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Evaluation of layer Velocity Disparity and Lithological Changes within the Subsurface Using High Resolution Downhole Seismic Method for Site Characterization

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Abstract **- The aim of this research work is to evaluate the velocities distribution and lithological changes within the subsurface, necessary for site characterization at a construction site located in the oil rich Niger Delta of Southern Nigeria using downhole seismic method. The downhole seismic survey was carried out with an offset distance of 3 m, at an interval of 1 m to a depth of 30 m. The seismic velocities which ranges from 457 m/s to 1972 m/s for the p wave velocity, and 291 m/s to 1066 m/s for s wave velocity connotes that there are two layers of unconsolidated and consolidated sand in the region under investigation. The range of Poisson's ratio 0.16 to 0.23 determined for the unconsolidated sand layer and 0.24 to 0.29 for the consolidated sand layer, gave a clear confirmation that the region under investigation is made up of two lithological unit of sand, from the surface down to a depth of 14 m, and from 15 m to 30 m. The determined shear, bulk and Young's modulus were able to delineate the unconsolidated and consolidated sand layers by registering low values down to a depth of 14 m. It is imperative to conclude that the area under investigation is characterized with two lithological units, the saturated and unsaturated sand layer of different elastic parameters. It was also recommended that proper engineering remediation is required to improve the strength of material down to a depth of 14 m, before erecting any structure.**

Keywords: Down Hole Seismic, Lithology, Velocity, Elastic Parameters, Characterization, Sand.

I. INTRODUCTION

It is customary to carryout geophysical investigation in a construction site to ascertain the engineering properties (elastic parameter) of the geologic layers under investigation, which will in turn enable the engineers, determine the load bearing capacity of the subsurface structure. The aim of this research work is to evaluate the disparity in seismic velocities of layers and lithological changes within the subsurface using high resolution downhole seismic method. In that respect, downhole seismic survey was carried out in the oil rich Niger Delta of Bayelsa State Nigeria, to determine the variation in the seismic velocity and lithological changes within the subsurface.

The downhole seismic survey is majorly carried out with the energy source station at a fixed offset distance from the test borehole. The measurement is mainly done at consecutive interval with depth in a borehole using geophone or a hydrophone to detect the seismic p and s arrival from the energy source at a fix distance from the borehole. "The Downhole Seismic Test makes direct measurements of compression (P-) or shear (S-) wave velocities, or both, in a borehole advanced through soil or rock" [12]. "The reliability of down-hole test results is directly related to the quality of the recorded signals, which heavily relies on the care taken during testing procedure and interpretation" [10].

II. LOCATION OF THE STUDY AREA

The site under investigation is at Yenagoa Bayelsa State, bounded by Latitude 4°53'43.62"N and Longitude 6°20'35.37"E, Latitude 4°53'57.88"N and Longitude 6°20'44.80"E, Latitude 4°53'51.79"N and Longitude 6°21'2.49"E, with an average elevation of 18 m above mean sea level. The imagery map of the survey area is shown in figure 1

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Figure-1: Imagery map of the survey site. Adapted from [3]

III. GEOLOGY OF THE STUDY AREA

"The study area is Yenagoa in Bayelsa state, within the fresh water and meander belt geomorphic unit of the Niger Delta", [7]. "The Formation of the present Niger Delta started during Early Paleocene as a result of the built up of fine grained sediments eroded and transported to the area by the River Niger and its tributaries". "The regional geology of the Niger Delta consists of three lithostratigraphic units; Akata, Agbada and Benin Formations, overlain by various types of Quaternary Deposits" [9], [11], [6]. "These Quaternary Sediments, according to [8] are largely alluvial and hydromorphic soils and lacustrine sediments of Pleistocene age". "The result of the overburden thickness analysis and the velocity distribution at the surface down to a depth of 5 m, has revealed that Bayelsa region is characterized with regions of low velocities and regions of high velocities that falls within the range of sandy clay" [2].

IV. INSTRUMENTATION

The major instruments used for this survey includes: Terraloc Mark6 Digital Seismography, Triaxial Hydrophone, Sledge Hammer, Base Plate, Trigger Geophone, Reel of Cable, Trigger Coil, Sealed Battery and Measuring Tape.

