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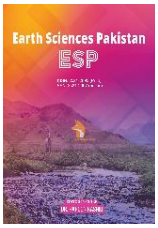

RESEARCH ARTICLE

CHARACTERIZATION OF SURFACE-WAVES IN THE CENTRAL SWAMP DEPOBELT IN THE NIGER DELTA, NIGERIA

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ABSTRACT

This paper presents a detailed study on refraction survey carried out in the Central Swamp Depobelt of the Niger Delta in order to compute the characteristics of the surface waves. Twenty-seven (27) boreholes were each drilled in the Central Swamp Depobelt of the Niger Delta to 66m. The borehole data were acquired using Seismograph McSeis-160MX Recorder, hydrophone detector and electric detonator as the source. Analysis of the results shows two-layer refractors. The consolidated-layer velocities range between 1580 and 1906ms^{-1}with an average of 1737.78ms^{-1}. Weathered-layer (surface) velocities range between 213 and 781ms^{-1} with an average of 504.81ms^{-1}. Air-blast low velocities range between 213 and 377ms^{-1} with an average of 307.33ms^{-1}. Depths from refracting surfaces range between 2.25 and 6.12m with an average of 4.58m. Dominant surface wave frequencies range between 5 and 10Hz. The layer thickness and velocity parameters can be applied in static correction in the processing of seismic reflection survey data. The dominant frequency information can also be integrated with the other parameters in detector and source arrays design necessary for attenuating the ground roll noise in the study area.

KEYWORDS

surface waves, borehole, frequency, velocity, layer thickness, Niger Delta, Nigeria

1. INTRODUCTION

Seismic data acquisition uses a controlled seismic source to generate impulsive sound waves. When any source is used to create seismic energy, the result is many kinds of waves, namely, body and surface waves. In seismic data acquisition, both signal and undesired surface waves are recorded simultaneously. Such undesired groundroll noise are the surface waves and are generated by the signal source (Linville and Meek, 1995). Surface waves usually has low velocity and low frequency (Anstey, 1993; Chukwueke and Ghosh, 2004; Hudson and Knopoff, 1967; Telford et al., 1976; McMechan and Sun, 1991). Due to their dispersive characteristics, surface waves can mask shallow reflections at short offsets and at long offsets (Claerbout, 1983; Saatcilar and Canitez, 1988; Henly, 2003; Mooney and Kaasa, 2005; Sengbush, 1983; Futherman, 2001; Chidi, 1988; Fitch, 1976; Short and Stauble, 1967; Uko et al., 1992). This paper aims at characterizing surface waves in terms of velocity, frequency, and depth at which they propagate. The results of this study could be useful to seismologists, geophysicists, geologists, and researchers who would like to know the characteristics of the surface waves in the area of study with the view of designing attenuation strategies.

2. THE STUDY AREA AND ITS GEOLOGY

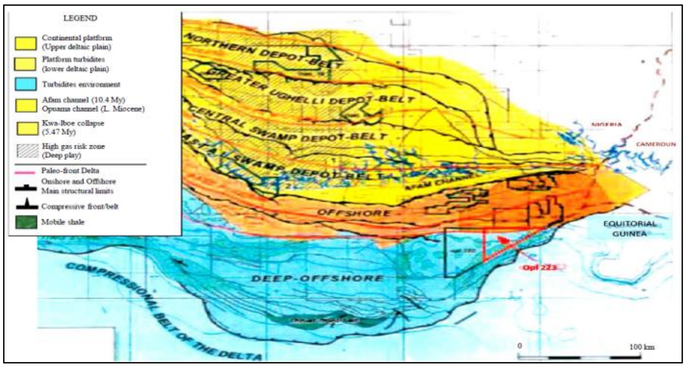

Figure 1: Map of Niger Delta showing study area.

