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*Original Research Paper*

# Predictive Model to Monitor Fluid and Gas Media Transport Influenced by Permeability in Concrete Pavement

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**Monitoring the deposition of fluid and gas media transport in concrete pavement has been thoroughly evaluated. The study was to monitor the effect of these two parameters, low permeability deposition in concrete pavement determined the level of imposed load or the rate of compression strength on pavement, the impact of permeability were evaluated in the deposition of fluid and gas transport in concrete pavement, the system expressed various variables that pressure the deposition of fluid and gas media transport in concrete pavement. It also dicretize various condition of fluid and gas transport in concrete pavement, these expressions were in phases through the derived solutions, the derived resolution integrated other models considered in various phases to produced the final model for the study, experts will definitely apply these concepts in monitoring fluid and gas media transport in concrete pavement.**

**Keywords:** Predictive model, fluid, gas, transport, permeability, concrete pavement.

## INTRODUCTION

Numerous recent studies encompass has shown a relationship subsist between the transport properties of concrete and performance. Virginia Department of Transportation, VDOT (Lane 2006) has in recent times performed two studies connected to the permeability of concrete. The first VDOT study (Ozylindrim 1998) examined the production and testing of low permeability concrete; while the second VDOT study, evaluates diverse techniques of permeability evaluation (Lane 2006). VDOT has planned the expansion of a record of the permeability properties for pavements used in their study location (Lane 2006). This would enable permeability properties to be measured and used in quality control procedures and service life prediction (Javier et al 2010).

Roads have achieved a very functional responsibility in meeting the strategic and developmental necessities, increase speed all-round growth. Scientific development in road construction technology has reserved pace with speedy changes in the meadow of infrastructural development. The globe has observed the engineering brilliance in Nigeria, India, etc in various fields of Civil Engineering together with road construction, and the competence of our engineers in implementing a scientific approach towards solving demanding problems. Sub-grades play an important role in imparting structural stability to the pavement structure as it receives loads imposed upon it by road traffic. Traffic loads require to be transformed in a way that the subgrade-deformation is between elastic limits, and the shear forces developed is between safe limits under unpleasant climatic and loading conditions. The sub-grade encompass unbound earth materials such as gravel, sand, silt and, clay that pressure the

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design and construction of roads. The assessment of properties of soil sub-grades, in terms of compactness, soil stiffness, strength, and other in-situ parameters is vital in the design of roads, and their performance. Conventionally, flexible pavements are designed based on the CBR procedures or by comportment in mind resilient deformations. The CBR progress to pavement planned gained popularity between practicing engineers in years past with the use of sophisticated computing authority and speed (Rollings 2003, Ch et al 2008).

The concept of flexible pavement plan gives more significance to the evaluation of the compactness of the sub-grades and the pavement layers. Other design philosophies for flexible pavement do exist, as well as those with an additional basis in the theory of the mechanics of materials—these include layered elastic and finite element approaches. In the conventional approach to design of flexible pavements using the Burmister's (1958) layer theory, it is required to estimate the elastic modulus of the sub-grade in order to determine the required layer-thickness of a pavement structure. Not withstanding the advances in these state-of-the art procedures for pavement design, the CBR procedures continue to be one of the most dependable techniques for pavement design, especially in the design of pavements for military and civilian aviation (Semen 2006, Ch et al 2008).

This method is supported by more than 60 years of field experience under a wide range of conditions throughout the world. In addition to this, the approach to quality control of pavements gives more importance to the determination of in-situ density and moisture content. But according to Chen et al. (1999), and Livneh and Goldberg (2001), although 'density' is a good indicator of the strength of granular subgrades, it is also necessary to investigate the modulus of the subgrade, since these measures represent different natural characteristics (Ch et al 2008). Modern devices such as the falling weight deflectometers (FWD), GeoGauges, dirt-seismic pavement analyzers (DSPA), and laboratory-based repetitive tri-axial tests are used to estimate the modulus of elasticity of pavement layers (Nazarian et al., 2002; Livneh and Goldberg, 2001; Rahim and George, 2002; and Sawangsuriya et al., 2002). But each of these devices has its advantages and disadvantages. The use of FWDs require the deployment of trained personnel in addition to heavy investments, although the results are reliable, while the use of laboratory-based repetitive tri-axial tests are not generally adopted due to cumbersome procedures in addition to the need for skilled professionals (Rahim and George, 2002; Chen et al., 2001).

