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Integrated of Seismic Refraction Tomography (SRT), and Multichannel Analysis of Surface Waves (MASW) for Verifying and Mapping a postulated Fault

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Abstract— **The location of the study site for the presented paper here is at Arkansas in the United States of America. Geophysical investigations using seismic refraction tomography (SRT) and multichannel analysis of surface waves (MASW) surveys have been jointly carried out on the basis of an experimental investigation in the field. The motive of this study is to validate and map a postulated fault, in the eastern part of Arkansas in the United State of America. The SRT techniques have shown their potentiality in successfully identifying the fault and generated remarkably similar images of the fault, while the MASW tool generated a slightly different image of the fault due to condition that the earth under survey made up of layers of material that increase in seismic velocity which consider the perfect case for SRT techniques. The results show that the integrated use of seismic refraction tomography and multichannel analysis of surface waves is an effective tool with great potential. They provide very useful data for shallow mapping applications.**

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

I. INTRODUCTION

According to the type of arrival waves picking up, the waveforms are analyzed in subsurface imaging in terms of the geophysical investigation techniques. Locating fractures is one of the varieties of engineering investigations used with low cost-effectiveness, reliability, range of validity, and efficiency. Compressional waves (P- waves) and shear waves (S-waves) are used for seismic refraction in vertical seismic profiling and seismic tomography, and Multichannel Analysis of Surface Waves (MASW) is such a technique which uses these surface waves for shallow subsurface profiling. The new Lidar data show linear highs that appear to be the Cottonwood Grove fault (also sometimes called the Blytheville fault) in the study site; some preliminary subsurface data were achieved to help suggest that this topographic high is a fault. The width of the ridge is about 416 ft, the geophysical lines (Figure 1) has been extended beyond the ridge in each direction. A comparative evaluation of the overall usefulness of the SRT and MASW techniques performed. The comparison showed that SRT is more significant than MASW tool, where the MASW tool generated a slightly different image of the fault. The paper demonstrates that integrated use of seismic refraction tomography and multichannel analysis of surface waves methods is an effective approach in terms of imaging of the fault due to the greater details of lateral offset of features across the fault.

II. GENERAL DESCRIPTION OF THE STUDY AREA

Mississippi Earthquakes occur every year throughout the county, state of Arkansas because Arkansas is located near one of the most hazardous earthquake zones in North America, which is the New Madrid seismic zone (NMSZ) [2]. This active earthquake zone extends from Cairo, Illinois, into Marked Tree (Poinsett County) [2]. The study site (Figure 1) located in the eastern part of Arkansas at Blytheville, Arkansas on the new Madrid Seismic Zone (NMSZ).

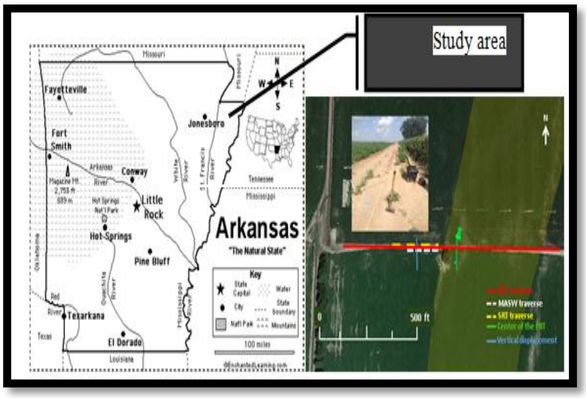

Figure 1. Study Area Location in Arkansas. [1]

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III. GEOLOGY AND STRATIGRAPHY

Arkansas is divided into a highland area in the northwest and a lowland region in the south and east [2]. The rocks in the highland area are dominated by well-lithified sandstones, shales, limestones, and dolostones of Paleozoic age. A thin drape of younger unconsolidated clays, sands, and gravel, termed alluvium, is often found in valley floors and associated with the streams and rivers. The sedimentary deposits of the lowlands are mainly unconsolidated clay, sand, and gravel of Quaternary age, poorly consolidated deposits of clay, sand, silt, limestone, and lignite of Tertiary age, and consolidated (to a limited extent) deposits of Cretaceous marl, chalk, limestone, sand, and gravel. In the late Paleozoic Era, a broad uplift domed the Ozark strata with little structural disruption. Figure 2 shows the West Gulf Coastal Plain and Mississippi River Alluvial Plain sub - regions of the Gulf Coastal Plain of Arkansas Simultaneously, a collision of two of the earth's mobile continental plates compressed the sediments of the abyssal plain into the Ouachita Mountains [2]. This multimillion-year-long process folded and faulted the Ouachita strata into a structurally complex mountain chain. The Arkansas River Valley area is the transition zone between the structurally simple Ozarks and the structurally complex Ouachitas with subdued characteristics in each region. Eastern and southern Arkansas is underlain by Cretaceous age through recent sedimentary deposits with small areas of igneous intrusions of Cretaceous age. Eastern and northeastern Arkansas is dominated by the Quaternary terrace and alluvial deposits with minor exposures of Tertiary units.