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This research was conducted in the south-eastern Central Swamp Depobelt between latitudes 4o35'N and 4o55'N and longitudes 6o00'E and 6o20'E in the Niger Delta (Figure 1). The Niger Delta is located at the West African margin of the Gulf of Guinea. The three geological Formations in the sub-subsurface of the Niger Delta are the Akata Formation, Agbada Formation and Benin Formation [Figure 2] (Doust and Omatsola, 1990; Hospers, 1971; Short and Stauble, 1967; Whiteman, 1982). The Akata Formation is lowest unit of the Niger Delta complex. It is mainly composed of marine shales with locally dark grey sandy and silty beds (Burke, 1972). Its thickness varies from 576m to about 6060m having the age which ranges from the Oligocene to Recent (Kogbe, 1976; Merki, 1972; Murat, 1972; Reyment, 1965; Weber and Daukoru, 1975). Agbada Formation overlies the Akata formation. It is made up primarily of alternating fluviomarine sandstones and marine shales. Its age ranges from Eocene in the north to Pliocene in the south. The sandy parts of the Formation constitute the main hydrocarbon reservoirs of the delta oil-fields and the shales constitute seals to the reservoirs. It has a variable thickness of about 4500m. Benin Formation is the topmost layer. It consists of coarse-grained gravely sandstones with minor intercalation of shales. It is a continental deposit which age ranges from Miocene to Recent. It has very little hydrocarbon accumulation and has a thickness in excess of 1820m (Short and Stauble, 1967).

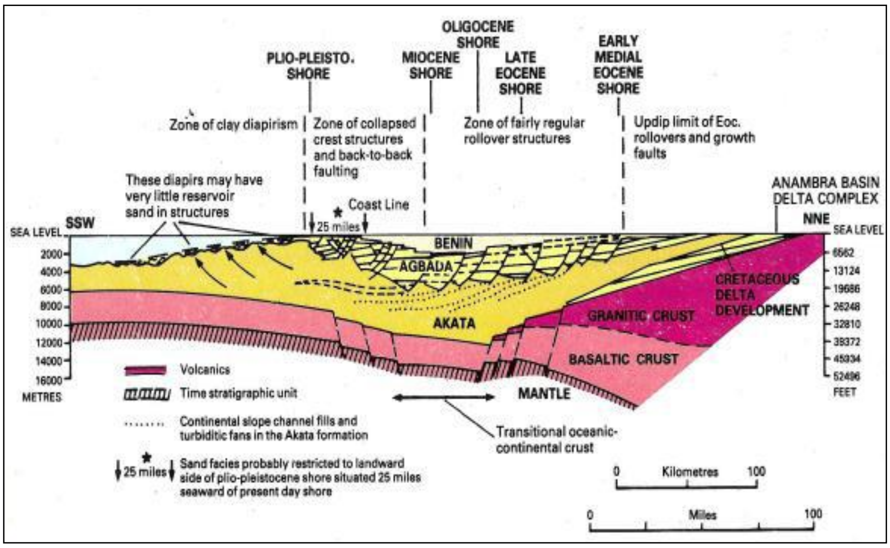

Figure 2: Schematic section showing Akata, Agbada and Benin Formations (Short and Stauble, 1967).

3. Materials and Methods

3.1 Survey Design, Equipment and Data Acquisition

The acquisition design comprises harness made of a single hydrophone unit secured on a marine rope and weighted on the lower end by a heavy metal (Figure 3). The marine rope is pre-calibrated at each depth point to be logged up to twelve channels as follows: 60m, 50m, 40m, 30m, 25m, 20m, 15m, 10m, 5m, 3m, 1m and 0m.

At every borehole location, a borehole was drilled to a depth of 66m using rotary method and flushed continuously for 20 minutes to enhance stability for smooth plastic casing. The rock/soil samples were collected at every 3m-depth interval. The drill cuttings were described based on field observations and classified based on Wentworth grade scale (Wentworth, 1922). The hydrophone harness was lowered into the cased hole filled with water to the required depth and properly secured to a peg to maintain stability (Figure 3). An electrical detonator as energy source was placed in a 2m deep hole at an offset of 2m away from the borehole. A Seismograph (McSeis-160MX v5.42) on the surface measures the travel times, T, of the generated seismic energy to the hydrophone in the borehole. These travel times of the waves were corrected for the slant travel and source paths were then plotted against the hydrophone depths, X.

