International Conference on Case Histories in Geotechnical Engineering

(2013) - Seventh International Conference on Case Histories in Geotechnical Engineering

02 May 2013, 2:00 pm - 3:30 pm

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Recommended Citation

George, E. A. J.; Atuboyedia, T. J.; Oju, M.; and George, T. E., "Punch-Through Foundation Failure of Oil Drilling Platform in the Deltaic Plain of the Niger River" (2013). *International Conference on Case Histories in Geotechnical Engineering*. 24.
https://scholarsmine.mst.edu/icchge/7icchge/session02/24

PUNCH-THROUGH FOUNDATION FAILURE OF OIL DRILLING PLATFORM IN THE DELTAIC PLAIN OF THE NIGER RIVER

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ABSTRACT

The deltaic plains of the Niger River are composed mostly of Pleistocene sediments. On the occurrence of low stands of the sea level due to eustatic changes, the sediments were exposed to temperature fluctuations during the Quaternary period, leading to strata sequence generated in these plains that allowed strong layers of soil to overlie weaker layers of the same age. Most of the onshore explorations for oil and gas in Nigeria take place within these plains of the Niger.

A well was to be drilled in search of oil and gas in allocation within these plains. As often done, a reinforced concrete slab was constructed for the drilling platform to support the drilling rig and the ancillary tools. The drilling operation commenced with the installation of a conductor casing 750mm diameter and 105m long. The drilling proceeded without any adverse event until a depth of 1000m was attained. At this depth the drilling bit got stuck in the hole and all attempts to retrieve the bit and the drilling string failed. The frantic lifting attempts inadvertently made the cellar slab to provide the reaction system for the applied uplift loads. A severe damage was caused to the cellar slab. Further attempts eventually caused the collapse of the drilling platform.
This paper presents the records and events that led to the collapse of the drilling platform, the findings of the post-failure investigation and the proffered solution for the reconstruction of the platform.

INTRODUCTION

The oil industry in Nigeria is mostly concentrated within the precincts of the Niger \delta. Consequently, the majority of the oil and gas explorations take place within the delta. The deltaic sediments belong mostly to the Pleistocene period. The fluctuations in the global sea level and temperature during the Quaternary era also had effect on the geotechnical properties of the sediments in this delta. Variations in the strength of the soil layers deposited in the same period are common.

An oil and gas exploration was planned to take place in an area within the plains of the Niger River. Preparations required for the exploration were made including the construction of a platform with plan dimensions of 13.0 x 30.9m. The platform was demarcated into cellar slab, cellar pit and hardstand areas. The cellar slab was to carry the drilling rig and was supported on tubular steel piles driven to depths of 21.0m.

The drilling of the well commenced with the opening of a hole by drilling to a depth of 105m and a conductor pipe of 750mm diameter was grouted into the hole. The drilling process went on smoothly using drilling mud to retain the walls of the hole to a depth of 1000m when the drilling tools got stuck. The frantic efforts made to retrieve the tools unintentionally caused the overloading of the platform. The supporting piles under the cellar slab were subjected to excess loads. The piles plunged into a weak zone just under the pile tips within the dense sand stratum. The platform eventually collapsed after going through a complicated sequence of events. A post-failure investigation was initiated to determine the causes of the failure and proffer solution for the reconstruction of the collapsed platform.

AREA GEOLOGY

The Niger River has been building the Delta since the Cretaceous period, millions of years ago. A large part of the sedimentary deposits are very recent in age, having been laid during the Pleistocene and Holocene periods. The total depth of deposits in the delta is thought to exceed 10,000m (Buckle, 1978). The enormous accumulation has been possible because the crust has been isostatically depressed by the great weight of the sediment.

The present day Niger Delta is flanked on either side by higher lying coastal plain which formed the ancient coast line and consist predominantly of Pleistocene sediments. On the occurrence of low stands of the sea level, the Niger Delta system eroded a large part of the coastal plain allowing the formation of coastal plain terrace on either side of the present delta.

The fall of the sea level relative to the land also allowed the rivers to cut down into the valley and the increased erosion made it possible for the rivers to carve new channels on the exposed land surface. At the rise of sea level, relative to the land in a period of marine transgression, some of these channels became submarine and reburied under further deposition of sediments.

The Niger Delta bears the scars of the climatic instability during the Quaternary period. During this period there were marked fluctuations in global sea level and temperature which resulted in buried channels below modern rivers and river terrace sequences along valleys. These features are salient in the Niger Delta and often have influence on engineering projects in the area. The map of the present day Niger Delta showing the various geological units is shown in Fig. 1.

