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Investigation of Road Pavement Failures Using Active and Passive Surface Wave Methods in Parts of Calabar Municipality, Cross River State, Nigeria

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ABSTRACT: *The active and the passive techniques of surface wave were employed to investigate some major road pavement failures within the Calabar metropolis, Cross River State. The dispersion curves from MASW (active) and ReMi (passive) were inverted to give a 1D shear wave velocity model. The aim of this study was to comparatively investigate the major causes of the incessant road pavement failures especially few months after its construction and repairs within the study area using the shear wave velocity and blow count (N values). These roads are all located within the same geologic setting of the Calabar Coastal Plan Sand and showed evidence of road failures ranging from pot holes, alligator cracking, rutting and shear failure cracking etc. For each site, two sets of data were collected; the Passive and the Active seismic surface wave data. The survey was able to gather the following data from each location; shear wave velocity, primary wave velocity, N-values for both the active and the passive data which were both derived by the Seisimager surface wave software. The software was used to delineate low velocity layers within the depth of 4m – 6m at the failed portions of the survey sites exception of location 1 (the control site) which showed an ideal situation of increasing velocity with depth. These low velocity layers were inferred to be the major cause of the incessant failure of the pavements in the survey areas. These velocities and the N- values (blow count) were used to classify each location into sites C, D and E, according to the 1997 National Earthquake Hazards Reduction Program (NEHRP).*
KEYWORDS: road, pavement, failures, active and passive surface wave methods, Calabar municipality, Cross River State, Nigeria

INTRODUCTION

Background of the study

The increasing rate of road pavement failures, especially few months after constructions along major roads in Nigeria is generating a lot of concerns to all stake holders involved in the road construction and maintenance industry. Basically, the road transport system is the critical infrastructure for attainment of all developmental goals, visions and national strategies in Nigeria where Calabar is not an exception. Therefore, its development and maintenance is fundamentally important to all economic aspirations: movement of goods and people, industrial products, agricultural produce, services (Osadebe *et al.,* 2004). In order to secure and preserve such valuable asset, timely and more economical measures for detecting potential zones of weakness, cavities and any other causes of road pavement deterioration have to be utilized.

Several geophysical techniques ranging from; Seismic, GPR, Resistivity, and Electromagnetic etc., have been used by different people to investigate road pavement failures which have shown remarkable outcome. This thesis focused on two main geophysical techniques; the active seismic surface wave and the passive seismic surface wave technique. The seismic surface wave methods present a non-intrusive and cost-effective method for deriving V_s profiles for many geotechnical engineering applications. Considering the source of energy used, surface wave methods may be grouped into: active-source and passive-source methods. While the active-source method measures surface waves produced by self-motivated sources such as sledge hammers, drop weights, bulldozers and hydraulic Vibroseis equipment, the passive-source method exploits the ambient vibrations triggered by natural and man-made (traffic, construction, factories) activities. The recently-developed seismic surface techniques for the delineation of near surface shear-wave velocity are the Multi-channel analysis of surface waves (MASW) by Park *et al.,* 2001 and the refraction micro tremor (ReMi) by Louie, 2001. The major difference between them is in the source of signal. MASW is an active-source method that needs spontaneous signal. ReMi, on the other hand, is a passive source technique, that records ambient noise or micro tremors prevalent in the municipal area (Stephenson *et al.,* 2005).

The basis of surface wave technique is the dispersive characteristics of Rayleigh waves when travelling through a layered medium. Studying the seismic radial anisotropy can provide the most direct evidence of the flow and deformation in the earth's interior. Radial anisotropy is manifested by the difference of shear wave velocity obtained by Rayleigh wave and Love wave inversion (Tianyang Gao *et al.,* 2022). Seismic properties like the shear wave velocity and shear modulus is usually used by geophysics and geotechnical engineers to evaluate the active properties of soil interaction. These two properties are often associated with active loading like the vehicular traffic, machineries, earthquake and dynamite explosions (Zainorabidin, 2015). The fundamental mode of the Rayleigh wave field produced by the source is used to generate the Shear-wave velocity profile.

Aim and objectives of the study

This study aimed at evaluating the subsurface (subgrade and sub-base) along some road pavements within parts of Calabar metropolis where there has been pavement failure, using seismic surface wave technique. The objectives of the study include:

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i. To utilize the dispersion characteristics of Raleigh type- surface wave in the imaging of the near subsurface layers by approximating 1D shear wave velocities.
ii. Delineation of anomalous zones under the pavements, within the different failure locations from the V_s^{30} and N-value data.

Locations of study areas
The study areas are located within the Calabar Municipality, Calabar, Cross River State. Calabar is found in the southeastern part of Nigeria within the Cross River Basin and is bounded by the Cameroon and Atlantic Ocean in the South and Cross River in the west and Odukpani in the North. Calabar is located in the rainforest region. It is known to be bounded by great rivers; Calabar River (westward) and the Great Kwa River (eastward). Being a coastal region, most of the major roads are known to be laid over swamps; like the Atimbo-Akpabuyo road, the Goodluck Ebele Jonathan bypass, parliamentary road and even the Calabar-Itu highway road are known to pass through the mangrove swamp cutting through a thick forest.

The study area cuts across some major and local roads within Calabar municipal, which include; Calabar Murtala Mohammed Highway (Destination Cross River round about) located at Latitude: 05°04.4821′N and Longitude: 008°35.778′E which served as the control site being that the pavements were still in good conditions, Parliamentary Extension Road by Prince Ville Hotel (Latitude: 05°01.129′N and Longitude: 008°21.410′E), Jonathan By-Pass (Latitude: 05°00.142′N and Longitude: 008°21.882′E) and Atimbo-Akpabuyo road (Latitude: 04°57.114′N and Longitude: 008°23.420′E). In all the failed road pavement segments of this survey, there are evidences that the pavement had been repaired severally, however, they are still characterized by potholes, ruts and cracks.

Geology of the study area
The study area is located within the Calabar Flank which is that part of the southern Nigerian sedimentary basin bordered by the Precambrian Oban Massif in the northern part and the Recent Niger Delta in the southern part (Murat, 1972). Geologically, it is made of coastal plain sands otherwise referred to as Benin formation, which is made up of sediments of tertiary age to recent, FIG 1. This formation comprises of predominantly coastal sediments which are basically alternating sequence of loose gravel, sand, sandstone, siltstone, minor clay lenses and the lignite formation which comprises essentially of shale, mudstone and clay and lignite series. They are strongly weathered and are characterized by coarse to fine sand texture in the surface to subsurface soils. Underlying the coastal plain sand, is the cretaceous Calabar Flank and Precambrian Oban Massif. The Afikpo syncline marks the northwestern limit while the Cameroon volcanic ridge bounds it in the east.

FIG. 1: Geology and location map of Calabar municipality showing study locations

THEORY/CALCULATION

Method and Instrumentation for the Seismic Surface wave

The geometric ES300 seismograph which is powered by a 12 Volt battery was employed in the collection of both the active and e surface wave. The Seismodule ES-3000 was operated

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from a Windows 7 (64 bit) based laptop. The seismograph has a band width of 1.75 Hz to 8 kHz and stores the recorded data in SEG-2 format in a Laptop PC media.

A 9kg sledge hammer which has a trigger connected via a cable to the seismograph served as a source that was used to generate the seismic energy recorded by the seismograph for the Multichannel Analysis of Surface wave (MASW) method, while the ambient noise from a nearby traffic and generator from a nearby compound as well as other sources of noise served as sources of signal for the Refraction Microtremor (ReMi) method. The seismograph recorded the travel time of impulses received at different geophones for a given array, from a particular source (passive/active).

Both the active and passive techniques utilized a 24 channel vertical geophones that were equally spaced at 1m inter geophone spacing (and a 6m offset for both the forward and the reverse shooting in the MASW). For the active method; a record length of 1 seconds and a sample interval of 0.5 milliseconds was utilized, whereas for the passive method; a record length of 30 seconds and sample interval of 2.0 milliseconds was used in other to accommodate the maximum number of samples capacity in the ES300 memory. The sledgehammer was hit vertically on a metal plate (which served as a medium to reduce the ground destruction at the source point) to generate the seismic signals that was recorded by the ES3000 seismograph. A trigger from the hammer connected to the seismograph served as a sensor to trigger the recording of signals whenever there was a hammer strike.

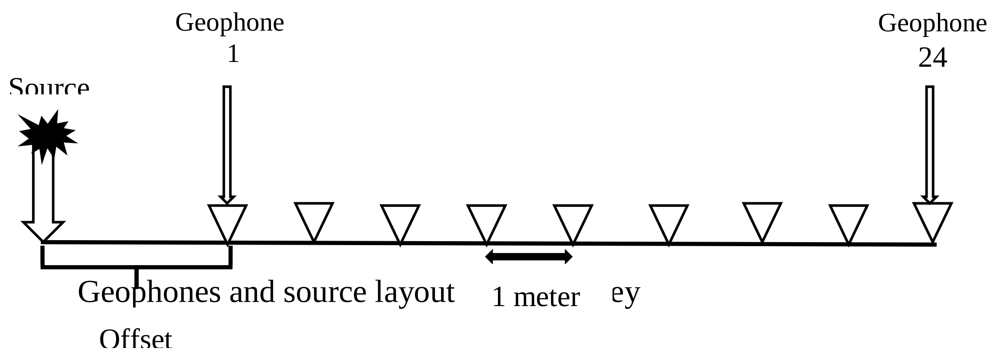


FIG. 2: Geophones and source layout ey

TABLE 1: Site soil classes as per recent NEHRP editions (BSSC 1995, 1998, 2004)

NEHRP Site class	Description	V_s (m/s)	N-value (blow count)	S_u (KPa)
A	Hard rock	>1500	-	-
B	Rock	760 – 1500	-	-
C	Soft rock/ very dense soil	360 – 760	>50	>100
D	Stiff soil	180 – 360	15 – 50	50-100
E	Soft soil	< 180	<15	<50
F	Soil requiring site-specific study	-	-	-

2.2 Data Analysis

The SeisImager software was utilized during the data analysis and the processing steps is described by the chart below (FIG 3). Surface wave seismic data were exported from the Geometric seismograph and was processed using the SeisImager software. The software is divided into two modules; Pickwin module and WaveEq module. This software is specifically used for the determination of dispersion curve of surface wave phase velocity in frequency domain and the shear wave velocity profile in the 1-D image. The surface wave analysis software automatically calls for functions from the Pickwin and the Wave Equation modules to walk through the processing flows The software was used to create a phase velocity-frequency graph which was further used to generate the dispersion curve that was interpreted to get the 1D shear wave velocities for each location. The SeisImager software automatically generated the table of values for shear wave velocity using the phase velocity gotten from equations 1 to 6 alongside the primary wave, density and the N-values.

