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Journal of Geography & Natural Disasters

Research Article

Application of Seismic Refraction Method to Characterize Injibara University Campus Building Site, Injibara, Northwestern Ethiopia

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ABSTRACT

Geophysical investigation using seismic refraction method was conducted for engineering characterization of the foundation conditions of Injibara University buildings construction site located in Injibara town of Amhara Regional State, Northwestern Ethiopia. The principal objective of the research was studying the suitability of the foundation earth materials underlying the site, where Injibara University is established. The seven refraction seismic spreads, seismic velocity models interpretation have provided valuable geotechnical information incorporated with available geologic information in the study area. Interpretation of geophysical data revealed that the subsurface geology of the area is composed of three layers. The topsoil consisted of clay, silt and sand mixtures having a 1-4 m thickness and 255-510 m/s p-wave velocity ranges are mapped over the whole area. The second layer attributed to the highly weathered and fractured vesicular basalt is characterized by 948-1802 m/s p-wave velocity range and revealed somewhat undulating morphology. The depth extent of this layer varies from about 10 m on the North West end and Southeastern parts and to about 27 m around the central part. The third layer occurred in the depth range of 10-27 m is characterized by greater than 2550 m/s average high p-wave velocity and it is due to moderately weathered and fractured basaltic bedrock, which is deeper near to the center of the profiles and gets shallower towards Northwest and Southeastern portions. Besides, analyses of collected data have suggested the possible locations of minor structural discontinuities (maybe local fractures).The geophysical results show that the bedrock is found at shallow depth in the Northwestern and Southeastern part of the study area, whereas in the central part of the survey area the bedrock is found relatively at high depth. Therefore, setting the building foundation is more recommended in the southeastern part of the construction site.

Keywords: Geophysical investigation; Construction site; Velocity model; Seismic refraction; P-wave velocity

INTRODUCTION

Construction of sustainable civil engineering structures require profound knowledge about the characteristics of subsurface earth materials, particularly physical properties of the underlying rocks/soils, distribution of tectonic elements, contents of moisture or fluid within them. Discontinuities in the form of bedding planes, joints, faults and folds highly determine the physical strength of rocks. Similarly, properties of materials filling voids, such as pure/mineralized water, air or both in unconsolidated soils or fractured rocks influence their physical characteristics. Therefore, the stability of civil engineering constructions depend on the correct assessment of the various physical and geotechnical properties of the underlying earth materials where the structures are intended to be constructed [1].

On the other hand, constructions undertaken over formation lacking bearing capacities often result in failures, manifested by cracks, settlements, displacements or total collapses. Particularly, those structures erected over areas where expansive soils are widely distributed demand special attention as their shrinking and swelling characteristics can easily cause damages due to their property variations as a result of moisture/fluid content fluctuations associated with seasonal changes.

Therefore, geotechnical investigation of any construction sites is essential to obtain reliable inputs that enable to develop economically and technically feasible structural designs incorporating mitigation measures to anticipated geo-hazard events.

Like elsewhere in the world, in Ethiopia public officials require

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Received: 08-Jan-2024, Manuscript No. JGND-24-29029; **Editor assigned:** 11-Jan-2024, PreQC No. JGND-24-29029 (PQ); **Reviewed:** 29-Jan-2024, QC No. JGND-24-29029; **Revised:** 05-Feb-2024, Manuscript No. JGND-24-29029 (R); **Published:** 12-Feb-2024, DOI: 10.35841/2167-0587.24.14.299

Citation: Teshome AM (2024) Application of Seismic Refraction Method to Characterize Injibara University Campus Building Site, Injibara, Northwestern Ethiopia. J Geogr Nat Disasters. 14: 299.

geotechnical investigation data acquired in accordance with the Ethiopian building construction code with accompanying recommendations prior to issuing a building permit in order to protect the safety of the public the surrounding environment [2].

Unlike drilling, pitting and trenching, geophysical methods are environmentally safe and also do not cause any substantial damages/concerns to the communities. Geophysical measurement responds to change in the physical, chemical, mechanical, elastic, radioactivity or thermal properties of the underlying earth materials. Because of such diverse characteristics, usually one or more of the properties correspond to certain features of earth materials, i.e., contact, discontinuity (fracture/fault zones).

