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Rainfall intensity effects on pavement base layers in Basrah City

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ABSTRACT

The main objective of this work is to study the effect of rainfall intensity on pavements layers thickness of two types of pavement structure, that is, flexible and rigid pavement. This is done by using Maple 13 software for modeling of this problem and calculation of the rainfall intensity and pavement infiltration. It was found that pavement infiltration increases with increasing rainfall intensity because increase in rainfall intensity caused an increase in the infiltrated water to the base and sub-base layers. Accordingly an increase in pore water pressure resulted which in turn causes an increase in porosity and decrease of base and sub-base degree of compaction. This leads to increase in time-to-drain, decrease in drainage coefficient for base and sub-base, and subsequently increase in their thickness. For flexible pavement, rainfall intensity 256 mm/h gives pavement infiltration, thickness and drainage coefficient of 3.2 m/day, 46 cm, 0.57 respectively, while rainfall intensity 25 mm/h gives pavement infiltration, thickness and drainage coefficient of 0.4 m/day, 18.5 cm and 1.7, respectively. In rigid pavement, rainfall intensity 256 mm/h gives thickness and drainage coefficient of 24.8 cm and 0.9 respectively, while rainfall intensity 25 mm/h gives thickness and drainage coefficient of 21.3 cm and 1.2, respectively. Drainage of accumulated water on pavement is rapidly drained in as short time as possible due to minimize potential moisture damage to a pavement structure. It was found that water in the pavement system can lead to modulus reduction and loss of strength for pavement. Saturation can reduce the dry modulus of both the asphalt layer (30% or more) and the base and sub-base modulus (50% or more). Similarly, modulus reduction of up to 30% can be expected for asphalt-treated bases, and over 50% for saturated fine-grained sub grade soils. It was found that soil types effects of moisture in pavement have been based on conditions of total saturation with loss of pavement strength which affect the state of stress through suction (effective porosity) or pore water pressure, and affect the structure of the soil through destruction of the cementation between soil particles, because of soil types difference in coefficient of permeability. Soil types used in this study include well-graded sand, uniform dense sand and fine-grain soil.

Keywords: Intensity, pavement, rainfall, drainage, sub base, base.

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INTRODUCTION

Moisture gets in the road structure through the normal circulation process of water. The main sources of water are precipitation, but also infiltration from water courses, absorption from the melting snow and capillary voids of soil assist in the accumulation of water in the structure as can be seen from Figure 1 (Saarenketo, 2005).

It is a well-known fact that water in pavement systems is one of the principal causes of premature pavement failure. Water in the pavement system can lead to moisture damage, modulus reduction, and loss of strength. Saturation can reduce the dry modulus of both the asphalt layer (30% or more) and the base and sub-base modulus (50% or more). Similarly, modulus reduction of up to 30% can be expected for asphalt-treated bases, and over 50% for saturated fine-grained sub grade soils.

The detrimental effects of water in the pavement system are significant:

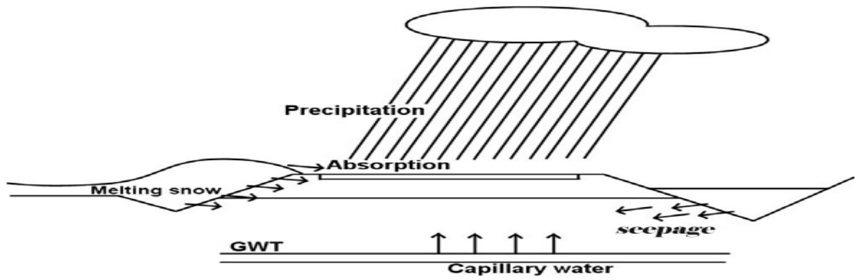

Figure 1. Main sources of the water in the road structure.

1. Water in the asphalt surface can lead to moisture damage, modulus reduction and loss of tensile strength. Saturation can reduce the dry modulus of the asphalt by as much as 30% or more.
2. Added moisture in unbound aggregate base and sub-base is anticipated to result in a loss of stiffness on the order of 50% or more.
3. Modulus reduction of up to 30% can be expected for asphalt-treated base and increase erosion susceptibility of cement or lime treated bases.
4. Saturated fine -grain roadbed soil could experience modulus reductions of over 50%.

LITERATURE REVIEW

According to Ariza and Birgisson (2002), studies on the effects of moisture in pavement have been based on conditions of total saturation with loss of pavement strength calculated using saturated flow assumptions. Yet roadbeds reach full saturation only when positive total heads are present (e.g., surface ponding, etc.) and distributed in such a manner that saturation of the pavement system is reached. The authors propose a first step toward a comprehensive approach to drainage and pavement design that integrates the true effects of moisture on pavement moduli and mechanistic-empirical pavement design. The authors used SEEP/W and DRIP software to analyze data collected at the Minnesota Road Research project (Mn/ROAD Cell 33, Cell 34, and Cell 35). The SEEP/W software modeled unsaturated flow under transient conditions through layered systems under complex boundary conditions and material characterizations.

