Evaluation of dynamic properties of site and Response of Motion Simulator Foundation

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Abstract

Geotechnical parameters such as shear wave velocity and shear modulus are very important parameters in ground response analysis. The dynamic properties of foundation material below the three axes motion simulator are evaluated using the Block vibration test, Multichannel Analysis of Surface Waves (MASW) and a seismograph. This paper presents the measurements of dynamic properties using Block vibration test and MASW. Paper also present the response of foundation material due to local site condition using SHAKE2000 and vibration measurements for a passive source. Vibration characteristics of foundation material have been monitored by a seismograph with tri-axial sensors to measure the peak particle velocity in all the three directions from the passive sources such as generator, pump house and industrial Buildings which are located at about 70m to 200m from the proposed motion simulator.

Keywords: Shear wave velocity, site effects, MASW, Shake and Isolation.

1 Introduction

Dynamic soil properties are very important for dynamic analysis and seismic response of important structures and sensitive machineries. Three axes motion simulator allow simultaneous attitude simulation in three degrees of freedom. Seismic response of the foundation and earthquake resistant design plays on important role in functioning of the system. In this paper measurement of dynamic properties of foundation materials using block vibration tests and MASW for the design of foundation of the three axes motion simulator have been discussed. Evaluation of response of motion simulator foundation due to the influence of nearby machinery is evaluated using vibration-monitoring system. Further the response spectrum for the site has been developed using the synthetic ground motion with measured dynamic soil properties.

2 Site Description

The proposed site is shown in Figure 1. Figure 1 also shows the location of other existing machines such as pump house, A/C Plant and generator room. The identified site was made up of filled up ground (debris) up to a depth of about 1.0 m above the existing ground level. The identified site is fairly flat. Detailed geotechnical investigation by drilling boreholes in the site has been carried out with boreholes at five locations in the site. Except north western part of the site, in all the other four boreholes hard rock is met at about 2m from the existing ground level. No ground water table is met in the site at the time of investigation (Jan 2006). The depth of investigation was up to a depth of 4.5m as hard rock is met at in all the locations. For Block vibration test pit has been excavated up to the proposed foundation level of 1.7m and concrete block has been constructed (for the location of pit see Figure 1) as per Indian code IS 5249:1992. MASW testing has been carried out along 3 alignments covering the total area of the site. Vibration test has been carried at 4 locations with different neighbouring machines under running conditions. The locations of theses testing points are shown in Figure 1.

3 Field Testing

Block vibration test has been used to evaluate dynamic properties of foundation soil system based on the test carried out with a foundation block size (1.5mx0.75mx0.70m) as per IS standard. Natural frequency of the system defined as number of cycles per unit time with which the system oscillates under the influence of forces inherent in the system. MASW is a geophysical method, which generates a shear-wave velocity (Vs) profile (i.e., Vs versus depth) by analysing Raleigh-type surface waves on a Multichannel record. Peak particle velocity (PPV) and frequency of vibrations has been measured to examine the influence of the vibration caused due to running of the existing machineries adjacent to the site of the proposed three axes motion simulator site using seismograph with triaxial sensors.

3.1 Block Vibration Test

The test was conducted in accordance with IS 5249:1992 (Indian Standard on dynamic properties of soil). The excavation was made up to the proposed foundation level (at about 1.7m below the existing ground level). Bedrock was visible in the excavated pit. A plain cement concrete block (M15) of size 1.5mx0.75mx0.70m is cast and cured and vibration test was conducted at the site. Mechanical oscillator was used to impart vertical dynamic harmonic force.