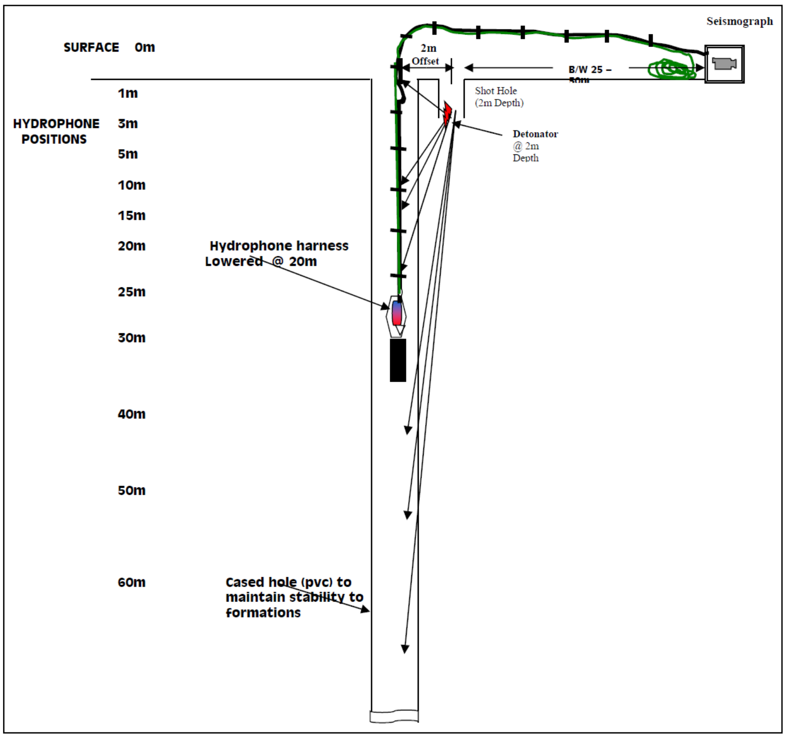

Figure 3: Data acquisition Equipment Setup

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3.2 Determination of depths and velocities of the layers

The velocities were computed from the inverse slopes of the corresponding graphs segments (Figure 4). The following governing equations were used to compute the thickness of layers:

$$Z_1 = \frac{t_1 v_1 v_2}{2(v_2^2 - v_1^2)^{1/2}} \quad (1)$$

$$t_1 = \frac{2z(v_2^2 - v_1^2)^{1/2}}{v_1 v_2} \quad (2)$$

where t_1 is the intercept times; Z_1 is layer thicknesses; v_1, and v_2 are layers' velocities. The velocities are computed from the reciprocals of the slopes of the straight-line segments of the graphs.

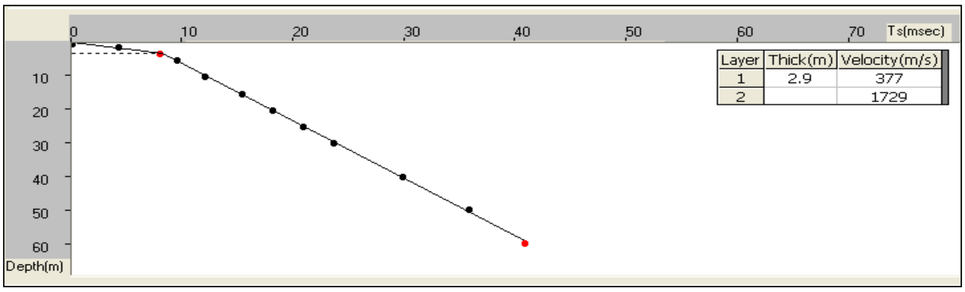

Figure 4: Depth-surface corrected time graph, example.

3.3 Determination of Dominant Frequencies

The frequency, f (Hz), of the wave travelling with the velocity, V (ms^{-1}), through the wavelength, λ (m), and frequency, f, were computed manually from the raw record. Frequency, f, was determined using the relation:

$$f = V/T \quad (5)$$

The period, T, was determined from the raw record as an interval time from peak to peak or trough to trough of the sinusoidal wave on the seismogram, while the velocity was calculated from the distance-time relationship.

