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APPLICATION OF SEISMIC REFRACTION SURVEY FOR ENGINEERING SITE CHARACTERIZATIONS OF WEYTO DAM CONSTRUCTION SITE, SOUTHERN ETHIOPIA

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Summary. The study area is geographically situated within the Southern Nations, Nationalities, and Peoples' Region (SNNPR), specifically encompassing portions of the Segen Zone and the South Omo Zone. It lies within the Benetsemay Woreda, in close proximity to the established urban center of Weyto Town. The terrain of the study area presents a topographically rugged landscape. Notably, this region forms an integral segment of the extensive Southern Main Ethiopian Rift System, a significant geological feature marked by considerable tectonic activity. To gain a comprehensive understanding of the subsurface characteristics at the proposed Weyto Dam construction site, a series of seismic refraction surveys were meticulously conducted. The geophysical survey was executed utilizing a sophisticated 24-channel refraction wave instrument, the Seis-24, a tool specifically designed to generate detailed velocity sections of the subsurface at the prospective dam construction location. The study area is distinguished by a multifaceted geological setting, exhibiting a diverse array of intricate tectonic structures and a variety of distinct geological formations. These formations include fine-grained aphanitic basalt, various clastic sediments, metamorphic gneiss, porphyritic basalt and accumulations of pyroclastic deposits. The application of the seismic refraction survey proved instrumental in effectively identifying the different subsurface units based on the analysis of their compressional wave velocity values and the determined thicknesses of these layers. The acquired data revealed that the seismic refraction survey successfully achieved a maximum depth of investigation reaching approximately 100 meters within the defined study area, providing valuable insights into the subsurface architecture relevant to the proposed dam project.

1. Introduction

The main purpose of constructing a dam is to impound water for several reasons, such as flood control, human water supply, irrigation, livestock water supply, and energy generation. They also provide an enhanced environment and recreation purpose (Long term benefits …, 2004). In most parts of the country, Ethiopian people faced a strong moisture shortage. To increase crop production, the residents were forced to use irrigation. To overcome the aim of irrigation, the governments of Ethiopia proposed and constructed dams at different times (Bihon, 2015). Preliminary insufficient investigation of geological structures, lithological types, soil strengths and seismic zones leads to a short lifespan of dam sites (Ivan, Samuel, 1987).

Dam failures are usually caused by inadequate design, improper construction, or inadequate maintenance. Failure of the dam can cause considerable loss of capital investment, income, possible property damage, and loss of life. Loss of the reservoir can cause severe hardship for those dependent on it for their livelihood and can upset the ecological balance of the area; therefore, it requires the detailed investigation of the foundation for the construction of safe and sustainable dam structures.

Geophysical methods are extensively used in dam investigations, both on dam construction projects and in the assessment of the condition of existing dam structures. These methods help in identifying local areas of concern that have no surface expression. Moreover, the methods help to delineate boundaries between residual soils, weathered rocks and fresh rock. It is also possible to locate anomalous foundation features such as dykes, cavities, fault zones and buried river channels (Fell et al., 2005).

Geophysics has many disciplines, of which seismology being the largest, especially in exploration geophysics. Refraction seismology measures arrival time of seismic waves at fixed positions on the ground after their generation at the focus. A small explosive charge or sledgehammer can be used for shallow seismic refraction investigations to generate seismic energy, which moves through the subsurface at a velocity depending on the subsurface material. Some of waves that travel through the subsurface are refracted at the interface between two layers back to the surface, where they are detected by geophones at fixed locations. These signals then are sent to a seismograph, which records the arrival time for signals. The arrival time depends on the velocity of waves in the layer it travels through, so knowing the time of arrival and the distance from the focus to the geophone, the velocity of the wave can be determined. The velocity of a particular earth material can vary over a wide range as a function of its age, depth of burial, degree of fracturing or porosity, and whether water or air fills the voids (Telford et al., 1976).

The velocity variation can also aid in determining the number of layers the wave has travelled through and their elastic properties, thus informing the engineer or geologist on the kind of material to expect at different depths within the subsurface. This research seeks to use the seismic refraction survey method to obtain the subsurface condition of the dam site. Boreholes, trenches and other invasive methods are conventionally used to investigate the subsurface, but they are discrete and may cause serious omissions in an attempt to delineate the boundaries of geological structures and the nature of the subsurface. This is a major issue in engineering site investigations that seismic refraction surveys address by providing more continuous data on the subsurface based on which engineering decisions can be made with some degree of certainty. A seismic refraction survey also gives the various layers in the subsurface by using the velocities of the seismic waves in the subsurface, thereby helping to reduce the number of boreholes that are required for subsurface investigation at a site. This reduces the cost involved in subsurface investigation. Seismic refraction is nondiagnostic like all geophysical methods, and a specific conclusion of the material making up the subsurface cannot be drawn from the results of seismic refraction survey alone. Therefore, it is very important that the investigation be supplemented with some boreholes and knowledge of the geology of the area so that the possible material makeup of the subsurface can readily be inferred (Bawuah et al., 2018).

2. Location and accessibility of the study area

The Weyto proposed dam is located in the SNNPR, which is specifically between Benetsemay Woreda and Ale Special Woreda near Weyto town. It is approximately 580 km Southwest of Addis Ababa. Geographically, the study area is bounded by the coordinates of 280589-288230 m E and 605700-613890 m N and covers an area of 76 square km (Fig. 1). The study area is accessible through the Addis Ababa-Araba Minch-Jinka main road and newly constructed dry weather road that branches from the Addis Ababa-Weyto asphalt road (25 km from Weyto Bridge).

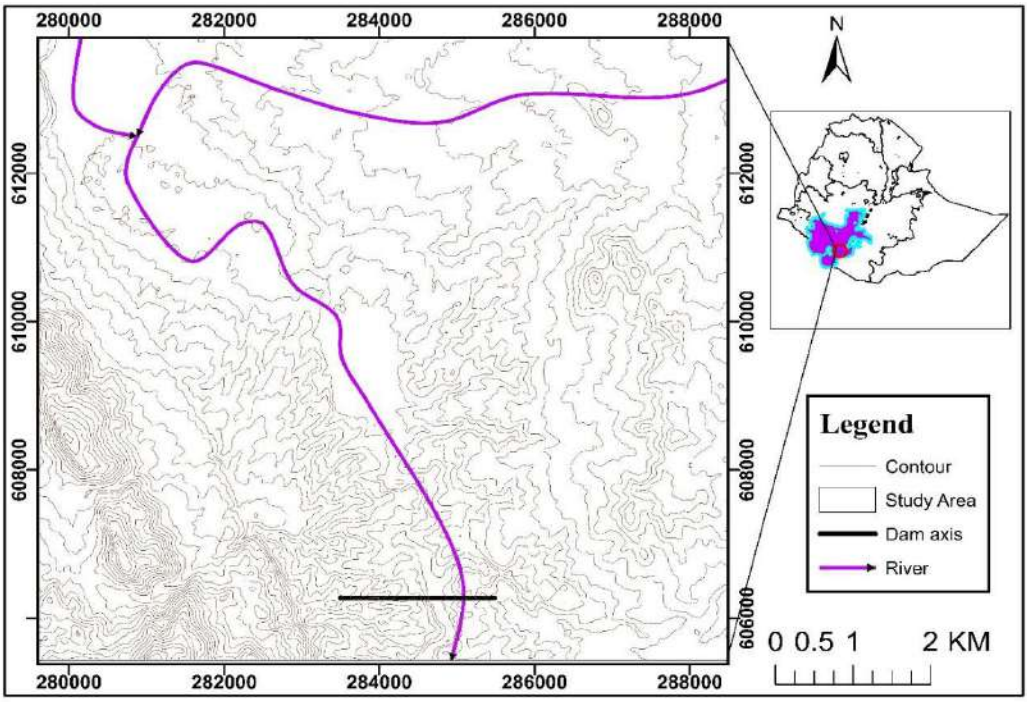

Fig. 1. Location map of the study area

The geophysical survey area is located between UTM (Adindan, Zone 37N) coordinates 281000 to 286500 m E and 604500 to 610500 m N. The locations of the proposed geophysical survey lines in the study area are shown in Fig. 2. The study area is located approximately 25 km upstream of the Weyto River Bridge and can be reached by 4 WD vehicles using dry weather roads that branch from the main high way connecting Arba Minch and Jinka Towns.

3. Geology of the study area

The geology of the study area belongs to the southern Ethiopian rift system, which is characterized by rift basins with fully defined margins and 300 km wide broad rifted zones characterized by half grabens and basin range-type tectonic features (Levitte et al., 1974). Precambrian basement rocks, Tertiary volcanic successions, Tertiary sediment deposits and Quaternary superficial deposits are major stratigraphic successions in the study area.

The crystalline basement rocks are overlaid by red sandstone, which is overlaid by volcanic flows. The detailed mapping of the area outlined lithologic units comprising superficial deposits, siliciclastic sediments, porphyritic basalt, felsites, pyroclastic deposits, aphanitic basalt and gneissic rock units. The crystalline basement rocks are part of the gneissic complexes consisting of quartzo feldspatic and biotite layered quartzo feldspatic gneiss. They outcrop in the central-eastern mapped area, and the left margin of the Weyto River is mainly uplifted by a series of faults with several orientations. The average foliation trend of this rock unit is 45-55/270-300 degrees in the eastern part of the map and 50/070 in the western part. The aphanitic basalt unit is described as dark gray to black in its fresh state and a brownish gray to greenish gray color on its weathered surfaces. It has a fine-grained texture, and its minerals are hardly seen in field lenses. It is highly and spherically weathered and at places completely decomposed to soil with only remnants of some core stones. Pyroclastic deposits are described as pinkish gray to brownish red and yellowish brown, fine grained, massive to layered, reworked, felsic volcano-sediments interlayered by ignimbrite layers. Felsites are mapped as light color (greenish gray, light gray to pinkish gray colored rock unit in its fresh state), fine grained in texture; and at places it is vesicular, intermediate composition. It is a volcanic flow unit consisting of intermediate to felsic lava flows and centers with localized lava flows forming NS-trending scarped plugs mainly following riverbanks of the Weyto River. Porphyritic basalt with well-developed olivine crystals within fine ground mass is mapped capping felsites and pyroclastic sediments in the central part of the project area found in the eastern portion of the Weyto River. It has dark grey weathered and black fresh surfaces. It is fine grained with phenocrysts in it. Generally, it is massive and has a thickness of 3 to 13 meters at the top of small hill topographies. Siliciclastic sediment deposits which thickness is in the range of tens of meters cover the majority of the project area, particularly the map peripheries of both the northern and southern maps. Most of the mapped outcrops of this unit show alternating layers of coarser and finer clastic beds. They are found as hybrid beds of clast-supported sediments with disturbed grading, possibly because they are continuously reworked materials. The unit in general is light brown, medium to coarse grained, massive to bedded, slightly consolidated, compositionally matured and unsorted and consists of sand and minor silt supported by pebble gravel.