For engineering applications, seismic refraction method is widely used to map the subsurface structures. This method depends on the acoustic impedance contrast of the subsurface materials [3].

The unique tectonic setting of Ethiopia results in complex geological and geo-morphological setups where along with these and continuously deteriorating environmental conditions, the country is very vulnerable for such geo-hazard risks, as volcanic, seismic, landslide and alike. Every year Ethiopia allocates quite a substantial amount of budget to the expansion of infrastructures: Roads, bridges, dams and building complexes. Particularly, to expand access to education the construction of universities are taking place in different parts of the country and among these is Injibara University.

To study the foundation conditions at site and evaluate its suitability for erecting a four story building to be used as dormitory for student, subsurface investigations were carried out employing seismic refraction method with an ultimate objective of generating inputs for civil applications.

Description of the study area

The research area, Injibara University site, is situated, in Awi Zone, Amhara Regional State about 447 km NW of Addis Ababa as shown in Figure 1. It is bounded by UTM coordinate 271602-272203 m Easting and 1211020-1211378 m Northing, and characterized by flat to gently sloping topography bounded by mountains and small hills from the Western and Southern side. It has an average elevation of about 2552 m amsl and located only about 1.5 km SW of the city center, just on the Injibara-Chagni asphalt road.

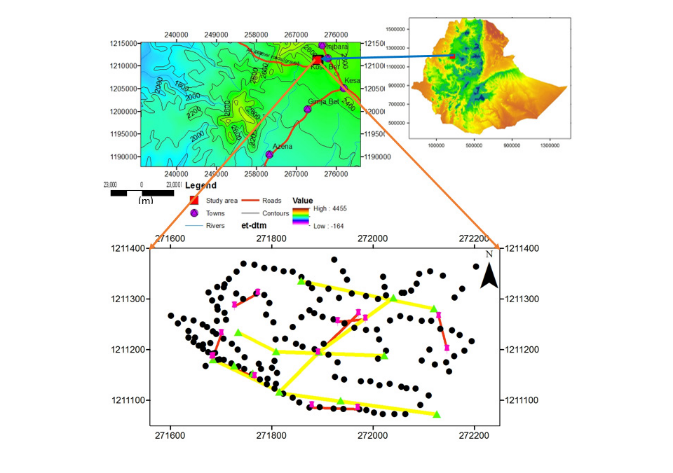

Figure 1: Location map of the study area. **Note:** (■): Study area; (●): Towns; (▬): Rivers; (▬): Roads; (▬): Contours.

The geology of the study area and its surrounding is dominated by the following rock units, scoraceous basalt, vesicular basalt, scoria, trachyte and recent alluvial deposits.

Vesicular basalt: This rock unit is covered large part of the study area and it is clearly out cropped at Ayo River bank and Mesni, Sutena and Zerket stream banks and beds. Ridges surrounding Injibara town are also covered by this unit. Weathering and fracturing are affecting this unit and it is not filled by secondary minerals. Previously drilled well data result indicates this unit gives potential amount of water to the wells.

Scoraceous basalt: Dark to brown color, weathering, fracturing and vesiculation are the major characteristics of this unit. This unit is dominantly observed at Ayo riverbank and Sutena streambed.

Scoria: This unit is found in western part from the study area and it is clearly out cropped along Injibara-Chagni road cut. It is weathered and its thickness reaches up to 15 meter. This unit is important for ground water storage and conductance, however it is not suitable for engineering foundation purpose.

Trachyte: This unit is found in western ridges of Injibara town that cover small area and it is characterized as fractured, weathered and reddish in color.

Alluvial deposits: Alluvial deposits are covering low land plain part of the study area and it consists of clay, silt, sand, gravel, cobbles and boulders that are basaltic origin. The clay unit covers large part of the study area. Gravels, cobbles and boulders are dominant on the beds of streams and its thickness varies from place to place as shown in Figure 2.