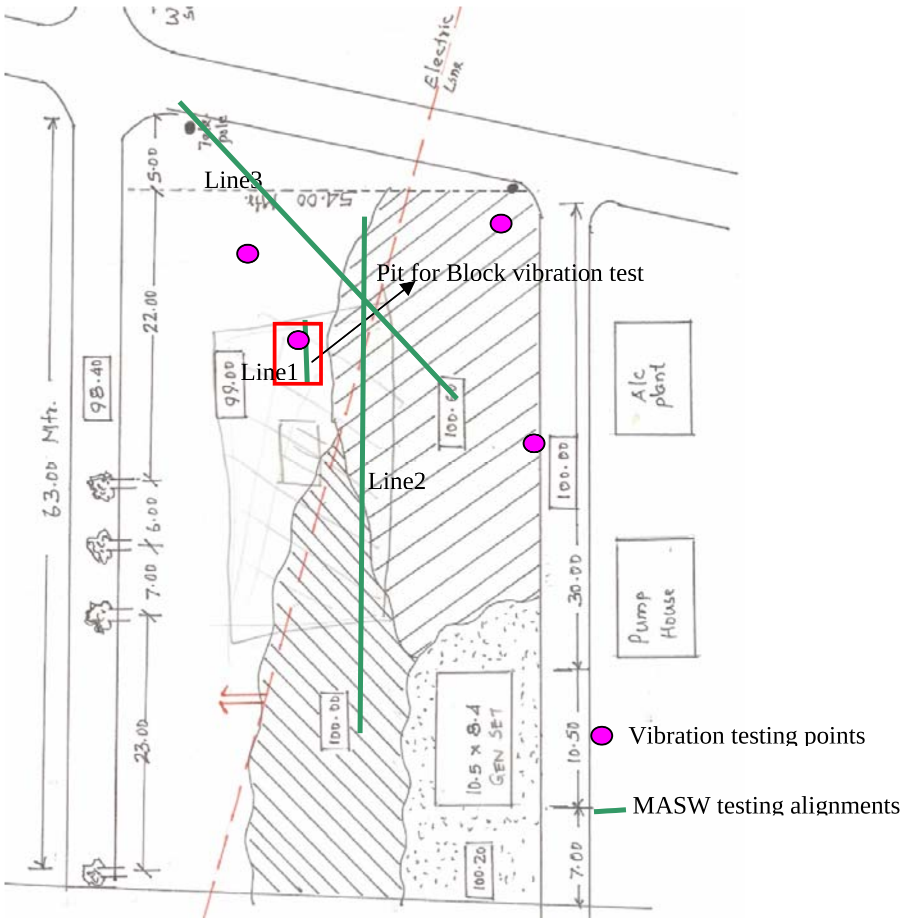

Figure 1.   Site plan with testing locations

The oscillator was connected to an electrical motor by means of a flexible shaft. The rotational speed of the motor was varied by varying the input voltage to the motor with the help of the speed control unit. Vibration meter was used for measuring the vibration response in terms of amplitudes. An electronic digital Tachometer was used to measure frequency of the oscillator. The frequency - amplitude response is obtained and it is shown in Figure 2. Based on the frequency - amplitude test results, resonance frequency and amplitude of the block are determined. Considering the dimensions of the proposed foundation and the frequency of the simulator in three directions, the dynamic properties are estimated and they are as follows:

Coefficient of elastic uniform compression = 1.93 x104 kN/m^3

Coefficient of elastic uniform shear = 1.93 x104 kN/m^3

Coefficient of elastic uniform non-uniform compression = 3.35 x104 kN/m^3
Coefficient of elastic non-uniform shear = 1.45 x104 kN/m^3
Shear modulus of foundation soil system=3.93 x104 kN/m^2

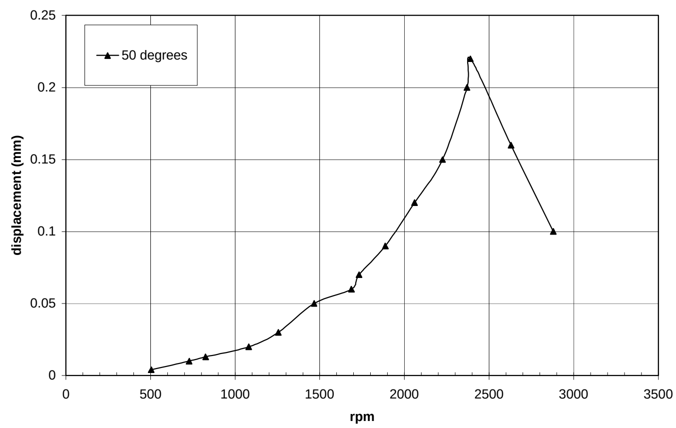

Figure 2. Frequency and displacement response of test foundation.

