

Design of A Portable Hydraulic Water Borehole Drilling Rig

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ABSTRACT:

One of mankind's most important needs – water has been a very scarce commodity in Nigeria. Federal, State and Local Governments are not doing enough to provide portable water for the Nigerian populace hence borehole drilling has become a big business. Water boreholes are being drilled with manual methods using the tripod and seismic systems. These methods do not produce high quality potable water. Borehole drilling rigs that can produce appropriate quality of water are imported and are costly and borehole drillers can hardly afford them. It therefore became imperative for Nigerian Engineers to design and produce effective and cheaper water drilling rigs. Consequently, a hydraulic water drilling rig has been designed. The design satisfies the requirements of drill diameter and depth and has economic advantage over the imported rigs. The manufacture of the rig in Nigeria will also enhance the technological development of the country.

KEY WORDS: Design, Portable, Hydraulic, Water, Borehole, Drilling, Rig.

1.0 INTRODUCTION

Water is one of the most important needs of mankind hence both National, State and Local Governments in every country work towards making potable water available for its population. In Nigeria, provision of water has become a serious political issue while pipes have remained dry in most cities. The consequences are that (Ikenyiri, 2009):

- (i) Households in neighborhoods operate their own water schemes;
- (ii) Those who cannot operate their own water schemes purchase water from street hawkers;
- (iii) Some people use water without adequate treatment; and,
- (iv) Water - borne diseases like typhoid fever and cholera which hitherto were only heard of, have become common diseases.

As a result of private water schemes' development, the demand for water borehole drilling has grown very high. In the Niger Delta region, oil pollution has rendered dangerous for consumption, river water, rain water and water from shallow aquifers (Ikenyiri, 2009). This necessitated that water drilling rigs must be rugged enough to withstand the different rock formations and depth requirements.

The ground water quality, depth of occurrence and methods of drilling are of great importance in borehole output or productivity (Todd, 1982). The high demand for borehole drilling has made some Nigerians to be drilling boreholes with manual methods using the tripod and seismic systems (Ikenyiri, 2009). These methods have the following advantages:

- i) Cheap and very easily affordable.
- ii) Light and very portable and can be transported with pick-up trucks or even wheel barrows ("trucks").

However, the disadvantages are very grave:

- i) They can only reach limited depths. While the seismic method can only drill to 60m, the tripod method can only drill to 70m.

- ii) Oil and other surface contamination can reach these depths, and so the water produced by these methods could be contaminated.
- iii) Water from these sources are difficult to purify and therefore not hygienic.

The drilling rigs that can drill holes of appropriate diameter and depth are imported and are very costly. Only government and oil companies can afford these rigs. It has therefore become necessary for the Nigerian Engineers to provide an answer to this important technological problem with a view to providing the necessary designs and consequently manufacture such drilling rigs within the country.

2.0 DESIGN OBJECTIVES

In order to satisfy the requirements of water quality, borehole depth and rock formations, the design objectives for the drilling rig were set as follows (Ikenyiri, 2009). The rig should be:

- i) Able to drill boreholes of up to 150mm diameter;
- ii) Able to drill boreholes to a depth of 500m;
- iii) Tough and reliable;
- iv) Simple and easy to maintain.
- v) Light enough to be mounted on a five ton 4×4 wheel truck for easy access to the various terrains of the Niger Delta and other regions of the country; and,
- vi) The rig should be cost effective when compared with the imported complex drilling rigs.

3.0 DESIGN OF THE DRILLING RIG

In accordance with the above stated objectives, the sub-systems that make up the drilling rig were selected as listed below:

- i) Carrier truck (4×4 wheel) with four (4) leveling jacks
- ii) Derrick structure with hydraulic ram for raising and lowering
- iii) Crown block assembly
- iv) Travelling block assembly
- v) Top drive assembly, and
- vi) Draw works

A schematic assembly drawing of the rig is shown in Fig.1 (Ikenyiri, 2009).

