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Geophysical Probing in Geotechnical Investigation for Shear Wave Velocity Assessment

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INFORMATION

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ABSTRACT

In near surface geology attenuation and shear wave velocity are main factors in field of earthquake engineering to determine the characteristics of soil and subsurface material. Before construction geotechnical and geophysical tools were used to find the characteristics of subsurface. In this study, a single bore was drilled up to 50 m depth at site for material assessment and water table measurement. Silty clayey and clayey silt material was found at several depths. Downhole seismic survey was conducted on this single bore whole having dia 12 inches. On the basis of this geophysical tool, four layers were marked. The shear wave velocity increases with depth at 7 m is 250 m/s and compression wave are 430 m/s due to increase depth compressional wave increases up to 1750 m/s and having same rate at 50 m depth of borehole. This means under subsurface water is main carriers of the P wave at constant velocity. Whereas shear wave velocity regularly increases from 250 m/sec to 550 m/sec at 50 m. The rapidly increase of shear waves velocity indicates better compacted soil at depth which is good for foundation designing as well as earthing system.

1. Introduction

The combination of geophysical data and geotechnical measurements may greatly improve the quality of buildings under construction in civil engineering (Soupios et al., 2005; Soupios et al., 2007). In the last decade, the involvement of geophysics and geotechnical methods in civil engineering has become a promising approach (Adepelumi et al., 2000; Akintorinwa et al., 2009). Geotechnical and geological model develop a relation that solves the many engineering problems (Rahiman, 2013). The role of sub surface investigation in construction in many areas of Saudi Arabia is increasingly with time and progress made large activities as in the eastern part of Saudi Arabia where many subsidence and settlements have been observed during the construction (Edgell, 1990).

In the view of increasing role of geophysical methods in the geotechnical site characterization, many authors recommended the use of in-hole geophysical methods when assessing, both in field and in laboratory, the parameters depicting the soil state and its stiffness at small strain. This stiffness seeks to focus the awareness to seismic transversal (S) and longitudinal (P) body waves generated both in field, during in-hole tests, and in laboratory using piezocristals (Jamiolkowski, 2012). During study following issues are discussed:

- ✓ Stiffness at very small strain as obtainable from the S and P velocities.
- ✓ Evaluation of undisturbed samples quality based on the comparison of S-waves velocities measured in field and in laboratory respectively.
- ✓ S-wave based evaluation of the coarse-grained soils susceptibility to cyclic liquefaction.

Using downhole method physical properties such as density, porosity, thickness, orientation, and lithological identification of soil and rock surrounding the borehole characteristics may be determined. These non-destructive in situ physical measurements of the soil, rock and fluids are collectively known as geophysical logging (Patrick, 1990; Sebastiano, 2012). The seismic refraction method is one of the most used methods in engineering applications to obtain the elastic properties of subsurface layers (Grant et al., 1965). The evolution of a simplified procedure for evaluating the liquefaction potential of sand deposits using data obtained from standard penetration tests is reviewed (Seed et al., 1983; Olorunfemi and Meshida, 1987).

Down hole seismic survey is very low priced, easily transported and simple procedure for any site. The downhole seismic survey has one borehole to proceed the whole experiment. Seismic source will be used as energy generator to produce the seismic waves (P waves and S waves) from a fixed distance on the flat surface of the borehole. A single clamp triaxial geophone slowly goes down in the hole. All the waves of first arrival measured and examine with the equal interval by a sting attached geophones. After combining the arrival time of both P and S waves to find the travel time versus depth curves for single hole. This is also useful for determine the velocities and the elastic moduli of the different stratification. Near surface velocity depth function graph can be determined easily by shear wave assessment utilizing the seismic downhole seismic survey. (Hunter et al., 2002).