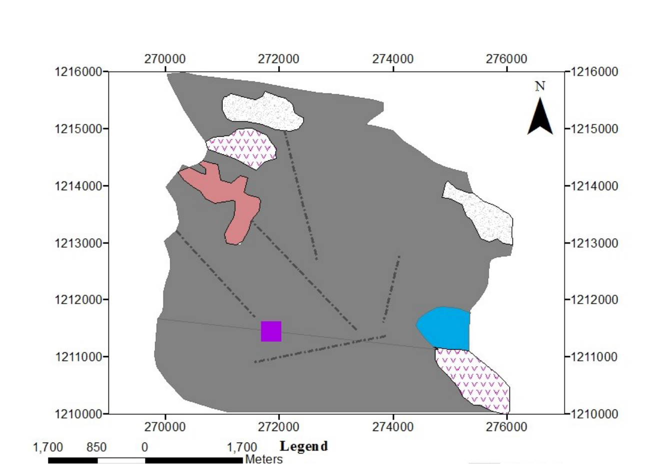

Figure 2: Geological map of the study area and its surroundings. **Note:** (■): Study area; (■): Upper baslt (vesicular basalt); (▨): Scoraceous basaltic cones; (□): Alluvial soil; (■): Trachyte flows and plugs; (■): Crater; (-·-·-): Lineaments.

Geological structures: The dominant geological structures observed on the area are lineaments, local fault, and medium to large spacing fractures with three major sets trending N-S, SE-NW and NE-SW direction [4,5].

MATERIALS AND METHODS

Data acquisition and instrumentation

The objective of refraction seismic survey was to determine the velocity of elastic waves propagation along different paths within the subsurface and indirectly assess the density characteristics. Every wave reaching the geophone produces a momentary impulse on a record of ground vibration called seismogram [3].

The survey was made employing the 48-channel Dolang Seismograph (JEA247ESAC500), though in this study only 12 and 24 channels were used at geophone spacing of 4-10 m. A 12 kg sledge hammer was used as source generate elastic waves propagation along seven lines (spread), i.e., having a length of 55-110 m. The sledge hammer was connected to the seismograph using the trigger cable to arm the seismograph as the impact is done. At each geophone and shot points location coordinates and elevation data were recorded using Garmin GPS map 62 as shown in Figure 3.

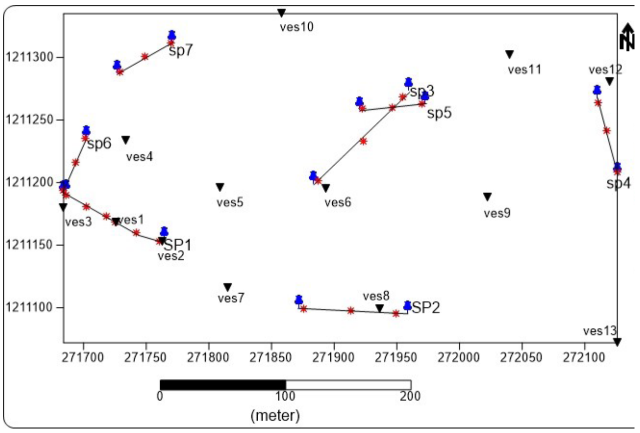

Figure 3: Seismic refraction survey lines (note that the red stars show shot points position). **Note:** (⬇): Initial and end geophone in a spread; (✱): Shot points; (—): Sp 1 spread-1; (▼): Ves points.

The geophones were laid on the ground at regular interval measured by a tape meter. Geophone spacing is determined based on accessibility conditions and the detail of the required information. The field procedure employed was an in-line spread in which the source and the geophones were placed in a straight line [6]. The geophones were connected to the seismograph *via* seismic cables. The source was activated at three different points for the six spreads and six different points for one spread along the spread. The locations of the shots were 2 m, 22 m, 42 m, 50 m, 70 m and 90 m on spread 1 and 4 m, 44 m and 82 m on spread 2 as shown in Figure 4.

Processing and presentation of seismic refraction data

The seismic refraction data were processed using the software programs PickWin95 and Plotrefa from the SeisImager software package. Raw field data in 'seg2' format were imported into PickWin95 and the first arrivals of the p-waves were chosen. A band pass filter frequency of 56.9 Hz low cutoff and 409.6 Hz high cutoff were applied to take out the low and high frequency noise. These cutoff frequencies were chosen considering the range of seismic frequencies and observing the seismogram (waveform). This was performed for each of the shot points along the spreads [2,3]. Then, the first arrival picked data were imported into Plotrefa, and a plot of time versus distance was generated. Plotrefa automatically checks reciprocal times for multiple shot locations. It is best if the Root Mean Square (RMS) error is less than 5%. Most of the data points in the spreads have RMS values below 5%; however, there are some data points with higher RMS errors. Data processing requires much care and experience as noise can be deceptive in picking first breaks. The main noise sources in the project area were movement of trucks, excavator, people and animals in the proximities of the survey lines [7].