4. Field procedure

The geophysical observations were made along survey lines, which had been laid out at the preselected sites. In the surveying work, the direction and layout of seismic lines and locations of seismic shot points and geophones were determined. The distance between geophones was 10 m, whereas the shot point intervals were 25 m, 50 m, 55 m, 100 m and 110 m. Survey work was planned and conducted at 2 sites, dam site option 1 and dam site option 2 along 20 lines. The layouts of these profiles are shown in Fig. 2. All seismic refraction lines were laid down on the ground.

5. Instrumentation and spread layout

The instrument used for the seismic refraction survey was the specialized engineering seismic wave-prospecting instrument known as the Seis-24 channel seismograph. The instrument accessories used during the fieldwork include a multichannel cable, trigger geophone cable and 25 pieces of geophones. Twenty-four pieces of geophones were set (Fig.3), each geophone at equal intervals driven into the ground so, that it would be in a straight line and connected with a multichannel cable to the main instrument. A trigger geophone was set at an approximately 2-4 m distance from a shot point. The interval between measuring geophones and shot points was more than 5 m. Explosives were used as a source of seismic energy and deployed with different weight ranges from 200 gm to 2000 gm depending on the position of the shot point. The stations of optimal offset shot points and weights of the optimal explosive were determined after field testing progressed enough. The methods of nine shots/spread (-95, 5, 30, 55, 80, 105, 130, 155, 180, 205, 305) and seven shots/spread (-105, 5, 60, 115, 170, 225, 335) were applied in the area of investigations and were found to be adequate. During the survey work, two to four geophone stations overlapped for every line; that is, an inline-profiling survey technique was conducted.

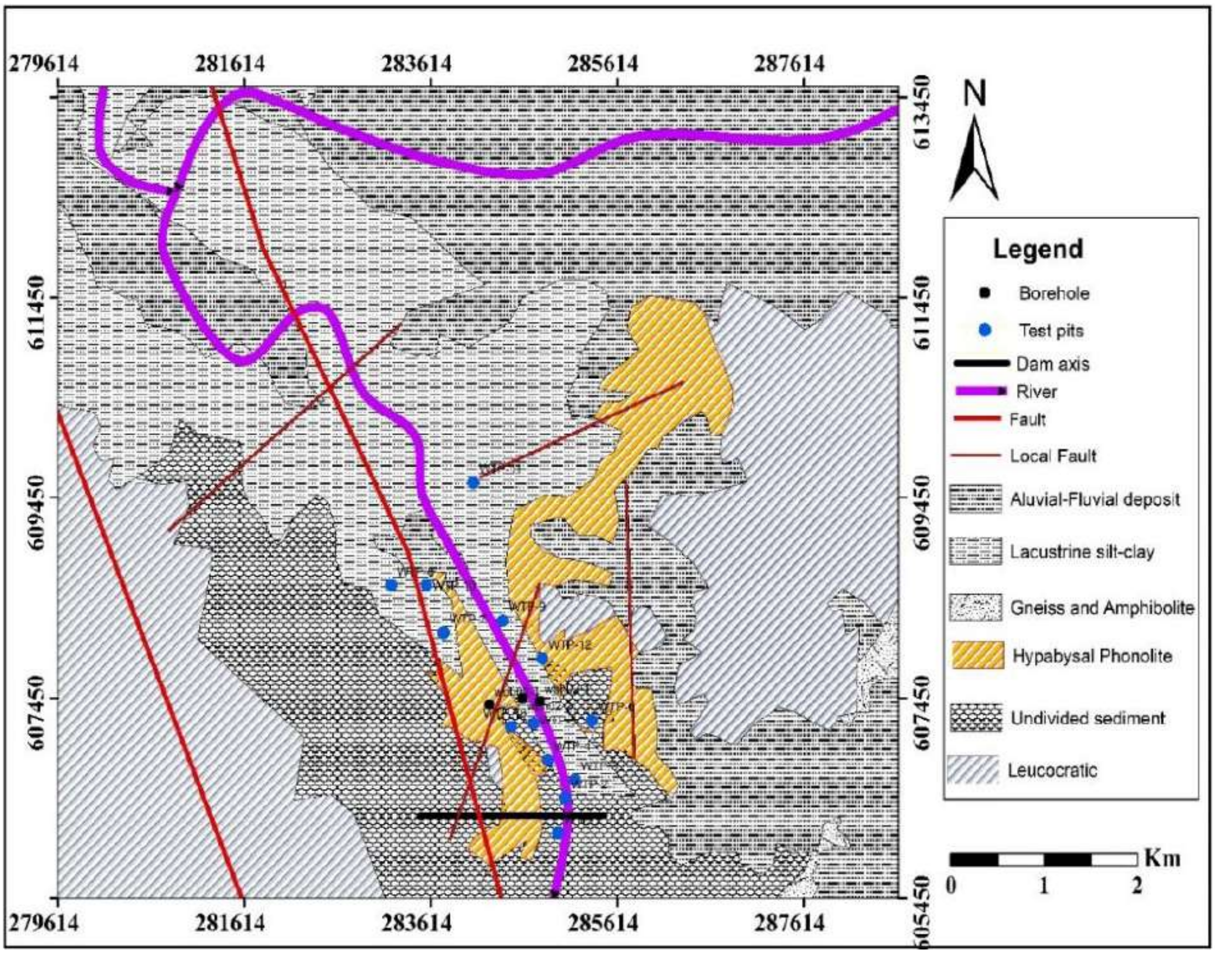

Fig. 2. Geological map study area

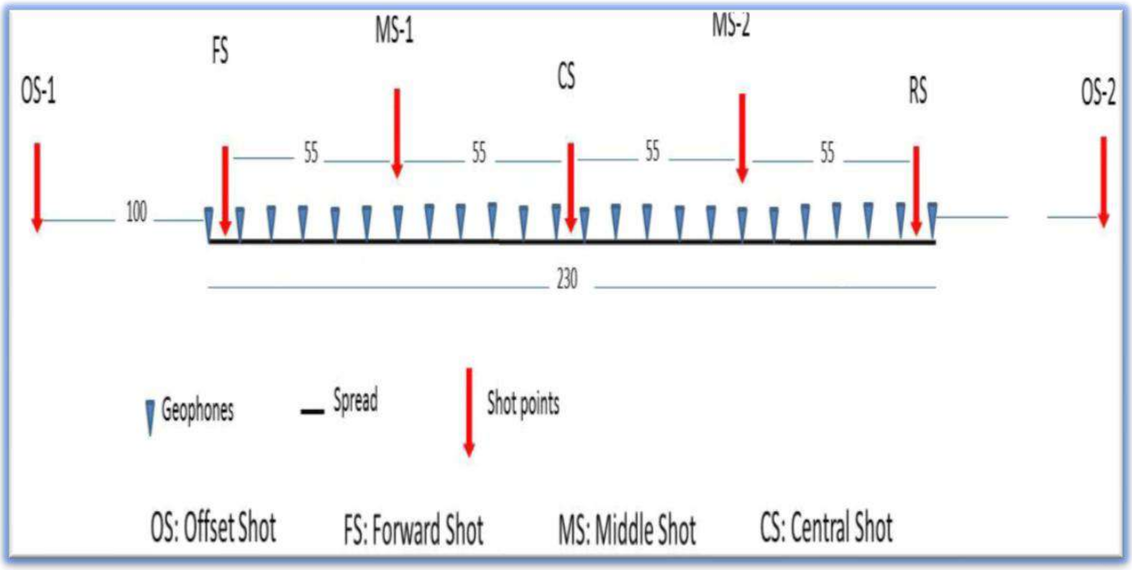

Fig. 3. Geometry of seismic refraction survey setup

6. Field parameters, data processing and data quality

The refraction seismic data were acquired using field parameters selected on site (Fig.4). These parameters enabled the acquisition of good-quality data (Table 1). Moreover, at some places, the repeated measurements were made to refine the data quality after correcting envisaged problems.

Table 1

Parameters of seismic refraction used

Energy source	Explosive
Geophone distance	10 m
Length of spread	230 m
Shot position	-105, 5, 60, 115, 170, 225, 330
	-95, 5, 30, 55, 80, 105, 130, 155, 180, 205, 305
Recoding time	1500 microseconds(ms)
Sampling	0.5
Filter	Open

The acquired seismic wave field can be described in two parts: travel times and amplitudes. Seismic amplitudes are more prone to the detrimental effects of noise compared to travel times. As such, travel time inversion is a very robust and accurate method to estimate the P-wave velocity-depth model of geological columns. Therefore, noise is filtered out from the wave signal until a high signal-to-noise ratio is obtained, and first arrivals are selected to produce the tomography section. The accuracy of interpretation depends on several factors, such as the scale of investigation, topography, geology and surrounding noise. All the above mentioned factors are possible contributors, as deeper depth was investigated with wide geophone spacing in topographically widely varying terrain and complex geologic conditions. The correlation of available borehole logs with seismic results indicates very good data for the upper, medium and bottom units. A comparison of seismic interpretation results and borehole logs shows that the difference between depths obtained from interpretation and borehole logs is less than 10%.