The central part of the Bootheel lineament (Figure 3) has been identified as a Holocene surface fault with both vertical and horizontal motion [2], A–A′ (Figure 2) indicates ~10 ft. of vertical offset of the braid-stream sand, but these could be related to either ground failure or uplift. Displacement on the fault is interpreted to be 10 ft in the vertical sense and at least 42 ft. in a right - lateral sense. A compression pop up between two - echelon segments of the BHF that may be associated with the large elliptical sandy area east of the study site may have contributed to the vertical component of displacement observed in the site. The Reelfoot thrust fault is responsible for most of the modern seismicity of the NMSZ (Figure 2). It is interpreted as an inverted basement normal fault. [3]. The Reelfoot Rift is formed during the breakup of the supercontinent Rodinia in the Neoproterozoic Era (about 750 million years ago). The resulting rift system applies as a weak zone deep underground the Earth's crust in the New Madrid seismic Zone makes the area weaker than much of the rest of North America. This weakness allows reactivating old faults around the New Madrid area, which makes it prone to earthquakes. Also, heating in the lithosphere below the area will increase the deep rock plasticity, which makes the compressive stress more concentrate in the shallower subsurface area where the faulting occurs.

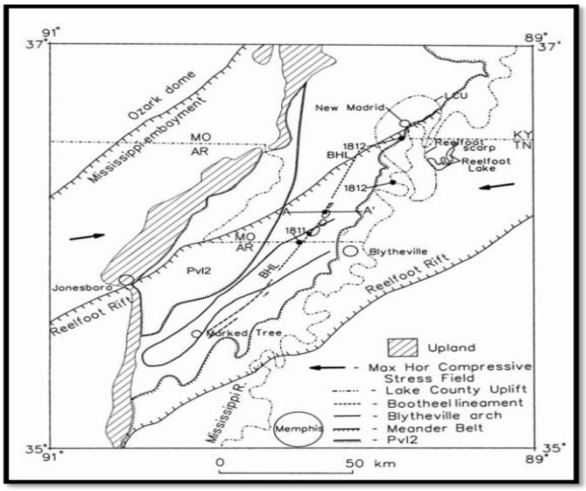

Figure 2. Location of Bootheel Fault in the NMSZ [4].

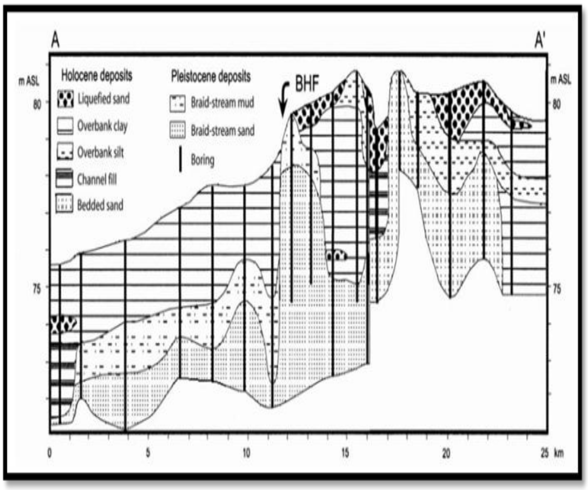

Figure 3. Cross section of the Western Mississippi River [5].

IV. THEORY AND METHOD

A. *Type of Acoustic(seismic)Waves*

Seismic waves are a type of oscillation that transports energy from one location to another without the transportation of matter, they propagate through a medium because of the interaction between the particles of the medium, they are classified into body waves and surface waves.

Body Waves: Body waves are those which travel through the entire volume of the earth, those waves are non-dispersive and travel at a speed proportional to the material density and modulus, the body waves are classified as either compressional waves (p-wave; P stands for primary) or shear waves (S-wave; S stands for secondary).

Compressional waves: Compressional waves as shown in (Figure 4) are characterized by particle motion parallel to the direction of the wave propagation. The velocity of propagation can be expressed in terms of axial modulus and density.

$$V_p = (E/\rho)^{0.5} \qquad (1)$$

where:
V_p is compressional wave velocity,
E is an axial modulus, and
ρ is a density.

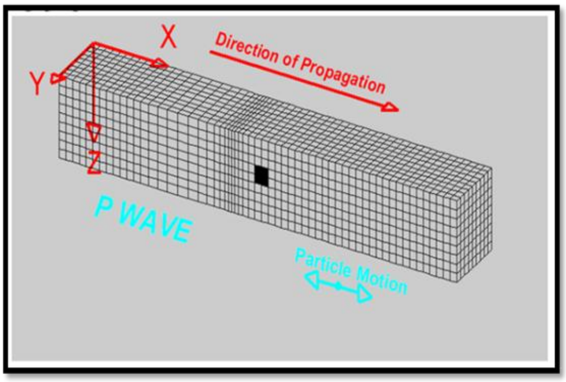

Figure 4. Compressional Wave Propagation [12].

Shear waves: The second type of body wave is a shear wave or S-wave as shown in (Figure 5), they are characterized by particle motion that perpendicular to the direction of wave propagation. S-wave is calculated using the equation:

$$V_s= (G/ \rho) \qquad (2)$$

where:
V_s is the shear wave velocity,
G is the shear modulus, and
ρ is a density.

