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Research article

FLUID PRESSURE MODEL TO PREDICT THE INFLUENCE OF VOID RATIO AND PERMEABILITY IN ALLUVIUM PREDOMINANT DEPOSITION IN RIVERS STATE, NIGERIA

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Abstract

Fluid pressure model to predict the influence of void ratio and permeability in alluvium predominant deposition has been evaluated. The study is to express the rate of fluid pressure under the influence of void ratio and permeability in the study location. The deposition of fluid pressures is influenced by these paramount parameters that are reflected from geological setting of the formation. Disintegration of the porous rocks is deposited in heterogeneous and homogeneous grain size reflecting the micropores and hydraulic conductivity in the formation; these are related to void ratio and permeability of the strata. But the focus of this study centred on alluvium structural stratification that is predominant in the study location. Based on these factors, mathematical model were applied to monitor fluid rate variation under the influence of void ratio and permeability. The systems were developed based on these variables that structured the governing equation to express fluid rate pressure in the study area. The study is imperative because fluid depositions and its rate of variations were not evaluated to showcase the determinants of fluid flow reflecting the yield of aquifers in the study area. The expressed model will definitely be applied as a conceptual framework to predict fluid pressure deposition in the study location.

Keywords: Fluid pressure, Model, Void ratio and Permeability.

1. Introduction

Down whole pressure transducers—coupled with electronic data loggers—are commonly used during ground water investigations to measure and record water levels in wells for long periods at relatively short intervals. Changes in barometric pressure often induce fluctuations in water level observations (Pascal 1973). Barometric pressure applies a load to the land surface as well as to the water surface in open wells (Jacob 1940). Barometric pressure changes because water level changes because the total head in an aquifer is the sum of the water level in the well plus the barometric pressure Nathanial J. T and Todd C. R .2007. Water level fluctuations are dependent on aquifer properties, properties of overlying materials, and the characteristics of the observation well. The lag between the water level fluctuation and the barometric stress complicates removal of barometric induced noise. Earth tides may also cause variation in water levels (Bredehoeft 1967; Hsieh 1987). These variations, which are clearly periodic, result from the elastic behavior of the aquifer skeleton. The physical deformation caused by gravitational and centripetal forces can affect the pore fluid pressure, resulting in water level changes in wells. The density and orientation of fractures are important determinants how these forces affect pore fluid pressure (Bower 1983). Rasmussen and Rasmussen (1997) describe how barometric response changes cause a range of ground water responses. Spane (2002) evaluated this approach and demonstrated how it improves smoothed aquifer water levels. The method removes more barometric noise from the data than a constant barometric efficiency because it incorporates the transient nature of the barometric efficiency of a well.

Bear (1979) presents a number of terms useful in considering soil moisture. The field capacity of a soil is the water content of the soil after all gravitational drainage has ceased. Any water content above this level, up to full saturation, is referred to as gravitational water. Marinho and Stuermer (1998) define the field capacity as "the maximum water content a soil can hold or store under a condition of complete wetting followed by drainage." Between the moisture content equal to the field capacity and that achieved when the soil is air-dried (moisture content equal to the hygroscopic coefficient), the soil water is referred to as capillary water. Within the capillary fringe, the soil retains a high degree of saturation (>75% according to Bear 1979, though most other references imply 85-90% as the minimum; for example Fredlund & Rahardjo, 1993a; Chenggang et al, 1998), but pore water pressures are negative with respect to the atmosphere. Significant groundwater flow may occur within the capillary fringe. Below the phreatic surface, pore water pressures are greater than atmospheric air pressure, and considered as positive water pressures. At the phreatic surface the pore water pressure is equal to the atmospheric pressure, and above the surface, pore water pressures drop below atmospheric and become negative. Such negative pressures are referred to as soil suction (or pore water tension). Soil suction actually has two components, matric and osmotic (or solute) (Fredlund and Rahardjo, 1993a; 1993b Richards, 1967 Eluozo, 2013). Oberg (1997) provides additional references to support this hypothesis. Thus, for 'straight' geotechnical engineering problems such as conventional slope stability analysis, not involving environmental aspects where pollutants and chemical gradients may be present, soil suction may be considered synonymous with matric suction. Matric suction is defined as "the difference between the pore-air and the pore-water pressures" (Fredlund and Rahardjo, 1993b; Fredlund and Barbour; 1992;