V. METHODOLOGY (DATA ACQUISITION)

An offset distance, that is, the distance between the shot and the borehole of 3 m as was used for this survey. The test borehole was drilled to a depth of 30 m. The Triaxial Hydrophone which was assigned to the first channel of the Digital Seismograph was connected to the first take out of the reel of cable. The digital seismograph was started, and the hydrophone was assigned to channel 1, while the remaining 11 channels were closed from receiving seismic signals. The trigger geophone was connected to trigger coil so as to trigger the seismograph when the shot is taken. The hydrophone was then lowered into the borehole starting with a depth of 0 m just below the surface. The seismograph was then armed, and a stack of 5 shot was taken, which was detected by the Hydrophone and recorded with the digital Seismograph. The recording procedure was repeated, and after each recording the Hydrophone was lowered to a deeper depth at interval of 1 m, until the depth of 30 m was sampled. The generated seismograms were recorded for onward processing at the geophysical workstation. The recording parameters are outlined as follows; Sampling interval 250µs, Number of Sample1000, Record Length 0.25s, Number of Stack 5, Data format SEG2, Delay Time (ms) 0, Offset Distance 3 m, Depth Interval 1m, Borehole Depth 30 m.

VI. DATA PROCESSING

The data processing which was recorded in SEG2 format was imported into an appropriate geophysical software which was used for the analysis. Band-pass frequency filter was applied to remove the effect of the surface waves that will contaminate the p or s waves. Gain filter was applied to remove the effect of Geometrical spreading. The first arrival times were picked, for both p and s waves. The picked arrival times were used in conjunction with the ray-paths to compute the interval velocities for both p and s waves. The interval velocities for both p and s waves were plotted against the various depth to generate interval velocity sections. The processed seismic traces can be found in the Appendixes.

VII. RESULTS

The analyzed parameters among others include p wave velocity, s wave velocity, bulk modulus, shear modulus, and Young's modulus. The p wave velocity and s wave velocity were determined down to a depth of 30 m. The result of the survey has shown that both the p wave velocity and s wave velocities increases with depth in the region under investigation. The velocity ranges from 457 m/s to 1972 m/s for the p wave velocity, and 291 m/s to 1066 m/s for s wave velocity. The very low range of p wave velocity values of between 457 m/s to 907 m/s within the first 14 m depth, gave a clear indication that the overburden material, is possibly composed majorly of unsaturated loose sand base on the velocity values [5]. This layer is underlain with consolidated and saturated sand layer base on the seismic velocities, which ranges from 1003 m/s to 1972 m/s, [1], down to a depth of 30 m. The Interval Velocity plots for both p waves and s waves velocities, (Fig. 2 and 3), also collaborated these results by showing a level of uniformity at the onset of the of both plot, and the registering of p wave values of less than 1400 m/s before 14 m depth. The range of Poisson's ratio which is between 0.16 and 0.23 for the overburden down to a depth of 14 m, is a confirmation that it made up of loose sand, after [4], and the range of Poisson ratio for the consolidated layer which

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is between the range of 0.24 to 0.29 is an indication that 15 m to 30 m depth is characterize by relatively dense saturated sand layer. Table 1 shows the value of offset distance, Depth, depth interval, the ray paths, and ray path interval that was used for the data acquisition. Table 2 illustrate the arrival time of p and s waves seismic signal with depth. A critical examination of table 3, indicates that the bulk modulus which is a measure of resistant to compression, shear modulus which is the ability of a material to resist transverse deformations and Young's modulus which measures the stiffness of a solid material experience a transition in value at a depth of 14 m, changing from values associated with loose unsaturated sand to values of dense saturated sand at a depth of 15 m to 30 m, with a difference of $10^8 Pa$ for each parameter at the transition depth of 14 m and 15 m, which is a clear demarcation of overburden layer of loose unsaturated sand, and consolidated layer of saturated sand. It became obvious that the overburden layer which is characterized with loose sand layer will require some level of engineering remediation to improve the mechanical property, the shear strength and the compressive strength before putting up any structure at the site under investigation.

