



RAINFALL INTENSITY EFFECTS ON Flexible PAVEMENT LAYERS

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Abstract: The main objective of this work is to study of effect of rainfall intensity on the thickness of pavements layers of flexible pavement structure. This is using Maple 13 software for modeling of this problem and calculation the rainfall intensity and pavement infiltration. It was found that pavement infiltration increases with increasing rainfall intensity because of, the increase in the 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 intends cause an increase in porosity and decrease of base and sub - base degree of compaction. Accordingly which leads to increase in time - to - drain, decrease in drainage coefficient for base and sub - base, and subsequently, request to increase their thickness. For flexible pavement, rainfall intensity 256 mm/hr is giving pavement infiltration, thickness and drainage coefficient 3.2m/day, 46 cm, 0.57 respectively and rainfall intensity 25 mm/hr is giving pavement infiltration, thickness and drainage coefficient 0.4 m/day, 18.5cm, 1.7 respectively. Drainage of accumulated water on pavement is accordingly drained rapid in as short time as possible due to minimize potential moisture damage to a pavement structure. It was found that soil type effects of moisture in pavement based on conditions of total saturation with loss of pavement strength from through 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. Where, soil types have been used in this study Well-graded sand, Uniform dense sand and Fine-grain soil.

Keywords: Rainfall intensity, Flexible pavement, Pavement infiltration, Drainage coefficient

الخلاصة: قدمت في هذا البحث دراسة تأثير الشدة المطرية على سمك طبقات التبليط في التبليط المرن (flexible pavement) قد تم كذلك حساب وقت التصريف (time-to-Drain) لطبقة الأساس (base layer) للتبليط. تم استخدام برنامج (Maple 13) لنمذجة هذه المسألة، حيث تم حساب الشدة المطرية (rainfall intensity) وكمية تسريب التبليط وذلك بسبب زيادة ارتشاح الماء لطبقات الأساس وتحت الأساس الحصول عليها أكدت بأن زيادة الشدة المطرية تسبب زيادة تسريب التبليط وبالتالي تقلل درجة حدل هذه الطبقات. وبالتالي زيادة وقت التصريف مما يؤدي إلى زيادة وضغط ماء المسام (pore water pressure) وبالتالي تقلل درجة حدل هذه الطبقات. وبالتالي زيادة وقت التصريف (time-to-Drain) مما يؤدي إلى نقصان في معاملات التصريف (drainage coefficient) للطبقات التبليط وبالتالي يتطلب زيادة في سمك طبقات التبليط. التبليط المرن عندما تكون الشدة المطرية 256 م/ساعة فهي تعطي تسريب التبليط وسمك معامل التصريف 3,2 م/يوم، 46 سم، 0,57 على التوالي و عندما تكون الشدة المطرية 25 م/ساعة فهي تعطي تسريب التبليط وسمك معامل التصريف 0,4 م/يوم، 18,5 سم، 1,7 على التوالي. وكذلك يجب أن يصرف الماء المتراكم على الرصيف خلال أقصر وقت ممكن، لتقليل ضرر الرطوبة المحتملة على تركيب التبليط. وتم الاستنتاج أيضا "إن نوعية التربة أثر بكميات الماء الواصلة إلى التبليط التي تكون مستندة على شروط الاشباع الكلي بخسارة قوة التبليط من خلال تأثيرها على الاجهاد نتيجة الامتصاص (ومسامية الفعالة) وضغط ماء المسام وكذلك تأثيرها على تركيب التربة من خلال تدمير التدعيم بين جزيئات التربة وذلك بسبب اختلاف التربة في معامل النفاذية (coefficient of permeability) و حيث إن أنواع التربة التي تم استعمالها في هذا البحث هي رمل ذات تدرج جيد ورمل كثيف منتظم والتربة الناعمة.

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1. 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 (Timo Saarenketo,2005).

