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Seismic refraction study of Gurara dam phase II, northwestern Nigeria

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Seismic refraction study has been carried out on Gurara Dam Phase II proposed axis with the aim of determining its feasibility for the founding of a dam. The field techniques involved off-end/reverse and split spread shootings on five profiles. The study site is situated on the Precambrian Crystalline Basement Complex rocks of North Central Nigeria. Velocity values obtained from the shots vary between 183 ms^{-1} in unconsolidated soil materials and 6522 ms^{-1} in the fresh bedrock. The overburden is presumably characterized by low to moderately high velocity varying between 183 and 1235 ms^{-1}. Fractured/partially weathered basement rocks within the study area are presumably defined by velocity ranging from 543 to 1667 ms^{-1}. The fresh bedrock is presumably characterized by velocity in excess of 2000 ms^{-1}. The results of the seismic refraction study conducted on the proposed dam axis showed that some portions of the western flank of the axis present noticeable seepage characteristics within the bedrock especially on profiles 1 and 2. Profile 4 on the eastern bank of Gurara River present a downward displacement of the bedrock. Profile 5 also on the eastern bank is characterized by significant fracturing of the bedrock with possibilities for seepage. The general characteristics of the materials within the investigated sections of Gurara Phase II dam study area indicate that they are competent and suitable. However, the existence of the delineated features susceptible to seepage requires some form of remediation to prevent seepage from the area proposed for reservoir through fractures and buried stream channels.

Key words: Seismic refraction, dam axis, velocity, overburden, seepage, fresh bedrock.

INTRODUCTION

Construction of large hydraulic structures which may involve impoundment of large water bodies requires the understanding of the general hydrogeophysical/ geological setting within the proposed site. At dam sites, surface geophysical studies (more importantly seismic refraction) remain a prerequisite to obtaining preliminary estimate of the strength, deformation and other physical properties of the rock mass and the thickness of overburden and weathered rock. The geophysical study results are needed to generally assess the suitability

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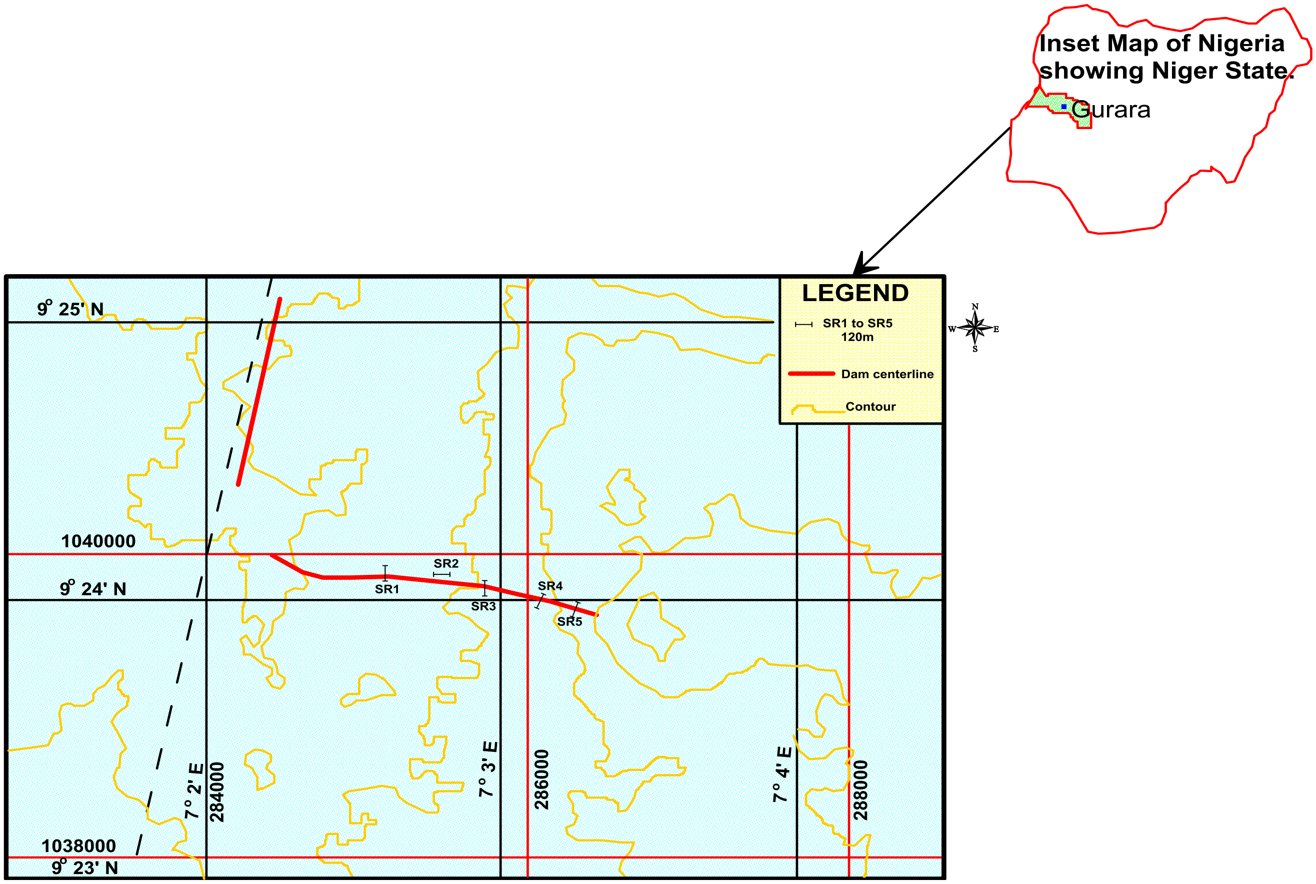

Figure 1. Base map of Gurara Dam Phase II area showing the proposed dam axis and the seismic refraction profiles.

of an area for the founding of a dam and enable the preliminary design and stability evaluation of the proposed structure. It also forms the basis for determining the type and extent of further investigations to be conducted during the final phase of the feasibility study and during design (Ueblacker, 2006). The seismic refraction method is the most frequently used geophysical means of investigating geological conditions at proposed dam sites. The seismic refraction method has been successfully utilized in areas where drilling has proved difficult due to the presence of massive pebbles to obtain results giving both depth to and quality of hard rock in terms of seismic velocity vis-à-vis strength (Rao et al., 2004). From the engineering vantage point, shallow seismic refraction has been used to study bedrock foundation properties in road tunnelling, dam sites, quarries, hydroelectric power plants, subway constructions, nuclear power plants and many other facilities (Abd El-Aal and Mohamed, 2010).

Detailed seismic refraction investigation carried out at Acheloos river dam (Central Greece) by Tselentis et al. (1987) enabled the determination of the deep layer structure and the dynamic behaviour of the foundation area within the dam environment. This study is aimed at delineating geologic/geophysical features such as overburden thickness, concealed basement topography, fractures/seepage channels(s) (where they exist) in the subsurface.

STUDY AREA DESCRIPTION

The Gurara Phase II Dam Project site (Figure 1) is situated about 62 km northwest of Abuja (administrative capital city of Nigeria) and 58 km southeast of Minna (Niger State capital city) metropolitan area. The main dam axis is oriented in West - East direction. The proposed upstream area of the dam is situated around Sana, Buru, Kumida and Shakwoi villages while the downstream is situated around Tuchi village. In the diagram of Figure 1, SR1 to SR5 corresponds to the profiles 1 to 5 while the red line indicates the proposed dam axis.