Fredlund and Hansan;1979; Fredlund; and Hwang 1994 Eluozo, 2013), Since the height of the capillary rise is dependent on the radius of the void in which said rise is occurring, it is clear that the capillary rise that will occur within a soil will be affected by particle size and grading, since this affects the size of the voids (or pores) within the soil mass.

2. Theoretical background

Fluid pressure is determined by the level of structural deposition of the soil under the influence of geological history. This is one of the major determinants of fluid pressure rate in soil and water environment. Subject to this relation, fluid pressure depositions develop several fluid variations depending on the structural deposition of the soil strata reflecting the geological history in the study area. Formation characteristics such as void ratio and permeability are the focus of this study, void ratio in soil are through the rate of disintegration of the porous rock in grain size structured with different variations deposits in either homogenous or heterogeneous in grain size deposition. The micropores between intercedes formation of the soil are the void ratios, while that of the permeability may take the advantage of the micropores as to be able to transmit fluid from one deposition to another. Therefore, the ability for such formations to transmit water determines the rate of permeability which can also be expressed at the rate of hydraulic conductivity in the formations. Fluid varies in different strata based on the rate of deposition of the grain size structures to be homogeneous or heterogeneous in the study location. Variation of void ratios also express in disintegration of the strata deposition of their grain size in different strata, which express different micropores known as void ration of the soil. Such deposition of intercedes including the grain size, it express several variations because the grain sizes are heterogeneous predominant in most conditions since it is determined by the rate of disintegration of these porous rocks. Fluids are influenced by different conditions such as climatic influence by high rain intensities that increase fluid depositions mostly in unsaturated vadose to saturated vadose, this can be described as aquiferous zones. The rate of hydraulic conductivity reflects the rate of permeability, subject to this relation, it is influenced by these conditions stated above. It is of interest that fluid pressure depositions reflect the influence of void ratio and permeability as expressed in this study.

3. Governing equation

$$Sop\frac{\partial^2 p}{\partial t^2} + \left[\varepsilon w\frac{\partial p}{\partial t}\right] w\frac{\partial p}{\partial t} - \frac{\partial p}{\partial x_1}\left[\frac{V_1 p}{\mu}\right]\left[\frac{\partial p}{\partial x_j} + Kg\frac{\partial p}{\partial x_i}\right] = QP_z \qquad \ldots\ldots\ldots\ldots \qquad (1)$$

Equation (1) is the governing equation to monitor fluid pressure under the influence of void ratio and permeability in the study location. Fluid pressure depositions are determined by the deposition of these two parameters as expressed in the system. Subject to this relation, void and permeability are structured to deposit in soil depending on the disintegration of the porous rock at different strata. The micropores between the intercedes of the soil express the rate of void ratios in the formation while the rate of hydraulic conductivities are expressed based on the rate of flow

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from one stratum to the other. Such conditions were considered in modifying the governing equation as expressed in equation (1).

Taking Laplace transformation of (1)

$$\frac{\partial^2 p}{\partial t^2} = S^2 P_{(t)} - SP - P_{(0)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (2)$$

$$\frac{\partial p}{\partial t} = SP_{(t)} - P_{(t)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3)$$

$$\frac{\partial p}{\partial t} = SP_{(t)} - P_{(t)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

$$\frac{\partial p}{\partial x} = SP_{(x)} - P_{(x)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (5)$$

$$\frac{\partial p}{\partial x} = SP_{(x)} - P_{(x)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

$$P = P_{(0)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (7)$$

Fluid depositions under the influence of the stated parameters are paramount in the system, it is transformed to Laplace. These influential variables that formulate derivative functions were transformed into Laplace to express their relationship in the system; this is through the application of these mathematical methods. Such expression will detail their relations with respect to their functions on the modified equations that determine fluid pressures influenced by void ratio and permeability at different strata.