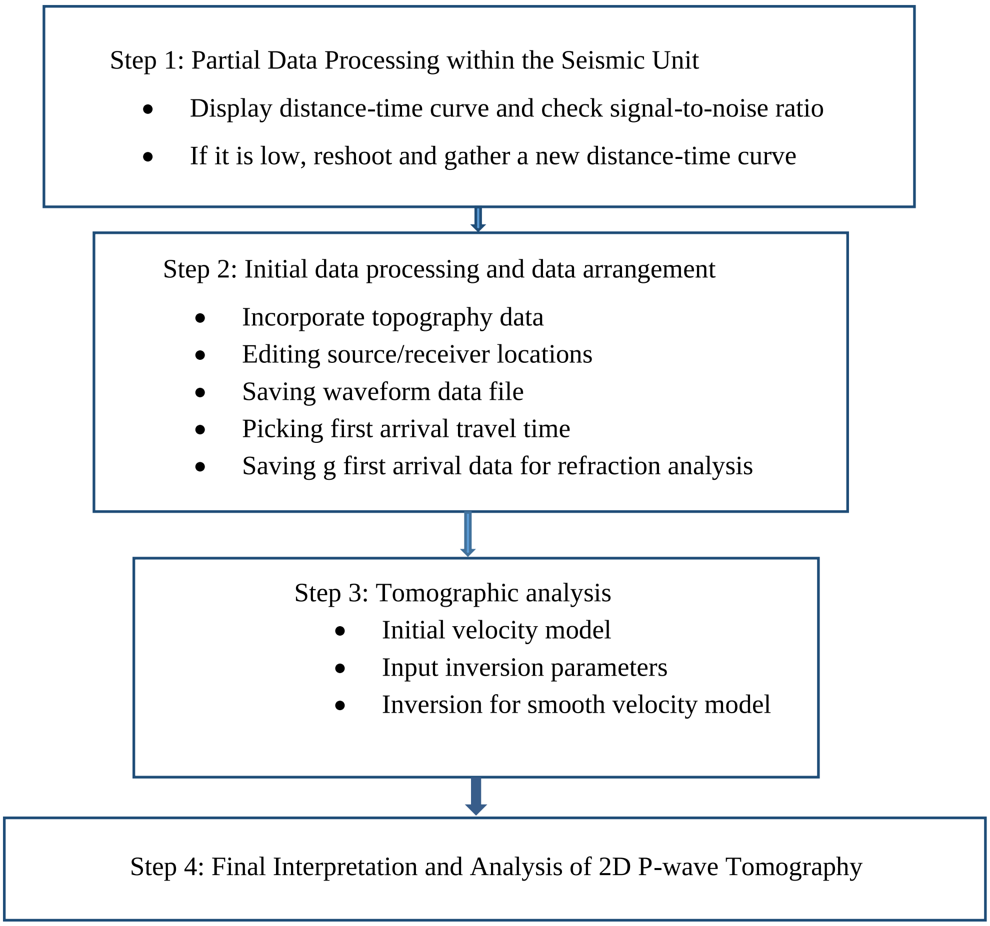

Fig. 4. Summary of data processing steps

7. Interpretation of seismic refraction data

Ten survey lines (Fig. 5) with a total length of 10512 m were conducted to characterize the geological features of foundations at the Dam Site.

Spread line-1

This line (Fig. 6) is acquired on the right side of the proposed dam with a survey direction NE-SW orientation with a turning point at SP-6. There are 20 shot points with 55 m source intervals along the line and two offset shots with 100 m distances from two ends of the line. The line extends from the UTM geographic coordinate of 284578E, 606022N (SP-1) to the SW direction and turns at SP-8 (284485E, 60519N) almost to the south direction and ends at 284606E, 605176N (SP-20). Topographically, the line is along a very ragged and sloppy surface, and it crosses the river between SP-15 and SP-16. This line is traversed by lines 10, 9, 8, 7, and 6 on the left and right sides of the Weyto River. The first layer is mapped with a wide range of thicknesses throughout the section. The thickest part of this layer is detected at the plateau between SP-3 and SP-11, where there is the minimum degree of erosion. The maximum thickness is measured to be approximately 40 m at and around SP-7. This weak material with P-wave velocity of < 1500 m/s could be related to the clastic sediments, which comprise fine sandy silt. The underlying layer with P-wave velocity measured in the range of 1500 m/s to 2500 m/s could correspond to highly weathered gneiss or clastic with consolidated gravels. This layer is either left with minimum thickness or totally eroded along the fault plane. Similar to the overlaying formation, this layer reaches its maximum thickness of approximately 20-25 m in the elevated part of the section.

The third layer, which looks at a constant thickness in the entire section with velocity values ranging between 2500 m /s and 4000 m /s, is correlated to highly or moderately weathered gneiss or fractured basalt. The bottom layer, which has a P-wave velocity value greater than 4000 m/s could be related to the slightly weathered basalt, and the slightly weathered gneiss is 114 m deep at SP 9 and 41 m just beneath the river channel. Successive normal faults that mimic the regional normal faults of the region are selected in the middle of the section. The other major structure identified from this section is two normal faults that created uplift from SP-3 to SP-14.

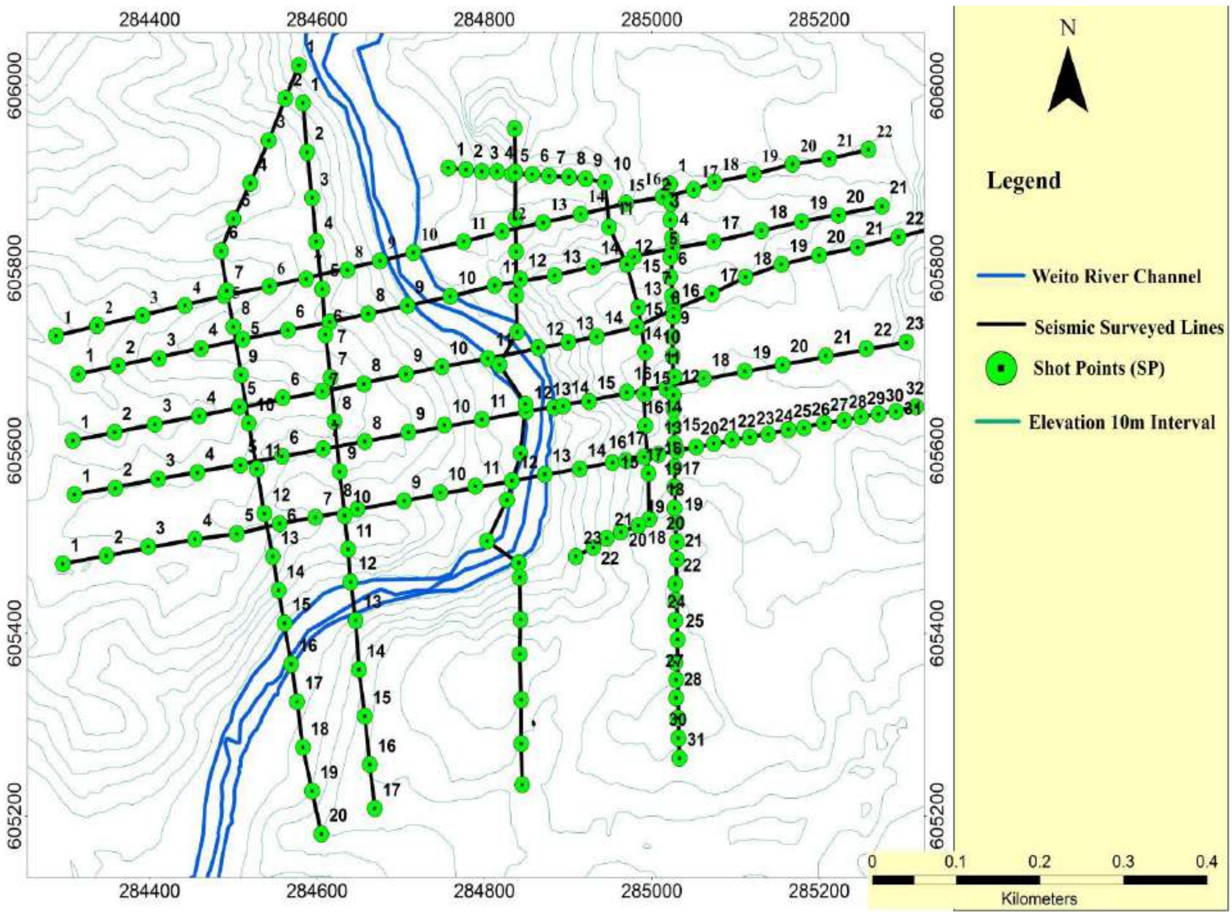

Fig. 5. Seismic Refraction Surveyed lines on Option-1

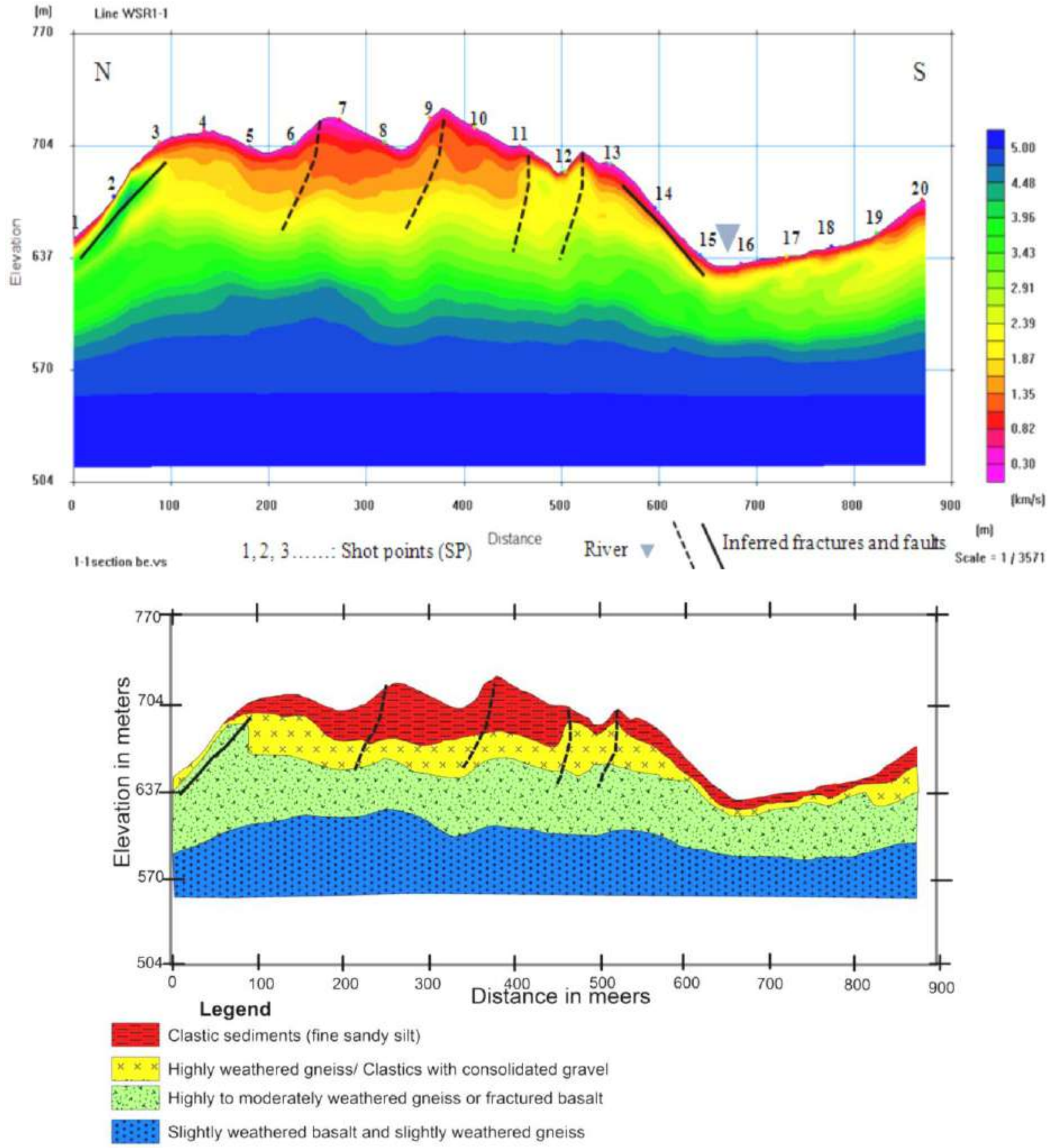

Fig. 6. Geo-seismic section of line-1

Spread line-2

This line is located on the right bank of the dam site acquired in the N-S direction. There are 19 shot points with 55 m intervals except the two offset shots, which are located 100 m away from two ends of the line. The line extends from UTM coordinates of 284583E, 605981N (SP-1) to 284669E, 605204N (SP-17). This line intersected all the dip lines (6, 7, 8, 9 and 10) and WBH1-3 between SP-7 and SP-8. Log data of WBH1-3 were used as priori data in data interpretation, and the interpreted parameters are comparable with the log data around the borehole. The section (Fig.7) revealed a layer with low p-wave velocity (> 1500 m/sec having a constant thickness of 6-10 m almost throughout the section. This low-velocity layer could be related to clastic sediments that comprise fine sandy silt.

