J. Ind. Geophys. Union (July 2004)
Vol.8, No.3, pp.223-228

Bed Rock investigation by Seismic Refraction Method - A case study

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ABSTRACT

A high – rise RCC Bridge is under construction across the Krishna River on the downstream side of the Nagarjuna Sagar Dam, Nalgonda district of Andhra Pradesh. This bridge is constructed parallel to the old bridge on the upstream side that collapsed a few years ago. The prime consideration for requisitioning this geophysical survey is to locate the hard rock depth at the three piers remain to be constructed in the central portion of the bridge where rock could not be found even at double the conventional founding level on the flanking pillars. Three seismic lines around 110 m to 160 m have been laid using, 24-Channel signal enhancement seismograph of ABEM, with 5 m spacing, one along the bridge alignment and two lines parallel to this alignment on the upstream and downstream side of the axis of the alignment.

Present seismic refraction data has yielded interesting results that depth to the hard rock for foundation purpose is of 20 m, 26 m and 18 m at three pier locations of the bridge respectively. Further it is noticed the depression type of feature emerged as a regional feature of a low velocity channel in the center of the river. Strong current of water flow in this channel in the past had filled it by the flowing pebbles/boulders.

Key words: Bedrock, refraction, Nagarjuna Sagar, Pier, Upstream, Downstream, Deep seated channel

INTRODUCTION

Geological Survey of India and the Central Water and Power Research Station, Poona have investigated bedrock conditions in a number of dam and bridge sites, using refraction methods[2]. A high-rise RCC bridge is under construction across the river Krishna on the downstream side of the Nagarjuna Sagar Dam, Nalgonda district, Andhra Pradesh (Fig. 1). This new bridge is constructed parallel to the old bridge on the upstream side which has collapsed a few years ago. This bridge is constructed to meet the traffic demands in the state between Hyderabad and its surrounding districts. The present bridge construction falls under the domain of Andhra Pradesh State Highway Projects, a division of R & B as part of the highway development project funded by World Bank.

The bridge is planned with a length of 630 m supported by 16 pillars in the north-south direction. Each pillar measures 3.5 m in diameter and 45 –50 m in height. The center-to-center distance between each pair of pillar is 37 m. Till date, 13 out of 16 pillars have already been erected from either end of the river (Fig. 2). Only pillars P-6 to P-8 are to be commissioned.

During excavation for foundation of these three pillars, it has been found that hard rock, which was hitherto found at 5-6 m depth, was missing at this level for all the three pier locations. Hence drilling was resorted to locate the hard rock depth. However, even after drilling up to 12 m depth, trace of hard rock was not found and further drilling was proved difficult due to the presence of massive pebbles. In order to assess this by geophysical survey, seismic refraction method can be resorted to, which can give both depth to and quality of hard rock in terms of seismic velocity vis-à-vis strength.

Field set-up:

Data acquisition unit	: ABEM Terraloc MK6
No. of channels	: 24
Source type used	: Hammer shot & Blasing
Trigger mode	: Manual (geophone input)
Channel spacing	: 5 m with 115 m profile length

Figure 1. Location of Nagarjuna Sagar Dam, Nalgonda district, Andhra Pradesh

Recording frequency	: 10 – 250 Hz
No. of stacks	: 1 for blasting and 5 –10 for hammer shots
Recording format	: SEG 2
Operating software	: MK 6 Ver 5.0
Display type	: Monochrome in wiggle or other formats
Data processing	: Manual & Automatic

DATA ACQUISITION AND INTERPRETATION

Seismic survey has been carried out along three lines around 110 m to 160 m using, 24-Channel signal enhancement seismograph of ABEM, with 5 m spacing, one along the bridge alignment and two lines parallel to this alignment on the upstream and downstream side of the axis of the alignment (Fig. 3). Five sets of readings were taken for each profile, two in the forward, two in the reverse and one in the middle. The long offset forward shots were recorded at -95 m and –55 m offset. The longest offset available for the reverse shot was +75 m only. The short offsets were taken at ±5 m. Ensured collection of maximum information on the subsurface stratigraphy by multiplicity of short locations by additional shots were also taken at the pier locations as well. Data were collected by the hammer source; roll-on data gather method with shots taken on alternate geophone locations.

Seismic refraction method gives the information about the subsurface in terms of seismic velocities. These velocities are directly related to the quality and strength of the medium. However, as qualitative classification exercise in the present case, following seismic velocity classification is used for identifying the subsurface stratigraphy in terms of soil, weathered or hard rock layer, wherever necessary.

