An Integrated Assessment of Liquefaction Susceptibility in Reclaimed Ground Overlying Soft Coastal Soils Using Multiple In-Situ Penetration Tests

Md. Shakil Mahabub[1*], ATM Shakhawat Hossain[2], Nusrat Jahan Retu[2], and Md. Shafiqul Islam[2]

[1]Matarbari Joint Venture Consultant (MJVC), Matarbari Ultra Supercritical Coal-Fired Power Project, Coxs bazar, Bangladesh

[2]Department of Geological Sciences, Jahangirnagar University, Dhaka, Bangladesh

(*Corresponding E-mail: shakilmahabub@gmail.com)

Abstract: This study investigates liquefaction potential in reclaimed coastal grounds underlain by soft alluvial soils through an integrated geotechnical approach. Due to low shear strength and high compressibility, these soils present serious stability risks during seismic events. Traditional methods, which rely on single-test data, may overlook complex subsurface conditions. Therefore, a combination of SPT, CPTu, Seismic Downhole (shear wave velocity, Vs), and pressure meter (PMT) tests were utilized to comprehensively evaluate the liquefaction risk. Factor of Safety (FS) and Liquefaction Potential Index (LPI) maps were developed, and ground improvement techniques like PVD-aided surcharge, dynamic compaction, and deep mixing were also assessed. The integrated method improves accuracy in liquefaction prediction and informs coastal infrastructure planning in seismically active zones.

Keywords: ***Liquefaction, Soft coastal soil, Reclaimed ground, Penetration tests.***

Introduction

Coastal land reclamation is common in densely populated deltaic nations like Bangladesh, where soft soils dominate. These soils exhibit high plasticity, low strength, and significant compressibility making them particularly vulnerable to seismic-induced liquefaction. Reclaimed land using dredged sand further increases complexity. While traditional SPT or CPTu-based evaluations offer partial insights (Table 1), this study integrates SPT, CPTu, Vs, and PMT to provide a more reliable liquefaction assessment for such challenging ground conditions (Figure 1).

Study Area and Geological Context

The study focuses on Matarbari Island, located in Bangladesh's active Indo-Burman subduction zone. The region is classified as seismic Zone III under the Bangladesh National Building Code (BNBC, 2020), with PGA values up to 0.28 g. Historical records show extensive liquefaction from regional earthquakes. The site's stratigraphy includes Holocene coastal deposits overlying Pleistocene formations, consisting of silt, clay, and fine sand.

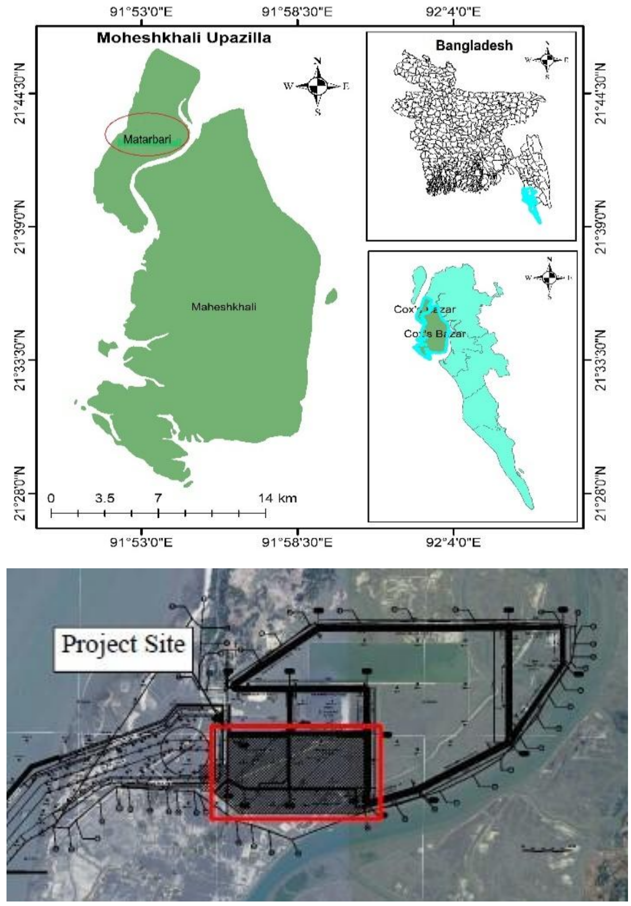


Figure 1, Site location and study area map.

