DYNAMIC CHARACTERISTICS OF ALLUVIAL DEPOSITS – A CASE STUDY

Sanjay Gupta
Ravi Sundaram
Anurag Goyal
Cengrs Geotechnica Pvt. Ltd, New Delhi
cengrs@vsnl.com

ABSTRACT: The dynamic behavior of alluvial deposits of the Indo-Gangetic Alluvium depends primarily on the soil type, density and compactness. The paper presents results of cross-hole seismic tests and seismic refraction tests conducted at a power plant site in Haryana. The borehole and static cone penetration test data have been correlated to the P-wave and S-wave velocities to generate a geophysical model of the site conditions. From the test results, a four-layer model has been established for the project site.

1. INTRODUCTION

The project site is in Yamunanagar, Haryana on the banks of the River Yamuna. Geotechnical investigations for the power plant included several boreholes, static cone penetration tests, plate load tests, seismic refraction tests, cross-hole seismic tests, etc.

For design of power plant, the dynamic characteristics of the soils play an important role. Of the various techniques available, cross-hole seismic tests and seismic refraction tests give reliable and consistent results and are superior to conventional block vibration tests. These tests are now being increasingly done as a part of geotechnical investigation for dynamically loaded structures.

2. GENERAL SITE CONDITIONS

2.1 Regional Geology

The Indo-Gangetic alluvial tract (Krishnan, 1981) is in the nature of a synclinal basin formed concomitantly with the elevation of the Himalayas to its north.

The older alluvium is dark coloured (called "Bhanger" – age Middle to Upper Pleistocene) and is generally, rich in concretions / calcium carbonate nodules (kankars).

The newer alluvium (called "Khadar" – age Upper Pleistocene to Recent) is light coloured and contains lenticular beds of sand and gravel.

2.2 Site Stratigraphy

Based on several boreholes drilled, stiff clayey silt with N-value of 8-10 is met at ground level, which extends to about 2~3 m depth. Fine sand is then encountered to 7 to 8 m depth (N=15 to 30). Below this, a layer of compact sand with pebbles/cobbles is met to 12.0~14.0 m depth. In this layer, SPT values range from 50 to 100+. Below this, hard clayey silt is met to 18.0 ~ 20.0 m depth, which is underlain by dense sand to final explored depth of up to 40 m. Groundwater is encountered at 2.0 - 3.5 m depth.

Profiles of typical boreholes in the Power House block showing the distribution of the strata and field N-values are presented on Fig.1. Typical results of static cone penetration test is shown on Fig. 2

