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Assessment of Local Seismic Hazard of Agartala based on Nonlinear Site Response Analysis

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Abstract. Followed by the recent moderate 3rd January 2017 Ambassa earthquake (*Mw* =5.7) epicenter located at Dhalai district of Tripura, the state witnessed cases of ground failures due to liquefaction, landslides and several cases of partial and complete damage of non-engineered/semi-engineered houses/buildings within the near vicinity of epicentral areas. Reconnaicense study of failures prompted to carry out local site response analysis of important urban agglomeration in order to estimate the seismic hazard for a future event. Above all, Tripura is situated in the severely vulnerable zone (zone V) as per seismic zoning map of India. In this context, the present study is aimed to perform one dimensional ground response analysis (1D GRA) of Agartala town, the capital place of Tripura where significant infrastructural growth is booming up presently due to its salient location in the global map. The geological condition of this area categorized as sedimented 'Bengal basin' with relatively younger alluvium/fluvial river deposits of Holocene age. Site classes D and E of the NEHRP classification are dominant in the area investigated.1D nonlinear GRA is performed using DEEPSOIL on twenty representative boreholes data. Synthetic ground motion is generated considering past local earthquakes using Boore's point source model (Boore 1983, 2003) and used in this study since reliable ground motion data from potentially damaging past earthquakes are scarce in this region.

Keywords: Site response; Earthquake; Seismic analysis, Ground motion; Geotechnical investigation

1 Introduction

The response of any structure depends on its regional seismicity, geology and local soil conditions, the nature of source mechanism. The local soil geology play an important role in governing the ground response. The evaluation of ground response is an important task, as it governs the safety of structures located in seismically prone areas. Site response estimation from geotechnical investigations involves a combination of wave propagation theory with the material properties and the expected ground motion computed at the site of interest. Soil material modelling can be broadly classified into three types, linear, equivalent –linear (EQL) and nonlinear (NL) models for one horizontal direction of shaking, and nonlinear models for multiple directions of shaking.1D ground response analysis (GRA) can be performed either in the time domain (nonlinear total and effective stress approaches) or in the frequency domain (linear and equivalent linear total stress approaches). However, in the sake of the inherent nonlinearity in soil behavior, a time-domain nonlinear GRA can model the soil response during an actual earthquake, more accurately than any frequency domain GRA method (Chi-Chin Tsai 2015).

1.1 Geological significance of Tripura

Agartala city is the capital of Tripura state, in the northeast of India. This is one of the fastest-growing cities in northeast India, with a population of 400,000residents and a high population density of 10.119 persons per km2 compared to other cities in northeast India. The city is located within the NW portion of the state having latitude of 23.78N–23.88N and longitude of 91.26E–91.33E within the western district of Tripura. The city covers an area of about 62.0 km^2 in its present form and functions by the authority of the Agartala Municipal Council (AMC). However, geologically the whole of the area in Tripura forms a part of the Tertiary Naga-Arakan-Yoma basin, a younger terrain that is located to the southwest of the Paleogene fold belt. It is likely that Neogene sediments were deposited on the folded, but not uplifted, Paleogene sediments, and were subsequently co-folded in the latter stage. The tectonic cycle ended with a weak deformation of Dupitila sediments (Fig. 1.). However, Dasgupta (1908) first classified the folded sediments of Tripura into 'coal measures' and 'Tipam' groups. The water table is very close to the ground surface and the central part of the city, which is close to the Haora river/Katakhal, which has soft clay, silty-sand alluvium deposits, and mostly sedimentary soils. These sediments, according to the Geological Survey of India (GSI), were laid down in the Surma basin during the tertiary age (which lasted for 65 million years) in a wide range of environmental conditions governed by localized tectonic movement.