Natural frequency of the soil foundation system is estimated considering that the unbalanced force is 20% of the total weight of the foundation and simulator. It is found that natural frequency of the foundation is 14.5 Hertz (870 rpm) and the maximum speed of the simulator is 134 rpm and the frequency ratio is 0.15 (134/870), which is less than the recommended value of 0.5. And also the amplitude is about 0.02mm, which is less than 0.25mm. These values are with in the permissible limit.

3.2 Geophysical Investigations

MASW is a geophysical method, which generates a shear-wave velocity (Vs) profile (i.e., Vs versus depth) by analyzing Raleigh-type surface waves on a multichannel record. MASW has been effectively used for identification of subsurface information and shear wave velocity measurements with higher signal-to-noise ratio (S/N) of surface waves. In the recent past, MASW tests have been effectively used for mapping 2-D bedrock surface and shear properties of overburden materials (Miller et al., 1999a), to identify weak spots (Miller et al., 1999b), Poisson’s ratio distribution (Ivanov et al., 2000a), generation of shear-wave velocity (Vs) profiles (Xia et al., 2000), detection of voids (Park et al., 1998), seismic evaluation of pavements (Ryden et al., 2001; Park et al., 2001a; 2001b), seismic characterization of sea-bottom sediments (Park et al., 2000; Ivanov et al., 2000b) and dynamic properties evaluation and site response studies (Anbazhagan et al 2007; Anbazhagan and Sitharam, 2006). MASW system used for this investigation consists of 24 channels Geode seismograph with 24 geophones of 4.5 Hz capacities. The seismic waves are created by impulsive source using a sledge hammer of 10 pounds on with 1'x1' size hammer plate ten shots are given using sledge hammer, these waves are captured by geophones/receivers. The captured Rayleigh wave is further analyzed using SurfSeis software. SurfSeis is designed to generate Vs data (either in 1-D or 2-D format) using a simple three-step procedure: i) preparation of a Multichannel record (some times called a shot gather or a field file), ii) dispersion-curve analysis, and iii) inversion. 1-D MASW test has been carried out close to 3 borehole locations (see figure 1, line 1 to 3) with 15 recording points. The optimum field parameters recommended by Park et al (1999) (source to first and last receiver, receiver spacing and spread length of survey line) are selected in such a way that required depth of information could be obtained. All the testing has been carryout with geophone interval of 0.5 to 1m and source to first and last receiver is varied from 5m, 10m and15m. A dispersion curve is generally displayed as a function of phase velocity versus frequency. Phase velocity can be calculated from the linear slope of each component on the swept-frequency record. The lowest analyzable frequency in this dispersion curve is around 10 Hz and highest frequency of 50Hz has been considered. A Vs profile has been calculated using an iterative inversion process that requires the dispersion curve developed earlier as input. A least-squares approach allows automation of the process (Xia et al., 1999) as inbuilt in SurfSeis. Vs have been updated after completion of each iteration with parameters such as Poisson's ratio, density,