In comparison to the above analysis, using dirt-seismic pavement analyzers (DSPA) is quick and easy, but the modulus-value determined, is considered to vary over wide ranges. The results obtained using GeoGauges show more consistency, but are highly sensitive to the preparation of the surface to be analyzed, and is considered to provide a composite stiffness that includes the effect of all layers up to an un-specified depth (Chen et al., 2005). But the invention of the portable falling weight deflectometers (PFWD) has revolutionized the field of pavement-evaluation mainly due to its simplicity, ease of use, portability, reliability, and ruggedness. But Huang (1993) justifies that 'dependence on observed performance is necessary because theory alone has not proven sufficient to design pavements realistically'. The CBR method, thus still serves as the foundation for the design of flexible and un-surfaced pavements and their evaluation, particularly in circumstances where 'expedient and contingency evaluation' of 'military airfield pavements' (Davit et al. 2002). But recently, there is a preference among road-engineers to adopt simpler, faster and more reliable methods of pavement evaluation, the results of which can correlate with the CBR test (Al-Amoudi et al., 2002), which is the most widely adopted traditional approach to pavement evaluation. Due to this reason, it is essential to correlate the results obtained through the CBR method, to that obtained using the FWD or PFWD (FAA, 1995; Barter et al., 1975). Also, according to the manufacturers of non-destructive testing equipment, the relationships between the CBR values and the moduli of elasticity are dependent upon the local geology (Phillips 2005).

## Theoretical Background

The developments of permeability in concrete are based on several conditions. The constituent known as binder with aggregate are blended together in precise proportions. The relative proportions of these materials determine the physical properties of the concrete pavement and ultimately how the characteristic performs as a finished pavement. The design system for determining the appropriate proportions of cement as a binder between aggregate in the concrete pavement is the Superpave Method. In concrete pavement, the binding agent cement and aggregate are blended together in accurate proportions.

The relative proportions of these materials determine the physical properties of the concrete pavement and ultimately how it level of performances as a finished pavement. The design technique for determining the appropriate proportions of binder and aggregate in the concrete formations is the Superpave technique. The concreteness of the compacted mix is the unit heaviness of the material combination (the weight of a specific volume of concrete formations). Density is imperative because the proper compactness in the finished product is important for lasting pavement performance. Mix properties are necessary to be calculated in volumetric terms as well as weight. Density allows us to convert from unit weight to volume. Air voids are small air spaces or pockets of air that occur between the coated aggregate particles in the final compacted concrete formation. A certain percentage of air voids is necessary in all dense-graded mixes to prevent the pavement from flushing, shoving, and rutting. Air voids may be enlarged or decreased by lowering or raising the binder content.

They may also be increased or decreased by controlling the amount of material passing the No. 200 sieve in the concrete pavement. The more fines added to the concrete pavement formation generally the lower the air voids. Voids in the mineral aggregate (VMA) are the void spaces that exist between the aggregate particles in the compacted concrete pavement, including the space filled with the binder. VMA represents the space that is available to accommodate the effective volume of the binder (i.e., all of the binder except the portion lost by absorption into the aggregate) and the volume of air voids necessary in the concrete pavement. The more VMA in the dry aggregate, the more space is available for the binder. Since a thick binder film on the aggregate particles results in a more durable HMA, specific minimum requirements for VMA are recommended and specified as a function of the aggregate size.

## Developed Governing Equation

$$V\frac{\partial c}{\partial t} = \frac{q}{A}\frac{\partial^2 c}{\partial z^2} + \frac{K_f}{n}\frac{\partial c}{\partial z} + \frac{\Delta\rho}{h}\frac{\partial^2 c}{\partial z^2} \quad ....... (1)$$

The expression here is the developed governing equation, the system are base on the variable that pressured the migration of fluid gas in concrete pavement, the behaviour of fluid gas in concrete formation were express through the permeability and porosity parameters in the system, other variables were expressed in the system, they also played several roles in the reaction of concrete formation, the parameters expressed in the governing equation were been resolved to generate the developed model for the study.

