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MODELLING OF THE EFFECT OF CRITICAL SEEPAGE FORCE ON THE AQUIFER SOIL MEDIUM OF A BOREHOLE

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ABSTRACT: *There have been records of failures and quicksand conditions in boreholes in recent times impeding the performance and operation of boreholes which may have resulted from various factors ranging from construction problems, drilling inaccuracies, fitting and installation problems, some chemical effects within the aquifer medium etc, but it has been ignored that the beneficial factor to the operation of water boreholes; seepage force could get to a considerable value that it becomes unsafe for the well operation thereby causing dislodgement of sand particles and sandstones from the wall of the borehole and the flow paths to the extent that sandstones experience boiling. The scouring of the particles collected at the wall of the transport pipe could damage the installations which is a huge financial loss to the owners of these facilities. Moreover, when soil particles flow, it makes the yield a poor one hence this research works to investigate the contribution of seepage force to the failure of boreholes. A mathematical/laboratory model was used and an expression for calculating the critical hydraulic head causing critical seepage deduced as* $h_{(x)}$ $=0.000524r^2[X_5(5-2SF_{x_2})]$. *Tables 2 and 3 and Figures 4, 5 and 6 have shown that there is strong agreement between the mathematical model and the laboratory check with closest agreement at the flow distance of 1.8m flow distance and a correlation analysis has shown a perfect correlation of 1.00975. It was also established that the well pump of 760watts power could be operated safely at 220volts beyond which the hydraulic head get more critical. Finally, irrespective of the fact that an increase in hydraulic head increases discharge, the system should be operated at a head safe for the performance of the well.*

KEYWORDS: Modelling, Seepage Force, Failure, Borehole, Groundwater.

INTRODUCTION

The present work is based on the study of the behavior and performance of water boreholes with respect to seepage force and it originated from borehole drilling engineering both for water and oil as fluids with different viscosities. A water borehole is a shaft usually vertical, excavated in the earth for bringing ground water to the surface for use (Chukwurah, 1992). An estimated 91% of total fresh water available to humanity is found as ground water which occurs in aquifers (Chukwurah, 1992). During water exploitation, few or several years after the drilling of a borehole, sand particles and small sandstone particles start to break away from the borehole surface. The number of particles which are transported by the fluid (water) can reach an amount that the transport pipes, well casings and other equipment will be damaged, in a short period of time, by the scouring of these particles (Baars, 1996). The only solution up till now is to change the electro pump (submersible pump) or make a new borehole which is especially a huge financial loss (Baars, 1996). The above work is targeted at solving many of

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these problems facing water borehole drilling, operation and performance relating to seepage force in the developing countries which amongst others includes borehole surface soil failure which leads to the failure of boreholes soon after drilling and commissioned for use. Through the simulation of the borehole behavior with the Finite Element Method of numerical study, solutions would be offered on both the micro and macro levels.

The present research work is worth a period of time because of the sensitive nature and its effect to the people more especially of the developing countries. Primarily, in Nigeria, water borehole is a source of water today for both urban and rural dwellers (Eduvie, 2006). Consequently, a research work that tries to solve problems facing water boreholes is worth embarking on because it will positively affect people and the immediate environment. In a situation whereby water boreholes fail to supply water to the populace few years after drilling, it has failed its usage. Presently, a lot of water boreholes drilled in this part of the world collapse soon after drilling and a lot more collapse few years after it has been put to use. For instance, the South-Eastern part of Nigeria is characterized by water borehole failures which no known engineering cause has been established.

Erroneously, these failures are often attributed to the failure of the electro pump. However, the present work is aimed at probing into the ignored aspect of the failures which is the failure of the soil at the well depth. The new solution to be expected at the end of the present research would be useful to both geologists, water resources engineering experts and geotechnical engineers as well as corporate establishments in borehole drilling. In addition with the effect of fluid viscosity considered, all the engineering factors involved in the present work equally affect oil well drilling. However, the result of this research would be useful to oil exploration companies in their well operations.

LITERATURE

Groundwater development in Nigeria

The establishment of the Nigerian geological survey in 1817 has as one of its major objectives to search for groundwater in the semiarid areas of the former northern Nigeria. These activities of the authorities of the Nigerian geological survey culminated in the commencement in 1928 of systematic investigations of towns and villages for the digging of hand dug wells. In 1938, a water drilling section of the geological survey was setup and by 1947; the engineering aspects of the water supply section were handed over to the public works Department, which is the forerunner of Nigeria's today's ministry of works while the geological survey maintained the exploration department. The aim of studying borehole failures is to identify the factors responsible for borehole engineering solutions. According to (Eduvie, 2006), the most plausible causes of these borehole failures can be attributed to

(i) Design and construction
(ii) Groundwater potential/hydro geological consideration and
(iii) Operational and maintenance failures.