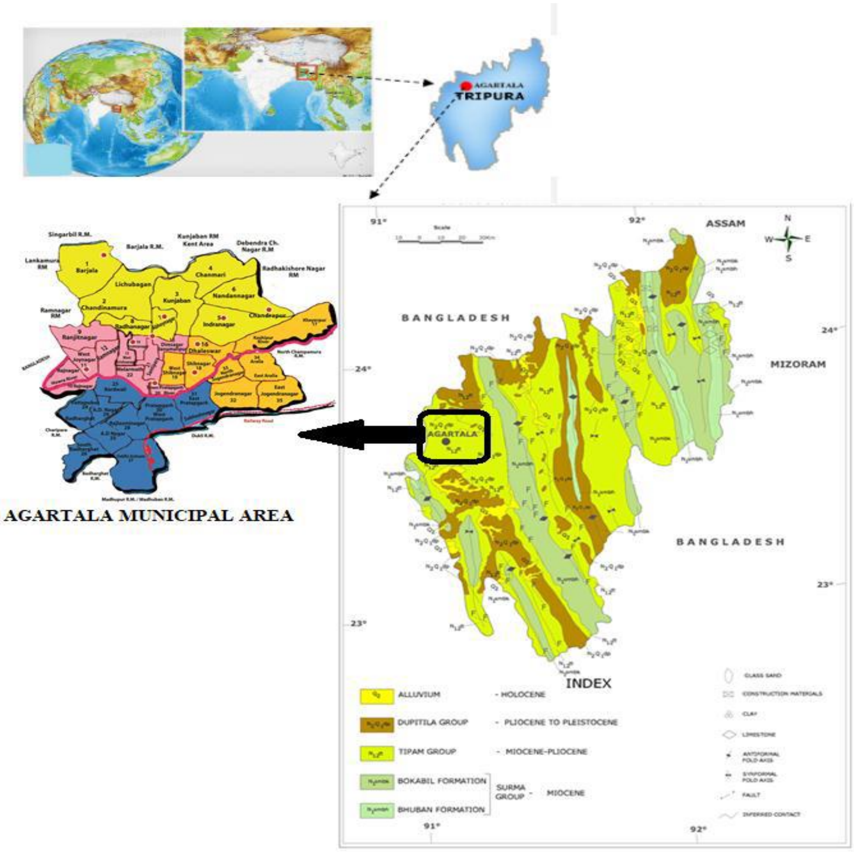


Fig.1. Geological map of the study area

1.2 Seismological significance of Tripura

Seismically, northeast India is active and this region is highly populated. The region falls under the highest zone V as per the seismic zoning map of India (BIS 2002). The seismotectonics of this area is complicated because interaction between the active north-south convergence along the Himalaya and the east-west convergence and folding within the Indo-Burma ranges, which attribute deformation known as subduction (Kayal 2008). These two mobile belts meet at the eastern syntaxes zone, which was the source zone of the 1950 Assam earthquake (Mw = 8.1), the 1897 Shillong earthquake (Mw = 8.7), and two large earthquakes (Mw > 7.0), such as 1930 Dhubri (Mw > 7.0) and 1918 Srimangal earthquakes (Mw > 7.5), which significantly affected the adjoining areas in this region. Further, it is also reported by some other researchers (Mukhopadhyay and Dasgupta 1988; Kayal 1996; Satyabala 2003) that the Indian plate actively subducts below the Burmese arc. Based on the previous earthquakes and geomorphological survey, this zone was subdivided into five parts. As per the tectonic framework, it is observed that the study area of Tripura lies within the Tripura fold belt zone, which is in the proximity of the Bengal basin and Indo-Burmese arcs in the western and eastern sides, respectively. It is observed that there are three active faults near Tulashekhar, Chamanu which are relatively near to the study area. The major fault lines are passing in the south through Rupaichari, Matabari, Hrishyamukh, Killa, Jampuijala, Jirania, and Manu**.**

2 Sample Borehole

Primarily, the analysis is carried out from sub-soil data retrieved from twenty boreholes (BH). BH were selected in such a manner that they are uniformly distributed across the central zone of Agartala municipality area (AMC).The SPT is the most important and common in situ tests used in all geotechnical investigations around the world. Shear wave velocity is one of the key parameters in seismic hazard evaluation, which plays an important role during an earthquake as it is directly responsible for the amplification or de-amplification of incoming ground motion at the ground surface which is effected by local soil characteristics. A typical bore log profile along with SPT-N value and shear wave velocity variation is presented in fig.2. Several correlations are proposed by various researchers, however for the present study, correlation proposed by Sil *et. al.* (2013) was taken into consideration. Correlations proposed by Sil *et.al.* (2013) was based on an extensive study on Agartala soil which included in situ tests and is deemed most suitable for the present study. 20 borehole profiles considered for the present study were classified as Site Class D (Vs30 180-360m/s) or Class E(Vs30 <180m/s). The Vs30 of each soil column classified according to the NEHRP site classification scheme (Table 1).

