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Soil Categorization Using Vs30 Mapping, to Evaluate Probable Structural Effects of an Earthquake on a Proposed Construction Site

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***Abstract* - This research work was carried out with the aim of using average shear wave velocity of the top 30 m (Vs30), technique to categorize the soil, and ascertain the probable resistance or damage that the structure placed on it could suffer in the event of damaging earthquake. In a bid to achieve this, downhole seismic survey was carried out in eight boreholes within the same site, all drilled to 30 m depth. The field procedure used involves lowering of hydrophone into the borehole at an interval of 1 m, and striking a sledge hammer on base plate at a fixed distance of 3 m to generate seismic signals. The data were processed and the results revealed that, the distribution of average shear wave velocity of the top 30 m (Vs30) is not always even within a given site; instead, you have regions with low Vs30, and regions with high Vs30. The results indicated the presence of overburden layer (lose sand layer) within the site under investigation, and also revealed that in most instances, regions with low Vs30 match up with regions with thick overburden, and regions with high Vs30 correspond with regions with thin overburden cover. The research has shown that, in the event of damaging earthquake the regions with low Vs30 and relatively thick overburden cover will experience more of the amplification of the low frequency seismic waves, and consequently more damage to structures erected within that vicinity. Hence, regions with low Vs30 and thick overburden cover will require engineering remediation to improve its resistance to shaking and load bearing capacity, and to reduce the amplification of low frequency seismic waves in the event of ground shaking induced by an earthquake.**

Keywords: Vs30, Earthquake, Construction Site, Downhole, Seismic, Shear wave.

I. INTRODUCTION

This investigation was carried out with the sole aim of making use of Vs30 technique to categorize the soil within a given site, and to ascertain the probable effect of a damaging Earthquake on any structure erected at the site. Therefore a high resolution downhole seismic method that has the ability to accurately determine the shear wave velocities, and delineate each layer was used in this research work. Previous research done in these area have shown that; "In post 1994 U.S. seismic codes a new soil categorization scheme was introduced, which uses Vs30 as the main categorization parameter" [4]. "[1] stated that "After conducting a detailed study in the Dinar Region, it is observed that the poor soil condition effects are clear on the damage distribution". "The high resolution downhole seismic method was able to identify two lithological units of sand layer base on their seismic velocities values" [2]. The instruments used for the data acquisition include ABEM Terraloc Digital Seismograph, Hydrophone, Sledge Hammer, Base plate, Reels of Cables and sealed 12 V Battery.

II. GEOLOGY OF THE AREA

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 [6], [7], [3]. These Quaternary Sediments, according to [5] are largely alluvial and hydromorphic soils and lacustrine sediments of Pleistocene age.

III. LOCATION OF STUDY AREA

The study area is located within the oil rich Niger Delta, of Delta State Nigeria. With an average elevation of 9 m above mean sea level. The Imagery Map of the survey area displaying the borehole point is shown in figure 1.

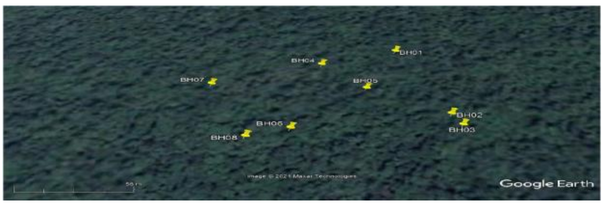

Figure 1: Imagery Map of the Survey area, displaying the various borehole locations

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IV. DATA ACQUISITION

The data acquisition for the downhole seismic test started with measurement of the depth of the drilled borehole, after which an offset distance of 3 m from the borehole was measured. The digital Seismograph was set up along with its accessories. The hydrophone was connected to the first takeout of the reel of cable connect to the Seismograph. The Hydrophone was first placed at the surface and the energy source was initiated by striking a sledge hammer on a base plate placed at an offset distance of 3 m to generate a seismic signal, which was detected by the hydrophone, and recorded by the Seismograph.

The hydrophone was then lowered into the hole at a depth of 1 m, and the energy source was used to generate seismic wave as before. The process was repeated, with each time the hydrophone being lowered at 1 m interval, until the highest depth of 30 m was sampled. The generated seismograms were recorded for onward processing at the workstation.

V. DATA PROCESSING

The downhole seismic data was processed by importing it into a dedicated software used for the data processing. The bandpass frequency filter was applied to filter out the surface wave signal. The gain filter was applied to remove the effect of geometrical spreading. The Primary and shear waves were identified, and their first arrival was picked. The picked arrival times were used along with other parameters to calculate the intervening primary and shear wave velocity in each layer, as shown in Table 1 and 2.