Local geology

The site of investigation is underlain by the Precambrian Basement Complex rocks of North Central Nigeria (Figure 2). The major lithological units are schist,

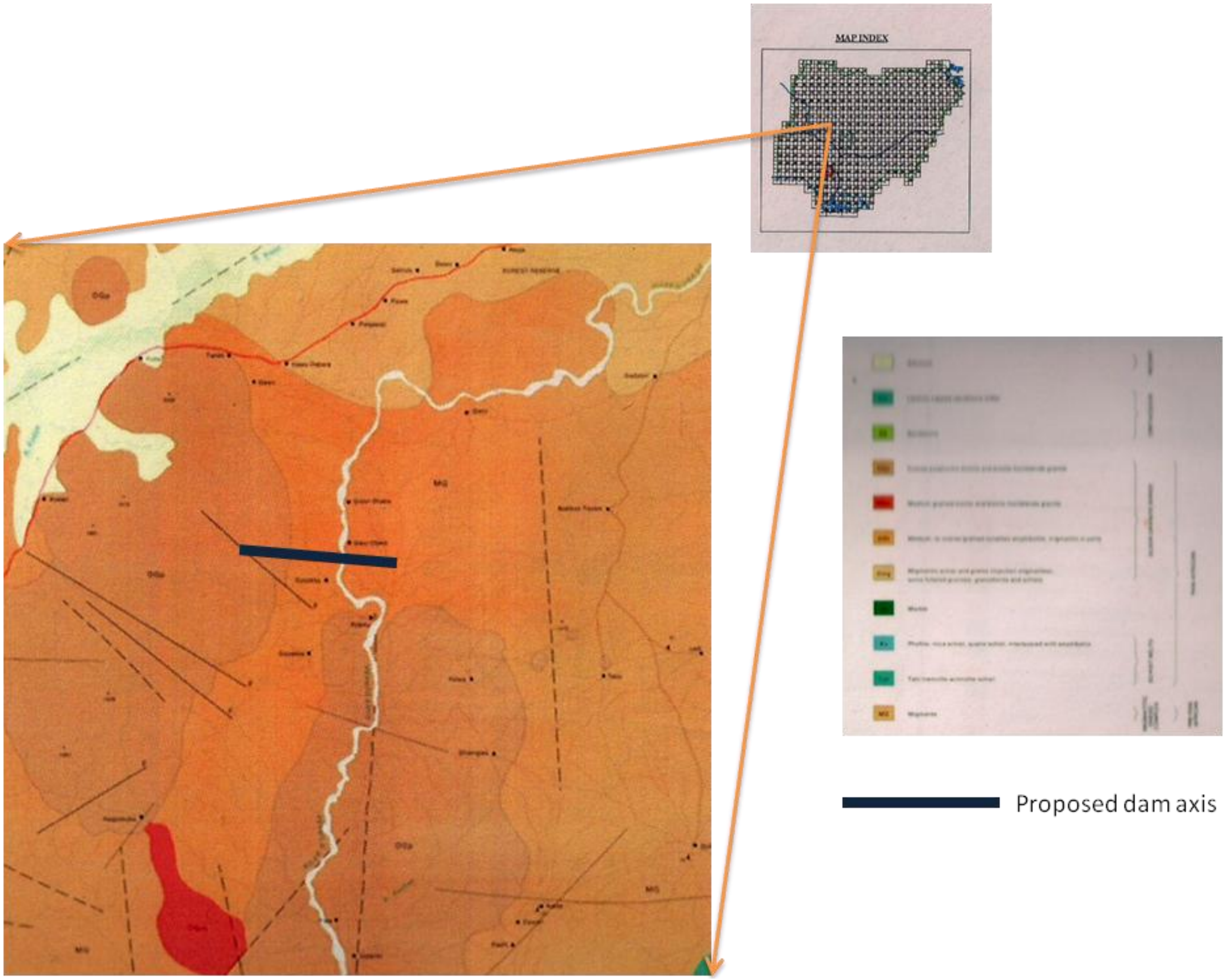

Figure 2. Geological map of Gurara Phase II Dam axis area (GSN, 2003 sheet 185).

migmatite gneiss, porphyroblastic gneiss and granite gneiss while minor units are the amphibolites, pegmatites and quartz veins. Evidences of tectonic activities, in form of multiple intrusive quartz veins cross-cutting micro faults and jointing abound in the study area. Linear structures especially joints were observed to predominate the structural patterns while localized faulting and folding were observed especially within the granite gneiss and migmatites. On the proposed upstream area of the study area, the migmatite gneiss occurs mostly on the eastern flank of river Gurara while the granite gneiss covers a wider portion of the area. The migmatite gneiss rocks do not show a definite contact with the granite gneiss but may have been intruded by the latter. The migmatite gneiss appears darker probably having a contact with the porphyroblastic gneisses between Burum and Kumida areas. The migmatite gneiss rocks are less resistant hence the large scale weathering observed when compared to the granite gneiss. Granite gneiss is the most widespread rock unit extending across the entire downstream area. At Tuchi, the rocks have sharp contact with the porphyroblastic gneiss in different locations. The Gurara Fall area which is situated northwest of Buru is predominantly underlain by porphyroblastic gneiss, granite gneiss and other small assemblage of rocks situated on the eastern limit of the area of study around profile 5.

Boulders and exposed parts of the bedrock show that porphyritic granite/coarse porphyritic biotite and biotite hornblende granite rock underlie the river bed.

Geomorphology

The Gurara in its course through the region displays two markedly distinct and straight flow channel directions which are NE - SW flow between Sana and Bonu and NW - SE flow between Bonu and Tuchi villages. Prominent range of hills extends across the region in the upstream area in a near East - West direction with relatively subdued peaks around Sana (≈482 m) and Shakwoi (≈492 m). Within this region, the Gurara River follows a near North - South flow direction traversing the range at average elevation of 465 m above mean sea level. The terrain, in general, is higher around Sana and Shakwoi in the upstream area (≈450 m) than around Tuchi in the downstream area (≈300 m). The group of tributary streams just north of Tuchi in the downstream area displays a trellis drainage pattern as the streams have cut into the metamorphic bedrock utilizing the foliation and jointing system. In general, drainage in the area is evidently structurally controlled since it tends to conform to the structural grain of the underlying basement rocks. Vegetation in the area varies considerably. In the upstream area, the vegetation consists of thin low shrub vegetation, scattered tall trees and grass. The banks of the Gurara River between Sana and Tuchi villages are characterized by tall trees, grasses and other riverine vegetation. The tributary courses draining into the Gurara channel are also densely vegetated. The drainage pattern is dendritic. Gurara lies within the guinea savannah belt of Nigeria characterized by parkland savannah, gallery forest and derived savannah.

METHODOLOGY

The ‘seismic refraction’ method was adopted for the surface geophysical investigation. A total of five (5) profiles, each measuring 120 m were occupied. Geophones were laid out at 5 m intervals along each of the profiles. Energy source was a weight drop consisting of 20 kg sledge hammer and steel plate. A total of seven (7) shots were taken on each profile - one shot at extremities, one shot at the middle of the profile, one shot inside the profile at 30 m of each profile extremity and two offset shots at 30 m of each extremity. Qualitative seismic refraction studies on the field involved evaluation of field monitor records (Figure 3) for distinct arrival wave train. Low signal to noise ratio usually associated with weight drop was minimized by repeating shot several times for selection of best records. ABEM Terraloc Mark 6, 24 Channel Seismograp (www.abem.com) was used for field data acquisition. Extraction of seismic refraction field data from the seismograph and picking of first breaks were undertaken using Pickwin™ Version 3.14 software. The first arrival times thus picked automatically and edited manually are utilized in generating time-distance plots.

