Estimation of Elastic Moduli of Alluvium Sediments

Piyush Sarkar-Research scholar, K. H. Singh, A. Shahi, S. P. Maurya
Indian Institute of Technology Bombay, Powai, Mumbai, Maharashtra, India- 400076
E-mail: piyush.gph@gmail.com

Keywords Borehole deviation, Elastic parameter, Alluvium, cross-hole seismics.

Summary

In geotechnical studies the estimation of elastic moduli of the subsoil through its seismic velocities is very important for the design of foundations and structures. This study discusses the Crosshole seismic and borehole deviation survey to evaluate the elastic moduli of the subsurface sediments for the design of foundations for a nuclear power project. Crosshole seismic studies are done to compute compressional (P) and shear (S) wave velocities upto a depth of 51 m. The results at reactor site show that the P-wave velocity varies from 442.27 m/s to 1287.33 m/s while the S-wave velocity show a variation of 228.44 m/s to 627.66 m/s. The Young modulus from 0.29 GPa to 1.62 GPa, the Bulk Modulus from 0.19 GPa to 1.58 GPa, the Shear modulus from 0.12 GPa to 0.62 GPa and the Poison's ratio from varies from 0.24 to 0.33.

Introduction

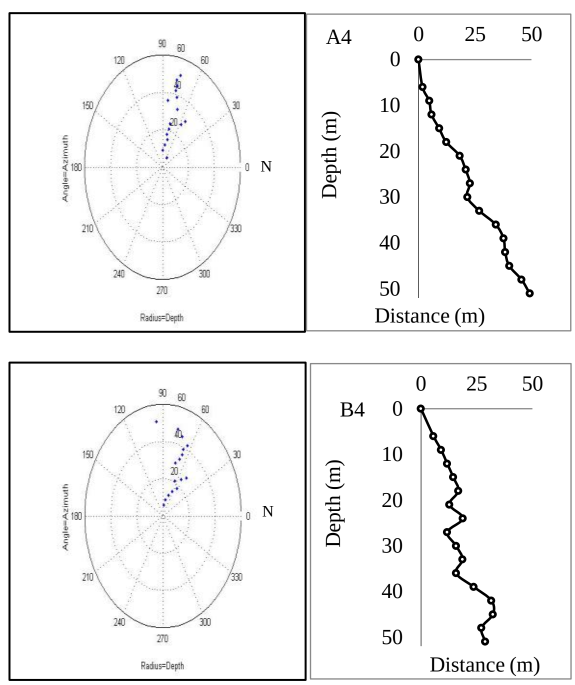
The electrical generators of nuclear reactors, which can at times vibrate within a relatively wide frequency range, the foundation block has to be designed in such a way so as to avoid resonance. Therefore, an important condition for designing the foundation of nuclear reactors is the correct estimation of elastic interaction between the host rock and the structure. This requires the knowledge of the dynamic rigidity moduli of ground, usually calculated from the shear wave velocities obtained from Crosshole seismic methods and geomechanical properties of the subsurface soil.

The shear modulus is fundamental for the study of the soil response to seismic or manmade vibrations (Cotton et al, 1986).Shear wave velocity estimated from cross hole seismic survey is useful in estimating the liquefaction resistance of the subsurface (Kumar and Singh, 2015). Among the geophysical methods used to obtain the in-situ seismic velocities, the crosshole seismics gives the most detailed form. The cross-hole method investigates the zone between two close boreholes (generally from 5 to 10 m), measuring the travel time of the compressional (P) and shear (S) waves from a source located in one hole to a geophone located in another hole. This paper describes the use of Crosshole seismic and borehole deviation tests to evaluate the dynamic moduli of Alluvium sediments required for designing the foundations of reactor buildings for a nuclear power project in North India.

Borehole Deviation Survey

The seismic crosshole and borehole deviation test was conducted at the proposed 2 X 700 MWe Nuclear Power project (GAPP) site in Haryana. The geophysical tests were conducted in 3 boreholes to assess the in-situ soil elastic properties of the subsurface. The borehole deviation survey is conducted to determine accurately the horizontal distance between the source and the receiver boreholes at test depth or at desired intervals (Eisner et al, 2006). This information serves as a crucial input during the estimation of velocities from the crosshole seismic survey (Bulant et al, 2006).

The borehole deviation survey consists of a series of dip and azimuth values measured at numerous depth points. The first reading was taken at 6.0m from the surface in the borehole and thereafter all readings were recorded at 3.0m depth interval both in downhole direction. The horizontal distance between the boreholes is computed using the ASTM standards D-4428/D-4428M-84 (2007) which determines the straight-line distance, 'L', from source to geophone (Figure 1).



