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Seismic Refraction Survey for High Rise Buildings – A Case Study

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ABSTRACT

Seismic refraction survey (SRS) is well accepted geophysical tool for subsurface characterization. Geophysical investigations are quick, economic, and large area can be covered in less time to determine the average depth and quality of bed-rock, rippability, presence of shear zones etc. SRS gives P-wave velocity of the subsurface which is used to map the elastic discontinuities. This paper presents the methodology, equipment, field procedures and interpretation of SRS for building towers at Amravati; the proposed capital of Andhra Pradesh. Construction of 30 to 50 storied building towers requires sound foundation to transfer the loads of super structure. The towers can be founded on rock by excavating the overburden, when the rock is available at economical depth. The survey was conducted along five lines each 150 m length for five towers. SRS results indicate that bedrock is available at depth of 15 m for four towers and at 20 m for one tower. Exploratory holes drilled in survey area confirmed the estimated rock profile using SRS.

Keywords:Seismic refraction survey; Building towers; Amaravati; Foundation investigations; Rock mass quality

1. INTRODUCTION

Andhra Pradesh Capital Region Development Authority is executing the work of Amravati city, the proposed capital of Andhra Pradesh. The city is located on right bank of river Krishna in Guntur district. The secretariat and heads of departments building is proposed in an integrated manner to bring efficiency of working. This building complex consists of five towers of G+40 floors in total area of 35.5 acres. The build-up area of each floor plate is 47mx47m with area of 2209 sq. m. Seismic refraction survey (SRS) was conducted for five building towers to ascertain the average depth to bedrock, quality and continuity of rock in the foundations.

The subsurface is consisting of layers of black cotton soil, sandy soil and gneiss rock. SRS were conducted along five lines of 150 m length each. Methodology, equipment, field procedures and interpretation of SRS are presented in this paper.

2. SEISMIC REFRACTION METHOD

Seismic refraction survey (SRS) is widely accepted as a non-destructive dynamic test for site characterization (Alex et al., 2011). SRS provides subsurface information over large areas at relatively low cost, locate critical areas for more detailed testing by drilling and can readily eliminate less favourable alternative sites. Seismic surveys can also reduce the number of drill-holes required to test a particular site and improve correlation between drill-holes.

SRS basically provides velocity of P-wave in subsurface strata. This involves planting geophones in a line with predetermined spacing into the ground. The seismic source can be hammer, weight drop or explosives. The seismic energy produces waves which are received by geophones and are recorded in the seismograph. The waves when reaches the interface of increased seismic velocity, waves get refracted as per Snell's law. The geophones near the shot location records direct waves whereas as at distance, refracted waves reaches faster than direct waves. Detailed information of the seismic refraction method can be found in the works of Sharma (2004), Telford et al. (1990) and Redpath (1973).

Analysis of seismic refraction data depends upon the complexity of the subsurface velocity structure. The slope intercept method is used when the subsurface target is planar in nature and to model multiple horizontal or dipping planar layers. A minimum of one end shot is required to model horizontal layers and reverse end shots are required to model dipping planar layers. In case of undulating subsurface, generalized reciprocal method (Palmer, 1980), reciprocal method (Hawkins, 1961) also referred as ABC method, Hales' method (Hales, 1958), delay time method (Wyrobek, 1956) and plus-minus method (Hagedoorn, 1959) are employed to obtain velocity section of subsurface. These methods generally require a minimum of 5 shot points per spread (near shots at ends, far-off shots and a center shot). Tomographic inversion technique is used (Zhang and Toksoz, 1998) when the subsurface strata are highly complex. Inversion techniques require a shot density ranging from 2 to 6 stations/geophones. Longer profiles are required for deeper exploration in this technique as it cannot use far-off shots. Hawkins (1961) reciprocal or ABC method of interpretation adopted for this study.

3. EQUIPMENT AND FIELD PROCEDURES

The equipment for the seismic refraction survey consists of 24 channel seismograph, computer, 10 Hz vertical geophones and cable with take-out at 6.5 m. Energy source is explosives (Class-2) which consist of 125g x 25mm gelatin sticks bundled together, is placed inside 150 mm diameter, 500 mm deep holes. Electric detonators are used for blasting operations. Power source for the equipment was supplied through 12V battery.

The field work consists of spreading cables, planting geophones firmly into the ground in linear array with spacing of 6.5 m, connecting cable with seismograph and computer. Mostly 5 shots survey conducted for each line. Operation of machineries, vehicular traffic and entry of animals were stopped in order to eliminate noise while conducting SRS. The cumulative length of survey for five lines is about 750 m. Site topography is nearly planner without undulations or change in elevation along the profile.

