Drainage investigation of surface runoff for highway pavement

Aqeel Al-adili.^{1,*}, Rasha Abdulamir ¹, and Hawra Abbas¹

¹ Building and Construction Engineering Department, University of Technology, Baghdad, Iraq

Abstract. The aim of this study is to establish the effect of heavy rainfall and the chosen pavement layers on the drainage design, material selection and rutting resistance of the flexible pavement. The test in present study was started with wheel track passing without load and without rain falling on the pavement for a period of time, and it was noticed that no distress appeared on the surface of the pavement. Then, the load is gradually added by using wheel track load of 106 psi for five tests without rain falling and five other tests with gradually increasing rain fall duration and intensity. Deterioration and distresses appeared on the pavement when increasing the wheel track load to (150 psi) under high intensity rain and long term duration of rain fall. By increasing the number of days, which is 103 days of study, when the pavement is saturated, the extra amount of the water will runoff. The clogging material which caused a decrease in the water seepage, increases the time of runoff ending. The clogging materials of fine particles that get deposited on the surface of the pavement resulted by passing the wheel track loading and wear & tear of the pavement surface, and other clogging materials such as salt in the water will penetrate to the pavement and seal the voids and decrease its water seepage. The water seepage decreases by increasing number of days, so the amount of the absorbed water decreases by 89% after 71 days of testing for high rain intensity (116 ml/min.).

1 Introduction

This study includes the results which are conducted from the laboratory model test and discussion of the results. The model was subjected to a duration of rainfall and the results of the amount of water absorbed through the pavement layer, under the effect of the simulate track loading weight, has been recorded. Analysis and discussions of the changes and distresses that obtained in the surface pavement are presented in this paper.

2 Selection of pavement layer thickness

In this study, a silty clay soil (with 400 mm thickness) has been used with a subbase type B (with 300mm thickness), concrete base (with 150 mm thickness) and an asphalt superpave pavement (with 50 mm thickness). The thickness of the pavement layer was chosen according to (*Iraqi standard specification for Roads & Bridges, 2003*) and (*Huang, 2004*). As shown in Figure 1.

Fig.1. Pavement Layer Thickness

3 Model preparation

The second phase in this study is the prototype laboratory simulation model. The details for the preparation and manufacturing of the model are described below.

3.1 Steel box

Steel container with external dimensions of (150 cm) length, (80 cm) width and (90 cm) depth is constructed by the researcher to simulate the pavement layers (subgrade, subbase, and concrete pavement and asphalt surface) as shown in Fig.2. The steel plate thickness is 4 mm which was used to manufacture each part of the box.

* Corresponding author: aqeeladili@hotmail.com

Fig.2. The Steel Box

Holes were distributed randomly around the steel box to allow the absorbed water by layer to drain out as shown in Fig.3, and four iron pipes as in Fig.4 welded above the edge side of the steel container to install distributed water pipe over it.

Fig.3. Holes Distributed Around the Steel Box

Fig.4. Iron Pipe Used to Install Distributed Water Pipe

3.2 Distribution water pipe

The distribution water pipe which was manufactured from 12 iron pipes with (1/2") inch (diameter?) and 70 cm length, are connected to frame as a water network with 150 cm length and 80 cm width and 150 cm height from the steel box top and installed over the steel box by screws.

There are holes of 2 mm in diameter distributed along the pipe and the distance between the holes is 3 cm to simulate the rainfall over the highway in the model as shown in Fig.5.

Fig.5. Network for Rainfall Simulation

There is a slot in the long side of the water network connected with plastic pipe to the water pump which let the water to flow from the water tank to the water network.

3.3 Water pump

An electrical water pump is used which is joined to the water tank to draw water from the water tank to the distribution water pipe by plastic water pipe, the intensity of the water pump is 30 l/min. and with a power of 550W.

3.4 Water tank

For this study, a cylindrical water tank with volume of 500 litres is used. The water tank is connected to the electrical water pump from the bottom and it contained a slot of 3/4" at the top of the tank.

3.5 Wheel truck

A framework of iron rectangular with 200 cm long and a 150 cm high has been manufactured. This frame contains ball bearing to facilitate the wheel movement. The wheel is manufactured by rubber tyre with 250 mm diameter and 80 mm width and the contact area between the surface of the pavement and the tyre is 17.7 cm² (2.454 in²). The rubber tyre is moved by three phase's motor with 0.2 m/s speed which is connected to the rubber by toothed wheels and fixed under iron plate which is used to carry the loads.

