SEISMIC REFRACTION SURVEY A RELIABLE TOOL FOR SUBSURFACE CHARACTERISATION FOR HYDROPOWER PROJECTS

Alex Varughese, Scientist ‘C’, Central Soil and Materials Research Station, New Delhi, alexvarughese@gmail.com
Pankaj Kumar, Assistant Research Officer, Central Soil and Materials Research Station, msinha72@gmail.com
Nripender Kumar, Scientist ‘D’, Central Soil and Materials Research Station, New Delhi, nipendra@nic.in

ABSTRACT: Seismic refraction survey is widely accepted as a non-destructive dynamic test for site characterization. It is used to determine the magnitude of seismic wave velocities and to locate significant elastic discontinuities of the subsurface. Seismic refraction survey plays an important role in the field of geotechnical investigations. This type of investigation is fast and economic, so large area can be covered in less time to determine the depth of bed rock, depth of overburden, estimating rippability, shear zones etc. The primary objective of this paper is to provide information about this method, equipment used, methodology adopted, data collected and interpreted for two projects namely Raoli and Seli project, H.P and Mapang Sirkari Bhyol HE Project Uttrakhand and its different applications in site investigation and site characterization. The disadvantages and the possibility of errors are also discussed. In all these projects the aim of the survey was to provide and evaluate the thickness and quality of the overburden and characteristics of the bedrock along the surveyed seismic lines. It is demonstrated that Seismic Refraction Survey is a reliable tool for subsurface characterization.

INTRODUCTION
Development of hydropower schemes which involve large structures demand initiation of a well-considered programme of investigation that would provide sufficient information, specially about the status of the subsurface condition towards facilitating:

- Site selection
- Feasibility evaluation
- Planning and establishing safe and economic project.

Besides the involvement of the requisite geological, geotechnical, hydrological and other relevant studies during the investigation stage of the scheme, the scope and extant of subsurface exploration would generally depends upon:

- Size and type of project
- Budget allocation
- Available time-frame
- Project site accessibility / approachability
- How obvious are the prevailing surface and subsurface conditions.

Of the various subsurface explorations involved during the investigation stage of hydropower projects Seismic Refraction Survey was found to be the best tool for geophysical investigation.[1]

SUBSURFACE INVESTIGATIONS
Direct and Semi-Direct Explorations:
The conventional subsurface exploration methods, generally in practice, include the direct and semi-direct exploration techniques viz.:

- Pitting
- Drifting
- Making Shafts
- Drilling (coring & non-coring)

These exploration techniques help in visual inspection and identification of the subsurface stratification / lithology, determination of physical characteristics as well as facilitate in conducting geotechnical and other in-situ and lab tests.

In order to accelerate the subsurface investigation programme, keeping in view the restricted time-frame and finance, calls for a comprehensive approach towards performing the needful explorations for generating adequate knowledge of the underground: Accordingly it necessitates initiation of a well-considered plan involving direct as well as indirect rapid and economic techniques, helpful in boosting the investigation programme.

Indirect Exploration
Geophysical methods are indirect exploration techniques as measurements recorded at the surface are used for interpreting the status of the subsurface.

Engineering Geophysics is a powerful means of subsurface explanation practiced worldwide. It is a scaled-down version of the techniques developed in the oil and mineral exploration sectors. The merit of this low cost aid lies in its rapidity in providing a reliable profile of the subsurface over a large aerial extent.

Its application in conjunction with geological, geotechnical and other investigations, results in a comprehensive study enhancing the efficiency and level of confidence. Technological advancements, in recent times and development of sophisticated computerized instrument systems and processing softwares like Multi Channel
Analysis of Surface Waves (MASW) have increased the versatility of application of engineering geophysics. Even then Seismic Refraction Survey is a very reliable technique.

In hydroelectric project investigation, for gainful and effective utilization of engineering geophysics, it is important to plan the application appropriate to the study objective, taking into consideration:

- The likely geological conditions.
- The corresponding favourable and limiting factors.
- The terrain conditions.

Seismic refraction Survey is most used technique in Hydro electric projects [2]. This was effectively carried out in many projects to evaluate the thickness and quality of the overburden and characteristics of the bedrock along the surveyed seismic lines.

THE SEISMIC REFRACTION SURVEY

In seismic refraction survey, elastic waves are generated artificially by explosive source or by mechanical hammer. By the virtue of the elastic behaviour of the rock, the elastic deformation propagates in all direction as spherical wave fronts.[3] On critical refraction the refracted waves travels along the interface and sends out secondary waves to the surface. These returning waves are recorded in the seismic refraction survey. A typical seismic profile consists of 24 number of vertical geophones uniformly spaced at a distance of 5 m. Explosive/ mechanical hammer is used for creation of waves. Usually five or seven shots are used for recording the waves depending upon the topography and lay out of the profile.