Subsurface strata	**Seismic velocities (km/sec)**
Soil layer (all types)	< 1.2
Pebbles/boulder mixed layer	1.2 - 2.0
Weathered rock layer	2.0 – 3.0
Hard rock layer	3.0 – 3.5
Massive rock strata	≥ 3.5

INTERPRETATION

The data for seismic section gathered during the present survey along the three lines are discussed below:

Line 1 (110 m):

This is 110 m long line along the bridge axis, recorded in the forward direction from P –5 to P –9. Starting point for this line is 13 m after the pillar P –5 and ending point is 12 m after pillar P –9. Seismic section along this line is shown in the Fig. 4. The thickness of the soil layer along this line varies between 6-8 m with an average seismic velocity of 0.5 km/s, indicating a loose soil. The seismic velocity in the second layer is in the rage of 1.2 to 1.8 km/s, indicating a stratum mixed with pebbles or boulders. The thickness of this layer undulates along this line, varying between 10-19 m. The maximum thickness of this layer is 40 m in the center of the line. Hard rock is mapped below this layer. Seismic velocity in the layer gradually increases downwards suggesting that the hard rock quality improves with depth. Velocity of this layer is found between 3.0 to 3.8 Km/s, with an average of 3.4 km/s. This is suggestive of a good rock mass with an average compressive strength of 80 Mpa[1], good enough for laying any civil foundation for superstructures. Except for the presence of an anomalous depression in the second layer in the center of the line, no other anomalous feature is mapped. This might be dismissed as a local disturbance, or may be attributed to the presence of old tributary of the river, that might have been filed up over the years due to river run-off.

Figure 2. View of bridge construction site showing three seismic lines (Line –1, Line –2, and Line-3) along bridge alignment