O'Donnell (2008) investigated water has a detrimental effect on pavement performance, primarily by either weakening subsurface materials or eroding material by free water movement. For flexible pavements, the weakening of the base, sub-base, or sub-grade when saturated with water is one of the main causes of pavement failures. In rigid pavement, free water trapped between the concrete surface and an impermeable layer directly beneath the concrete, moves due to pressure caused by loadings. This movement of water (referred to as pumping) erodes the subsurface material, creating voids under the concrete surface. In frost areas, subsurface water will contribute to frost damage by heaving during freezing and loss of sub-grade support during thawing. Poor subsurface drainage can also contribute to secondary damage such as cracking or swelling of subsurface materials studied factors influencing the amount of free water entering the pavement system, which include:

i) Climatic factors of rainfall and temperature (freezing and thawing).
ii) Ground water.
iii) Roadway geometry.
iv) Pavement type and condition.

Accumulation of moisture introduced into the pavement sub-grade from any of the sources can adversely affect pavement performance, leading to accelerated pavement deterioration.

In summary, the discussion of previous literatures was studying about pavement performance that includes the effect of moisture on decreased pavement life and the quality of the subsurface drainage. In this study, we present the effect of water (rainfall intensity) on pavement layers (base and sub-base), through its effect on time-to-drain, drainage coefficient and thickness for base and sub-base (pavement layers) and affect the state of stress through suction or pore water pressure on pavement layers.

METHODOLOGY

The IDF formulas are the empirical equations representing a relationship between maximum rainfall intensity (as dependant variable) and other parameters of interest such as rainfall duration and frequency (as independent variables). There are several commonly used functions found in the literature of hydrology applications (Maha and Ahmed, 2012), basic forms of equation used to describe the rainfall intensity duration relationship are summarized as follows in Basrah city:

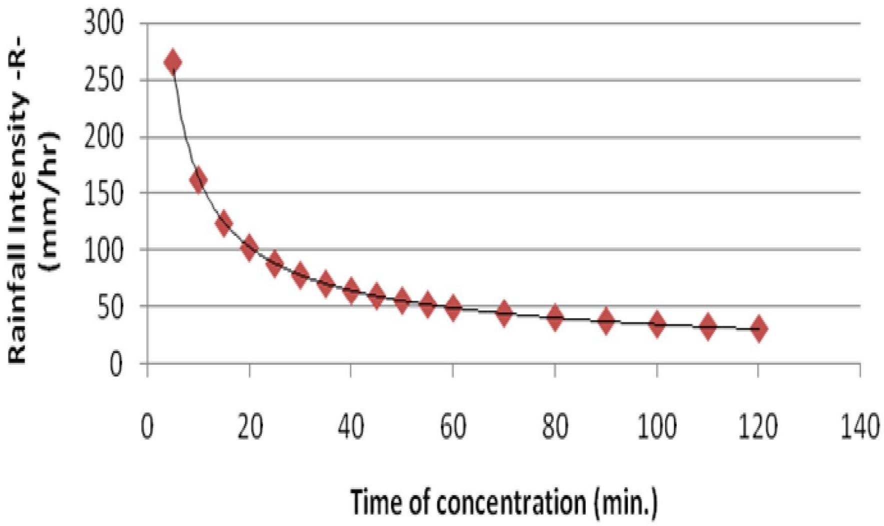

Figure 2. Intensity-Duration-Frequency curves (IDF curve) for Basrah city.

$$R = \frac{373.0575 \times T_R^{297.05 \cdot 10^{-3}}}{t_c^{0.66}}$$

From Intensity-Duration-Frequency curves (IDF curves) for Basrah city rainfall intensity was evaluated IDF curve is shown in Figure 2.

In this method, a design rainfall and an infiltration ratio are selected.

Based on these parameters, the pavement infiltration (q) is determined using equation:

$$q_i = 0.024 (C).(R)$$

Where;

q_i = Pavement infiltration, (m^3/day/m^2 of pavement)
C = Infiltration ratio
R = Rainfall rate (mm/h).

Figure 3 shows the relationship between rainfall intensity and infiltration pavement. It can be seen that the infiltration pavement increases with increasing rainfall intensity.

Guidance for the quality of drainage based on 85% saturation is provided in Table 1. The 85% saturation method considers both the water that can drain and the water retained by the effective porosity quality of the material (ERES, 1999).

The time for drainage of these layers is a function of effective porosity, length of the drainage path, thickness of the layers, slope of the drainage path, and permeability of the layers. Past criterion has specified that the base and sub-base obtain a degree of 85% drainage. The equation for computing the time for 85% drainage is (FHWA, 2006):

$$t_{85} = \frac{n_e * L^2}{k * (H + S * L)} * 24$$

Where

t_{85} time for85ercent drainage (h), n_e = effective porosity of the soil, k = coefficient of permeability(m/day), H_O , L and H = base and sub-base geometry dimensions.

