A Comparison of Three Geophysical Methods for Determining the Depth to Bedrock

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Abstract—**The location of the study site for the presented research here is at Illinois in USA. Geophysical investigations were conducted to characterize the subsurface. At the site, borehole control, downhole seismic (DHS), seismic refraction tomography (SRT) and multichannel analysis of surface waves (MASW) data were acquired for the purpose of seismic site characterization. Shear wave and compressional wave velocities were used to estimate depth to bedrock. The data analyses showed the depth to bedrock determined by DHS, MASW and SRT is in good agreement with borehole data.**

Index Terms: **seismic refraction tomography (SRT), multichannel analysis of surface waves (MASW), and downhole seismic (DHS).**

I. INTRODUCTION

Geophysical methods have been playing a vital role in subsurface imaging in the recent past. The main advantages geophysical methods over conventional intrusive site investigation techniques are cost-effectiveness and efficiency. Geophysical methods are used for a variety of engineering investigations, including: seismic site characterization, bedrock depth delineation, rock type definition, layer boundaries mapping, water table detection, groundwater flow detection, locating fractures, weak zones, expansive clays, etc. This research is based on the case study in which geophysical methods were used in combination to determine the depth to bedrock. The study site as shown in Figure 1 is located within the New Madrid Seismic Zone in the Granite City 7.5' quadrangle just east of St. Louis, Missouri. The quadrangle lies on the western portion of the Illinois basin in the Saint. Louis metro east area. Borehole control, downhole seismic (DHS), seismic refraction tomography (SRT) and multichannel analysis of surface waves (MASW) data were acquired for the purpose of bedrock determination.

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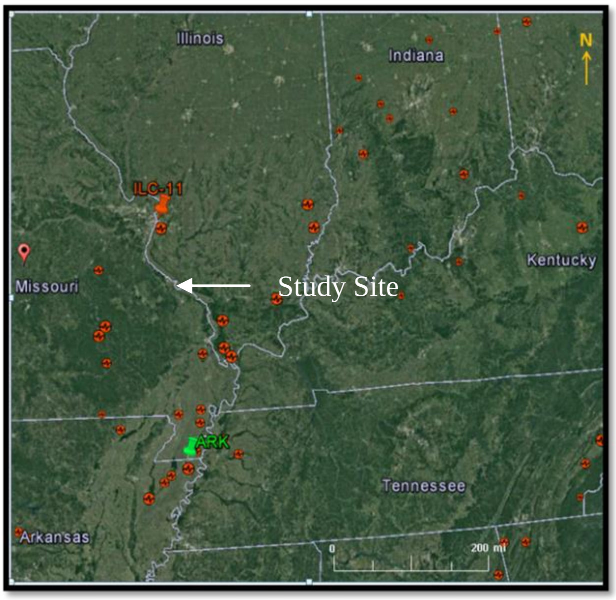

Figure1. Study Site Location

II. GEOLOGY AND STRATIGRAPHY

The Granite City 7.5' quadrangle is just east of Saint. Louis, Missouri, the quadrangle lies on the western portion of the Illinois basin in the Metro east Saint. Louis area, bedrock does not outcrop on the Illinois portion of this quadrangle. Holocene and Quaternary units along the flood plain of the Mississippi river cover the entire Illinois portion. This surficial material ranges in thickness from less than 50 ft near the chain of rocks canal to approximately 125 ft along the eastern half. More than 100ft of sand with some gravel resting over Mississippian limestone, the depths to bedrock are generally about 96ft to 128ft, the loess is thickest (up to 93 ft) at the bluffs immediately east of the Mississippi river valley (Figure 2), and thins to the east and northeast

