 8 are prone to liquefaction, and four, including Chok-Alom, Nishindra Shahpara, Banani, and Naruly Westpara, have an FS greater than one. As the magnitude of the earthquake increases, the FS diminishes, and all areas are vulnerable to liquefaction with magnitudes of 6.5, 7, and 7.5. To mitigate the geohazard for a 6.5 earthquake magnitude, Jamil Nagar, Nishindra Shahpara, Thanthania, and Banani zone require 100 kPa; Shakharia Namabala and Naruly Westpara zone require 200 kPa; and Mothura, Chokrampur, and Chok-Alom zone require a 300 kPa surcharge load. Among 12 zones, the Bhabanigonj zone requires a maximum surcharge load of 400 kPa. This research might be extremely useful in mitigating the geohazard in other liquefaction-prone areas.

Declaration of Conflict of Interests

The authors state that there are no conflicts of interest.

Nomenclature

Symbol	*Description*
SPT-N	*Standard penetration test blow number*
PGA	*Peak ground acceleration*
FS	*Factor of safety*
MW	*Earthquake magnitude*
LPI	*Liquefaction Potential Index*
CSR	*Cyclic stress ratio*
CRR	*Cyclic resistance ratio*
rd	*Stress reduction factor*
σv	*Total overburden stress*
$\sigma v'$	*Effective overburden stress*

References

[1.] Hossain, M.B., Roknuzzaman, M. and Rahman, M.M. (2022). Liquefaction potential evaluation by deterministic and probabilistic approaches. Civil Engineering Journal. 8(7), 1459-1481. https://doi.org/10.28991/CEJ-2022-08-07-010

[2.] Rahman, M.M. (2025). GIS based allowable bearing capacity thematic maps of shallow foundation for Bogura District, Bangladesh. International Journal of Engineering and Geosciences. 10(3), 329-338. https://doi.org/10.26833/ijeg.1589939

[3.] Rahman, M.A., Ahmed, S. and Imam, M.O. (2020). Rational way of estimating liquefaction severity: an implication for Chattogram, the port city of Bangladesh. Journal of Geotechnical & Geol. Engineering. 38(2), 2359–2375.

[4.] Rahman, M. M., Hossain, M. B. and Sayed, A. (2025). Prediction of soil liquefaction using machine learning approaches. Engineering Transactions. 73(2), 257-277. https://doi.org/10.24423/engtrans.3360.2025

[5.] Seed, H.B. and Idriss, I.M. (1971). Simplified procedure for evaluating soil liquefaction potential. Journal of the Soil Mechanics and foundation Divisions. 97(9), 1249–1273.

[6.] Rahman, M.Z., Siddiqua, S. and Kamal, A.M. (2015). Liquefaction hazard mapping by liquefaction potential index for Dhaka City, Bangladesh. Engineering geology. 188, 137-147. https://doi.org/10.1016/j.enggeo.2015.01.012

[7.] Das, S., Ghosh, S. and Kayal, J.R. (2019). Liquefaction potential of Agartala City in Northeast India using a GIS platform. Bulletin of engineering geology and the environment. 78(4), 2919-2931.

[8.] Sayed, A. and Rahman, M.M. (2025). M5 soft computing techniques for assessment of soil liquefaction. Journal of Rehabilitation in Civil Engineering. 13(3), 199-214. https://doi.org/10.22075/jrce.2025.34669.2134

[9.] Rahman, M. M., Thakur, S., Ahmed, S. T., Yasmin, R. (2025). GIS-based development of liquefaction hazard and soil distribution maps for Dinajpur Sadar, Bangladesh. International Journal of Engineering and Geosciences, 11(2), 263-273. https://doi.org/10.26833/ijeg.1662672

[10.] Rahman, M.M., Hossain, M.B. and Roknuzzaman, M. (2023). Effect of peak ground acceleration (PGA) on liquefaction behavior of subsoil: A case study of Dinajpur Sadar Upazilla, Bangladesh. AIP Conference Proceedings. 2713, 030002.