The input data and output data of program is shown in Table 2.

CASE STUDIES AND RESULTS

Flexible pavement

Flexible pavement consists of a surface layer constructed of flexible materials (typically asphalt concrete) over granular base and sub-base layers placed on the existing, natural soil. Flexible pavement is shown in Figure 4.

Soil properties

The effect of soil type is studied by using three types of soil each for base and sub-base layers. The soil properties include density and coefficient of permeability and are given in Table 3.

Soil type of uniform dense sand (base) and fine-grain soil (sub-base)

Results are:

a) Figure 5 presents the effect of rainfall intensity on

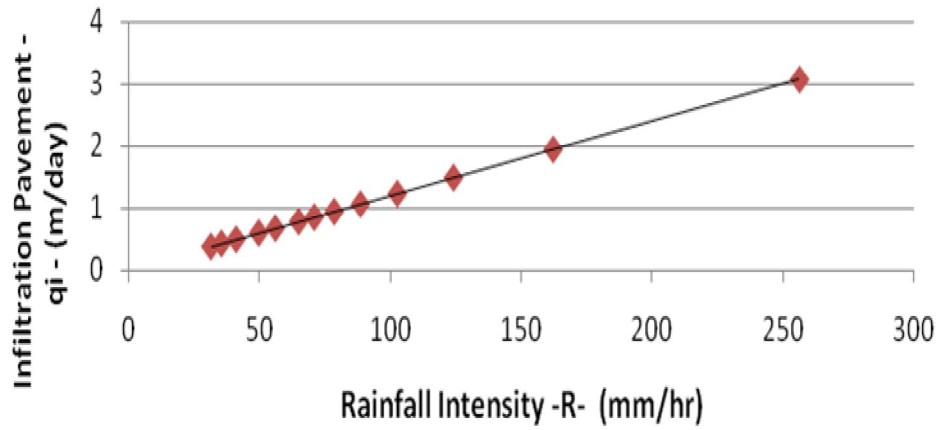

Figure 3. Relationship between rainfall intensity and infiltration pavement.

Table 1. Pavement rehabilitation manual guidance for time to drain from 100 to 85 percent saturation (FHWA, 1994).

Quality of drainage	Time-to-drain
Excellent	Less than 2 hours
Good	2 to 5 hours
Fair	5 to 10 hours
Poor	Greater than 10 hours
Very Poor	Much greater than 10 hours

Table 2. input parameters.

Input parameter	Description
t_c	Time of concentration
C	Infiltration coefficient
S_C	The transverse slope of the drainage layer
S_L	The longitudinal slope of the drainage layer
X	The length of the transverse slope of the drainage layer
g_d	Dry density
g_w	Density of water
G_S	Specific gravity of solid
WL	Water loss
k	Coefficient of permeability
H	Thickness of the drainage layer
CBR	California bearing ratio
D_D	Directional distribution factor
D_L	Lane distribution factor
AADT	Average annual daily traffic
g	The annual traffic growth rate
t	Service life, year
Z_R	Standard normal deviation
S_O	Overall standard deviation error
PSI_o	Initial serviceability index
PSI_t	Terminal serviceability index
F_C	Compressive strength
J	Joint load transfer coefficient

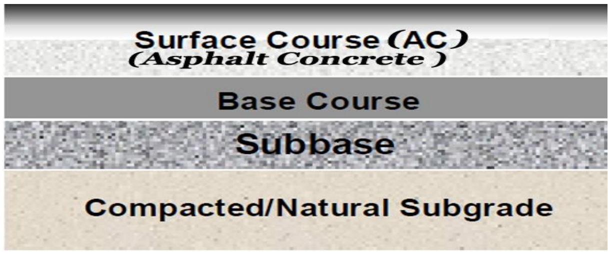

Figure 4. Flexible pavement.

Table 3. Soil type, density of dry and coefficient of permeability (FHWA, 2006).

Soil type	Density of dry (kN/m^3)	Coefficient of permeability (m/day)
Well-graded sand (dense)	18.2	500
Uniform sand (dense)	17.1	400
Fine-grain soil*	11.9	300 × 10^{-3}

*Less than 5% smaller than a 0.075 mm (No. 200 U.S. sieve).