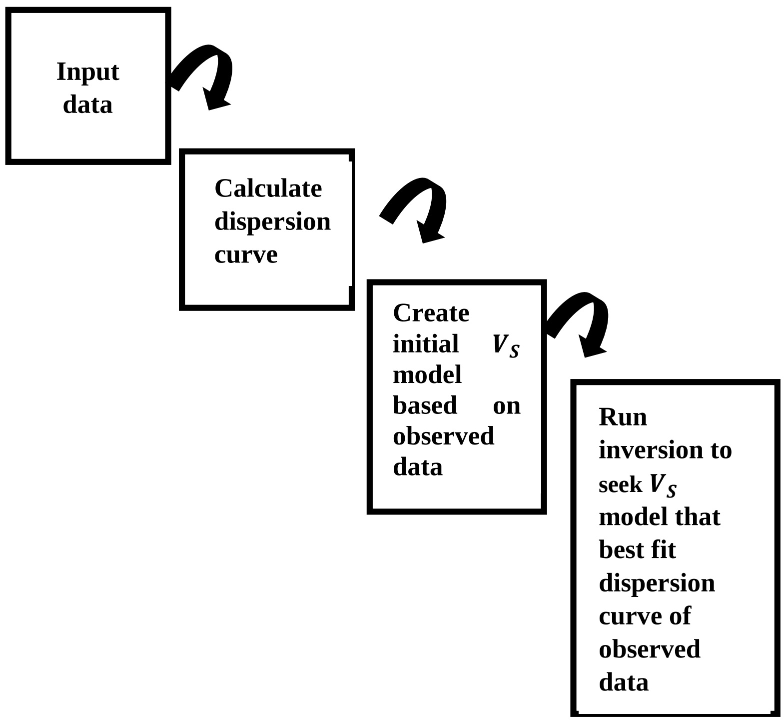


FIG 3: General Processing flow chart

To calculate the phase velocity, we consider waves; *f(t)* and *g(t)*, its Fourier transform;

$$F(\omega) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} f(t) \cdot \exp^{-i\,\omega\,t}\, dt \qquad (1)$$

$$G(\omega) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} g(t) \cdot \exp^{-i\,\omega\,t}\, dt \qquad (2)$$

Amplitude and phase

$$F(\omega) = A_f(\omega) \cdot \exp^{-i\,\emptyset_f(\omega)} \qquad (3)$$

$$G(\omega) = A_g(\omega) \cdot \exp^{-i\,\emptyset_g(\omega)} \qquad (4)$$

Phase difference

$$\Delta\emptyset(\omega) = \emptyset_f(\omega) - \emptyset_g(\omega) \qquad (5)$$

Phase velocity

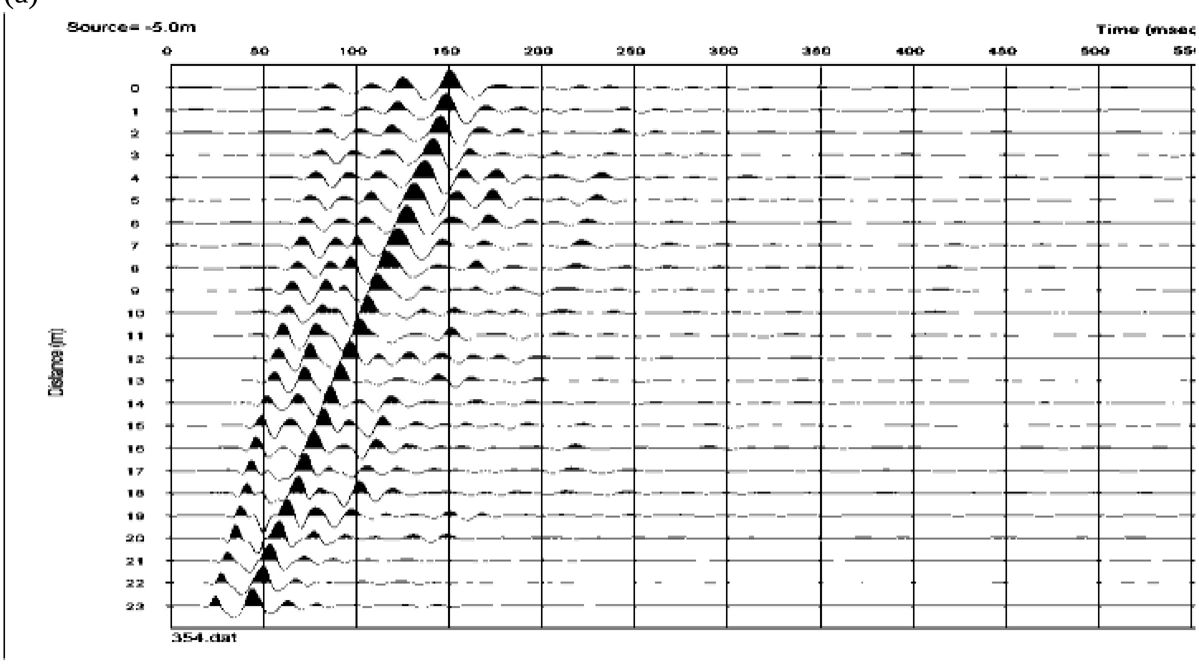
$$c(\omega) = \frac{\omega.\Delta x}{\Delta\emptyset_f(\omega)} \qquad (6)$$

The phase velocity is plotted against frequency to produce the dispersion curve from which inversion is done to model the shear wave velocities. Surface wave seismic data were exported from the Geometric seismograph and was processed using the SeisImager software. The software is divided into two modules; Pickwin module and WaveEq module. This software is specifically used for the determination of dispersion curve of surface wave phase velocity in frequency domain and the shear wave velocity profile in the 1-D image. The surface wave analysis software automatically calls for functions from the Pickwin and the Wave Equation modules to walk through the processing flows.

The MASW data and the ReMi data have similar processing flow chart. However, slight differences still exist in some stages. Upon launching the surface wave wizard, it automatically calls for the Pickwin module which displays the field data in a waveform, the waveforms were further adjusted to display properly as shown in FIG. 4a. and 4b. Subsequently, the parameters for the calculation of phase velocity was set as well as the frequency band based on the expected field velocity. This results in the phase velocity – frequency plot (frequency domain) which also shows an automatically picked dispersion curve shown as red points that were been saved for further use by the WaveEq module FIGS. 5 and 6. Progressively, the WaveEq module was launched and the dispersion curve displayed with the phase velocity in the vertical axis and the frequency in the horizontal. The dispersion curve is now smoothened to remove noisy picks FIGS. 8 and 9.

RESULTS

(a)



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(b)

