Extended Abstract **DOI: https://doi.org/10.64862/ajeg.2025.2sp.37.137** **Open Access**

Engineering Geophysics for Site Characterization for Local Seismic Hazard Assessment in Barishal City, Bangladesh

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Received: August 18, 2025, Accepted: September 5, 2025

Abstract: Various engineering geophysical methods are available for seismic site characterization, including both invasive and non-invasive techniques. In this study, Multichannel Analysis of Surface Waves (MASW), Downhole Seismic Testing (DST), and Standard Penetration Tests (SPT) were employed to evaluate local seismic site effects, particularly amplification characteristics, within the mapped area. A regional seismic hazard map for Bangladesh, developed through probabilistic seismic hazard assessment (PSHA) by Azari et al. (2021), provides Peak Ground Acceleration (PGA) values at bedrock corresponding to a 10% exceedance probability in 475 years. The study area, located in Barishal, covers approximately 92 km^2 and is dominated by thick deposits of unconsolidated to loosely consolidated late Holocene to recent fluvial and deltaic sediments. This research estimates near-surface one-dimensional shear wave velocity (Vs) profiles at 1 m depth intervals within the upper 30 m of soil. DST investigations were conducted under the GPAC project implemented by BGR, LIAG, and GSB. MASW results were validated against DST measurements to ensure reliability. A dataset from 13 boreholes, including DST and SPT records, was used to develop a regression model for estimating shear wave velocity from SPT N-values. A SAGA–ISEG-based algorithm was applied to correlate uncorrected SPT N-values (1.5 m intervals) with corresponding mean Vs values. The resulting exponential relationship for Barishal is expressed as y = 107.9x^0.192 with R^2 = 0.6308. Local site conditions were classified based on VS30 values, representing the average shear wave velocity of the top 30 m soil column. The VS30 values range from 145 m/s to 216 m/s, indicating relatively soft soil conditions. According to the national building code, the study area falls into seismic site classes SC and SD, highlighting moderate to high amplification potential and the need for careful engineering design considerations.

Keywords: **Shear wave velocity, Seismic hazard, Seismic soil classification.**

Introduction

Geotechnical characterization of the subsurface material, especially the stiffness of the topmost soil layers, is usually the first task for any foundation design activity at a given site. Nature of seismic ground motion at a site significantly depends on the stiffness properties of the topmost part of the earthen materials in the subsurface (Foti et al.,2014). These properties are considered as important parameters in the field of geotechnical studies because the earthquake induced ground motion and resulting damages are mainly influenced by the local soil properties. Generally, the shallow overburden soil properties largely contribute to the dynamic response of the structure placed on the ground surface. In this setting, geophysical techniques are considered reliable methods to estimate the elastic properties or stiff behavior of subsurface soils. In recent years measurement of these soil properties by conducting seismic wave propagation methods have become common approach for site response analysis (Mattews et al., 1997). The main objectives of research are to derive the average shear wave velocity of the upper 30 m depth (VS_{30}) of the ground for each of the test sites and correlate with SPT value in Barishal city

Methodology

Downhole Seismic Testing (DST), commonly referred to as PS logging, is an efficient and reliable method for determining shear wave velocity (Vs) profiles using a single borehole under field conditions. The parameter VS30, defined as the thickness-weighted average shear wave velocity of the upper 30 m, is widely adopted in seismic geotechnical site characterization and local seismic hazard assessments. This study focuses on deriving shallow subsurface Vs–depth profiles and VS30 values across different geomorphic units within the investigated area. The field investigations were carried out using a downhole system that includes a horizontally polarized shear (SH) wave source at the surface, paired downhole probes equipped with three-component geophones, and a digital seismograph for data acquisition. Tests were conducted at 13 selected borehole locations where Standard Penetration Tests (SPT) had been performed up to approximately 30 m depth, with 3-inch PVC casing installed in each borehole. Data acquisition utilized six active channels arranged within two in-line probes, each containing receivers with a natural frequency of 10 Hz. SH waves were generated by applying repeated horizontal impacts in opposite directions on a wooden shear plank at each test depth. The recorded waveforms were analyzed using the interval method to determine Vs–depth profiles. Data processing was performed with SeisImager/Pickwin, where SH wave arrivals were identified on appropriate sensor components at 1 m depth intervals. Interval travel times were then used to compute in-situ one-dimensional shear wave velocity (ΔVs) profiles. An ISEG-based algorithm was applied to correlate uncorrected SPT N-values (at 1.5 m intervals) with corresponding measured Vs values, resulting in an exponential regression relationship between these parameters. Additionally, at 12 locations, both active and passive Multichannel Analysis of Surface Waves (MASW) tests were conducted to validate and compare the PS logging-derived Vs profiles, enhancing the robustness and consistency of the site characterization.

Results and discussion

The resulting velocity models from the PS logging of the topmost 30 m show that most of the study area have very low ΔVs values mainly ranging from 80 m/s to slightly more than 250 m/s. The calculated VS_{30} values throughout the area range between 152 m/s and 177 m/s. The combination of MASW active and passive Remi results show the shear wave velocity (VS_{30}) varies from 151 m/s to 184 m/s but finally this data was not used for regression analysis. This exponential regression formula was used to calculate the shear wave velocity from the SPT information within the 92 remaining boreholes. The VS_{30} values range between 145 m/s and 216 m/s. Based on VS_{30}, the studied areas are classified into two seismic site classes, SC and SD (Figure 1). *SC* class covers 10% of the area whereas *SD* class covers 90% area.

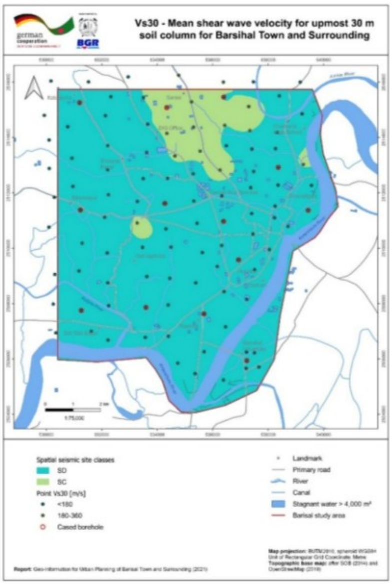

Figure 1, Seismic site class map at Barishal area based on VS30; cased geotechnical boreholes for P-S logging are marked with red circle.

For the calculation of site-specific amplification factors, an empirical method implemented in the National Earthquake Hazard Reduction Program (NHERP) of the USA was employed (Seyhan & Steward, 2014), and local PGA maps are computed from regional PGA data with the VS_{30}-based amplification data.

Conclusion

Passive seismic measurements with the analysis of H/V for fundamental frequencies and array microtremor measurement for shear wave velocity profiles and identification of the depth of the engineering bedrock are important information for site characterization, especially for seismic microzonation. Therefore, we will integrate geophysical and geotechnical data in the future with the results from passive seismic measurements. If we can incorporate well planned (500 m to 200 m spacing H/V and spiral galaxy array survey) microtremor data will help in details site characterization of the area.

Acknowledgement

The authors are grateful to the German–Bangladesh technical cooperation project Geo-information for the Implementation of a Climate-Change-Resilient Urbanization (GICU), funded by the Government of the Federal Republic of Germany through its commissioning Federal Ministry for Economic Cooperation and Development (BMZ) and by the Government of the People's Republic of Bangladesh through the Ministry of Power, Energy and Mineral Resources (MPEMR), and implemented jointly by the Federal Institute for Geosciences and Natural Resources (BGR) and the Geological Survey of Bangladesh (GSB).

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