Table 1. Site classification system as per NEHRP design manual

NEHRP site class	Description	V_{s30}
A	Hard rock	>1500m/s
B	Firm and hard rock	760-1500m/s
C	Dense soil, soft rock	360-760m/s
D	Stiff soil	180-360m/s
E	Soft clays	<180m/s

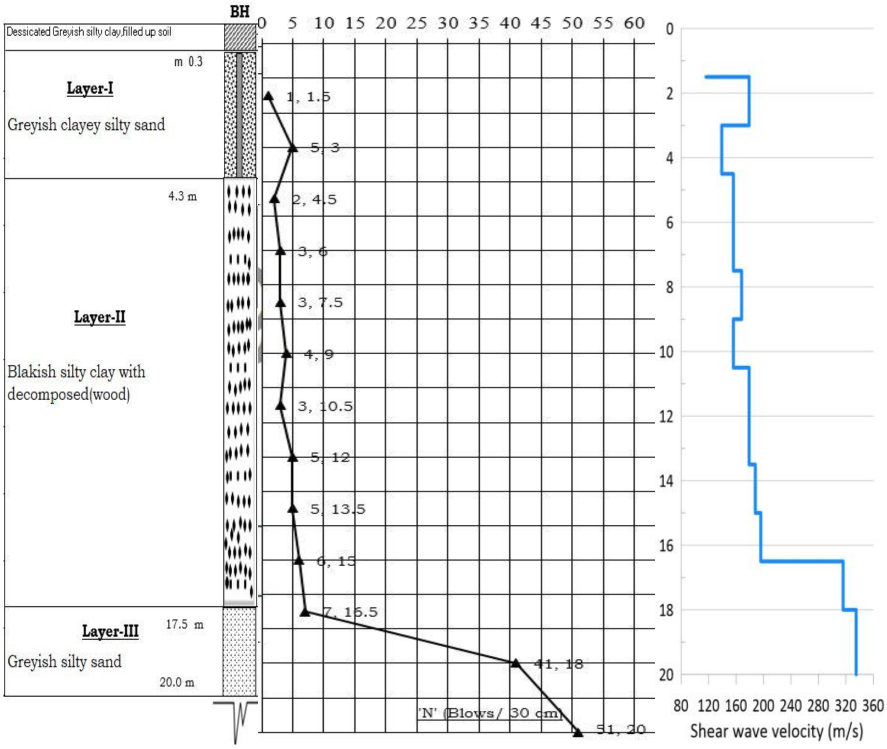


Fig.2. A typical bore log profile along with SPT-N value and shear wave velocity variation

Table 2. Name and locations of the salient five sites used for this study

Borehole profile No	Name of site	Location of site
BH1	Gandhi school Road	23.8825662,91.291366
BH2	Dashamighat, Hariganga Road	23.828000,91.265533
BH3	North Banamalipur	23.839450,91.289542
BH4	Ujan Abhoynagar	23.847881,91.288744
BH5	South Badharghat Railway Station	23.893869,91.277146

3 Methodology

This paper focusses on a non-Masing criteria based nonlinear 1D GRA carried out using DEEPSOIL v6.0 and liquefaction potential assessment of a soil profile in Agartala. Nonlinear time history analysis is done in DEEPSOIL considering soil profile which is converted into a mass-spring – dashpot system using MDOF lumped mass parameter model. The dynamic equation as follows is solved at each time step using the numerical integration process by Newmark β method (Newmark, 1959).

