Design And Development Of Mini-Powered Water Drilling Rig

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ABSTRACT

Water drilling in Nigeria was initiated as most other technologies in the country by much of western technologies and machineries. As early as the 1960s, huge drilling machines started to be imported into the country for water borehole construction. Together with these machineries came complex spare parts and high maintenance costs. Today's trend is that Nigerians import used and obsolete gigantic machineries to bore holes which locally evolved portable machines would do very easily and economically. The National Board for Technology Incubation of the Nigerian Federal Ministry of science and Technology in 2011, in keeping to its mandate of bringing technology to the grassrootsentered into collaboration with Hydraulic Equipment Development InstituteKano in the National Agency for Science and Engineering Infrastructure of the Nigerian Federal Ministry of Science and Technology to articulate and foster the creation and proliferation of improved local technologies for water drilling. This project NBTI/COL/2011/17 is one of such authorization with the following dictate:

"To design and develop a locally based portable mini-powered drilling rig, capable of drilling up to 45meters depth. The operations, maintenance and spare parts shall be readily affordable and within the limitations and capabilities of the technology regime of the locality".

KEY WORDS: Water Drilling, Mini-Powered, Technology, Incubation.

1.0: INTRODUCTION

Geological study of Nigeria and the machinery possibilities for water borehole prospecting in the country carried by the team explains as follows:

1. That the Nigerian land mass divides into two broad parts.

(a). Igneous and metamorphic rock area comprising about fifty percent.

(b). Sedimentary areas within which are scattered areas of alluvial deposits, comprising about fifty percent.

2. That manual drilling methods and mini-powered rigs can bore most areas within the sedimentary zone and some strongly weathered areas in the metamorphic zone.

3. That high depth and percussion rigs are needed in less than 30% of the sedimentary zone and the strong rock areas of the metamorphic zone.

Another complimentary study on the technology capability of Nigerian fabricators shows-

1. That Nigerian engineers and fabricators possess ability to produce equipment for all cadre of water drilling in the country.

2. That the only necessary ingredient lacking in water drilling rig fabrication industry in Nigeria is standardization.

3. That once standardization is infused, our local technology shall satisfy the water drilling technology needs of the country.

Strengthened by these painstaking studies, a mini-motorized water drilling rig powered by a 16kw Diesel engine with capability for depths of more than 60meters is developed and hereby presented.