Other accessories that completed the design of the drilling rig include:

- i) Hydraulic power unit
- ii) Mud pump
- iii) Mud hose assembly
- iv) Hydraulic hoses, and
- v) The drilling stems

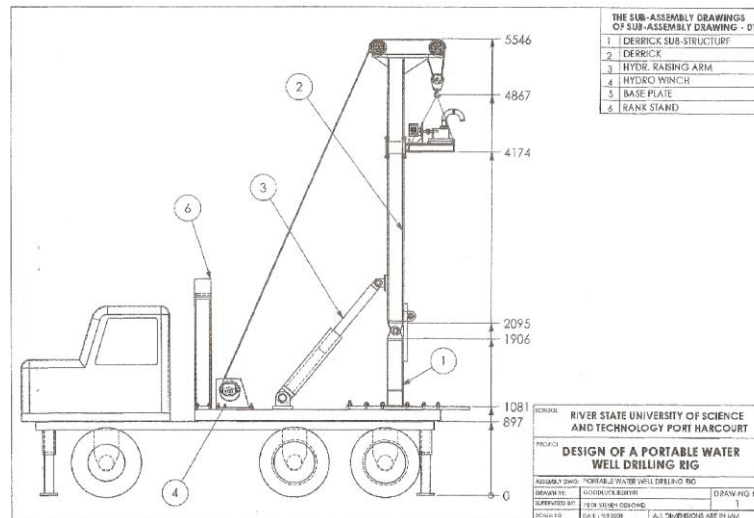


Fig. 1: Schematic Assembly Drawing of Drilling Rig

3.1 CARRIER TRUCK

The total weight to be carried by the carrier truck is made up of;

- (i) Weight of derrick = 2669kg
 - (ii) Weight of travelling block = 200kg
 - (iii) Total drill string weight = 1083kg
- Total weight of drilling rig assembly is 3952kg

A 5-ton - 4 wheel drive truck was therefore selected as the rig carrier. Since the truck is to be used on various rough terrains, it is to be equipped with four (4) leveling jacks.

3.2 DERRICK STRUCTURE WITH HYDRAULIC RAM

The main derrick structure was chosen to be a 200mm×200mm square steel tube [1]. This choice was made to suit the complete design. The hollow square section provides for easier attachment and operation of the travelling block, even though it is known that the hollow circular section has the advantage of having greater stiffness against twisting (McGinley, 1999). The design is also done such that no twisting moment or torque will be applied to the derrick structure.

Welded to the upper end of the derrick are brackets for the mounting of the crown block. The lower end of the hollow square derrick is blinded with a flat plate and a bracket with a pin hole is welded to the flat plate. This feature is for the attachment of the derrick to a substructure attached to the floor of the carrier truck. A hydraulic cylinder is attached between the floor of the carrier truck and near the lower end of the derrick (see Fig. 2).