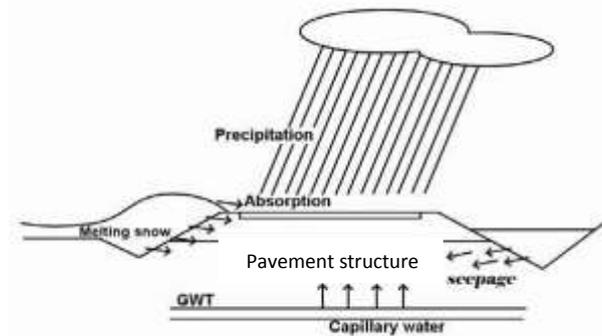


Figure (1) Main sources of the water in the road structure (Timo Saarenketo,2005)

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 percent can be expected for asphalt-treated bases, and over 50 percent for saturated fine-grained sub grade soils (Paola Arizaet.,al.,2002).The detrimental effects of water in the pavement system are significant as follow:(AASHTO Design Guide 1993)

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 percent 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 percent or more.
3. Modulus reduction of up to 30 percent 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 percent.

The main objective of this research is to establish:

- A. Development of computer model that used to calculate layer thickness of flexible pavement.
- B. Investigate the effects the rainfall intensity (R) on the layers of flexible pavement.
- C. Calculation of pavement infiltration using physically base formula in depending on cross slopes and longitudinal slopes to quickly drain moisture from pavement surface .

- D. Determining the best drainage coefficient of base pavement and sub-base pavement following rainfall infiltration in the pavement system.

2. Background

Paola Arizaet. al., 2002 studies on the effects of moisture in pavement has 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 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. They 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.

Michael J. 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 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:

- ❖ Climatic factors of rainfall and temperature (freezing and thawing).
- ❖ Ground water level.
- ❖ Roadway geometry.
- ❖ 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.

3. Analysis of Collected Data

The IDF formulas are the empirical equations representing a relationship among 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, basic forms of equation used to describe the rainfall intensity duration relationship in Basrah city (Atallah, 2012)(see figure (2)):

$$R = \frac{373.0575 \times T_R^{297.85 \times 10^{-3}}}{t_c^{0.66}} \text{ --- (1)}$$

Where

R = rainfall intensity (mm/hr).

T_R = return period in years.

t = duration in minutes.

From Infiltration ratio and rainfall intensity, infiltration pavement (q) is determined using equation (2)

$$q_i = 0.024 (C).(R) \text{ --- (2)}$$

Where;

q_i = Pavement infiltration, (m³/day/m² of pavement or m/day) ,

C = Infiltration ratio (asphalt concrete pavement 0.33-0.5).

R = Rainfall rate,(mm/hr).

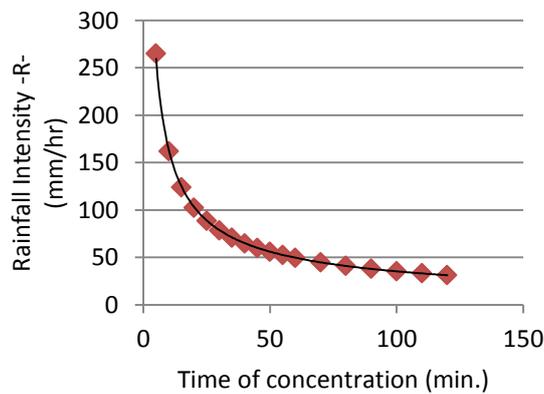


Figure (2) Intensity-Duration curve for Basrah city (Atallah, 2012)

Figure 3 shows the relationship between rainfall intensity and infiltration pavement while assume Infiltration ratio equal to 0.5. It can be seen that the infiltration pavement increase with increasing rainfall intensity.

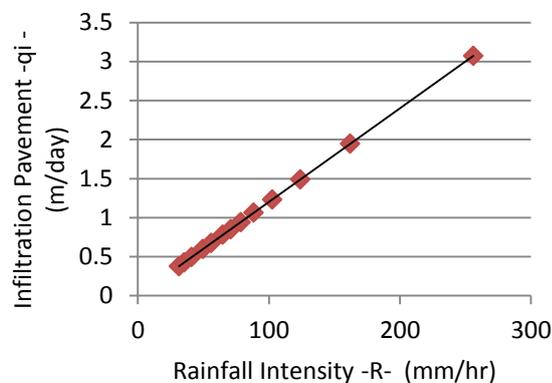


Figure (3) Relationship between rainfall intensity and infiltration pavement(C=0.5)

Guidance for the quality of drainage based on 85 percent saturation is provided in Table (1) .The 85 percent saturation method considers both the water that can drain and the water retained by the effective porosity quality of the material [AASHTO1993].

