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Dynamic soil properties for seismic ground response studies in Northeastern India

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ABSTRACT

Stiffness and damping properties of soil are essential parameters for any dynamic soil structure interaction analysis. Often the required stiffness and damping properties are obtained from the empirical curves. This paper presents the stiffness and damping properties of two naturally occurring sandy soils collected from a river bed in a highly active seismic zone in the Himalayan belt. A series of resonant column tests are performed on the soil specimens with relative densities representative of the field and with varying confining pressures. The test results are compared with the available empirical curves. Furthermore, a ground response analysis study is also carried out for a bridge site in the region using both the empirical curves and experimentally obtained curves. It has been observed that the application of empirical modulus and damping curves in ground response prediction often leads to underestimation of the seismic demands on the structures. The established soil curves can thus be utilized in performing seismic ground response studies for the design of new structures or requalification/re-assessment of existing structures in the northeastern part of India.

1. Introduction

India is one of the most active seismic countries in the world, particularly the North and Northeastern parts due to the Himalayan seismic belt. Assam (see Fig. 1a), one of the seven Northeastern states of India, witnessed two great earthquakes (moment magnitude, $M_w > 8.0$) and many large earthquakes ($6.0 < M_w < 8.0$) since the first instrumentally recorded seismic event in 1897. Fig. 1(a) presents the past seismic events in and around India along with the seismic faults and seismic history in Northeast India. Bureau of Indian standards [22] classified Assam as seismic Zone V, which is considered as one of the highest seismic zones in the world. The mighty Brahmaputra River, the widest river in Asia, flows through Assam and many lifeline structures like road and railway bridges were constructed on this river even before the first seismic code developments in India. Due to the rapid urbanization and population growth, several such bridges are proposed on this mighty river. Fig. 1(b) presents the location of major bridges on Brahmaputra River in Assam. Due to the high seismicity of this region, the seismic vulnerability assessment of these very structures is therefore needed in order to mitigate the potential loss during any future seismic event.

The design engineers need the seismic demanding forces on the structures before proceeding for any earthquake resistant design or to assess the seismic safety of existing structures. These seismic forces can be reasonably estimated with the help of Ground Response Analysis (GRA) studies and the underlying soil properties are required for such studies. In particular, variation of shear modulus and damping with strain are essential to model the soil behavior and are often considered from standard curves, see for ex. Seed and Idriss [40], Vucetic and Dobry [47], Ishibashi and Zhang [25], Darendeli [10], Vardanega and Bolton [46]. The reliability of such curves in ground response estimation is often questioned. This calls for high quality input data of stiffness and damping of soils, especially for design or safety assessment of very important structures in seismic prone regions. This paper presents such stiffness and damping variation curves for two sandy soils collected from two bridge locations in Assam (shown in Fig. 1b), and compared with the available soil curves to see the variability of the ground response. Based on the objective, this paper is structured in the following way.

1. Resonant Column (RC) tests are performed on two sands for a range

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Nomenclature

A	Coefficient for G_{max}
C_u	Coefficient of uniformity
C_c	Coefficient of curvature
D	Damping ratio
D_{min}	Minimum damping ratio
D_i	Thickness of layer
D_{masing}	Masing damping at any given curvature coefficient
e	Void ratio
e_{max}	Maximum void ratio
e_{min}	Minimum void ratio
e_{target}	Target void ratio
$F(e)$	Function of void ratio
f_{nz}	Resonant frequency
G	Secant shear modulus
G_{max}	Maximum shear modulus
G_s	Specific gravity of soil solids
K_o	Coefficient of at-rest lateral earth pressure
k	Stress correction factor
M_w	Moment magnitude
N_{avg}	Average Standard Penetration Test (SPT) value
P_a	Atmospheric pressure
R^2	Correlation coefficient
R_d	Relative density
V_s	Shear wave velocity
σ'_m	Mean effective confining pressure
γ_{ref}	Reference shear strain
γ	Shear strain
α	Curve fitting parameter for modulus reduction
β	Scaling coefficient for damping ratio
γ_{tot}	Total unit weight
$\sigma'_{m\text{-}I}$	Mean effective confining pressure of particular soil layer
γ_{r1}	Reference shear strain at atmospheric pressure

of confining pressures and initial void ratios and the corresponding modulus and damping curves are plotted.
2. Experimentally obtained curves are compared with the available empirical curves.
3. A seismic site response study is performed to demonstrate the importance of having the site specific soil curves.