Quantitative interpretation of time-distance plots involved computation of gradients of segments identified, determination of depth to refractor interface using the intercept time method. Thicknesses of refractors adopted in this study are:

$$Z_1 = \frac{t_1 V_1 V_2}{2\left(V_2^{\,2} - V_1^{\,2}\right)^{\frac{1}{2}}}$$

and for multi-layer observation:

$$Z_2 = \frac{t_2 V_1 V_2}{2\left(V_2^{\,2} - V_1^{\,2}\right)^{\frac{1}{2}}} - Z_1 V_2 \frac{\left(V_3^{\,2} - V_1^{\,2}\right)^{\frac{1}{2}}}{V_1\left(V_3^{\,2} - V_2^{\,2}\right)^{\frac{1}{2}}}$$

The time-distance plots for the shots on entire profile length are used to generate composite travel time-distance plots (Figures 4 to 8). A combination of the interpreted time-distance plots are utilized for generating seismic refraction (geo-velocity) sections.

RESULTS AND DISCUSSION

The seismograms showed that the records of shots taken at the extremities and within the profiles present moderately discernible records while those taken at 30 m offset present barely discernible records. Velocity values obtained from the shots vary from 183 m/s in the unconsolidated soil materials to 6522 m/s in the fresh bedrock. Using Palmer (2001) classification of seismic velocity values of friable soil to approximate about 400 m/s, weathered material to approximate 700 m/s, and a main refractor with an irregular interface to approximate seismic velocities between approximately 2000 and 5000 m/s, the overburden in Gurara Phase II site is therefore presumably defined by low to moderately high velocity values varying between 183 and 1235 m/s. Fractured/partially weathered basement rocks within the study is defined by velocity values ranging from 543 to 1667 m/s. Thicker low velocity layers (ranging from 8.45 to 12.24 m) were delineated on profiles 1 and 2. The near-surface higher velocity values mostly in excess of 2000 m/s (Tshering, 2006) obtained within the vicinity of the river (profiles 3 and 4) indicate the possibility of shallow fresh basement rocks. Geo-velocity section generated for profile 1 is presented in Figure 9. The profile which is located on the extreme west of the dam axis is characterized by low velocity values varying between 263 and 571 m/s which are diagnostic of overburden materials with thickness values varying between 8.45 and 18.68 m.

Adopting Kilty et al. (1986) deduction that velocities in the bedrock range from 1,829 to 7,620 m/s, the bedrock in this study is consequently presumably characterized by higher velocity values ranging from 1087 to 5000 m/s. A column of low velocity materials (285 to 290 m/s) were delineated between Station 30 and 70 m perhaps indicative of weak materials. Existence of fractured basement (defined by 571 to 725 m/s) is suspected at the southern flank of the profile. Geo-velocity section generated for profile 2 is presented in Figure 10. Profile 2 is the only profile located parallel to the proposed dam axis. The overburden materials are characterized by low velocity values varying between 185 and 597 m/s with thickness values ranging from 8.11 to 13.74 m. The bedrock is characterized by fairly high velocity values varying between 1000 and 1613 m/s. Low velocity materials (243 to 383 m/s) were delineated between

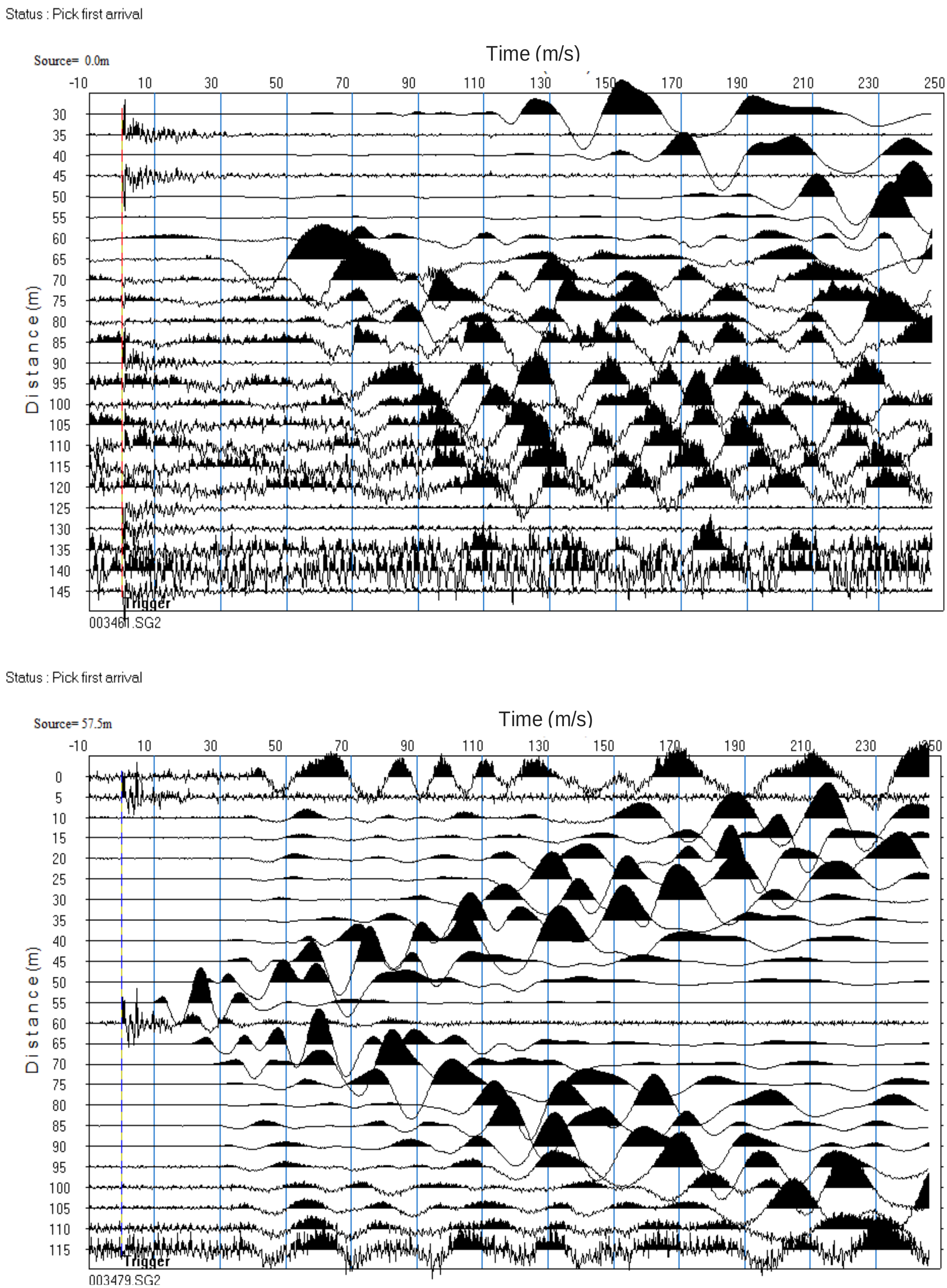

Figure 3. Typical field monitor records.