Table 1: Primary and shear wave velocities distribution pattern with depth for boreholes 1 to 4

	BH1		BH2		BH3		BH4	
Depth (m)	P wave Velocity (m/S)	S wave Velocity (m/s)	P wave Velocity (m/S)	S wave Velocity (m/s)	P wave Velocity (m/S)	S wave Velocity (m/s)	P wave Velocity (m/S)	S wave Velocity (m/s)
1	661	396	566	343	622	372	425	271
2	675	404	574	348	645	386	437	278
3	693	414	583	353	684	409	449	286
4	721	429	602	360	745	443	472	300
5	748	445	626	375	844	499	493	313
6	773	460	657	393	982	578	511	313
7	834	493	709	422	1179	689	552	338
8	929	546	775	461	1438	822	618	370
9	1040	608	883	522	1770	994	709	422
10	1170	684	1044	611	2136	1193	819	485
11	1324	761	1262	734	2462	1367	953	561
12	1506	856	1552	892	2708	1504	1117	653
13	1716	964	1912	1074	2857	1586	1316	756
14	1948	1088	2419	1343	2910	1615	1553	882
15	2200	1224	2601	1444	2911	1616	1827	1026
16	2464	1368	2797	1553	2913	1617	2139	1194
17	2718	1509	2898	1609	2914	1617	2482	1378
18	2773	1540	2910	1615	2915	1618	2723	1512
19	2779	1543	2911	1616	2916	1618	2776	1541
20	2785	1546	2912	1616	2917	1619	2782	1544
21	2791	1549	2913	1617	2918	1619	2788	1548
22	2797	1553	2914	1617	2919	1620	2794	1551
23	2802	1555	2915	1618	2920	1620	2799	1554
24	2805	1557	2916	1618	2921	1621	2803	1556
25	2807	1558	2917	1619	2922	1621	2806	1557
26	2808	1558	2918	1619	2923	1622	2808	1558
27	2809	1559	2919	1620	2924	1622	2809	1559
28	2810	1559	2920	1620	2925	1623	2810	1559
29	2811	1560	2921	1621	2926	1623	2811	1560
30	2812	1560	2922	1621	2927	1623	2812	1560

Table 2: Primary and shear wave velocities distribution pattern with depth for boreholes 5 to 8

	BH5		BH6		BH7		BH8	
Depth (m)	P wave Velocity (m/S)	S wave Velocity (m/s)	P wave Velocity (m/S)	S wave Velocity (m/s)	P wave Velocity (m/S)	S wave Velocity (m/s)	P wave Velocity (m/S)	S wave Velocity (m/s)
1	376	247	1015	594	772	460	692	412
2	392	258	1034	604	781	465	705	419
3	412	262	1056	617	790	470	713	424
4	452	288	1099	642	808	478	727	432
5	513	315	1163	679	833	493	735	436
6	598	367	1251	723	887	524	742	440
7	871	515	1382	794	916	539	755	448
8	997	586	1580	903	993	584	784	465
9	1530	869	1841	1034	1114	651	822	486
10	1760	989	2134	1185	1293	747	877	519
11	2284	1270	2435	1352	1518	863	955	562
12	2686	1491	2703	1501	1855	1042	1063	622
13	2825	1568	2910	1615	2208	1229	1215	706
14	2892	1606	2911	1616	2567	1425	1427	825
15	2910	1615	2912	1616	2788	1548	1705	958
16	2911	1616	2913	1617	2898	1609	2026	1132
17	2912	1616	2914	1617	2910	1615	2358	1310
18	2913	1617	2915	1618	2911	1616	2652	1465
19	2914	1617	2916	1618	2912	1616	2840	1568
20	2915	1618	2917	1619	2913	1617	2910	1606
21	2916	1618	2918	1619	2914	1617	2911	1606
22	2917	1619	2919	1620	2915	1618	2912	1605
23	2918	1619	2920	1620	2916	1618	2913	1605
24	2919	1620	2921	1621	2917	1619	2914	1605
25	2920	1620	2922	1621	2918	1619	2915	1604
26	2921	1621	2923	1622	2919	1620	2916	1604
27	2922	1621	2924	1622	2920	1620	2917	1605
28	2923	1622	2925	1622	2921	1621	2918	1605
29	2924	1622	2926	1623	2922	1621	2919	1606
30	2925	1622	2927	1623	2923	1622	2920	1606

VI. RESULTS AND DISCUSSION

The results of the downhole seismic test to determine the Primary and shear wave velocities distribution pattern with depth is shown in table 1 and 2. The primary and shear waves velocities registered a general increase of seismic wave velocity with depth. The range of seismic velocities within the site is between 376 m/s to 2927 m/s for primary wave and 247 m/s to 1623 m/s for shear wave.