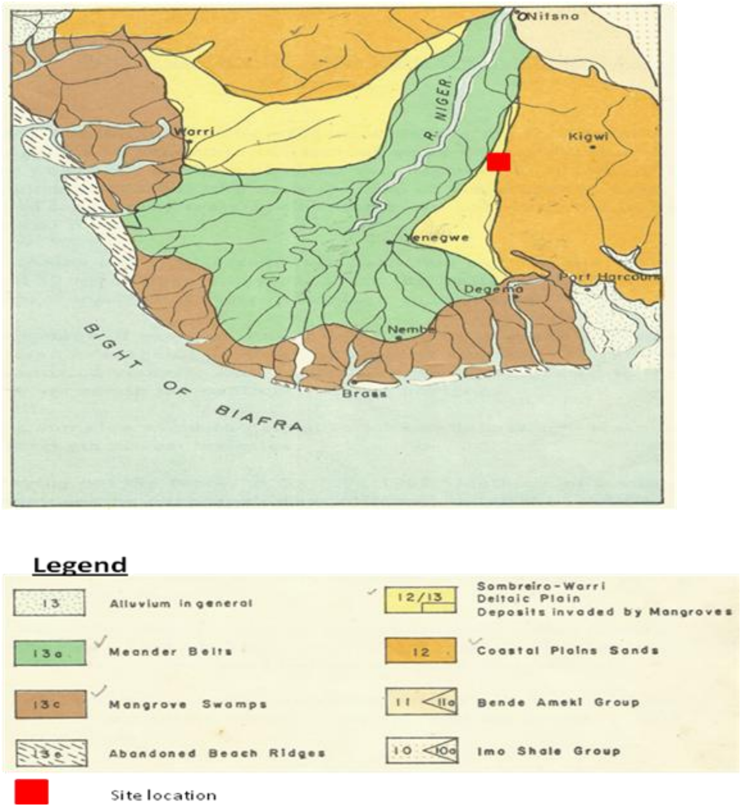


Fig. 1: Map of the Niger Delta showing the various geological units.

THE PLATFORM

It is a common practice in onshore exploration to provide reinforced concrete slab as a platform to support the drilling rig and the ancillary tools. The drilling rig is the heaviest equipment to be deployed on the platform and is placed within the section of the platform designated as cellar slab. The rig is supported on two skids. The plan dimensions of the various sections of the platform are shown below and also at Fig 2.

Platform slab = 13.0 x 30.9m
Cellar slab = 13.0 x 25.0m
Cellar pit area = 3.5 x 9.3m
Hardstand area = 13.0 x 5.0m
Skid = 2.6 x 20.0m
Rig Load = 13,000 kN

The platform was constructed with concrete vibrated to achieve a dense state and reinforced with 12mm high tensile steel. The reinforcement was spaced at 150 mm intervals in both directions. The cellar slab was supported on ground beams arranged in a grid over the foundation piles and interlocked with the pile caps.

Forty four tubular steel piles of 250mm diameter and 21.0 long were installed beneath the cellar slab with 22 piles under each skid. Fig. 2 shows the configuration of the cellar slab and the pile layout, and Fig. 3 shows the pile section.

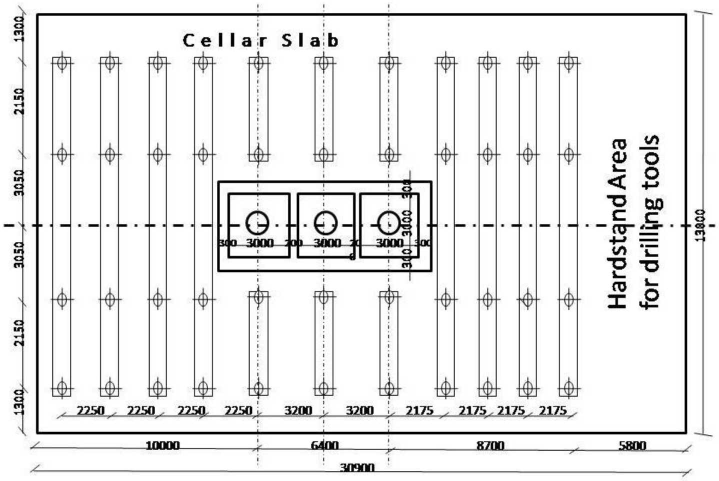


Fig. 2: Drilling Platform showing the cellar slab, hardstand area and piling layout