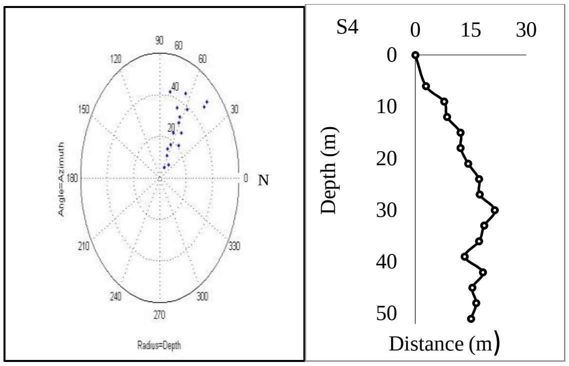


Figure 1: Polar Diagrams showing azimuth vs depth along with borehole deviation for borehole: A4, B4 and S4.

The polar diagram in Figure (1) shows the azimuthal variation of the boreholes at every 3.0 m depth upto 51m while the scatter plots shows the variation of boreholes with vertical.

Cross-Hole Seismic Survey

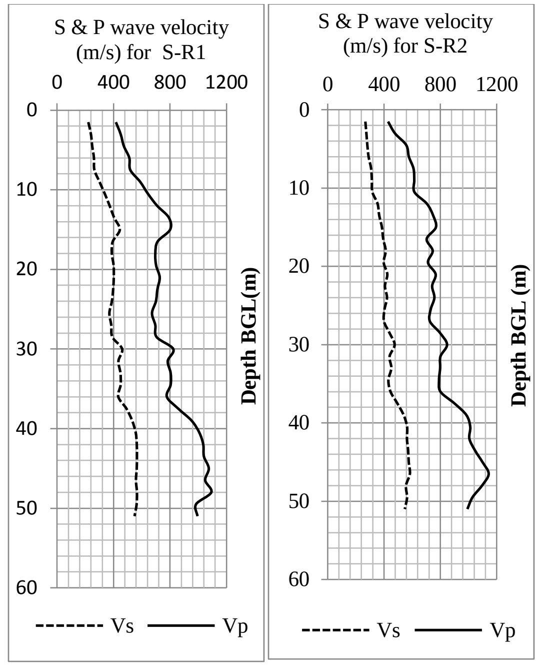
Crosshole seismic survey takes advantage of generating and recording (seismic) body waves, both the P- and S-waves, at selected depth intervals where the source and receiver(s) are maintained at equal elevations for each measurement. Particle motions generated with different seismic source types used during crosshole testing are three-dimensional (Dowrick, 2003). Therefore, three component geophones with orthogonal orientations yield optimal results when acquiring crosshole P- and / or S-wave seismic signals.

Data processing and reduction

The basic data processing flow included the following:

- The survey data are imported into the software.
- The source and receiver geometry correction for any deviation (obtained from borehole deviation tests) are applied.
- Frequency filters to remove noise.
- Pick first breaks.
- Compute the velocities for P-waves and S-waves.
- Calculate the dynamic elastic modulus of the alluviums

In figure 2(a), the variations of S-wave and P-wave velocity near the surface (2m) are 220 m/s and 416 m/sec respectively. The values gradually increase to 444 m/s and 800 m/s at a depth of 15 m and then steadies to a value of 400 m/s (S wave) and 710 m/s (P wave) between 15-28.5 m depth. From 28.5m, the velocity increases and reaches a maximum of 557 m/s for S wave and 1092m/s for P-wave at around 47-49 m before decreasing slightly at 50 m.



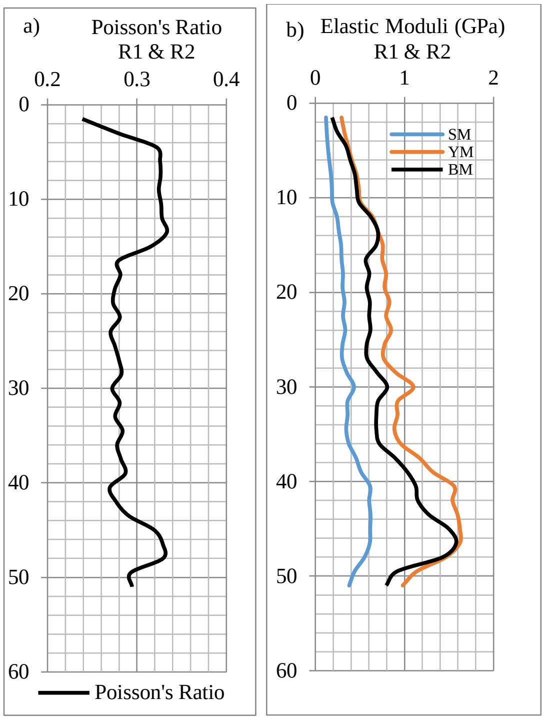
a) b)

Figure 2: Compressional and shear wave velocity variation with depth (a) for Receiver 1, (b) Receiver 2.

