Geophysical Characterization of Metro Station Sites

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***Abstract*—Seismic refraction tests are an effective tool to characterize the ground and correlate to the borehole profile and assess the trend of the rock formation. The paper presents case studies of the application of the tests to enhance the reliability of geotechnical data at metro station sites in Delhi. Data from three selected underground station sites are illustrated in detail.**

Keywords—geophysical characterization, seismic refraction tests, metro station sites

I. INTRODUCTION

Geotechnical investigation for metro and other linear lines and stations conducted at the project conception stage in urban areas presents several challenges. The alignment and station locations tentatively fixed in the initial investigation often change subsequently due to various reasons. Add to this, land related issues, congested localities, and heavy traffic.

If locations of boreholes drilled are somewhat off the station locations, the borehole data may not match with the actual ground profile due to the dipping nature off the Delhi rocks. At the construction stage, sufficient time may not be available to drill deep boreholes to obtain further data along the alignment or station sites.

Geophysical tests such as seismic refraction tests and electrical resistivity tests offer a reliable option to characterize the ground and supplement limited borehole data so to confirm continuity of the strata and assess the depth to rock.

The paper presents case study of three selected stations of the underground section of the Delhi Metro corridor wherein seismic refraction tests were used to enhance the reliability of the geotechnical investigation program.

II. PROJECT ALIGNMENT

The alignment of the metro line starts from RK Ashram near Paharganj in central Delhi to Azadpur in north Delhi, covering a distance of about 10 km. It passes through Nabi Karim, Sadar Bazar, Pul Bangash and Ghanta Ghar and ends at Derawal Nagar near Kingsway Camp.

Six stations are planned along the route. A satellite image showing the approximate stretch and the stations is illustrated on Fig. 1.

Fig. 1. Satellite image showing stations investigated

III. SITE CONDITIONS

A. Regional Geology

In the project area, an overburden of alluvium is underlain by Delhi Quartzite [1]. The generalized geology of the area is presented in Table 1.

TABLE I. GENERALIZED GEOLOGY

Period	Formation	Description
Recent	Newer Alluvium	Unconsolidated, inter-bedded lenses of sand, silt gravel and clay confined to flood plains of Yamuna river.
Quaternary	Older Alluvium	Unconsolidated inter-bedded, inter-fingering deposit sand, clay and kankar, moderately sorted, thickness variable, at places more than 300 m.
Pre-Cambrian	Pegmatite and Quartz Veins Quartzites (Delhi Quartzite) with minor Schist Bands	Well stratified, thick-bedded brown to buff colour, hard and compact, intruded locally by pegmatite and quartz veins inter-bedded with mica schists.

The rocks of the Delhi Supergroup are exposed in the main Aravali mountain chain extending from Delhi in south-westward direction through parts of Haryana and Rajasthan. The rocks belong to the Alwar Group comprising primarily of quartzite with micaceous schist bands [2].

The rock is highly fissured and jointed due to the tectonic activity and consequent folding. Preferential weathering takes place along the joints due to seepage of water. The filler material in the joints / fissures is usually sand / sandy silt. Variation in rock quality / degree of weathering occurs over short distances.

B. The Investigation Program

In the initial phase, boreholes were drilled at 100-150 m along the alignment. The boreholes were drilled to 15-40 m depth.

Due to the variation in the rock level over the route and limited borehole data in the vicinity of stations, it was decided to perform seismic refraction tests at the stations. The intention was to fill the gap between the boreholes and establish continuity of strata.

The sites for the stations were along major roads with heavy traffic. The noise due to vibrations the traffic movement tend to mask the seismic data . Therefore, the tests were conducted at night when the traffic disturbance was minimum. The length of the seismic lines ranged from 120 to 420 m depending on the space availability.

Fig, 2 a schematic of the test procedure. A 24-channel seismograph was used. The geophones were spaced 5 m apart. The data was processed using Rayfract software.

Fig, 3 is a photo of the seismic refraction test in progress.