Table 1 Pavement rehabilitation manual guidance for time to drain from 100 to 85 percent saturation [AASHTO1993]

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

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 percent drainage. The time for 85 percent drainage is approximately twice the time for 50 percent drainage. The equation for computing the time for 50 percent drainage is (FHWA, 2006):

$$t_{50} = \frac{ne*L^2}{2*k*(H+S*L)} \text{ --- (3)}$$

Therefore the time for 85 percent drainage is computed by the equation (4)

$$t_{85} = \frac{ne*L^2}{k*(H+S*L)} \text{ --- (4)}$$

Where

t_{85} = the time for 85 percent drainage the water (hr),

n_e = effective porosity of the soil.

k = coefficient of permeability (m/day),

H, L and H = base and sub-base geometry dimensions.

4. Computer Program

A computer program has been developed using Maple 13 software. Maple is a powerful software program that can be used to solve general purpose mathematical problems. Problems in the areas of mathematics, science and engineering (and many more) can be investigated using either Maple’s in-built commands, or by utilizing Maple’s powerful native programming language to create your own personalized programs (Edwards and Antic, 2008). Maple provides an interactive problem-solving environment, complete with procedures for performing symbolic, numeric, and graphical computations. At the core of the Maple computer algebra system is a powerful programming language, upon which the Maple libraries of mathematical routines are built (Monagan, et. al., 2005). In order to solve rainfall intensity effect on the pavement and solve equations the pavement thickness, a computer program has been developed

using Maple 13 software. The input and output data of program is shown in table (2) and table (3).

Table (2) Input parameters

Input parameter	Description
t_c	Time of concentration.
C	Infiltration coefficient.(0.33-0.5)
S_C	The transverse slope of the drainage layer(2-6)%
S_L	The longitudinal slope of the drainage layer.(0.3-0.5)
X	The length of the transverse slope of the drainage layer..(7.3m)
g_d	Dry density.(11.9-18.2)
g_w	Density of water.(1gm/cm ³ at 25°C)
G_s	Specific gravity of solid.
WL	Water Loss.
H	Thickness of the Drainage Layer.
CBR	California Bearing Ratio.(subbase=35,base=80)
D_D	Directional distribution factor.(0.3-0.7)
D_L	Lane distribution factor.(0.5-1)
AADT	Average annual daily traffic.(ESAL(43.51292758 *10 ⁶ kN))
g	The annual traffic growth rate .(4%)
t	service life, year.(20)
Z_R	Standard normal deviation .(-1.476-(-3.75))
S_O	Overall standard deviation error.(0.4-0.5)
PSI_0	Initial serviceability index.(4.2-5.0)
PSI_t	Terminal serviceability index.(2-2.5)

Table (3) Output parameter

Output parameter	Description
R	Rainfall Intensity
q_i	Pavement Infiltration.
S	slope of the drainage layer.
L	length of the drainage layer
k	Coefficient of Permeability
n	Porosity .
n_e	Effective porosity.
t85	Time for 85 percent drainage.
M	Percent of time Pavement Structure is Moisture Quality of Approaching Saturation.
MR	Resilient Modulus of sub- grade.
MRs	Resilient Modulus of sub- base.
MRb	Resilient Modulus of base.
G	growth rate for vehicle.
ΔPSI	Loss of Serviceability.
W18	number of 18 kip equivalent single axle loads (ESALs).
SN1, SN2, SN3	Structural Number for layer 1, 2 and 3, respectively.

5. Case Studies and Discussion of Results

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.