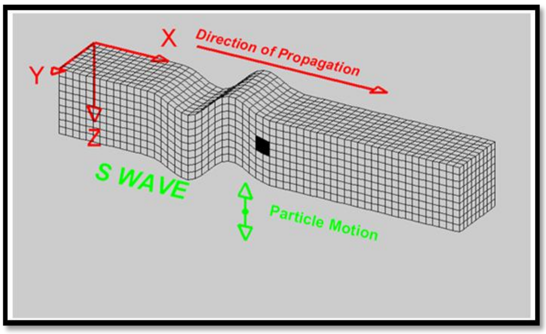

Figure 5. Shear Wave Propagation [12].

Surface Waves: There are two primary types of surface waves: Rayleigh and Love waves. Unlike body waves, surface waves travel only along the earth's surface and they are dispersive.

The velocity of propagation is mostly a function of material rigidity, shear modulus and hence shear wave velocity).

Rayleigh waves: Rayleigh wave particle motion is usually described as retrograde elliptical, Rayleigh waves (Figure 6) motion is both parallel and perpendicular to the direction of wave propagation, they are responsible for much of the damage and destruction associated with earthquakes. When a compressional wave source used, more than two-thirds of total seismic energy generated is imparted into Rayleigh waves [16]. The shear-wave velocity is the dominant parameter influencing changes in Rayleigh-wave phase velocity, it has been shown that Rayleigh-wave phase velocity data can be inverted and used to generate reliable corresponding shear-wave data [17], their velocity is a function of both the shear-wave velocity of the subsurface and the compression-wave velocity of the subsurface. The interrelationships between Rayleigh-wave velocities within the uniform medium, shear-wave velocities, and compression-wave velocities in a uniform half-space are expressed in the following equation:

$$V_R^6 - 8V_S^2V_R^4 + (24 - 16\, V_S^2 / V_p^2)\, V_S^4V_R^2 + 16(V_S^2/ V_p^2 - 1)\, V_S^6= 0 \qquad (3)$$

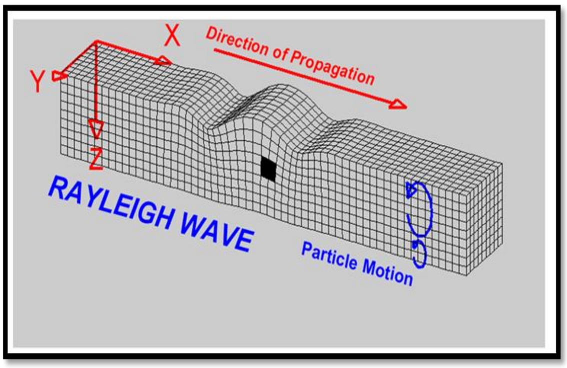

Figure 6. Rayleigh Wave Propagation [12].

Love waves: Love waves were named after Edward Hough Love, they are horizontally polarized surface waves which are the second components associated with the shear component, it's tending to be the most destructive wave at the surface of the earth. Love wave and its direction of propagation are shown in (Figure 7).

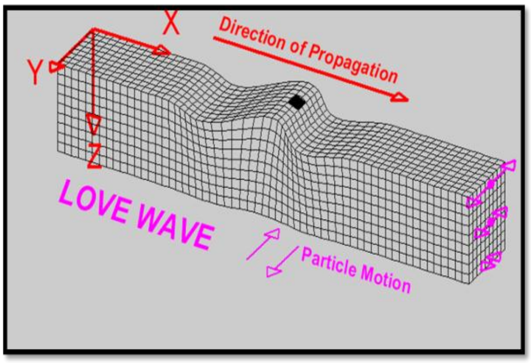

Figure 7. Love Wave Propagation [12].

B. *Multichannel Analysis of Surface Waves (MASW)*

MASW is a noninvasive, continuous profiling method that can study the subsurface to depths more than 30 meters depending on the seismic source and site condition, Rayleigh waves travel along or near the ground surface; these waves are typically characterized by low velocity, low frequency, and high amplitude that decreases with depth. they have a particle motion counterclockwise concerning the direction of the travelling 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 [22]. There is little variation between the Rayleigh waves and shear waves, the velocity of the Rayleigh waves is very close to shear wave velocity. For all practical purposes, the Rayleigh waves can be assumed as 92% of the shear wave velocity according to [23], 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 [17]. 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, According to [24], 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. The analyzed data can then be used to create the Phase velocity frequency spectrum.

The MASW data acquisitions in this study were performed using 24 channels seismic equipment Seistronix RAS - 24, and 4.5 Hz geophones (Figure 8). The sampling interval used is 0.5 millisecond and recording time is 1,000 millisecond. Seven lines were overlapped with 10 ft distance as shown in (Figure 9). 24 Geophones are coupled firmly into the ground with a spacing of 2.5 ft.; hence the total length of the survey line is 57.5 ft. The offset distance was 10 ft. from the first geophone were used for the seven lines; one record at each source location was obtained. 20 lb sledge hammer and the impact steel plate with dimensions of 1ft x 1 ft were used as the signal sources for data acquisition as a choice to deliver appropriate impact power into the ground, and field laptop.

Figure 8. Location of the shot points for MASW array line.

