Use of PS Logging and Ground Response Analysis using DEEPSOIL in BUET-JIDPUS, BUET, Dhaka

A. S. M. Fahad Hossain, Naveel Islam, Mehedi Ahmed Ansary

Abstract— With the increased use of machines on super structures along with constructions on loose sands and soft clays in Bangladesh, the chances of collateral effects are increasing. Degree of damage during earthquake strongly depends on dynamic characteristics of building as well as amplification of soil. So for measurement of dynamic properties and site amplifications, seismic wave velocities determination is necessary. The paper deals with the use of PS Suspension Logging Downhole Seismic Testing System for measurement of compression and shear wave velocities also determination of the dynamic soil properties and site response using DEEPSOIL (Hashash et al., 2011) V5.1.

Index Terms— Soil Amplification, Dynamic Soil Properties, PS Logging, Downhole Seismic, DEEPSOIL, Response Spectrum, Peak Ground Acceleration.

I. INTRODUCTION

Few of the major earthquakes over the years, alike the Sumatran Earthquakeor the Great Indian Earthquake along the coast of bordering countries of Bangladesh has augmented the demand for earthquake resistant designs for the vibration induced parameters of soil [1]-[2].For this reason accurate and proper soil investigation has become an essential concern to grasp precise knowledge about the underground soil condition. The PS suspension logging method directly measures and provides accurate and high-resolution shear (S) wave and compression (P) wave velocity profiles [3]. During an earthquake, the subsurface soil column acts like a filter with strain-dependent properties that can increase the duration and amplitude of shaking in a narrow frequency band related to the soil thickness, physical properties (P and S-wave velocities, densities), shape of the surface and subsurface boundaries [4].The spectral content (amplitude, period, and phase) and duration of earthquake recordings can therefore be significantly affected by local site conditions, especially at unconsolidated soil and sediment sites with a near-surface impedance contrast with underlying bedrock. The response of the ground is therefore of great importance for earthquake engineering. The response of soils to cyclic loading is controlled mostly by the mechanical properties of the soil. The most common types of dynamic loadings are, machine vibrations, seismic loading and cyclic transient loading, etc. The dynamic properties associated with these dynamic loadings are shear wave velocity (Vs), shear modulus (G), damping ratio (D), and Poisson's ratio (v), Young's Modulus (E) of soil [5].

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There are two aspects for safety against earthquake hazards: firstly, safety against potentially destructive dynamic forces and secondly, the safety of a site itself related with geotechnical phenomena such as amplification, land sliding and liquefaction [6]. Dynamic effects have been taken into consideration in design codes in many countries around the world to mitigate the risk from earthquakes. To ensure the safety of structures under earthquake loading, often using zoning maps based on geological assessments of seismic hazards which are embodied in building codes or regulations. The site safety during earthquakes is related to geotechnical phenomena such as amplification, land-sliding, mudflow and fault movements. For this study a 100ft borehole was prepared using Standard Penetration test and a 2.75in PVC pipe case was installed at Japanese Institute of Disaster Prevention and Urban Safety, BUET. After than the suspension PS Logging apparatus was used to measure the seismic wave velocities by downhole seismic method. Then using the compression wave velocity and shear wave velocity different dynamic soil properties were calculated and later using that shear wave velocity data, equivalent linear site response analysis of the soil was performed using the DEEPSOIL software.

II. HISTORY OF PS SUSPENSIONLOGGING

P-S suspension velocity logging was first developed in the mid-1970s to measure seismic shear-wave velocities in deep, uncased boreholes; it was originally used by researchers at the OYO Corporation of Japan [7]. It gained acceptance in Japan in the mid-1980s and was used for other velocity measurement methods to characterize earthquake site response. Public Works Research Institute (PWRI) has measured S-wave velocities in boreholes using the PS suspension logging tool since 1980. Since the early 1990s it has gained acceptance in the U.S., especially among earthquake engineering researchers [8].