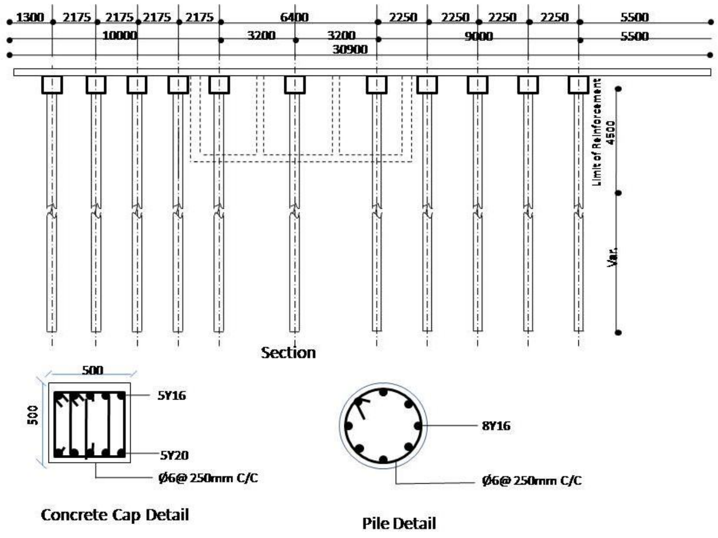


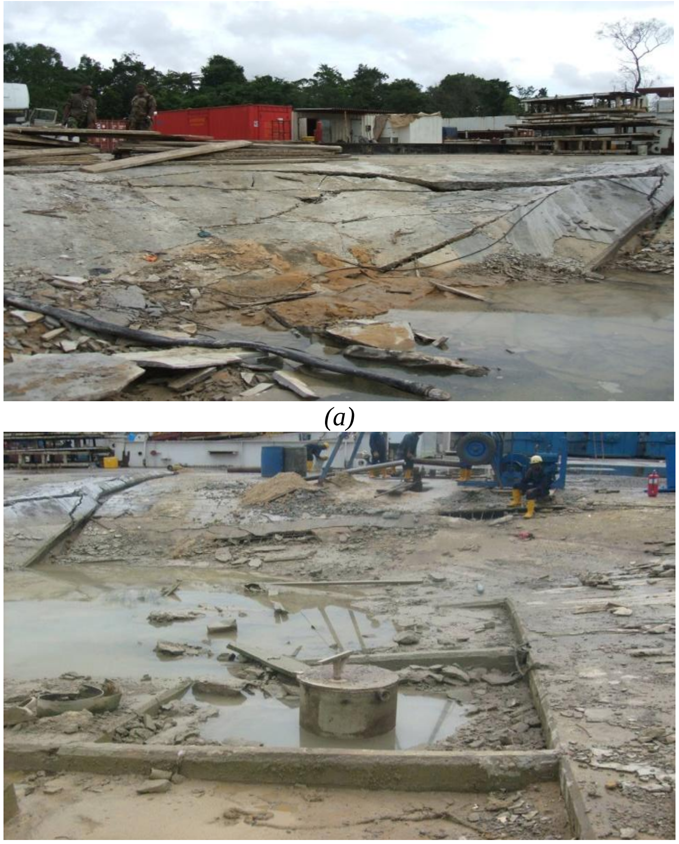
Fig. 3: Drilling Platform showing the cellar slab, hardstand area and piling layout

COLLAPSE OF THE DRILLING PLATFORM

The record of events leading to the collapse of the drilling platform which was made available during the post-failure investigation was not sufficiently detailed. However, collated historical background of events follows.

After the preparation of the site and the drilling platform in place, the drilling rig was up. It took few days to carry out minor modification work on the cellar pits before drilling commenced. The conductor casing, 750mm diameter was successfully installed to a depth of 107m without any section of the platform showing any distress. A drilling bit was run into the hole to drill deeper into the formation using drilling mud to retain the sides of the whole.

The drilling of the well continued without any noticeable event until the hole had achieved a depth of 1000m. At this depth the drilling string with the attached bit got stuck and all attempts to turn the bit and lift the string failed. The frantic lifting attempts, inadvertently, made the cellar slab to provide the reaction system for the applied uplift loads. The efforts to retrieve the drilling tools went on for two days without success before a depression of 150mm was noticed around the cellar pit. As the efforts to retrieve the tools continued, the depression became bigger and bigger. Large cracks developed in concrete at many sections of the platform with some of the broken concrete sliding towards the cellar pit area. The efforts were stopped and the rig lowered to avoid accidents. At the time of the post-failure investigation, the depression had achieved a depth of about 1.5m and filled with rain water around the cellar area.



(a)

(b)

Fig. 4. Collapsed slab and cellar pit.