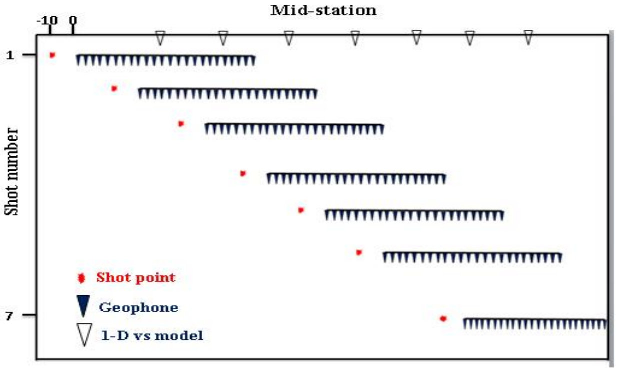

Figure 9. Location of the shot points for MASW traverses lines.

C . Seiesmic Refraction Tomography (SRT).

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" [30], 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 [31] 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. Careful picking and optimum shots are required to give accurate results. The SRT is also known as velocity gradient or diving-wave tomography [36]. It uses the first arrival travel time of seismic waves. When a seismic wave encounters a velocity discontinuity, some of the energy is reflected and some is refracted, but this study only focuses on refracted energy. The SRT data acquisitions were performed using 24-channels seismic equipment Seistronix RAS - 24, the sampling interval used is 0.25 millisecond and recording time is 0.25 millisecond. The seismic refraction survey line has been done by 280 ft. as the total length of a survey line, using 14 HZ Vertical Geophones with 10 ft. geophone spacing. Both of the Offset forward and backward distances were equal 25 ft. 20 lb sledge hammer and the impact steel plate with dimensions of 1ft x 1 ft were used as the signal sources for data acquisition as a choice to deliver appropriate impact power into the ground, and field laptop. Seven vertical stacks were sufficient to get good results. 29 shot points are done for the survey line, 10 ft as a distance between each shot. The location of the shot points for survey line is shown in (Figure 10).

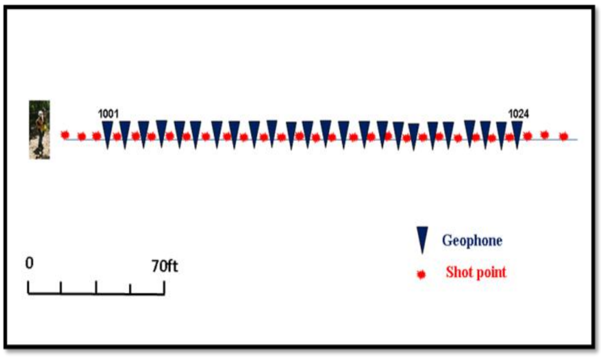

Figure 10. Location of the Shot Points for SRT Traverse Line.

V. RESULTS AND INTERPRETATION

A. MASW resultsdata.

The Processing data of the all records was performed using the SurfSeis software package, developed by the Kansas Geologic Survey (KGS). The total records in the study lines were 7 records. Various processing parameters; frequency ranges, and phase velocities were used to generate dispersion curves and 1-D shear wave velocity profiles for all of the records.

The results of the shot gathers, the dispersion curves and the inverted of 1D shear wave velocity modules for all records have shown from (Figure 13) to (Figure 31) , and the 2D model profile from MASW data is shown in (Figure 32).

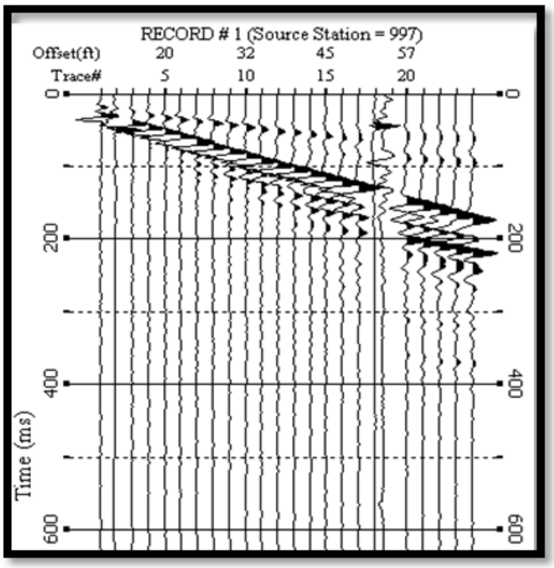

Figure 11. Shot Gather Used for Line 1.

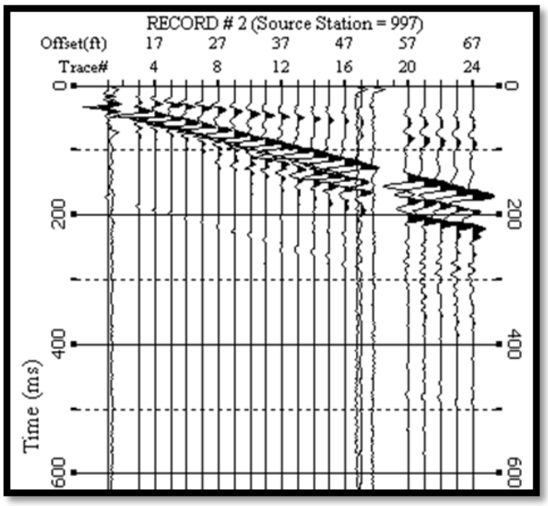

Figure 12. Shot Gather Used for Line 2.