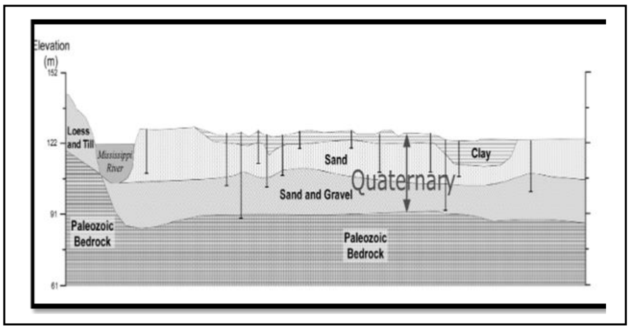

Figure 2. B-A Cross-Section of Surficial Geology in the Study Area [1]

The Illinois portion of the quadrangle is underlain by the Ste.Genevieve limestone and Saint.Louis limestone throughout the majority of the quadrangle with major material types includes silty, clayey, sandy and gravelly alluvium.

Table 1. Geologic and Stratigraphic Units in Misouri[2]

System	Series	Formation	Thickness (ft)	Thickness (m)
Mississippian	Meramecian	Ste. Genevieve Formation	1 – 4	0.3 – 1.2
		St. Louis Formation	0 – 50	0 – 15
		Salem Formation	100	46
		Warsaw Formation	40	12
	Osagean	Burlington-Keokuk Formations	100 – 150	30 – 46
		Fern Glen Formation	30 – 50	9 – 15
	Kinderhookian	Chouteau Group Undif.	15	4.5
Unassigned Devonian-Mississippian		Bushberg Formation	10	3
		Glen Park Formation	15	4.5

III. METHODOLOGY

A. DHS data acquisition

Downhole allows direct measurements of travel times from a source at the surface to a geophone at depth in a borehole (Figure 3). [19] Stated that the interval and average velocities of the borehole surrounding material can be measured. Downhole seismic surveying provide detailed information on the engineering properties of subsurface soils and rock. The velocity profiles obtained from downhole surveys used to construct the site response modeling for earthquake hazard evaluation and structural design.

The downhole seismic surveying (DHS) ***is*** the destructive method used in this study. Downhole seismic surveying (Figure 3) is an important field method for determining the p-wave and s-wave velocities and other geotechnical site investigations.

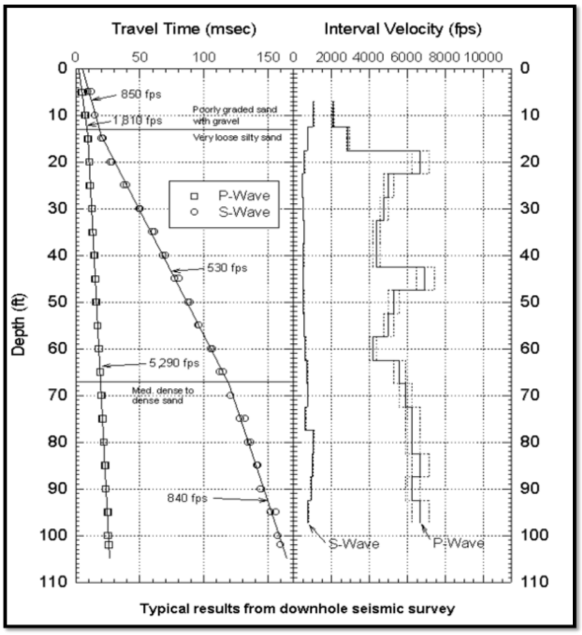

Figure 3. Arrival Time Curve from Downhole Seismic Test[3]

B. MASW data aquiition.

Noninvasive continuous profiling method that can study the subsurface to depths more than 100ft depending on the seismic source and site condition.

Rayleigh waves travel along or near the ground surface; these waves are typically characterized by a low velocity, low frequency, and high amplitude that decreases with depth. The Rayleigh waves have a particle motion counterclockwise with respect to the direction of the travel wave; it moves with a rolling motion with the waves across the ocean. Due to the accurate determination of phase velocities for horizontally traveling fundamental modes of the Rayleigh waves, MASW can be used in many different sites successfully [4].

The Rayleigh waves can be assumed as 92% of the shear wave velocity according to [5], so 0.92Vs is the practical value used by the geotechnical engineers for a Rayleigh wave velocity.