The hydraulic cylinder is to be used to raise the derrick during operation

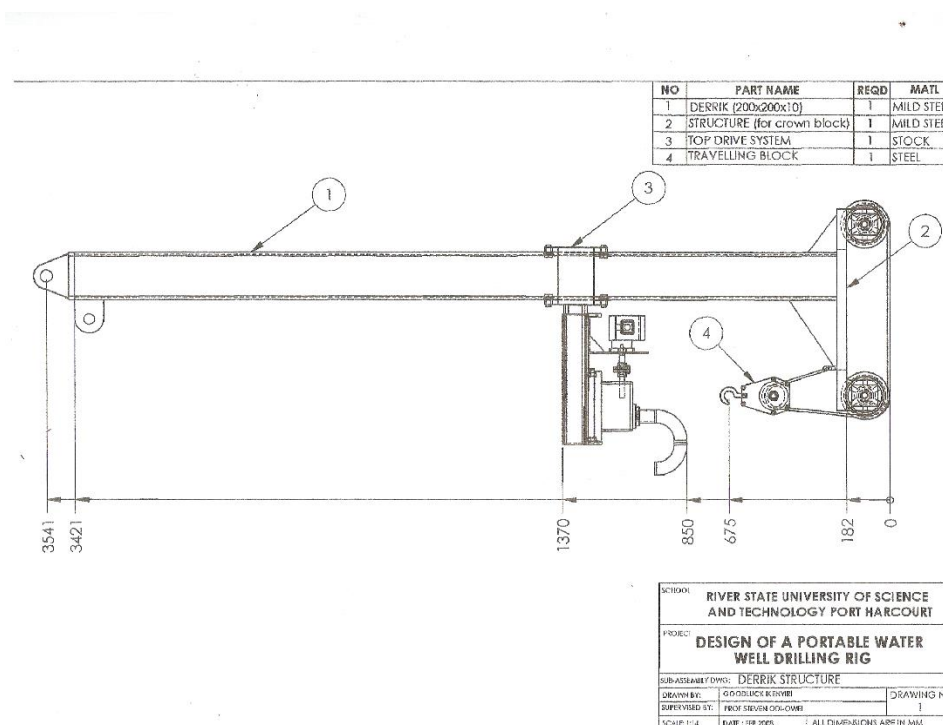


Fig.2: Derrick and Hydraulic Cylinder Assembly

and lower it when not in use, respectively. The total weight of the derrick and travelling block was calculated and a maximum possible weight was put at 500N. A “mill type CD 210” hydraulic cylinder was consequently selected from Mannesman Rexroth manual (Mannesman). The mill type CD 210 hydraulic cylinder has the following characteristics:

- i) Operating pressure - up to 20MPa (200bar)
- ii) Piston speed - up to 0.5m.s⁻¹
- iii) Piston diameter - 100mm
- iv) Rod diameter - 56mm
- v) Stroke - 2,400mm.

3.3 CROWN BLOCK ASSEMBLY

The crown block is made up of the components as shown in Fig. 3 and Table 1 below.

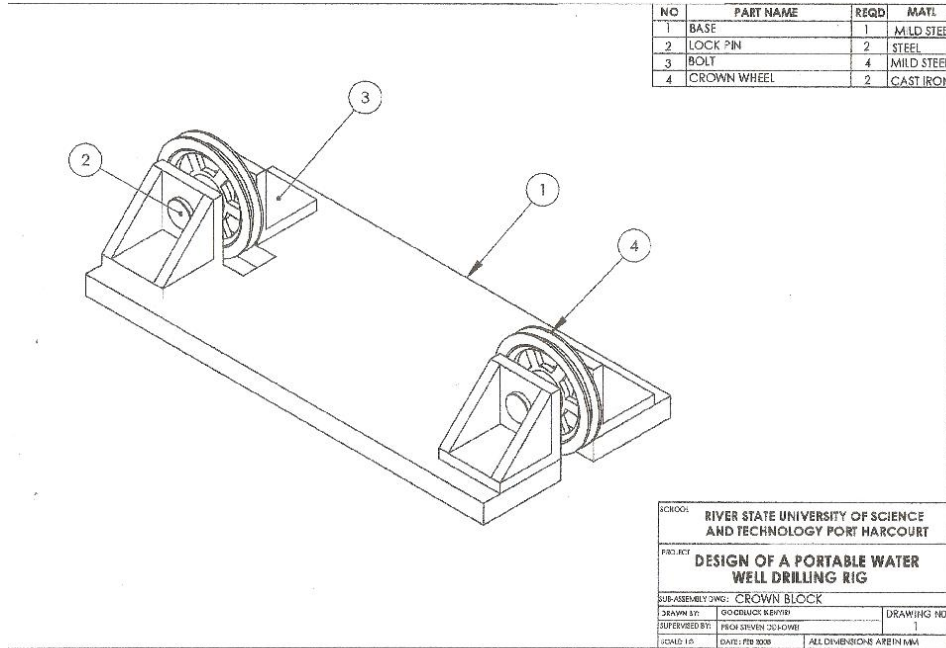


Fig. 3: Crown Block Assembly

TABLE 1: COMPONENTS OF THE CROWN BLOCK

S/No.	PART NAME	QTY	MATERIAL
1.	Base Plate	1	Mild Steel
2.	Lock Pin	2	Mild Steel
3.	Bolt	4	Mild Steel
4.	Crown Wheel	2	Cast Iron

The crown block assembly is mounted at the top of the derrick with brackets by welding the base plate on to the top end of the derrick and the brackets.