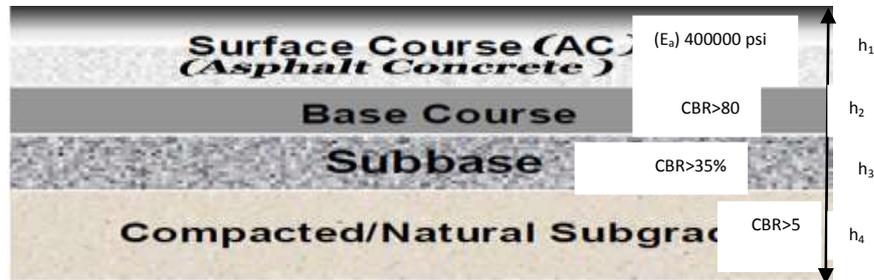


Figure 4 flexible pavement layer

5.1. 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 (4)

Table (4) Soil Type, values 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	300x10 ⁻³

5.1.1. For soil type of Uniform dense sand (base) and Fine-grain soil (sub-base):

Results are:

- ❖ Figure (5), present the effect of rainfall intensity on 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 intends cause an increase in porosity and decrease of base and sub - base degree of compaction.

As it can be seen from figure (5) for 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.

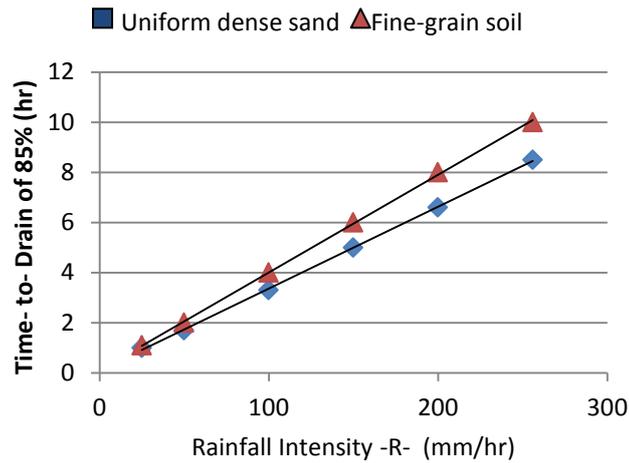


Figure (5) Relationship between rainfall intensity and Time to-Drain of 85% for sub- base (Fine-grain soil) and base(Uniform dense sand).

❖ Figure (6), shows the relationship between rainfall intensity and the drainage coefficient for sub - base (fine-grain soil) and base (uniform dense sand). As it 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/hr). 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 . As it can be seen from this figure for a certain rainfall intensity, drainage coefficient is higher in uniform dense sand than fine-grain soil.

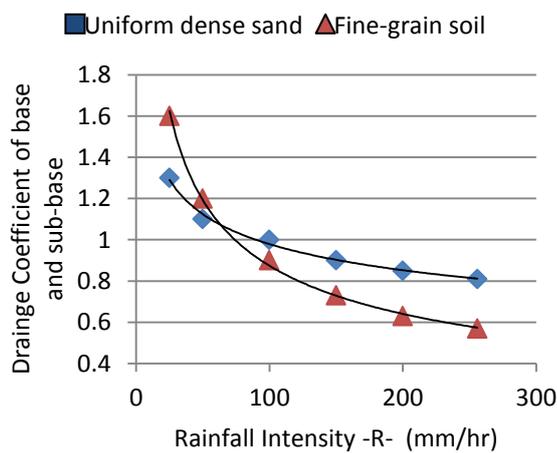


Figure (6) Relationship between rainfall intensity and drainage coefficient for sub- base (Fine-grain soil) and base(Uniform dense sand).

❖ Figure (7), shows the relationship between rainfall intensity and sub - base (fine-grain soil) and thickness of base (uniform dense sand). As can be seen from this figure , a slow increase in rainfall intensity can be related at the beginning to extent on rainfall intensity (150mm/hr) after that relation in

tend to be almost linear with constant increase in values of thickness base (uniform dense sand)and sub - base (fine-grain soil). As it 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.

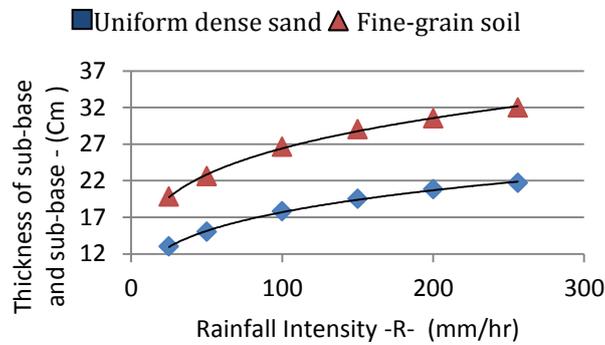


Figure (7) Relationship between rainfall intensity and thickness for sub- base (Fine-grain soil) and base(Uniform dense sand).