The MASW method estimates S-wave velocities by exploiting the Rayleigh wave's dispersive nature through mathematical inversion [6]. Dispersion is the apparent velocity of the surface-wave that depends on the period and reflects the velocity variation with depth. Different frequencies have different velocities.

The fk-spectrum method is the most commonly used for the dispersion curve measurements related to the characteristics of surface wave data, or those data analyzed to transform into the fk-domain. [7].

The MASW data acquisitions in this study were performed using 24 channels seismic equipment Seistronix RAS - 24, and 4.5 Hz geophones. The sampling interval used is 0.5 ms and recording time is 1,000 millisecond. One survey line is used as shown in Figure 4. Twenty Four geophones are coupled firmly into the ground at 100 ft away of the ILC-11 borehole with spacing of 5 ft; hence the total length of survey line is

115 ft. The sources outside the array line at offset distances 60 ft, 35 ft, and 10 ft (3 records at each source).

C. SRT data aquiition

Tomographic inversion is generally best used when velocity contrasts are known to be more gradational than discrete, when strong horizontal velocity variations are known to exist, or in extreme topography.

Tomography is currently used in many fields such as geophysics, atmospheric science, and materials science. It uses the mathematical procedure called tomographic reconstruction. Seismic refraction tomography (SRT) is a newly- devolved cost effective technique for site characterization compared to conventional seismic refraction due to the capability of seismic refraction tomography to detect "hidden layers" [8], which cause erroneous interpretation of data. An initial module of the ray paths is constructed to associate with their respective measured travel times close to the true P-wave velocity distribution as well as smoothing constraints [9] in order to achieve reliable results during inversion.

Tomographic inversion displays the data in a mode that is more true to real life by showing gradual transitions of velocities instead of very sharp transitions from one velocity to another. In any surface refraction inversion technique, including tomography, it must be assumed that velocity increases with depth.

If all geometrical data and first break picks have been input, the computer would be able to build a theoretical model close to field data using a different algorithm.

Seismic waves travel at different speeds in different materials. When an explosion or an impact occurs in the surface, waves travel away in all direction (Figure 4.12). A ray is an arrow perpendicular to the wave front, indicating the direction of travel at that point on the wave front.

The SRT data acquisition was performed using 24-channels seismic equipment Seistronix RAS - 24 (Figure 4). The sampling interval used is 0.25 millisecond and recording time is 0.25 millisecond. The seismic refraction survey line is 235 ft using 14 Hzl geophones with 5 ft geophone spacing as shown in Figure 4.The Offset forward and backward distances were equal 60 ft. The signal sources for data acquisition used a heavy sledge hammer (20 lb.) and the impact steel plate with dimensions of 1ft x 1ft and seven vertical stacks were sufficient to get a good first arrival record. 24 shot points with 10 ft. as a distance between each shot were done for the survey line.

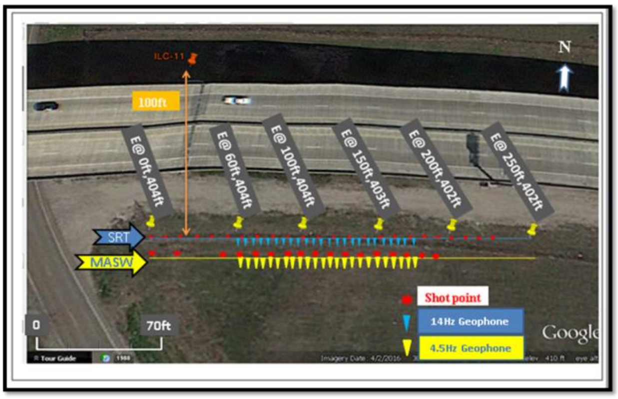

Figure 4. Site Map Showing the Elevations of Marked Testing Locations

IV. RESULTS AND INTERPRETATION

A. Borehole Data.

The borehole data of the ILC-11, with depths reached up to 120 ft that performed in 2008 in the Granite City 7.5'quadrangle in Southwestern of Illinois, the data from 90 to 120ft is shown in Figure 5.