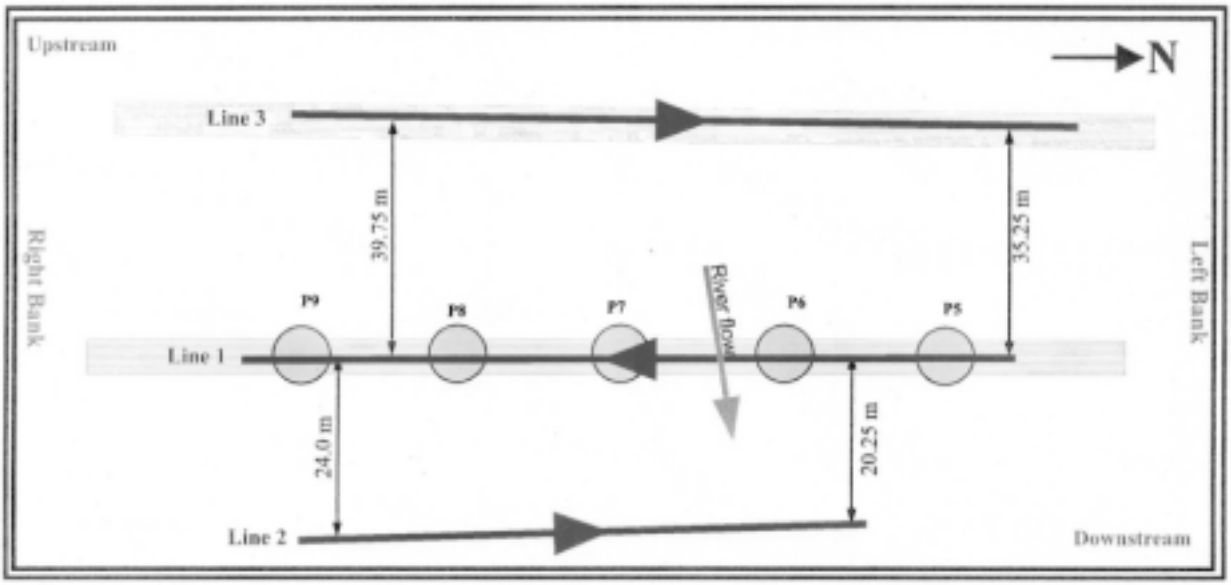

Figure 3. Schematic plan for geophysical survey

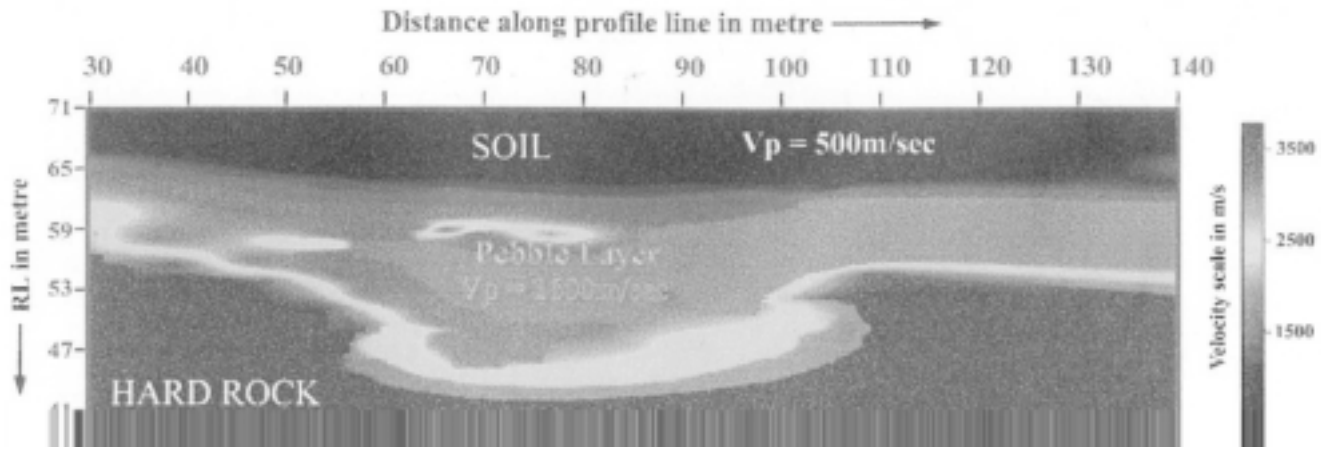

Figure 4. Seismic section for Line –1 along bridge axis

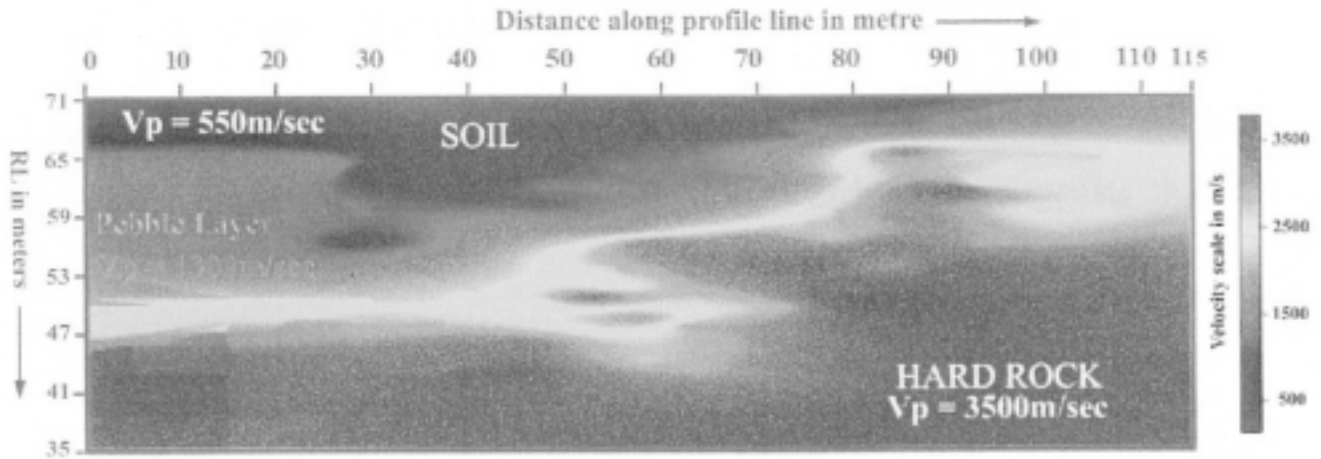

Figure 5. Seismic section for Line –2 downstream of Line –1

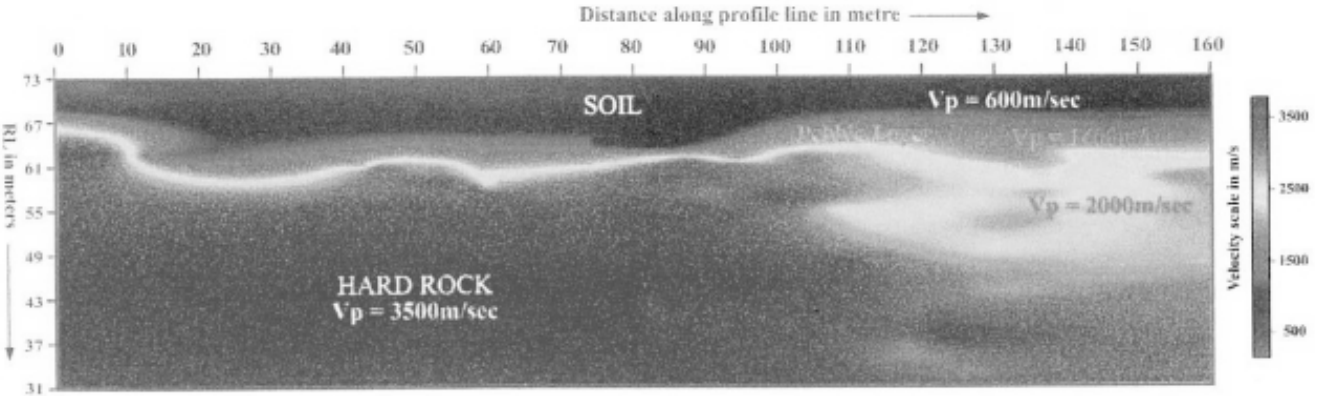

Figure 6. Seismic section for Line –3 along coffer-dam

Line 2 (115 m):

115 m long line is away 22 m downstream of line 1. This is recorded in the reverse direction from P –9 to P –5. However, section is presented as mirror section for better visualization.

Seismic section along this line is shown in Fig. 5. The thickness of the soil layer along this line varies between 5 m to 10 m with an average velocity of 0.6 km/s, indicating loose soil. Below this layer of velocity 1.2 km/s showing the stratum mixed with pebbles or boulders having a maximum thickness 30 m near P-9 and tapering on either side of the line. Hard rock layer is mapped below this boulder layer of velocity 3.5 km/s, suggestive of a good rock mass with a compressive strength of 90 Mpa, good enough for laying civil foundation for superstructures.

Line 3 (160 m):

This is 160 m long selected 37 m west (upstream) of line 1 along an existing cofferdam. This line is also recorded in the reverse direction, but the seismic section (Fig. 6) is presented as mirror image (forward direction) for better visualization.

This section shows that the thickness of the soil layer having velocity of 0.6 km/s varies between 3 m to 8 m. Velocity of the second layer is comparatively higher along this line about 1.4 km/s - 2.0 km/s indicating a stratum mixed with pebbles gradually ending up with weathered rock towards the end. This layer has a maximum thickness of 15 m – 18 m in the last part of the line 40 m. Hard rock layer is mapped below this layer with similar quality like the previous line,