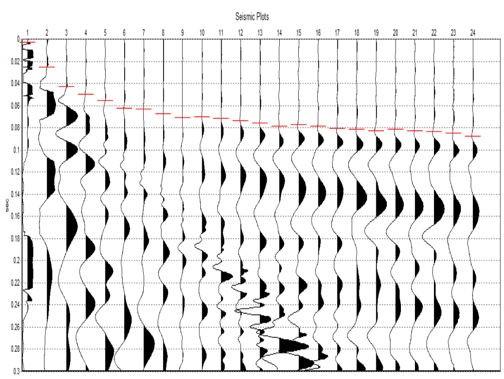
4. INTERPRETATION

4.1 Exploratory Drill-holes

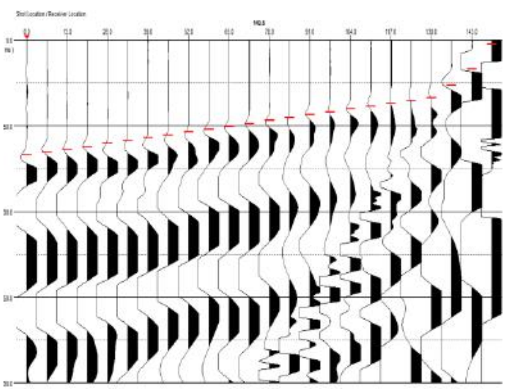
The study of drill-holes logs shows that the area is covered with 3 to 7 m thick black cotton soil followed by 5 to 10 m thick sandy material and rock below that depth. Fine grained, blackish to grey coloured gneiss type of rock is encountered at this site.

Seismic Refraction Data

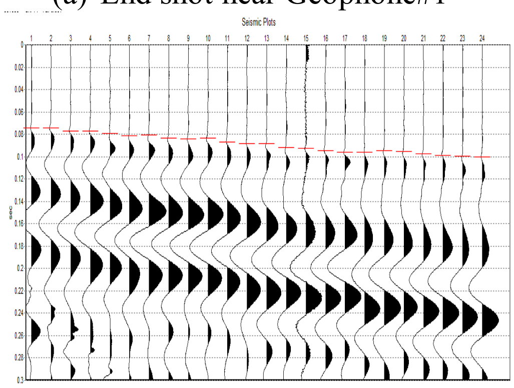
The seismic records for end shots, middle shot and far-off shot are shown in Fig. 1. The first step in data processing is to pick the arrival time of first energy received at each geophone for each shot point. It may be remembered that the P-wave travels faster than shear and surface waves. The first arrivals on each seismic record are either a direct arrival from a compressional (P) wave travelling in the uppermost layer or a refracted arrival from a subsurface interface where there is a velocity increase. The arrival times are plotted against geophone distance to get time-distance graphs.



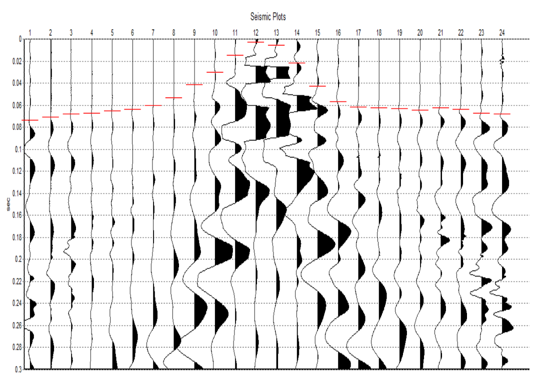
(a) End shot near Geophone#1



(b) End shot near Geophone#24



(c) Far-off shot



(d) Middle shot

Fig. 1 - Seismic records of end shots, far-off shot and middle shot for Tower #1

The objective of this study was to find the depth to bedrock, therefore subsurface has been interpreted for two-layer case using reciprocal or ABC method. This method is used when information on thickness of the various layers, depth to bedrock is required under each geophone. The velocity section for all towers except tower #4 is presented in Fig. 2. The results of tower #4 is similar to tower#5.

All the data was processed in ‘Refractor’ module of ‘Geogiga’ program. The geometry of profile, shot location and picking up first arrival are to be done manually. Number of layers is assigned based on the time-distance curve.

Interpretation of results such as average wave velocity in layer#1 and layer#2, depth to bedrock for each survey line is presented below.

4.2 Tower#1

The line was trending in N-S direction, 149.5 m length, G1 geophone at 0 m chainage towards N-direction. The overburden thickness (Black cotton soil + sandy strata) is 13 m. The bedrock is estimated at depth below 13 m. Average P-wave velocity of first and second layers are 485 m/s and 4955 m/s respectively.

4.3 Tower#2

The line was trending in N-S direction, 149.5 m length, G1 geophone at 0 m chainage towards N-direction. The overburden thickness (Black cotton soil + sandy strata) is 15 m. The bedrock is estimated at depth below 15 m. Average P-wave velocity of first and second layers are 433 m/s and 5825 m/s respectively.