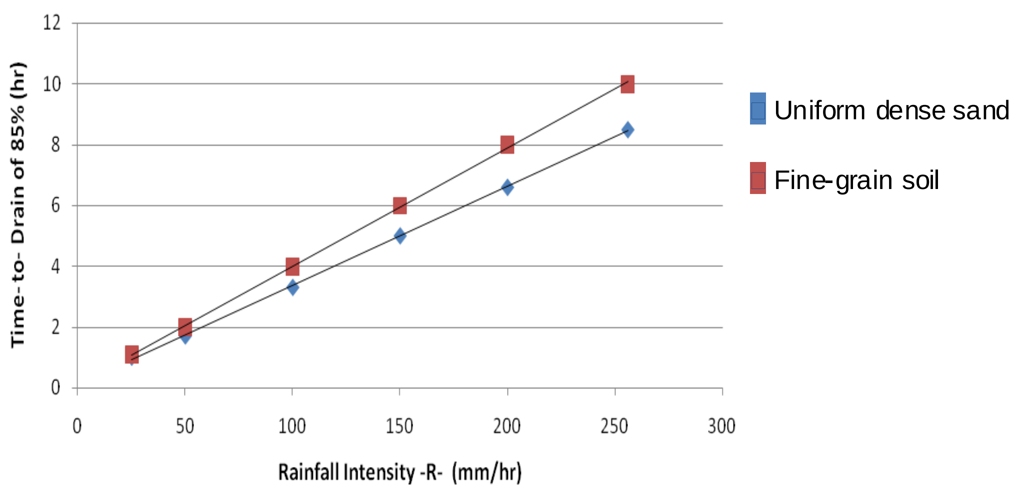

Figure 5. Relationship between rainfall intensity and Time to-Drain of 85% for sub- base (fine-grain soil) and base (uniform dense sand).

Time-to-Drain (t_{85}) for base (uniform dense sand) and sub–base (fine-grain soil). Increase in rainfall intensity caused an increase in the infiltrated water to the base and sub-base layers. Accordingly an increase in pore water pressure resulted which in turn caused an increase in porosity and decrease of base and sub-base degree of compaction. Figure 5 shows relationship between rainfall intensity and time-to-drain. As can be seen from this figure for a certain rainfall intensity, the time-to-drain is higher in fine-grain soil than uniform dense sand, because of permeability coefficient for uniform dense sand is higher than fine-grain soil.

b) Figure 6 shows the relationship between rainfall intensity and the drainage coefficient for sub-base (fine-grain soil) and base (uniform dense sand). As can be seen from this figure a rapid decrease in the values of drainage coefficient for fine-grain soil (sub-base) and uniform dense sand (base) occurs at the start and for extent a rainfall intensity of 150 mm/h. After that, less reduction in intensity can be noticed and the relationship tends to be a semi linear one. This can be related to the effects of annual average rainfall, drainage condition at the road structure and time-to-drain (Table 2). Figure 6 shows relationship between rainfall intensity and drainage coefficient for fine-grain soil (sub-base) and uniform dense sand (base). As can be seen from this figure for a certain rainfall intensity, drainage coefficient is higher in uniform dense sand than fine-grain soil.

c) Figure 7 shows the relationship between rainfall intensity and sub-base (fine-grain soil) and base (uniform

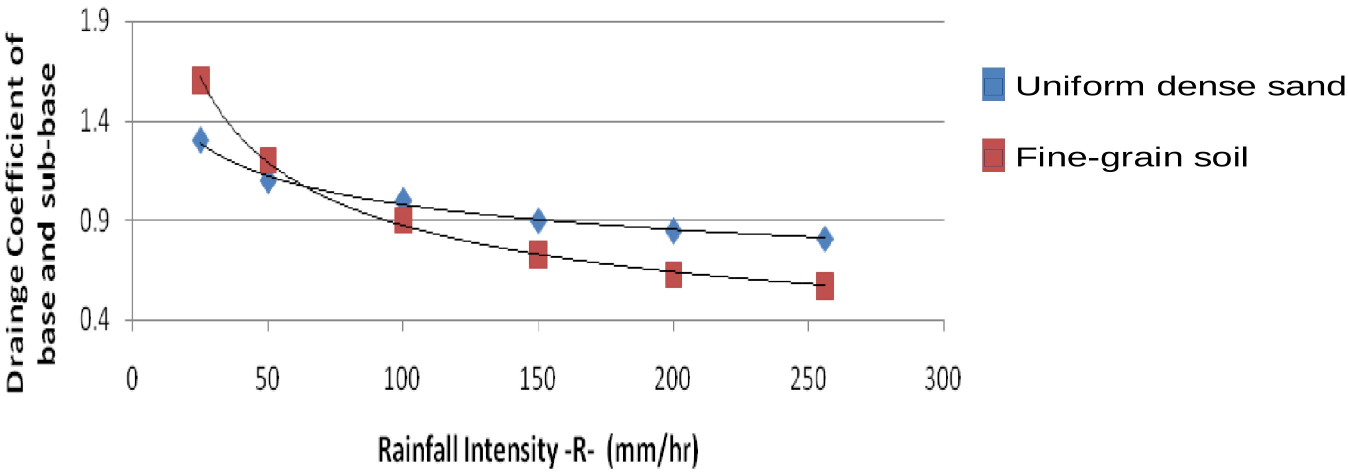

Figure 6. Relationship between rainfall intensity and drainage coefficient for sub-base (fine-grain soil) and base (uniform dense sand).