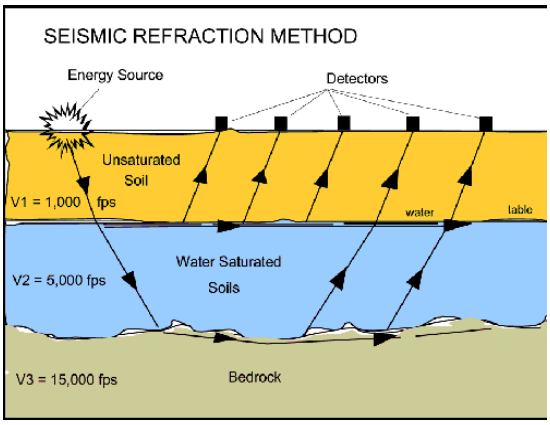

Fig. 2. Schematic sketch of Seismic refraction test

The geophones (natural frequency 10 Hertz), were embedded in the RCC / asphalt pavement after drilling holes through the pavement. The test procedure was ion general accordance with ASTM D 5777-18 [3].

Fig. 3. Seismic refraction test in progress

C. Generalized Stratigraphy along the Corridor

In general, an urban fill (road paving, etc.) is met at ground level below which overburden of alluvium is encountered to depths ranging from 3 m to 20-25 m.. It is underlain by Delhi Quartzite (rock). The degree of weathering of the rock ranges from moderate to severe at shallow depth to hard slightly weathered rock at deeper levels. Zones of mica occur sandwiched between the limbs of the folded rock.

IV. STATION 1

At the station in central Delhi near RK Ashram near Paharganj, the depth to rock varies from 9 to 25 m. The seismic line was 240 m long (see Fig. 4).

Below the road paving, the overburden soil consists of silty sand / sandy silt of low plasticity with localized zone of clayey silt of medium plasticity. The Primary wave velocity, V_p in the soil ranges from 500 to 1200 m/s. The underlying rock is weathered to about 25-30 m depth with V_p in the range of 1200 to 2500 m/s. The deeper rock is probably hard, moderately to slightly weathered.

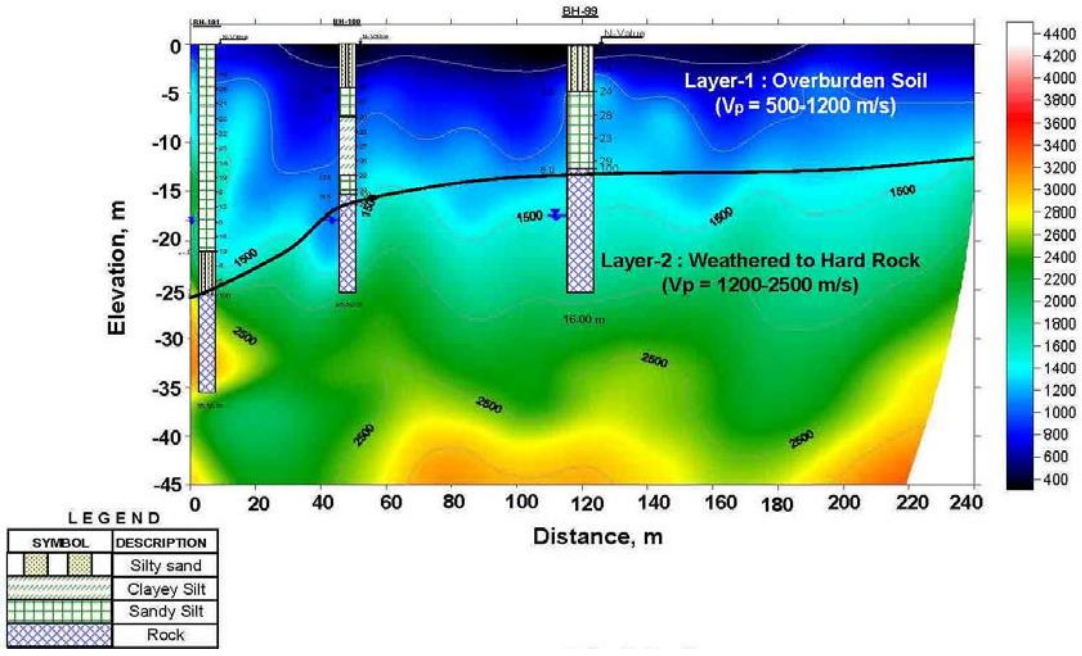

Fig. 4. Seismic profile and boreholw data at Station 1 (RK Ashram)

V. STATION 2

This station is planned in the congested Sadar Bazaar area along the alignment. Data from 4 boreholes to 14-15 m depth were used for the interpretation. The seismic line at this location was about 420 m long (see Fig. 5).