Submitting equation (2), (3), (4), (5), (6) and (7) into equation (1), yields

$$Sop\left[S^2 P_{(t)} - SP_{(t)} - P_{(0)}\right] - \varepsilon w\left[SP_{(t)} - P_{(t)} - wSP_{(t)} - P_{(x)}\right] - \left[\frac{Vp}{\mu}\right] - \left[SP_{(x)} + Kg\frac{\partial p}{\partial x_j} + pgP_{(x)}\right] = QP_z \quad \ldots (8)$$

$$SoP_{(x)} - SoSP^1{}_{(t)} - P_{(0)} - \varepsilon w\, SP_{(0)}\ \varepsilon wP_{(0)} - wSP_{(t)} - P_{(0)} - \left[\frac{Vp}{\mu}\right] - \left[SP_{(0)} - P_{(x)} + Kg\, SP_{(x)}\right] = QP_z \quad \ldots.. \quad (9)$$

Equation (9) expresses the disintegration of the parameters into Laplace transform. This is to streamline the functional parameters in the system the direction of expressing their functions in details is to showcase the fluid variable depositions in different formations. The expression of these parameters in this mathematical concept is to monitor the behaviour of fluid depositions at different pressures under the influence of formation characteristics, it is denoted as paramount variable that express more of the fluid behaviour is in the system. Equations (6) to (9) are

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derived solution to integrate these variables and also to express their functions in the system, subject to their relations, the equation express various concept base on the behaviour in the system as the parameters modified from the governing equation.

Considering the following boundary condition at

$$t=0, P^{1}{}_{(0)} = P_{(0)} \qquad \text{..................} \quad (10)$$

$$P_{(t)}\left[Sop\,S^{2} - Sop - \varepsilon w - w - \frac{Vp}{\mu} + Kg\right] = 0 \qquad \text{..................} \quad (11)$$

But considering the boundary condition

$$\text{At } t > 0,\ P^{1}{}_{(0)} = P_{(0)} = P_{(0)} \qquad \text{..................} \quad (12)$$

Boundary conditions were considered in the system on the process of deriving the solution for fluid pressure deposition influenced by void ratio and permeability in the system. The expressed boundary values are considered based on the behaviour of fluid under the influence of the stratigraphy through the disintegration of the porous rock that reflects on the particle grain size at different strata. The deposition of void ratios and permeability are considered on the boundary condition established as such expression play major roles on the limits of fluid flow in soil and water environment. Subject to this relation, the rate of fluid flow and its pressure are determined through the expression of the boundary value that is reflected on the deposition of the strata under the influence of void ratio and permeability.

$$P_{(x)} - Sop\,S_{(t)} - \varepsilon w\,S_{(t)} - w\,S_{(t)} - \frac{Vp}{\mu}\,S_{(x)}\,QPz = Sop\,P_{0} + SoPPo + \varepsilon w P_{0} + w P_{0} + \frac{Vp}{\mu}P_{0} \quad \ldots (13)$$

$$\left[Sop - \varepsilon w - w - \frac{Vp}{\mu} - QPz\right]P_{(t)} = \left[Sops + Sop + \varepsilon w + w + \frac{Vp}{\mu}\right]P_{0} \qquad \text{..................} \quad (14)$$

$$\frac{P_{(t)} = Sop + \varepsilon w + w - \dfrac{Vp}{\mu}}{Sop - \varepsilon w - w - \dfrac{Vp}{\mu} - QPz}\,P_{0} \qquad \text{...................................} \quad (15)$$

Applying Quadratic expression, we have

$$S = \frac{b \pm \sqrt{b^{2} - 4ac}}{2a} \qquad \text{................................} \quad (16)$$

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Relating the derived solution from Laplace transformation, quadratic functions were found suitable to structure the derived solution; this is to prepared platform of expressing the variables by considering different conditions under the influence of formation variations in the environment. Such concept introduced will definitely showcase the pressure of fluids in detail considering several variations from formation characteristics such as void ratio and permeability. Fluctuations from the deposition of the formations are reflected in the systems which subject the fluid pressure to deposit different variations of fluid flow in different strata.