III. METHODOLOGY FOR DOWNHOLE SEISMIC TEST

PS Logging test can be performed in two method- Downhole seismic and Uphole Seismic method. The downhole seismic test requires only 1 borehole (preferably a 3in diameter hole with PVC pipe installed up to the depth in which competent soil or rock is reached) to be used for the geophone receiver. Usually PVC pipes are used tostabilize the hole during the test to avoid soil from the side of the borehole to fall inside. The standard for the test technique is set forth in the ASTM D4428/D4428M. For the test, a wooden plank source is used.

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A 6in x 30in area approximately 10ft from the borehole is cleared off. 6in x 6in x 30in (or similar) wooden plank in the cleared off area is positioned and pinned down by driving a vehicle onto the plank so that one of the drive wheels is centered on the plank as shown below. The plank was extended farther beyond the outside diameter of the tire. The sensor is mounted on to the wooden plank. The plank is hit separately on both ends to generate shear wave energy in two different directions. It is also hit vertically in the downward vertical direction to generate vertically polarized compressional wave energy. The shear wave energy is polarized in the direction parallel to the plank as is the transverse component. The shear component is used to measure the shear wave energy. The vertical component is used to measure the vertically polarized compressional wave energy. Typically 3-5 records are taken for each type of wave – shear east going, shear west going and compressional vertical. According the "SYSTEM REFERENCE MANUAL 2007 - CROSSHOLE AND DOWNHOLE SEISMIC TEST [9], 8 records are taken for each wave type. In all, 3 different tests are performed at each depth for the 3 different wave polarizations collected; all depths are recorded together in one file. Figure 1 shows the field setup of the test.

Figure 1: Installation of PS Logging Equipment (Downhole seismic method) in field (Date of testing, 02/08/13)

From the calculated travel time of the compression and shear wave, the velocity was determined by dividing the distance of the source to receiver by the travel time. Both compression wave and shear wave velocity are determined in this method.

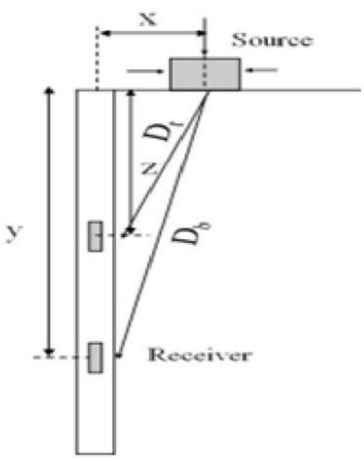


Figure 3: PS Logging test in Seismic Downhole method

Equations used,

$$D_t = \sqrt{(z^2 + x^2)} \quad \text{(i)}$$

$$D_b = \sqrt{(y^2 + x^2)} \quad \text{(ii)}$$

$$V_p = \frac{(D_b - D_t)}{(t_b - t_t)} \quad \text{(iii)}$$

Here,

D_t = Distance between top receiver to source

D_b = Distance between bottom receiver to source

t_t = Travel time of wave to top geophone

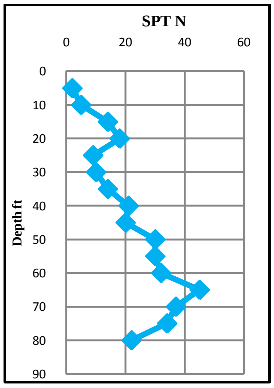
t_b = Travel time of wave to bottom geophone

The calculated compression and shear wave and also the SPT N values at different depth are shown in Table 1

Table 1: Calculated Compression (P) Wave Velocity and Shear (S) Wave Velocity and SPT N Value.

Depth ft	SPT N Value	P wave Velocity, ft/s	S wave Velocity, ft/s
6	2	1369	136
11	5	870	433
16	14	3168	758
21	18	2597	1316
26	9	2917	295
31	10	3034	1324
36	14	6276	1041
41	21	6421	1572
46	20	2175	656
51	30	6790	1366
56	30	3377	821
61	32	3218	533
66	45	3913	703
71	37	2298	731
76	34	3443	1286
81	22	2476	1339

The calculated compression and shear wave and also the SPT N values at different depth are shown at Figure 2.