$$[M]\{\ddot{u}\}+[C]\{\mathring{u}\}+[K]\{u\}=-[M]\{I\}\ddot{u}_g \tag{1}$$

Where [M] is the mass matrix, [C] is the viscous damping matrix, [K] is the stiffness matrix, u is the vector of relative nodal displacement, $\ddot{u}_g$ is the acceleration at the base of the soil column,{I} is a unit vector. The nonlinear model developed by Phillips and Hashash (2009) with hysteretic damping reduction factor, referred to as MRDF procedure, has been employed in the DEEPSOIL code, for performing nonlinear non-Masing GRA. The model used in DEEPSOIL is the pressure-dependent hyperbolic model which defines the inter-relationship between the stress and strains developed in the soil subjected to a cyclic loading and unloading phenomenon. Generally, the development of cyclic shear stress due to the cyclic strains or vice versa is governed by Masing and Extended Masing rules (Park, 2003). The hyperbolic model is a modification of the original strain-dependent hyperbolic MKZ (Matasovik Kondner and Zelasko) model Equation

$$\tau = \frac{\gamma G_{mo}}{1+\beta\left(\gamma\frac{G_{mo}}{\tau_{mo}}\right)^s} = \frac{\gamma G_{mo}}{1+\beta\left(\frac{\gamma}{\gamma_r}\right)^s} \tag{2}$$

Where G_{mo} is the initial shear modulus, τ_{mo} is the shear stress at 1% shear strain ,γ is the shear strain and γ_r is the reference shear strain. The model parameter β and s are used to define the shape to the backbone curve. The pore water pressure generation model for sands (Matasovic 1992), for clays (Matasovic and Vucetic 1995), and the pore water pressure dissipation model (Terzaghi 1925) are implemented in DEEPSOIL code.

3.1 Description of seismic loading

In the present analysis recent moderate 3rd January 2017 Ambassa earthquake (*Mw* =5.7) epicenter located at Dhalai district of Tripura are used as input motion. Due to the unavailability of recorded data Dhalai2017, synthetic ground motions considering past local earthquakes using Boore's point source model (Boore 1983,2003) are used with peak ground acceleration of 0.056(g) (fig.3).

Table 3. Presented details of Earthquake around the study area used for this

Long(o)	Lat(o)	Name	Year	Month	Day	Hypocentral Distance (km)	Focal depth(km)	Magni-tude	Max Acc(g)
91.9	24.1	Dhalai Tripura	2017	1	17	61.71	28	5.7	0.0556

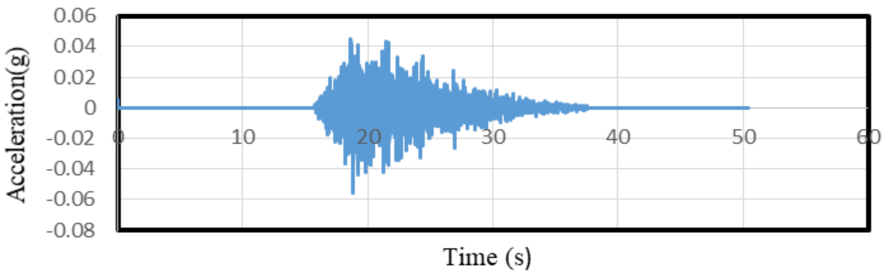


Fig. 3. Synthetic bedrock motion DHALAI 2017 with PGA 0.056g

4 Results and Discussion from GRA Studies

4.1 Peak ground acceleration (PGA) with depth

Ground response analyses are carried out on 20 BH at Central Agartala using synthetic motion. Salient 5 boreholes from five important locations are selected from a total sample of 20 boreholes to present Peak ground acceleration (PGA) at the top surface for five different site locations at Agartala (Table 4) (fig.4.).The results of acceleration time history and stress time history are obtained for all 20 BH. It has been observed that the PGA of input motions gets amplified at surface.

Table 4. Salient 5 boreholes selected from a total sample of 20 boreholes presenting Peak ground acceleration (PGA) at the top surface for five different site locations at Agartala

Borehole profile No	Peak ground Acceleration (g)
BH1	0.06080
BH2	0.07650
BH3	0.06862
BH4	0.07620
BH5	0.05919