As shown in Table 1, the crown block consists of a base plate carrying two sheaves over which the drilling line (cable) from the draw works passes before it is reeved over the sheave in the travelling block and finally attached back to the base plate of the crown block through a shackle. The diameter of the two equal sheaves was calculated to be 952mm from the equation

$$D = 34d \tag{1}$$

Where D = diameter of the sheave and d = diameter of the cable = 28mm (see section 3.6.1). Consequently, the sheave diameters were chosen to be 960mm

3.4 TRAVELLING BLOCK ASSEMBLY

The travelling block hangs from the wire rope attached to the crown block through the two pulleys of the crown block and the winch of the draw works. It serves to carry the top drive system and the drill string during operation. A schematic assembly drawing of the traveling block assembly is shown on Fig. 4.

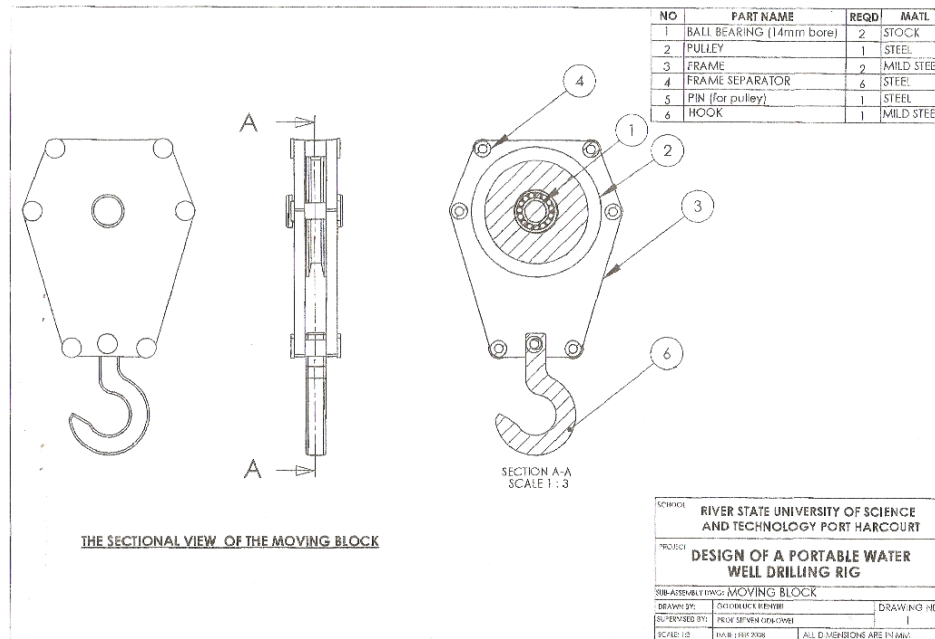


Fig. 4: Schematic Assembly Drawing of Travelling Block.

The traveling block was selected based on the drill string weight. In the design of the drill string, an API standard drill pipe of 60.3mm outside diameter, 50.7mm inside diameter, 4.8mm wall thickness was selected (Mannesman, 1993). The weight of the drill string was then calculated from the equation (Sedco Forex)

$$W_{dst} = N_L \times W_{nom} \quad (2)$$

where

$$N_L = \text{Total length of drill string} = 150m$$

$$W_{nom} = \text{Nominal weight} = 7.22kgm^{-1}$$

Therefore

$$W_{dst} = 150m \times 7.22kg/m = 1,083kg \times 9.81ms^{-2} = 10,264N$$

This weight was used to select the traveling block from the manual (), and the one having a weight of 200kg was chosen.