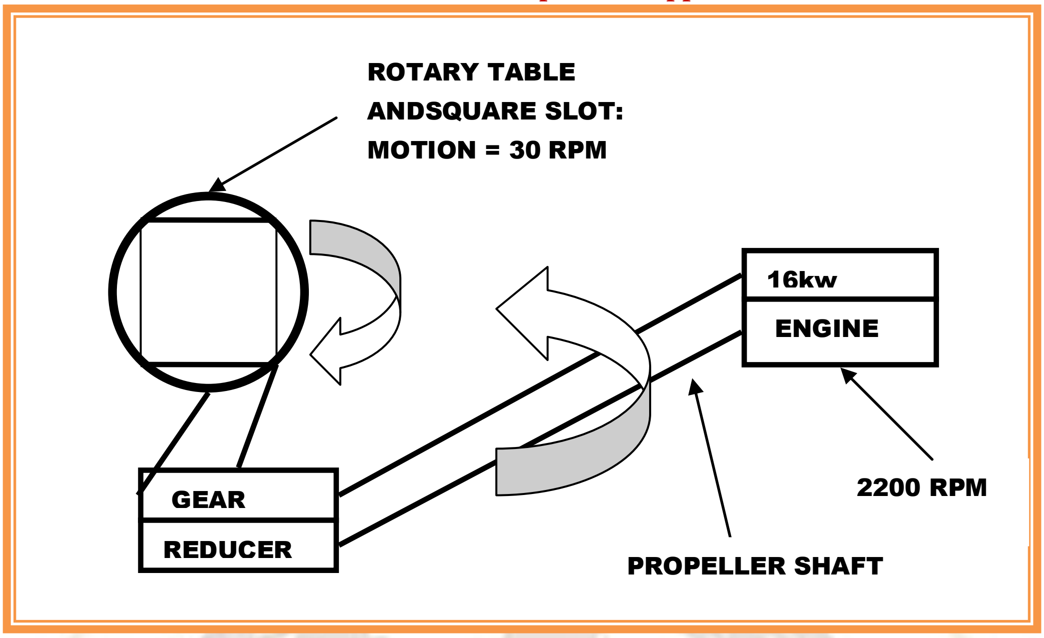

FIGURE 1: ENGINE – ROTARY TABLE MOTION LINKAGE OF THE MINI-MOTORIZED DRILLING RIG

2.0: EQUIPMENT DESCRIPTION

The equipment is purely a mechanical contrivance with the common rotary table drive system. (See Figure 1). The Rotary Table Drive System is a vertical hollow shaft assembly on two bearings. At one end of the hollow shaft is attached a bevel gear while a square slot with tolerance to admit a Kelly is installed inside the central hollow space of the shaft. A Kelly is a square pipe that slides through the central slot of the rotary table. The drill bit is attached to the down end of the Kelly at the onset of drilling. The bevel gear of the rotary table is driven by a matching pinion from a 20:1 gear reducer. The gear reducer is powered by a 16kw diesel engine through a propeller shaft.

The working speed of drilling is set at 30 RPM, though slight variations in speed could be achieved through the governor of the engine. As the engine drives the bevel gear in the clockwise direction, the square slot in the rotary table drives the Kelly which sides down simultaneously as it cuts earth.

3.0: DESIGN METHODOLOGY

The Design considerations that guided the project in the critical areas of drilling power and stanchion capability are discussed hereunder. The winch and wire rope selection are based on the manufacturer's specification of 3tonnes (3000kg) and matching wire rope.

3.1: STRENGHT OF SOILS AND ROCKS

Unconfined Compressive Strength (UCS) of a rock or soil is defined as the strength of the rock or soil sample when crushed in one direction without lateral strain. Unconfined Compressive Strength is also referred to as Uniaxial Compressive Strength. It is a primary index in determining the drillability of a formation as well as in determining the most suitable drilling or excavation method for any formation.It is the strength of a rock or soil sample when crushed in one direction (uniaxial) without lateral restraint. **(ALLABY AND ALLABY 1999).** The UCS of non-cohesive soils cannot be measured since the sample will crumble on drying. Soils are classified into types A, B, and C by **REPORT BSS-121(2009); AMERICAN SOCIETY FOR TESTING MATERIALS (ASTM) STANDARDS D653-85 AND D2XSS.**

Type C soils are of 48KPa UCS or less. Type B soils are of UCS between 48KPa and 144KPa while Type A soils are of UCS 144KPa and above.

Rocks are classified by strength with the gradient measuring from soft completely weathered rocks of the sedimentary family to the very hard metamorphic and igneous rocks. Accordingly very weak rocks are of UCS between 1.25 and 5MPa; weak rocks are classified as rocks of UCS less than 12.5MPa; rocks of medium strength has UCS between 12.5MPa and 50MPa. Strong rocks have UCS of between 50MPa and 100MPa while very strong rocks have UCS between 100MPa and 200MPa. Rocks of UCS above 200MPa are graded as extremely strong rocks **(HAWKINS 1998)**. Weak rocks comprise of some weakly compacted sedimentary rocks or some very highly weathered igneous or metamorphic rocks. Medium strength rocks comprise of some foliated metamorphic rocks and highly weathered igneous and metamorphic rocks. Strong rocks comprise low grade metamorphic rocks and marbles while very strong rocks are mainly of plutonic, hypabyssal and extrusive igneous rocks.

3.2: ROTARY DRILLING FORMULAR

Three distinct actions are evident in rotary drilling

(a) The rotary motion which cuts and chips the rock or earth

(b) The sliding down of the drill string which claims the depth drilled

(c) The flushing which cools the bits and removes debris.