The second layer with p-wave velocities between 1500 m/sec and 2500 m/sec is associated with highly weathered gneiss or clastic with consolidated gravels. This layer has a maximum thickness of 30 m around SP-7 and almost vanishes along slant surfaces, which could be the fault plane (between SP-11 and SP-12). This layer is relatively thick to the south part of the river. The third layer, which could slightly be related to moderately weathered gneiss filled by quartz or pegmatite veins with P-wave velocity range between 2500 and 4000 m/sec., is detected at different depths in the section. In areas such as fault planes, the third layer is either underlain by the thin portion of clastic sediments or exposed to the surface without the above mentioned two layers. Its maximum thickness is identified in the northern part of the section, which is measured to be approximately 60 m, while the eastern side of the river is relatively thin with a thickness of only 30 m. The bottom layer that has P-wave velocity greater than 4000 m/s has been detected at a shallow depth of 45 m at the river channel and gets down deep to 100 m depth at the WBH1-3 location. This layer could correspond to slightly weathered gneiss or fractured basalt. Weak zones are identified around SP-5 and SP-8 bounded by the low velocity layer within these inferred fractured zones. The other possible structure picked in this section is a fault which is located between SP-11 and SP-12.

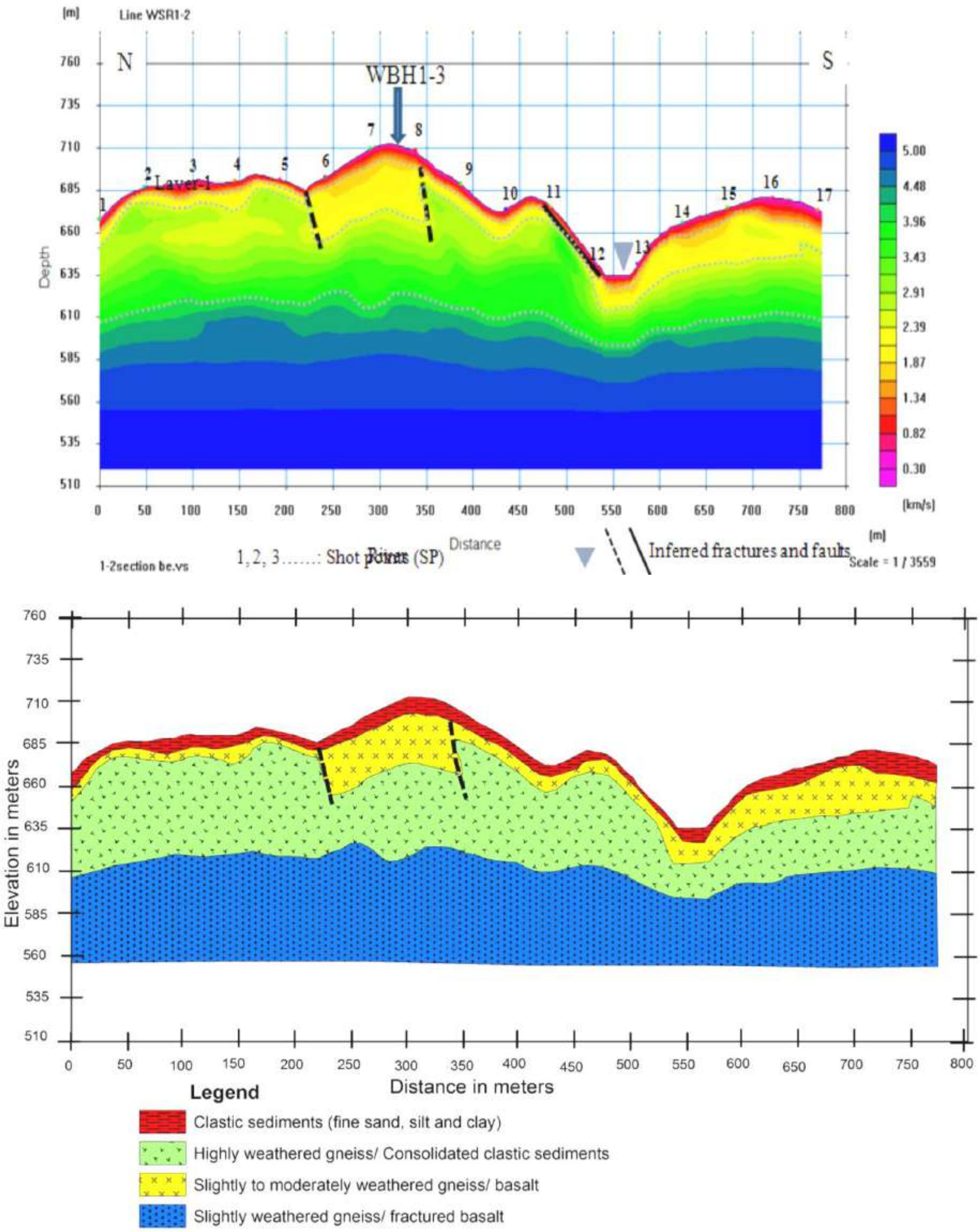

Fig 7. Geo-seismic section of line-2

Spread Line-3

Line-3 is surveyed in the N-S orientation, and it crosses the river at two places (SP-6 and SP-12). There are 18 shot points with 55 m intervals except the two offset shots, which are located 100 m away from two ends of the line. The line extends from UTM coordinates of 284836E, 605958N (SP-1) to 284845E, 605229N (SP-18) with a total ground survey length of 910 m. This line (Fig.8) is traversed by lines 4, 10, 9, 8, 7, and 6 from the upstream to downstream direction. Topographically, the central part of the line is situated in a flat surface following the river channel. Apart from the central part, the other portion of the line is located on a hilly and ragged surface. Since the central part of the line is acquired along the river channel where there is high energy attenuation because of thick alluvial sand, it was difficult to obtain deeper data. To solve this problem, a large amount of explosive was deployed in a deep shot hole. The top layer with a P-wave velocity value greater than 1500 m/sec has almost a constant 6 m thickness in the central part of the section and reaches its maximum thickness of 20 m at SP-15. This low-velocity layer is related to colluvium sediments, which are composed of fine sand, silt and clay according to borehole data and field observations.

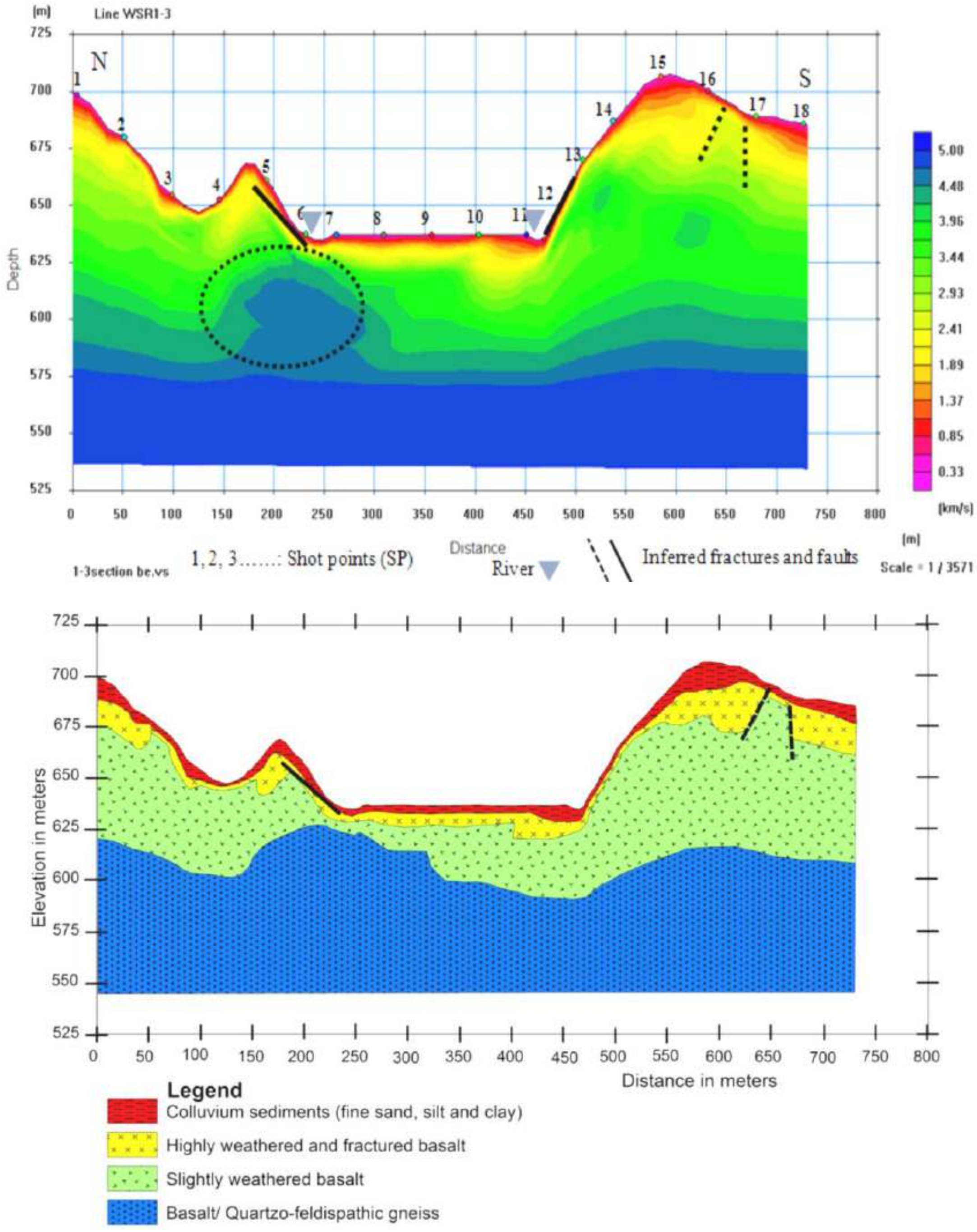

Fig. 8. Geo-seismic section of line-3

The second layer with P-wave velocities ranging from 1500 m/s to 2500 m/s, which could be related to the highly weathered and fractured basaltic rock, is spotted only in a few parts of the section. This formation is missing in the slope areas and some points, such as SP-3, SP-4, SP-6 and SP-7. At the hill tops (SP-1, between SP-4 & SP-5 and SP-15), this formation reaches its maximum thickness of 20 m. The third layer has P-wave velocity ranging from 2500 m/s to 4000 m/s, which could be related to the slightly weathered basaltic rock identified at various depths. It is detected at a shallow depth at SP-6 with a thickness of less than 10 m, gets deep towards the south side of the section and measures approximately 50 m in thickness on both ends of the section. The bottom layer with P-wave velocity value of more than 4000 m/s may be correlated to basalt rock or quartzo-feldspathic gneiss with pegmatite or quartz vein intrusions. At the river crossing between SP-7 and SP-6, this layer could be exposed or detected at shallow depths similar to the overlain formation. The minimum depth to its top surface is 20 m along the river channel, whereas the maximum depth is located at SP-15, which is measured more than 90 m.