TABLE-I

Acquisition Parameter; Offset, Depth, Depth Interval, Raypath and Raypath Interval

Depth (m)	Offset Distance (m)	Depth Z1 (m)	Depth Z2 (m)	RayPath R1 (m)	RayPath R2 (m)	Delta R (m)
1	3	0	1	3.000000000	3.162277660	0.162277660
2	3	1	2	3.162277660	3.605551275	0.443273615
3	3	2	3	3.605551275	4.242640687	0.637089412
4	3	3	4	4.242640687	5.000000000	0.757359313
5	3	4	5	5.000000000	5.830951895	0.830951895
6	3	5	6	5.830951895	6.708203932	0.877252038
7	3	6	7	6.708203932	7.615773106	0.907569173
8	3	7	8	7.615773106	8.544003745	0.928230639
9	3	8	9	8.544003745	9.486832981	0.942829235
10	3	9	10	9.486832981	10.44030651	0.953473528
11	3	10	11	10.44030651	11.40175425	0.961447742
12	3	11	12	11.40175425	12.36931688	0.967562626
13	3	12	13	12.36931688	13.34166406	0.972347187
14	3	13	14	13.34166406	14.31782106	0.976156999
15	3	14	15	14.31782106	15.29705854	0.979237478
16	3	15	16	15.29705854	16.27882060	0.981762055
17	3	16	17	16.27882060	17.26267650	0.983855906
18	3	17	18	17.26267650	18.24828759	0.985611089
19	3	18	19	18.24828759	19.23538406	0.987096471
20	3	19	20	19.23538406	20.22374842	0.988364354
21	3	20	21	20.22374842	21.21320344	0.989455019
22	3	21	22	21.21320344	22.20360331	0.990399876
23	3	22	23	22.20360331	23.19482701	0.991223698
24	3	23	24	23.19482701	24.18677324	0.991946235
25	3	24	25	24.18677324	25.17935662	0.992583379
26	3	25	26	25.17935662	26.17250466	0.993148033
27	3	26	27	26.17250466	27.16615541	0.993650758
28	3	27	28	27.16615541	28.16025568	0.994100266
29	3	28	29	28.16025568	29.15475947	0.994503794
30	3	29	30	29.15475947	30.14962686	0.994867389

TABLE-2

Depth, Picked Arrival Time for P and S Waves, P Waves Interval Time and S Waves Interval Time

Depth (m)	P time t1 (s)	P time t2 (s)	P Delta t (s)	S time t1 (s)	S time t2 (s)	S Delta t (s)
1	0.00313056	0.003485653	0.000355093	0.004914979	0.005472476	0.000557497
2	0.003485653	0.004440984	0.000955331	0.005472476	0.006981899	0.001509423
3	0.004440984	0.005793616	0.001352631	0.006981899	0.009132583	0.002150684
4	0.005793616	0.007381371	0.001587755	0.009132583	0.011672991	0.002540409
5	0.007381371	0.009073738	0.001692366	0.011672991	0.014397701	0.002724710
6	0.009073738	0.010817777	0.001744040	0.014397701	0.017223046	0.002825345
7	0.010817777	0.012569841	0.001752064	0.017223046	0.020078910	0.002855864
8	0.012569841	0.014304852	0.001735011	0.02007891	0.022924328	0.002845417
9	0.014304852	0.015988476	0.001683624	0.022924328	0.025702307	0.002777979
10	0.015988476	0.017577598	0.001589123	0.025702307	0.028340250	0.002637943
11	0.017577598	0.019040989	0.001463391	0.02834025	0.030784113	0.002443863
12	0.019040989	0.020375558	0.001334569	0.030784113	0.033026189	0.002242076
13	0.020375558	0.021578958	0.001203400	0.033026189	0.035059935	0.002033746
14	0.021578958	0.022655206	0.001076248	0.035059935	0.036889556	0.001829622
15	0.022655206	0.023631515	0.000976309	0.036889556	0.038559044	0.001669488
16	0.023631515	0.024515189	0.000883674	0.038559044	0.040078964	0.001519920
17	0.024515189	0.025320308	0.000805119	0.040078964	0.04147182	0.001392857
18	0.025320308	0.026057489	0.000737181	0.04147182	0.042754515	0.001282695
19	0.026057489	0.026740129	0.000682639	0.042754515	0.043949134	0.001194619
20	0.026740129	0.027382758	0.000642630	0.043949134	0.045080162	0.001131028
21	0.027382758	0.027994288	0.000611530	0.045080162	0.046162570	0.001082408
22	0.027994288	0.028582761	0.000588473	0.046162570	0.047210052	0.001047482
23	0.028582761	0.029151449	0.000568688	0.047210052	0.048222317	0.001012265
24	0.029151449	0.029707161	0.000555712	0.048222317	0.049217041	0.000994725
25	0.029707161	0.030248079	0.000540917	0.049217041	0.050190693	0.000973651
26	0.030248079	0.030780027	0.000531949	0.050190693	0.051153520	0.000962827
27	0.030780027	0.031305769	0.000525741	0.051153520	0.052110369	0.000956849
28	0.031305769	0.031823799	0.000518030	0.052110369	0.053058364	0.000947996
29	0.031823799	0.032338286	0.000514487	0.053058364	0.054005021	0.000946656
30	0.032338286	0.032842783	0.000504497	0.054005021	0.054938339	0.000933319