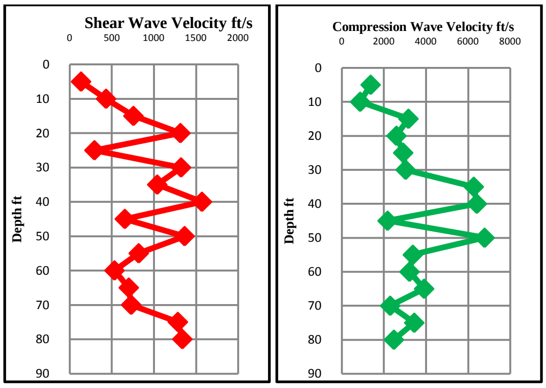


Figure 2: (a) SPT N Value (b) S Wave Velocity (c) P Wave Velocity

IV. DETERMINATION OF DIFFERENT DYNAMIC SOIL PROPERTIES

The equations for determining the dynamic properties are as follows,

$$G = \rho V_s^2 \qquad \text{(iv)}$$

$$M = \rho V_p^2 \qquad \text{(v)}$$

$$\nu = \frac{\left[0.5\left(\frac{V_p^2}{V_s^2}\right)-1\right]}{\left[\left(\frac{V_p^2}{V_s^2}\right)-1\right]} \qquad \text{(vi)}$$

$$E = 2G\,(1+\nu) \qquad \text{(vii)}$$

$$K = \frac{E}{3(1-2\nu)} \qquad \text{(viii)}$$

Here,

G = Shear Modulus
M = Constrained Modulus
ρ = Density
V_s = Shear Wave Velocity
V_p = Compression Wave Velocity
ν = Poisson's Ratio
E = Young's Modulus

Different Dynamic properties of the soil profile near BUET-JIDPUS, BUET, Dhaka was calculated from the Shear and compression wave velocity and is shown below in Table 2.

Table 2: Dynamic properties of soil at BUET-JIDPUS, BUET, Dhaka.

Depth ft	P Wave Velocity m/s	S Wave Velocity m/s	Density ρ	Shear Modulas G	Constrain Modulas M	Youngs Modulas E	Poissom's Ratio v	Bulk Modulas K
6	418	42	1.76	3109	307965	9296	0.49	303819
11	266	133	1.84	32595	130382	86921	0.33	86921
16	966	232	1.84	99181	1719523	291473	0.47	1587281
21	792	402	1.84	297787	1155857	790016	0.33	758808
26	890	91	1.76	14596	1396139	43634	0.49	1376678
31	925	404	1.76	287681	1508107	795231	0.38	1124532
36	1914	318	2.00	202544	7337528	601883	0.49	7067469
41	1958	480	2.00	461475	7678764	1354919	0.47	7063463
46	664	201	2.00	80920	883084	234598	0.45	775190
51	2071	417	2.00	348288	8590652	1030146	0.48	8126269
56	1030	251	2.00	126187	2124909	370593	0.47	1956660
61	982	163	2.00	53216	1931474	158140	0.49	1860520
66	1193	215	2.08	96289	2964696	285634	0.48	2836311
71	701	224	2.08	104519	1023612	301671	0.44	884253
76	1050	393	2.08	321725	2296560	912761	0.42	1867594
81	755	409	2.08	348454	1187389	900631	0.29	722784

V. EQUIVALENT LINEAR SITE RESPONSE ANALYSIS

Equivalent Linear Site amplification was performed using the DEEPSOIL. . In DEEPSOIL (Hashash, Y.M.A. et al., 2011), rock depth is assumed to be below the last layer, so to prevent erroneous results the last layer was assumed to be the same up to a depth of 100m. In this study, The Kobe Earthquake in south-central Japan on January 17, 1995 (Mb-7.2);The Imperial Valley earthquake in Mexico–United States border on October 15, 1979; The Northridge earthquake in the north-central San Fernando Valley region of Los Angeles, California on January 17 1994 (Mb-6.7) and The Kocaeli Earthquake at Kocaeli, Turkey on August 17, 1999(Mb-7.4) was selected as input motion for ground response analysis. All input motions were converted to Site class A, to be imposed on the bottom of the bed rock. The Spectral Acceleration Variation of the different input motions are shown in figure 3:

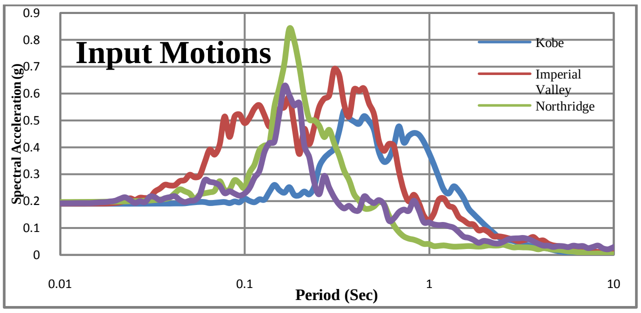


Figure 3: The Spectral Acceleration Variation of the different input motions.

Response Spectra

Response spectra of four earthquakes are shown in Figure 4. Among the four earthquakes, Imperial Valley earthquake produces highest (1.103g) peak spectral acceleration (PSA) for this site and Kocaeli earthquake produces lowest (0.609g) peak spectral acceleration (PSA). It is observed that initially soil surface response is more than input response for some earthquakes for this site. The comparison of PSA of the site soil for different input motions is shown in figure 5.

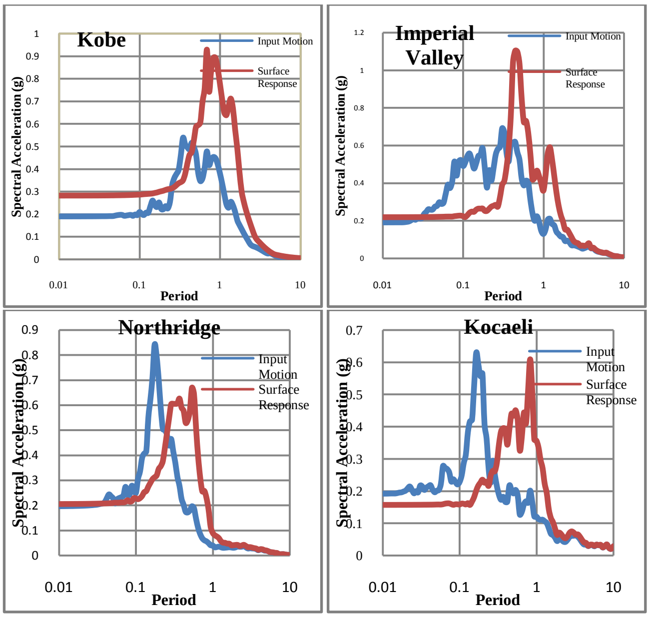


Figure 4: Response Spectra for the site JIDPUS, BUET

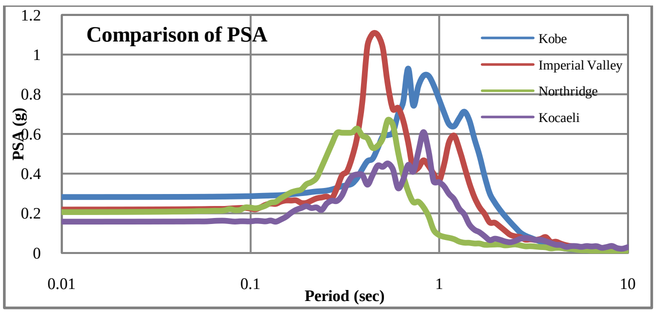


Figure 7: Comparison of PSA for different input Motion for the site JIDPUS, BUET.