PRE-DRILLING GEOTECHNICAL INVESTIGATION

The report from the pre-drilling geotechnical investigation presented generalized strata of a layer of soft silty clay 5.0m thick, underlain by fine to coarse sand stratum which extended to the end of the boring at 30.0m. Standard penetration tests taken in the sand layers gave N values which ranged between 20 and 52. Light cable percussion boring was used for the investigation and it appeared that the strands, seams and thin bands of sand and clay were not captured.

Four cone penetration tests were conducted at the site using light weight cone penetrometer and according to the report all the four cone soundings terminated at 7.0m. The report recommended the use of piles for the foundation suggested that the piles be driven to depths of 15.0m, but was not explicit on the type, size and safe working load of the piles. However, the platform was constructed with 44 tubular steel piles, 250mm diameter and 21.0m long underneath the cellar slab section. No pile loading test was carried out to confirm the load carrying capacity of the piles (fig.3)

POST-FAILURE INVESTIGATION

The failure of the drilling platform was not anticipated and causes of the failure were not obvious. Post-failure investigation was needed to ascertain the causes of the collapse of the platform and recommend appropriate procedure for the reconstruction of the platform. The investigation began with a visit to the site to see the extent of the damage and make a decision on the procedures to adopt for the investigation. The following approaches were considered.

1. Post failure geotechnical investigation to characterize the site adequately.
2. Plate bearing testing on the slab in the areas that suffered no distress.
3. Taking cores from the slab to assess the strength of the concrete.
4. Retrieving the piles to evaluate their post-failure conditions.

Post-failure geotechnical investigation

Three borings with soil sampling and three cone penetration tests were carried out at the site. Two borings and two cone penetration tests were located around the collapse cellar slab. Reference boring and cone penetration test were located at a distance of about 13m from the platform. These reference tests were needed to determine the original soil conditions that prevailed at the site prior to the project. Fig. 5 shows the plan of the cellar slab and the locations of the boreholes and the cone penetration tests carried out during the post-failure investigation.

The borings were carried out using percussion drilling method which allowed disturbed samples to be collected every 0.75m intervals. Cohesive soils were retrieved with 75mm diameter thin-walled Shelby soil sampler. Standard penetration tests were performed in the borehole when cohesionless soils were encountered. The test was conducted essentially in accordance with the procedure described in BS1377; Part 9; in 1990 edition with minor variation. The blow counts for the test drive were not limited to 50, the full blow counts for the test drive were recorded. This allowed a comparison to be made the N values from the standard penetration test and those derived from the cone penetration tests.

The cone penetration tests were performed using the piezocone. The profiles from the tests provided continuous information on the thickness of each layer of the soil. The profiles of the measured and derived soil parameters were also obtained. Correlation in the information from the borings, laboratory test results and cone penetration tests allowed the soil profile in each test location to be defined. The soil profiles around the cellar slab area and at the reference location are shown in figs 6 and 7. The soil profiles from the various test locations were relatively similar. A layer of predominantly medium dense sand fill about 2.5m thick covered the whole site. The sand fill was placed on stiff alluvial clay about 3.0m thick. In turn the clay was underlain by prevalent stratum of sand which extended to the end of the boreholes at 30m. In essence, the sand underneath the site was indeed dense with the SPT, N values exceeding 60 around the cellar slab area and 70 at the reference location.

However, some relatively weak zones within the dense sand were noticed. It also appeared that this was typical of the site. The most outstanding was that between depths of 21.4 and 23.4m. The following table gives the details of the layer.