For the loads, two metal cylinders filled with concrete mix in order to obtain to the required weight have been used. The weight of each cylinder is 80 Kg, and the weight of the motors is 90 Kg, it will add to the load of the cylinders which generate (149 psi) load on the pavement in the contact area between the tyre and the pavement. The loads are placed above the iron plate of the wheel as shown in Fig.6. And Fig.7 show the loaded laboratory model test.

Fig.6. Simulate Track Loading

Fig.7. Loaded Laboratory Model Test

4 Selection of rain intensity for long and short terms

For this study, two types of rain intensity were selected: high intensity rain with 116 ml/min., and low intensity rain with 58 ml/min.

Two aspect of drainage control have been considered in this research, namely a short-term and a long-term intensity rain. The short-term intensity rain takes at periods of time such as 30 minutes, one hour and two hours in the day.

The long-term intensity rain started at the same time of the short term rain but continued for four months. During this periods, the effect of the rain on the pavement and it's deflection, if happened, and its effect on the drainage has been studied.

5 Starting the test

The test began with turning on the water pump and opening the faucet to the required water intensity which was previously selected, then the water pump withdraw the water from the water tanker in which its amount of water was calculated before starting the test, then the water starts to flow through the plastic pipe to arrive to the water distribution network in order to simulate the rain fall in the pavement, which was executed and explained previously. In the meantime the wheel track which is loaded with two cylindrical loads is run along the pavement through the test time, and then the changes on the pavement layer during the rain and under the influence of wheel track loading are recorded.

During the test, the water drains and moves toward a channel which was set on the side slope of the pavement, and returns back to the water tanker through the larger plastic pipe and pours on the top of the tanker.

6 Amount of the absorbed water through the pavement layer

After ending the rain trial for short and long term and for the required period of time, the amount of water that goesout from the water tanker, the amount of water that is drained and returned back to the tanker and the amount of water that is absorbed through the pavement layer should be determined. In order to calculate the amount of the water that is drained and that is absorbed through the pavement layer, the amount of the water in the water tanker before beginning the test needs to be calculated. For this purpose, and before filling the tanker with water, the amount of added water to the tanker is determined.

After ending the test by one or two hours, the height of water has been recorded and the amount that was indicated on the tanker has been checked and then the result has been obtained. The amount of absorbed water can be then calculated by taking the differences between the amount of water before starting rainfall and the amount of water in the water tanker after rain falling.

7 Test result for high intensity rain

This step represents the study result of the amount of absorbed water, ending time of seepage and vertical drainage for high intensity rain (116 ml/min.) during the study period.

7.1 Amount of absorbed water

The rain intensity test was conducted for two different times. Before beginning the test, the amount of the water in water tanker has been calculated, then after two or one hour rain falling and after ending the test, the amount of water has been calculated again. The differences between the amount of water before starting the test and amount of water after ending the test is referred to the amount of absorbed water by the pavement layer.

Amount of absorbed water = Amount of water before rain falling (wb) – Amount of water after ending the rain fall (wa) (1)

Table 1 shows how to number the days of testing according to the date of the test.

Table 2 shows the results which has been recorded after two hours (120 min) rain falling for (116 ml/min.) intensity rain.

Table 1. Days numbering according to the date.

Intensity ml/min	Time of Test (minute)	Date of test	Days Numbering
116	60	17/04/2016	1
116	60	18/04/2016	2
58	120	26/04/2016	10
58	120	27/04/2016	11
58	120	28/04/2016	12
58	60	28/04/2016	12
58	60	04/05/2016	18
58	60	05/05/2016	19
116	120	08/05/2016	22
116	120	09/05/2016	23
116	120	10/05/2016	24
116	60	12/05/2016	26
116	120	17/05/2016	31
116	120	24/05/2016	38
116	120	26/05/2016	40
116	60	31/05/2016	45
116	120	15/06/2016	60
116	120	19/06/2016	64
116	60	26/06/2016	71
58	120	03/07/2016	78
58	120	17/07/2016	92
58	120	18/07/2016	93
58	120	24/07/2016	99
58	120	25/07/2016	100
58	60	26/07/2016	101
58	60	27/07/2016	102
58	120	28/07/2016	103