Where $a = Sop\varepsilon w,\ \ b\ =\ \dfrac{wVp}{\mu},\ c\ =\ KgQPz$

$$S\ =\ \frac{\frac{WVp}{\mu}\sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\,Kg\,QPz}}{2Sop\varepsilon w} \qquad \text{.......................... (17)}$$

$$S_1\ =\ \frac{\frac{Wkg}{\mu} - \sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\,Kg\,QPz}}{2Sop\varepsilon w} \qquad \text{.................................... (18)}$$

$$S_2\ =\ \frac{\frac{WVp}{\mu} + \sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\ KgQPz}}{2Sop\varepsilon w} \qquad \text{.................................... (19)}$$

$$S_1\ =\ \frac{\frac{WVp}{\mu}\left[+\sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\ KgQPz}\right]}{2Sop\varepsilon w} S_2 + \frac{\frac{WVp}{\mu} - \left[\sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\,Kg\,QPz}\right]}{2Sop\varepsilon w}$$

$$\ell^{\left[\frac{\frac{WVp}{\mu} + \sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\,Kg\,QPz}}{2Sop\varepsilon w}\right]\frac{L}{v}\left[-\frac{WkP}{\mu} - \frac{\frac{WVp}{\mu}\sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\ KgQPz}}{2Sop\varepsilon w}\right]} \qquad \text{................................ (20)}$$

Application of inverse Laplace in equation (21) were subject to the relation on variation of the soil structural deposition variation, this is to express the level of influenced by disintegration of the porous rock, it reflects the variation of the fluid pressure at different strata. These showcase the conditions of fluid flow expressing variations of the flow net from permeability and void ratio. In line with this relation, it is obvious that the pressure of fluid at different strata will be heterogeneous, therefore, inverse Laplace transformation application were found necessary in

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the system considering such condition, so that the variation of pressure of fluid can be reflected on the derived solution.

Applying Laplace inverse of the equation, we obtain

$$P_{(t)} = \left[Sop\,\varepsilon w + Sop\,\varepsilon w + \frac{wKp}{\mu} \right] P_{(0)}\,\ell^{\frac{\left[\frac{WVp}{\mu} \sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\ QPz} \right] t\ +}{2Sop\varepsilon w}}$$

$$\frac{\left[\frac{WVp}{\mu} \sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\ KgQPz} \right] t}{2Sop\varepsilon w} \qquad \ldots\ldots\ldots \quad (21)$$

But if $t = \frac{d}{v}$

$$P\left[L, v\right] = \frac{Sop\varepsilon w}{L/v} + Sop\varepsilon w + \frac{WVp}{\mu} P_0\,\ell^{\frac{\left[\frac{WVp}{\mu} + \left[\sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\,Kg\,QPz} \right] \right] \frac{L}{v}}{2Sop\varepsilon w}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

Considering the following boundary conditions at

$$t = 0,\ P^1{}_0 = 0,\ P_0 = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

Boundary values were expressed again to integrate the inverse Laplace conditions that were applied in the system. The boundary condition showcase the time limit considering the inverse phase of the system, initial and final pressure rate of flow within the intercedes of the formation were noted under the influence of the micropores of the soil matrix. The reflection of void ratio and the hydraulic conductivity in the formation are the major influenced expressed in the boundary value of the system . This boundary formation showcases the limit of pressure flow with respect to time and distance. The study precisely focuses on the paramount variables but never undermined other dependent variables that also influence pressure rate of fluid at different strata in the system.