Spread line-4

Due to the design of this line, it can be divided into four segments based on the orientation of the line. The first and fourth segments are surveyed along almost the E-W direction. The second and third segments extending from SP-10 to SP-19 are surveyed in the N-S and NW-SE orientations, respectively. All segments of the line are surveyed on the left side of Option-1 with a total length of 920 m. There are 23 shot points with 55 m intervals for the central segments (Segments 3 and 4) and 25 m intervals for segments 1 and 4. This line is traversed by lines 10, 9, 8, 7, and 6 on the left side of the Weyto River. The line (Fig. 9) extends from UTM geographic coordinates of 284754E, 605910N (SP-1) to 284904E, 605482N (SP-23). The interpretation for this line is controlled by WBH1-1, which is situated between SP-14 and SP-13 of this line.

The top layer with P-wave velocity value of less than 1500 m/s is identified only in some parts of the section corresponding to clastic sediments, which comprise sand, clay and silt. This layer is missed almost in parts between SP-8 and SP-11 of the section; however, it is identified from SP-1 to SP-8 and around the borehole location, which has a thickness of approximately 10 m. At the north end of the section, this layer measured 20 m in thickness, while the maximum thickness of approximately 45 m was noticed around SP-18. There are clear structures picked at two different places, SP-16 and SP-5, which could be faults and that is the reason to discover a wide variation in thickness of this layer within a few meter intervals. Most structures can manifest on the surface, such as the above mentioned two faults, while few cannot have surface signatures and die in the ground. The underlying layer where its occurrence is more or less similar to the top low velocity layer is mapped at different portions with a very wide range of thicknesses. Its velocity is demarcating between 1500 m/s and 4000 m/s, which corresponds to highly or moderately weathered and fragmented volcanic rocks. Even if its degree of weathering decreases with depth, this layer goes to a depth of 75 m around the borehole location with poor rock quality. It could be exposed to the surface in the portion between SP-7 and SP-11. The bottom layer, which is related to slightly weathered basalt rocks that have P-wave velocity of more than 4000 m/s is placed at a depth of between 75 m and 105 m from the surface.

Spread Line-5

This line is surveyed along the N-S direction parallel to the Weyto River extending from UTM coordinates of 285022E, 605918N (SP-1) to 285032E 605225N (SP-32). There are 32 energy source points with 25 m intervals that are acquired to the left side of the river. All the dip lines (parallel to the dam axis) are traversed by this line. Successive valleys and hills are encountered across the 830 m length. Topographically, the line (Fig.10) is situated on the elevation variation from 723 m to 685 m above mean sea level. WBH1-1 is located just 40 m to the west side of SP-9, and it is conceivable to constrain the interpretation of this line by the borehole data based on the 2D P-wave velocity tomography section of Line 5. Four layers have been identified. The first top layer having P-wave velocity value of less than 1500 m/s is interpreted as either clastic sediments comprising sand, silt and clay or highly weathered trachyte basalt, or it could be both formations. This layer is identified at the south end of the line with a maximum thickness of 41 m for a length of approximately 180 m. Its thickness decreases when it goes towards the center of the section and is almost lost at SP-14. Near the WBH1-1 location, an average thickness of 20 m is measured on the northern part of the line. The underlying layer characterized by P-wave velocity ranging from 1500 m/s to 2500 m/s possibly represents highly weathered or fractured and decomposed basaltic rock. From SP-4 to SP-24, except of the intrusion of the high velocity layer in the central part, the thickness of the second layer somehow ranges from 20 to 30 m. On the south side underneath the thick top layer, the second layer has a constant thickness of approximately 14 m.

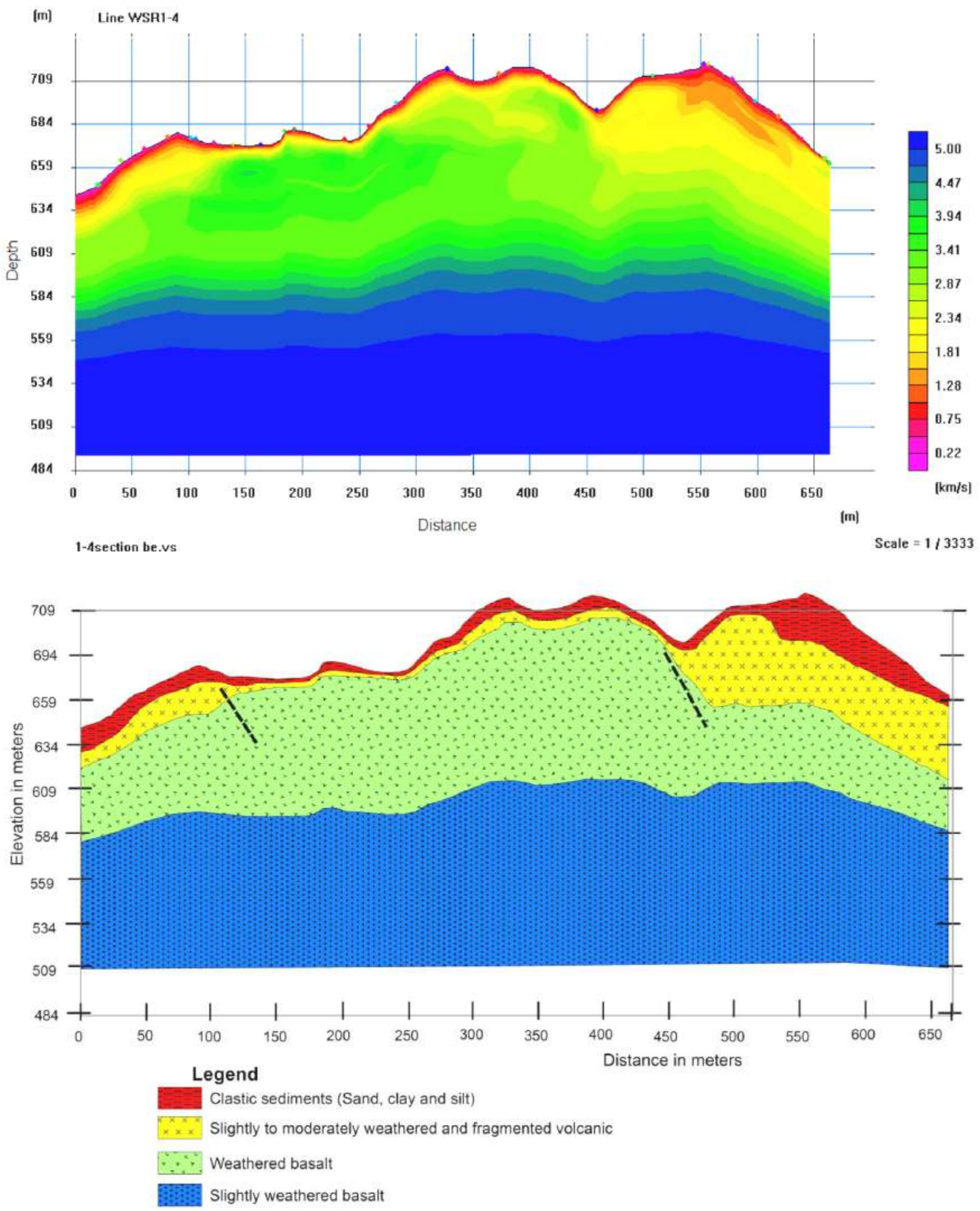

Fig. 9. Geo-seismic section of line-4

The third velocity layer has compressional wave velocities between 2500 m/s and 4000 m/s, which could be related to the slightly weathered aphanitic basalt intercalated with a highly weathered rock matrix. It is mapped near or exposed to the surface around SP-14, although it is found deep down to 55 m in the southern part of the line. It is unconformably underlain by the above layer. Regarding its thickness distribution, apart from the north end and SP-16 of the line where it has a maximum thickness of 46 m thickness, it has a constant thickness of 15-20 m throughout the section. The bottom layer that has P-wave velocity value of more than 4000 m/s is detected at a depth of 55 m to 85 m from the surface. This layer could be similar to the overlaying layer with only varying degrees of weathering of the basalt rock and/or the rock matrix, or it could be related to slightly weathered gneiss. According to the borehole data, the formation encountered from 26 m to the final depth of the borehole is mafic volcanic rock.