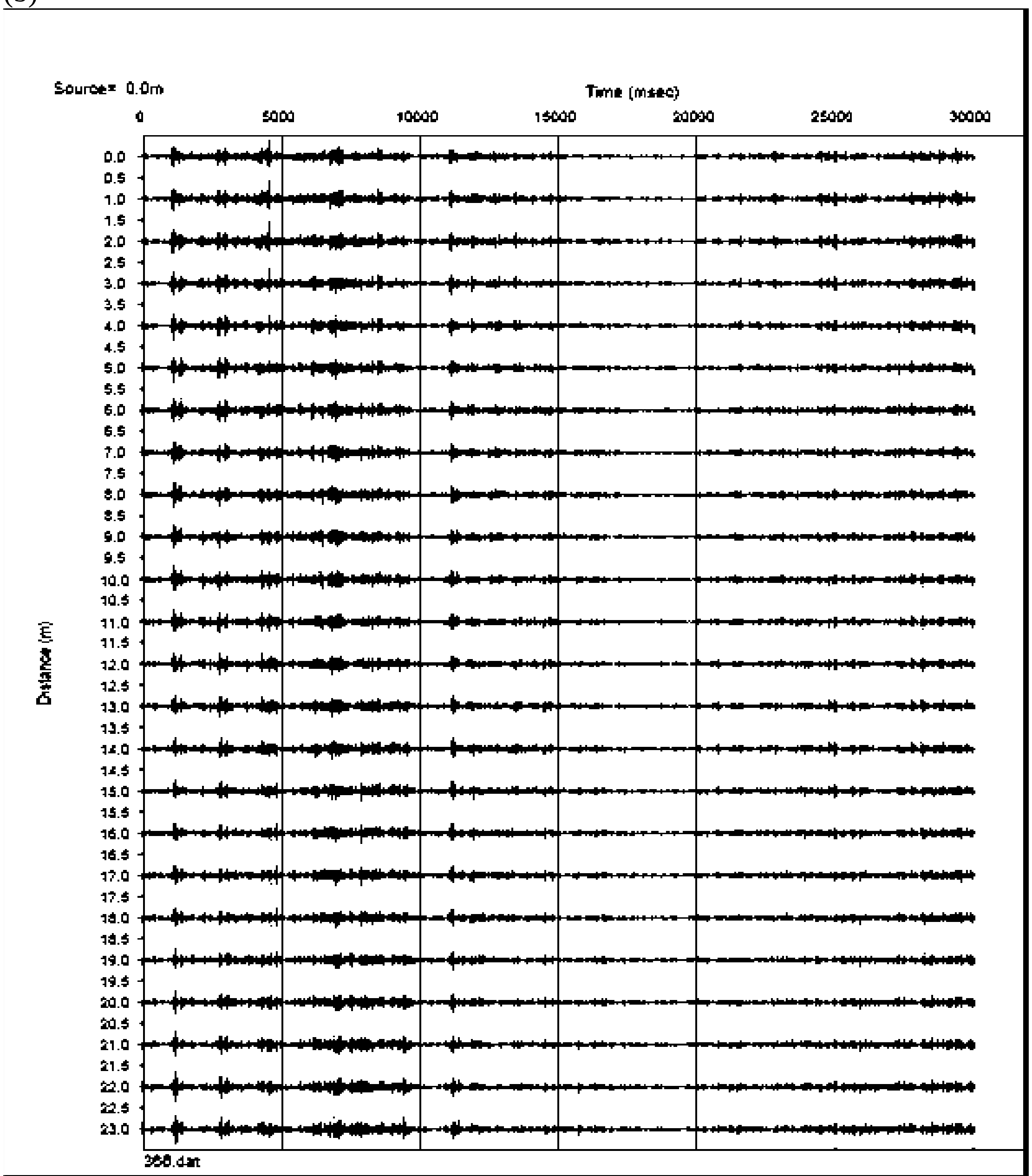
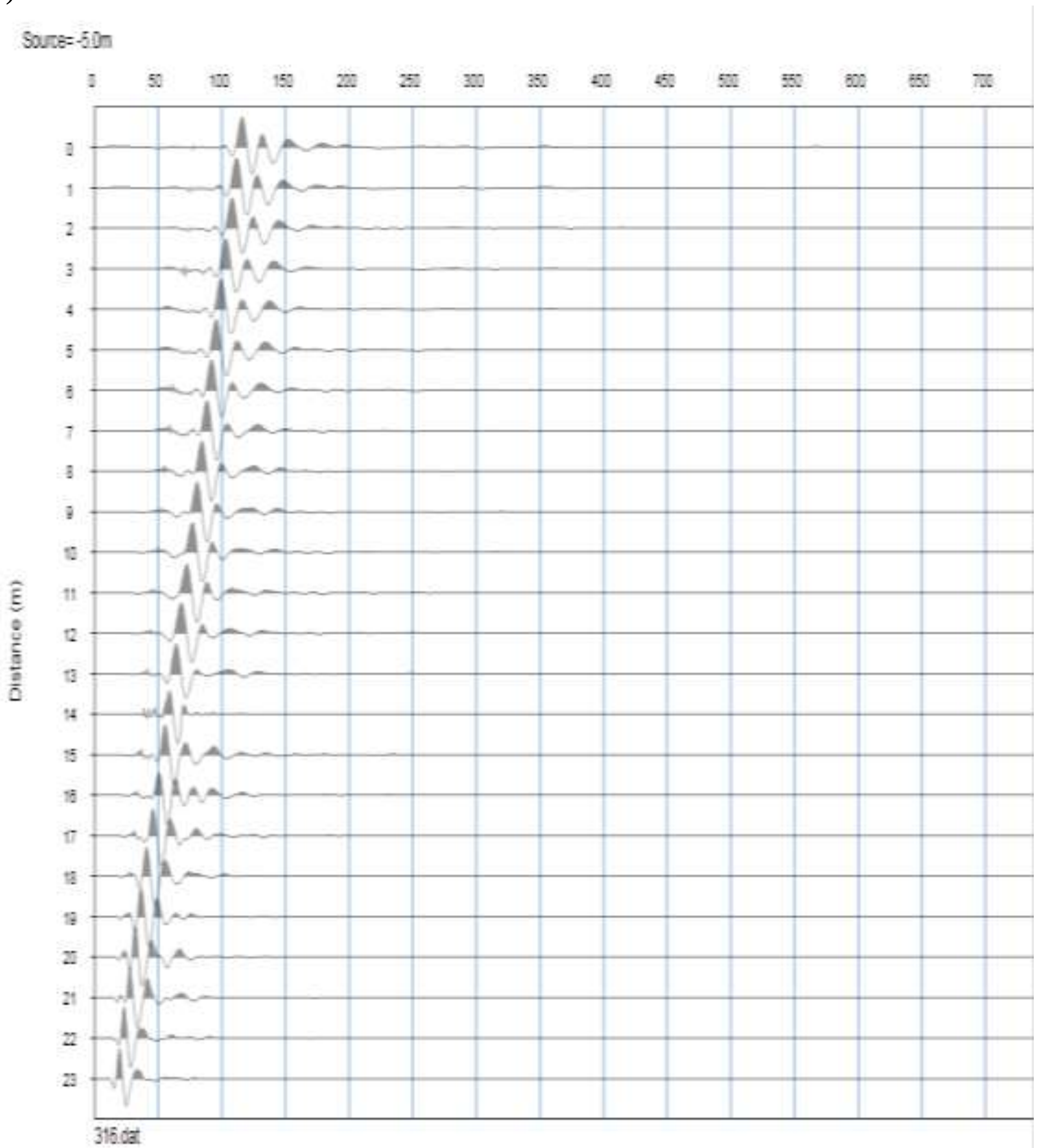


FIG. 4 (a) Active-data waveform - location 1; Destination Cross River Roundabout
(b) Passive - data waveform - location 1; Destination Cross River Roundabout

(a)


Source= -5.0m
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
Distance (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
316.dat

(b)

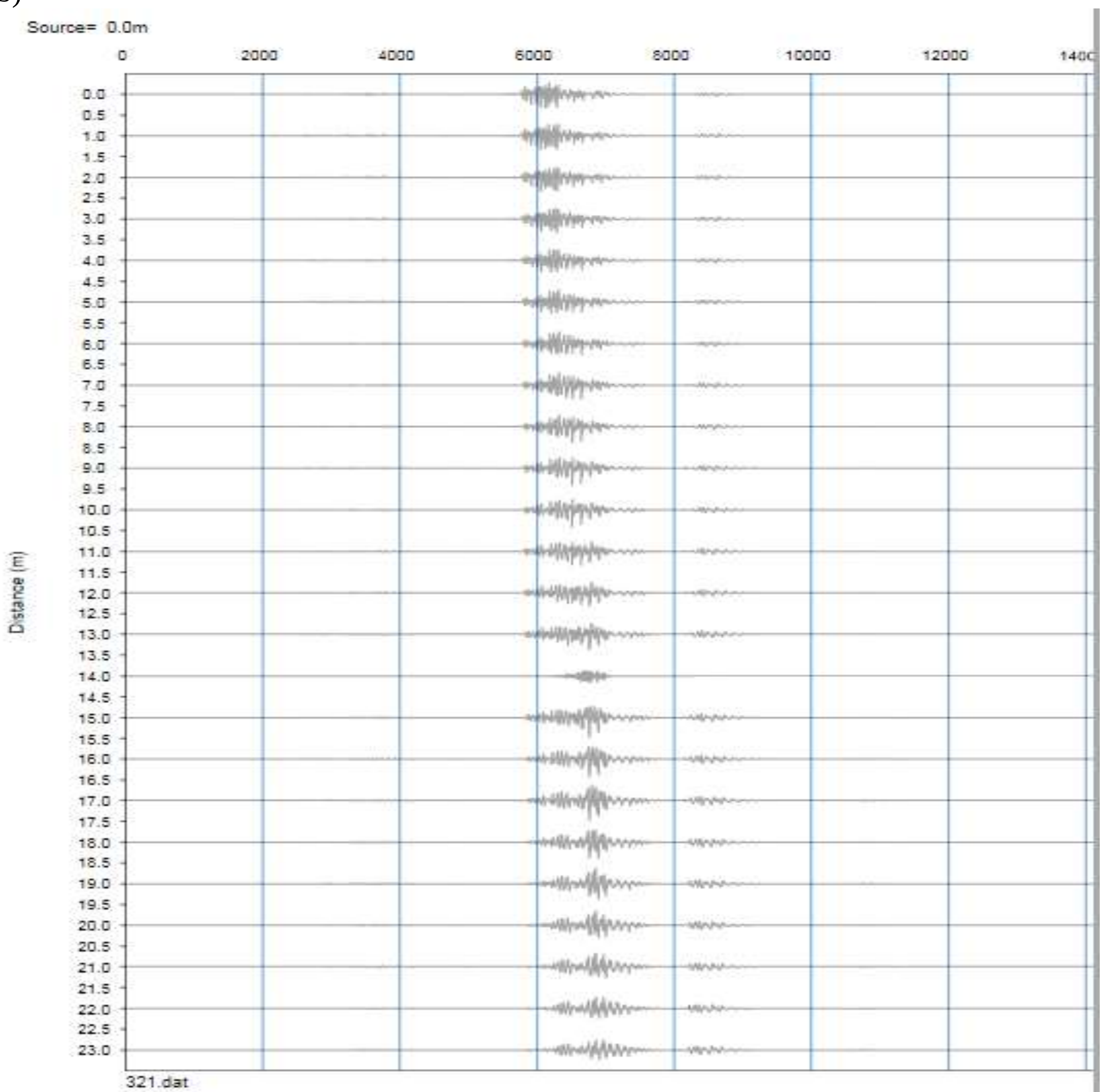
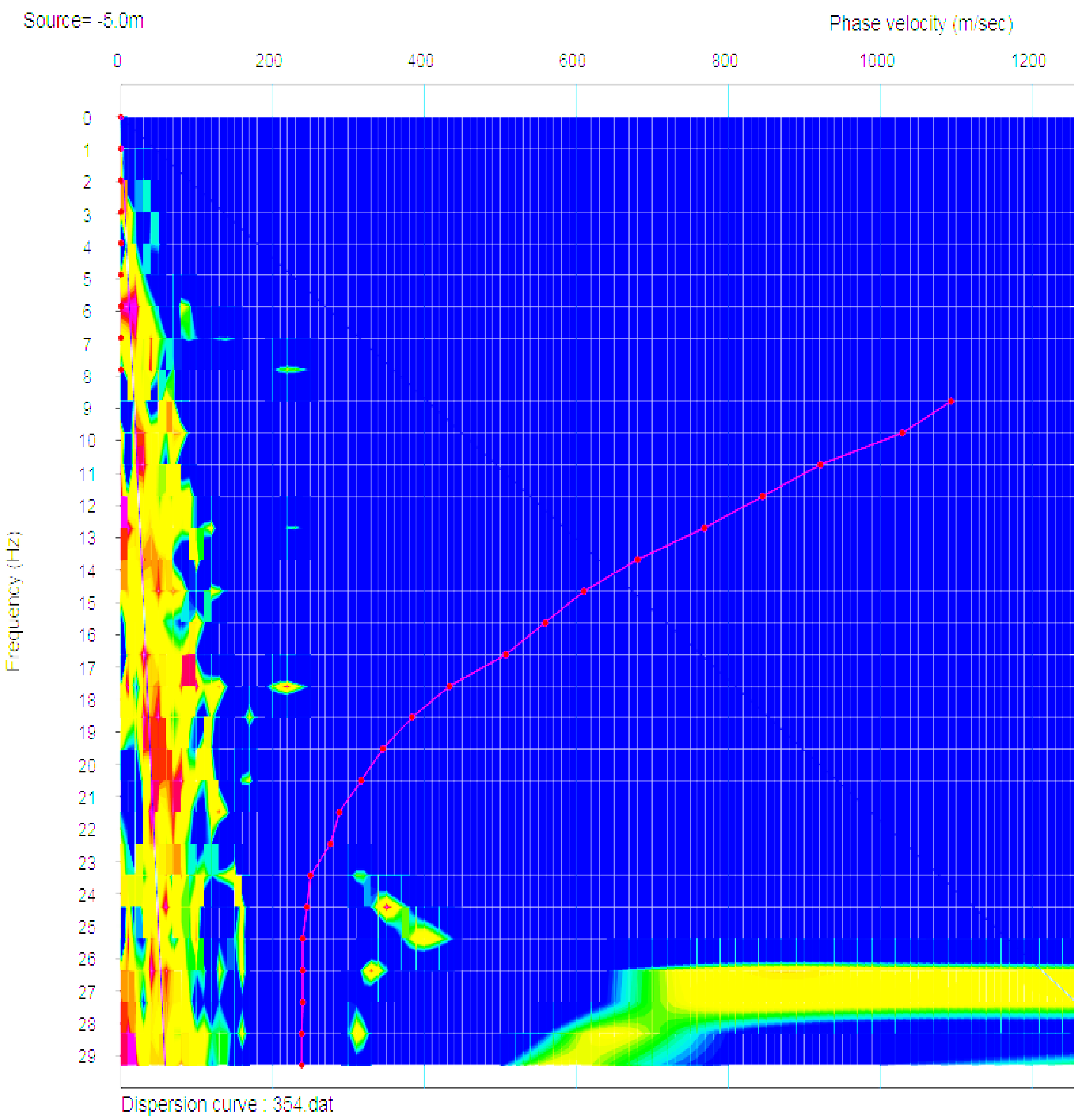