**Nomenclature**

| | | |
|---|---|---|
| V | = | Velocity of flow in the media (M/s) |
| q | = | Mass flow rate $M^3$/s |
| A | = | Specimen pressure |
| $P_a$ | = | Flow length through the specimen |
| h | = | |
| n | = | Porosity |
| t | = | Time of flow on concrete permeability |
| z | = | Thickness of plain concrete formation |
| $k_f$ | = | permeability coefficient |

$$V\frac{\partial c}{\partial t} = \left(\frac{q}{A} + \frac{\Delta\rho_a}{h}\right)\frac{\partial^2 c}{\partial z^2} + \frac{K_f}{n}\frac{\partial c}{\partial z} \quad ..............(2)$$

$$V\frac{\partial c_1}{\partial t} = \left(\frac{q}{A} + \frac{\Delta\rho_a}{h}\right)\frac{\partial^2 c_1}{\partial z^2} \quad ............ (3)$$

$$V\frac{\partial c_1}{\partial t} = \frac{K_f}{n}\frac{\partial c_2}{\partial z} \quad ............(4)$$

$$\left(\frac{q}{A} + \frac{\Delta\rho_a}{h}\right)\frac{\partial^2 c_3}{\partial z^2} = -\frac{K_f}{n}\frac{\partial c_3}{\partial z} \quad ............ (5)$$

The solution is of the form:

$$c = (t,z) = c_1(t,z) + c_2(t,z) + c_3(t,z)$$

Let $c = TZ$ ............. (6)

$$\frac{\partial c}{\partial T} = T^1 Z \quad ............. (7)$$

$$\frac{\partial c}{\partial z} = TZ^1 \quad ............. (8)$$

$$\frac{\partial^2 c}{\partial z^2} = TZ^{11} \quad ............. (9)$$

Consider (3)

$$VT^1 Z = \left(\frac{q}{A} + \frac{\Delta\rho_a}{h}\right)TZ^{11} = \rho_a^{\ 2} \quad ......... (10)$$

$$VT^1 Z = \varphi^2 \quad .......... (11)$$

$$\int\frac{dT}{T} = \int\frac{\rho^2}{V}dt \quad ............ (12)$$

$$Ln\,T = \frac{\rho_a^{\ 2}}{V} + c \quad ............. (13)$$

$$T = A\ell^{\frac{\rho^2}{V}t} \quad ............ (14)$$

Again $\left(\frac{q}{A} + \frac{\Delta\rho}{h}\right)TZ^{11} = \varphi^2$

$$\left(\frac{q}{A} + \frac{\Delta\rho}{h}\right)Z^{11} = \rho_a^{\ 2} \quad .......... (15)$$

$$Z = B\ell^{\frac{\rho}{\frac{q}{A}+\frac{\Delta\rho}{h}}Z} + C\ell^{-\frac{\rho}{\frac{q}{A}+\frac{\Delta\rho}{h}}Z} \quad ......... (16)$$

Combined (14) and (16) gives

$$c_1(t,z) = \left(B\ell^{\frac{\rho}{\frac{q}{A}+\frac{\Delta\rho}{h}}Z} + C\ell^{-\frac{\rho}{\frac{q}{A}+\frac{\Delta\rho}{h}}Z}\right)A\ell^{\frac{\rho^2}{V}t} \quad ... (17)$$

The expression in [17] show displayed model under the influences of flow rate within the specimen, the system establish change of flow with respect to thick of concrete formation including other characteristics of the concrete structures, the system developed is to monitor the medial influenced by concrete formation in various dimension, therefore it will be insignificant if the express flow rate under the impact of time are not considered, the expressed model considered these transport influences of gas in this phase as it developed in the expressed model at [17].

Consider equation (4)

$$V\frac{\partial c_2}{\partial t} = \frac{K_f}{n}\frac{\partial c_2}{\partial z}$$

$$VT^1Z = \frac{K_f}{n}TZ^1$$

$$V\frac{T^1}{T} = \frac{K_f}{n}\frac{Z^1}{Z} = \tau \quad ........... \quad (18)$$

$$V\frac{T^1}{T} = \tau \quad ........... \quad (19)$$

$$\int\frac{dT}{T} = \frac{\tau}{V}\int dt \quad ........... \quad (20)$$

$$Ln\,T = \frac{\tau}{V} + \alpha \quad ............ \quad (21)$$

$$T = C\ell^{\frac{\tau}{V}t} \quad ............. \quad (22)$$

Again $\frac{K_f}{n}\frac{Z^1}{Z} = \tau$

$$\int\frac{dz}{z} = \int\frac{\tau n}{K_f}dz \quad ............. \quad (23)$$

$$Ln\,z = \frac{\tau n}{K_f}z + b \quad ........... \quad (24)$$

$$z = \Delta\ell^{\frac{\tau n}{K_f}} \quad ........... \quad (25)$$

Combining (22) and (25), gives;

$$c_2\,(t,z) = CD\ell^{\left(\frac{1}{V}+\frac{n}{K_f}\right)\tau} \quad ............ \quad (26)$$