Figure 4: Field setup, data acquisition and instrumentation of seismic refraction survey.

Layers were assigned by identifying crossover points, which occur where the slope (1/v) changes. The crossover point separating vesicular basalt and basalt is minor, but the change in slope between the top soil and bedrock is distinct. After the layer assignment, a time-term inversion model can be run. Velocity is calculated, and from the model depth is inferred. Velocity models for each spreads were generated using different first arrival picks in order to gain an understanding of model sensitivity.

This was done for the seven spreads and for each of the source. See a typical example of Figures 5 and 6.

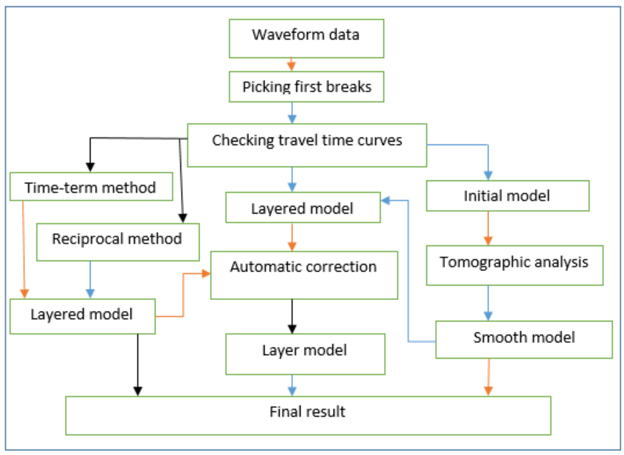

Figure 5: Processing flow for seismic refraction data analysis.

RESULTS AND DISCUSSION

In this work, interpretation has been made based on the results of seismic refraction with the help of a borehole lithological log data. The borehole data helps to understand the vertical geological section of the study area and to correlate these different units with the seismic refraction velocity model sections. The depth of the boreholes used for lithological correlation is 296 m; whereas the depths of the seismic velocity models are about maximum depth 20-35 m, i.e. the depth of the geophysical sections is smaller as compared to the depth of the borehole depth. A borehole used in the interpretation of the geophysical data is found near the boundary of the study area drilled by Amhara design and supervision works enterprise collaboration with Amhara water, irrigation and energy bureau for water supply purpose to Injibara University for the coming year consumption [8].

Interpretation of seismic refraction data

Data were processed using the software programs PickWin95 and Plotrefa from the SeisImager software package. These programs allow cross-sectional areas of the subsurface beneath each spread to be plotted, thus modeling the bedrock interface using a time-term inversion method was employed. A three-layer model was employed to represent the basalt bedrock, vesicular basalt and a thin top soil layer. Raw field data were imported into PickWin95 and then before picking the first arrival times, band pass frequency filter using upper and lower cut off frequency of 409.6 HZ and 56.95 HZ respectively was applied to remove the noise and improve signal to noise ratio [9]. The first arrival times were picked up using the auto-pick option of the system for all records and few adjustments were made manually where it seems necessary. This was performed for each of the shot points along the spreads. Then, the first arrival data were imported into Plotrefa, and a plot of time versus distance (1/v) was generated as shown in Figure 6. Plotrefa automatically checks reciprocal times for multiple shot locations [7]. It is best if the Root Mean Square (RMS) error is less than 5%. Most of the data points in the spreads have RMS values below 5%; however, there are some data points with higher RMS errors.