2. Soils characterization

The two soils representing the typical soils from the region, are collected from the shore of the mighty Brahmaputra River (near two bridge locations shown in Fig. 1b) which flows from China towards Assam and merges in Bay of Bengal (Fig. 1b). Standard procedures for soil sampling were followed according to Indian Standard: IS 2132 [23] and IS 10042 [24]. One of the soils is named as BP which is collected from Guwahati region near Saraighat Bridge and the other as BG, collected near Bongaigaon City. Table 1 presents the index properties of both the soils determined from the laboratory tests. The grain size distribution curve for both the soils is given in Fig. 2. Both the soils are classified as poorly graded (SP) fine grained sands according to the Unified Soil Classification System (ASTM D 2487 [4]). Field Emission Scanning Electron Microscopic (FESEM) pictures of both the sands can be seen in Fig. 3(a) and (b). It is clear from the index properties, gradation curve and the FESEM pictures that the maximum particle size of BG sand is 1 mm while that of BP sand is 0.425 mm and both possess similar sub-angular shape. Also both the sands can be considered as clean sands as their Fine Content (FC) is less than 5%. The only significant difference between both the sands is the size of the particles due to which their uniformity (C_u) and curvature coefficients (C_c) vary.

3. Test equipment and methodology

Laboratory tests were performed using a fixed-free configuration of the RC apparatus (Fig. 4a) supplied by GDS Instruments, UK available at the Surrey Advanced Geotechnical Engineering (SAGE) laboratory, University of Surrey, UK. Fig. 4(b) presents the schematic view of the RC apparatus along with some instrumentation details. The basic principle involved in RC testing is the theory of wave propagation in prismatic rods (Richart et al. [37]), where a cylindrical soil specimen is harmonically excited till it reaches the state of resonance (peak response). The testing procedures were reported in many studies (Hardin [18], Drenvich et al. [12], ASTM D 4015 [5]). Further details about the RC apparatus utilized and its calibration can be found in Cox [9].

3.1. Sample preparation

Specimen preparation was carried out as per the standards of ASTM D 4015 [5] and ASTM D 5311 [3]. Cylindrical specimens of 50 mm diameter and 100 mm height were prepared targeting three different relative densities of loose, medium dense and dense states (30%, 50% and 70%). The sand was air pluviated using a funnel directly in to the split mould that was fitted with the latex membrane. The filling was done in four layers with each layer being compacted gently using a wooden rod giving equal amounts of tap on the sides of the mould. Many number of trials were performed to check the effect of height of fall and the energy given to the mould to fix the exact values so as to reach the required relative density. Once the soil specimen is ready, then the top cap is put over the sample, the latex membrane is stretched around it, and fixed using the O-rings (Fig. 4b). The electromagnetic driving system is then carefully placed over the top cap on the specimen, levelled and fixed on the top cap with the screws provided as shown in Fig. 4(a). Instrumentation like LVDT and accelerometer were installed after confirming the system alignment. Instrumentation is connected to the computer to record the data using the GDSLAB program (GDSLAB, 2.1.0 [14]). Table 2 summarizes the testing program and output expected in each test.

After making sure of the proper arrangement of the equipment, the triaxial cell is slowly lowered on to the resonant apparatus to allow it for confining the sample to the required initial state of the stress. The targeted confining pressure is then applied using the pressure controller in GDSLAB program. Once the targeted confining pressure is applied on to the sample, the axial deformations (if any) during the sample preparation and cell pressure application are monitored using the vertical LVDT with which the exact sample density can be calculated (reported in Table 2). It is clear from the Table 2 that the void ratio of the samples after sample preparation did not vary much (within ± 2%) and can closely represent the targeted void ratio (e_{target}).

3.2. Testing procedure

In brief, the soil specimen is excited under a harmonic torsional vibration, induced in the form of electric voltage through the electromagnetic drive system, consisting of four magnets. Initially a small amount of electric current (say 0.001 V) is passed through the magnetic coils with frequency ranging from 30 to 250 Hz, with an increment of 5 Hz in order to excite the sample (typically called as broad sweeping). The frequency corresponding to the maximum amplitude of vibration is considered as the resonant frequency of the sample. Once the rough estimation of fundamental frequency at 5 Hz interval is completed, then a fine sweep is performed with ± 5 Hz on either side of the