[11.] Hossain, A., Ashikuzzaman, M. and Salan, M.S.A. (2019). GIS based liquefaction potential assessment considering different earthquake magnitude for Rajshahi District, Bangladesh. In 2nd International Conference on Planing, Architecture & Civil Engineering.

[12.] Sana, H. and Nath, K. (2016). Liquefaction potential analysis of the Kashmir valley alluvium, NW Himalaya. Soil Dynamics and Earthquake Engineering. 85, 11-18.

[13.] Lai, C. G., Conca, D., Famà, A., Özcebe, A. G., Zuccolo, E., Bozzoni, F., ... & Cosentini, R. M. (2019). Mapping the liquefaction hazard at different geographical scales. In Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions (pp. 691-704). CRC Press.

[14.] Ilgac, M., Cetin, K. O., & Kayen, R. E. (2022, January). Updated SPT-based seismic soil liquefaction triggering global database. In Geo-Congress 2022 (pp. 308-317).

[15.] Özener, P. T., Greenfield, M. W., Sideras, S. S., & Kramer, S. L. (2020). Identification of time of liquefaction triggering. Soil Dynamics and Earthquake Engineering, 128, 105895.

[16.] Geyin, M., Baird, A. J., & Maurer, B. W. (2020). Field assessment of liquefaction prediction models based on geotechnical versus geospatial data, with lessons for each. Earthquake Spectra, 36(3), 1386-1411.

[17.] Green, R. A., Bommer, J. J., Rodriguez-Marek, A., Maurer, B. W., Stafford, P. J., Edwards, B., ... & Van Elk, J. (2019). Addressing limitations in existing 'simplified'liquefaction triggering evaluation procedures: application to induced seismicity in the Groningen gas field. Bulletin of Earthquake Engineering, 17(8), 4539-4557.

[18.] Rawat, A., Kumar, D., Chatterjee, R. S., & Kumar, H. (2022). A GIS-based liquefaction susceptibility mapping utilising the morphotectonic analysis to highlight potential hazard zones in the East Ganga plain. Environmental Earth Sciences, 81(13), 358.

[19.] Juang, C. H., Ou, C. Y., Lu, C. C., & Luo, Z. (2010). Probabilistic framework for assessing liquefaction hazard at a given site in a specified exposure time using standard penetration testing. Canadian geotechnical journal, 47(6), 674-687.

[20.] Rahman, M. M., Hossain, M. B., Sayed, A., & Thakur, S. (2024, February). Assesment of liquefaction potential based on the logistic regression machine learning algorithm. In 7th International Conference on Civil Engineering for Sustainable Development (ICCESD 2024), Bangladesh.

[21.] Beyzaei, C. Z., Bray, J. D., Cubrinovski, M., Bastin, S., Stringer, M., Jacka, M., ... & Wentz, R. (2020). Characterization of silty soil thin layering and groundwater conditions for liquefaction assessment. Canadian Geotechnical Journal, 57(2), 263-276.

[22.] Al-Zaman, M.D.A. and Monira, N.J. (2017). A study of earthquakes in Bangladesh and the data analysis of the earthquakes that were generated in Bangladesh and its' very close regions for the last forty years (1976-2016). J Geol Geophys. 6(300).

[23.] Ali, H. (1998). Earthquake database and seismic zoning of Bangladesh. Bangkok. 59-74.

[24.] Bangladesh National Building Code (BNBC) 2020.

[25.] Idriss, I. M. and Boulanger, R.W. (2006). Semi-empirical procedures for evaluating liquefaction potential during earthquakes. Soil Dynamics and Earthquake Engineering. 26(2-4), 115–130.

[26.] Iwasaki, T., Tokida, K.I., Tatsuoka, F., Watanabe, S., Yasuda, S. and Sato, H. (1982). Microzo- nation for soil liquefaction potential using simplified methods. In: Proceedings of the 3rd international conference on microzonation, Seattle. 3(2), 1310–1330.

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