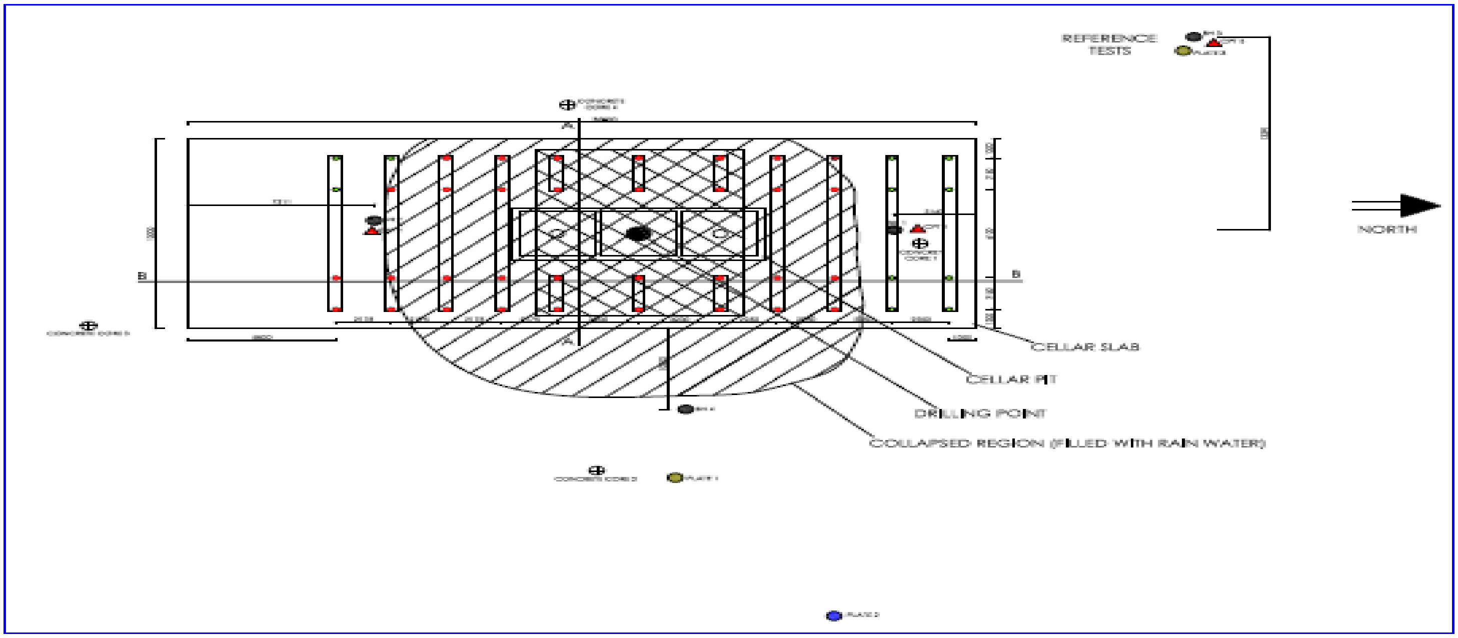


Fig. 5. Site plan showing test points

Table 1. Weak zones within the dense sand

Location	Test Point	Depth (m)		SPT N, blows/0.3m	CPTU, q_c (MPa)
		From	To		
Cellar Slab Area	BH 1 CPTu 1	21.4	23.0	20	6-9
	BH2 CPTu 2	21.7	23.1	20	6-10
Reference Location	BH3 CPTu 3	21.9	23.4	25	5-11

Table 2. strength parameters at the tip of the pile

Location	Test Point	Depth (m)	SPT N, blows/0.3m	CPTU, q_c (MPa)
Cellar Slab Area	BH 1 CPTu1	21.0	53	28
	BH2 CPTu2	21.0	63	34
Reference Location	BH3 CPTu3	21.0	82	47

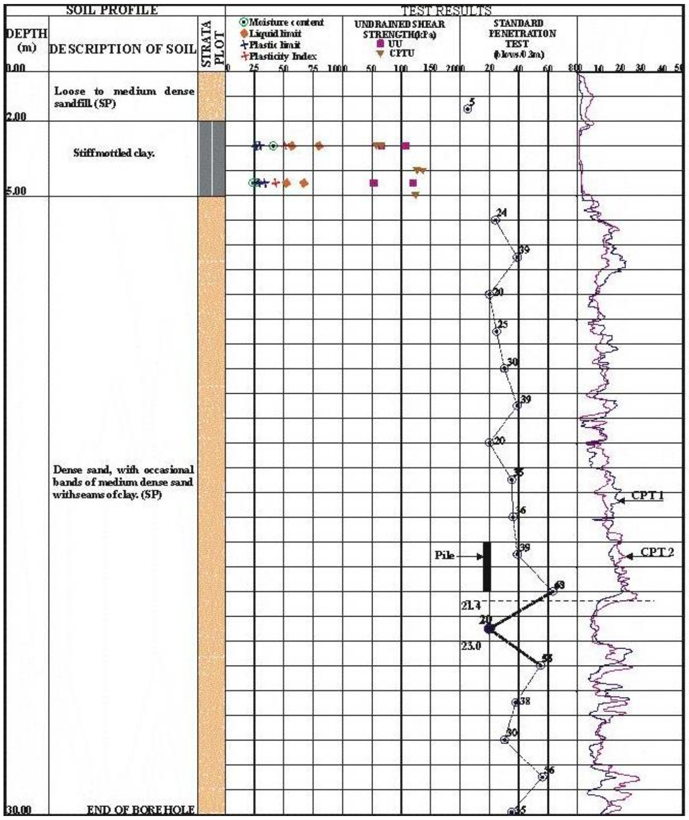


Fig. 6 Soil profile around the cellar slab.