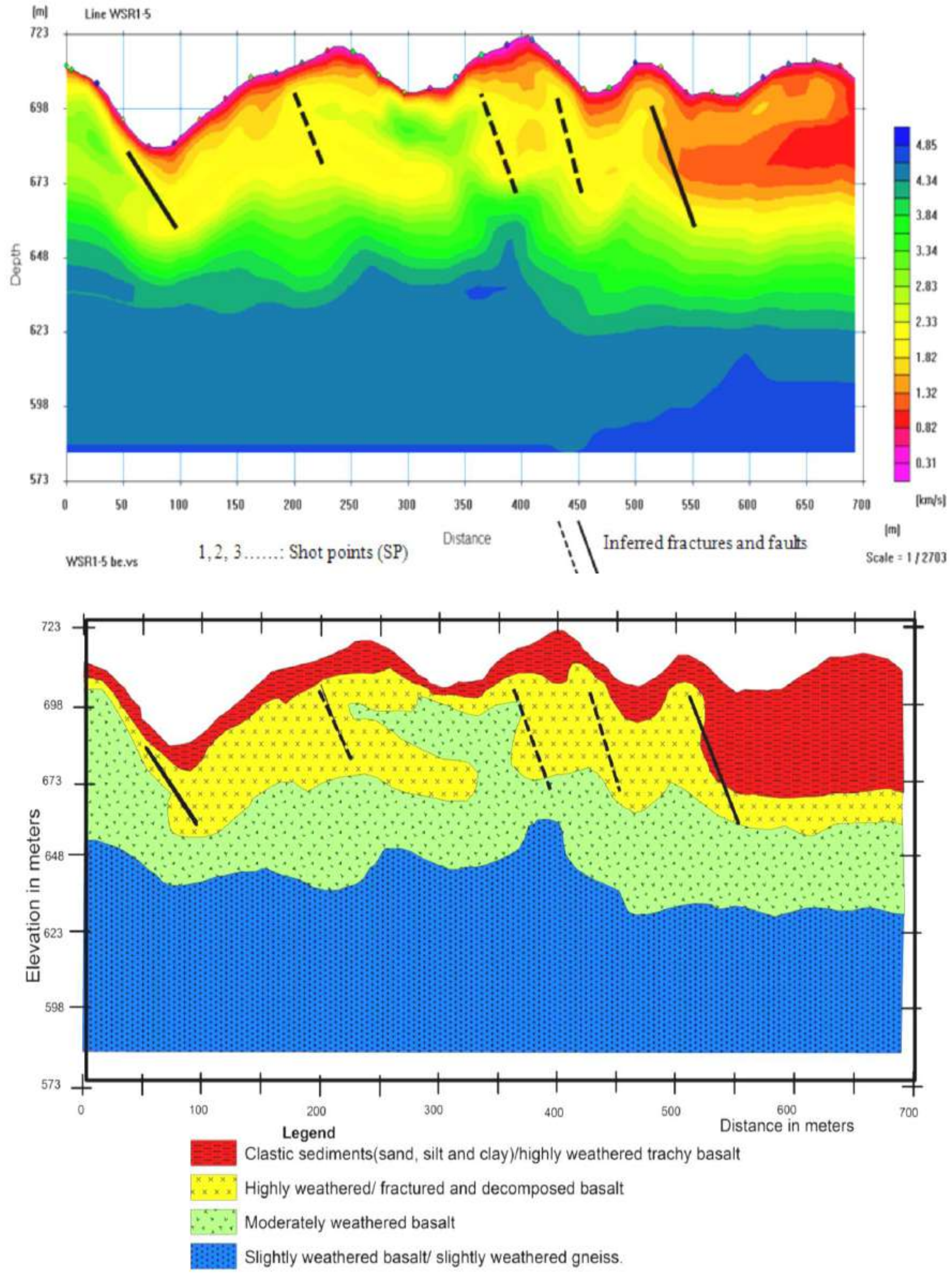

Fig. 10. Geo-seismic section of line-5

Spread Line-6

Line WSR1-6 is surveyed parallel to the dam axis along the E-W direction, which intersects the river at SP-13. This line extends from UTM coordinates of 284296E, 605476N (SP-1) to 285321E 605648N (SP-32) situated to the downstream side of the proposed dam axis. There were two setups for explosive shot point intervals; the whole right side of the section and the sloppy part of the left part were surveyed with 55 m source interval, while the other part of the line was surveyed with 25 m source interval. Line 6 is intersected by lines 1, 2 and 3 to the west side of the river and lines 4 and 5 to the left side. Four seismic layers have been identified that correspond to different geological layers. As always, the first layer that has P-wave velocity below 1500 m/s is identified at different parts of the line with a wide range of thicknesses. The section (Fig.11) of the first 200 m length from the right side has predominantly composed of clastic sediment or highly weathered and fractured rock, which could be denoted by this low velocity layer. Around this part of the section, the top layer has a maximum thickness of 33 m; however, at slant areas, just at both sides of the river channel has no chance to preserve these weathered and loose clastic sediments. This layer has a constant thickness of approximately 8 m on the plateau area to the eastern part of the river. The underlying layer that has relatively higher P-wave velocity is represented by compressional wave velocities on the order of 1500 m/s-2500 m/s, which are associated with highly weathered and fractured basaltic rock. Its thickness varies from very thin or possibly vanishes at the slant surface to 33 m at the plateau areas. There is a thin squashed layer mapped with high velocity from SP-5 to SP-10, which could be due to a volcanic layer overlay on palaeosoils or volcanic clastic. The third layer, which is characterized by a compressional velocity ranging from 2500 m/s to 4000 m/s is exposed to the surface at the river valley or identified profoundly when it goes away from the river channel. This layer is related to slightly or moderately weathered basalt or moderately weathered gneiss.

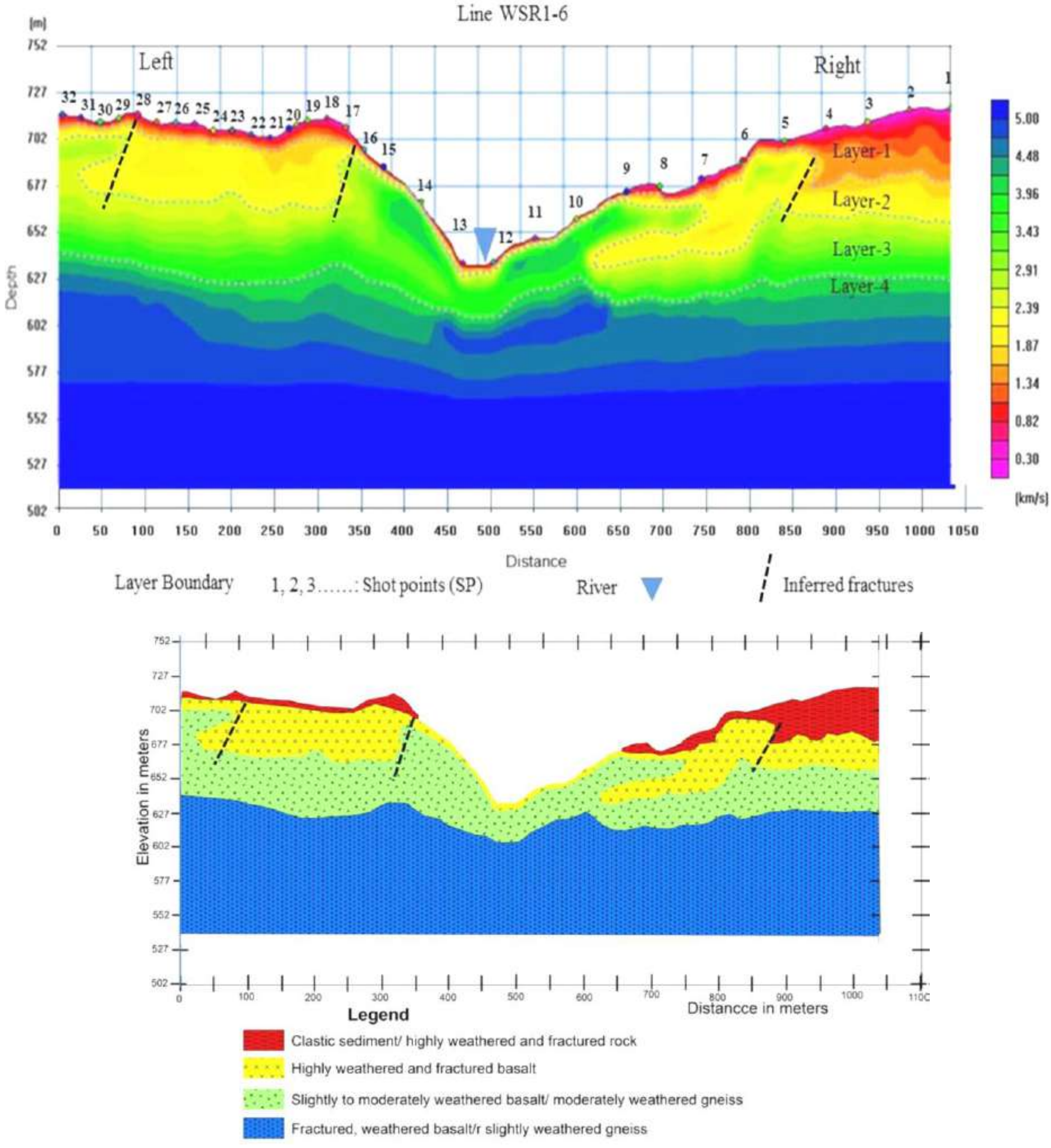

Fig. 11. Geo-seismic section of line-6

Its thickness varies from its least thickness of 20 m at SP-12 to maximum value of 62 m thickness at SP-16. The isolated spot with an inverted velocity distribution mapped beneath SP-10 to SP-14 could be related to the existence of water in the fractured basalt rock. It can be observed from 2D P-wave velocity tomography section of Line WSR1-6 that the bottom layer is generally represented by over 4000 m/s velocity. The depth to basement is near the river channel, which is only 30 m deep; however, it is traced between 80 and 96 m depth around the elevated areas. This layer could be related to fractured, weathered basalt or slightly weathered gneiss.

Spread Line-7

Line 7 is surveyed along the E-W orientation and crosses the river between SP-13 and SP-14. There are 23 shot points with 55 m intervals except two offset shots, which are located 100 m away from two ends of the line. The line extends from UTM geographic coordinates of 284310E, 605552N (SP-1) to 285307E, 605719N (SP-23) with a total ground survey length of 1190 m. This line (Fig.12) is traversed by lines 5 and 4 to the left side, while lines 3, 2 and 1 cross the right side of the river.