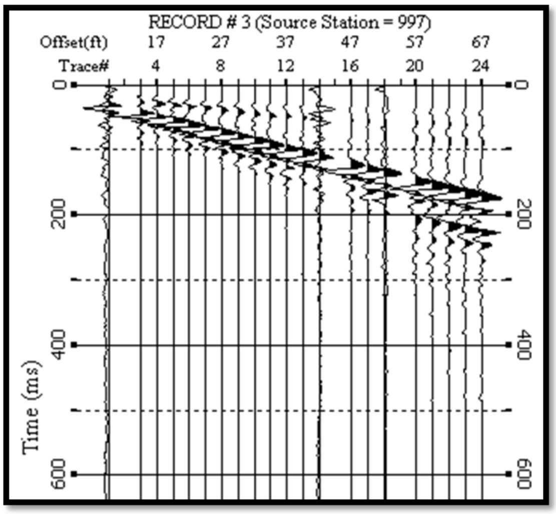

Figure 13. Shot Gather Used for Line 3.

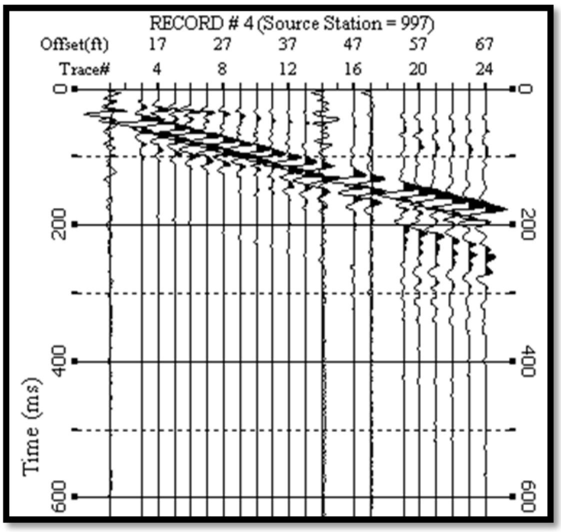

Figure 14. Shot Gather Used for Line 4.

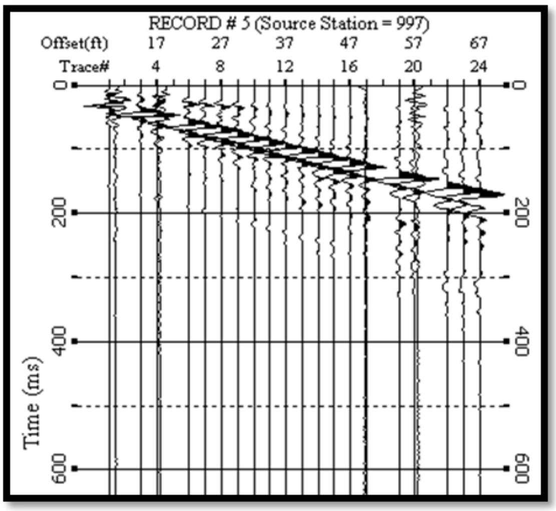

Figure 15. Shot Gather Used for Line 5.

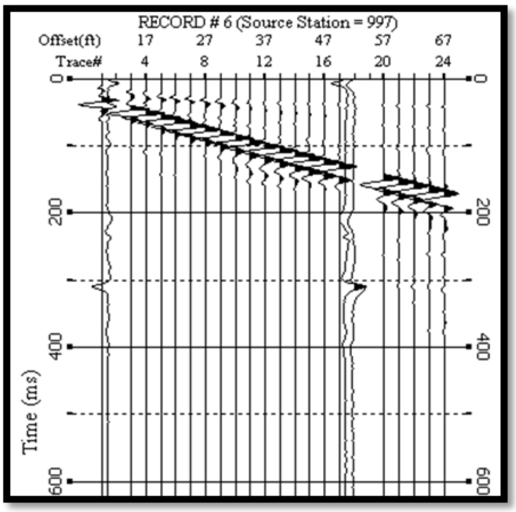

Figure 16. Shot Gather Used for Line 6.

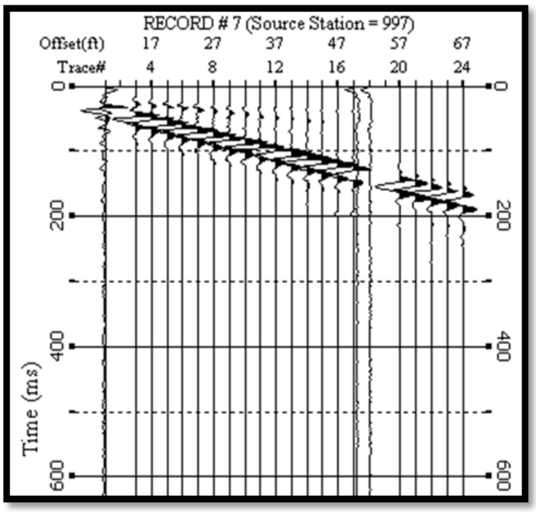

Figure 17. Shot Gather Used for Line 7.