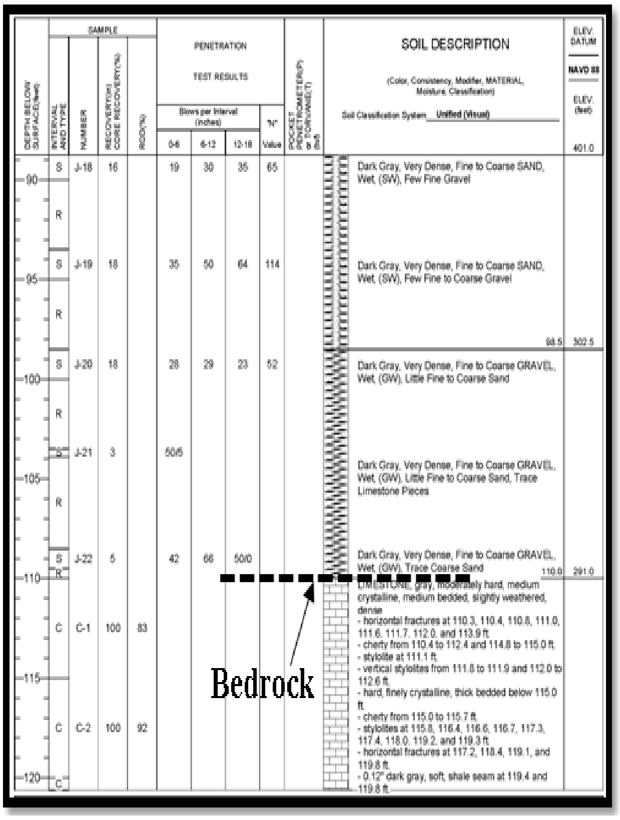

Figure 5. Borehole Data Showing the Depth to Bedrock [10]

B. DHS reults data.

The DHS results of the ILC-11 borehole Figure 6 shows the depth to the bedrock at 110 ft.

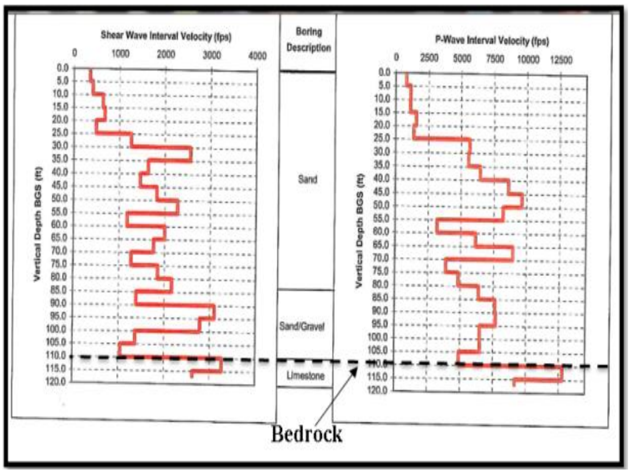

Figure 6. S and P-Wave Velocity Model Showing the Depth to Bedrock Using DHS.

C. MASW resultsdata.

Surface seismic wave profile reached depths to 120 ft as shown in Figure 7; it shows the bedrock aligned in the southwest to northeast ranged from 100 to 110 ft. which is conformable to the borehole data results