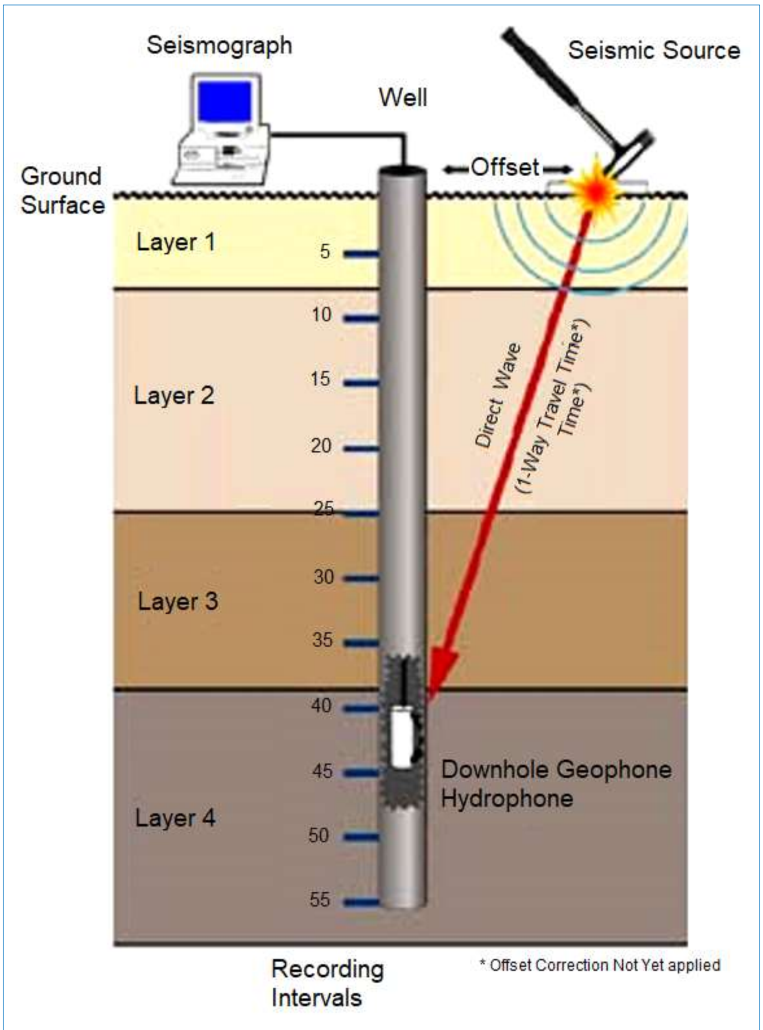

Fig. 1. Cross sectional view of downhole seismic survey and experimental procedure (Geo-vision geophysical services)

Downhole seismic velocity logging is a very useful method for measuring seismic wave velocity. This method has been used more than 50 years ago. Seismic downhole survey based on a surface source to spawn P-waves and S-waves that travel down through the soil or rock layers where they are measured and recorded by a sensor which is protected in a borehole shown in Fig 1. Travel time is measured using a trigger at the surface and a digital seismograph recording as an output.

P-wave energy is normally provided by a hammer and plate or weight drop similar to shallow seismic reflection and refraction profiling surveys. Polarized S-waves are generated using a shear wave hammer. This comprises two hammers connected to either end of a plank that is held to the ground using a vehicle or heavy weight. Collecting both positive and negative polarized (so called A and B). For S-waves two separate hammers used which enables the S-wave arrivals on the receiver shot records to be distinguished from those of P-waves and coherent noise (Oyedele et al., 2011).

In engineering seismology downhole seismic for shear wave velocity and attenuation in near surface assessment of material is direct estimation of material analysis (Parolai et al., 2010). For dynamic soil-structure interaction problems involving large strains, such as earthquake shaking, low-amplitude dynamic properties form the starting points in these analyses as well as giving valuable reference levels. Low-amplitude shear modules are obtained at a site by performing field and/or laboratory measurements to obtain profiles of shear wave velocity. Shear modulus is then calculated for each material once the in-situ density has been determined using the formula in Eq. 1.

$$Vs = \sqrt{\frac{G}{\rho}} \tag{1}$$

where; ρ is density of the soil, Vs is shear wave velocity and G is shear modulus, respectively.

Shear wave velocities are obtained in the field by performing seismic tests such as cross hole and down hole surveys. Shear wave velocities and shear moduli are also obtained in the laboratory by performing dynamic tests such as resonant column, cyclic simple shear, cyclic triaxial shear and cyclic torsional shear. However, the most representative values of low-amplitude dynamic properties are obtained with in-situ tests. Compressional wave velocities are also obtained by these surveys from which other elastic moduli are also obtained. This research will enable us to prevent the assets and lives from natural hazards or disasters. The purpose of this research is to evaluate the subsurface material and fault detection as well as any seismic activity in this vicinity through geotechnical and geophysical techniques.