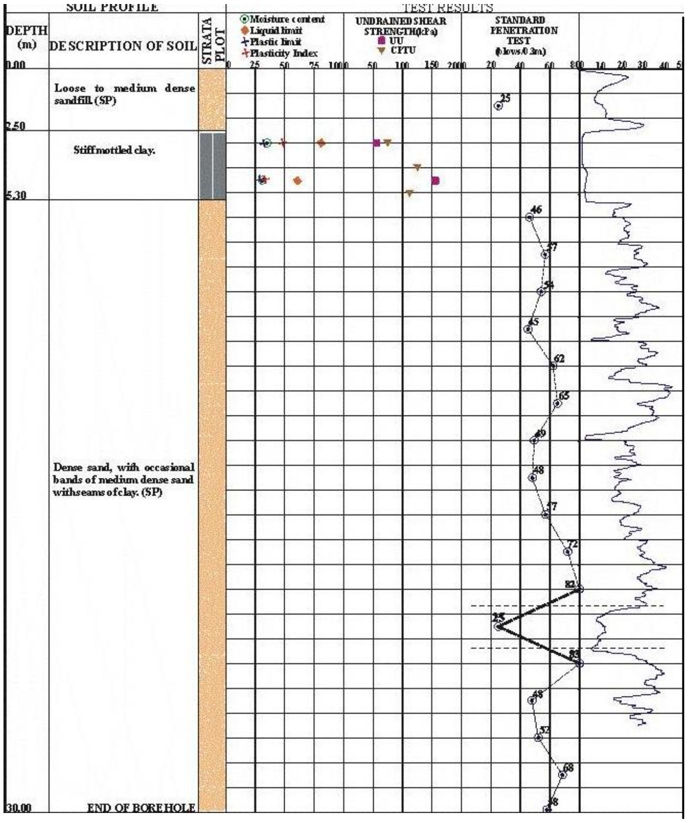


Fig. 7. Soil profile around reference location.

Laboratory Tetsing

Laboratory testing was carried out to determine the index and engineering properties of the soils. The undrained shear strength of the clay was obtained from the laboratory tests and cone penetration tests. To determine the undrained shear strength from the cone data, the relationship shown below was used.

$$q_c = S_u N_k + p_o \qquad (1)$$

Where q_c = cone resistance
S_u = undrained shear strength
N_k = cone factor (taken as 15)
p_o = total vertical stress

Plate Loading Test

Cyclic plate loading tests were conducted on the sandfill and the hardstand using 450 mm circular steel plate. The main objective of the tests was to determine the deformation characteristics of the materials. The plate was loaded to one and half times the applied pressure of 250kPa. The results of the tests are presented in Table 3

Table 3. Results from Plate load test

Area	Test Point	Cycle No.	Applied Pressure (kPa)	Residual Settlement(mm)	Elastic Settlement (mm)	Total Settlement (mm)
Sandfill	PL1	1	62.5	0.072	0.740	0.813
		2	125.0	0.167	1.875	2.042
		3	187.5	0.185	2.725	2.910
		4	250.0	0.325	3.350	3.675
		5	312.5	0.075	4.150	4.225
		6	375.0	0.250	4.975	5.225
Hardstand	PL2	1	62.5	0.369	0.256	0.625
		2	125.0	0.206	0.575	0.781
		3	187.5	0.125	0.875	1.000
		4	250.0	0.188	1.313	1.500
		5	312.5	0.162	1.725	1.887
		6	375.0	0.113	2.225	2.338
Sandfill	PL3	1	62.5	0.100	0.375	0.475
		2	125.0	0.200	1000	1.200
		3	187.5	0.044	1.594	1.638
		4	250.0	0.062	2.004	2.106
		5	312.5	0.113	2.638	2.750
		6	375.0	0.094	4.275	4.369

Concrete Core Testing

Cylindrical concrete cores 100mm diameter were cut out from various sections of the concrete structures using rotary cutting tool. The cores were tested for their compressive strengths which were found to be relatively low. However, the rebound hammer tests conducted on the cores using the Schmidt hammer showed high compressive strengths for the cores. The results of the tests are shown in Table 4.

Table 4. Concrete strength test results.