FIG. 5(a) Active-data Waveform – location 2; Parliamentary Road
(b) Passive - data Waveform – location 2; Parliamentary road

(a)


Source= -5.0m
Phase velocity (m/sec)
0
200
400
600
800
1000
1200
Frequency (Hz)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
Dispersion curve : 354.dat

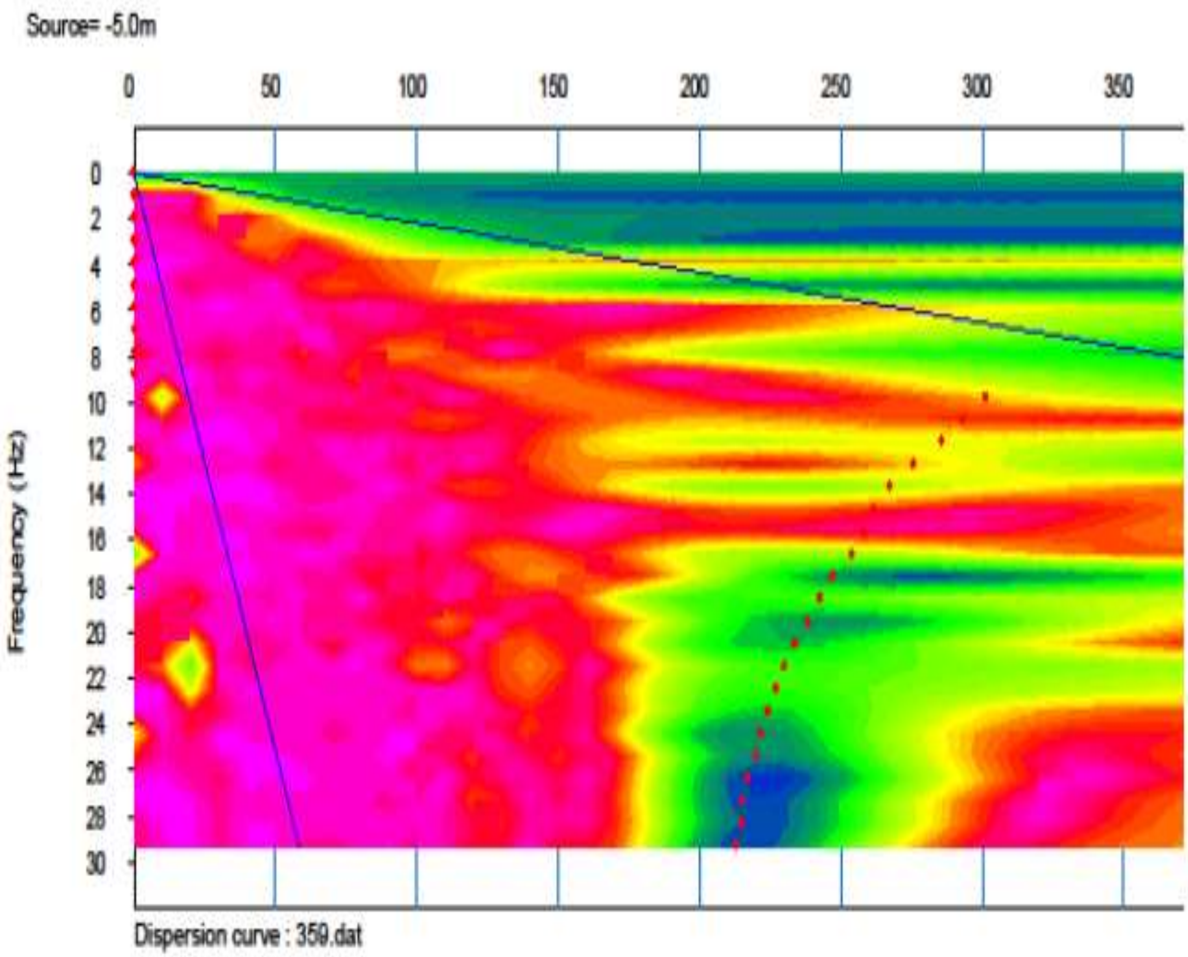
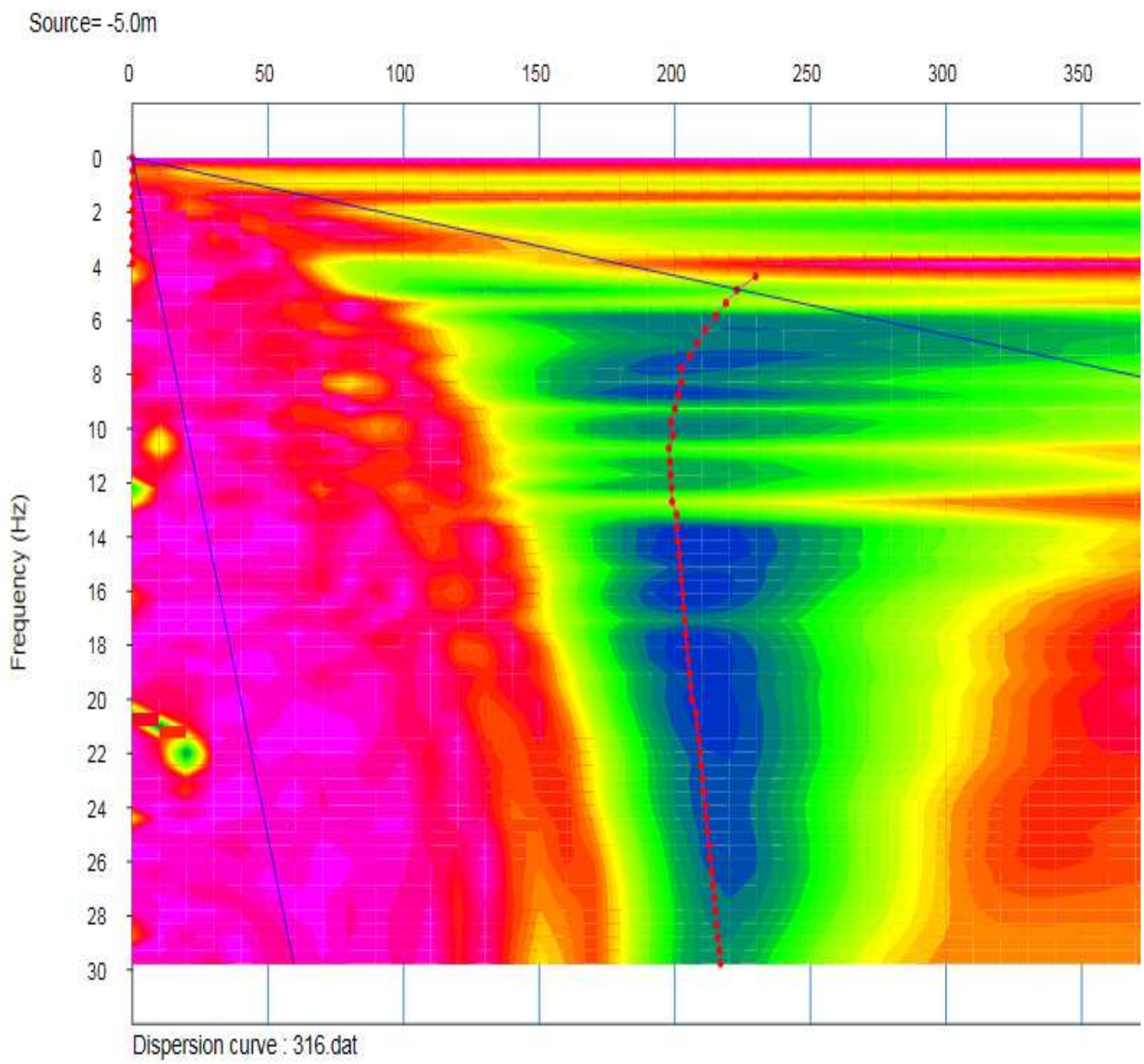


FIG. 6 (a) Active data phase velocity - frequency curve – location 1; Destination Cross River Roundabout
(b) Passive data phase velocity - frequency curve – location 1; Destination Cross River Roundabout


Source= -5.0m
0
50
100
150
200
250
300
350
Frequency (Hz)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Dispersion curve : 316.dat

(a)