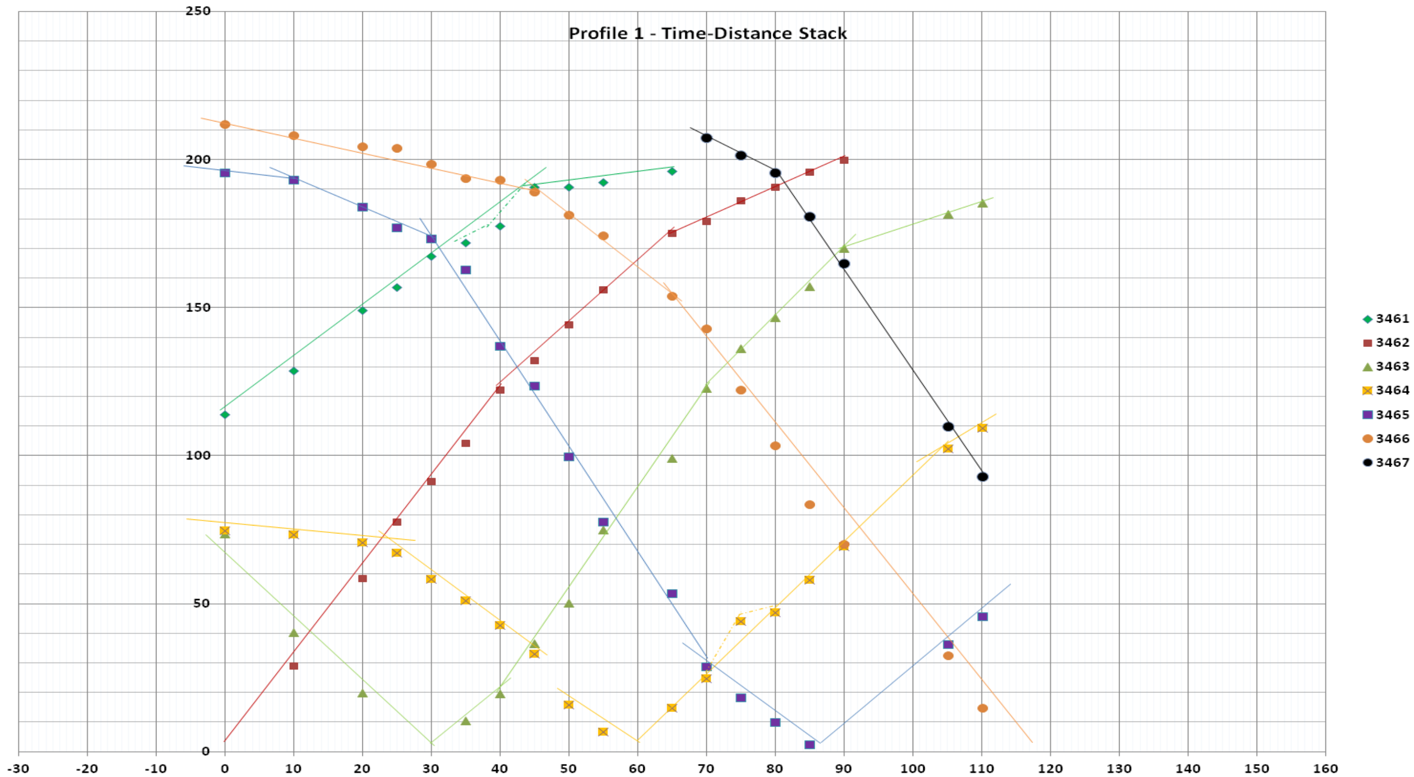

Figure 4. Composite travel time-distance plot of profile 1.

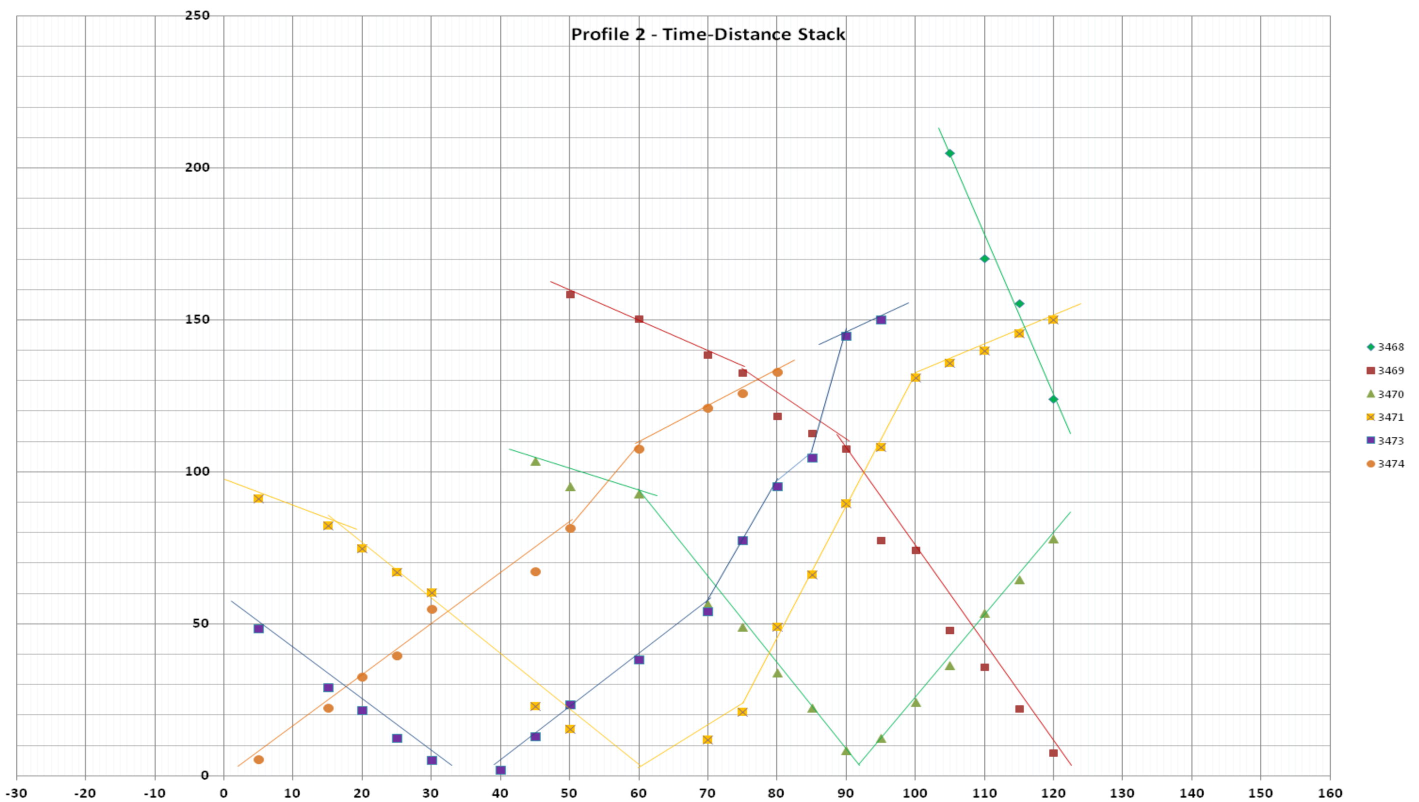

Figure 5. Composite travel time-distance plot of profile 2.