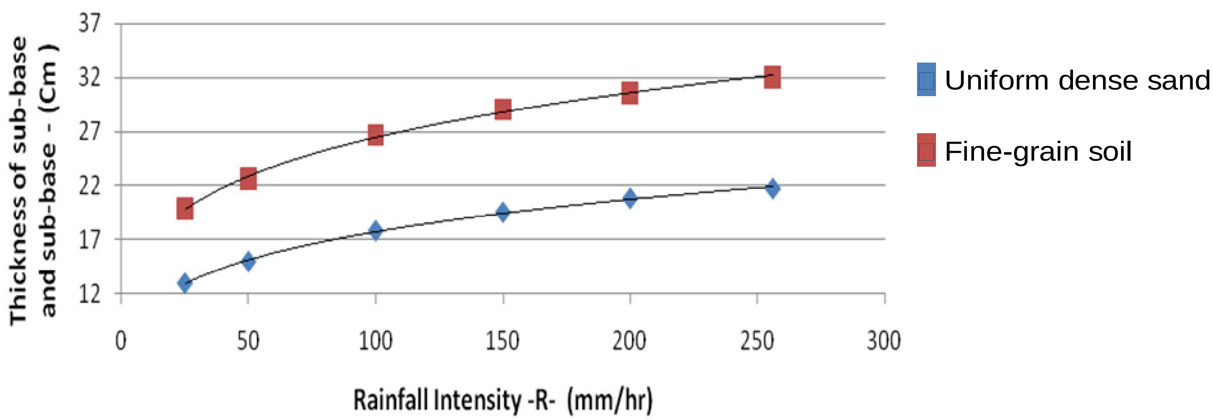

Figure 7. Relationship between rainfall intensity and thickness for sub-base (fine-grain soil) and base (uniform dense sand).

dense sand) thickness. As can be seen from this figure, a slow increase in rainfall intensity can be related at the beginning to extent on rainfall intensity (150 mm/h) after that relation intends to be almost linear with constant increase in values of thickness base (uniform dense sand) and sub-base (fine-grain soil). Figure 7 shows relationship between rainfall intensity and thickness for fine-grain soil (sub-base) and uniform dense sand (base). As can be seen from this figure for a certain rainfall intensity, thickness is higher in fine-grain soil than uniform dense sand, because of permeability coefficient for uniform dense sand is higher than fine-grain soil.

Soil type of well-graded sand (dense) (base) and fine-grain soil (sub-base)

Results are:

a) Figure 8 presents the effect of rainfall intensity on Time-to-Drain (t_{85}) for base (well-graded sand) and sub–base (fine-grain soil). Increase in rainfall intensity caused an increase in the infiltrated water to the base and sub-base layers. Accordingly, an increase in pore water pressure resulted which in turn caused an increase in porosity and decrease of base and sub-base degree of compaction. Figure 8 shows relationship between rainfall intensity and time-to-drain. As can be seen from this figure for certain rainfall intensity, the time-to-drain is higher in soft clay than well-graded sand, because of permeability coefficient well-graded sand is higher than fine-grain soil.

b) Figure 9 shows the relationship between rainfall intensity and the drainage coefficient for sub-base (fine-grain soil) and base (well-graded sand). As can be seen from this figure, a rapid decrease in the values of drainage coefficient for fine-grain soil (sub-base) and

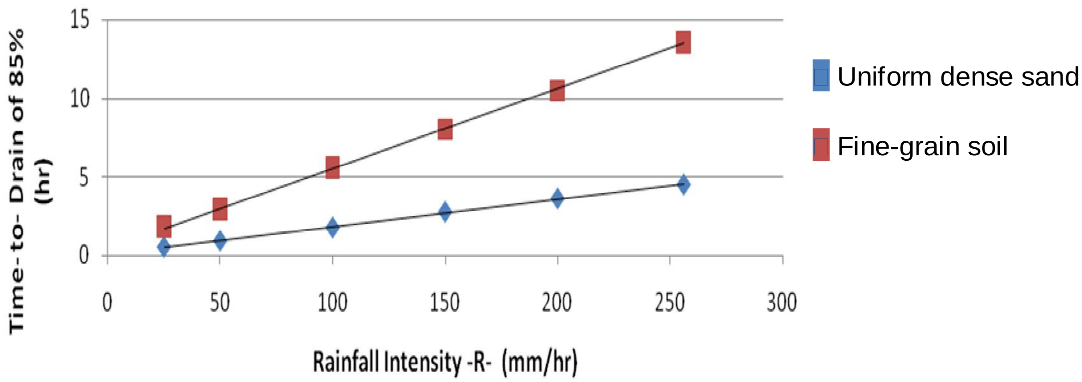

Figure 8. Relationship between rainfall intensity and time-to-drain of 85% for base (well-graded sand (dense)) and sub-base (fine-grain soil).