Data Acquisition

A seismic spread usually consists of 24 – geophones connected to the recording system (ABEM TERRALOC), (Fig.1) by two 12 – conductor cables. A seismic unit basically consists of geophones, seismic cables, seismic energy source, blaster, amplifiers and recording device. The amplifier’s function is to boost the signal detected by the geophones to a level suitable for input to the recording device. The main energy source used was low charge blasting. For each spread of 24 geophones, 5 shots were executed: 3 shots within the profile to obtain the lateral velocity variation in the top layer(s) and 2 far shots on either side of the spread, to provide the true seismic velocity of the “sound” rock surface [5]. The seismic record from each shot was verified in the field for the accuracy of the data.

Interpretation Techniques

There are various methods of interpretation of seismic refraction field data viz. Intercept Time method, Critical Distance method, Hale’s method, Wave Front method and Hawkins method or Plus - Minus method or ABC method [5]. In this case, interpretation of seismic data was done using ABC method. This method provides information on thickness of the various layers, depth.

Fig.1 Seismic Refraction Survey Under Progress at Mapang Sirkari Bhyol HE Project, Uttarakhand using ABEM TERRALOC

to bed rock under each geophone and rock quality. The interpretation procedure consist of picking up of first arrivals of P-wave from the records. The time–distance plots are drawn for all the shot points. The interpretation of P-wave velocity and depth of various layers of subsurface formations are then performed by plus-minus method. The bed rock depth has been calculated at every geophone position to arrive at the bed rock profile.

Precision and Limitations

The depth of bed rock computed from seismic refraction data should be accurate with in +/- 10% of the actual depth [6]. Other phenomenon such as velocity inversion and hidden layers diminish the procedure for interpretation [7]. However, weathered bedrock may have velocity very close to the overburden velocity which may lead to wrong interpretation. These cases may be avoided by correlation with borehole information. Extreme care should be taken when Seismic Refraction Survey is conducted along the valley. Depending on the profile of bed rock and if the geophone is not vertical it can give erroneous depths (Fig . 2). For an actual depth of AB we may get the depth as AC. To overcome this more seismic lines close to each other must be laid along the valley and a general profile of the bed rock must be determined. Depth to the bed rock must be determined by joining the arc with geophone as centre.

CASE STUDIES

In this paper two projects namely Raoli and Seli project, Himachal Prades and Mapang Sirkari Bhyol HE Project Uttarakhand are situated in Himalayas. Both the two are for Hydro Power generation.
Seismic Refraction Survey a Reliable Tool for Subsurface Characterisation for Hydropower Projects

Raoli and Seli Hydro Electric Project, Lahaul and spiti, Himachal Pradesh

The project envisages the construction of two nos of dams one at Seli and the other at Raoli in Lahul and Spiti district of Himachal Pradesh for the generation of power. These project area is located on the river Chenab (Chandrabhaga River) in the d/s of Udaipur at a distance of 10 kms and 22 Kms respectively from Udaipur on the road to Jammu. The project contemplated as a run of the river scheme, envisages the construction of a 90 M high concrete gravity dam with nearly 4.8 km long Head Race Tunnel. Further, underground surge shaft and power house to be located nearly 1.25 km d/s of the Kurched Nala confluence with Chandrabhaga river to utilize 41 cumecs of water through a gross head of 120 M to generate 42 MW (installed capacity 166 MW) of power at Seli. The project site is accessible by road via Rohtang Pass where hours of road blockages due to land slides very common. The planting of geophones is given in Fig.3. A length of 470m each was surveyed at Raoli and Seli and Project, H.P.

Fig.2 Seismic Lines laid on a Slope

In the project area, the rocks occurring at and in the vicinity of the proposed dam site are porphyroblastic gneisses and schist which are included in the Central Himalayan Crystalline.[8] The region is bounded by two major planes of dislocations the Main Central Thrust in the south while the Dar Mastoli Fault marks the Northern limit with the rocks of the Tethyan zone. The MCT is an important structural discontinuity in the area which separates the rocks of Garhwal group, from those of the central crystalline group comprising porphyroblastic augen chlorite mica schist and phyllitic quartzites. The MCT dip at a moderately high angle towards north and crosses Goriganga river about 10 km upstream of Jangjibi. The Dar Martoli Fault demarcates the boundary between central Himalayan Crystalline and rocks of Tethyan zone i.e Budhi Schist etc.

From the nearest place District HQ Munsiari it takes two days of trekking through difficult terrain to reach the site (Fig.4). The entire equipments were carried on Mule. A length of 283m of Seismic Refraction survey was carried out across the dam axis.

Mapang Sirkari Bhyol HE Project Uttrakhand

The Mapang Sirkari Bhyol H.E. Project a run of the river scheme envisages the construction of a 83 M high concrete gravity dam across the river Goriganga at Mapang in the district of Munsiari, Uttrakhand and a 12 km long HRT passing through high mountainous tract (4000m) on the left bank of Goriganga followed by a surge shaft and under ground power house north of Rargari on the left bank with an installed capacity of 370 MW.