3.4 Lithologic Description

During the drilling, the cut rock/soil samples were collected and classified into various lithologies for each stratum, using Wentworth Scale (Wentworth, 1922).

4. RESULTS AND DISCUSSION

The results of the layer-depths, thicknesses, and wave frequencies are presented in Table 1, and Figures 5 - 9.

Table 1: Summary of the result of the Surface Wave Survey

Borehole Number	**Eastings**	**Northings**	**Elevation (m)**	**Weathered layer thickness (m)**	**Weathered layer velocity (ms^{-1})**	**Consolidated layer velocity (ms^{-1})**	**Frequency (Hz)**
UH-01	410429.58	75569.62	3.67	9.2	576	1748	9.60
UH-02	413409.39	76820.17	2.25	11.2	446	1670	7.43
UH-03	416300.33	80300.00	3.37	5.5	417	1726	6.95
UH-04	418115.12	82018.16	3.31	9.8	428	1906	7.13
UH-05	422875.53	85021.84	4.46	9.8	696	1757	11.60
UH-06	424806.90	88046.89	4.70	5.0	410	1799	6.83
UH-07	420801.82	91401.32	4.70	4.7	309	1699	5.15
UH-08	420349.13	87586.03	4.76	10.7	500	1651	8.33
UH-09	417855.85	85130.81	3.93	2.7	405	1703	6.75
UH-10	413773.01	82863.42	3.04	10.8	492	1810	8.20
UH-11	409726.20	80561.77	2.84	9.5	745	1811	12.42
UH-12	407867.26	78169.23	3.15	13.9	573	1712	9.53
UH-13	403430.76	80537.37	3.26	2.9	377	1729	6.28
UH-14	407198.87	831125.05	3.58	5.3	282	1719	4.70
UH-15	410687.19	85999.85	3.23	9.6	651	1747	10.85
UH-16	414097.54	882336.2	3.82	10.4	539	1580	8.98
UH-17	416740.99	91962.44	4.84	2.8	359	1719	5.98
UH-18	400343.96	83672.40	3.09	3.2	672	1830	11.20
UH-19	405383.80	86391.09	4.91	16.5	589	1725	9.82
UH-20	409302.94	90251.11	4.08	4.8	417	1717	6.98
UH-21	412299.78	936224.07	5.63	3.3	213	1750	3.55
UH-22	410338.83	96324.89	5.89	5.5	304	1770	5.07
UH-23	404996.35	91060.74	3.63	8.7	608	1740	10.13
UH-24	397461.17	85885.95	4.67	4.8	556	1741	9.27
UH-25	400179.88	90248.43	3.90	10.3	661	1677	11.02
UH-26	403968.27	95664.25	5.44	13.1	622	1772	10.37
UH-27	406894.45	99109.03	6.12	13.8	781	1712	13.02
Average				**8.07**	**504.81**	**1737.78**	**8.42**

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4.1 Lithology

The study area is predominantly sand, clay, and clayey sand. The soil sequences vary in size from fine through medium to coarse (Figure 5). The sand is an admixture of the various sizes but demarcation is based on the size as define by Wentworth scale of classification. The sequences conform to the typical deltaic depositional environment.