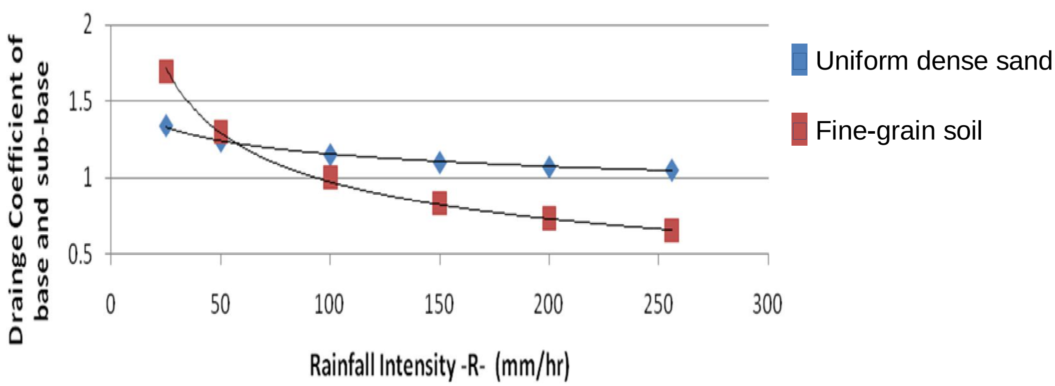

Figure 9. Relationship between rainfall intensity and drainage coefficient for base (well-graded sand (dense)) and sub- base (fine-grain soil).

well-graded sand (base) occurs at the start and for extent a rainfall intensity of (150 mm/h). After that less reduction in intensity can be noticed and the relationship tends to be a semi-linear one. This can be related to the effects of annual average rainfall, drainage condition at the road structure and time-to-drain (Table 2). Figure 9 shows relationship between rainfall intensity and drainage coefficient for fine-grain soil (sub-base) and well-graded sand (base). As can be seen from this figure for a certain rainfall intensity, drainage coefficient is higher in well-graded sand than fine-grain soil.

c) Figure 10 shows the relationship between rainfall intensity and sub-base (fine-grain soil) and base (well-graded sand) thickness. As can be seen from this figure, a slow increase in rainfall intensity can be related at the beginning to extent on rainfall intensity (150 mm/h) after that relation intends to be almost linear with constant increase in values of thickness base (well-graded sand) and sub-base (fine-grain soil). Figure 10 shows relationship between rainfall intensity and thickness for fine-grain soil (sub-base) and well-graded sand (base). As can be seen from this figure for a certain rainfall intensity, thickness is higher in soft clay than well-graded sand, because of permeability coefficient for uniform dense sand is higher than fine-grain soil.

Soil type of well-graded sand (dense) (base) and uniform dense sand (sub-base)

Results are:

a) Figure 11 presents the effect of rainfall intensity on Time-to-Drain (t_{85}) for base (well-graded sand) and sub–base (uniform dense sand). Increase in rainfall intensity caused an increase in the infiltrated water to the base and sub-base layers. Accordingly, an increase in pore water pressure resulted which in turn causes an increase in porosity and decrease of base and sub-base degree of compaction. Figure 11 shows relationship between rainfall intensity and time-to-drain. As can be seen from this figure for a certain rainfall intensity, the time-to-drain is higher in uniform dense sand than well-graded sand, because of permeability coefficient well-graded sand is higher than soft clay.

b) Figure 12 shows the relationship between rainfall

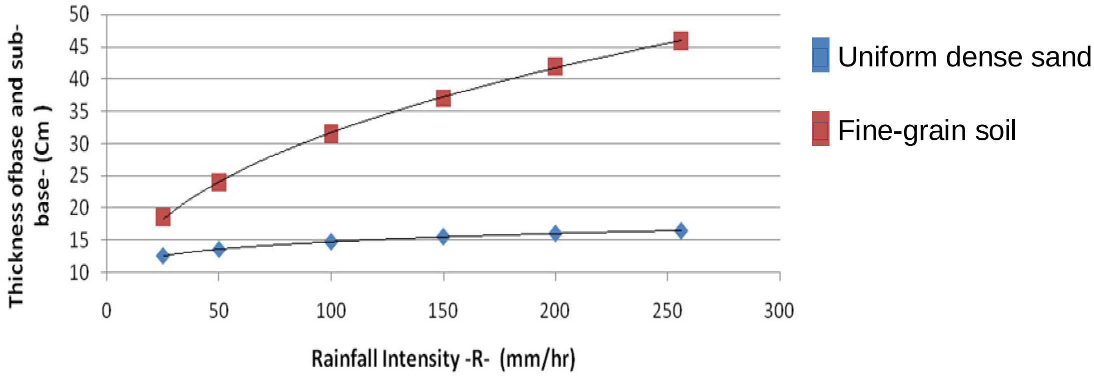

Figure 10. Relationship between rainfall intensity and thickness for base (well-graded sand (dense)) and sub-base (fine-grain soil).