With the foregoing, Eduvie has failed to recognize the purely engineering factors that could cause the failure of boreholes and this has stimulated the present research work to establish seepage force as one of those factors that cause failure or operational inefficiency of water boreholes.

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Finite Element Method

The Finite element method is a numerical tool for determining approximate solutions to a large class of engineering problems (Roland et al, 2004). This method was originally developed to study the stresses in complex air frame structures in 1960 by Clough and was later extended to the general fields of continuum mechanics in 1965 by Zienkiewicz and Chenng (Roland et al, 2004).

The solution of a continuum problem by finite element method is approximated by the following step by step process thus;

- Discretize the continuum
- Select interpolation or shape functions,
- Form element equations (formulation),
- Assemble the element equations to obtain a system of simultaneous equations,
- Solve the system of equations and
- Calculate the secondary quantities.

Many practical problems in engineering are either extremely difficult or impossible to solve by conventional analytical methods. Such methods involve finding mathematical equations which define the required variables (Bui & Sako, 2008). For instance, the distribution of stresses (pressure) and displacements in a solid component or of pressure and velocities in the flow of a fluid might be required (Roger, 1996). The limitation of continuum approaches thus the FEM motivated the development of DEM (David & Lidija, 2001). One of the essential ingredients for a successful finite element analysis of a geotechnical problem is an appropriate soil constitutive model (Mahabadi et al, 2012).

METHODOLOGY AND FORMULATION

Seepage Force Modeling

Soils are premeable to fluids (water) because the voids between soil particles are interconnected. The degree of permeability is characterized by the permeability coefficient K, also referred to as hydraulic conductivity. The basic concepts of seepage and flow through granualr soil materials viz fluid velocity, seepage quantity, discharge velocity, hydraulic gradient etc. obey Darcy's law thus

$$q = KiA \qquad (1)$$

Where,

q = discharge in m^3/s
K = hydraulic conductivity or permeability constant
i = hydraulic gradient
A = cross section area of flow region

The seepage quantity q is the volume of water passing through the pores voids of a soil cross-section area during a unit interval. q is the flux of water:

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$$q = \int_A v_f \; dA \qquad (2)$$

Where vf = fluid velocity and
A = total cross section area of medium

Three discrete particles; target, contactor and support particles and the fluid flow through the contact zone were considered as in Fig.1 below;