TABLE-3

P Waves, S Waves and Elastic Parameters

Depth (m)	P wave Velocity (m/S)	S wave Velocity (m/s)	Density (kg/m3)	Poisson's ratio	Bulk Modulus (Pa)	Shear Modulus (Pa)	Young's Modulus (Pa)
1	457	291	1515	0.16	145208321.8	128325025.9	297375223.8
2	464	294	1520	0.17	152494825.3	131114431.9	305723386.6
3	471	296	1526	0.17	159987151.2	133906607.6	314090343.2
4	477	298	1531	0.18	166898397.5	136058476.2	320958456.7
5	491	305	1542	0.19	180520303.2	143410457.2	340155084.2
6	503	310	1551	0.19	193083792.7	149553696.7	356594052
7	518	318	1563	0.20	208887180.0	157821427	378213253.7
8	535	326	1575	0.20	227380185.7	167651532.9	403729022.8
9	560	339	1593	0.21	254981540.9	183549999.4	444089766.4
10	600	361	1621	0.22	301234274.3	211798730.4	514754399.0
11	657	393	1658	0.22	373611689.4	256677827.3	626549873.3
12	725	432	1700	0.23	471362803.7	316549160.8	775948425.8
13	808	478	1746	0.23	607903619.6	399209959.7	982549894.2
14	907	534	1798	0.24	796550646.0	511702770.5	1264366105
15	1003	587	1843	0.24	1008882470	634211472.2	1573019806
16	1111	646	1891	0.24	1282242407	789039879.9	1964219374
17	1222	706	1937	0.25	1603658629	966311665.0	2414057849
18	1337	768	1981	0.25	1981427342	1169489656	2931683776
19	1446	826	2020	0.26	2384726798	1379119112	3468693524
20	1538	874	2051	0.26	2763693411	1566482813	3952650760
21	1618	914	2078	0.27	3124081007	1736018490	4394131473
22	1683	946	2098	0.27	3441916403	1875635619	4761920867
23	1743	979	2117	0.27	3724175837	2029449886	5152429216
24	1785	997	2129	0.27	3960944638	2117284164	5391240830
25	1835	1019	2144	0.28	4248250658	2228103492	5689621417
26	1867	1031	2153	0.28	4450793286	2290956172	5866341487
27	1890	1038	2160	0.28	4609522325	2329139489	5980179456
28	1919	1049	2168	0.29	4805215799	2384052028	6137190769
29	1933	1051	2172	0.29	4919478105	2397094971	6186466430
30	1972	1066	2183	0.29	5181665754	2480254848	6416923534