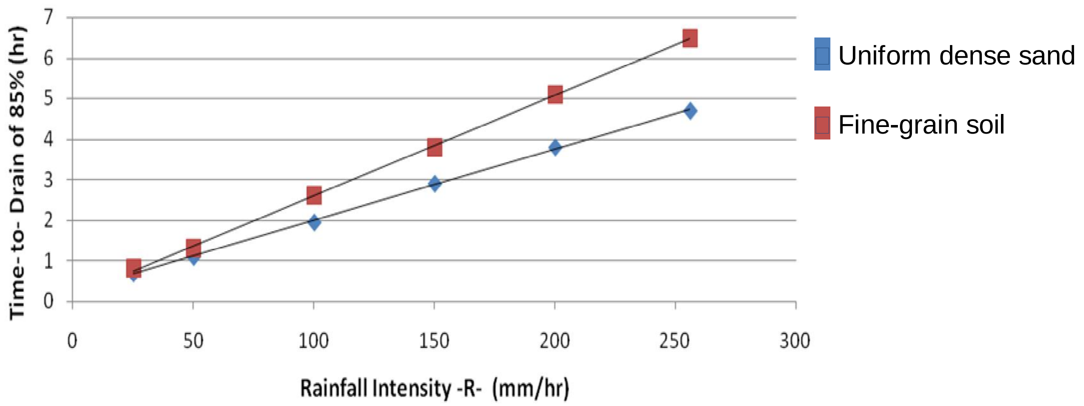

Figure 11. Relationship between rainfall intensity and Time-to-Drain of 85% for base (well-graded sand (dense)) and sub-base (uniform dense sand).

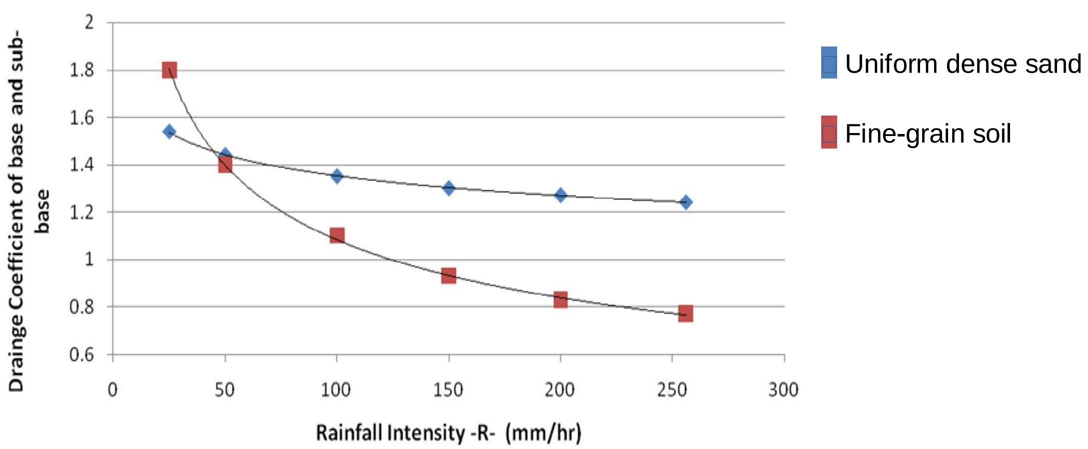

Figure 12. Relationship between rainfall intensity and drainage coefficient for base (well-graded sand (dense)) and sub-base (uniform dense sand).

intensity and the drainage coefficient for sub-base (uniform dense sand) and base (well-graded sand). As can be seen from this figure, a rapid decrease in the values of drainage coefficient for uniform dense sand (sub-base) and well-graded sand (base) occurs at the start and for an extent a rainfall intensity of 150 mm/h.

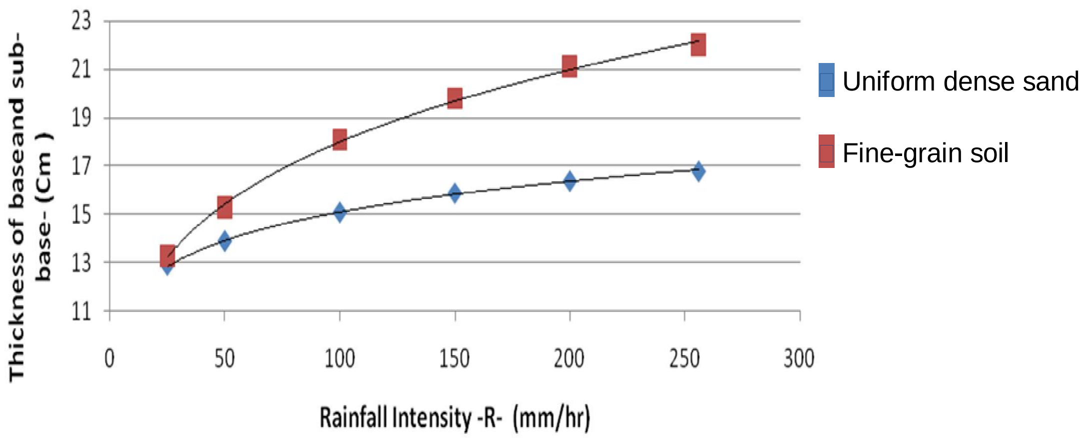

Figure 13. Relationship between rainfall intensity and drainage thickness for base (well-graded sand (dense)) and sub-base (uniform dense sand).