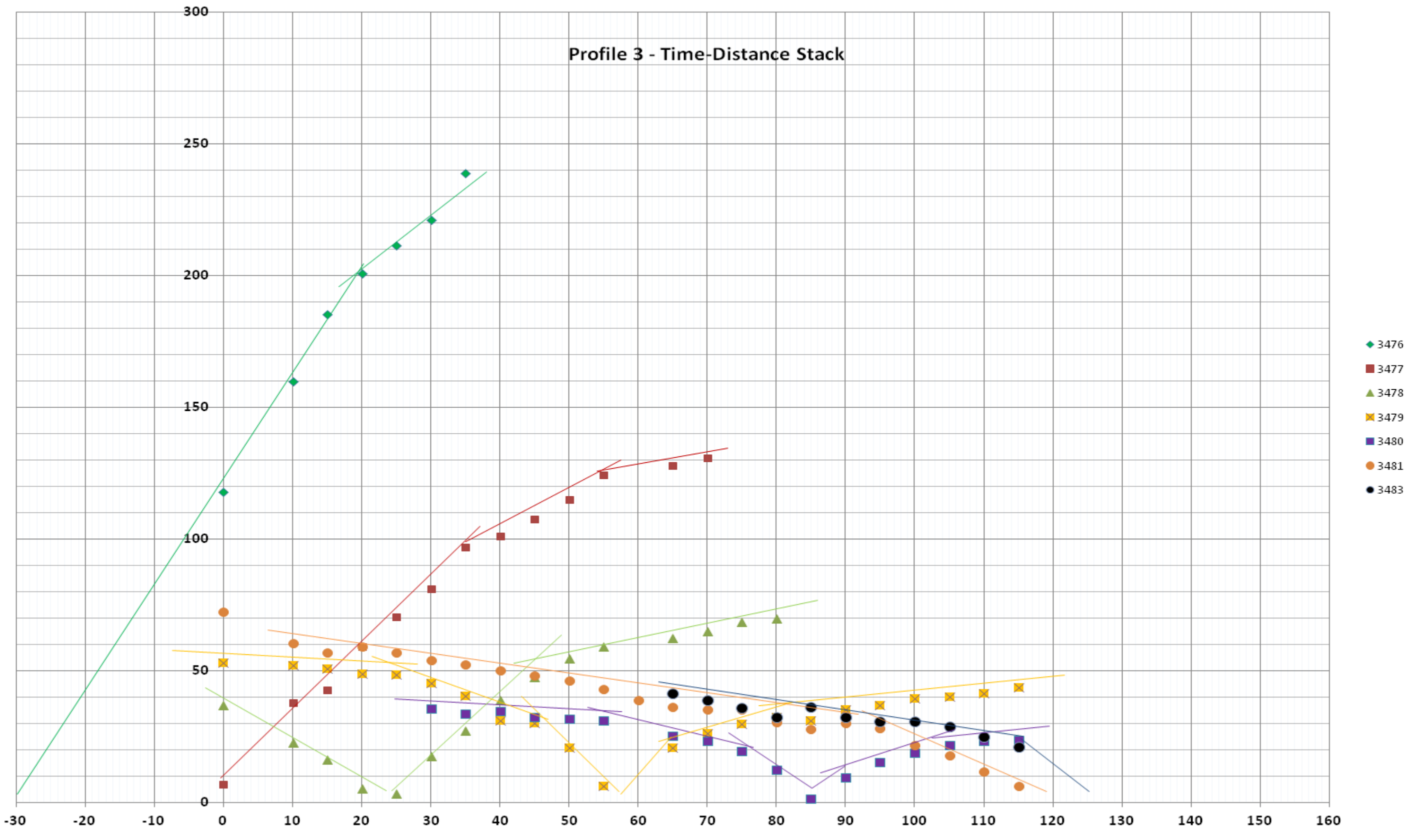

Figure 6. Composite travel time-distance plot of profile 3.

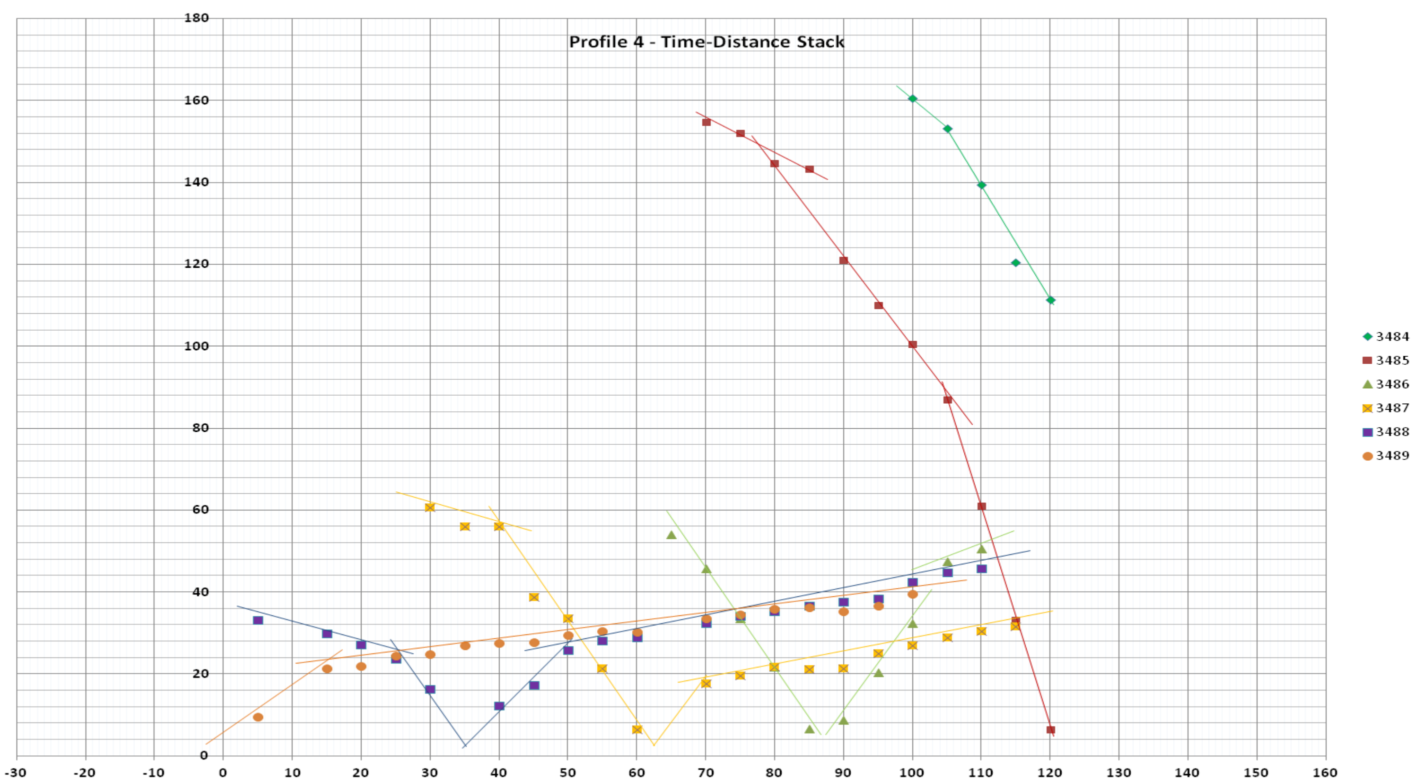

Figure 7. Composite travel time-distance plot of profile 4.