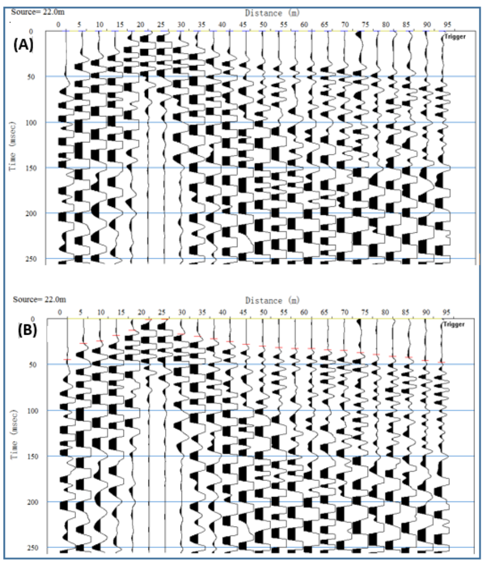

Figure 6: (A): Sample of waveform; (B): A waveform with picked first breaks.

Layers are assigned by identifying crossover points, which occur where the slope of 1/v changes. The crossover point separating vesicular basalt and basalt is minor, but the change in slope between the top soil and bedrock is distinct. After the layer assignment, a time-term inversion model can be run. Velocity is calculated and the model depth is inferred. Velocity models for each spreads were generated using different first arrival picks in order to gain an understanding of model sensitivity [10,11].

The model produced using the above software packages were interpreted according to the area geology and the parameters determined from the model. Because of noise data of the seismic refraction spread three, first arrival picking of p-wave travel times was very difficult. Therefore, spread three was not considered in the processing and interpretation part.

Velocity model for spread-1

The seismic refraction velocity model for spread one is presented as in Figure 7. This is 92 m long profile which runs NW-SE direction. The model is generated using time-term inversion method. The velocity model represents seismic velocities between 280 m/s and 1758 m/s. The top most layer shows low p-wave velocity varies 280-520 m/s and is about 1.5-3 m thick with slight difference along the spread. The velocity indicates that the top layer is composed of soil deposits. The second layer is located at a depth of about 2-3 m [12]. The velocity of this layer ranges 1400-1355 m/s and from the lithological log in the study area this layer is probably weathered and fractured vesicular basalt. The p-wave velocity in the third layer is relatively high and from local geology and lithological log this layer is possibly moderately weathered and fractured basalt [13]. This moderately weathered and fractured basalt is regarded as the bed rock in the building site. The velocity of the model shows that the third layer is relatively strong rock type. Its velocity is 1758 m/s. The depth of this layer is varies along the spread. It extends relatively high depth to the left ends of the model as shown in Figure 7.

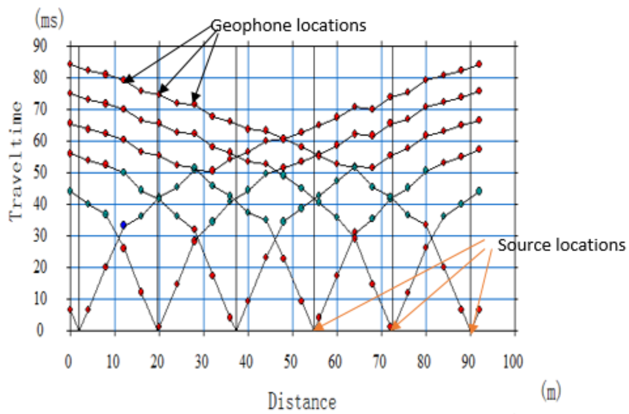

Figure 7: Time-distance plot of the spread.

Velocity model for spread-2

The seismic refraction of spread two lie in the same line as that of spread one laying in NW-SE direction and its velocity model is presented in Figure 8 with total spread length of 88 m. From the velocity model generated from this profile, the time-term inversion model show three p-wave velocity layers. The model presents seismic velocities between 458 m/s and 1500 m/s. The top layer shows low p-wave velocity of 458 m/s and the thickness of this layer is almost similar along the spread. The p-wave velocity indicates that the top layer consists soil deposits of clay, silt and sand. The p-wave velocity of the second layer is varying 900 m/s-1250 m/s and from the lithological log in the study area this layer more likely to be slightly weathered and highly fractured vesicular basalt [6]. The p-wave velocity in the third layer is relatively high 1500 m/s and from the lithological log this layer is probably moderately weathered and fractured basalt. This moderately weathered and fractured basalt is regarded as the bed rock of the site. The velocity of the model shows that the third layer is relatively competent rock formation. The depth of this layer is different at the left and right ends of the velocity model. It is relatively deeper in the left side of the velocity model than towards the right end. From the velocity model we can see that the velocity change among each layer is not gradational i.e. sharp or abrupt.