Table 4. Minimum and maximum values of parameters for flexible pavement.

Soil type	Time-to-drain (h)		Drainage coefficient		Thickness (cm)	
	Min.	Max.	Min.	Max.	Min.	Max.
Well-graded sand (dense)	0.7	4.7	1.05	1.54	12.6	16.8
Uniform sand (dense)	0.80	8.5	0.77	1.8	13	22
Fine-grain soil	1.0	13.6	0.57	1.7	18.5	46

After that, less reduction in intensity can be noticed and the relationship tends to be a semi-linear one. This can be related to the effects of annual average rainfall, drainage condition at the road structure and time-to-drain (Table 2). Figure 12 shows relationship between rainfall intensity and drainage coefficient for uniform dense sand (sub- base) and well-graded sand (base). As can be seen from this figure for a certain rainfall intensity, drainage coefficient is higher in well-graded sand than uniform dense sand.

Figure 13 shows the relationship between rainfall intensity and sub-base (uniform dense sand) and base (well-graded sand) thickness. As can be seen from this figure, a slow increase in rainfall intensity can be related at the beginning to extent on rainfall intensity (150 mm/h) after that relation intends to be almost linear with constant increase in values of thickness base (well-graded sand) and sub-base (uniform dense sand). Figure 13 shows relationship between rainfall intensity and thickness for uniform dense sand (sub-base) and well-graded sand (base). As can be seen from this figure for a certain rainfall intensity, thickness is higher in uniform dense sand than well-graded sand, because of permeability coefficient for uniform dense sand is higher than uniform dense sand. Table 4 shows minimum and maximum values of parameters for flexible pavement.

CONCLUSIONS

From the results of the present work, the following conclusions can be drawn:

1. The increase in rainfall intensity will cause a decrease in the drainage coefficient and increase in the thickness of base and sub-base layers from through influence on moisture content and resilient modulus for the soil. For flexible pavement, rainfall intensity 256 mm/h gives thickness and drainage coefficient of 46 cm and 0.57 respectively, while rainfall intensity 25 mm/h gives thickness and and drainage coefficient of 18.5 cm and 1.7, respectively. In rigid pavement, rainfall intensity 256 mm/h gives thickness and drainage coefficient of 24.8 cm and 0.9 respectively, while rainfall intensity 25 mm/h gives thickness and drainage coefficient of 21.3 cm and 1.2, respectively.
2. The study results is sensitive to accumulated water amount, where soft clay soil needs about 60% more thickness and time-to-drain than well graded sand soil and uniform dense sand soils, and soft clay soil needs about 40% less drainage coefficient than well graded sand soil and uniform dense sand soils.
3. Different soil type will influence thickness of base and sub-base layers through influence on density of dry soil

and coefficient of permeability, because increase in coefficient of permeability will shorten the drainage path and reduce the time-to-drain, thus leading to increase in drainage coefficient and thickness of base and sub-base layers. Well-graded sand gives thickness for flexible and rigid pavement of 16.8 and 23 cm respectively at coefficient of permeability of 500 m/day; soil uniform sand gives thickness for flexible and rigid pavement of 22 and 24 cm respectively at coefficient of permeability of 400 m/day; while soft clay gives thickness for flexible and rigid pavement of 46 and 24.8 cm respectively at coefficient of permeability of 300 m/day.

4. This study confirms as mentioned by AASHTO that water in the pavement system can lead to modulus reduction and loss of strength for pavement. Saturation can reduce the dry modulus of both the asphalt layer by 30% or more, and the base and sub-base modulus by 50% or more. Similarly, modulus reduction of up to 30% can be expected for asphalt-treated bases, and over 50% for saturated fine-grained sub grade soils.

5. To minimize potential moisture damage to a pavement structure, drainage of accumulated water in permeable base must be accomplished at the shortest time possible by using collector drains. They are effective means for rapid removal of water from the pavement section as such it has to be adequately provided.

6. Permeable bases are used to satisfy three main functions. Firstly, the base must be permeable enough so the base course can drain within the design period. Secondly, the base must be stable enough to support pavement construction operations. Finally, the base course must have enough stability to provide necessary support for the pavement structure.

RECOMMENDATIONS

The following recommendations may be outlined for future research as extension of the present work:

1. Developing of new equations that accounts for capillary action, rising water table and seepage from higher ground and not only rainfall intensity and infiltration.
2. It is recommended to investigate the effects of drainage collection system. A conventional recommended collection system consists of trench, slotted pipe and aggregate backfill.
3. Future studies should incorporate effect of mean annual rainfall in addition to rainfall intensity on drainage coefficients for pavement.
4. Studying problems which are attributed to accumulated water within pavement layers as a principal cause for pavement deterioration and which include: stripping of asphalt pavement, joint displacement in concrete pavements, reduction in pavement strength due to positive pore-water pressures in the base course layers and shrinking and swelling of sub-grade materials due to water content changes.

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