Thus a driller should ensure among other things the employment of a mud pump with enough pressure for the maximum depth and size of hole intended. A sizeable weight on bit (WOB) is also necessary to ensure a simultaneous sliding of the drill string as the hole is cut. The weight on bit (WOB) is the total weight of the Kelly, drill pipes and the bit executing the drilling. Drilling is achieved by the sliding and rotary actions of the drill bit. The drilling power required at the bit is given by:

$POWER_{DRILLING} = POWER_{SLIDING} + POWER_{CUTTING}$------ (1.1)

a. POWER OF SLIDING

Effective force of sliding

$F_{SLIDING} = \mu \times WOB$

Hence effective sliding torque

$T_{SLIDING}$ = Force x Distance = μ x WOB x R_C------------ (1.2)

Where

WOB = Weight on bit.

R_C = Radius of centre of pressure of the cutting elements of the bit.

μ = coefficient of sliding friction.

Thus

$POWER_{SLIDING} = TORQUE_{SLIDING} \times W$ rads/sec.

$= (\mu \times WOB \times R_C) \times (2\pi/60 \times RPM)$ (ZACNY AND COOPER 2007) - ---------------(1.3)

b. POWER OF CUTTING

Work done or energy expended in crushing a volume of rock is given by

E_{ROCK} = UCS x V joules.

= UCS x π D^2 /4 x d_{PR} (ZACNY AND COOPER 2007) ------ (1.4)

Power to break a rock **:**

$POWER_{CUTTING} = WORK_{PER\ REVOLUTION} \times (2\pi/60 \times RPM)$ watts

= (UCS x Area x d_{PR}) x $(2\pi/60 \times RPM)$ watts --- (1.5) ------(ZACNY AND COOPER 2007)

Where

$$Area = \pi/4\ (D^2_{out} - D^2_{IN}) \quad (m^2)$$

D_{OUT} = Outside diameter of cutting element of the bit. (m)

D_{IN} = Inner diameter of the cutting element of the bit. (m)

UCS = Unconfined compressive stress of the rock. (N/m^2)

d_{PR} = Depth of cut per revolution.(m)

RPM = Rotational speed in Revolutions per minute.

c. TOTAL DRILLING POWER

Total drilling power in rotary drilling is given by**:**

$POWER_{DRILLING}$

$= (\mu \times WOB \times R_C) \times (2\pi/60 \times RPM) + (UCS \times Area \times d_{PR}) \times (2\pi/60 \times RPM)$

(ZACNY AND COOPER 2007) ------ (1.6)

3.3: THE DRAW WORKS

The draw works of the **MINI-MOTORIZED RIG** comprises a four legged stanchion of steel pipe section and a 60:1 velocity ratio winch and wire rope assembly. The stanchion is shown in figure 2 and designed to carry the weight of drill pipes ordinarily called drill stems, and the bit up to a depth of more than 60meters. The drill stems are pipes of 2.375inch (60.325mm) diameters, 10ft (3.048m) length and of mass approximately equal to 66.5lb (30kg). The stanchion legs are made of pipes 2.95inch (75mm) external diameter, 2.56inch (65mm) internal diameter and 18ft (5.49m) length.

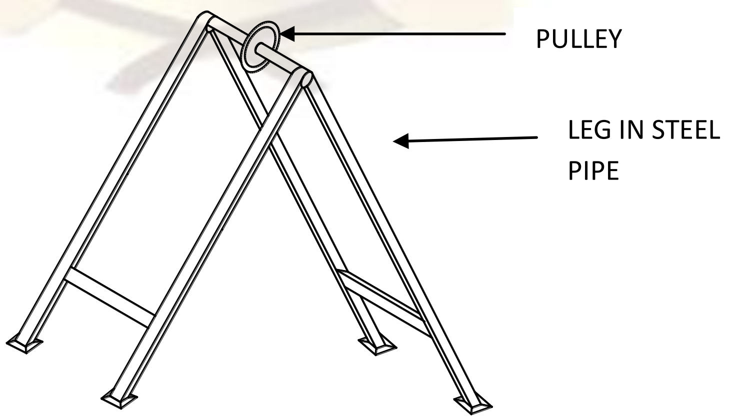

FIGURE TWO: SCHEMATIC DIAGRAM OF FOUR LEGGED STANCHION

TABLE 1: ALLOWABLE COMPRESSIVE STRESS VERSUS SLENDERNESS RATIO FOR COLUMNS (KHURMI 1968).