The results of the average shear wave velocity of the top 30 m (Vs30) distribution are shown in table 3, figure 2 and 3. The figures depict regions of low Vs30 and regions of high Vs30 distribution. Borehole 4 is located in the region with the least Vs30, while borehole 6 is located in the region with the highest Vs30, and the general picture of the investigated site showed that, region with high Vs30 is sandwiched by region with low Vs30. To effectively evaluate the effect of damaging earthquake on the site under investigation the overburden thickness within the site were determined. The range of primary wave velocities of between 376 m/s to 1099 m/s and 247 m/s to 642 m/s for shear waves indicate the occurrence of overburden (loose ground) cover, within the site under investigation, as shown in table 3.The determined thickness of the overburden cover is shown in figure 4 and 5. The thickness of the overburden showed a striking correlation with the average shear wave velocity of the top 30 m (Vs30). It is evident that apart from very few selected point, the region with high overburden thickness like borehole 4 has very low average shear wave velocity of the top 30 m (Vs30), while regions with very thin overburden cover like borehole 6 has high average shear wave velocity of the top 30 m (Vs30).

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It is apparent that structures placed within the region with low average shear wave velocity of the top 30 m (Vs30) and large thick overburden will be more affected by damaging earthquake than region with high average shear wave velocity of the top 30 m (Vs30) and small overburden thickness. Therefore, it gave an indication that regions with low average shear wave velocity of the top 30 m (Vs30) will see more amplification of the low frequency seismic waves from a damaging earthquake. To ascertain this further, the site coefficients at short and 1 second period was determined as shown in table 4. The values of the site coefficients at short and 1 second period were plotted against the boreholes number as shown in figure 6. It was very evident that the amplification factor is highest at the region with the least average shear wave velocity of the top 30 m (Vs30) and thick overburden cover where borehole 4 is located, and least within the region where borehole 6 is located.

Hence region with low average shear wave velocity of the top 30 m (Vs30) and large overburden thickness will require some level of engineering remediation to increase its load bearing capacity and reduce the amplification of low frequency wave in the event of ground shaking due to seismic waves.

Table 3: Coordinate points and the determine Vs30 and Overburden Thickness at each borehole

Borehole Point	Easting (Degree)	Northing (Degree)	Vs30 (m/s)	Overburden Thickness (m)
BH1	5.593414	5.902992	830	9
BH2	5.593528	5.902294	772	10
BH3	5.593553	5.902186	976	6
BH4	5.592997	5.902894	634	11
BH5	5.593178	5.902603	759	8
BH6	5.592750	5.902272	1151	4
BH7	5.592411	5.902761	924	8
BH8	5.592533	5.902228	763	12

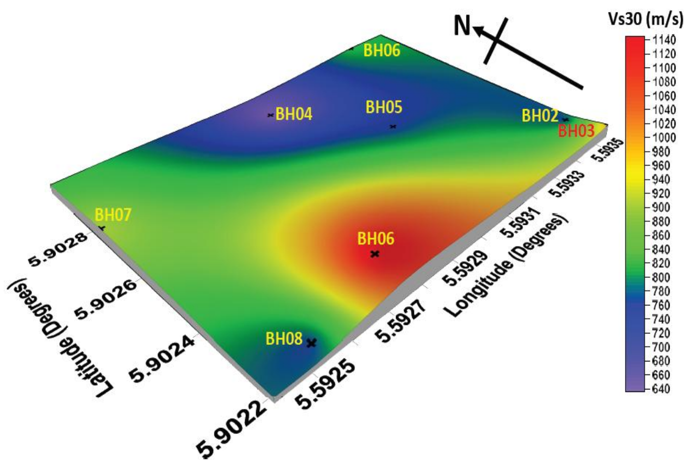

Figure 2: Site distribution of Vs30 within the survey area

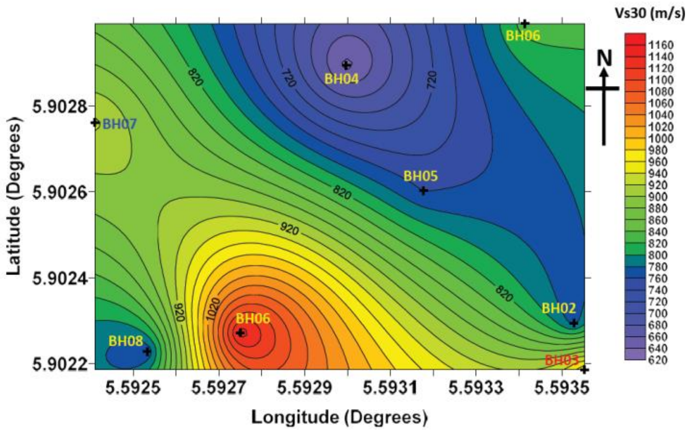

Figure 3: Equivalent contour map of site distribution of Vs30 within the survey area