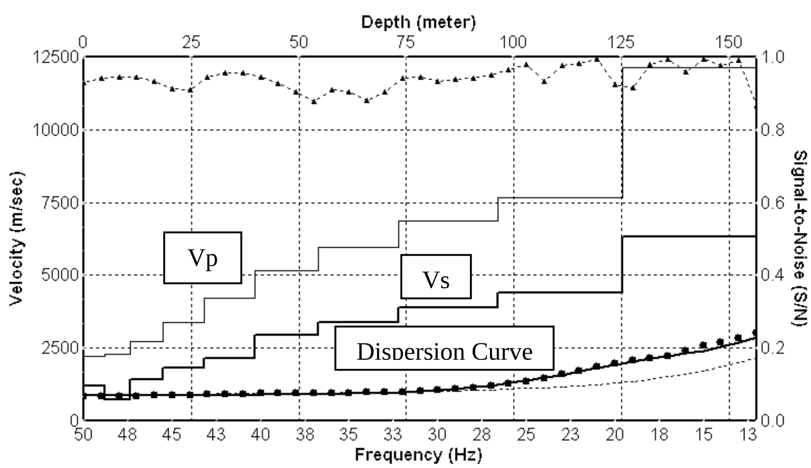

Figure 3. Typical Vs and Vp Plot with Dispersion Curve for Line 1.

and thickness of the model remaining unchanged. An initial earth model is specified to begin the iterative inversion process. The earth model consists of velocity (P-wave and S-wave velocity), density, and thickness parameters. Typical 1D Vs and Vp profile with dispersion curve is shown in Figure 3 for the line 1. The shear wave velocity values obtained from each survey line for the different layers fall within the recommendations of NEHRP "Vs"- soil classification of site categories (Martin, 1994) and IBC code site classification (IBC-2000). The shear wave velocity as obtained from the MASW test has been used to evaluate shear modulus for site, which is shown in Table 1 for line 1.

Table 1: Dynamic properties of soil layers with depth
Using MASW system for line 1 (Parallel to Vibration Block)

Depth (m) from GL	Vs m/sec	Density g/cc	Shear Modulus MN/m^2	Poisson Ratio	Young's Modulus MN/m^2
1.7-10	700	2.00	980	0.2	2352
10-18.4	1150	2.0	2645	0.2	6348
18.4-27.5	1850	2.00	6845	0.2	16428
>27.5	2100	2.00	8820	0.2	21168

3.3 Evaluation of peak particle velocity and frequency of vibration

The proposed site boundary is close to the existing power house, pump house and A/C plant and the approximate distances from the proposed site boundary are given in Table 2. The peak particle velocity (PPV) and frequency of vibrations were measured at the site by running the machines of power house, pump house and A/C plant. The vibration measurements were done to examine the influence of the vibration caused due to running of the existing machineries adjacent to the site of proposed three axes motion simulator.

A seismograph monitored vibration characteristics with triaxial sensors to measure the PPV in all the three directions. Different vibration characteristics measured by seismograph include, PPV, frequency and air overpressure. The distance between seismograph and the nearest major source of vibration was ranging from 0.5m to 9 m as indicated in Table 2. Vibration measurement was conducted with different combination of sources viz. only one source, two sources and all the three sources under running conditions. The vibration parameters measured for different distances are given in Table 2 for various combinations of sources. The vibration levels recorded with all the combinations was ranging from 0.13 to 0.25 mm/s.