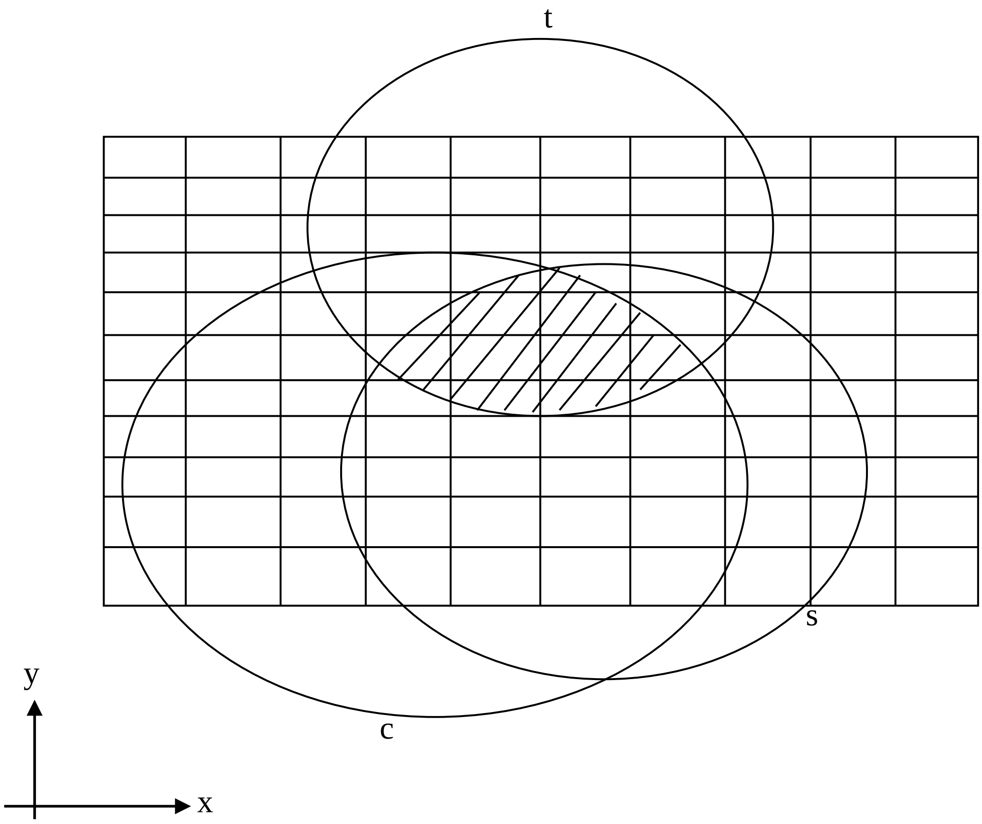

Figure 1: Discretisation of contactor, target and supporter discrete elements' contact zone to finite elements

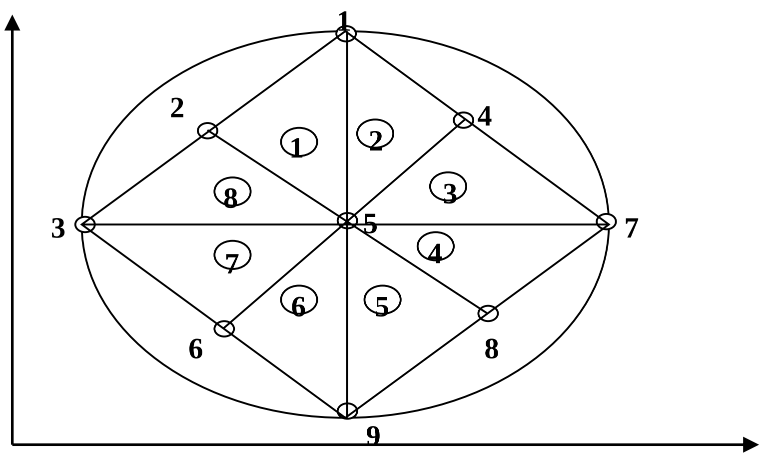

Figure 2: Elements and nodal points of the contact zone

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At the particle locations, v_f is zero. Which goes to show that v_f can be discretized within the voided and the solid media for a constant area. Saturated soil volume or mass is sujected to three forces; (Fox et al, 2010);

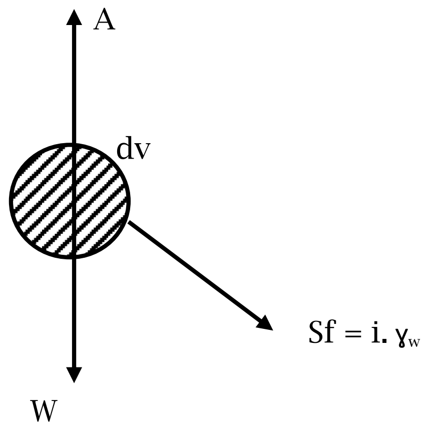

Figure 3: Soil volume subjected to three force components

In strict agreement with (Fox et al, 2010); seepage force (Fig.3) as a volume force is given by the expression (Sivakugan, 2005),

$$S_F = i.\ \gamma_w \qquad (3)$$

Where

i = hydraulic gradient

γ_w = unit weight of water KN/m^3

Consider the elemental area under study, the elemental hydraulic head dH that causes flow of water in the soil mass or volume is given as

$$dH = S_F.dx.\ \gamma_w^{-1} \qquad (4)$$

Assuming a three dimensional flow in x, y and z directions, the elemental head dH will be the algebraic sum of the heads in three directions thus

$$dH = Hx + Hy + Hz \qquad (5)$$

Discretizing the distinct particles into finite elements as shown in Figures 1 and 2 and considering the seepage forces in three directions of flow through the nodes of the elements, we would have;

$$\begin{aligned} SF_x &= SF_{x1} + SF_{x2} + SF_{x3} \ldots\ldots\ldots\ldots SF_{xn} \\ SF_y &= SF_{y1} + SF_{y2} + SF_{y3} \ldots\ldots\ldots\ldots SF_{yn} \qquad (6) \\ SF_z &= SF_{z1} + SF_{z2} + SF_{z3} \ldots\ldots\ldots\ldots SF_{zl} \end{aligned}$$

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But;

$$H_x = (SF_{x1}\,X_1 + SF_{x2}\,X_2 + SF_{x3}\,X_3 \ldots\ldots\ldots\ldots (SF_{xn}\,X_n)\ \frac{1}{\gamma_w}$$
$$H_y = (SF_{y1}\,X_1 + SF_{y2}\,X_2 + SF_{y3}\,X_3 \ldots\ldots\ldots\ldots (SF_{yn}\,X_n)\ \frac{1}{\gamma_w} \qquad (7)$$
$$H_z = (SF_{z1}\,X_1 + SF_{z2}\,X_2 + SF_{z3}\,X_3 \ldots\ldots\ldots\ldots (SF_{zn}\,X_n)\ \frac{1}{\gamma_w}$$

The above equation gives rise to the global matrix equation, thus Equation 8.