$$P_{(x)} = \left[\frac{Sop\varepsilon w}{t} + Sop\varepsilon w + \frac{WVp}{\mu} \right] P_0\,\ell^{\frac{\left[\frac{WVp}{\mu} \left[\sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\ KgQPz} \right] \right] \frac{L}{v}}{2Sop\varepsilon w}} +$$

$$\frac{\left[\frac{WVp}{\mu} \left[\sqrt{\frac{WVp^2}{\mu} + 4Sop\varepsilon w\ KgQPz} \right] \right] \frac{L}{v}}{2Sop\varepsilon w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (24)$$

At $P^1{}_0 = t \neq 0$

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Again, $P_0 = P_{(0)}$ so that

$$P_0 \left[Sop\varepsilon w + \frac{WVp}{\mu} \right] P_0 [1 + 1] i.e.\ 0 = \left[0 + \frac{WVp}{\mu} \right] 2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (25)$$

$$\Rightarrow \quad \frac{WVp}{\mu} + \frac{WVp}{\mu} = 0$$

$$P_{(x)} = \left[2 \frac{Sop\varepsilon w}{2} \right] P_0 \, \ell^{\frac{\left[\frac{WVp}{\mu} \left[\sqrt{\frac{WVp}{\mu} + 4Sop\varepsilon w + KgQPz} \right] \right] \frac{L}{v}}{2Sop\varepsilon w}} + {\frac{\left[\frac{WVp}{\mu} \left[\sqrt{\frac{WVp}{\mu} + 4Sop\varepsilon w + KgQPz} \right] \right] \frac{L}{v}}{2Sop\varepsilon w}} \qquad \ldots\ldots\ldots \quad (26)$$

Moreover, $e^x + e^{-x} = 2Cos\,x$ therefore, we have

$$P_{(x)} = \left[2 \frac{Sop\varepsilon w}{t} \right] P_0 \, Cos \frac{\left[\frac{WVp}{\mu} \left[\sqrt{\frac{WVp}{\mu} + 4Sop\varepsilon w + Kg\,QPz} \right] \right] \frac{L}{v}}{2Sop\varepsilon w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (27)$$

The expression in (27) is a final model equation. This expression reflects all the conditions that were considered to influence the fluid pressure deposition at different strata in the system. Paramount parameters were structured in the system to extensively express their functions on the deposition of fluid pressure rate in soil and water environment. Such conditions were considered to streamline the behaviour of fluid pressure under the influence of formation characteristics noted to be paramount variables that determine the deposition of fluids. The study focuses on the fluid rate as it determines the increase of aquiferous yield coefficient of groundwater system under the influence of the micropores, the deposition of fluid pressure rate reflect the structure of variation of void ratio as expressed in the stratification of the formation.

4. Conclusion

The deposition of fluid pressure influenced by permeability and void ratio has been streamlined based on the geological setting in the study location. These conditions were observed from hydrogeological studies that reflect different yield coefficient at different formations in the study area. Reflecting these conditions is expressed on the rate of fluid deposition based on disintegration of the stratification of the porous rock. The deposits of the strata at different particle grain sizes showcasing void ratio and permeability. Subject to this relation, it was observed that fluid pressure developed at different rate are reflected on the structural stratification between the intercedes of the strata reflecting void ratio and permeability. Other dependent variables were also considered in the system but were made insignificant due to two paramount parameters which are independent variables that reflect every other influence of fluid flow and its pressure rate in soil and water environment. The study is imperative because the fluid flow determine the yield rate mostly at aquiferous zone and lack of information of fluid pressure which express the yield rate of aquiferous zone were not made available. This predictive model from the derived governing equation, have developed a model which is a conceptual framework that can be applied to monitor the flow of and its pressure rate in the study location. Experts in this profession will definitely apply this concept to determine the best yield aquiferous zone in construction and design of water wells.

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