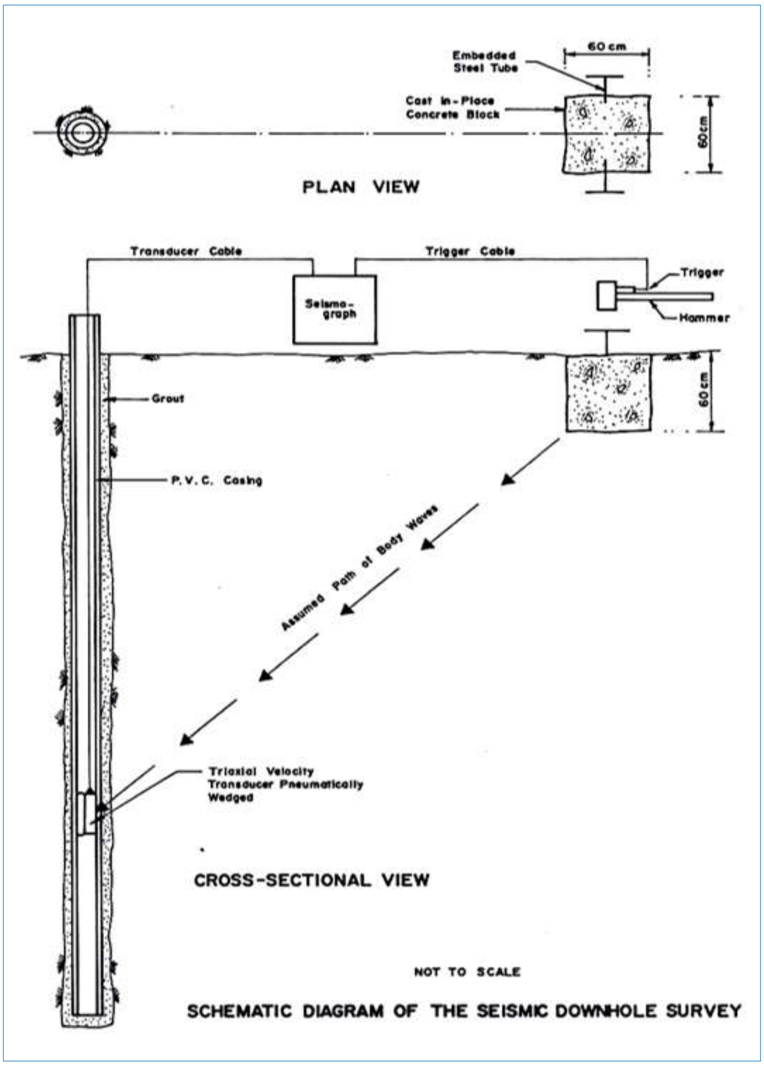

Fig. 2. Schematic diagram for downhole seismic survey

2. Method

The standard SPT test ASTM 1586 (2011) was used for drilling the bore hole at depth of 50 m. Make profile and mark the water table. The site area is underlain by alluvial deposits consisting mainly of fine to medium grained material deposited. The surface material is stiff clayey silt. In the borehole (BH-01) drilled at the site, stiff clayey silt was encounter up to about 11m depth. From 11 to 14 m depth, medium dense silt sand is present. Below 14 m depth, dense to very dense fine sand was encountered up to 50 m which is the maximum depth of the borehole. Water table was encountered at a depth of about 4.4 m below natural ground level. Seismic waves velocities are calculated from the corresponding travel times once the travel distance has been determined. Schematic diagram of downhole seismic survey is shown in Fig. 2.

There several techniques to explore subsurface material but in geophysical exploration seismic downhole survey is one of the main nondestructive testing NDT in which easily explore the subsurface material in the form sound waves (Abomohanran, 2013).