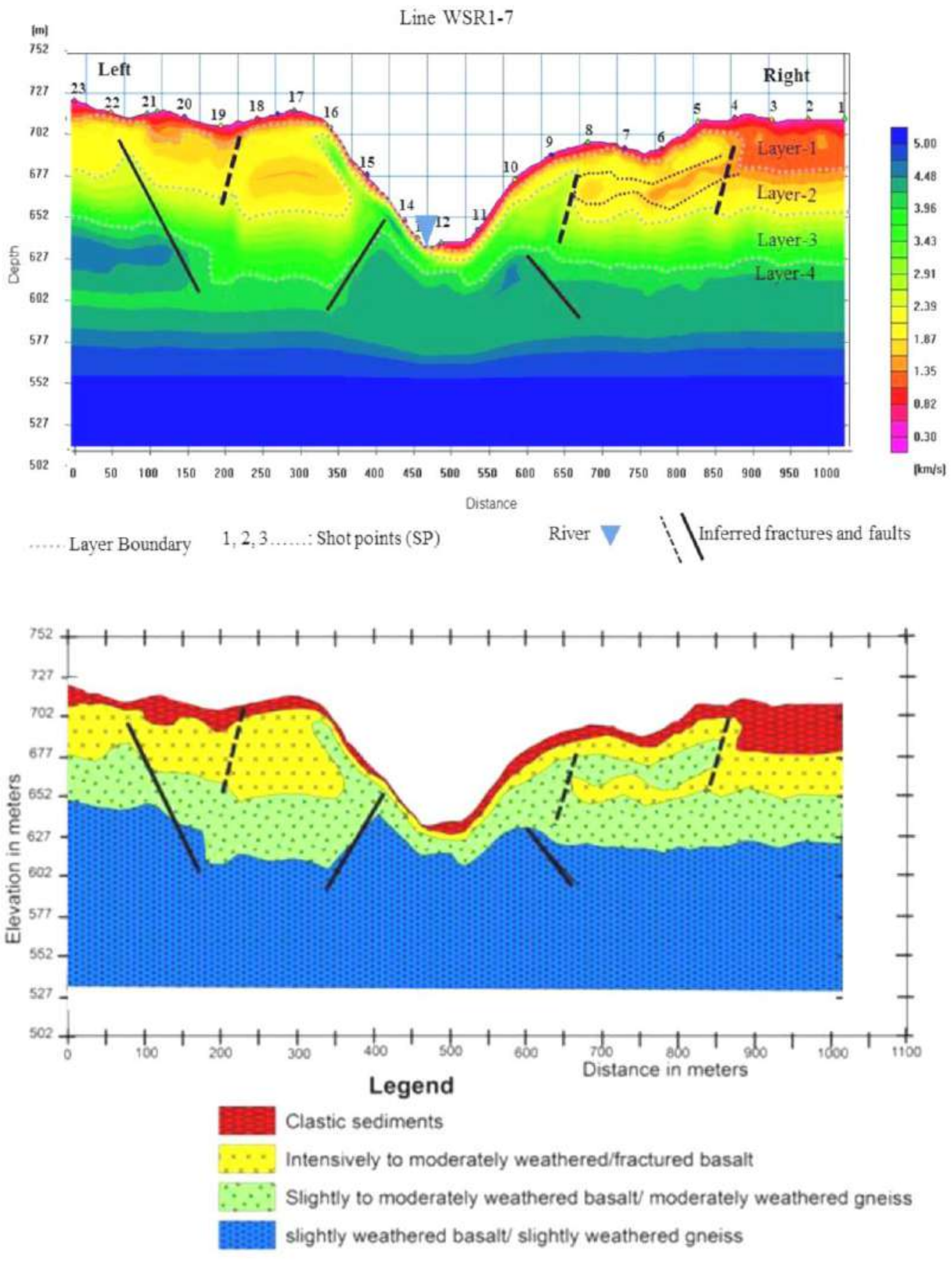

Fig. 12. Geo-seismic section, Line WSR1-7

The top layer outlined by P-wave velocity value of less than 1500 m/s is identified throughout the section except the slope surface to the left side of the river. This seismic layer corresponds to clastic sediments that comprise sand, clay and silt. The thickest part of this layer is found to the right end of the section with a thickness of 40 m. This layer has almost a constant thickness between 5-10 m from SP-5 to the river channel and from SP-17 to the left end of the section. Since highly weathered rocks and loose sediments could not exist on a highly inclined surface, this top clastic sediment was missed in parts between SP-14 and SP-17. In some parts, the underlying layer is squeezed within this layer (see SP-4 to SP-9). The underlying layer characterized by P-wave velocity between 1500 m/s and 2500 m/s is traced in almost all parts of the section. This layer is attributed to intensively or moderately weathered/fractured basalt having very poor rock mass quality or highly weathered gneiss. Relatively, it is very thick to the left side of the section than to the right side. The thickness varies from 50 m at SP-18 to very thin or completely absent along the slant surface of the left side of the river. The third layer characterized by a compressional velocity ranging from 2500 m/s to 4000 m/s is exposed to the surface at the river valley or detected profoundly when it goes away from the river channel. This layer corresponds to slightly or moderately weathered basalt or moderately weathered gneiss. Its thickness varies from its least thickness of 7 m at the river channel to maximum thickness of 50 m at SP-10. The bottom layer that has P-wave velocity value of more than 4000 m/s is detected at a depth of 17 m beneath the river channel to 102 m at SP-18 from the surface. This layer could be similar to the overlaying layer with only varying degrees of weathering of the basalt rock, or it could be related to slightly weathered gneiss. There are inferred structures at various depths of the section that could be faults or fracture zones. Based on the 2D P-wave tomography section and field observations, these structures are not manifested on the surface. The two inferred faults are picked inside the third and bottom layers, while the fractures are displayed in the first two layers.

Spread Line-9

This line (Fig.13) extends from W (SP-1) to E (SP-21) marked by UTM geographic coordinates of 284314E and 605683 N and 285280 E and 605869 N, respectively. It is surveyed parallel to the dam axis, which crosses lines 1 and 2 to the right and Lines 3, 4 and 5 to the left side of the river. There are 21 shot points with 55 m intervals and offset shots placed 100 m away from the first and last geophone locations. One borehole (WBH1-2) is located between SP-10 and Sp-11 of this line. The interpretation of this line is well constrained by these core drilling data. The top layer, which is characterized by a compressional P-wave velocity value of less than 1500 m/s is identified all over the section with various thicknesses. The left part of the section has constant thickness of approximately 7 m, while the right part shows from 45 m around SP-3 to 10 m towards the valley. This velocity layer could be related to clastic sediments and highly weathered and fractured basalt or gneiss along the slant surface. The underlying unit is characterized by P-wave velocities varying between 1500 m/s and 2500 m/s, which could be associated with intensively fractured and weathered gneiss or highly fractured basalt. This layer could be missed around SP-11 and become thick at two specific points; in the right part, 35 m thickness is identified for more than 100 m lateral distance, and to the left side, it has similar thickness but has small area coverage. The third velocity unit covers the entire section and is clearly indicated by 2500 m/s to 4000 m/sec velocity related to slightly or moderately weathered basalt with poor rock mass quality or weakly to moderately weathered gneiss. The thickness varies from 20 m at SP-7 to 70 m around SP-15. This layer could be exposed at an inclined surface and identified at depth of approximately 75 m to the right end of the section. In some areas, slightly weathered and fractured basalt rock is found between low-velocity layers. This could be due to volcanic layer overlay on paleosoils or ground water being detected. According to the 2D P-wave velocity tomography section of line WSR1-9, the fourth layer is represented by velocity value greater than 4000 m/s, which is attributed to slightly weathered gneiss or slightly to moderately weathered basalt. The depth of the bedrock surface varies between 40 m at the central part and 100 m to the right end. The inferred structures that could be fractured or fault zones have been identified on both sides of the river around SP-7 and SP-18.

8. Discussion

Refraction seismic investigations were carried out with objective of the determining the thickness of the overburden materials, identifying the subsurface layers, and estimating the depth to the bedrock, presence of geologic structures and groundwater conditions. It is well understood that types of rocks, degree of weathering and geological structures are the main controlling factors for dam site selection. To address these controlling factors, seismic refraction investigation is the primary choice over other geophysical investigation methods. Therefore, the results from such seismic measurements may assist in dam site selection and rock engineering.

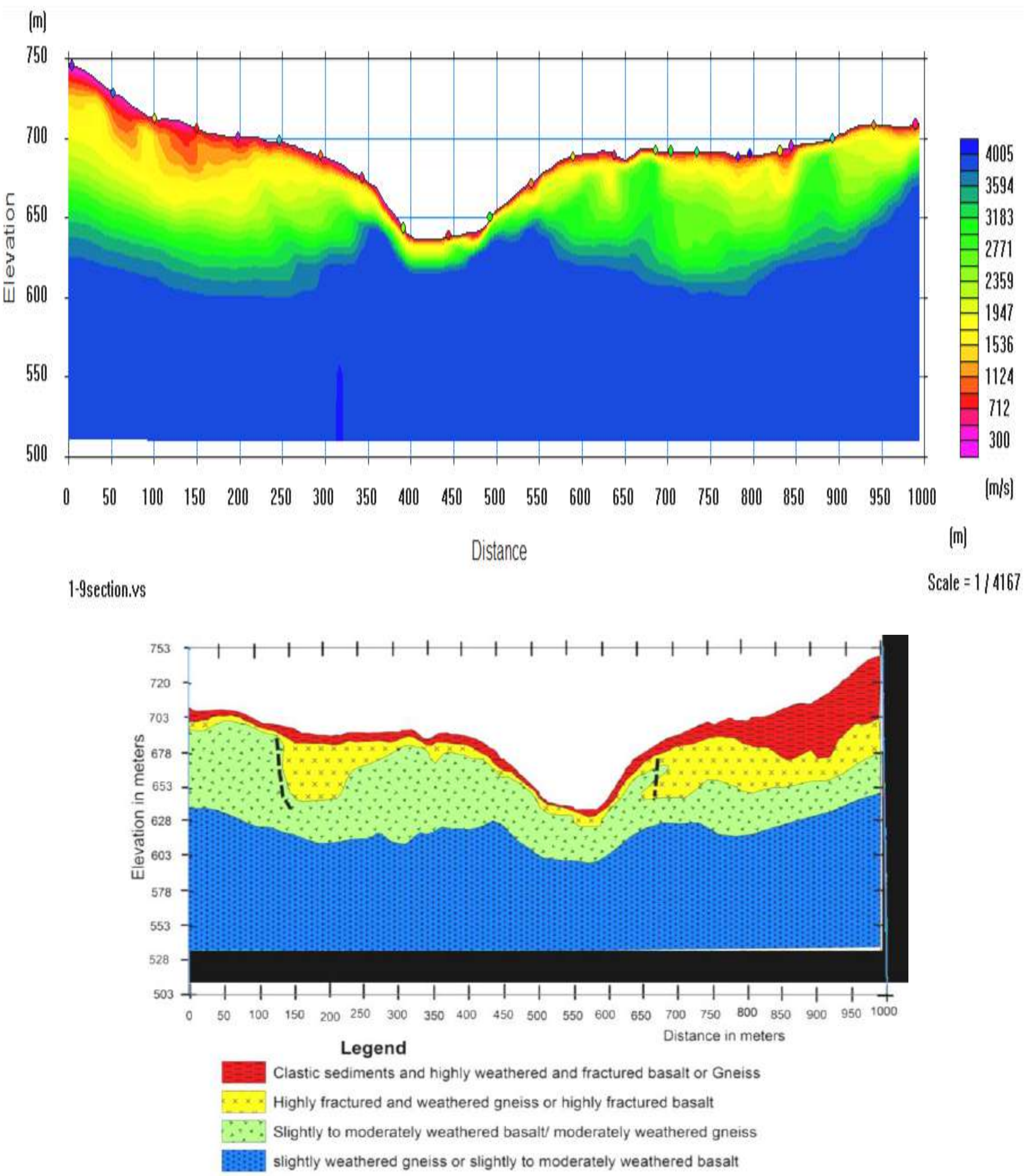

Fig. 13. Geo-seismic section of line-9

Practically, if any dam site shows any occurrence of active faulting irrespective of its attitude (i.e., dip & strike) under no circumstances, dam construction should not be undertaken. The Weyto dam sites are geologically and tectonically complex and characterized by faults and fracture zones that are identified in almost all seismic sections. Furthermore, the project is located in the southwestern part of the Main Ethiopian Rift, which is tectonically an active area. It has been recognized that most of the seismic sections and the borehole data except WBH1-2 do not show groundwater, at least up to the drilling depth. Therefore, the absence of groundwater in most parts of the project site will minimize the risk of dam failure.