5.1.2. For soil type of Well-graded sand (dense)(base) and Fine-grain soil (sub -base):

Results are:

- ❖ Figure (8), present 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 tends cause 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 it 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.

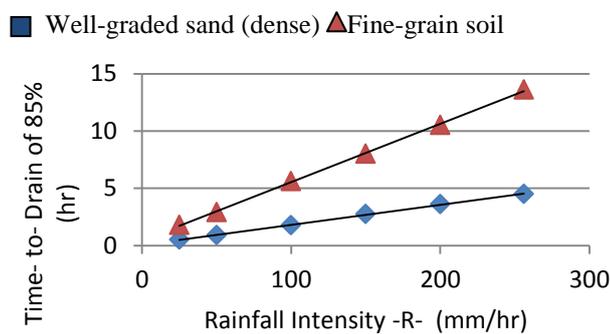


Figure (8) Relationship between rainfall intensity and Time-to-Drain of 85%for base(Well-graded sand (dense)) and sub- base (Fine-grain soil).

- ❖ Figure (9), shows the relationship between rainfall intensity and the drainage coefficient for sub - base (fine-grain soil) and base (well-graded sand). As it

can be seen from this figure a rapid decrease in the values of drainage coefficient for fine-grain soil (sub - base) and well-graded sand(base) occurs at the start and for extent a rainfall intensity of (150 mm/hr). 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 (see to table (2)). As it can be seen from this figure for certain rainfall intensity, drainage coefficient is higher in well-graded sand than fine-grain soil.

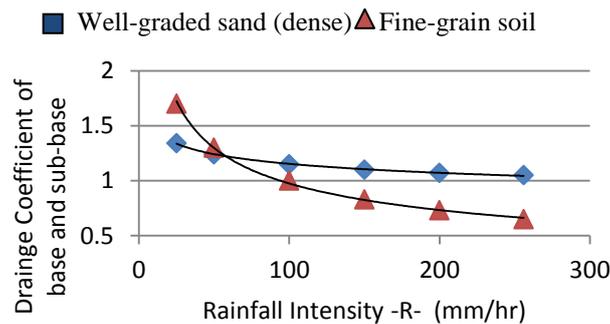


Figure (9) Relationship between rainfall intensity and drainage coefficient for base(Well-graded sand (dense)) and sub- base (Fine-grain soil).

❖ 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 (150mm/hr) after that relation in tend to be almost linear with constant increase in values of thickness base (well-graded sand) and sub - base (fine-grain soil). As it 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.

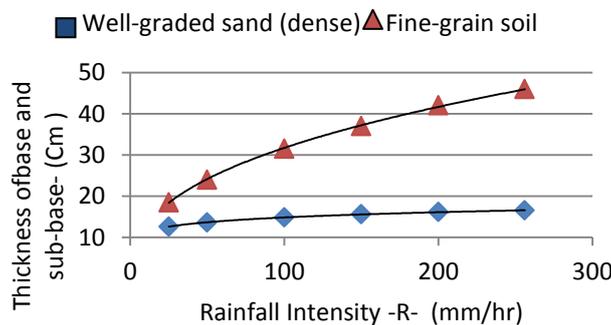


Figure (10) Relationship between rainfall intensity and thickness for base(Well-graded sand (dense)) and sub- base (Fine-grain soil).

5.1.3. For soil type of Well-graded sand (dense)(base) and Uniform dense sand (sub-base) :

Results are:

❖ Figure (11), present 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 tends cause an increase in porosity and decrease of base and sub - base degree of compaction. As it can be seen from this figure for 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.