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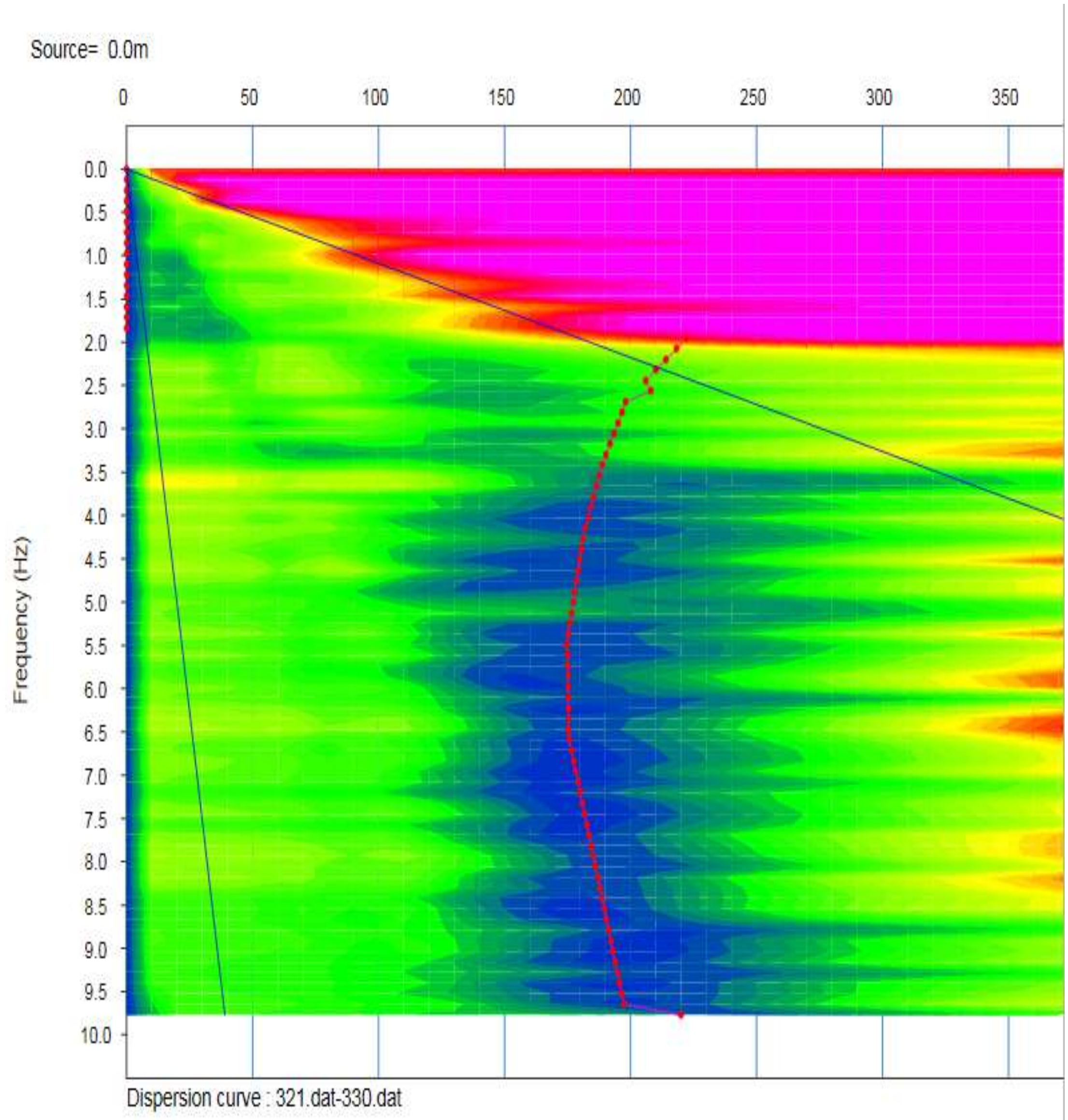

(b)

FIG. 7 (a) Active data phase velocity - frequency curve – location 2; Parliamentary road
(b) Passive data phase velocity - frequency curve – location 2; Parliamentary road

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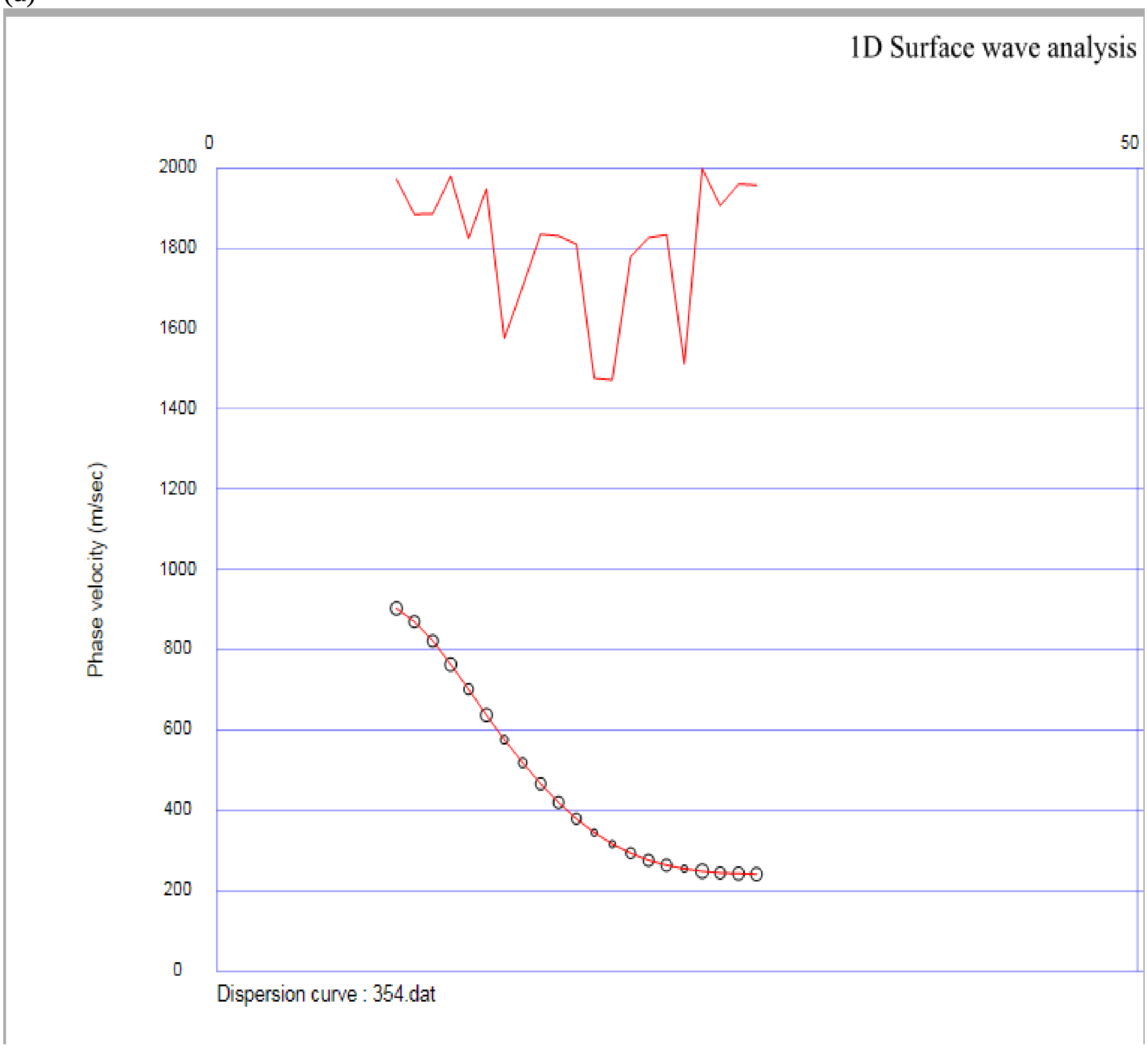
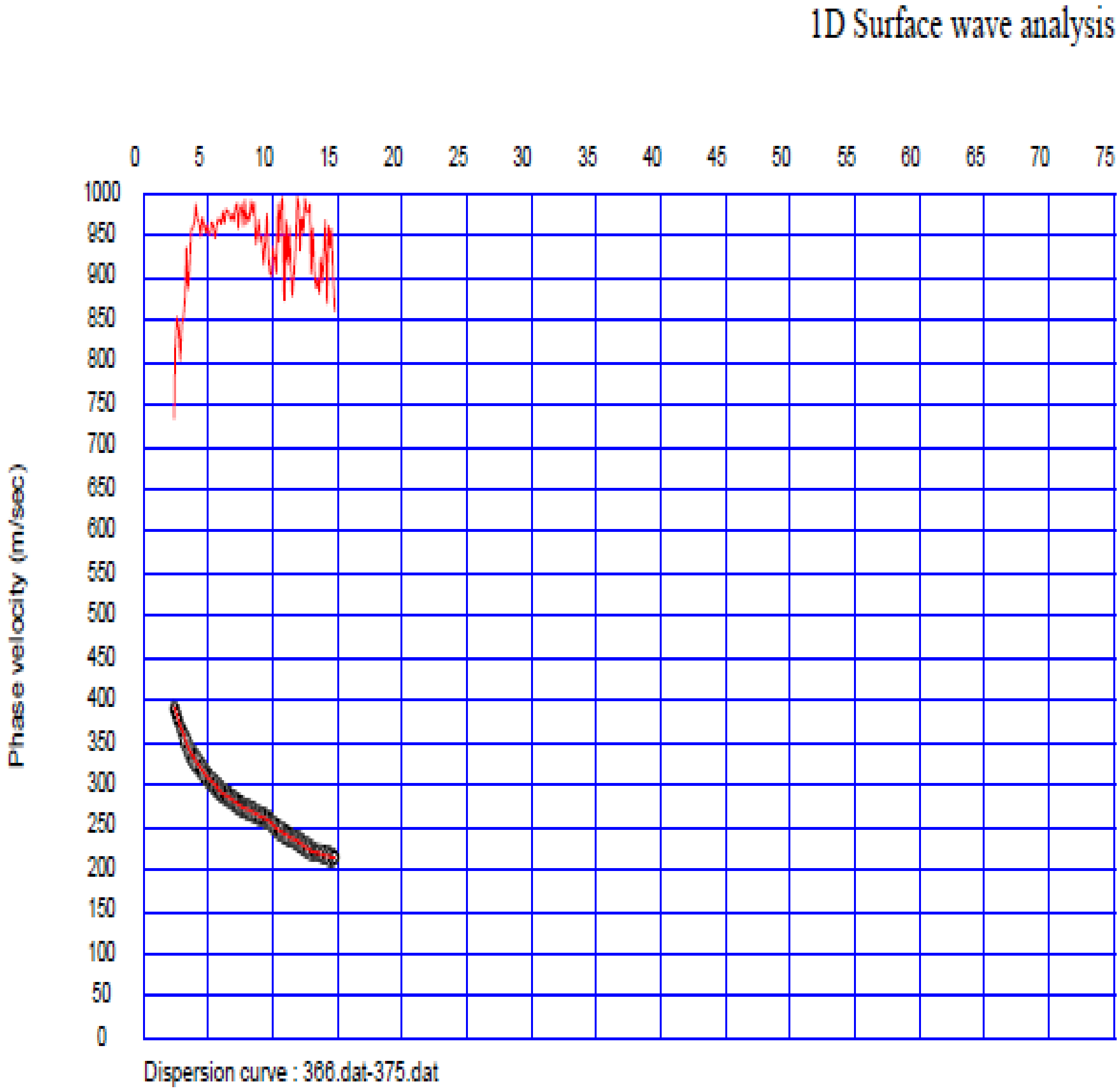
(a)