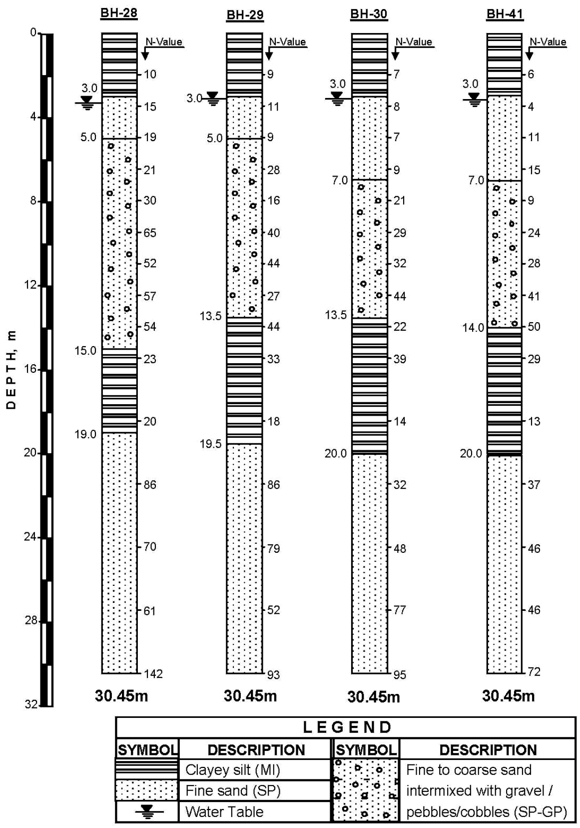

Fig. 1 Borehole Data

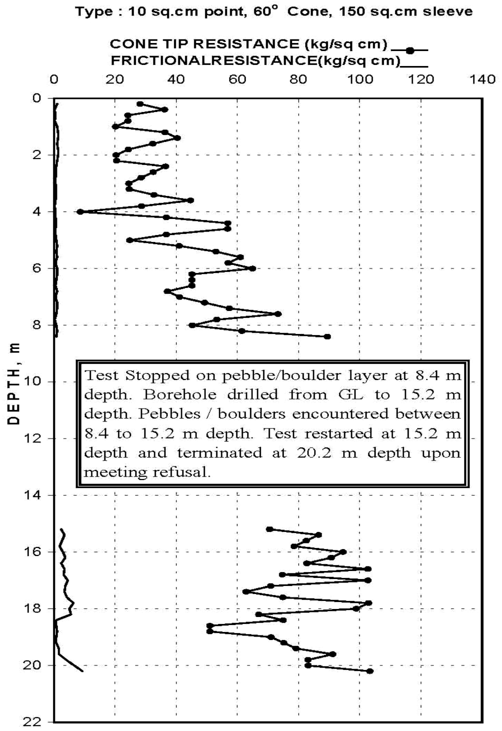

Fig. 2 Typical Static Cone Penetration Test Results

3. FIELD TESTS

3.1 Testing Plan

To generate data regarding the dynamic response of the soils, a combination of seismic refraction tests and cross-hole seismic tests were adopted. Seismic refraction tests were done on the ground surface along selected lines to give a generalized global assessment of wave velocities. Cross-hole seismic tests were done in boreholes and give specific localized profile with depth.

At the project site, seismic refraction tests were conducted along five lines. Also, six cross-hole seismic tests were done at the location of various dynamically loaded facilities such as the turbo-generators, mill building and crusher house.

3.2 Seismic Refraction Tests

For the seismic refraction survey work, a 5-kg sledgehammer was struck vertically on a steel plate to generate P-wave. Elastic wave are generated at a point at or near the ground surface as illustrated on Fig. 3.

The times of arrival of the seismic energy that has traveled along discontinuous or interfaces between surface layers and refracted back to the surface is recorded at several points (24 Nos.).

Fig. 3 Seismic Energy by Hammer Impact

Low frequency (10Hz) spike geophones were used to record seismic signals. The travel times of these elastic waves are detected by series of geophones, placed in line into the ground and connected to the seismograph, via the geophone cable. A 24-channel signal enhancement seismograph was used to conduct the test. In general, the spacing between the geophone was kept as 5 m. Fig 4 shows the data acquisition system.

3.3 Cross-Hole Seismic Tests

The cross hole seismic test consists of generation of horizontally traveling P and S waves at a particular level in a source borehole and recording their arrivals at same level in one or two nearby receiver boreholes. Two receiving holes are used for timing accuracy when true zero time cannot be measured.

To conduct this test, one source borehole and two receiver boreholes were drilled along a line to 25 m depth. Fig 5 presents a schematic of the test.

The test was conducted at depth intervals of 1.5 m. The standard SPT hammer (63.5 kg) was used to generate the impact See Fig. 6.