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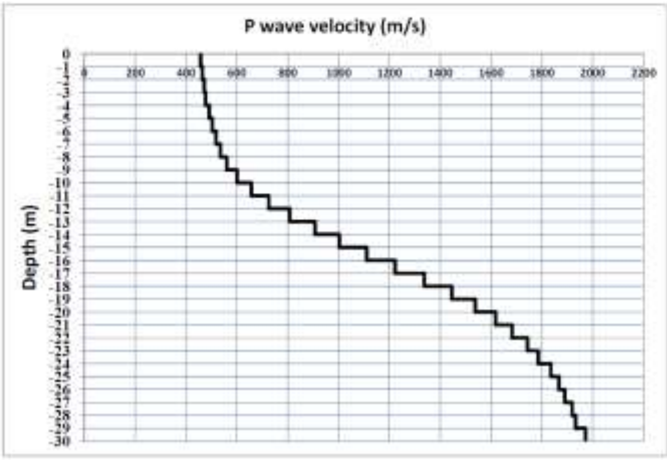

Figure-2: P wave interval velocity plot for downhole survey

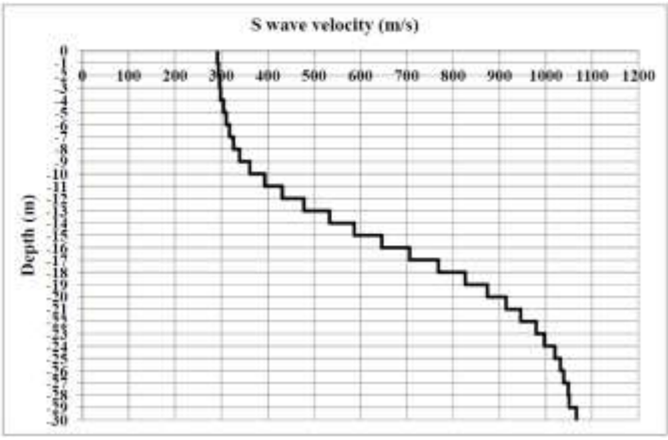

Figure-3: S wave interval velocity plot for downhole survey

VIII. CONCLUSION

The high resolution downhole seismic method was able to identify two lithological units of sand layer base on their seismic velocities values. The range of Poisson's ratio determined for each layer also gave a good confirmation of the two lithological layers of sand from the surface down to a depth of 14 m, and from 15 m down to 30 m. The determined shear modulus, bulk modulus and Young's modulus also showed a general increase with depth. These parameters were able to delineate the interface between the saturated and unsaturated sand layer at a depth of 14 m, with a difference of $10^8 Pa$ for the values at the interface. It is essential to conclude that the area under investigation is characterized with two lithological units, the saturated and unsaturated sand layer of different elastic parameters. It was also recommended that proper engineering remediation is necessary to improve the strength of material down to a depth of 14 m, before putting up any structure.