The thickness overburden at this station location is about 2-3 m with V_p of 500 to 1000 m/s. As interpreted from the seismic profile (See Fig. 5), weathered rock with V_p of 1200 to 2400 m/s is met below the thin overburden to about 22-33 m depth. Below this hard rock (V_p > 250000 m/s) is likely to be met.

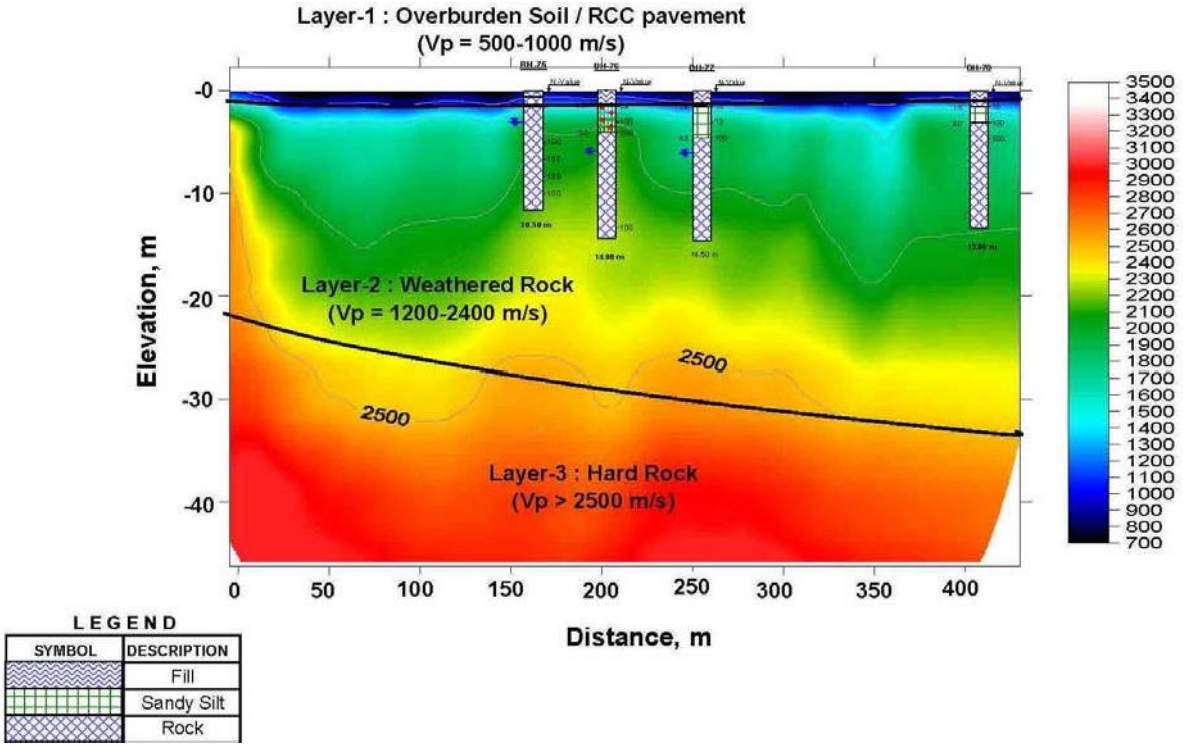

Fig. 5. Seismic profile and boreholw data at Station 2 (Sadar Bazar)

VI. STATION 3

This station is located at Derawal Nagar near Kingsway Camp. Two boreholes drilled in the area indicated the presence of hard silty clay to 40 m depth below a surficial 3-4 m thick fill. The seismic line was 240 m long. The seismic profile and the borehole data are illustrated on Fig. 6.