(b)

FIG. 8 (a) Active data dispersion curve - location 1; Destination Cross River Roundabout
(b) Passive data dispersion curve - location 1; Destination Cross River Roundabout

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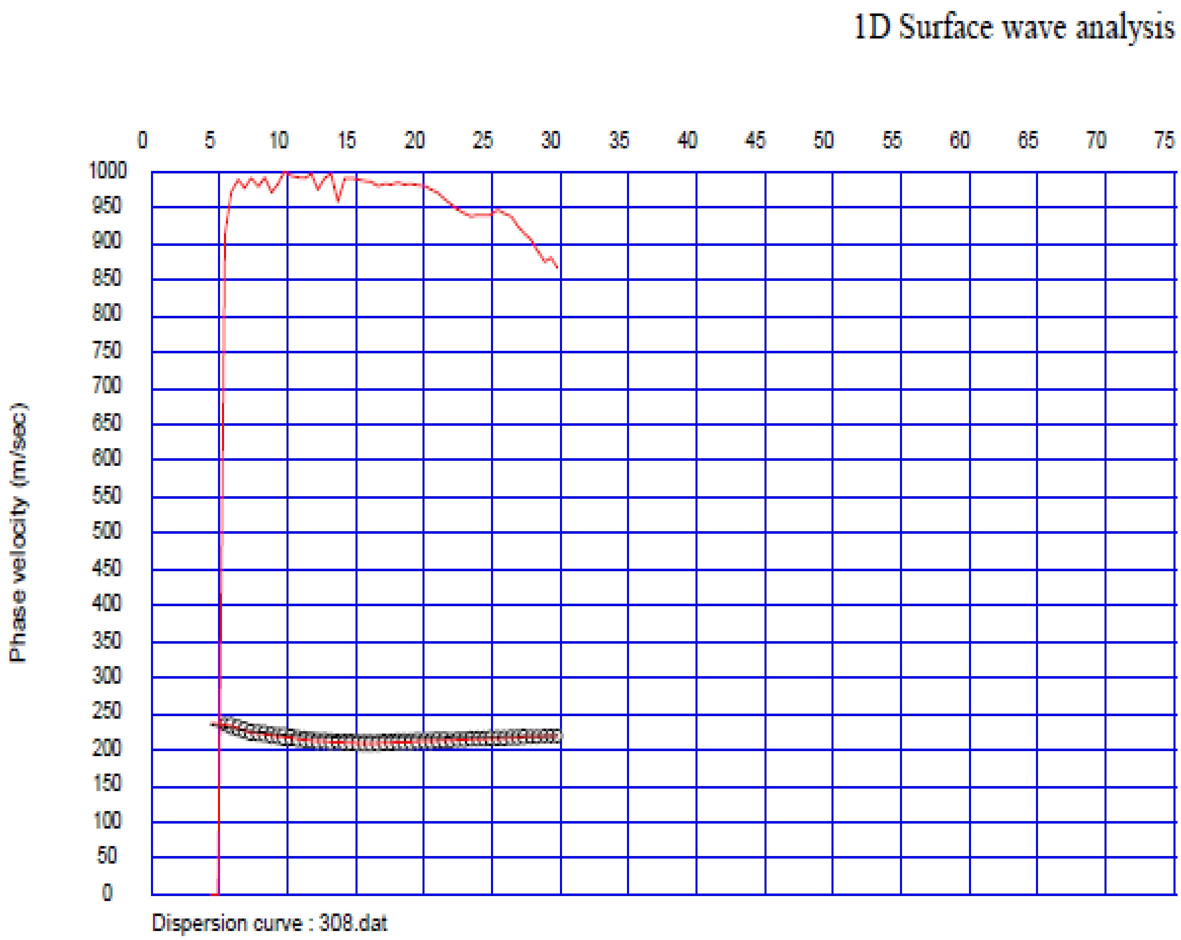
(a)



(b)

FIG. 9 (a) Active data dispersion curve – location 2; Parliamentary road
(b) Passive data dispersion curve – location 2; Parliamentary Road

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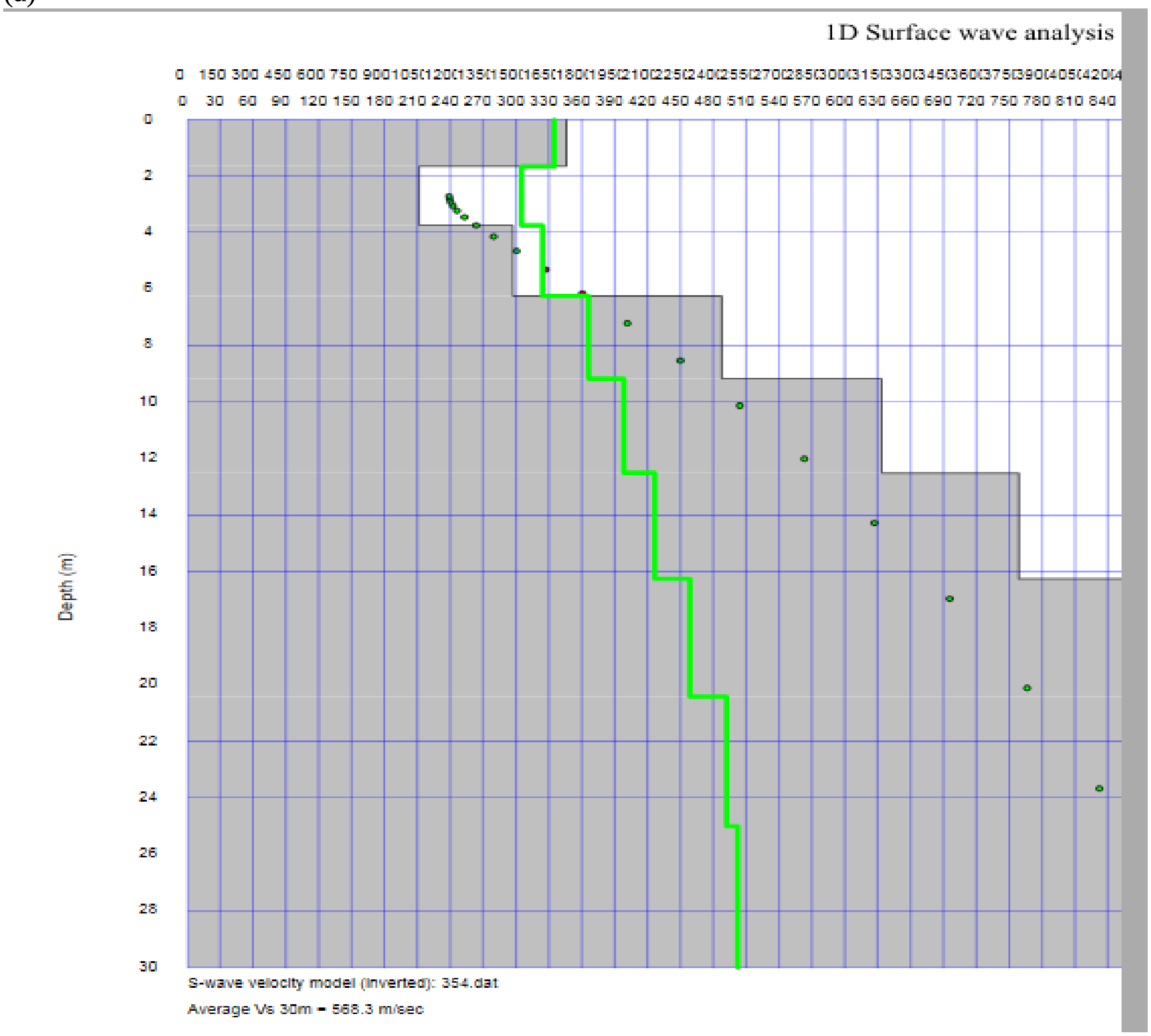
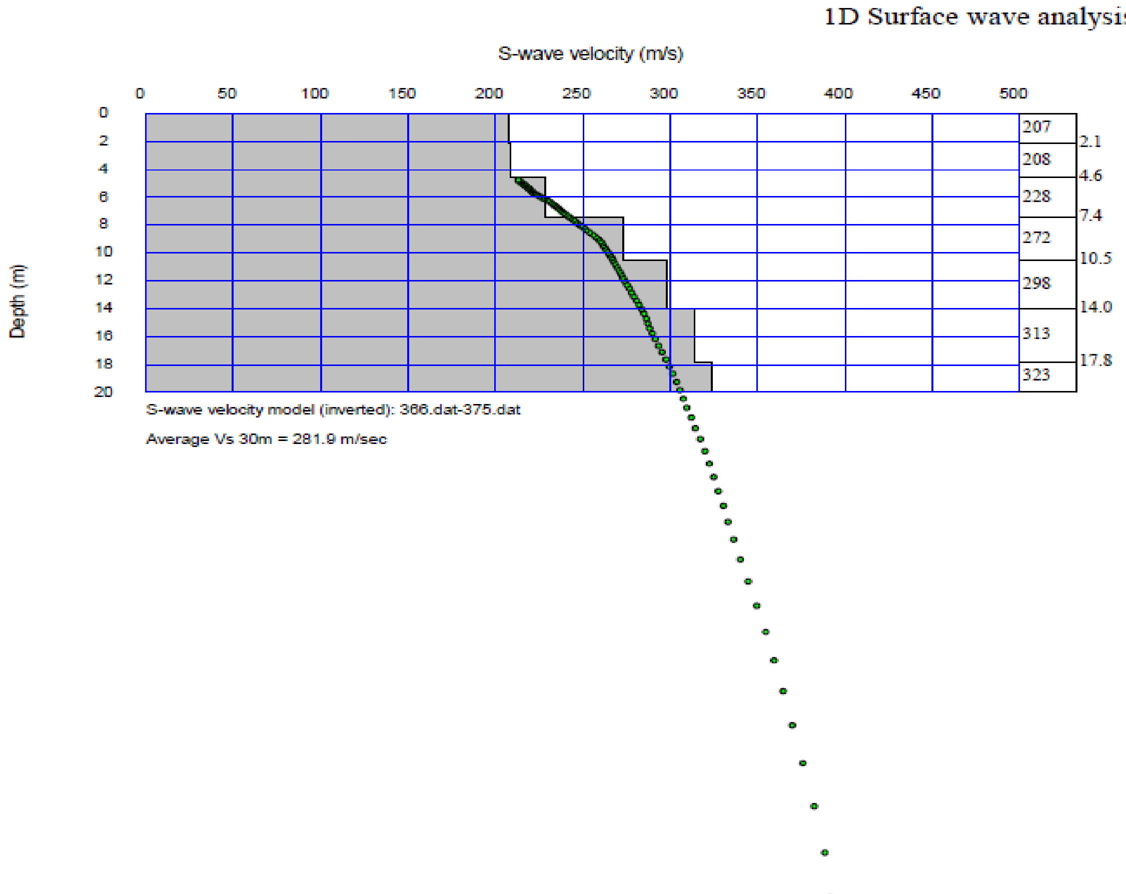
(a)