L_e/k	Stress (σ_c) (MPa)	L_e/k	Stress (σ_c) (MPa)	L_e/k	Stress (σ_c) (MPa)
0	125	90	92.8	180	33.6
10	124.6	100	84.0	190	30.0
20	123.9	110	75.3	200	27.0
30	122.4	120	67.1	210	24.3
40	120.3	130	59.7	220	21.9
50	117.2	140	53.1	230	19.9
60	113.0	150	47.4	240	18.1
70	102.5	160	42.3	300	10.9
80	100.7	170	37.7	350	3.6

The four legged stanchion carries the load of the drill stems and bit during the entire period of drilling. The legs are thus subjected to compressive stresses and taken as columns. The Bureau of Indian Standards (I.S.I) provides a table for allowable compressive stress for mild steel columns based on slenderness ratio of sections from 0 – 350. The values are shown above in TABLE 1 and were relied upon for the selection of the pipe size used for the stanchion legs.
The parameter that determines which value of compressive stress to employ in structural evaluation of a column is called Slenderness Ratio. It is defined as the ratio of the effective length of the column to the least radius of gyration of the section.
Slenderness Ratio

$$S = L_e/k \quad \text{-------------- (1.7)}$$

$$k = \sqrt{\frac{I}{A}} \quad \text{------------------ (1.8)}$$

For hollow pipes

$$A = \pi/4\,(D^2 - d^2) \quad \text{--------------- (1.9)}$$

$$I = \pi/64\,(D^4 - d^4) \quad \text{--------------- (1.10)}$$

(KHURMI 1968)
Where
L_e = Effective or equivalent Length of Column.
k = Least radius of gyration.
I = Moment of Inertia.
A = Area.
D = External Diameter of pipe.
d = Internal diameter of pipe.
Both the slenderness ratio and the permissible stress in Table 1 are computed through an empirically determined fixture of equivalent lengths depending on the end conditions of a column. The fixture for the four legged stanchion is that of a column with one end fixed and the other hinged. Its equivalent length for structural analysis and computation is given as:

$$Le = L/\sqrt{2} \text{(KHURMI 1968) ---------------- (1.11)}$$

The choice of length of drill stem of 10ft (3.048m) is predicated on the common standard lengths in the market: 10ft, 15ft, 20ft for water Drilling and 30ft, 40ft, 60ft and 100ft for oil drilling. The 10ft length elects a Kelly length of about 3ft longer to take care of back-fill during the period of drill stem replacement. The length of the ROTARY TABLE underlines the minimum height of stanchion leg of 18ft (5.49m).

4.0: EQUIPMENT DESIGN

4.1: DRILLING POWER

Equation 1.6 above gives drilling power:

$$POWER_{DRILLING} = (\mu \times WOB \times R_C) \times (2\pi/60 \times RPM) + (UCS \times Area \times d_{PR}) \times (2\pi/60 \times RPM) \quad \text{----------------- (1.6).}$$

Drilling is saddled with constantly varying parameters. The whole terrain starts with differing degrees of soil and regolith and transverses through differing types of rocks. Where investigations show soil and rock samples, the unconfined compressive stress (UCS) of the strongest rock is used in computation. As the terrain varies, the coefficient of sliding friction (μ) and depth of cut (d_{pr}) per revolution vary simultaneously as drilling progresses. The weight on Bit (WOB) varies progressively on each addition of a drill stem.