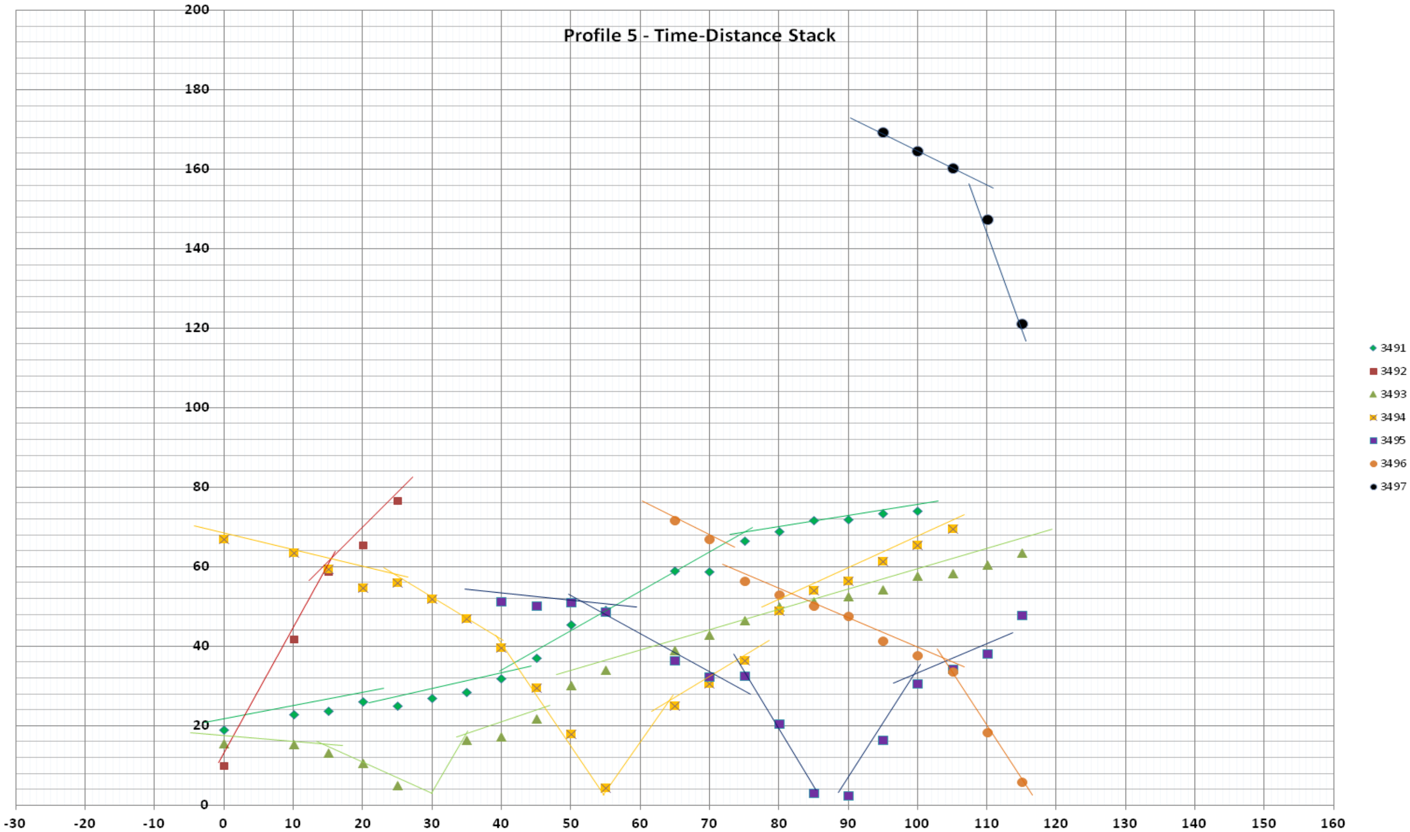

Figure 8. Composite travel time-distance plot of profile 5.

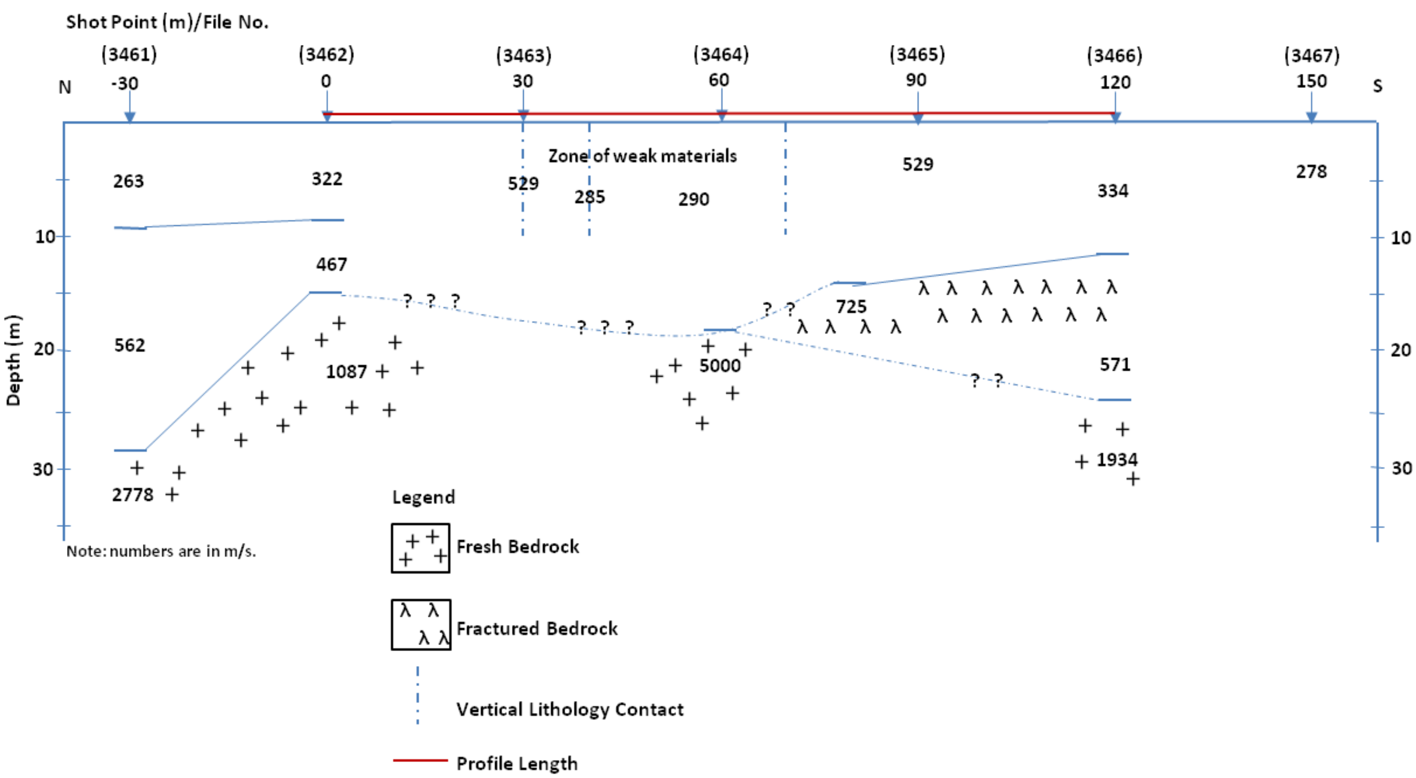

Figure 9. Seismic refraction (geo-velocity) section of profile 1.