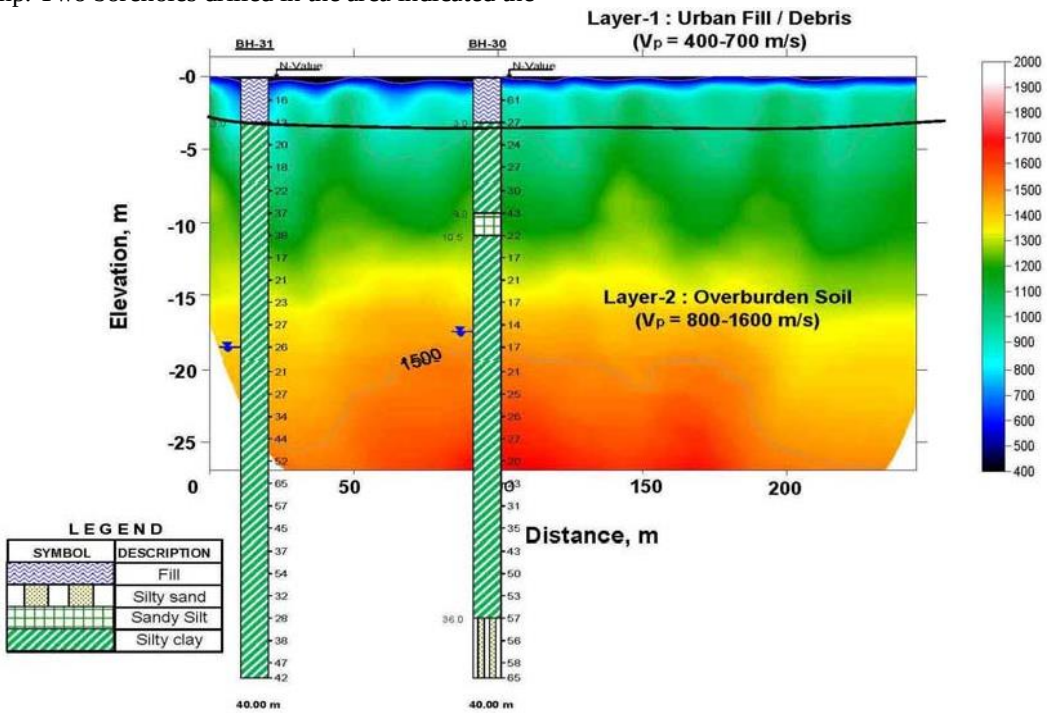

Fig. 6. Seismic profile and boreholw data at Station 3 (Derawal Nagar)

Below the fill, silty clay of medium to high plasticity is encountered. The P-wave velocity, V_p in the fill ranges from 400 to 700 m/s. V_p in natural soils increases gradually with depth from 800 m/s at shallow depths to 1600 m/s at greater depths.

VII. Concluding Remarks

Seismic refraction tests can be used effectively in conjunction with borehole data to confirm the continuity of strata and identify the trend of bedrock. Along the metro corridor planned from central to north Delhi, seismic refraction tests were performed at six station sites along the 10 km long alignment. The paper presents results of three of these station sites.

Table II summarizes the interpretations of stratigraphy as assessed by the seismic refraction tests at three station sites after matching with the borehole data

TABLE II. INTERPRETED STRATIGRAPHY AT STATION SITES

Location	Layer	Depth, m		Interpreted V_P, m/s	Interpreted Strata
		From	To		
Station 1	1	0	9~25	500-1200	Overburden Soil / RCC pavement
(RK Ashram)	2	9~25	45	1200-2500	Weathered to Hard Rock
Station 2	1	0	2~3	500~1000	Overburden Soil / RCC pavement
(Sadar Bazar)	2	2~3	23~33	1200~2400	Weathered Rock
	3	23~33	50	>2500	Hard Rock
Station 3	1	0	3~4	400-700	Urban Fill / Debris
(Derawal Nagar)	2	3~4	27	800-1600	Soil

References

[1] M. S, Krishnan, Geology of India and Burma, CBS Publishers, Delhi, 1986.

[2] S. M. Naqvi & R.R. Rogers, Precambrian geology of India, Oxford University Press, New York, 1896.

[3] ASTM D 5777-18, Standard Guide for using the Seismic Refraction Meethod for Subsurface Investigation, 2018.