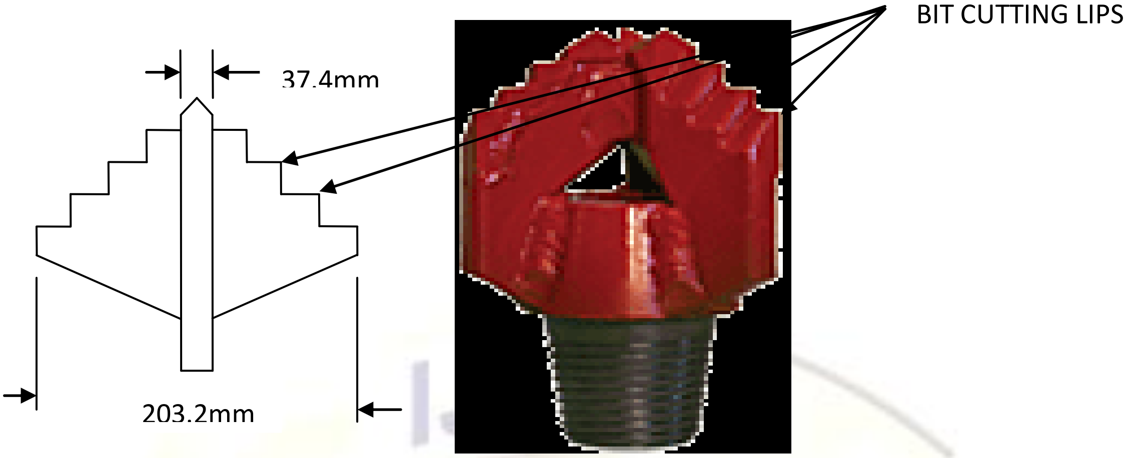

FIGURE 3: DRAG BIT

In motorized drilling, three parameters of the Drilling Power Equation are closely constant. These are the radius of the center of pressure of the cutting elements of the bit (R_c) which is usually approximated as the average radius of the bit, the cutting area of the bit (Area) and the Revolutions per minute (RPM). It is custom to hold the coefficient of sliding friction as well as the depth of cut per revolution constant. The weight on bit employed for computation is the maximum weight on bit possible during drilling. This the projected weight at the highest depth.

For the 8inches (203.2mm) carbide drag bit shown in figure 3, the average radius (R_c) and cutting area are estimated as follows:

(1). $R_c = 0.2032 + 0.0374 / 2$

$= 0.1203m$

(2). $Area = \pi/4(0.2032^2 - 0.0374^2)$

$= 0.03133m^{2.}$

Coefficient of sliding friction is estimated from friction measurement of tungsten carbide bit on nugget sandstone with mud as drilling fluid. The highest value of 0.04 is taken. **(FINGER AND GLOWKA 1989).**

(3). DEPTHOF CUT (d_{PR})

Take the effective drilling time during one day as eight hours. Take time of change of pipe and the time of drilling to be equal. Time of effective drilling per day is fours. Take five days of drilling to do a maximum of 50meters. Time for rotary drilling equals 20hours. Which is 20 × 60minutes =1200minutes or 12000 revolutions at 10rpm. Projected depth of cut per revolution:

$d_{PR} = \times 1000/12000$ **(mm)**

$= 4.22mm$

$POWER_{DRILLING}$

$= (\mu \times WOB \times R_C)x(2\pi/60 \times RPM) + (UCS \times Area \times d_{PR}) \times (2\pi/60 \times RPM)$

----------------- (1.6).

$\mu = 0.04$

WOB (at maximum of 60meters) = 5886N

$R_c = 0.1203m$

$Area = 0.03133m^{2.}$

$d_{pr} = 0.00422m$

The power rating of the diesel engine is 16kw. It is assumed that at average performance, at least 75% of this power shall be effectively transmitted for drilling. This leaves 12kw. Employing this value of power and other parameters, equation 1.6 comes handy for the determination of the optimum terrain for the ***MINI - MOTORIZED RIG***.