And finally the prototype well failure test was conducted as shown in Figure 4 below

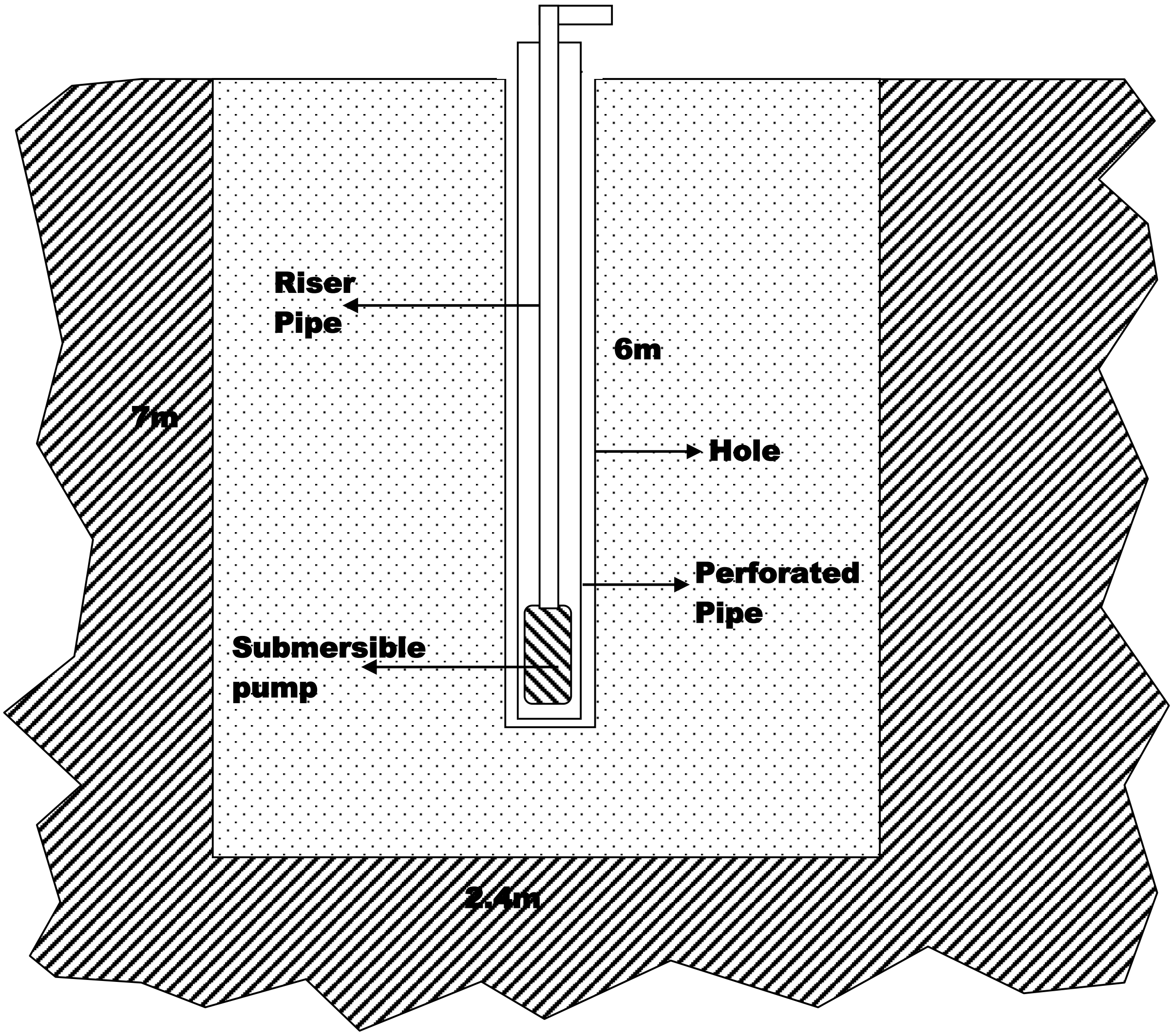

Figure 4: Prototype well failure test setup

At the same time a power regulator of 10 voltage speeds was fabricated to power the submersible pump at 10 different voltages supplied between 150 volts and 240 volts.