Consider equation (5)

$$\left(\frac{q}{A}+\frac{\Delta\rho}{h}\right)TZ^{11} = -\frac{K_f}{n}Z^1T$$

$$\left(\frac{q}{A}+\frac{\Delta\rho}{h}\right)\frac{d^2z}{dz^2} = -\frac{K_f}{n}\frac{dz}{dt} = -\alpha^2 \quad ... \quad (27)$$

$$\left(\frac{q}{A}+\frac{\Delta\rho}{h}\right)\frac{d^2z}{dz^2} = -\alpha^2 \quad ...... \quad (28)$$

$$Z = E\,Cos\frac{\alpha}{\sqrt{\frac{q}{A}+\frac{\Delta\rho}{h}}}z + F\,Sin\frac{\alpha}{\sqrt{\frac{q}{A}+\frac{\Delta\rho}{h}}}z \quad .... \quad (29)$$

Also $+\frac{K_f}{n}\frac{dz}{dz} = +\alpha^2$

$$\int\frac{dz}{z} = \frac{n\alpha^2}{K_f}\int dz \quad ......... \quad (30)$$

$$Ln\,z = \frac{n\alpha^2}{K_f}z + d \quad ....... \quad (31)$$

$$z = G\ell^{\frac{n\alpha^2}{K_f}z} \quad ....... \quad (32)$$

Combining (29) and (32) yield

$$c_3\,(t,z) = \left(E\,Cos\frac{\alpha}{\sqrt{\frac{q}{A}+\frac{\Delta\rho}{h}}}z + F\,Sin\frac{\alpha}{\sqrt{\frac{q}{A}+\frac{\Delta\rho}{h}}}z\right)G\ell^{\frac{n\alpha^2}{K_f}z}$$

……….(33)

The flow rate of the gas in the media are pressured by the characteristics of concrete formation, in line with is conceptual frame work, the developed model considered change of flow rate in various dimension through the specimen pressure, the condition of the concrete can only be monitored in the phase when the degree of porosity are very high in concrete formation, this implies that the concrete pavement will definitely not meet design life expectancy, the degree of high porosity within the concrete formation are expressed in the derived solution at this phase with respect to thickness of the concrete pavement, the rate flow rate are determined by the degree of concrete permeability.

Therefore, combined equations (17), (26) and (33) give

$$c(t,z) = c_1(t,z) + c_2(t,z) + c_3(t,z)$$

$$c_1(t,z) = \left(B\ell^{\frac{\rho}{\frac{q}{A}+\frac{\Delta\rho}{h}}Z} + C\ell^{-\frac{\rho}{\frac{q}{A}+\frac{\Delta\rho}{h}}Z}\right)A\ell^{\frac{\rho^2}{V}t} \quad +$$

$$c_2\,(t,z) = CD\ell^{\left(\frac{1}{V}+\frac{n}{K_f}\right)\tau} \quad +$$

$$c_3\,(t,z) = \left(E\,Cos\frac{\alpha}{\sqrt{\frac{q}{A}+\frac{\Delta\rho}{h}}}z + F\,Sin\frac{\alpha}{\sqrt{\frac{q}{A}+\frac{\Delta\rho}{h}}}z\right)G\ell^{\frac{n\alpha^2}{K_f}z}$$

The deposition of fluid and gas transport media in concrete pavement has been evaluated through this developmental model, the deposition of such constituent is the major factor that determined the behaviour of the fluid and gas transport in the concrete pavement. The fluid flow between the concrete are determined by the formation and the level of placement in the construction process, the developed model examines various variables that influence the system in order to developed model influenced by all the influential parameters in the system. The derived solutions generate various models in accordance with the behaviour of the fluid and gas media from concrete pavement.

## CONCLUSION

Fluids in concrete only take place when concrete for various constructions are very permeable and based on that condition, the rate of it workability will be very low. The deposition of gas migrating through fluid can be possible if the constituents of concrete formation are structured to the specification based on design. The deformation of concrete has been evaluated from various experts which has expressed several reasons why most concrete formations do not meet their optimum designed life expectancy, the deposition fluid and gas in concrete pavement were considered to be one of the major deformation of concrete strength, therefore the tendency of experiencing several rate of deformation are very much possible in the construction process.

Based on these conditions, the rate of this migration has not been monitored, this has caused insufficient information that will assist in preventing these deformations in any concrete pavement. It is imperative that the rate of fluid and gas transport media should be monitored, so that prevention and management of concrete formation and placement can be thoroughly handled. Development of mathematical model was one of the best approaches found that can thoroughly determine the rate of fluid and gas transport media in concrete formation, the developed model has definitely expressed various dimensions from most parameters that pressure the migration process in concrete pavement.

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