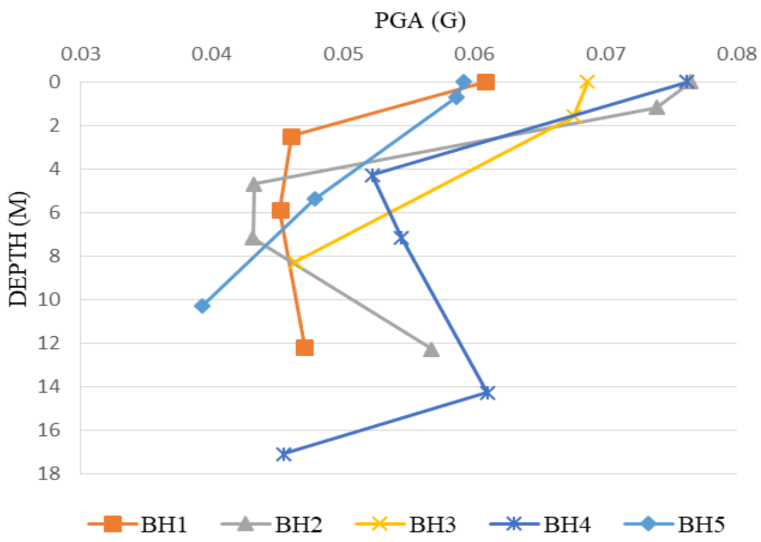


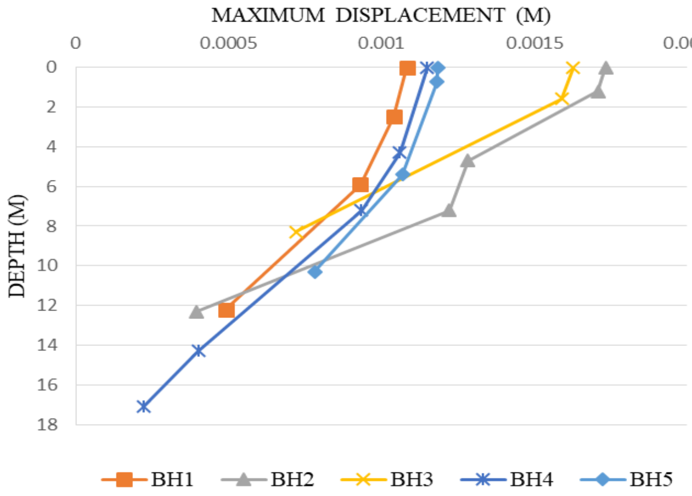
Fig.4. PGA profiles in Central region of Agartala for EQ Dhalai (2017) EQ

Peak ground displacement (PGD) and Maximum strain (%) with depth

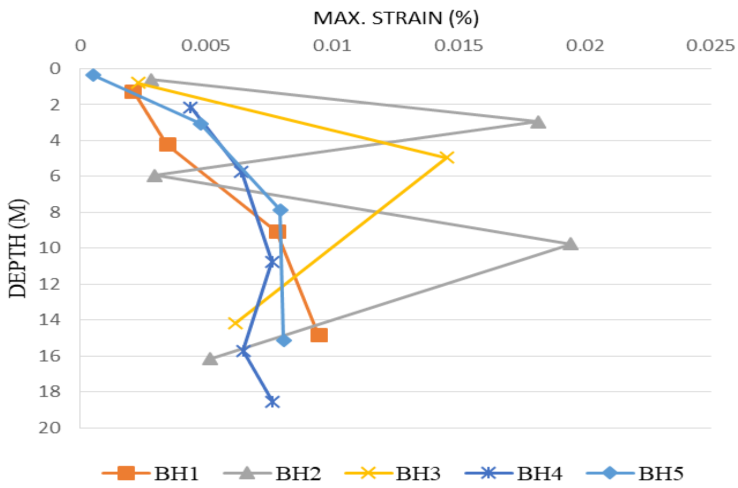
Maximum displacement and Maximum strain at a depth of every layer is calculated for 20 boreholes subjected to the ground motion from DEEPSOIL analysis. Salient 5 boreholes selected from a total sample of 20 boreholes to present Peak ground displacement (PGD) and maximum strain(%) at the top surface for five different site locations at Agartala (table5)(fig.5.).Max displacements occurs due to loss of strength of soil strata subjected to numerous cyclic loading.