From equation 1.6, the Unconfined Compressive Stress (UCS) of the strongest rock particle in such formation is:

$UCS = 60 \times (POWER_{DRILLING} - (\mu \times WOB \times R_C)x(2\pi/60 \times RPM)$

$$2 \times \pi \times RPM \times AREA \times d_{PR}$$

$$= \frac{60 \times [12 \times 1000 - (0.04 \times 5886 \times 0.1203) \times (2 \times \pi \times 30/60)]}{2 \times \pi \times 30 \times 0.03133 \times 0.00422}$$

$= 28{,}676{,}504 N/m^2 = 28.67 N/mm^2 = 28.67 MPa.$

Inferences from above UCS and Paragraph 3.1, shows equipment can transverse some terrains of medium strength rocks.

4.2: RIG STANCHION

Two thick steel pipes were considered for application.

(a) 2.95inches (75mm) Diameter steel pipe of 5mm thickness

(b) 1.875inches (47.6mm) Diameter steel pipe of 4mm thickness.

Equivalent length for the two pipes is as follows

$L = 18ft \times 12 \times 25.4$

$= 5486.4mm$

$Le = L/\sqrt{2}$ ---------------- (1.11)

$Le = 5486.4/\sqrt{2}$

$= 3879.5mm$

Slenderness Ratio

$S = Le/k$ ……………….. (1.7)

Where

k= least radius of gyration

$k = \sqrt{\frac{I}{A}}$ ………………. (1.8)

Where

I = moment of Inertia of section

A= Area of section

For Pipe (a) 2.95inches (75mm) ×5mm

$I = \pi/64(D^4 - d^4)$

$= \pi/64\ (75^4 - 65^4)$

$= 676{,}915mm^4$.

$A = \pi/4\ (D^2 - d^2)$

$= 1099.56mm^2$

$K = \sqrt{\frac{676915}{1099.56}}$

$= \sqrt{615.6}$

$= 24.8mm$

$S = 3879.5/24.8$

$= 156.4$

For Pipe (b) 1.875inches (47.6mm) × 4mm

$I = \pi/64\ (D^4 - d^4)$

$= \pi/64(47.6^4 - 39.6^4)$

$= 131286.3mm^4$

$A = \pi/4\ (D^2 - d^2)$

$= \pi/4\ (47.6^2 - 39.6^2)$

$= 547.9mm^2$.

$K = \sqrt{\frac{I}{A}}$

$= \sqrt{\frac{131286.3}{547.9}}$

$= \sqrt{239.62}$

$= 15.48mm$

$S = 3879.5/15.48$

= 250.6

Table 1 shows allowable compressive stress σ_c for pipe

(a) = 45.46 MPa

(b) = 17.4 MPa

The allowable compressive stress of pipe (a) is about three times that of pipe (b). This is the basis for selection and utilization of the 2.95inches (75mm) × 5mm pipe in the stanchion construction. The universal stress equation is hereunder employed to determine the safe load.

σ_c = P/Area) ------------------ (1.12)

P = Safe load (N)

Area = Area (mm^2)

Hence

Safe Load P = Area(mm^2) x σ_c (N/mm^2)

$= 1099.56 \times 45.46 \times 10^3 N$

$= 49.98 \times 10^3 N$

Total Load for 60m depth using 3.048m length of 30Kg Pipes

Number of Pipes = 60/3.048

= 19.68

$\cong 20\ \mathit{Lengths}$

Weight = 20 × 30 × 9.81 N

= 5886N

Weight on each leg = 1471.5 N

This is 1/33 of the safe load for the leg.