Materials and Methods

A total of 100 SPT boreholes, 115 CPTu soundings, 32 PMTs, and 5 seismic downhole tests were conducted. Soil samples from SPT boreholes underwent lab testing (grain size analysis, direct shear, consolidation, and triaxial tests). Liquefaction susceptibility was assessed using factor of safety (FS) and liquefaction potential index (LPI) value based on an integrated approach for these penetration tests by following Youd et al. (2001); Idriss and Boulanger (2008); Boulanger and Idriss (2014). Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR) were derived from test-specific empirical formulas. Correction factors (e.g., MSF) adjusted results for earthquake magnitude and local conditions.

FS < 1.0 indicated liquefiable layers. LPI calculations incorporated FS depth profiles to assess surface-level deformation risk.

Table 1, In situ penetration tests scope for evaluating liquefaction susceptibility based on different features.

Feature	PMT	SPT	CPT	Vs
Past measurements at liquefaction sites	Sparse	Abundant	Abundant	Limited
Type of stress-strain behavior influencing test	From small to large strain	Partially drained, large strain	Drained, large strain	Small strain
Quality control and repeatability	Good	Poor to good	Very good	Good
Detection of variability of soil deposits	Good	Good for closely spaced tests	Very good	Fair
Soil types in which test is recommended	All	Non-gravel	Non-gravel	All
Soil sample retrieved	Yes	Yes	No	No
Test measures index or engineering property	Engineering	Index	Index	Engineering

Results and Discussion

SPT and CPTu Results: Indicated several zones with FS < 1.0, particularly in reclaimed sand overlying soft clay layers.

Vs Profiles: Low shear wave velocities (<150 m/s) were noted in upper 10–12 m, consistent with high liquefaction potential.

PMT Findings: In-situ stiffness and strength were low in untreated zones but showed improvements post-treatment.

LPI Mapping: Liquefaction risk zones were clearly demarcated, with LPI >15 in untreated sectors and shown in Figure 2.

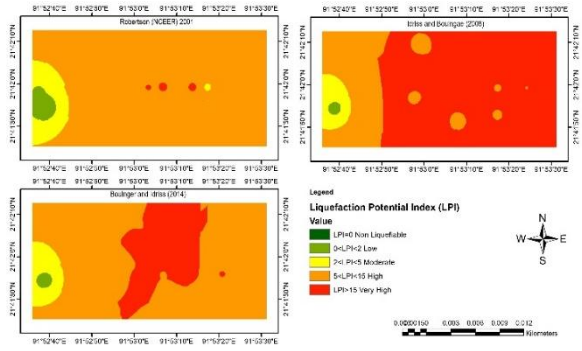
Post-reclamation ground improvement (PVD + dynamic compaction) significantly reduced FS < 1 zones and improved stiffness, reducing LPI values across the site (Figure 2).

Implications and Recommendations

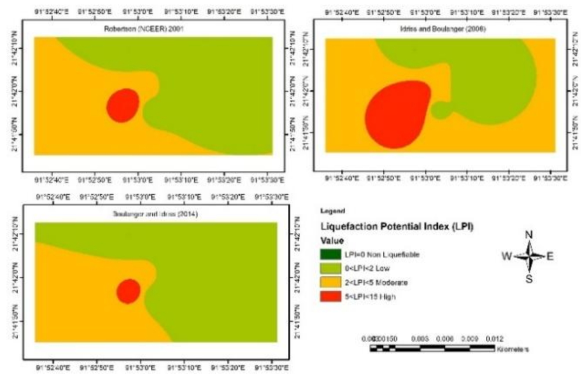
- Multi-method testing improves liquefaction risk prediction, especially in complex reclaimed sites.
- Ground improvements, particularly PVD-aided surcharge and DMM, are effective in mitigating liquefaction in soft coastal zones.
- Monitoring post-treatment performance is essential to evaluate long-term ground stability.

Conclusion

This study provides a novel integration of SPT, CPTu, Vs, and PMT to enhance liquefaction assessment for reclaimed soil along with existing soft coastal soils. The approach enables more accurate zoning and design decisions for infrastructure development in seismically vulnerable coastal regions.



(a)



(b)

Figure 2, Liquefaction risk map based on LPI values for (a) existing ground, and (b) improved ground.

Future Work

- Expand dataset for machine learning-based prediction models.
- Long-term monitoring of treated ground behavior under dynamic loading.
- 3D numerical modeling to capture soil-structure interaction during seismic events.

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