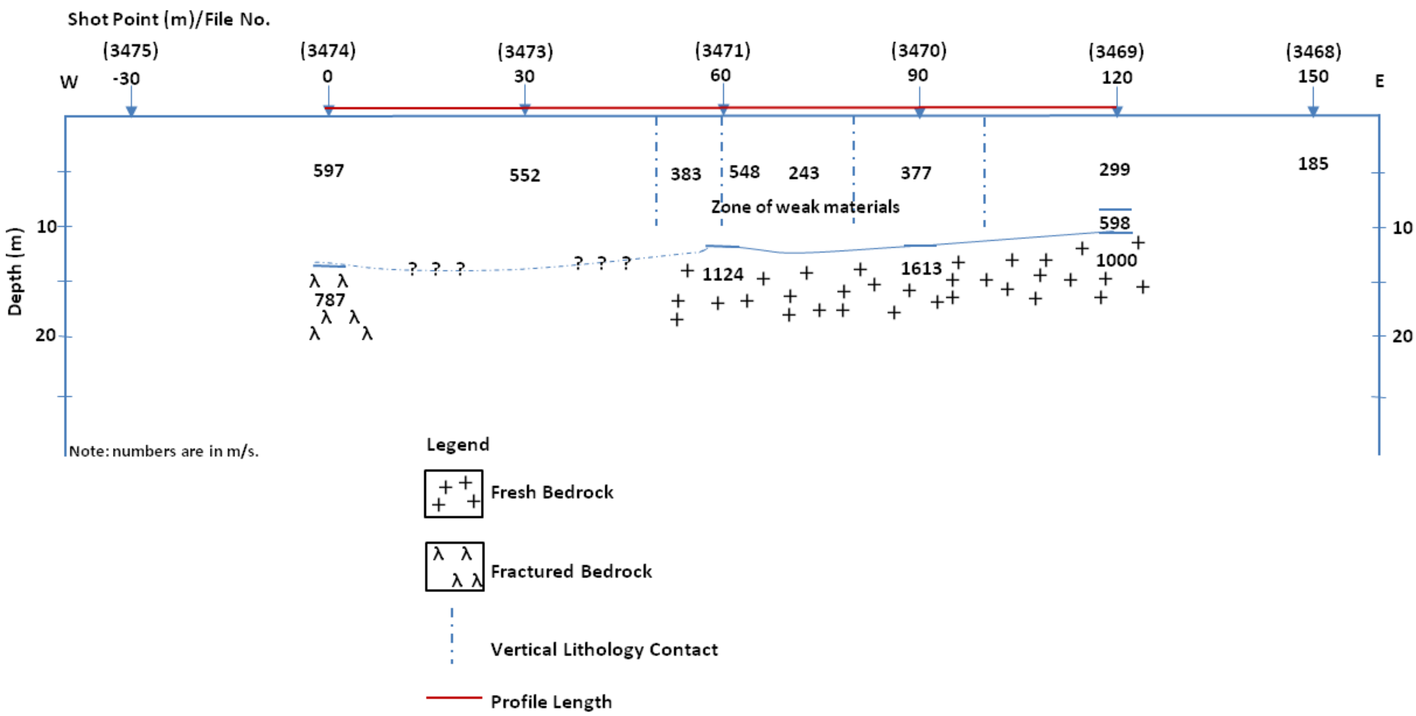

Figure 10. Seismic refraction (geo-velocity) section of profile 2.

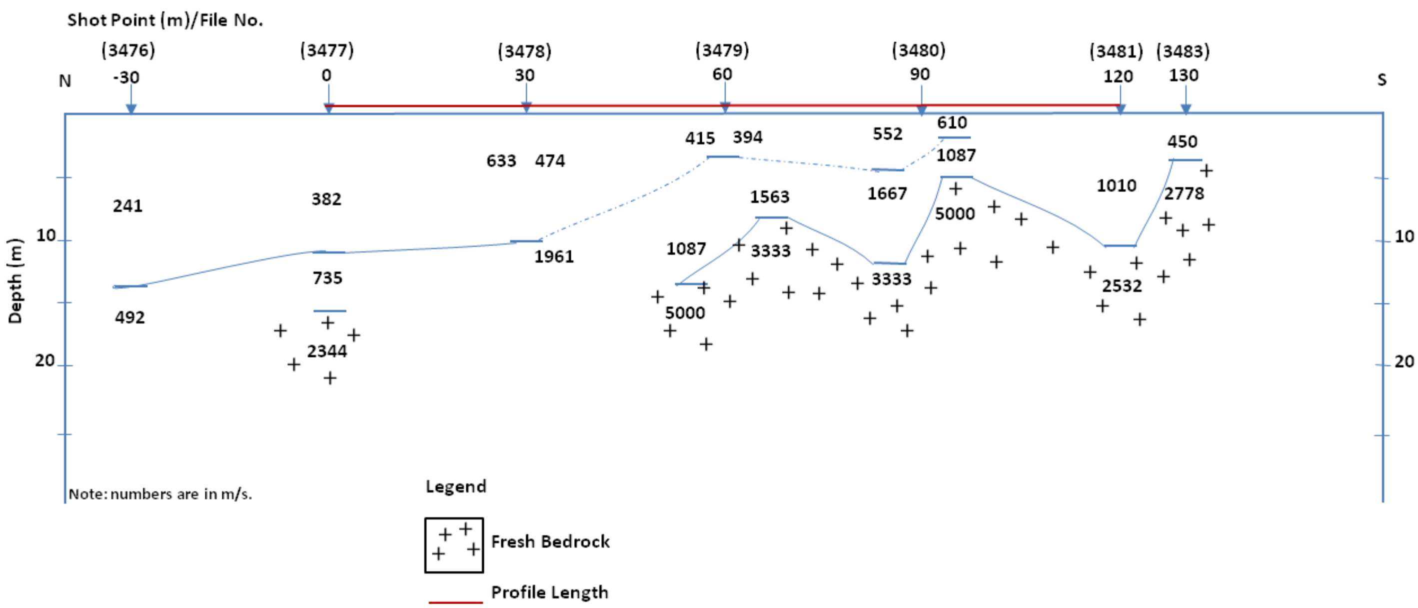

Figure 11. Seismic refraction (geo-velocity) section of profile 3.

Station 50 and 100 m presumably indicative of weak materials. Existence of fractured basement (defined by 787 m/s) is suspected beneath the western limit of the profile. Geo-velocity section generated for profile 3 which is proximal and parallel to the Gurara River on the western flank is presented in Figure 11. Overburden materials beneath the profile are relatively thin and characterized by low velocity values varying between 241 and 1010 m/s with thickness values ranging from 1.47 to 13.82 m. A transition layer of moderate to high velocity values (492 to 1667 m/s) was delineated between the overburden and the high velocity fresh bedrock. The