4.4 Tower#3

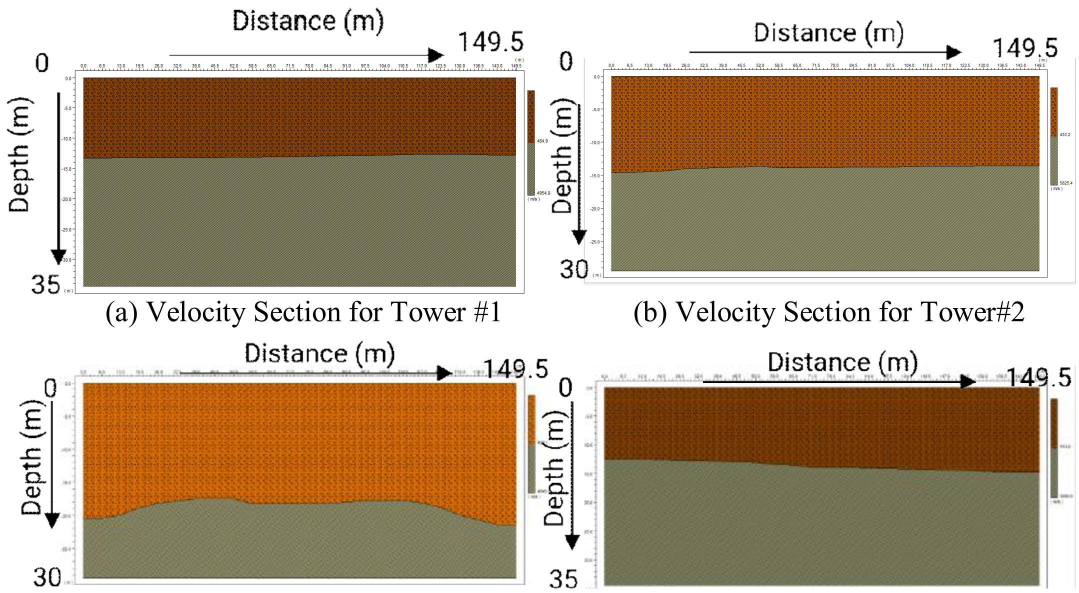
The line was trending in N-S direction, 149.5 m length, G1 geophone at 0 m chainage towards N-direction. The overburden thickness (Black cotton soil + sandy strata) varies from 18 to 20 m. The bedrock is estimated at depth below 20 m. Average P-wave velocity of first and second layers are 420 m/s and 5846 m/s respectively.

4.5 Tower#4

The line was trending in E-W direction, 149.5 m length, G1 geophone at 0 m chainage towards E-direction. The existence of high voltage overhead electric lines across the Tower-4&5 sites in E-W direction warranted to align the profile line parallel to electric line keeping sufficient offset distance. During the data acquisition, frequency filter option (50 Hz) in the equipment has enabled authors to eliminate the possibilities of error due to electric lines.The overburden thickness (Black cotton soil + sandy strata) varies from 13 to 15 m. The bedrock is estimated at depth below 15 m. Average P-wave velocity of first and second layers are 482 m/s and 5382 m/s respectively.

4.6 Tower#5

The line was trending in E-W direction, 149.5 m length, G1 geophone at 0 m chainage towards E-direction. The overburden thickness (Black cotton soil + sandy strata) varies from 13 to 15 m. The bedrock is estimated at depth below 15 m. Average P-wave velocity of first and second layers are 514 m/s and 5846 m/s respectively.



(a) Velocity Section for Tower #1 (b) Velocity Section for Tower#2

(c) Velocity Section for Tower#3 (d) Velocity Section for tower#5

Note: (i) Subsurface layer#1: Black cotton soil + Sandy strata; (ii) Layer#2: Gneiss rock mass

Fig. 2 - Seismic velocity section for different building towers

5. CONCLUSIONS

Seismic refraction survey conducted for foundation investigations of five building towers under construction in Amravati, the proposed capital of Andhra Pradesh has been presented. Results of SRS such as velocity of layer#1, layer#2 and depth to bedrock are summarized in Table 1.

Table 1 - Summary of SRS results for five building towers

Tower No.	P-wave Velocity in 1st layer (m/s)	P-wave Velocity in 2nd layer (m/s)	Depth to Bedrock (m)
Tower#1	400 to 600	4000 to 6000	13
Tower#2	400 to 500	5500 to 6000	14 to 15
Tower#3	400 to 500	5500 to 6000	18 to 20
Tower#4	400 to 600	5000 to 6000	13 to 15
Tower#5	400 to 600	5500 to 6000	13 to 15

SRS conducted at this site further confirmed the following;

- P-wave velocity greater than 5000 m/s indicates the presence of good quality of rock mass.
- Presence of any shear or low velocity zone is not detected along the survey lines for Tower#1 to #5.
- Depth to bedrock is less than 15 m for 4 towers and less than 20 m for Tower#3.
- Depth of bedrock estimated from SRS and obtained in drill-holes matches closely.
- SRS also confirmed the continuity of bedrock over the tower area i.e. in between drill-holes.

Seismic refraction survey proved as less time consuming, cost effective and reliable tool for foundation investigations required for high rise building towers.

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