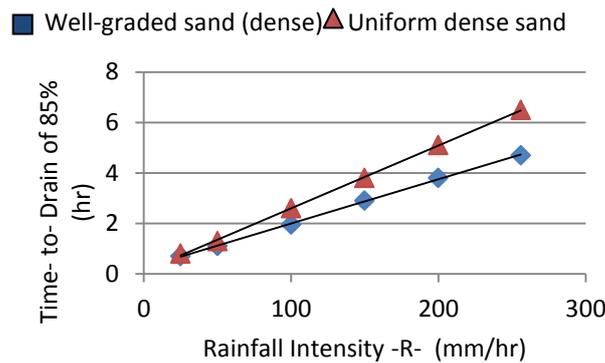


Figure (11) Relationship between rainfall intensity and Time-to-Drain of 85% for base(Well-graded sand (dense)) and sub-base (Uniform dense sand).

❖ Figure (12), shows the relationship between rainfall intensity and the drainage coefficient for sub - base (uniform dense sand) and base (well-graded sand). As it 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 extent a rainfall intensity of (150 mm/hr). 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. As it can be seen from this figure for certain rainfall intensity, drainage coefficient is higher in well-graded sand than uniform dense sand.

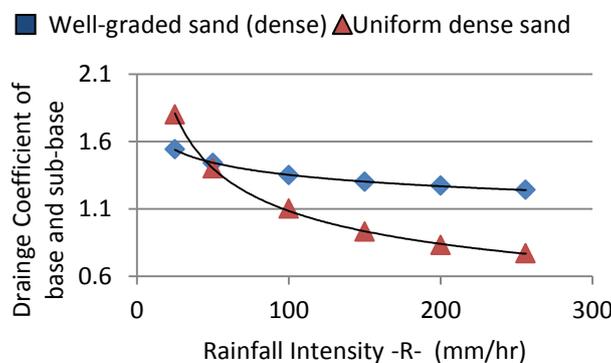


Figure (12) Relationship between rainfall intensity and drainage coefficient for base(Well-graded sand (dense)) and sub-base (Uniform dense sand).

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 (150mm/hr) after that relation in tend to be almost linear with constant increase in values of thickness base (well- graded sand) and sub - base (uniform dense sand).. As it 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) summarized the result on the computer program.

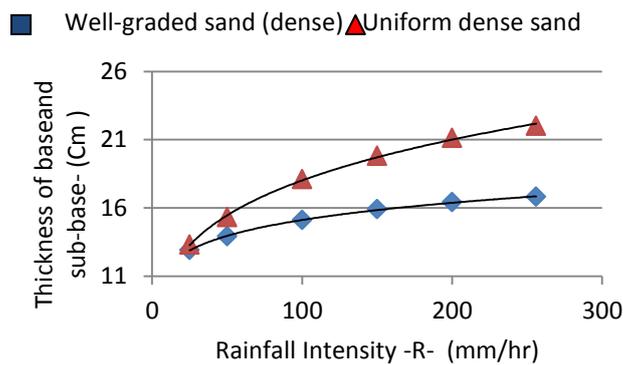


Figure (13) Relationship between rainfall intensity and drainage thickness for base(Well-graded sand (dense)) and sub-base (Uniform dense sand).

Table (4) minimum and maximum values of parameters for flexible pavement (computer program)

Soil Type	Time-to-Drain (hr)		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

6. 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/hr) is giving thickness and drainage coefficient(46 cm, 0.57)respectively and rainfall intensity(25 mm/hr)is giving thickness (18.5cm, 1.7)respectively.
2. The study results is sensitive to accumulated water amount, where; soft clay soil is needing to thickness and time - to- drain larger than well graded sand soil and uniform dense sand soils about (60%) and soft clay soil is needing to drainage coefficient less than well graded sand soil and uniform dense sand soils about (40%).

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 reduces the time-to-drain and lead to increase in Drainage Coefficient and Thickness of base and sub-base layers. When soil type (well - graded sand) is giving thickness for flexible (16.8 cm) due to coefficient of permeability have taken (500 m/day) and soil type (uniform sand) is giving thickness for flexible (22 cm) and due to coefficient of permeability have taken (400 m/day) and soil type (soft clay) is giving thickness for flexible (46 cm) due to coefficient of permeability have taken (300 m/day).

7. References

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