3.5 TOP DRIVE ASSEMBLY:

The top drive assembly carries the systems that drive the drill string and is therefore made up of the components shown in Table 2 below. Its main functional systems are a hydraulic motor which drives a swivel mechanism that in turn drives the drill string rigidly attached to it through screw threads. Also attached to the top drive assembly is a frame that guides the top drive system during operation. Fig. 5 shows the arrangement of the components of the top

drive system. The hydraulic motor was selected as the KADIBS TDS 1, which has the following characteristics (Ikenyiri, 2009):

- i) Motor speed = 2200 rev./min
- ii) Output speed = 220 rev./min
- iii) Drilling Torque = 2030Nm

TABLE 2: TOP DRIVE ASSEMBLY

S/No.	PART NAME	QUANTITY	MATERIAL
1	Slider Guide	2	Mild Steel
2	Rollers (14mm bore)	4	Mild Steel
3	Hex. Head Bolt(14mm)	4	Mild Steel
4	Motor and Frame	1	Mild Steel
5	Lifting eye	2	Mild Steel
6	Base Frame (channel)	2	Mild Steel
7	Base Frame (channel)	2	Mild Steel
8	Goose Neck	1	Mild Steel
9	Hollow Tube	2	Mild Steel
10	Flange Coupling	1	Mild Steel
11	Hex. Head Bolt & Nut	4	Mild Steel
12	Base Plate	1	Mild Steel
13	Guide (Thick plate)	1	Mild Steel

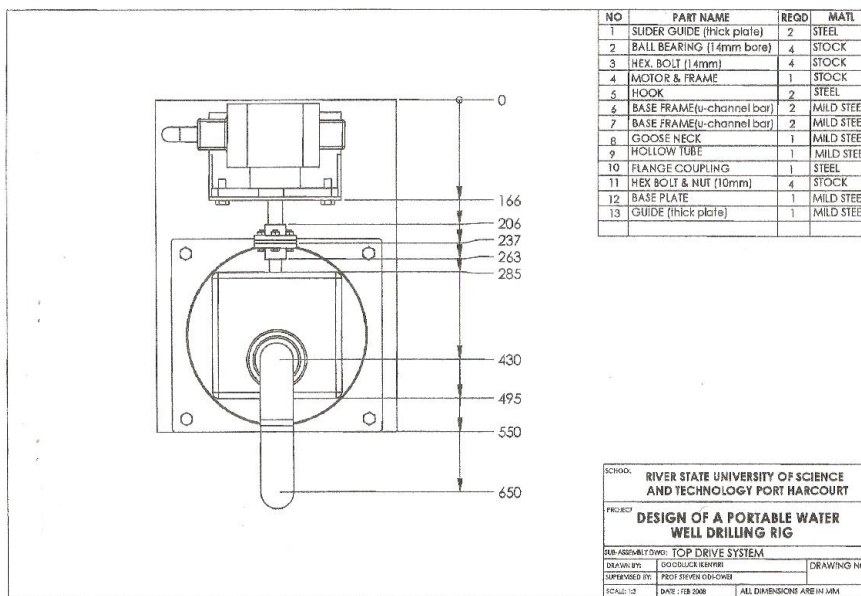


Fig. 5: Top Drive system Assembly (Plan View)

3.5 DRAW WORK

The draw works consist of a hydraulic winch and a cable which is wound around the drum at one end, and terminates at the crown block after passing over the two pulleys in the crown block and the pulley in the travelling block. (See Fig. 1) The draw work and the traveling block work together to raise or lower the drill string as necessary.

3.6.1 SELECTION OF WIRE ROPE

The wire rope that is wound round the drum of the hydraulic winch and terminates at the crown block carries the full weight of the top drive system, the traveling block and its own weight (Hamrock et al, 1999). It is a very critical component of the drilling rig as its failure will not only stop the operation of the rig but will also endanger the lives of the operators. Consequently, it was properly selected by the use of equations and tables outlined in reference (Hamrock et al, 1999).