RESULTS AND DISCUSSION

The result of the geophysical examination carried out on the sample under study is as tabulated in Table 1 below;

Table 1: Geophysical properties of soil sample under study (Onyelowe, 2013; Alaneme, 2014)

Parameter	Result	Parameter	Result
Liquid Limit	14.00	OMC	7.075%
Plastic Limit	6.67	Specific Gravity G	2.857
Plasticity Index	7.33	Proven Ring Factor k	0.004105KN/div
Cu	6.79	Area of Shear Box	0.01m2
Cc	1.52	Normal Stress σ	10.275KN/m2
Classification(AASHTO)	A-2-4	Frictional angle	480
Grading	Well graded	Cohession	40KN
MDD	1.84mg/m3	Soil Type	Gravel and sand
Ɣsat	19.26KN/m3	Ɣw	9.8KN/m3
Ɣb	9.46KN/m3	ic	0.9653
K	1.794E-5cm/s		

$$\frac{A}{\gamma_w L}\begin{bmatrix}
0 & -SF_{x2} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & SF_{y2} & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -SF_{z2} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -SF_{x4} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & SF_{y4} & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -SF_{z4} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & SF_{x4} & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -SF_{y4} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & SF_{z4} & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & SF_{x8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & -SF_{y8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & SF_{z8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -SF_{x8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & SF_{y8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -SF_{z8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -SF_{x6} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & SF_{y6} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -SF_{z6} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & SF_{x6} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -SF_{y6} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & SF_{z6} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & SF_{x2} & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -SF_{y2} & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & SF_{z2} & 0 & 1
\end{bmatrix}
\begin{bmatrix} X_1 \\ X_2 \\ X_5 \\ X_1 \\ X_4 \\ X_5 \\ X_4 \\ X_5 \\ X_7 \\ X_5 \\ X_7 \\ X_8 \\ X_5 \\ X_8 \\ X_9 \\ X_5 \\ X_6 \\ X_9 \\ X_3 \\ X_5 \\ X_6 \\ X_2 \\ X_3 \\ X_5 \end{bmatrix}
= f(x)
\begin{bmatrix} \frac{H_1}{2} \\ H_2 \\ H_5 \\ H_1 \\ H_4 \\ H_5 \\ H_4 \\ H_5 \\ H_7 \\ H_5 \\ H_7 \\ H_8 \\ H_5 \\ H_8 \\ H_9 \\ H_5 \\ H_6 \\ H_9 \\ H_3 \\ H_5 \\ H_6 \\ H_2 \\ H_3 \\ \frac{H_5}{2} \end{bmatrix} \qquad 8)$$

Boundary conditions;

$^5SF_{odd} = 0$; $SF_5 = 1$; $0 < SF_{even} < 1$; $0 < X < L$ (Munjiza, 2004) Where,

$^5SF_{odd}$ = seepage force at odd nodes except node 5,

SF_5 = seepage force at node 5,

SF_{even} = seepage force at even nodes, h = critical hydraulic head; X = flow distance

Solving equation 8 above gives;

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$$\frac{A}{\gamma_{w}.L}\begin{bmatrix} X_2(-SF_{x2})+X_5 \\ X_2(SF_{y2})-X_5 \\ X_2(-SF_{z2})+X_5 \\ X_4(-SF_{x4})+X_5 \\ X_4(SF_{y4})-X_5 \\ X_4(-SF_{z4})+X_5 \\ X_4(SF_{x4})-X_5 \\ X_4(-SF_{y4})+X_5 \\ X_4(SF_{z4})-X_5 \\ X_5+X_8(SF_{x8}) \\ -X_5+X_8(-SF_{y8}) \\ X_5+X_8(SF_{z8}) \\ X_5+X_8(-SF_{x8}) \\ -X_5+X_8(SF_{y8}) \\ X_5+X_8(-SF_{z8}) \\ X_5+X_6(-SF_{x6}) \\ -X_5+X_6(SF_{y6}) \\ X_5+X_6(-SF_{z6}) \\ -X_5+X_6(SF_{x6}) \\ X_5+X_6(-SF_{y6}) \\ -X_5+X_6(SF_{z6}) \\ X_2(SF_{x2})+X_5 \\ X_2(-SF_{x2})-X_5 \\ X_2(SF_{x2})+X_5 \end{bmatrix} = \begin{bmatrix} \frac{H_1}{2} \\ H_2 \\ H_5 \\ H_1 \\ H_4 \\ H_5 \\ H_4 \\ H_5 \\ H_7 \\ H_5 \\ H_7 \\ H_8 \\ H_5 \\ H_8 \\ H_9 \\ H_5 \\ H_6 \\ H_9 \\ H_3 \\ H_5 \\ H_6 \\ H_2 \\ H_3 \\ \frac{H_5}{2} \end{bmatrix} \qquad (9)$$