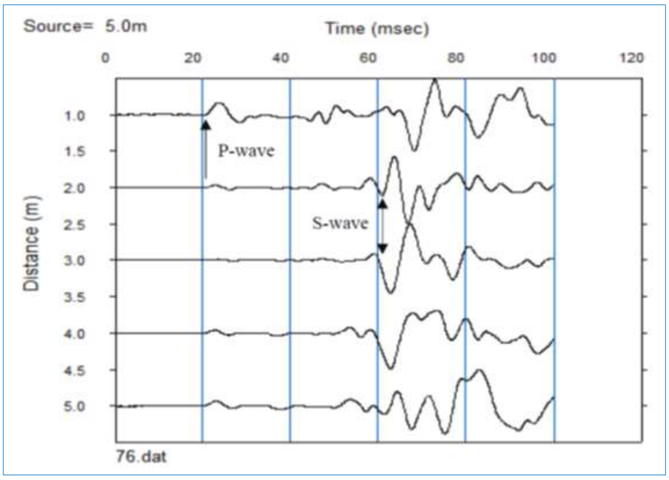

Fig. 3a. Typical seismic record 15-m depth

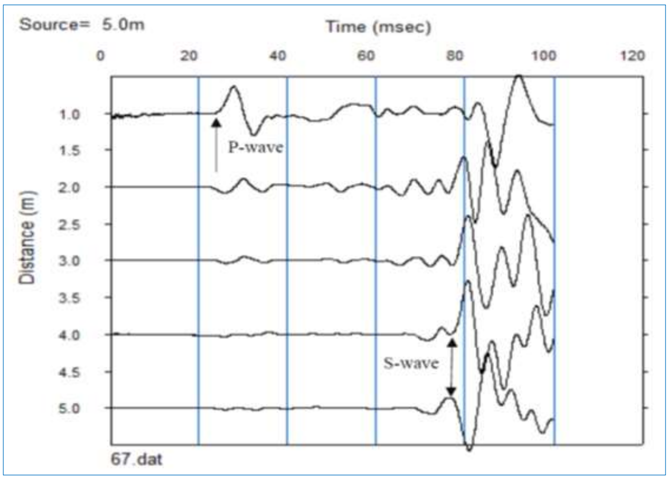

Fig. 3b. Typical seismic record 20-m depth

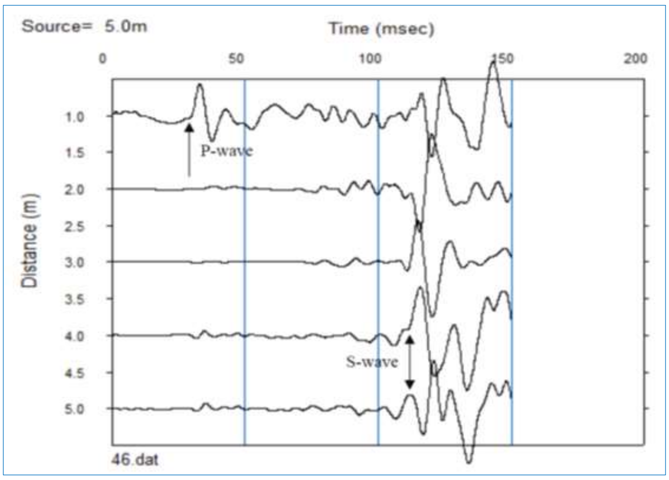

Fig. 3c. Seismic record 30-m depth

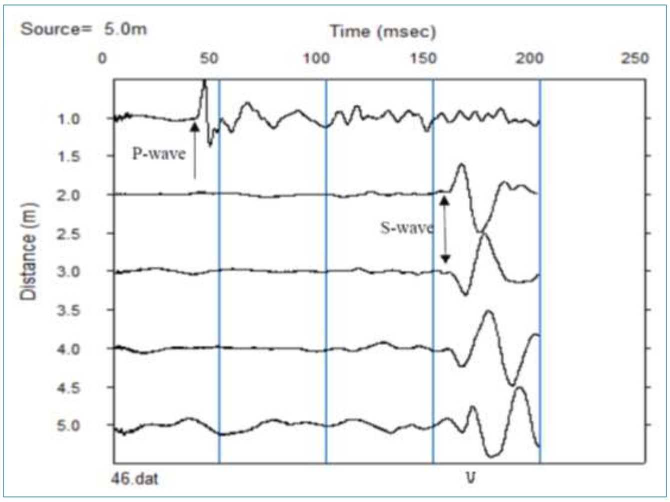

Fig. 3d. Seismic record 20-m depth

2.1. Equipment

For downhole seismic survey in accordance with (ASTM 7400, 2011) The seismic waves were recorded on a 24-channel signal enhancement seismograph geode of Geometrics USA. A specially designed borehole triaxial geophone with electric clamping device developed by Geo stuff USA was placed in the borehole. A concrete block with angular steel rods was used as seismic wave source for generation of shear and compression waves. The compression and shear waves were generated by striking the concrete block with a sledgehammer. A triggering device was attached to the sledgehammer to trigger the seismograph on the generation of the seismic waves. A 12-volt battery was used to power the seismograph. The controller of the Geo stuff borehole geophone is powered with an internal 24-volt battery.