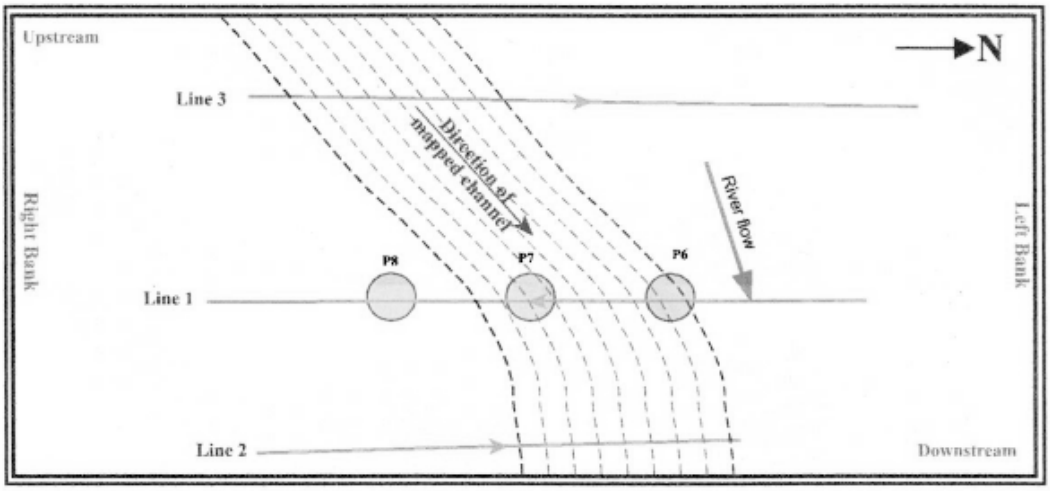

Figure 7. Plan showing river channel

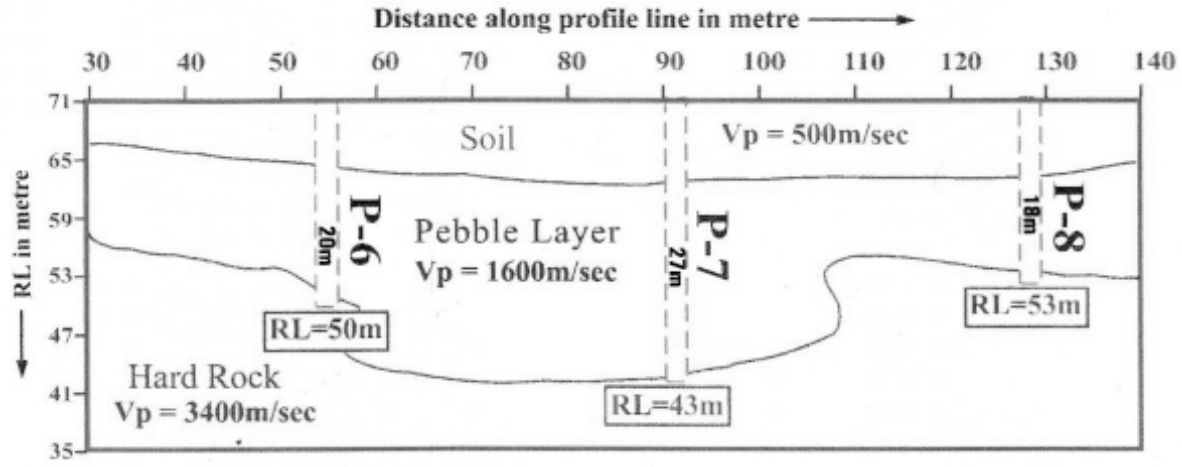

Figure 8. Founding levels for various piers

with an average velocity of 3.5 km/s. The anomalous thick low velocity layer observed in the other two lines is seen noticed towards the end (P –9). Table summarizes the results of subsurface stratigraphy along the three lines as obtained from the seismic refraction survey.

Line ID	Line Length	Location	Average thickness & depth	Remarks
Line – 1	110 m	P –6	Soil = 7.0 m Pebble = 30 m Hard rock = 20 m	Loose top soil followed by a layer filled with pebbles, cobbles and soil
		P -7	Soil = 7.5 m Pebble = 19 m Hard rock = 27 m	Hard rock depth maximum at pier location P -7
		P –8	Soil = 8.0 m Pebble = 10 m Hard rock = 18 m	
Line –2	115 m	22m Downstream	Soil = 9 m Pebble = 15 m Hard rock = 15-24 m	Hard rock is at a depth between 15-24 m, deeper in the beginning of the line
Line –3	160 m	37m Upstream	Soil = 9 m Pebble = 15 m Hard rock = 15-24 m	Hard rock is mapped relatively shallower along this line

DISCUSSION AND CONCLUSION

Seismic refraction study has shown that the rock mass along the bridge alignment has a very undulating trend. The quality and strength of the overall strata along this alignment appears to be reasonably good. The minimum compressive strength of the hard rock is 70 Mpa and to the extent up to 90 Mpa, which satisfies the IRC-78 criteria for the foundation layout. The topsoil layer is also more or less uniform, but the second layer comprising riverine material has swollen in the center of the alignment posing a problem for foundation design.

Further seismic results have shown the presence of a depression in the hard rock layer resembling a nallah type feature in the middle of the line 1. Seismic sections of other two lines 2 and 3 showed that this feature was on the southern side of line 3 and northern end of line 2. Thus, it appears that a deep-seated channel is crossing the bridge alignment between pillars P –6 and P 9 (Fig. 7), showing southwest – northeast trend. Maximum depth of this channel is mapped 24 m along line-3, 27 m along line-1 and 20 m along line-2. The sudden depression in the hard rock layer at P- 6 pier, as compared to its availability at 4 m - 5 m on the flanking pillars on either side, suggested some local disturbance. Strong current of water flow in this channel in the past had filled it by the flowing pebbles/boulders. At present this channel is packed with riverine deposits and buried within the river floor.

IRC –78 criteria defines that the founding level for bridges should be 0.6 m below the rock level having a crushing strength in excess of 10 Mpa. From the present results, hard rock is found at 20 m depth at pier location P –6, 27 m at pier P –7 and 18 m at pier location P –8 (Fig. 8). Accordingly the recommended founding levels (RL) for these piers are 50 m, 43, and 53 m respectively. Appropriate foundation design has to be evolved for such a deep foundation.

ACKNOWLEDGEMENTS

Authors are very grateful to the Andhra Pradesh State Highway Projects, a division of R & B as part of the highway development funded by World Bank.

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