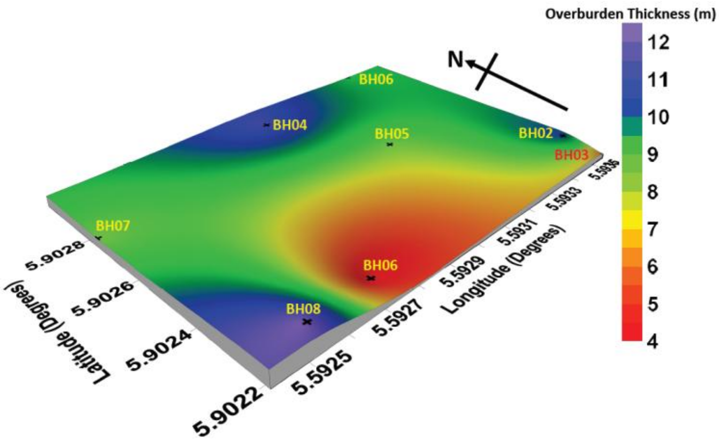

Figure 4: Site distribution of overburden within the survey area

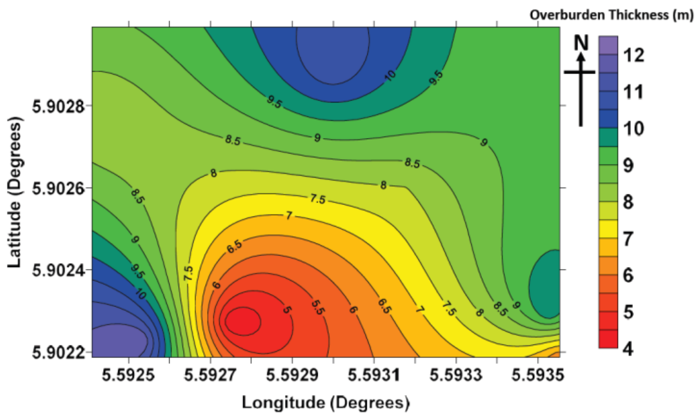

Figure 5: Equivalent contour map of site distribution of overburden within the survey area

Table 4: Fv and Fa Site Coefficient at short and 1 second period

Boreholes	Easting (Degree)	Northing (Degree)	Fa Site Coefficient at short period	Fv Site Coefficient at 1 second
BH1	5.593414	5.902992	1.1	1.2
BH2	5.593528	5.902294	1.2	1.3
BH3	5.593553	5.902186	1	1.1
BH4	5.592997	5.902894	1.3	1.5
BH5	5.593178	5.902603	1.2	1.3
BH6	5.592750	5.902272	0.9	1
BH7	5.592411	5.902761	1.1	1.1
BH8	5.592533	5.902228	1.2	1.3

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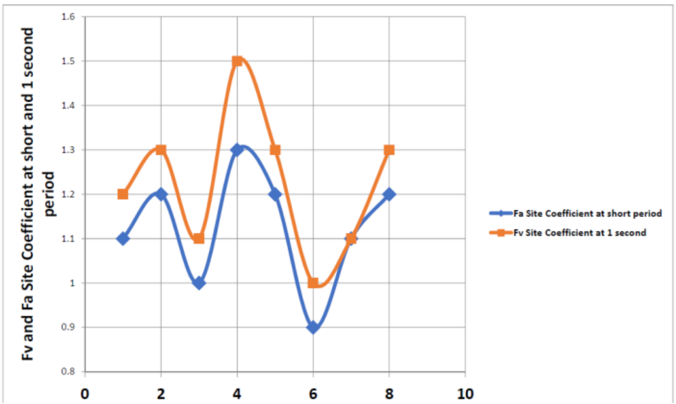

Figure 6: Plot of Fv and Fa Site Coefficient at short and 1 second period versus Borehole numbers

VII. CONCLUSION

The research work has brought to the fore that the distribution of the average shear wave velocity of the top 30 m (Vs30) is not always even within a given site; rather we can have regions of low Vs30 and regions of high Vs30. It has also shown to a large extent that the overburden thickness correlate very well with the average shear wave velocity of the top 30 m (Vs30). The study has also revealed that in the event of a damaging earthquake, structures erected within the regions of low Vs30 characterize with thick overburden, will experience more amplification of the low frequency seismic waves that could eventually damage the structures, except if some level of engineering remediation is applied to increase the resistance to shaking and improve its load bearing capacity of the soil.

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