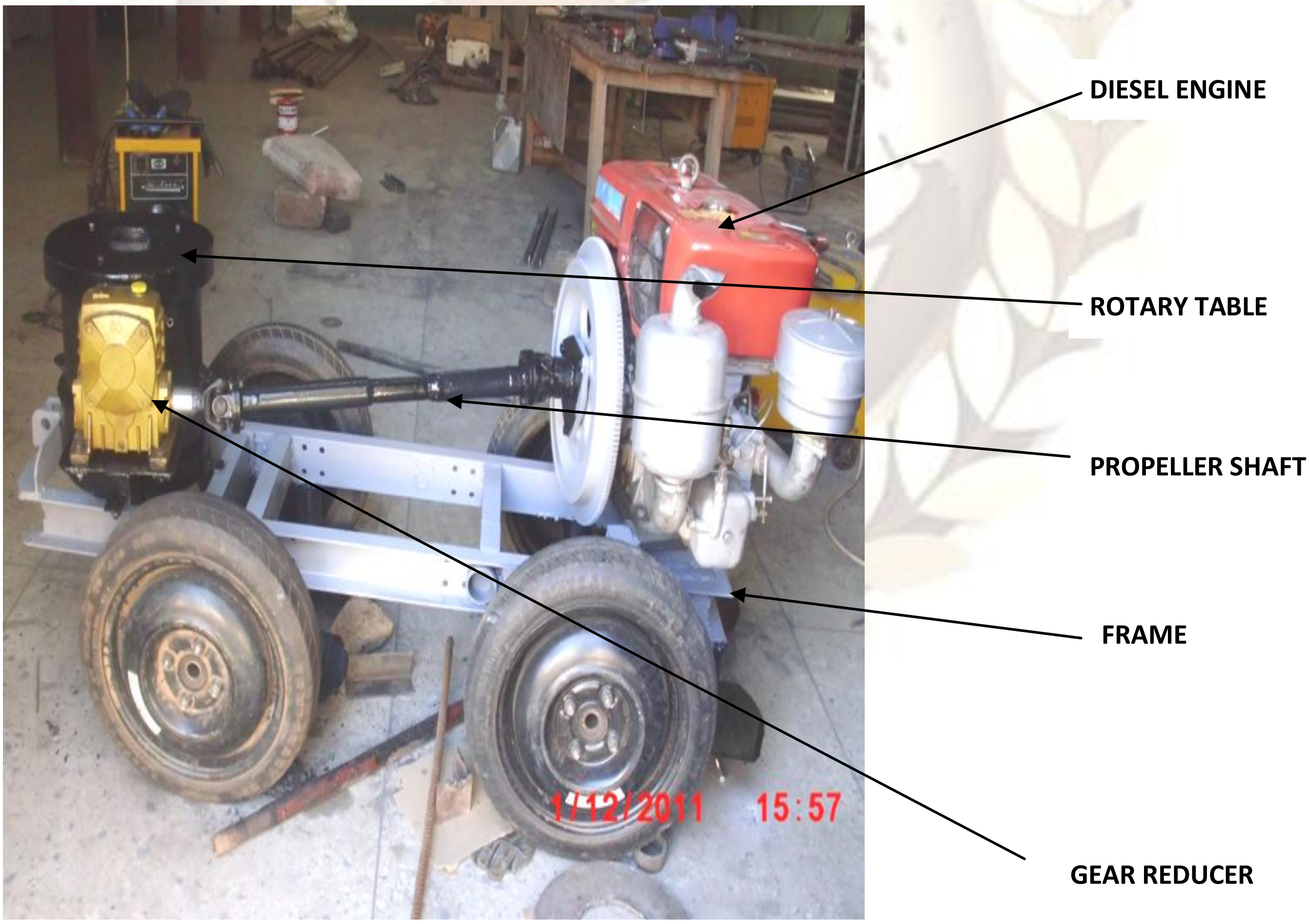

FIGURE 4: MINI POWERED WATER DRILLING RIG.

5.0: CONCLUSION

The equipment is presented in figures 4. The equipment can execute drilling to depths of more than 60meters in soil and very weak rock formations and up to a maximum of 60meters in foliated and highly weathered igneous and metamorphic rocks. The stanchion has the static capability to carry loads ten times the design depth of sixty meters. It is however recommended for not more than two times the design depth to allow for a factor of safety of fifteen for dynamic working conditions. The winch of three tone capacity can carry load twice the WOB for the 60meter depth.

The equipment is now operational after the successful test run in November 2012. It is found to meet a little more than the design ratings.

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