In order to determine the shear wave and compressional wave velocities of the subsurface material at proposed site, downhole seismic survey was performed at site. For borehole one (BH 01) was drilled up to 50 m and three inches' diameter PVC casing was installed in the borehole. The annular space between the borehole and PVC casing was grouted with cement bentonite slurry. As the source was at a horizontal distance of 5.0 m away from the borehole, the arrival times of compression (P) and shear (S) waves represents the travel time along the slant path between the source and the geophone.

At each depth of testing, two records of compression and polarized shear waves were obtained on the signal enhancement seismograph. During the down hole survey, accuracy of the seismograph and triggering system was also monitored. The arrival time of compression and shear waves noted from the seismic record for each depth of testing. Typical seismic record at different depth showing arrival of Compression (P) and shear (S) waves is presented in Fig. 3a-3d with distance.

3. Results and Discussion

The compression waves were generated by striking the hammer on top of the concrete block. The shear waves were generated by striking the hammer on the sides of the steel rods embedded at an angle in the concrete block. In order to recognize the arrival of shear waves on the horizontal geophones, polarity reversal method was used. For this, hammer was struck on one side of the steel rod and shear waves were recorded and then hammer was struck on the steel rod on opposite side so that the polarity reversal of the shear wave was recorded which helped in the recognition of arrival of shear waves. Compression wave arrival was recorded by the vertical geophone. The arrival time of P and S waves are given in Table 1. The corrected P and S waves arrival is mentioned in the table after applied the correction on the recorded times to convert the slant path time to vertical path times (Fig. 4).

Table 1. Arrival time of P and S wave with their corrected time arrival

Depth (m)	Arrival Time (msec)		Arrival Time (msec)	
	P Direct	P Corrected	S Direct	S Corrected
1	16.4	3.22	25.6	5.02
2	17.6	6.54	21.9	8.13
3	16.5	8.49	23.8	12.24
4	16.5	10.31	26	16.24
5	17.8	12.59	28	19.80
6	18	13.83	30.5	23.43
7	19.4	15.79	35	28.48
8	17.9	15.18	38.1	32.31
9	18.3	16.00	41.4	36.19
10	18.7	16.73	43.2	38.64
11	18.9	17.21	45.7	41.60
12	19.3	17.82	50.3	46.43
13	20	18.67	53.6	50.03
14	20.4	19.21	57.8	54.43
15	20.9	19.83	60.8	57.68
16	21.7	20.71	62.8	59.94
17	22.4	21.49	66	63.32
18	22.7	21.87	70.5	67.93
19	23.3	22.53	74.1	71.66
20	23.9	23.19	76.9	74.60
21	24.3	23.64	81.1	78.89
22	25	24.38	84.6	82.50
23	25.3	24.72	88	85.99
24	25.3	24.77	91.5	89.58
25	26.3	25.79	94.3	92.47
26	27.4	26.91	98.5	96.73
27	27.8	27.34	102.2	100.49
28	28	27.56	105.5	103.86
29	28.7	28.28	108.4	106.82
30	29.8	29.39	112	110.48
31	30.5	30.11	115.2	113.73
32	30.9	30.53	118.8	117.38
33	31.6	31.24	122.1	120.72
34	31.8	31.46	125.5	124.16
35	32.6	32.27	129	127.70
36	34	33.68	132.2	130.94
37	34.2	33.89	135.6	134.38
38	35.2	34.90	138.5	137.32
39	35.2	34.91	141.7	140.55
40	35.6	35.33	144.3	143.19
41	36.1	35.83	146.7	145.62
42	36.9	36.64	149.7	148.65
43	37.5	37.25	152.6	151.58
44	38.1	37.86	155.1	154.11
45	37	36.77	158.5	157.53
46	37.1	36.88	161.6	160.65
47	38.8	38.58	163	162.09
48	39.4	39.19	166.1	165.21
49	40.1	39.89	167	166.14
50	40.6	40.40	169.4	168.56