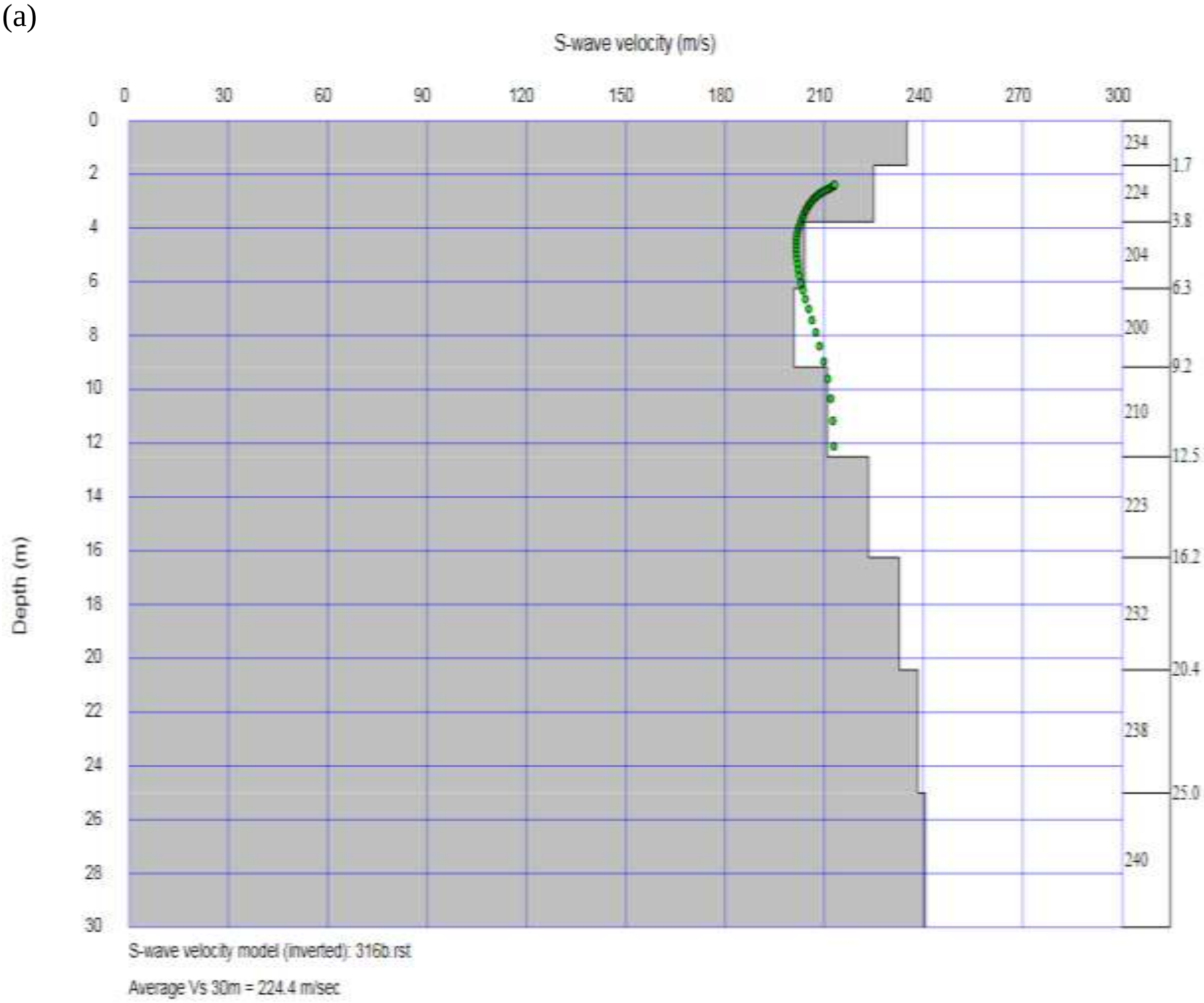


(b)

FIG. 10 (a) Active data 1D shear wave velocity profile – location 1; Destination Cross River Roundabout

(b) Passive data 1D shear wave velocity profile – location 1; Destination Cross River Roundabout.

(a)


S-wave velocity (m/s)
0
30
60
90
120
150
180
210
240
270
300
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
234
224
204
200
210
223
232
238
240
1.7
3.8
6.3
9.2
12.5
16.2
20.4
25.0
S-wave velocity model (inverted): 316b.rst
Average Vs 30m = 224.4 m/sec

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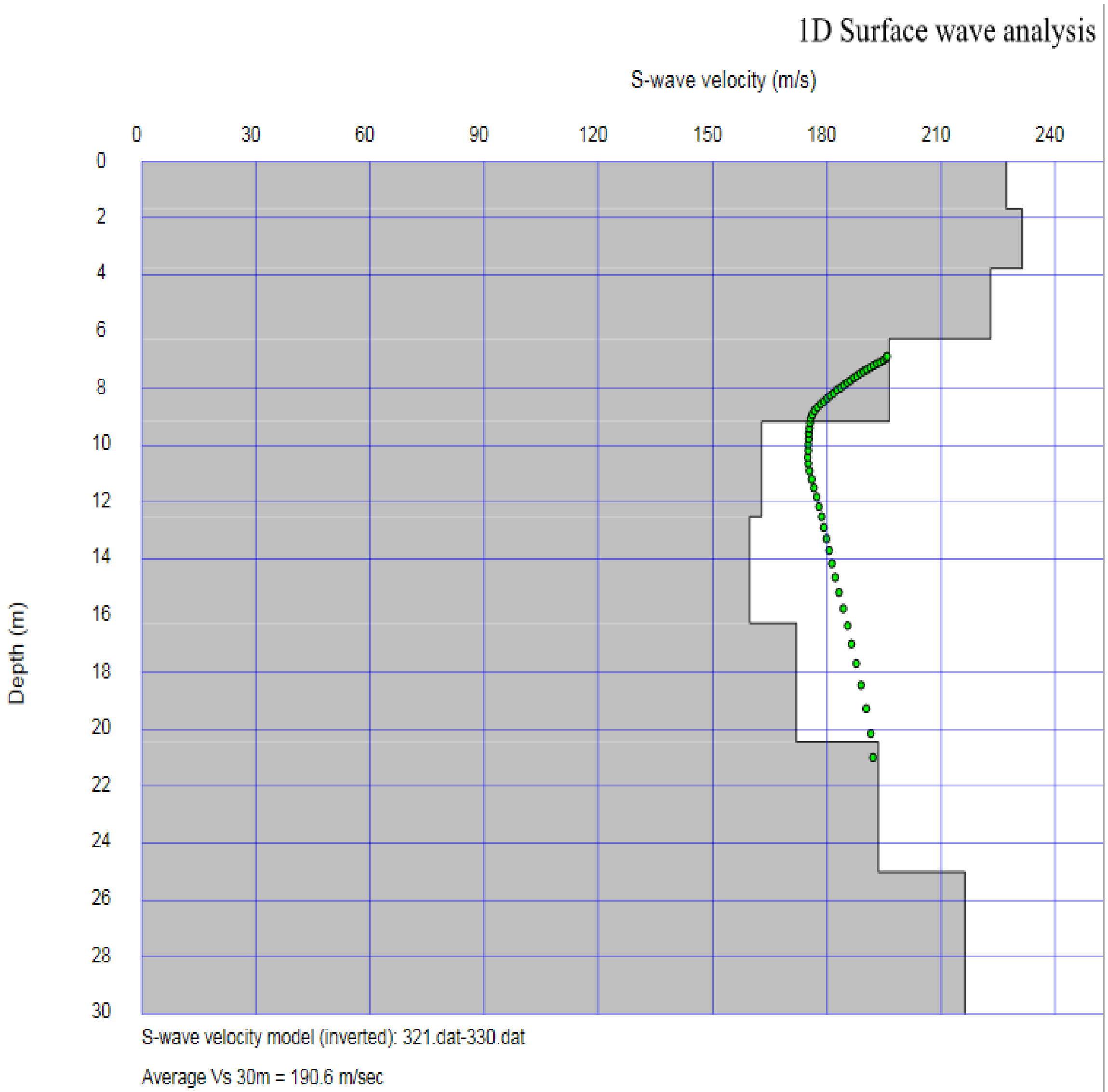

(b)

FIG. 11 (a) Active data 1D shear wave velocity profile – location 2; Parliamentary road
(b) Passive data 1D shear wave velocity profile – location 2; Parliamentary road

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TABLE 2: Location 1; Destination Cross River Roundabout table of values- Active data

Depth (m)	S-wave velocity (m/s)	P-wave velocity (m/s)	Density (g/cm^3)	N-Values
0.00	214.53	1531.09	1.80	12.52
1.33	216.46	1533.25	1.80	12.88
3.00	248.31	1567.80	1.81	19.95
5.00	306.29	1630.34	1.83	38.93
7.33	346.04	1672.74	1.84	57.42
10.00	356.02	1682.50	1.84	62.86
12.99	362.63	1688.91	1.84	66.65
16.33	366.29	1692.41	1.84	68.82
20.00	368.03	1694.06	1.84	69.87
31.99	368.03	1694.06	1.84	69.87