Equation 9 above will give the hydraulic head at different points in the flow region from where the head that causes the separation of particles is established thus;

$$h_{(x)} = \frac{A}{\gamma_{w}.L}\{[X_2(-SF_{x2})+X_5] + [X_2(SF_{y2})-X_5] + [X_2(-SF_{z2})+X_5] + [X_4(-SF_{x4})+X_5] + [X_4(SF_{y4})-X_5] + [X_4(-SF_{z4})+X_5] + [X_4(SF_{x4})-X_5] + [X_4(-SF_{y4})+X_5] + [X_4(SF_{z4})-X_5] + [X_5+X_8(SF_{x8})] + [-X_5+X_8(-SF_{y8})] + [X_5+X_8(SF_{z8})] + [X_5+X_8(-SF_{x8})] + [-X_5+X_8(SF_{y8})] + [X_5+X_8(-SF_{z8})] + [X_5+X_6(-SF_{x6})] + [-X_5+X_6(SF_{y6})] + [X_5+X_6(-SF_{z6})] + [-X_5+X_6(SF_{x6})] + [X_5+X_6(-SF_{y6})] + [-X_5+X_6(SF_{z6})] + [X_2(SF_{x2})+X_5] + [X_2(-SF_{x2})-X_5] + [X_2(SF_{x2})+X_5]\} \qquad (9)$$

And finally,

$$h_{(x)} = \frac{A}{\gamma_{w}L}[X_5(5-2SF_{x_2})] = 0.000524r^2[X_5(5-2SF_{x_2})] \qquad (10)$$

Where, SF_{x_2} = the seepage force in the flow system,

= [0.1, 0.2, 0.3, ...1.0], (10)

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r= average radius of discrete particle= 0.002857m

X= flow distance

γ_w= unit weight of water = 1000kg/m^3

L= cross sectional length of the flow medium = 6m and

X_5 varies between 0.6 and 6.0.

Solving Eq. 10 with the given data of parameters would give the model for the hydraulic head causing quicksand effect within the medium or flow region thus;

Table 2: Critical hydraulic head and seepage force model

SF_{x_2}	Critical hydraulic head $h_{(x)} = 0.000524r^2[X_5(5-2SF_{x_2})]$ @ X_5 equals										Lab. Critical head, h_c
	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0	
0.1	.123E-7	.247E-7	.370E-7	.493E-7	.616E-7	.739E-7	.862E-7	.985E-7	1.11E-7	1.23E-7	.327E-7
0.2	.118E-7	.236E-7	.354E-7	.472E-7	.590E-7	.709E-7	.826E-7	.944E-7	1.06E-7	1.18E-7	.313E-7
0.3	.113E-7	.226E-7	.339E-7	.451E-7	.565E-7	.677E-7	.790E-7	.904E-7	1.02E-7	1.13E-7	.299E-7
0.4	.108E-7	.215E-7	.323E-7	.431E-7	.539E-7	.646E-7	.754E-7	.862E-7	.970E-7	1.08E-7	.286E-7
0.5	.103E-7	.206E-7	.308E-7	.411E-7	.513E-7	.616E-7	.718E-7	.821E-7	.924E-7	1.03E-7	.272E-7
0.6	.097E-7	.195E-7	.292E-7	.390E-7	.487E-7	.585E-7	.682E-7	.780E-7	.877E-7	.975E-7	.259E-7
0.7	.092E-7	.184E-7	.277E-7	.370E-7	.462E-7	.554E-7	.646E-7	.739E-7	.832E-7	.924E-7	.245E-7
0.8	.087E-7	.175E-7	.262E-7	.349E-7	.436E-7	.523E-7	.611E-7	.698E-7	.785E-7	.873E-7	.232E-7
0.9	.082E-7	.164E-7	.247E-7	.328E-7	.411E-7	.493E-7	.575E-7	.657E-7	.739E-7	.821E-7	.218E-7
1.0	.077E-7	.154E-7	.231E-7	.308E-7	.385E-7	.462E-7	.539E-7	.616E-7	.693E-7	.770E-7	.204E-7

Below is the matlab solution of Eq. 9;

```
r = 0.002857; %Radius of discrete particle in an aquifer
SFx2 = 0.1:0.1:1.0; %Define seepage force with range from 0.1->1.0 in steps of 0.1
X5 = 0.6:0.6:6.0; %Define flow distance with range from 0.6->6.0 in steps of 0.6
for n=1:10
   H = 0.000524*r^2*(X5(n).*(5-2.*SFx2));
   plot(Nx2,H);
   if n == 10
      gtext(['X5 = ' num2str(X5(n))]);
   else
      gtext(num2str(X5(n)));
   end
   hold on;
end
grid on; xlabel('Seepage force, SFx2');
ylabel('Head causing seepage, H(x)');
title('Graph of Head causing seepage against Seepage force');
hold off
```