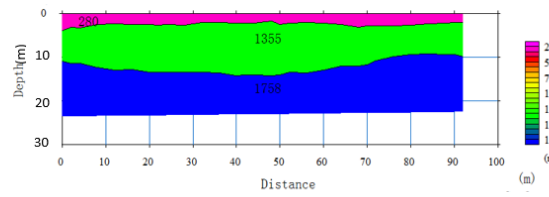

Figure 8: Seismic refraction velocity model of spread-1.

Velocity model for spread-4

In spread four, the first layer in the velocity model essentially shows in Figure 9 low-velocity material overlying on medium velocity layer. This 300 m/s indicates that the top layer is dominated by soil deposits of clay, silt and sand with thickness ranging from 2-3 m.

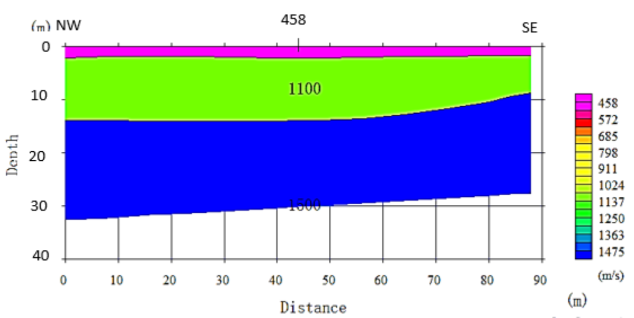

Figure 9: Seismic refraction velocity model of spread-2.

The velocity of the second Layer with p-wave velocity 1200 m/s indicates moderately zone which is possibly weathered and highly fractured vesicular basalt from the lithological log near by the boundary of the study area. The depth for this layer extends up to about 12 m.

The third layer which has a relatively high p-wave velocity material 3000 m/s at the base of the velocity model is interpreted as to represent moderately weathered and fractured basalt and it is considered as bed rock in the area. This layer is suggested relatively good for setting civil structures.

Velocity model for spread-5

The seismic refraction of spread five laying in E-W direction which crosses profile four of the electrical resistivity sounding survey. As shown in velocity model in Figure 10 the thickness of the first top layer is vary 2-3 m with seismic velocity of 255 m/s. Information from the lithologic log and the velocity value this layer is more likely made up of top soils of clay, silt, and sand. The second layer with p-wave velocity value 1092 m/s is corresponding to weathered and highly fractured vesicular basalt. This layer from the geoelectric section has low resistivity due to its high moisture content. The third layer has relatively high p-wave velocity 2225 m/s and it is found at a depth up to about 10-12 m. From the calculated velocity and borehole information, this layer may be moderately weathered and fractured basaltic formation. This layer is relatively competent and therefore it is regarded as the bed rock in the study area [14].

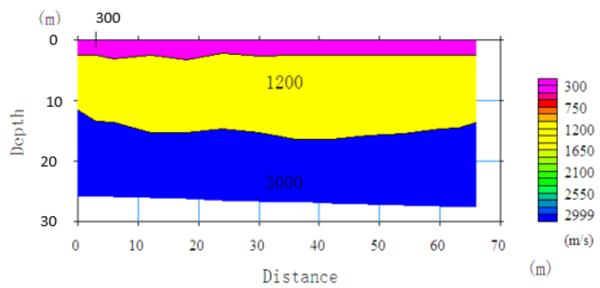

Figure 10: Seismic refraction velocity model of spread-4.

Spread-6 velocity model

Spread six is parallel to profile four of the resistivity sounding survey which lies along SW-NE direction. The seismic velocity model of this spread is shown in Figure 11. The top layer of the velocity model for spread six is about 3-4 m thick with average p-wave velocity of 510 m/s. Layer 2 and 3 have average velocities of 948 m/s and 2555 m/s respectively. The third layer is buried about 11-13 m deep in the spread line. The second layer of spread six has relatively low velocity as compared to other spreads in the survey area. This may due to the presence of completely weathered and fractured vesicular basalt. Some intercalation of clay material in the vesicular basalt.