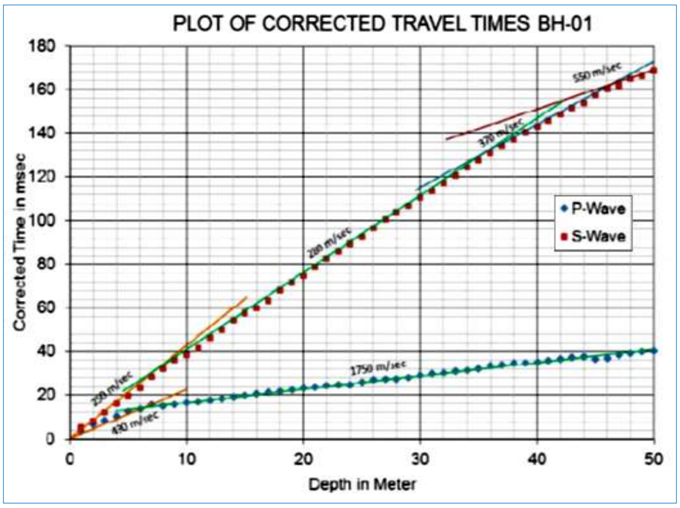

Fig. 4. Plot corrected arrival time

Four velocity layers were obtained in which the shear wave velocities increase with depth. The top layer representing the near-surface soil having low shear wave velocity of 250 m/sec which extends up to about 7 m depth. Below 7 m depth soil having higher seismic wave velocity is present which extends up to 34 m depth. The shear wave velocity at depth from 7 m to 34 m was measured 280 m/sec. From 34 m to 46 m, shear wave velocity was 370 m/sec below 46 m depth, 550 m/sec shear wave velocity was encountered.

The change of velocity represents the better compaction and lithification of soil with depth. The material up to about 7 m depth shows compression wave velocity of 430 m/sec. Below this, the soil shows compression wave velocity of 1750 m/sec which indicates that water becomes the main carrier of compression waves in sandy soils below water table. The compression and shear wave velocity profile obtained for BH-01 is given in Table 2.

Table 2. Velocity of the seismic waves with respect to depth from borehole 1

Lithology	Compressional wave velocity (m/sec)	Shear wave velocity (m/sec)
Top soil up to 7 m depth	430	250
Soil from 7-34 m depth	1750	280
Soil from 34-46 m depth	1750	370
Soil from 46-50 m depth	1750	550

4. Conclusions

During investigation, the subsurface was explored to a maximum depth of 50 m below the existing ground surface. Various soil layers were encountered at site below the existing surface which described in bore hole logs. Four velocity layers were obtained in which the shear wave velocities increase with depth. The top layer representing the near-surface soil having low shear wave velocity of 250 m/sec which extends up to about 7 m depth. Below 7 m depth soil having higher seismic wave velocity is present which extends up to 34 m. From 7 m to 34 m, the subsurface material shows shear wave velocity of 280 m/sec. From 34 m to 46 m, the subsurface material shows shear wave velocity of 370 m/sec. Below 46 m depth, the shear wave velocity increase to 550 m/sec, the change of velocity represents the better compaction condition of the soil with depth. The material up to about 7 m depth shows compression wave velocity of 430 m/sec, whereas more depth soil shows compression wave velocity of 1750 m/sec increases which indicates that water becomes the main carrier of compression waves having constant velocity in sandy soils below water table. The results of geotechnical and geophysical investigation have shown that sub soil at site is competent to withstand the structural load. The in-situ geotechnical and geophysical testing has helped in accurate engineering site characterization for the economical and safe static and dynamic design and earthing design of electrical installation.

5. Recommendations

On the basis of the geotechnical results, shallow foundations have been proposed to structural engineer. The shallow foundation may be square, strip foundations at 12 feet from NSL. If required back filling, engineering fill A-2-4(0) should be used as a back fill material. The foundation trenches / pits must be protected from ingress of water during foundation construction. For the dynamic design of foundation, compressional and shear wave velocities of the sub soil obtained through seismic down hole survey should be used.

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