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The model resulting from the above matlab programme is a shown in Fig.4 below and at the same time the result of the laboratory investigation conducted using the prototype well failure setup as shown in Table 1 and Figure 5 below

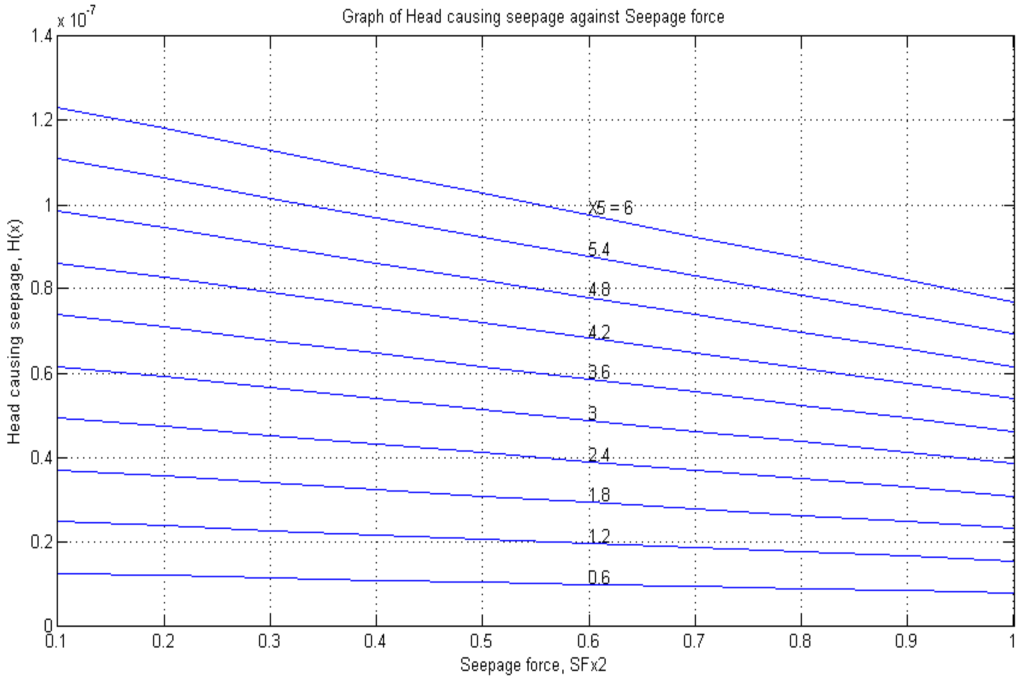

Figure 4: Model of critical head causing failure in a water borehole

Table 3: Prototype well failure test result and critical hydraulic head

Voltage	Pump discharge, q (m^3/s)	Critical hydraulic head, h_c	Generated pump power,P_o(hp)
150	0.03313	0.02041	1.95
160	0.03536	0.08052	2.08
170	0.03757	0.10561	2.21
180	0.03978	0.35565	2.34
190	0.04199	0.56687	2.47
200	0.04420	0.77234	2.60
210	0.04641	0.89934	2.73
220	0.04862	0.91123	2.86
230	0.05083	1.01023	2.99
240	0.05304	1.25599	3.12

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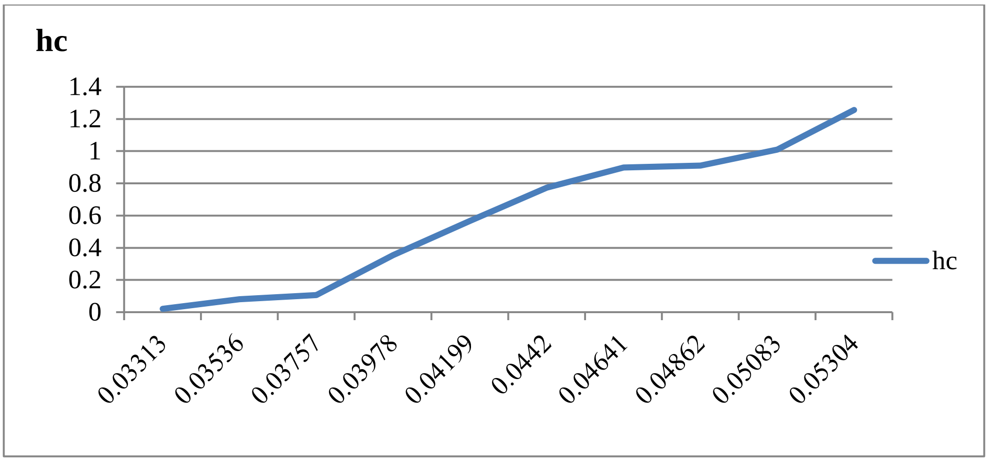