In order to satisfy the operational conditions of the drilling rig, a 28mm, 6×19 standard hoisting wire rope was selected. The material selected was the mild plow steel which has

- i) Modulus of elasticity $E = 80.68GPa$ ($12 \times 10^6 psi$)
- ii) Strength (allowable stress) = $551.2MPa$ ($80Kpsi$)

A safety factor of 5 was used in the calculations (Hamrock et al, 1999).

4.0 ACCESSORIES

4.1 HYDRAULIC UNIT

The hydraulic unit is the main unit that supplies hydraulic fluid to all the systems at appropriate pressures. It consists of a reservoir tank, and a pump. The pump supplies hydraulic fluid to the hydraulic motor that drives the winding drum of the draw works, the hydraulic motor of the top drive system, the hydraulic cylinder that positions the derrick and the mud pump.

The pump which is a positive displacement pump, was selected to have the following characteristics [6]:

- (i) Type: A2FO, series 6
- (ii) Displacement: 10 to 250m³
- (iii) Maximum speed: 315 to 1450 rev./min
- (iv) Maximum Power: 218KW
- (v) High Pressure: 450bar

To drive the pump, a 250KW diesel engine was selected. A v – belt system was also selected to transmit torque from the engine to the pump.

4.2 MUD PUMP

The drilling mud requirement was determined to be 1.8m³/min. Consequently, a mission type centrifugal pump No. C200 was selected. The pump has the following characteristics

- (i) Size: 3x4R and C
- (ii) Drive: 25KWx285 bar hydraulic motor.

Hydraulic fluid is supplied to the pump by the main hydraulic unit.

5.0 ECONOMIC COMPARISON

The cost of producing the prototype of the hydraulic drilling rig as designed is Ten Million, Three Hundred and Twenty Four Thousand Naira (**₦10,324,000.00**). A break down of the cost is as shown in table3 below.

Thus, a reasonable market price at which a prospective buyer can acquire the rig has been put at Twelve Million, Three Hundred and Eighty Eight Thousand, Eight Hundred Naira (**₦12,388,800.00**) [1].

The price of comparable drilling rigs in the United States of America (USA) range from Twenty Million, Two Hundred and Fifty Thousand Naira (**₦20,250,000.00**) to Thirty One Million, Two Hundred and Fifty Thousand Naira

(**₦31,250,000.00**) using an exchange rate of One Hundred and Fifty Naira to the dollar. These prices do not include freight charges and custom duties [8]. This shows that significant savings can be made if the hydraulic drilling rig designed is produced in Nigeria as compared to importing the comparable drilling rig from other countries.

TABLE 3: SUMMARY OF DRILL RIG COSTING

S/#	DESCRIPTION	QTY	COST	REMARK
1	Used 4 – wheel truck	1	6,000,000.00	
2	Leveling jacks (hydraulic cylinders)	4	200,000.00	
3	Hydraulic raising cylinder (ram)	1	50,000.00	
4	Square tube derrick structure	1	100,000.00	
5	Hydraulic winch (Dawworks)	1	320,000.00	
6	Base plate (Derrick sub-structure)	1	60,000.00	
7	Crown block assembly	1	155,000.00	
8	Traveling block assembly	1	135,000.00	
9	Top drive system	1	280,000.00	
10	Mud hose assembly	1	45,000.00	
11	Hydraulic hose assy (TDS loop)	1	55,000.00	
12	Guide dolly system assembly	1	50,000.00	
13	Hydraulic hose assy (Hydraulic power unit)	1	60,000.00	
14	Hydraulic power unit	1	800,000.00	
15	Centrifugal mud pump	1	450,000.00	
16	Goose neck swivel	1	10,000.00	
17	Drilling stems	100	500,000.00	
	Add 20% miscellaneous and other handling cost		1,054,000.00	
	Total		10,324,000.00	

6.0 CONCLUSION:

From the above, it can be concluded that the hydraulic borehole drilling rig designed satisfies all the design objectives. Specifically, the design has significant economic advantage over imported drilling rigs. Its manufacture in Nigeria will also advance the needed technological development of Nigeria.

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