TABLE 3 e data

Depth (m)	S-wave velocity (m/s)	P-wave velocity (m/s)	Density (g/cm^3)	N-Values
0.00	207.11	1523.27	1.80	11.19
2.14	208.15	1524.33	1.80	11.37
4.61	228.35	1545.61	1.80	15.28
7.417	272.70	1593.14	1.81	26.89
10.54	298.26	1620.73	1.82	35.77
14.01	313.24	1637.85	1.83	41.81
17.80	323.54	1650.37	1.83	46.35
21.92	332.16	1660.85	1.84	50.40
26.37	341.84	1671.97	1.84	55.23
31.15	356.75	1688.28	1.85	63.28
36.26	377.86	1710.91	1.85	75.99
41.70	389.47	1722.48	1.85	83.68
47.47	400.84	1733.37	1.85	91.71
53.57	414.26	1746.19	1.85	101.85
72.85	427.38	1758.67	1.85	112.49

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TABLE 4: Location 2; Parliamentary Road table of values-Active data

Depth (m)	S-wave velocity (m/s)	P-wave velocity (m/s)	Density (g/cm^3)	N-Values
0.00	228.95	1541.27	1.79	15.40
1.33	226.98	1539.45	1.79	14.99
3.00	217.87	1531.26	1.79	13.15
5.00	180.31	1522.53	1.79	10.40
7.33	204.73	1519.15	1.79	11.79
10.00	207.12	1521.26	1.79	11.20
12.99	212.75	1526.44	1.79	12.19
16.33	219.04	1532.25	1.79	13.38
20.00	224.49	1537.29	1.79	14.47
31.99	328.95	1641.27	1.79	18.40

TABLE 5: Location 2; Parliamentary Road table of values - Passive data

Depth (m)	S-wave velocity (m/s)	P-wave velocity (m/s)	Density (g/cm^3)	N-Values
0.00	191.03	1502.47	1.78	8.65
1.66	191.01	1502.45	1.78	8.65
3.75	190.97	1502.48	1.78	8.64
6.25	190.23	1501.88	1.78	8.54
9.16	191.22	1503.20	1.79	8.68
12.50	194.10	1506.40	1.79	9.10
16.24	195.69	1507.90	1.79	9.34
20.41	198.89	1510.95	1.79	9.84
24.99	203.18	1515.05	1.79	10.55
39.99	207.82	1519.46	1.79	11.32

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TABLE 6: Site classification at the studied locations, according to the NEHRP code.

			V_s^{30} (m/s)		Site
Survey Site	**Latitude**	**Longitude**	**Active**	**Passive**	**Class**
Location 1	$05°04.4821'N$	$008°35.7780'E$	566.3	281.9	C
Location 2	$05°01.129'N$	$008°21.410'E$	224.4	190.0	D
Location 3	$05°00.142'N$	$008°21.882'E$	169.9	137.0	E
Location 4	$04°57.114'N$	$008°21.882'E$	174.2	143.5	E

DISCUSSION

It is found that, the chance of a successful survey is usually much higher with the surface wave method than with other seismic methods, particularly in detecting the near-surface anomalies and the low velocity layer. Moreover, surface waves respond effectively to the various types of near-surface anomalies that are common targets of geotechnical investigations; such as the low velocity layers, caves and the near-surface structures (Mohamed, Abu El Ata, Azim and Taha 2013). Various locations were investigated and the survey shows a low velocity layer at all the sites except for the control site which revealed a rather continuously increasing velocity with depth.

Location 1; Destination Cross River roundabout

Data from location 1 (Destination Cross River Roundabout) which was tagged ‘control site’; revealed a normal Earth condition, where the velocity of the corresponding layering increased with depth. The active data for the control site consist of samples down to a depth of 31m, a shear wave velocity ranging from 214.5 m/s to 368.0 m/s, P-wave velocity ranging from 1531m/s to 1694 m/s and an N value of 12.52 to 69.87(see Table 1). For the passive data; a record of ambient noise, it is obvious that the sampling depth increased to a depth of 72m (low frequencies travels deeper) with the shear wave velocity ranging from 207.117 m/s to 427.389m/s, P wave velocity ranged from 1523.27 m/s to 1758.67 m/s and N values ranging from 11.19 to 112.49 (Table 2).
Generally, it is noticed that the velocity increased correspondingly with depth.

Location 2; Parliamentary Road

The parliamentary road which was tagged 'Failure Site 1' runs from the Effioette Roundabout and connects with Jonathan bypass, it has recorded quite a handful of road failures, such as pot holes, cracking and rifting. The road shows evidence of road maintenance and repairs. In failure site 1, the active method was able to sample the subsurface down to a depth of about 31m, it has a shear wave velocity ranging from 180.31m/s to 328.95m/s, a P wave velocity of 1519 m/s to 1641 m/s and an N value of 10 to 18. A low velocity layer exists at a depth of 5m with a thickness of about 2m, which is enough to cause significant effect on the surface. The ReMi technique sampled a deeper depth of about 40m. The shear wave ranged from 190m/s to 207m/s, P wave of 1502m/s to 1519m/s and an N value of 8.5 to 11. The low velocity soil layer is present within a depth of 3m to 6m, as previously shown by the active wave technique.

Location 3; Jonathan bypass

The Jonathan bypass road cuts across a mangrove swamp that spanned over 4km with a thick forest. The survey in this location sampled to a depth of 31m for the MSAW method. This site has a range of shear wave velocity from 140.95m/s to 182.79m/s, P wave velocity of 1456m/s to 1492m/s and an N value of 3.91 to 7.5. The low velocity layer can be found within the depth of 5m. The passive signal here was able to sample down to a depth of about 40m. The first layer has a shear wave velocity of about 197m/s and a P wave velocity of 1512m/s. The site shear wave velocity ranges from 140m/s to 224.58m/s, P wave of 1450m/s to 1536m/s and an N value of 3.21 to 14.41. The low shear wave velocity layer can be found at a depth of about 6m below the surface.

Location 4: Atimbo- Akpabuyo Road

The Atimbo Akpabuyo road is a road with heavy traffic. The road is mostly subjected to great stress as heavy duty trucks seems to be the major commuters of the road as well as other intercity haulers. The swampy terrain which the road cuts across also plays a major impact on the nature of the underlying geology of this area. The Multichannel Analysis of surface wave technique was able to sample down to a depth of about 31m. The first layer had a shear wave velocity of 170.77m/s, P wave velocity of 1487.45m/s and N value of 6.0. Generally, the site had a shear wave velocity ranging from 124.76m/s to 212.21 m/s, P wave velocity of 1432.78m/s to 1513.09m/s and N value between 2.22 to 12.10. The ReMi data in this site has resolution down to a depth of about 40m, a first layer v_s of about 139.88m/s, v_p of 1459.91m/s and N value of 3.20. The site has a shear wave velocity ranging from 129.24m/s to 182.09m/s, P wave velocity from 1423.51 to 1511.05m/s and N value from 2.49 to 7.43. The shear wave velocity increased correspondingly with depth until a depth of about 5m to 12m, then a further increase was noticed.

SUMMARY/CONCLUSION

The multichannel analysis (MASW) and the Refraction Microtremor (ReMi) techniques of surface wave were employed to investigate the causes of road pavement failures within the Calabar

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metropolis, Cross River State. The dispersion curves obtain from MASW and ReMi were inverted to give a 1D shear wave velocity model; as well as to obtain the V_s^{30} for each study location.

Prior to the major field work, a preliminary and reconnaissance survey was carried out to determine some inherent field/acquisition parameters. For each site, two sets of data were collected; the Passive and the Active seismic surface wave data. The survey was able to gather the following data from each location; shear wave velocity, primary wave velocity, N values for both the active and the passive data which were both determined by the Seisimager surface wave software. The software was able to delineate low velocity layers within the depth of 4m – 6m at the failed portions of the survey sites except for location 1 (the control site) which showed an ideal situation of increasing velocity with depth. These low velocity layers were inferred to be the major cause of the incessant failure of the pavements in the survey areas. The average shear wave velocity for the first 30m ($\mathbf{v^{30}}_s$) in the control site was 566.3m/s for the active wave and 281.9 m/s for passive wave, N-values of about 12 – 113 for both active and passive. The $\mathbf{v^{30}}_s$ for location 2 (Parliamentary road) is 224.4m/s and 190.0m/s for the active and passive wave respectively and an N-value range of 11-19 count . Location 3 (Jonathan bypass) revealed a $\mathbf{v^{30}}_s$ of 169.9m/s active wave velocity and 137.0 m/s passive wave velocity as well as N-value of 3-13. Lastly, location 4 showed an average $\mathbf{v^{30}}_s$ of 174.2 m/s and 143.5 m/s active and passive wave velocity respectively with an N-value between 2 to 12.

These velocities and the N- values (blow count) were used to classify each location according to the 1997 National Earthquake Hazards Reduction Program (NEHRP) into sites C, D and E. The control site (Location 1) is classified as class C, which depicts a very dense soil or soft rock, Location 2 is class D; a stiff soil, Locations 3 and 4 are both classified as E; which is very soft soil. Generally, the low velocity layers beneath the study areas has a velocity ranging from about 120 m/s – 180 m/s, and is inferred to be that of a peat since the road cuts across a swampy terrain. As the peat dries it shrinks and cracks, making soils difficult to wet. When peat dies it becomes waxy and doesn't reabsorb water easily, hence, there is bound to be shrinkage of subsoil during the different seasons as the water table level changes within the subsurface and this is reflected on the surface as a collapse of the road pavement.

In the engineering community, shear wave analysis technique has gone beyond its normal use for estimation of shear wave velocity just as a function of depth to a more productive use of detecting anomalous zones within the subsurface (Miller *et al*., 2001). The low velocity layers that are present in all the failure sites have been inferred to be the major contributor to the pavement deterioration in the survey locations.The V_s^{30} for the active surface waves in the areas of interest varies between 169.9m/s to 224.4 m/s for the failed sites and about 566.3m/s for the control site. For the passive wave, it varies between 137m/s to 190m/s for the failed sites and about 300m/s for the controlled site. According to the NEHRP, the sites with V_s^{30} less than 180m/s have been correlated to soft soil which is suspected to be as a result of the swampy terrain through which the road cuts across. These soft soils have been evident in locations 2, 3, and 4 and have been classified as site D, E, and E respectively according to the NEHRP.

However, the physically evident road failure observed along locations 2,3and 4 of the study locations may solely not be as a result of the instability in the underground geology alone but may also be due to factors like drainage, engineering techniques applied during construction of the roads as well as the quality of materials used for the construction of some of these roads. It is observed in this study that majority of the areas were constructed over clay and swamp, hence, their contributions to the failure. This implies that responses to the underlying materials to imposed stresses is a dominant factor responsible for failures. For durability of Nigeria roads, such factors which result to failure of road should be adequately checked and remedied.

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