Figure 5: Critical hydraulic head and discharge curve

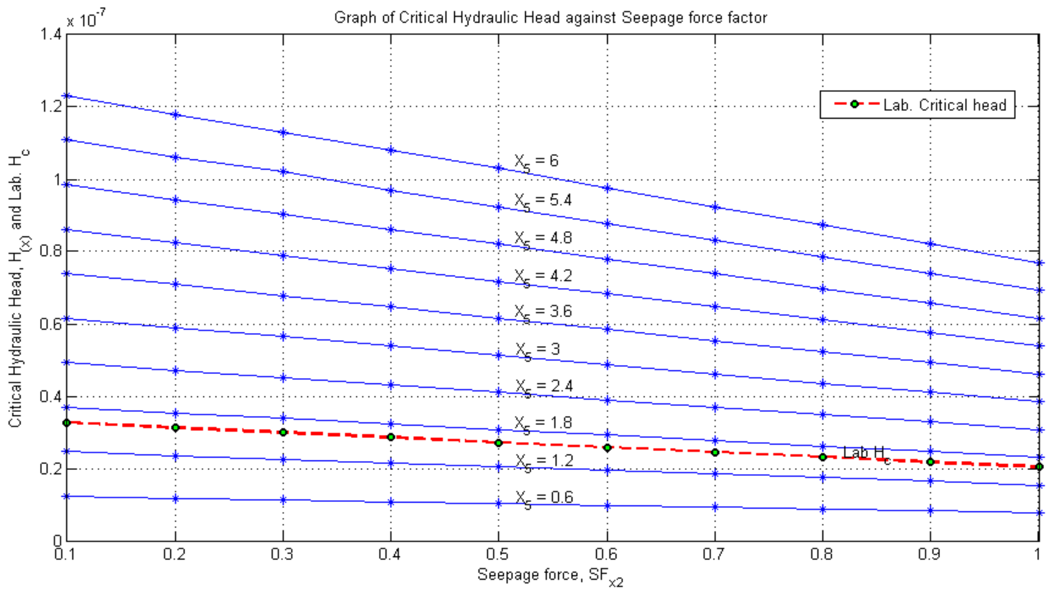

Figure 6: Model and laboratory critical hydraulic head of system

From the foregoing, it could be deduced and established that the head causing critical seepage which consequently causes dislodgement of particles is expressed as $h_{(x)}$ = $0.000524r^2[X_5(5-2SF_{x_2})]$ as shown in Eq.9 generated from the element model. Tables 2 and 3 and Figures 4, 5 and 6 have shown that there is strong agreement between the mathematical model and the laboratory check with closest agreement at the flow distance of 1.8m flow distance and a correlation analysis has shown a perfect correlation of 1.00975.

From Fig.4, it can be deduced that a decrease in the critical hydraulic head causing critical seepage is accompanied with an increase in seepage force which is evidence that dislodgement of particles increases the channel of flow thereby increasing seepage to a critical point with its attendant quicksand effect (Eduvie, 2006; Munjiza, 2004). Fig.5 also affirms the above assertion because it has shown that an increase in the critical hydraulic head brings an increase in discharge.

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Table 2 also shows that increase in flow distance increases the hydraulic head considerably. Table 3 has also shown that increase in voltage increases critical hydraulic head which in turn causes quicksand effect.

CONCLUSION

Interestingly, the following could be concluded from the foregoing;

1. That an expression has been deduced from the model as shown in Equation 9 to compute critical hydraulic head causing quicksand effect in boreholes across Umuahia and other south eastern urban and suburban dwellings.
2. That the well pump of 760watts power could be operated safely at 220volts beyond which the hydraulic head gets more critical (Eduvie, 2006).
3. That irrespective of the fact that an increase in hydraulic head increases discharge, the system should be operated at a head safe for the performance of the well.
4. That the above model can be used for the design of boreholes against failure and also monitor the performance of other boreholes

FURTHER RESEARCH

The scope of this research is being extended to study how to achieve safe pumping out of the critical state i.e. achieving equilibrium condition where hydraulic head restoring failure or dislodgement of discrete particles within the flow region is enhanced by investigating the counter effect of inter-granular force that exist between particles.

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