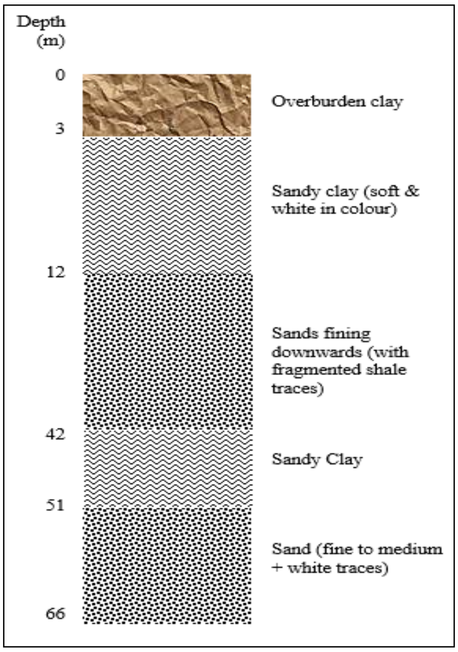
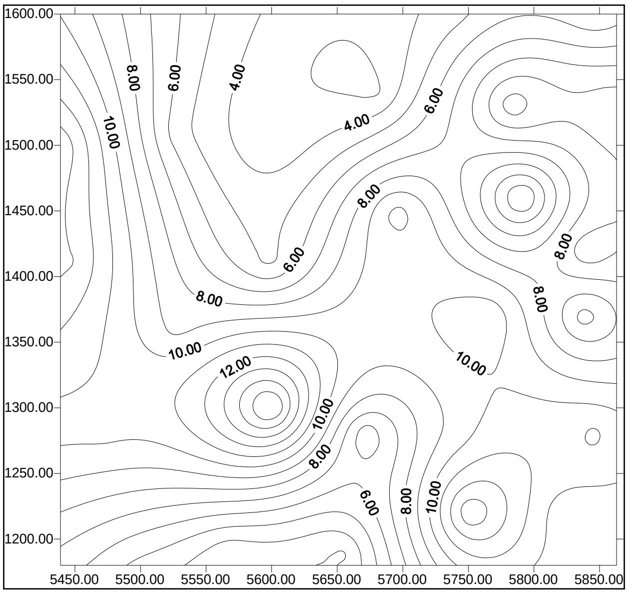


Figure 5: Display of Lithology for UH-1, example

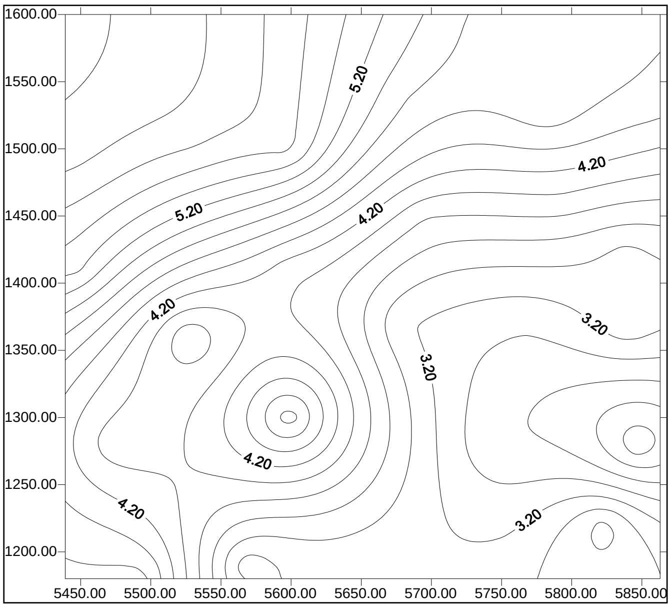
4.1 Layer Velocity and Thickness Structure

Results of the velocity structure analysis within the prospect area reveal that the high velocity ranges from 1580ms^{-1} to 1906ms^{-1} with an average of 1737.78ms^{-1}. The lithology here is dominated by consolidated coarse sands. The weathered layer velocity ranges from 213ms^{-1} to 781$ms^{-1}$with a simple average of 504.81 ms^{-1} within clay soil. The study area exhibit 2-layer cases. The thickness of the first layer varied from 2.70m to 16.5m. The isopach contour map (Figure 6) for the first layer is compared with the elevation map (Figure 7) of the study area. There is a thickening of first layer northwards accompanying the increase of elevation. The velocity of the consolidated second layer is presented in Figure 8. It is observed from the velocity plots that all the borehole locations exhibit two layers as shown in the travel time plots. The first measured velocity may have been mixed up with air wave velocity having an average of 307.33ms^{-1} (Figure 9).