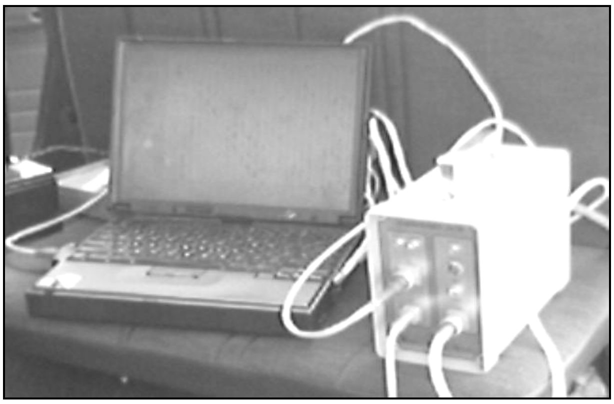

Fig. 4 The Recording System: Seisomograph & Laptop

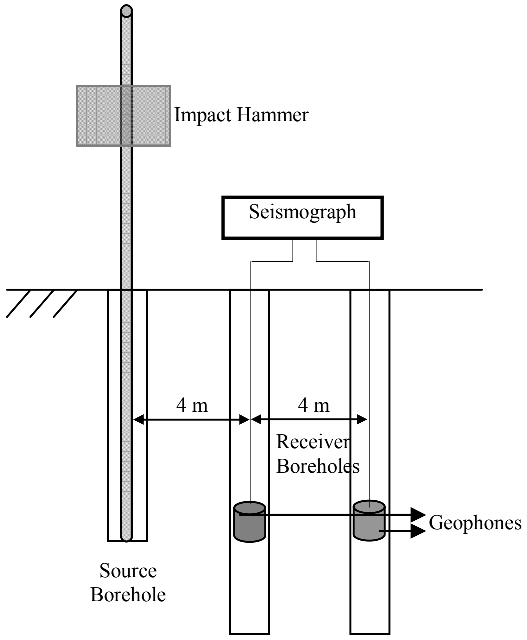

Fig. 5 Schematic of Cross-Hole Seismic Test

The geophones were placed in the receiver boreholes at the same level at which the impact was created. The geophones were kept in place in the borehole using an inflatable bladder. A photograph of the geophone is shown on Fig. 7.

The receiver boreholes were drilled prior to start of the test. To keep the hole open, PVC casing was placed and cement grouted to ensure contact with the soil. The source borehole was advanced as the test progressed.

Fig. 6 SPT Hammer as Energy Source

4. TEST RESULTS

The tests have been analyzed in detail to develop a geophysical model of the area. From the test results, a four-layer model has been established. as described below:

Fig. 7 Geophone with Inflatable Bladder

- The first layer (2-4 m) consists of clayey silt has P-wave velocity of the order of 300 to 600 m/sec.
- The second layer (fine sand) extends to a depth of 6~8 m has P-wave velocity of about 800-900 m/sec.
- The third layer, sand with pebbles and cobbles, has P-wave velocity of 1600-1800 m/sec extends to 12-15 m depth.
- The last layer of the model has a P-wave velocity in the range of 2100-2600 m/sec. Comparing with borehole data, this layer consists of an upper hard clayey silt deposit to about 20 m depth and dense sand below. Since the wave velocities in both these layers are comparable, the geophysical test does not distinguish between these layers.

Table 1 summarizes the lithology and dynamic parameters as interpreted from the tests. From the P-wave and S-wave velocities, dynamic shear modulus, Young's modulus and Poisson's ratio have been calculated.

Fig 8 presents the velocity model as developed from one typical seismic refraction line in the Power House area. This illustration shows the lateral variation in the depth of occurrence of the four layers.

Typical results of one cross-hole seismic test in the Power House are presented on Fig 9. It presents the variation of the wave velocities with depth at the test location.

The test results were compared with published correlations as given below:

$V_s\ (m/sec) = 91\ N^{0.337}$ (Imai, 1977)
$G\ (MPa) = 12\ N^{0.8}$ (Ohasaki & Iwasaki-Ref Swami Saran, 1999)
where N = Observed SPT value.

Layer 1 N = 9 V_s = 191 m/sec G = 70 MPa
Layer 2 N = 25 V_s = 270 m/sec G =158 MPa
Layer 3 N = 200 V_s = 543 m/sec G = 831 MPa
Layer 4 N = 75 V_s = 390 m/sec G = 380 MPa

The values of V_s and G are based on the N-value correlations as given above.