The most identified faults from seismic tomography sections exist on both upstream and downstream sides and frequently dip towards the downstream side, which will decrease the suitability of sites for dam construction. The foundation rock or rock mass under the dam axis and reservoir area has to provide stable support with little or no deformation and avoid settlement under all conditions of saturation and loading. Igneous and metamorphic rocks are the most desirable rocks at the dam site. These are strong and durable due to their dense character, interlocking texture, hard silicate mineral composition, occurrence of negligible porosity and permeability, absence of any inherent weak planes, resistance to weathering and tendency to occur over wide areas. However, it should be checked that the selected rocks are not affected by weathering or fracturing or dykes or any geological structures such as shearing, faulting and jointing. Thus, all plutonic rocks, such as granites, syenites, diorites and gabbro, are very competent and desirable rocks for the foundation at the dam site. However, another consideration should be taken into account; volcanic rocks, which are generally vesicular or amygdaloidal, are not desirable since they will be permeable and contribute to porosity and hollowness, in turn contributing to the weakness of rocks. Massive basalts, which are very fine grained, are one of the toughest rocks in nature. However, they can be adversely affected when they are vesicular and permeable. The seismic section revealed thick loose sediments in most parts of the dam sites apart from the central part along the river channel and the slope areas. From the core drilling data and geological mapping, the types of rocks dominating the dam sites are fractured and weathered gneiss and igneous rocks.

10. Conclusion

The seismic refraction investigations were carried out along topographically surveyed lines. The interpreted results satisfactorily met the objectives and depths of investigations (over 100 m) despite the complexity of the study area. Accordingly, maximum depth of approximately 110 m is attained by the refraction seismic survey in the right and left parts of dam site. Based on the results of the refraction, seismic investigation in conjunction with the available borehole logging data, the seismic layers and their respective geological layers are summarized below.

Table 2

Seismic layers with corresponding geological layers

Seismic Layers	P-wave velocity (m/sec)	Geological layers
Layer-1	<1500	Clastic sediment consists of gravels, boulder size of rock fragments and fines, fluvial deposit, sandy silt gravely sandy silt
Layer-2	1500-3000	Intensively to moderately weathered and fractured basalt and gneiss, having very poor rock mass quality
Layer-3	2500-4000	Moderately to slightly weathered and fractured basalt and gneiss, having poor rock mass quality
Layer-4	>4000	Moderately to slightly weathered and slightly fractured and fragmented to fresh basalt and slightly weathered gneiss

REFERENCES

Bawuah G., Baffoe E., Darko B., Hadir I. A.A., Ogbetuo D. The use of seismic refraction survey in geotechnical investigations. International Journal of Engineering Research and Science, Vol. 4(7), 2018, pp. 6-17.

Bihon K. Factors affecting agricultural production in Tigray region, Northern Ethiopia. PhD thesis, Uuniversity of South Africa, 2015.

Fell R., MacGregor P., Stapledon D. Geotechnical engineering of dams. Taylor and Francis Group PLC. London, UK, 2005, pp. 180-181.

Ivan A., Samuel H. Techniques for prevention and detection of leakage in dams and reservoirs, Venezuela, 1987.

Levitte D., Columba J., Mohr P. Reconnaissance geology of the Amaro horst, Southern Ethiopian rift. Geological society of America Bulletin, Vol. 85(3), 1974, pp. 417-422.

Long-term benefits and performance of dams. British Dam Society 13 Conference, 2004, Canterbury, Kent, Thomas Telford. London, 676 p.

Telford W.M., Geldart L.P., Sheriff R.E., Keys D.A. Applied geophysics. Cambridge University Press. 1976.

ЛИТЕРАТУРА

Bawuah G., Baffoe E., Darko B., Hadir I. A.A., Ogbetuo D. The use of seismic refraction survey in geotechnical investigations. International Journal of Engineering Research and Science, Vol. 4(7), 2018, pp. 6-17.

Bihon K. Factors affecting agricultural production in Tigray region, Northern Ethiopia. PhD thesis, Uuniversity of South Africa, 2015.

Fell R., MacGregor P., Stapledon D. Geotechnical engineering of dams. Taylor and Francis Group PLC. London, UK, 2005, pp. 180-181.

Ivan A., Samuel H. Techniques for prevention and detection of leakage in dams and reservoirs, Venezuela, 1987.

Levitte D., Columba J., Mohr P. Reconnaissance geology of the Amaro horst, Southern Ethiopian rift. Geological society of America Bulletin, Vol. 85(3), 1974, pp. 417-422.

Long-term benefits and performance of dams. British Dam Society 13 Conference, 2004, Canterbury, Kent, Thomas Telford. London, 676 p.

Telford W.M., Geldart L.P., Sheriff R.E., Keys D.A. Applied geophysics. Cambridge University Press. 1976.

ПРИМЕНЕНИЕ СЕЙСМИЧЕСКОЙ СЪЕМКИ МЕТОДОМ ОТРАЖЕННЫХ ВОЛН ДЛЯ ОПРЕДЕЛЕНИЯ ИНЖЕНЕРНЫХ ХАРАКТЕРИСТИК УЧАСТКА СТРОИТЕЛЬСТВА ПЛОТИНЫ ВЕЙТО, ЮЖНАЯ ЭФИОПИЯ

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Резюме. Выделенный район исследования, являющийся центром важнейших геологических исследований, географически расположен в Регионе южных наций, национальностей и народов (SNNPR), в частности, охватывая части зоны Сеген и зоны Южный Омо. Точнее, он находится на территории вореда Бенетсемай в непосредственной близости от городского центра Вейто Таун. Располагаясь в пределах скромной долины, местность района исследования представляет собой топографически пересеченный ландшафт. Примечательно, что этот регион является составной частью обширной Южной Главной Эфиопской рифтовой системы, характеризующейся значительной тектонической активностью. Чтобы получить полное представление о характеристиках грунта на предполагаемом месте строительства плотины Вейто, была проведена серия сейсморазведочных исследований. Основными целями этих геофизических исследований были достижение достаточной глубины проникновения и точное определение глубины залегания коренных пород. Кроме того, исследования были направлены на оценку качества недр и выявление наличия и распределения геологических трещин – важнейших параметров, определяющих структурную целостность плотины. Было выявлено, что объекты плотины Вейто имеют сложную геологическую и тектоническую структуру и характеризуются наличием разломов и зон трещин, которые выявлены почти на всех сейсмических разрезах. Геофизические исследования проводились с помощью высокоточного 24-канального прибора преломляющихся волн Seis-24, разработанного с целью получения скоростных разрезов на участке строительства плотины. Территория исследования отличается многогранной геологической обстановкой, демонстрирующей разнообразные сложные тектонические структуры и множество различных геологических формаций. Эти образования включают мелкозернистый афанитовый базальт, различные обломочные осадки, метаморфический гнейс, порфировый базальт и скопления пирокластических отложений, образовавшихся в результате вулканической деятельности.
Ключевые слова: *плотина, геофизические исследования, недра, волны сжатия, фундамент*

VEYTO BƏNDİNİN TİKİNTİ SAHƏSİNDƏ MÜHƏNDİSLİK XÜSUSİYYƏTLƏRİNİN MÜƏYYƏNLƏŞDİRİLMƏSİ ÜÇÜN ƏKS OLUNAN DALĞALARIN ÜSULU ƏSASINDA SEYSMİK TƏDQİQATIN TƏTBİQİ, CƏNUBİ EFİOPİYA

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Xülasə. Araşdırma üçün seçilmiş ərazi mühüm geoloji tədqiqatların mərkəzi olmaqla, coğrafi baxımdan Cənubi Millətlər, Milliyyətlər və Xalqlar Regionunda (SNNPR), xüsusilə Seqen zonası ilə Cənubi Omo zonasının bəzi hissələrini əhatə edir. Daha dəqiq desək, bu sahə Benetsemay Voreda ərazisində, artıq formalaşmış şəhər mərkəzi olan Veyto qəsəbəsinin birbaşa yaxınlığında yerləşir. Ərazi nisbətən dərin vadidə yerləşməklə, mürəkkəb və dağlıq relyefə malikdir. Qeyd olunmalıdır ki, bu region yüksək tektonik aktivliklə səciyyələnən geniş Əsas Efiopiya Rift Sisteminin tərkib hissəsini təşkil edir. Veyto bəndinin nəzərdə tutulan tikinti sahəsində yeraltı qatların xüsusiyyətlərini öyrənmək məqsədilə seysmik tədqiqatlar aparılmışdır. Bu geofiziki tədqiqatların başlıca məqsədi süxur qatlarına kifayət qədər dərin nüfuz etməklə, əsas (bərk) süxurların yerləşmə dərinliyinin dəqiq müəyyən edilməsindən ibarət olmuşdur. Eyni zamanda, aparılan tədqiqatlar yerin dərinliklərindəki mühəndis-geoloji xüsusiyyətlərin qiymətləndirilməsi, geoloji çatların mövcudluğu və onların ərazi üzrə paylanmasının müəyyənləşdirilməsi məqsədi daşıyırdı. Bu amillər bəndin struktur dayanıqlığını müəyyən edən əsas geoloji göstəricilər hesab olunur. Tədqiqat nəticələri göstərmişdir ki, Veyto bəndi üçün nəzərdə tutulan ərazi mürəkkəb geoloji və tektonik quruluşa malikdir. Demək olar ki, bütün seysmik profillərdə qırılma və çat zonaları müşahidə olunmuşdur. Bəndin tikinti sahəsində sürət kəsimlərinin qurulması məqsədilə geofiziki ölçmələr Seis-24 markalı 24-kanallı refraksiya cihazı vasitəsilə həyata keçirilmişdir. Tədqiqat sahəsi müxtəlif mürəkkəb tektonik strukturları və zəngin litoloji tərkibi ilə səciyyələnən çoxşaxəli geoloji mühitə malikdir. Buraya incə dənəli bazaltlar, müxtəlif mənşəli çöküntü və dağıntı materialları, metamorfik qneyslər, porfirli bazaltlar və vulkanik fəaliyyət nəticəsində formalaşmış piroklastik yığıntılar daxildir.
Açar sözlər: *bənd, geofiziki tədqiqatlar, yerin təki, sıxılma dalğaları, təməl*