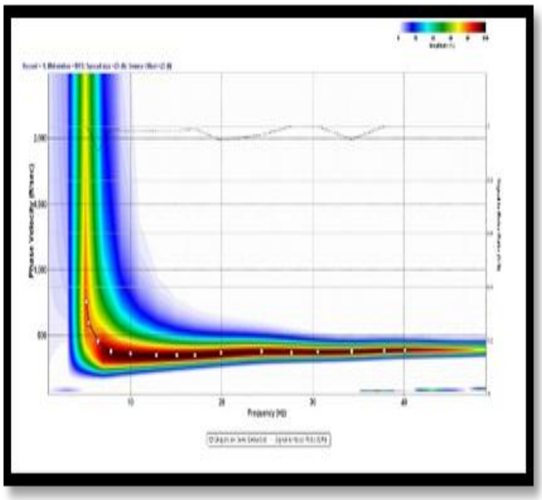

Figure 18. Disspartion Curve for Shot Line 1.

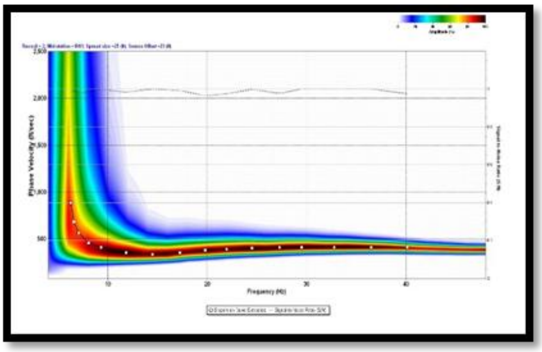

Figure 19. Disspartion Curve for Shot Line 2

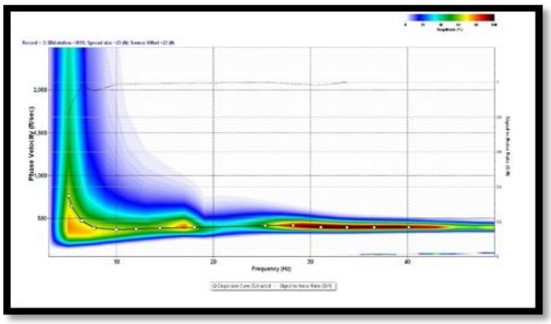

Figure 20. Disspartion Curve for Shot Line 3

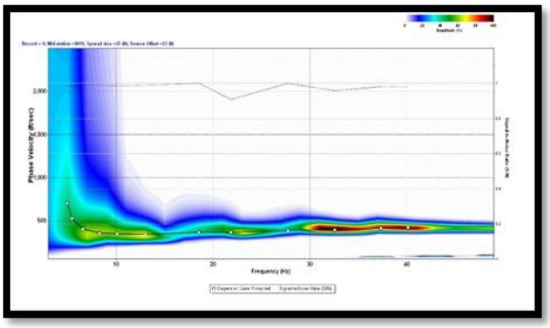

Figure 21. Disspartion Curve for Shot Line 4

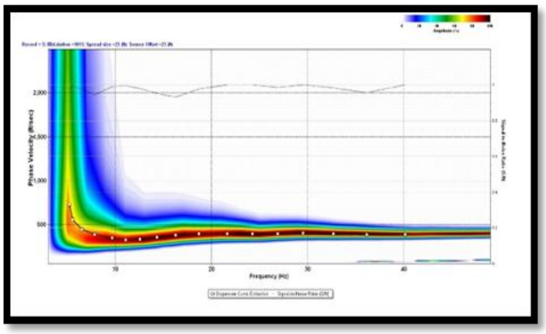

Figure 22. Disspartion Curve for Shot Line 5

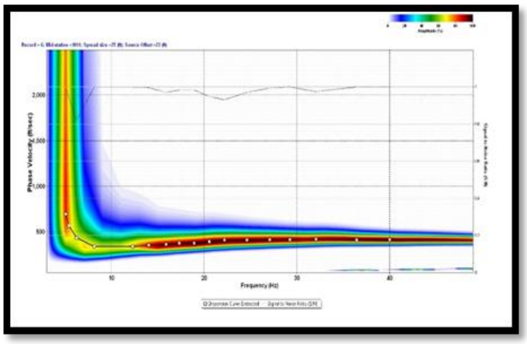

Figure 23. Disspartion Curve for Shot Line 6

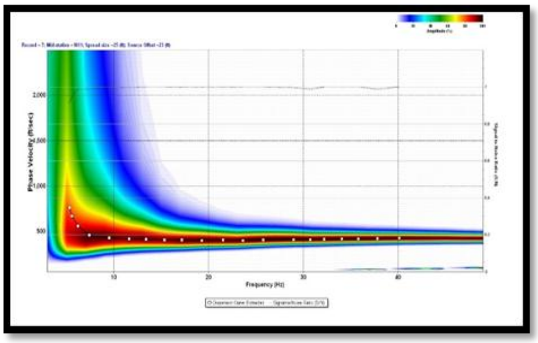

Figure 24. Disspartion Curve for Shot Line 7

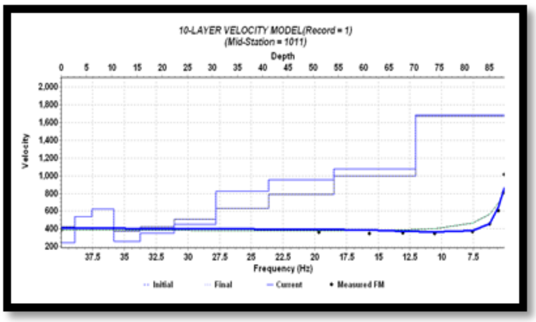

Figure 25. The Inverted of 1D Shear Wave Velocity Module 1.