Reference Point	Section	L/d	Crushing Test (N/mm^2)	Schmidt Hammer Test (N/mm^2)
Core 1	Cellar Slab	1.51	10.1	19
Core 2	Ground Beam	1.95	10.3	22
Core 3	Hardstand	1.53	10.1	24
Core 4	Hard Slab	1.42	10.6	23

Fig. 8. Picture Showing sample after coring

PLATFORM FOUNDATION

The loading arrangement on the drilling platform allowed the concentration of the heavily loaded equipment on the cellar slab section of the platform. Consequently, the cellar slab section was supported on piles. The piles were under the two skids that carried the drilling rig.

The first investigation did not give the pile capacity of the piles, therefore referential design of the piles became necessary. Analysis was carried out to estimate the load carrying capacity of a single tubular steel pile 250mm diameter and 21.0m long using the soil parameters from the reference boring and core sounding.

The axial pile capacity of the pile was computed using two methods; the American Petroleum Institute (API) method which was data from standard penetration tests (SPT) and the LCPC (Laboratoire Central des Ponts et Chaussées) method which uses the cone resistance values from the cone penetration tests. The API recommended practice RP-2A WSD of 1993 and the LCPC method proposed by Bustamante and Gianeselli (1982) were followed in the computations. The calculated axial pile capacity for a single pile from the API method was about 1800kN and that from LCPC method was about 2200 kN. However, the applied loads on the cellar slab required an axial pile capacity of 1750 kN from each of the piles.

DRILLING METHOD

The drilling of the oil commenced with the installation of a conductor casing, 750 mm diameter to a depth of 105m. A drilling bit was run into the hole to drill deeper into the formation using drilling mud alone to retain the sides of the hole. However, the geology of the project areas revealed that the thickness of the unconsolidated and highly permeable is large. Because of the inherent instability of the formation due to high formation pressure and the enormous depth of the well, drilling fluid alone occasionally fail to support the walls of the hole effectively.

It is a common practice in this project area to commence the drilling of oil well by opening a hole by driving to a depth of about 100m or more and then insert a conductor pipe which is grouted into the hole and. A drilling bit is then run into the hole to drill deeper into the formation. More pipes of smaller diameters are grouted into place as the drilling process continues until the target depth in the hydrocarbon reservoir is reached. This method of well drilling is found to be safe and effective.

POSSIBLE CAUSES OF THE COLLAPSE

The following possible causes of the collapse of the platform were examined.

1. Settlement of the sandfill.
2. Poor quality of concrete.
3. Structural failure of the piles.
4. Overloading of the drilling platform

Settlement of the sandfill

The thickness of the sandfill was about 2.0m and it covered the whole site. Although few portions in the sandfill were relatively loose, the fill was mostly medium dense calculations carried out to estimate the settlement of the fill gave a value of about 15mm under the applied pressure of 250kPa. Plate bearing tests were also carried out on the sandfill, with the test pressure raised to one and half times the applied pressure. The maximum settlement recorded was 5.0mm. It could be said that any settlement in the sandfill will be minimal and cannot cause the collapse of the platform.

Poor quality concrete

Concrete cores were cut out from various sections of the platform and tested for compressive strength. Rebound hammer tests were also carried out on the cores. The compressive strengths of the cores were comparatively low when subjected to the crushing test. However, the strengths from the rebound hammer tests were high. It is envisaged that the reduction in compressive strength could be due to the effects of the collapse. There was no evidence to show that the collapse of the platform emanated from the concrete.

Structural failure of piles

The tubular steel piles used for the foundation were installed by driving to the required depth of 21.0m. Damage to some of the piles during driving could be possible and that would reduce the load capacity of the affected piles. Five of the working piles were extracted from the ground randomly under the cellar slab for examination. All the piles were reasonably straight and there was no indication that the piles had suffered some damage.

Fig. 9. Picture showing extraction of pile.

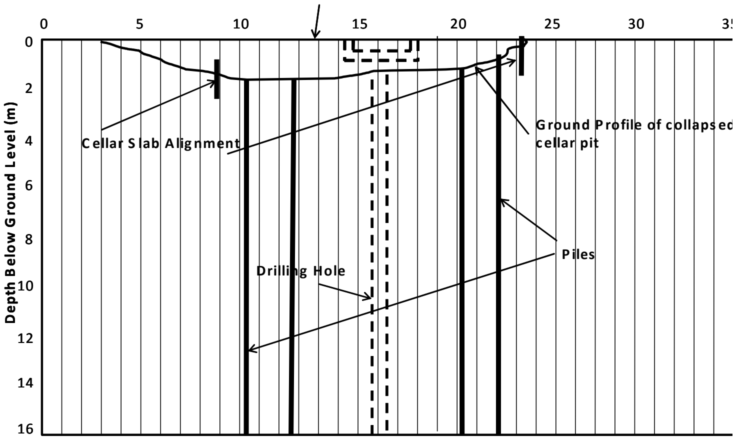
Overloading of the platform

It was understood that the drilling of the well went on without any noticeable event to a depth of 1000m when the drilling bit got stuck. During this time, the platform performed satisfactorily and showed no signs of distress.