Table 2. Machine induced vibration data and related parameters

Event No	Depth of monitoring	Machines running	Distance	PPV	Frequency	Air over pressure
			m	mm/s	Hz	dB(L)
1	Surface	Power House (300 hp)	4.3	0.13	<5 Hz	105 dB
2	Surface	Power House (300 hp)	4.3	0.13	<5 Hz	106 dB
3	Surface	Power House (300 hp)	1.0	0.25	<5 Hz	109 dB
4	Surface	Power House (300 hp)	0.5	0.25	10 Hz	110 dB
5	Surface	Power House (300 hp) & Pump house (30 hp)	4.3	0.13	<5 Hz	104 dB
6	Surface	Power House (300 hp) & Pump house (30 hp)	9.1	0.13	<5 Hz	105 dB
7	Surface	Power House (300 hp) & Pump house (30 hp)	16	0.13	<5 Hz	111 dB
8	Surface	Power House (300 hp), Pump house (30 hp)& A/C plant	16	0.13	<5 Hz	107 dB
9	Surface	Power House (300 hp), Pump house (30 hp)& A/C plant	9.1	0.13	<5 Hz	105 dB
10	Surface	Power House (300 hp), Pump house (30 hp)& A/C plant	4.3	0.25	<5 Hz	105 dB
11	Surface	Power House (300 hp), Pump house (30 hp)& A/C plant	4.3	0.25	<5 Hz	106 dB
12	One feet from surface	Power House (300 hp), Pump house (30 hp)& A/C plant	4.3	0.13	<5 Hz	105 dB
13	One feet from surface	Power House (300 hp), Pump house (30 hp)& A/C plant	4.3	0.13	<5 Hz	105 dB
14	One feet from surface	Power House (300 hp), Pump house (30 hp)& A/C plant	3.1	0.13	<5 Hz	106 dB
15	Surface	Power House (300 hp), Pump house (30 hp)& A/C plant	1.0	0.25	<5 Hz	108 dB
16	Surface	Power House (300 hp), Pump house (30 hp)& A/C plant	0.5	0.25	<5 Hz	109 dB

4 Ground Response Analysis

Even though the proposed foundation are at about 1.7m from the existing ground level with a very little soil overburden, the site-specific response study has been carried out to develop the response spectrum for the foundation design of three axes motion simulator as per the requirement of the agency. For the response studies the synthetic ground motion developed by Sitharam and Anbazhagan (2007), Sitharam et al (2006) along with MASW shear wave velocities (Anbazhagan et al 2007) have been used. The response spectrum obtained using SHAKE2000 for the site is shown in Figure 5. Figure 5 shows the response spectrum for site using synthetic ground motion as input. The shape of the ground level spectrum is similar to the rock level but the amplitude of spectral acceleration increased.

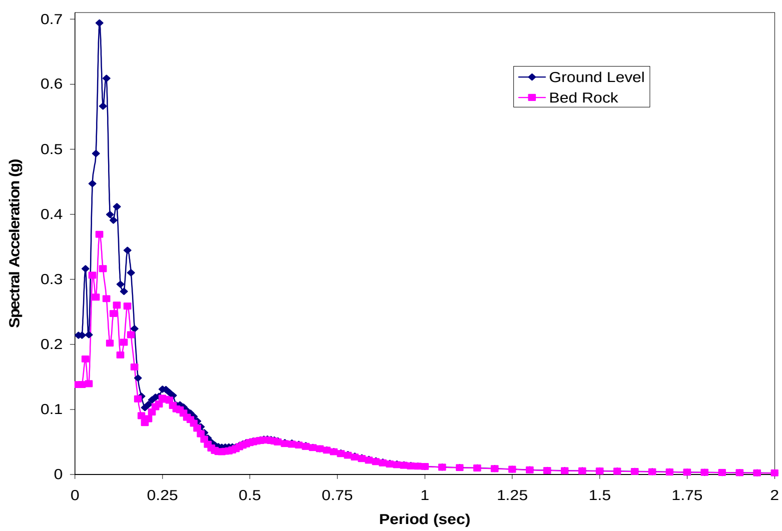

Figure 4. Response spectrum for site

5 Summary

The proposed site is suitable for establishing 3-axes motion simulator. The natural frequency of the foundation measured using block vibration test is well with in the permissible limits. The vibration levels recorded with all the combinations of different machines (A/C Plant, pump house, power house) operating close to the proposed 3-axes motion simulator was ranging from 0.13 to 0.25 mm/s. The vibration levels recorded indicate that the PPV induced by machines is below the human perceptible limit of 0.25 mm/s. The PPV recorded is not hazardous to the proposed three axes motion simulator. The dynamic properties measured using MASW test and site response studies using SHAKE shows that the site material having character of transforming the surface/ body waves vibrations with out amplification.

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