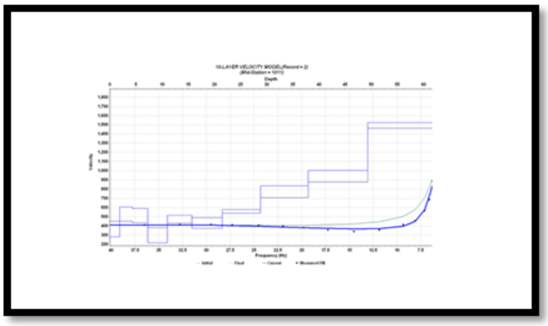

Figure 26. The Inverted of 1D Shear Wave Velocity Module 2.

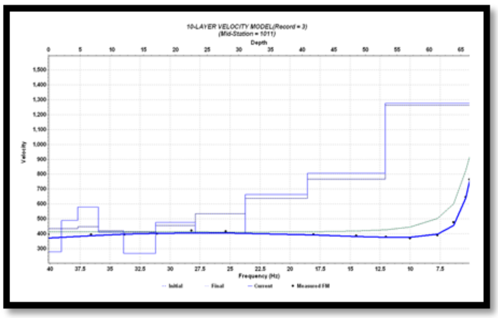

Figure 27. The Inverted of 1D Shear Wave Velocity Module 3

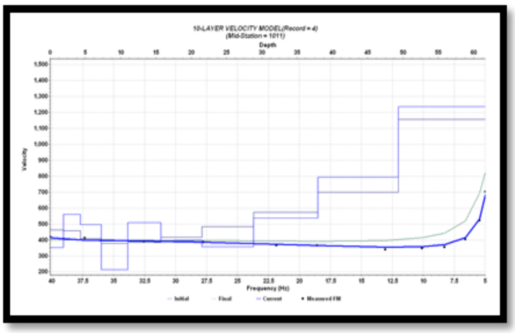

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Figure 28. The Inverted of 1D Shear Wave Velocity Module 4

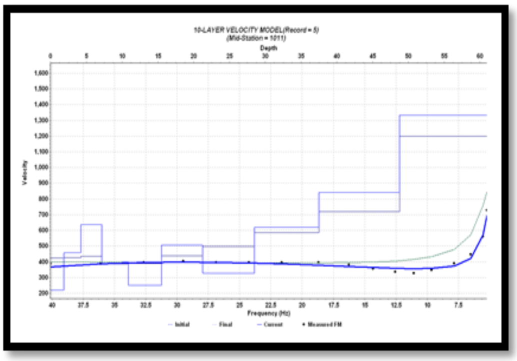

Figure 29. The Inverted of 1D Shear Wave Velocity Module 5.

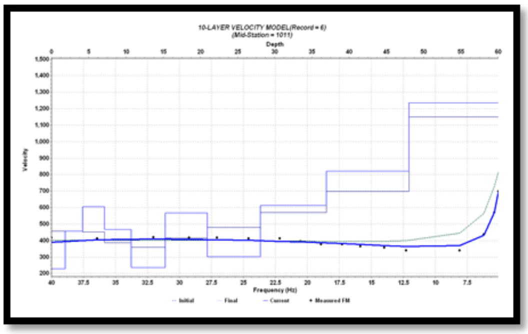

Figure 30. The Inverted of 1D Shear Wave Velocity Module 6

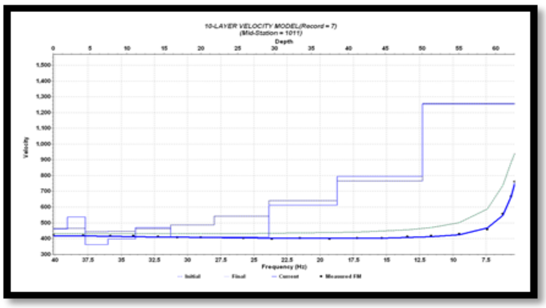

Figure 31. The Inverted of 1D Shear Wave Velocity Module 7

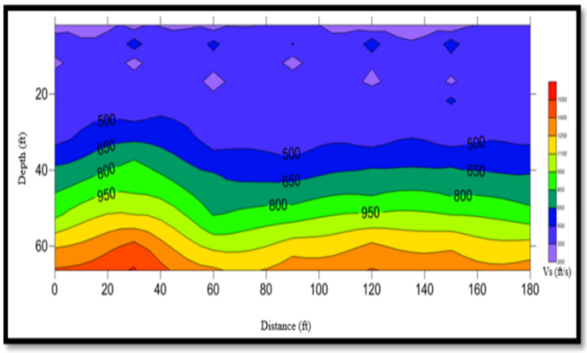

Figure 32. 2D Model Profile from MASW Data.

D. *SRT results data.*

The results of the SRT data processing are shown in (Figure 33), (Figure 34), and the 2-D P-wave velocity model profile from SRT inversion is shown in (Figure 35).