Table 5. Salient 5 boreholes selected from a total sample of 20 boreholes presenting Peak ground displacement (PGD) and maximum strain (%) at the top surface for five different site locations at Agartala

Borehole profile No	Peak ground displacement (PGD) (m)	Max strain (%)
BH1	0.001084	0.00943
BH2	0.001734	0.01945
BH3	0.001627	0.01452
BH4	0.00115	0.00760
BH5	0.00118	0.00806



(a)



(b)

Fig.5. (a) PGD and (b) Max strain (%) profiles in Central region of Agartala for Dhalai (2017) EQ

Amplification factor (A_F)

The amplification ratio is defined as the ratio of amplification at the surface to that of the bed rock. Amplification factor gives an idea about the amplification/attenuation of ground accelerations as the stress waves propagate through the soil medium. This is indicative of the damage expected at a particular location. However higher amplification has been observed in a range between 1.06-1.37.Salient 5 boreholes selected from a total sample of 20 boreholes to present amplification factor at the top surface for five different site locations at Agartala at Table.6.

Table 6. Salient 5boreholes selected from a total sample of 20 boreholes presenting Amplification factor at the top surface for five different site locations at Agartala

Borehole profile No	Amplification factor
BH1	1.09
BH2	1.37
BH3	1.23
BH4	1.37
BH5	1.06

Response spectra

Response spectrum describes the maximum response of a single-degree-of-freedom (SDOF) system, subjected to a particular input motion, as a function of the natural period (or natural frequency) and the damping ratio of the system (Kramer, 1996. For any particular site, the 5% damped surface spectral acceleration plot can be obtained based on the GRA study. Spectral acceleration at the ground surface, i.e. the response spectra with 5% damping, is shown in fig.6. at five selective BH locations for the motion Dhalai2017.The high value of spectral acceleration has been observed in BH2. It serves as an essential guideline for seismic design of structures. It can be seen that highest responses are expected for structures having low natural period in the range of 0.1 - 0.2 s.

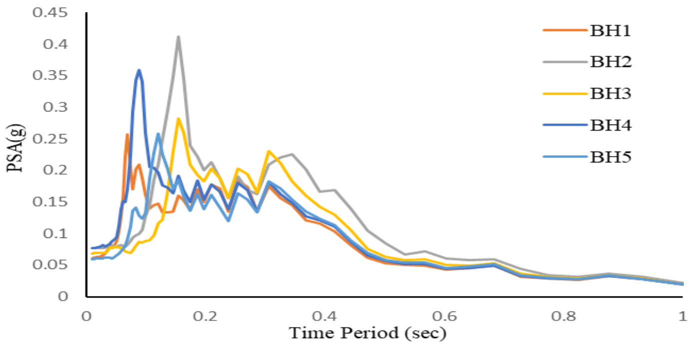


Fig.6. Spectral acceleration at the ground surface with 5% damping at at five selective BH locations for the motion Dhalai2017 EQ.

5 Summary and Conclusions

The site response analysis of the central region of Agartala and the detailed site effect analysis of soil profiles are presented in this study. A total of 20 SPT N boreholes were analyzed with the aim to study the dynamic properties of the soil and to evaluate the behavior of soils upon application of seismic load. The SPT N values were used to evaluate the Vs30 for all borehole locations. In the NEHRP site classification scheme, site classes D and E are prevalent in the study area. Peak ground acceleration (PGA) at surface obtained for twenty boreholes, located at central zone of Agartala ranges from 0.059g to 0.076g.From results obtained it can be stated that the maximum increase in PGA is found to be at ground surface which indicates amplification of the motions due to the presence of soft soil deposit. Peak ground displacement (PGD) were evaluated from twenty boreholes distributed uniformly at central zone of Agartala. It is observed that PGD at the surface level is on the higher side. The range of PGD is found to be in the order of 0.001 to 0.017. Results indicated wide range along with higher value which gives rise to possibility of ground cracks or failure in future earthquakes. It is observed from the fig that higher strain range is noted for motion Dhalai EQ 2017. Higher strain indicates more dissipation of energy during the cyclic loading phenomenon and hinting at further softening of the soil stratum with the number of loading cycles. Amplification has been observed for the motion Dhalai EQ 2017 with amplification factor range between 1.06-1.37. High value of spectral acceleration has been observed for Dhalai EQ 2017 motion. The plots also reflect that higher spectral acceleration is obtained as a result of a higher amplitude of input motion.

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