In figure 2(b), the variations of S-wave and P-wave velocity near the surface (2m) are 267 m/s and 429 m/sec respectively. The values steadily increases to 412 m/s at 18m for S waves while it goes to 769 m/s for P-waves at a depth of 15.0 m. The velocity remains constant at an approximate value of 406m/s (S wave) between 18.0-27.0 and ~730 m/s (P wave) between 16.5-27 m depth. There is a sharp increase in the value of both P and S wave between 27 to 30 m and reaches a maximum of 475m/s for S wave and 847m/s for P wave. The velocities then remain steady around 440m/s for S wave and 800m/s for P-waves between 31.5 - 36m. Further down the velocities first increase and then remain more or less steady for S wave (563m/s). For P wave the value increases to a maximum of 1143m/s at around 46.5m but again decreases to 992m/s around 51 m.

Calculation of Elastic Moduli

The elastic parameters of soil/rock are calculated from Seismic wave and the Bulk Density of the corresponding subsurface strata (Michalopoulos et al., 1979). The calculations are based on IS Code 13372 (Part-2).



a) b)

Figure 3: Variation of Poisson's ratio, Shear Modulus (SM), Bulk Modulus (BM) and Young Modulus (YM) with depth for R1 and R3.

The Poisson's ratio varies from 0.24 to 0.33 between depths 2-14m (Figure 3a). Beyond 14 m depth, there is a decrease in this value from about 0.33 to 0.28 where after it remains constant upto a depth of 42.5 m. The value again increases to 0.33 around 47-48m but decreases to 0.29 beyond 48m. The Figure (3b) shows the trend of elastic parameters of subsurface alluvium soil through the entire length of borehole. The values of Shear, Bulk and Young modulus at a depth of 1.5 m are 0.1, 0.25 and 0.26 GPa respectively. These values gradually increase to 0.33, 0.76 and 0.86 respectively at a depth of 15.5 m and between 15.0-27.5 m they remain constant. Further below 27.5 m depth, all three parameters first increase for the next 3 meters and then steadies for up to a depth of 34.5 m. The Shear, bulk and Young modulus reach their maximum of 0.65, 1.68 and 1.73 GPa at 46.5 m respectively and then steadily decreases up to 51 m depth by nearly half their values except for Young's modulus which decreases by 37%.

Conclusion

From the observed data it is interpreted that eight layers are observed having thickness of 5.25m, 6.0m, 4.5m, 12.0m, 10.5m, 6.0m, 4.5m and 2.25m respectively on the basis of variation geophysical parameters.

Layers	Layer thickness (m)	P-wave velocity (m/s)	S-wave velocity (m/s)	Poisson's Ratio	Shear Modulus (GPa)	Bulk Modulus (GPa)	Young Modulus (GPa)	Inferences for lithology/formations
1st	5.25	475.1	260.4	0.28	0.13	0.26	0.33	Unconsolidated Silt
2nd	6.0	601.2	305.5	0.33	0.18	0.45	0.47	Loosely compact Silt
3rd	4.5	736.1	374.3	0.33	0.26	0.67	0.70	Moderately compact Silt
4th	12.0	731.1	406.1	0.28	0.31	0.56	0.79	Hard and compact Silt
5th	10.5	814.8	450.9	0.28	0.38	0.74	0.98	Very hard and compact Silt
6th	6.0	1007.9	556.0	0.28	0.59	1.15	1.50	Compact Sandy Silt
7th	4.5	1098.0	558.1	0.33	0.59	1.50	1.57	Compact Sandy Silt
8th	2.25	858.5	463.9	0.29	0.41	0.86	1.06	Compact Silt formation

References

1. ASTM Standard D-4428/D-4428M-84, 2007, Standard Test Seismic Testing." American Society for Testing 885-898. Methods for Materials. Crosshole 1984, pp.
2. Bulant P., Eisner L., Psen ˇ cˇ´ık I. and Le Calvez J. 2006, Borehole deviation surveys are necessary for hydraulic fracture monitoring. Abstracts of SPE Annual Technical Conference, San Antonio, SPE 102788, Society of Petroleum Engineers.
3. Cotton, J.F., Deletie, P., Jacquet-Francillon, H., Lakshmanan, J., Lemeine, Y. & M.Sanchez, 1986, Curved ray seismic tomography: Application to the Grand Etang Dam (Reunion Island), First break, 4, 25-30.
4. Dowrick, D., 2003, Earthquake Risk Reduction, John Wiley and Sons, New York
5. Eisner L. and Bulant P. 2006, Borehole deviation surveys are necessary for hydraulic fracture monitoring. 68th EAGE meeting, Vienna, Austria, Extended Abstracts, P305.
6. Michalopoulos, A.P., Hanson, K.R., Raynand, D.A. & Arias, R.P. 1979, Measurement, selection and use of dynamic soil properties in design, Proceedings of the Seventh European Conference on soil mechanics and Foundation Engineering.