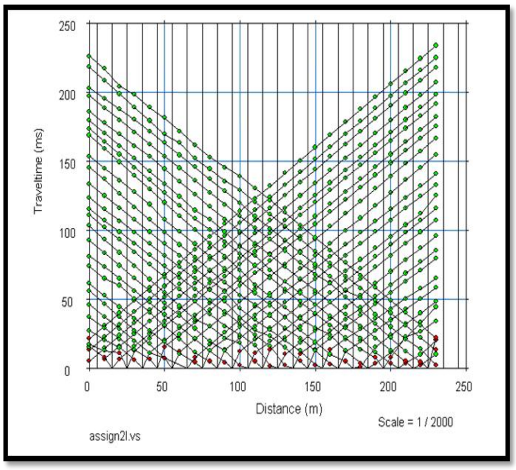

Figure 33. The Assigning Layers of the First Arrivals.

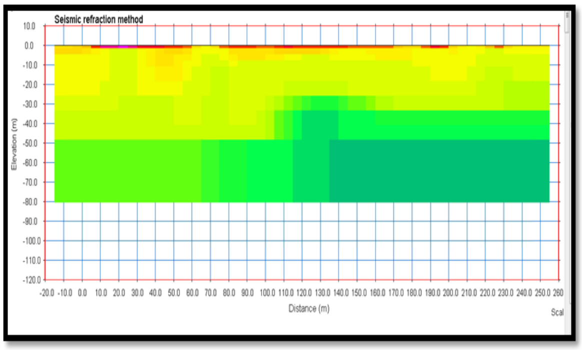

Figure 34. The Synthetic Velocity Model for the Test Site.

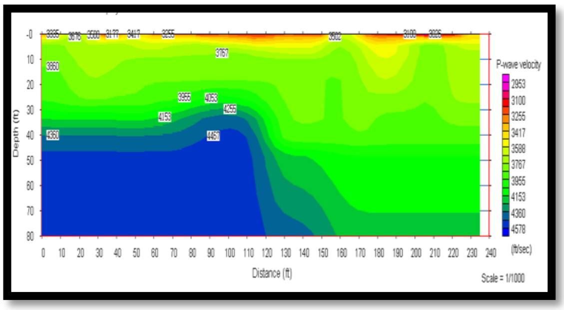

Figure 35. 2-D P-Wave Velocity Model Profile from SRT Inversion.

VI. DISSCUSIONS

SRT and MASW data were acquired with the purpose of mapping a postulated fault. It is found that the chance of a successful survey is usually much higher with the SRT method than MASW method, especially in detecting the near-surface anomalies with the low - velocity layer. The p-wave energy can be generated by using a 20 lb. sledge hammer as the signal sources for data acquisition and the impact steel plate with dimensions of 1ft x 1 ft as a choice to deliver appropriate impact power into the ground, and field laptop, followed by simple field logistics and processing. Most importantly, primary waves respond effectively to the various types of near-surface anomalies that are common targets of geotechnical investigations. The Shear wave velocity model profile was formed by MASW, and the P-wave velocity model was formed by SRT inversions are correlated together (Figure 36) showing SRT has a vertical displacement of approximately 40 ft, where the MASW showed a vertical displacement of approximately 15 ft in the fault zone. The SRT techniques have shown their potentiality in successfully identifying the fault and generated remarkably similar images of the fault, while the MASW tool generated a slightly different image of the fault due to condition that the earth under survey made up of layers of material that increase in seismic velocity which consider the perfect case for SRT techniques.

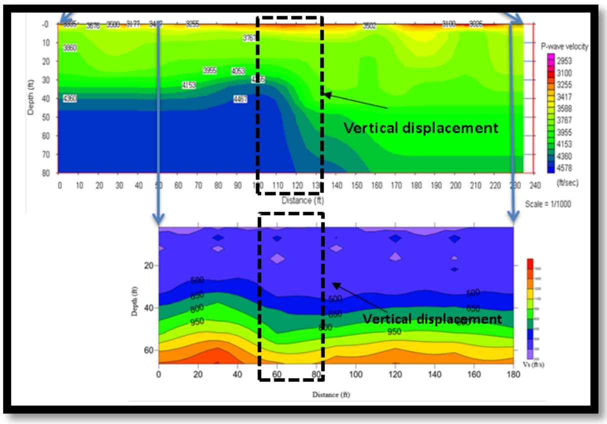

Figure 36. W-E Model Profiles Resulting from SRT and MASW Data Show the Vertical Displacement.

VII. CONCLUSION

. Based on the SRT interpretations, the upthrown block is characterized by compressional wave velocities in the range of 4100-4578 ft/s, whereas the downtrown block is characterized by compressional wave velocities in the range of 3500-4000 ft/s. the fault have a remarkable with seismic refraction signatures. More specifically, SRT has a vertical displacement of approximately 40 ft, where the MASW showed a vertical displacement of approximately 15 ft. All these observations lead to the conclusion that integrated use of seismic (SRT, MASW) methods are an effective approach in mapping the fault.

ACKNOWLEDGMENT

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[1] http://www.zoomschool.com/usa/statesbw/arkansasbw.GIF .Map of study site in Blytheville,Nov 2016.

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