Maximum Peak Ground Acceleration (PGA)

Maximum Peak Ground Acceleration (PGA) at different depths of four earthquakes for this site is shown in figure 8. PGA at surface and that at bedrock is obtained from the analysis. The peak ground acceleration values at surface are observed to be in the range of 0.157g (Kocaeli) to 0. 281g (Kobe) and that of the bedrock were observed to vary from 0.181g (Kobe) to 0.189 g (Northridge). The impedance in the acceleration values can be observed. Such as, a sudden rise within few meters can cause considerable damage to the sub and super structure resulting in huge loss.

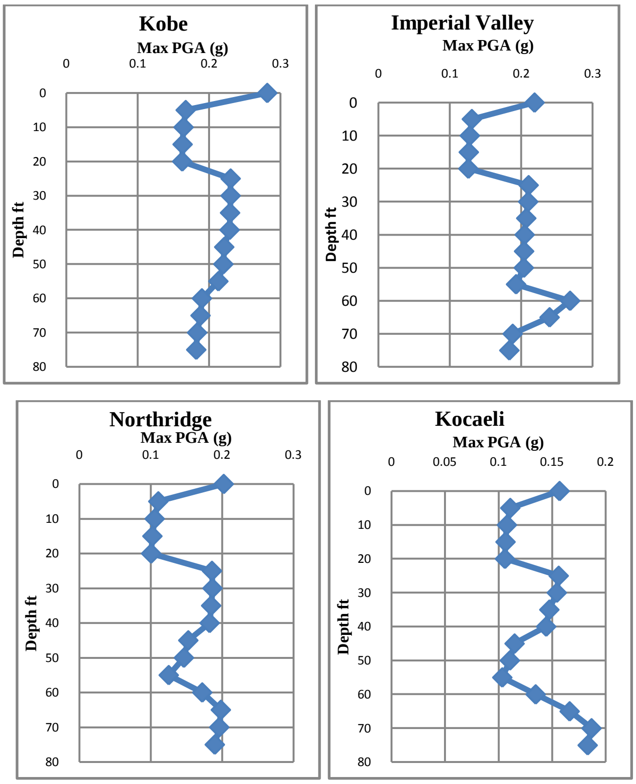


Figure 8: Maximum Peak Ground Acceleration for the site JIDPUS, BUET

Site amplification factors at sub surface layers are often used as one of the parameters for estimation of ground response. The amplification factor is the ratio of peak ground acceleration at surface to that of acceleration at hard rock. The amplification factors are determined as;

Amplification Factor = PGA recorded at ground surface / PGA recorded at hard rock

Amplification Factor (For Kobe earthquake) = 1.547

Amplification Factor (For Imperial Valley earthquake) = 1.192

Amplification Factor (For Northridge earthquake) = 1.066

Amplification Factor (For Kocaile earthquake) = 0.856

Hence, the amplification factors have also been computedand it has been identified that similar to the peak ground acceleration values, the variation is within 0.856 (Kocaile) to 1.547 (Kobe).

VI. CONCLUSION

Being a precise and accurate testing method for determining compressional and shear wave velocities the use of PS Suspension Logging Downhole Seismic test is getting its importance day by day among the researchers. With this research paper, the suspension PS Logging equipment was first used in Bangladesh University of Engineering and Technology (BUET).

The author tried hard to represent the use of Suspension Logging Downhole technique. But being less economical which requires skilled manpower may be the cause that it is not widely used in Bangladesh for research work. But considering its accurateness its demand is being felt nowadays. The different dynamic soil properties and the site amplification parameters may be used for creating seismic zoning mapsfor an effect of a definite earthquake motion over area. So using the test data the author calculatedthe dynamic properties of soil and performed the site response analysissoftware like DEEPSOILv5.1. From the equivalent linear analysis of DEEPSOIL, Imperial Valley earthquake produces highest (1.103g) peak spectral acceleration (PSA) for this site and Kocaeli earthquake produces lowest (0.609g) peak spectral acceleration (PSA). The peak ground acceleration values at surface are observed to be in the range of 0.157g (Kocaeli) to 0. 281g (Kobe) and that of the bedrock were observed to vary from 0.181g (Kobe) to 0.189 g (Northridge).

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