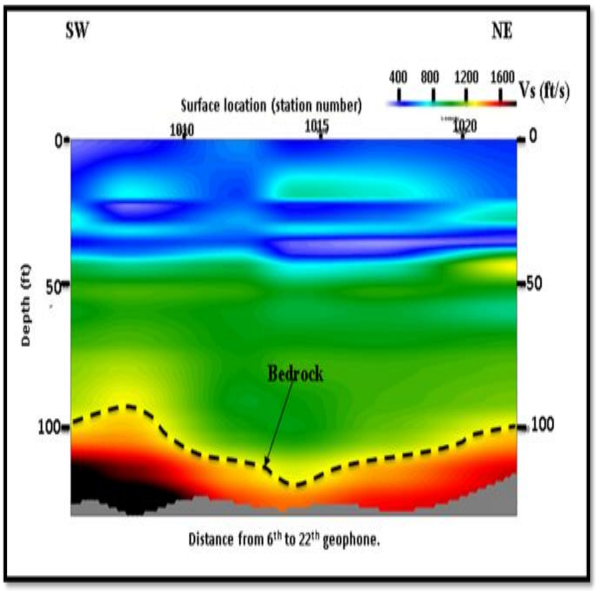

Figure 7. S-Wave Velocity Model Profile Showing the Depth to Bedrock Using MASW

D. SRT results data.

The compressional wave profile as shown in Figure 8, reached depths up to 120 ft.; it shows the bedrock aligned in the southwest to northeast ranged from 100 to 105 ft. which is conformable to the MASW and borehole data results.

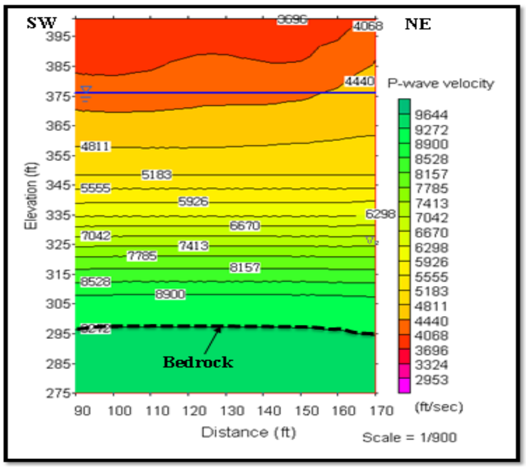

Figure 8. P-Wave Velocity Model Profile Showing the Depth to Bedrock Using SRT

Table 2. Results of depth to bedrock for all methods

Method	Depth to bedrock (ft)
Downhole seismic	110ft
SRT	105ft
MASW	100-110ft

V. Disscusion

At the study area, borehole control, downhole seismic, seismic refraction tomography and multichannel analysis of surface waves data were acquired with the purpose of bed rock measurment. Using borehole control as a grou nd truth data. the downhole seismic shows the depth to bed rock reached to 110ft, where the seismic refraction tomography has a little different depth reached to 105ft, and multichannel analysis of surface waves data have a ranged depth fluctuated from 100ft to 110ft which means that the data analyses showed the depth to bedrock determined by DHS, MASW and SRT is in good agreement with borehole data.

VI. CONCLUSIONS

Several geophysical methods can be applied to locate and map the depth to bedrock at a site. This paper presented the depth to bedrock using borehole control, downhole seismic, seismic refraction tomography and multichannel analysis of surface waves data. The data analyses showed the depth to bedrock determined by DHS, MASW and SRT is in good agreement with borehole data.

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BIOGRAPHIES

Faraj Mohamed Eljabri was born in Kasir Al-akhyar city, Libya.In 1993; he had B.Sc. Degree in Geological Engineering at the faculty of engineering, Tripoli University, and a Master's degree at the same university in 2006. He received his PhD in Geological Engineering from Missouri University of Science and Technology in December 2017. Faraj is a member of European Association of Geoscientists & Engineers (EAGE). He had been in Libyan 2007 Conference & Exhibition of 3rd North African /Mediterranean Petroleum. Summer training in September, 1992, with Schlumberger company in wire line logging in Sarir Field, Arabian Golf oil company, Sarir –Libya. Drilling course in mud logging & gas detection instrumentations (Als2 system) with Geoservice company, Safax ,Tunisia May, 1997 . Safety course in H2S gas with Total Company in July, 2003. Transportation Infrastructure Conference , Jefferson City, MO, September 13, 2013.MASW/SurfSeies workshop held at Kansas Geological Survey, Lawrence, Kansas June 19-20, 2014.