Table 1. Test Results Obtained From the Seismic Tests correlated to the Lithology

Depth, m		P-wave velocity, V_p, m/sec		Shear wave velocity, V_s, m/sec		Field N-Value	Cone Tip Resistance (q_c), kg/cm^2	Lithology	Design V_p, m/sec	Design V_s, m/sec	Poisson's ratio	Dynamic Young's Modulus, MPa	Dynamic shear Modulus, MPa
From	To	SRT	CHST	SRT	CHST								
0	3	300 - 600	300 - 600	120-250	105-230	8-10	10-20	Clayey silt	450	180	0.40	165	59
3	8	800 - 900	600-1000	400-450	275-450	15-30	40-60	Fine sand	710	350	0.33	595	224
8	13	1600 - 1800	1400-2000	850-1000	700-975	50-100+	Refusal	Pebbles/ Cobbles with sand	1650	850	0.30	3741	1439
> 13		2100 - 2600	2000-2500	1050-1300	900-1100	50+	>100	Hard clayey silt/ compact sand	2000	1000	0.34	5198	1939

The V_s and G computed from N-value correlations show reasonable agreement with the corresponding values in Table 1 where N≤ 30. In hard/dense soils, the N-value correlations underestimate V_s and G.

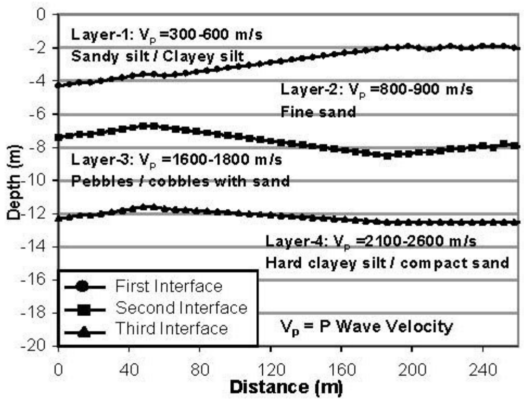

Fig. 8 Stratigraphy and wave velocities from seismic refraction test

5. CLOSURE

Cross-hole test and seismic refraction test can provide useful results for design of dynamically loaded foundations. The quality of data from these tests is superior in comparison to block vibration tests. Since the tests give profile of dynamic soil properties with depth, it is a more realistic assessment of the soil behavior. In conjunction with borehole data, the results have been successfully used for the power plant under construction in Indo-Gangetic alluvium.

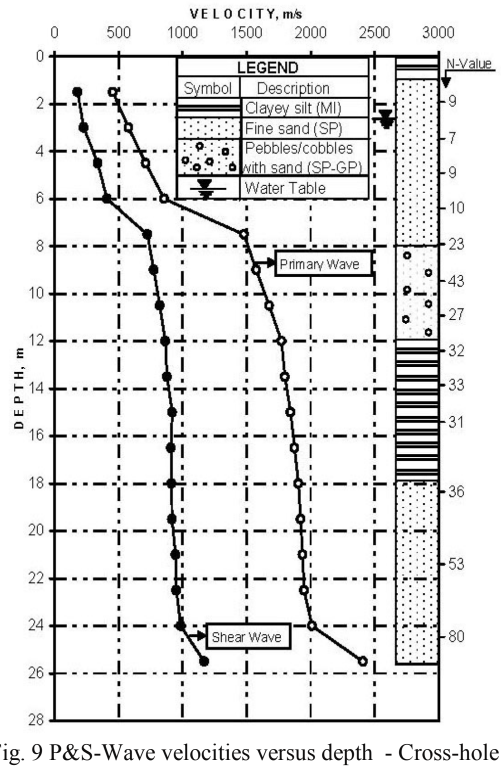

Fig. 9 P&S-Wave velocities versus depth - Cross-hole Test (Typical)

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