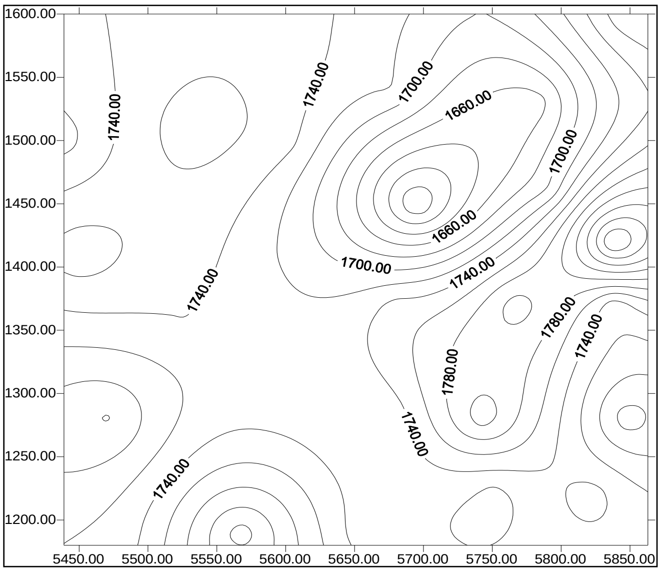
Contour interval: 1m

Figure 6: Weathered-layer thickness contour map



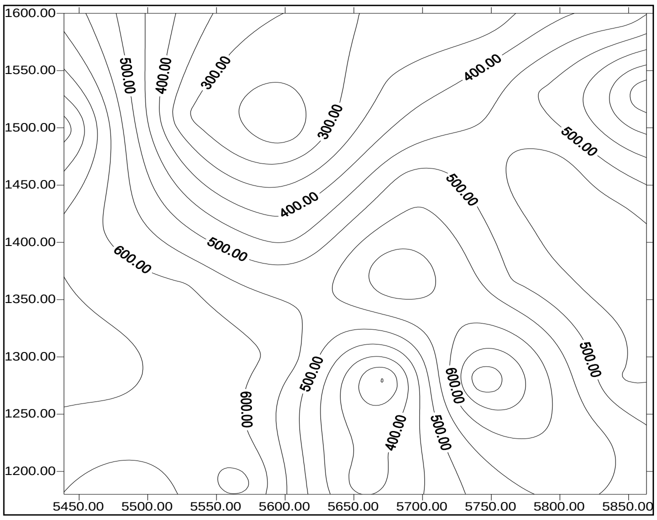
Contour Interval: 0.2m

Figure 7: Elevation Contour map of the study area



Contour interval: 20ms^{-1}.

Figure 8: High-velocity contour map



Contour Interval: 50ms^{-1}

Figure 9: Low-velocity-layer contour map

4.2 Dominant Frequencies

The dominant frequency in the spectrum of any given signal is the frequency at which the highest of that signal occurs. In the borehole event in which the variable of paramount interest is the ground roll velocity, the dominant frequency is the frequency at which the highest amplitude of ground roll velocity occurs. Dominant frequencies have been abstracted for each location, Table 1. There is predominance of frequency within the range of 5 – 10 Hz. This implies that this range of frequencies will constitute noise on seismic data. The knowledge of the dominant groundroll frequencies enables the design of optimum detector array geometry which could help suppress this ground roll noise. Denham, Dix, Geyer and Hales and Edwards observed that any seismic source, especially surface source, generates a pattern of surface waves or ground roll (Denham, 1979; Dix, 1952; Geyer, 1976; Hales and Edwards, 1955).

5. CONCLUSION

The following conclusions are reached:

(i) Consolidated-layer velocities range between 1580 and 1906ms^{-1} with an average of 1737.78ms^{-1}.

(ii) Rayleigh ground roll velocities range between 213 and 781ms^{-1} with an average of 504.81ms^{-1}.

(iii) Air-blast low velocities range between 213 and 377ms^{-1} with an average of 307.33ms^{-1}.

(iv) Depths from reflecting surfaces range between 2.25 and 6.12m with an average of 4.58m.

(v) Principal dominant surface-wave frequencies range between 5 and 10 Hz.

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