In the project area, the rocks occurring at and in the vicinity of the proposed dam site are porphyroblastic gneisses and schist which are included in the Central Himalayan Crystalline.[8] The region is bounded by two major planes of dislocations the Main Central Thrust in the south while the Dar Mastoli Fault marks the Northern limit with the rocks of the Tethyan zone. The MCT is an important structural discontinuity in the area which separates the rocks of Garhwal group, from those of the central crystalline group comprising porphyroblastic augen chlorite mica schist and phyllitic quartzites. The MCT dip at a moderately high angle towards north and crosses Goriganga river about 10 km upstream of Jangjibi. The Dar Martoli Fault demarcates the boundary between central Himalayan Crystalline and rocks of Tethyan zone i.e Budhi Schist etc.

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DISCUSSIONS OF RESULTS

Raoli and Seli HE Project HP

A total of 585m length of Seismic Refraction Survey was conducted with 5m spacing at Seli dam site and 350m length was surveyed at Raoli dam site. It was found that the velocity of the first layer varies from 500-1800 m/sec, second layer varies from 3400 to 4800 m/sec. From visual examination as well as from geophysical interpretation it can be confirmed that the first layer consists of river borne materials i.e. sands / highly weathered rock. second layer consist of bed rock. The depth of the bed rock zone varies from 4 to 22 m. The bed rock velocity in the investigated area can be taken as 3400-4800m/sec. However, a thickness of 25-50cm of dry sand is present in almost all areas were have been investigated could not be interpreted. No shear zones was detected along the surveyed seismic lines. The results of seismic refraction tests (Table 1) was calibrated by drill holes at suitable locations at

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various sites confirm the findings of Seismic Refraction Survey. A geoseismic section of one profile is shown at Fig. 5

**Table 1** Summary of Results of Seismic Refraction Tests

<table>
<thead>
<tr>
<th>Profile No:</th>
<th>Length (m)</th>
<th>Velocity (m/sec)</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110004</td>
<td>235</td>
<td>600-1500</td>
<td>4-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3750-4000</td>
<td></td>
</tr>
<tr>
<td>110005</td>
<td>235</td>
<td>600-1000</td>
<td>8-22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3400-4000</td>
<td></td>
</tr>
<tr>
<td>110001</td>
<td>115</td>
<td>1500-1800</td>
<td>4-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4200-4800</td>
<td></td>
</tr>
<tr>
<td>550001</td>
<td>235</td>
<td>550-1600</td>
<td>5-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3400-4200</td>
<td></td>
</tr>
<tr>
<td>550002</td>
<td>115</td>
<td>500-750</td>
<td>6-12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3400-4000</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 5** Geoseismic section of Profile No:110004 & 5

**Mapang Sirkari Bhyol HE Project Uttrakhand**

One seismic line of the length 115m with 5m geophone interval was surveyed (Fig. 6). Here the Geophysical model suggests a two layer case. The velocities for first and second layers is 1200 m/s and second layer velocity from 4400 to 5600 m/sec respectively. Results show that first layer comprises compacted boulder and sand from the ground surface and the second layer comprises of weathered to bed rock. The depth of the first layer varies from 10m to 19 m. The fresh rock boundary has been established. The area was limited to conduct Seismic Refraction Survey due to the topography and submergence more lines could not be laid.

**CONCLUSIONS**

In both the projects Seismic Refraction Survey was utilized to evaluate the thickness and quality of the overburden and characteristics of the bedrock along the surveyed seismic lines. The bed rock was established in both cases. From the evaluated compressional wave velocities the geological layers can be generally classified as shown below. The survey results were presented as P-wave velocity profiles. The seismic survey results gave an insight on the P-wave velocity and vis a vis in terms of the stratigraphy. The Seismic Refraction Survey has been proved as one of the most reliable tool for subsurface characterisations for hydropower projects. This method plays an important role in geotechnical investigations as this fast, economical, reliable, and can cover a large area to delineate the subsurface. Seismic Refraction Survey was very effectively used Raoli and Seli HE Project HP and Mapang Sirkari Bhyol HE Project Uttrakhand projects for the subsurface delineation.

**Table 2** Classification of Geological Layers with P wave Velocity

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Velocity (m/sec)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 1000</td>
<td>overburden</td>
</tr>
<tr>
<td>2</td>
<td>1000-1400</td>
<td>highly weathered rock</td>
</tr>
<tr>
<td>3</td>
<td>1400-2500</td>
<td>weathered rock</td>
</tr>
<tr>
<td>4</td>
<td>2500-4000</td>
<td>weak zone in bedrock</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 4000</td>
<td>bedrock</td>
</tr>
</tbody>
</table>

**REFERENCES**

5. Sjo'gren, Bengt (1984), Shallow Refraction Seismic Chapman & Hall.