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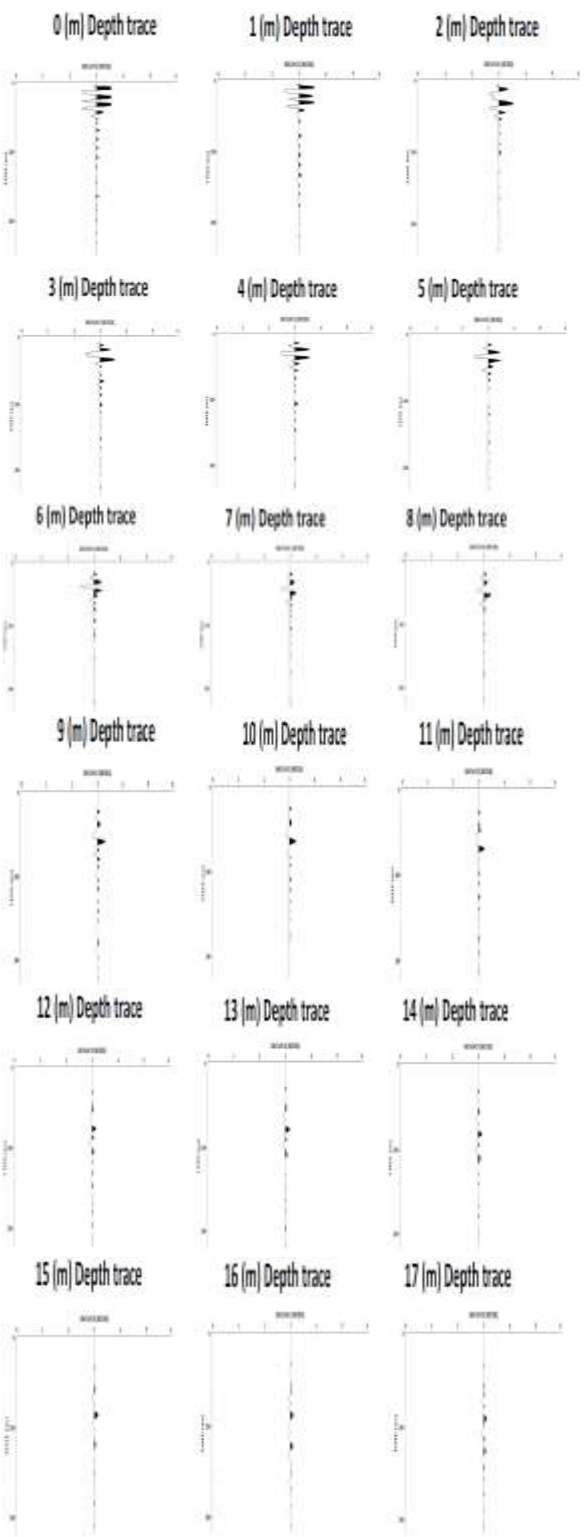
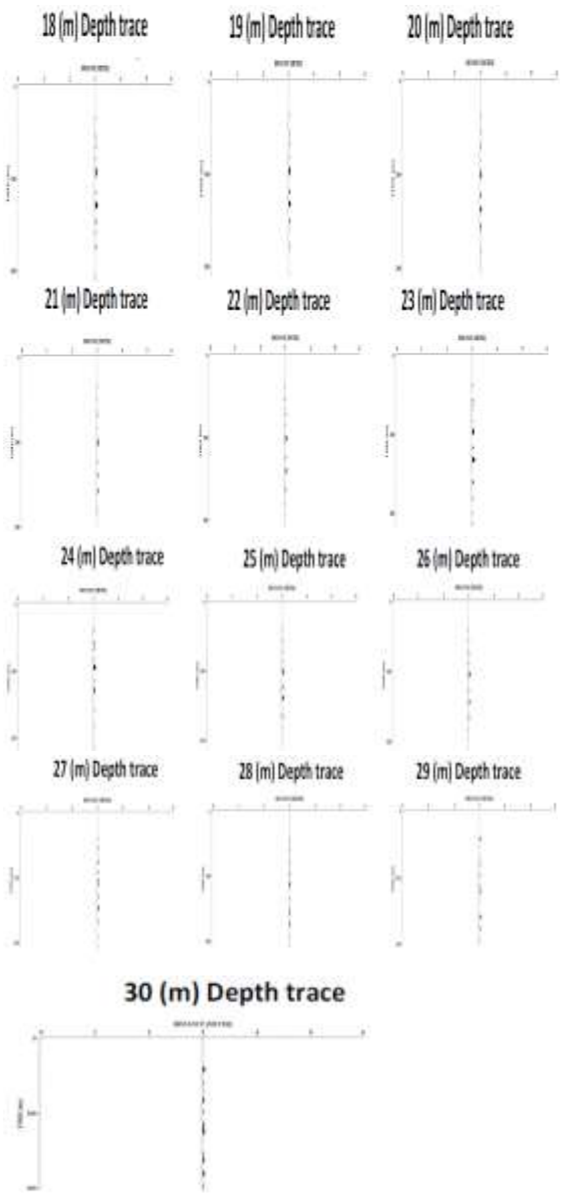
APPENDIXES

Thirty one Seismic Traces generated from the surface 0 m depth to a depth of 30 m, arranged side by side in consecutive row of three each.





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