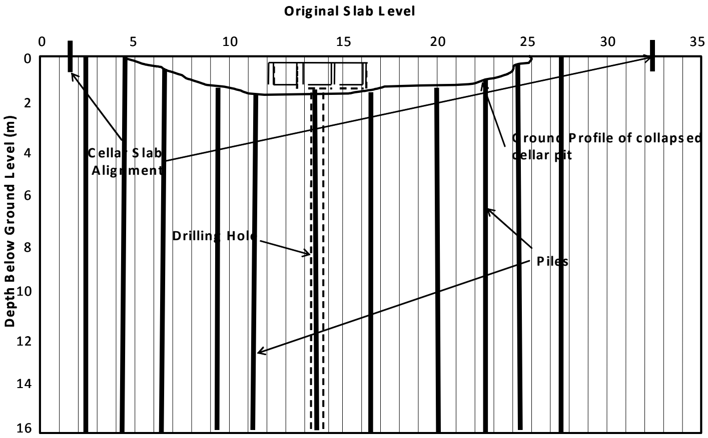
The two methods used in estimating the load carrying capacity of the piles gave values that were greater than the required ultimate load per pile of about 1750kN. It was considered that the piles could support the applied loads without sinking as they did if the cellar slab was not subjected to excess loads.

All evidence pointed to the fact that the collapse of the platform and all the support structures began when the drilling bit got stuck in the hole. Since this happened suddenly, frantic attempts were made to retrieve the bit and the drilling string. The attempts achieved no success. However, the attempts continued. Unintentionally, the platform began to provide the reaction needed for the uplift loads to turn and lift the drilling tools in the hole. Consequently, the cellar slab became highly overloaded. This caused the relatively small diameter piles supporting the cellar slab to be subjected to excess loading. The soil profile obtained from the second investigation revealed that a weak soil zone existed just beneath the tips of the piles around the cellar pit. The piles began to move into weak zone. The initial downward movement was 150mm. This served as a warning and the rig was lowered and removed from the platform. Nevertheless, efforts to retrieve the drilling string and bit persisted. The higher applied loads caused the piles to punch through the top dense sand into the weak layer just beneath the pile tips. The downward movement of the piles and the slab produced a depression of about 1.8m in depth around the cellar pit area and also imposed high lateral loads on the remaining piles and other connected structures causing a large portion of the platform to yield and collapse.

Fig. 10 Picture showing collapse area.



(a)



(b)

Fig. 11. Sections showing depression at cellar pit Area

DISCUSSION AND CONCLUSIONS

A case history of the collapse of an oil drilling platform in the deltaic plains of the Niger River is presented in this paper. The post-failure investigation traced the main cause of the collapse to the plunging of the piles under the cellar slab into a weak zone of the soil column just beneath the tips of the piles. The plunging of the piles was caused by the overloading of the drilling platform and the overloading originated from the uncontrolled attempts to free the drilling string and bit that got stuck in the hole.

The failure was unexpected. However, there were lapses in the execution of the project which led to this complicated sequence of events. The original geotechnical investigation was far from adequate. The cone penetration tests were terminated at significantly shallow depth of 7.0m due to small size of the equipment used. The borings alone could not produce reliable soil profile because of the drilling method used. The common features of the sediments in the region where several relatively thin weak zones exist within strong soils were not given any consideration.

The method adopted for the drilling of the well by using drilling mud throughout was not compatible with the type of formation in the region. Excessively thick layers of unconsolidated and highly permeable formation overlie the rocks that contain the hydrocarbons. Drilling a well entirely with drilling mud to hold the walls of the hole in this geological region is precarious.

A method in which after the grouting of the conductor pipe into the hole, smaller diameter pipes are grouted into place and the process continues until the target depth is reached is considered optimal.

It was suggested that the site be abandoned and another area about 100m from the distressed area be considered for the drilling. This was rejected. It was insisted that the well was to be drilled within the original area. The following recommendations were made.

1. The collapsed platform should be lifted and the site cleaned.
2. All the piles in the ground should be extracted.
3. Another geotechnical investigation should be conducted using few borings and more cone penetration tests.
4. Heavier cone penetrometer that can penetrate to depths in excess of 30.0m be used.
5. The new geotechnical investigation should characterize the site adequately for the new drilling program.

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