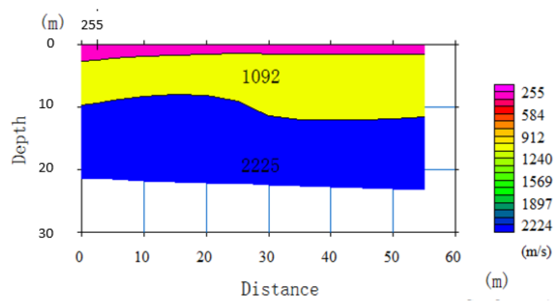

Figure 11: Seismic refraction velocity model of spread-5.

Velocity model for spread-7

Velocity model generated for spread seven located to the Northwestern end of the survey area as shown in Figure 12. As the p-wave velocity, model Figure 13 shows the thickness of the top most layer varies from 2-3 m with velocity of 273 m/s. This very low p-wave velocity indicates the top layer is composed of clay, silt and sand deposits. From the lithological log in the study area the second layer is more likely to be weathered and highly fractured vesicular basalt with p-wave velocity varies 1400-1802 m/s. This layer is mapped at depth ranges 3-15 m deep with irregular morphology. Moderately weathered and fractured basalt is mapped below this layer with velocity of 2527 m/s [4]. The p-wave velocity of this layer suggests that it is competent enough to be the bed rock of the study area and it is located at a depth of about 20-25 m. From the velocity model we can point out that for each layer velocity it is changed abruptly, it does not show gradational change. Relatively this bed rock is one the most competent one. The competent rock formation is relatively at shallow depth in the left side of the velocity model as compared to right end of the spread.

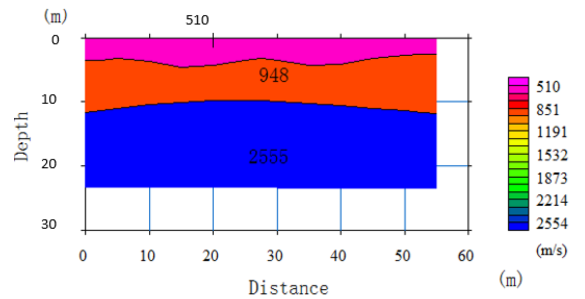

Figure 12: Velocity model of spread-6.

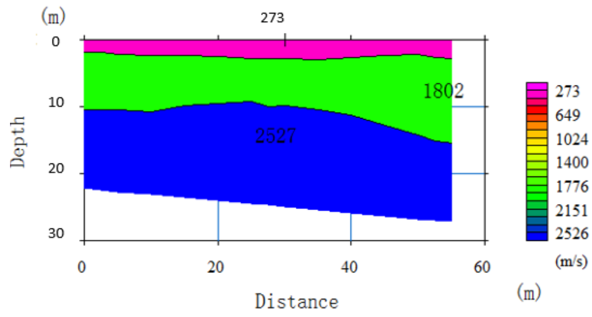

Figure 13: Velocity model of spread-7.

CONCLUSION

Geophysical studies involving seismic refraction method was carried out for engineering site characterization of the building construction site at Injibara University, southwest of Injibara town, Northwestern Ethiopia. Based on the results of collected data the following conclusions are made:

Based on geo-seismic property contrasts, 255-3000 m/s for p-wave velocity ranges, three different subsurface layers the study area are delineated that are associated with different geological units. The top soil, characterized by 255-510 m/s p-wave velocity ranges, is associated with the response of the upper layer composed of clay, silt and sand. The relative p-wave velocity variations are due to heterogeneousF nature of these top soils in terms of their compositions, degree of compactions and moisture contents. Over the area, its thickness varies from about 1 m at the SE part to 4 m on NW flank of the study area. The second layer attributed to the highly weathered and fractured vesicular basalt is characterized by 948-1802 m/s p-wave velocity range and revealed somewhat undulating morphology. The third layer in the study area is described by relatively high p-wave velocity on average greater than 2250 m/s values, which are interpreted as responses of moderately weathered and fractured basaltic bedrock is assumed to acquire suitable geotechnical characteristics to bear loads from heavy civil engineering structures. The depth to the surface of this competent formation ranges from about 10 m in the NW end and SE part to 27 m near to the central part of the study area.

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