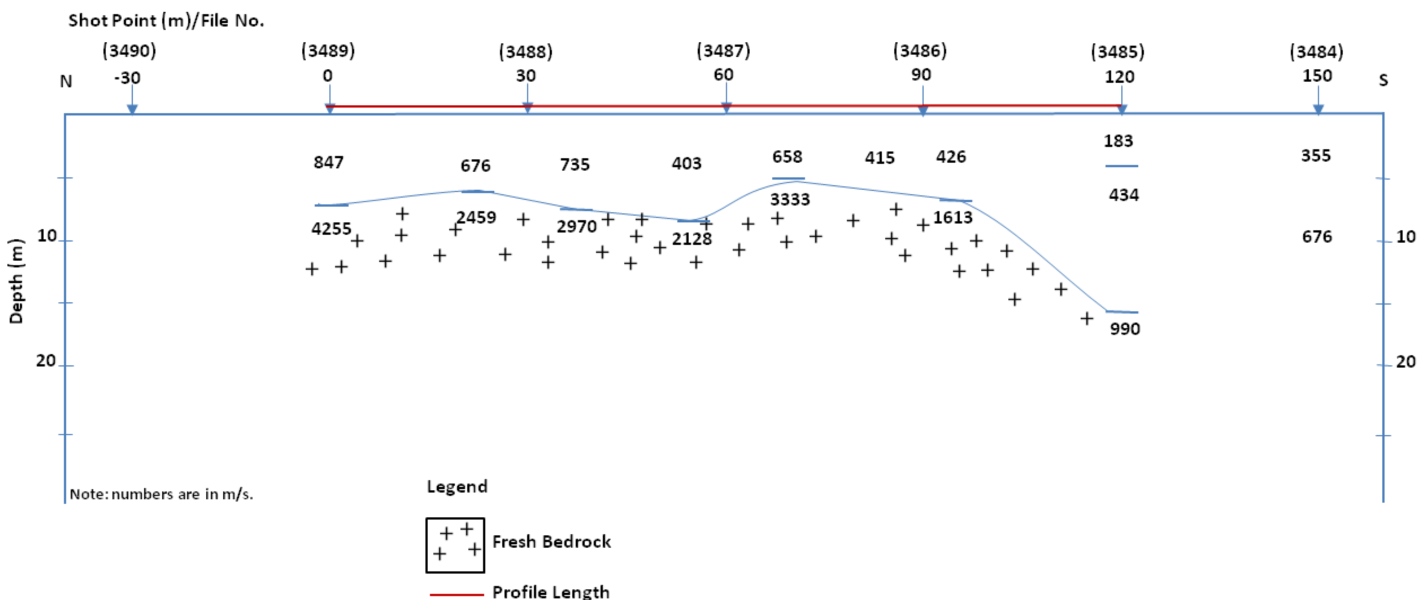

Figure 12. Seismic refraction (geo-velocity) section of profile 4.

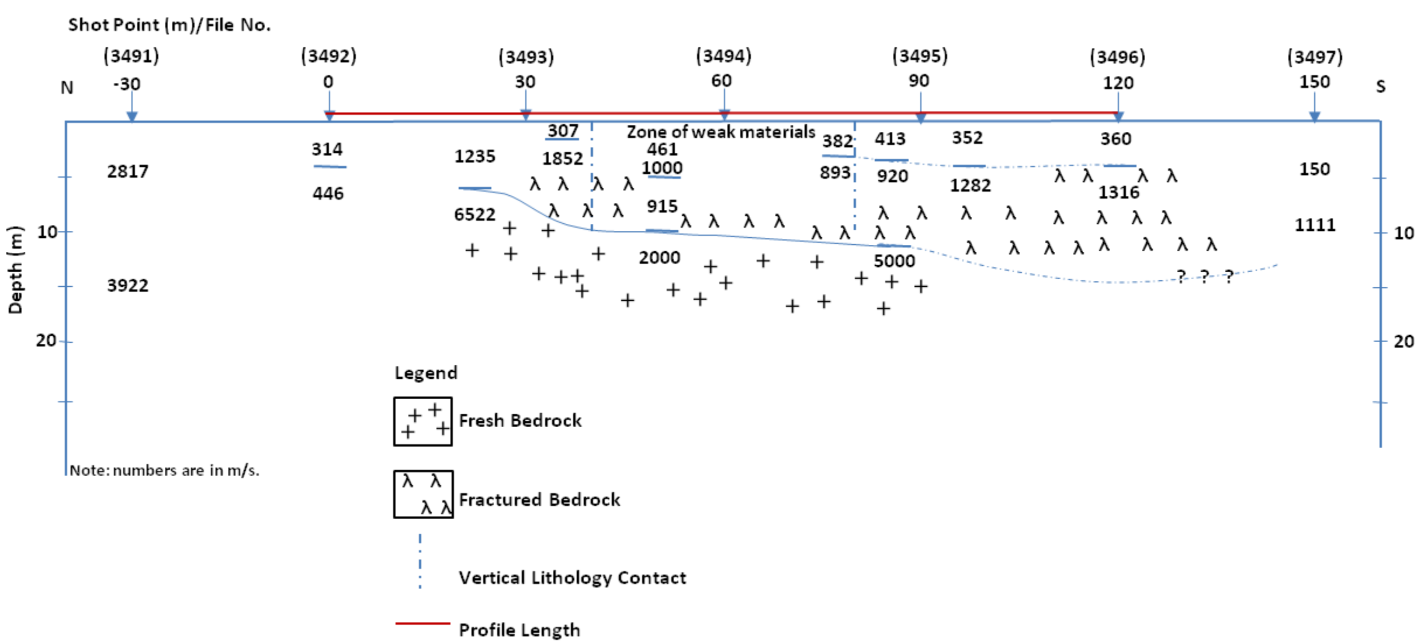

Figure 13. Seismic refraction (geo-velocity) section of profile 5.

bedrock is characterized by very high velocity values varying between 2344 and 5000 m/s. Geo-velocity section generated for profile 4 which is proximal and parallel to the Gurara River on the eastern flank is shown in Figure 12. Overburden materials beneath profile 4 are relatively thin on the northern flank but thicker on the southern limit. The profile is underlain by low velocity materials with values varying between 183 and 847 m/s with thickness values ranging from 4.04 to 15.61 m. The bedrock is characterized by moderately high velocity values varying between 990 and 4255 m/s.

Geo-velocity section generated for profile 5 which is located on the extreme eastern flank of the dam axis is presented in Figure 13. Overburden materials (with velocity values of 190 to 1235 m/s) beneath profile 5 are generally thin (1.87 to 5.6 m). The overburden is underlain by moderately high velocity column with values varying between 446 and 1852 m/s and thickness averaging 5 m that is presumably diagnostic of fractured bedrock. The fresh bedrock is characterized by very high velocity values varying between 2000 and 6522 m/s. The Gurara Dam Phase II project site (dam axis) is underlain by overburden materials that increase westwards. The North-South profiles (1, 3, 4 and 5) are underlain by bedrock of irregular relief. However, the bedrock morphology presents fairly flat relief along the dam axis around profile 2. The bedrock is displaced downwards on the southern flanks of profiles 1 and 4. The seismic refraction sections showed that the river channel area is underlain by basement rocks of relatively higher velocity values as observed in profiles 3 and 4. This suggests the possibility of changes in lithology especially when compared with bedrock velocity values obtained in profiles 1, 2 and 5 that are at some distance from the river channel.

Conclusion

The results of the seismic refraction study conducted at five profiles on the Gurara Phase II dam axis have shown that some portions on the western flank present noticeable seepage characteristics within the bedrock especially on profiles 1 and 2. Profiles 1 and 4 present characteristics exhibiting possible downward displacement of the bedrock on the southern flank. Profile 5 on the eastern bank is characterized by significant fracturing of the bedrock with possibilities for seepage. The seismic refraction sections of the dam axis show that the bedrock presents no threatening fracturing characteristics. However, the weak materials delineated on the western flank (profiles 1 and 2) of the river present buried stream channel characteristics that require some focus at engineering design stage. This will most likely prevent the seepage of impounded water from the reservoir through the delineated fractured bedrock and buried stream channels.

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