Fig.8 shows the relationship between the amount of absorbed water and the time for two hours raining under track loading for high rain intensity which is 116 ml/min. This figure shows that the amount of the water that is absorbed through the pavement layer slightly decreases with the increase in time . At the first day of the test the pavement layer needed more amount of water to be saturated and after the saturation, the amount of the water decreases. The amount of absorbed water reached its highest point (45.5 letters) at the first day of test. At

the final day of test for this rain intensity, the amount of water records its lowest value which is 10 letters with percentage of 78% after 64 days of testing as shown in Table 2. The amount of water that seeped through the pavement layer decreases rapidly by increasing clogging materials of fine particles deposited on the surface of the pavement which resulted in passing the wheel track loading and the wear of the pavement surface, so the amount of absorbed water decreases which is the same as mentioned by (*Fang and ONG, 2005*).

Table 2. Test result for amount of absorbed water for (116ml/min.) rain intensity for two hours.

Amount of Absorbed Water (letters)	Days Numbering	Date of Test	Time of Vertical Drainage Ending (Sec)
45.5	22	08/05/2016	188
35.5	23	09/05/2016	188
25.5	24	10/05/2016	188
20.5	31	17/05/2016	240
20.5	38	24/05/2016	241
15.5	40	26/05/2016	241
15.5	60	15/06/2016	243
10	64	19/06/2016	245

Fig. 8. The Relationship Between The Amount of Absorbed Water and The Time (day) for Rain Intensity (116ml/min.) for Two Hours.

Fig.9 shows the relationship between the amount of absorbed water and the time of vertical drainage ending for (116ml/min.) rain intensity for two hours. By passing the days and increasing rain falling test under wheel track repetitions on the pavement, the clogging materials and other distress that appeared on the pavement causes the accumulation of water on the surface which needs more time to evaporate and seep.

Fig.9. The Relationship Between Amount of Absorbed Aater and Time of Vertical Drainage Ending for (116ml/min.) Rain Intensity for Two Hours.

Fig. 10. The Relationship Between The Amount of Absorbed Water and The Time for Rain Intensity (116ml/min.) for One Hour.

Table 3 and Fig.10 show the results of amount of absorbed water that is obtained after one hour (60 min) of rain fall.

Table 3. Test result for amount of absorbed water for (116ml/min.) rain intensity for one hour.

Date of Test	Days Numbering	Amount of Absorbed Water (letter)	Time of Vertical Drainage Ending (Sec)
17/04/2016	1	50.5	120
18/04/2016	2	47.5	180
12/05/2016	26	10.5	240
31/05/2016	45	15.5	241
26/06/2016	71	5.5	247

Fig.10 shows that the amount of absorbed water decreases as time increases and its highest value which is 50.5 letters at the first day of testing (17 April) and arrived to its lowest value, 5.5 letters, at the end of the third month of the test at (26 June) with percentage of 90% after 71 days, as shown in Table 3. By increasing the number of days and increasing clogging materials of fine particles deposited on the surface of the pavement which result in passing the wheel track loading and wearing the pavement surface, the water seepage decreases.

Fig.11 shows the relationship between amount of absorbed water and time of vertical drainage ending for (116ml/min.) rain intensity for one hour.

Fig.11. The Relationship Between Amount of Absorbed Water and Time of Vertical Drainage Ending for (116ml/min.) Rain Intensity for Two Hours.

The amount of absorbed water in the long duration of rain fall is less than that for the short duration of rain fall because more of the water is runoff, which is the same as indicated by (Day et al., 1981; Hunt et al., 2002; Valavala et al., 2006; Collins et al., 2008) that was taken for permeable pavement. Moreover, by increasing the clogging materials that penetrated to the pavement by increasing number of days, the water seepage decreased.

8 Test result for low intensity rain

This step represents the result study of amount of absorbed water, ending time of seepage and vertical

drainage for low intensity of rain (58 ml/Min.) as selected previously.

8.1 Amount of absorbed water

Figures compiled of more than one sub-figure presented side-by-side, or stacked. If a multipart figure is made up of multiple figure types (one part is lineart, and another is grayscale or color) the figure should meet the stricter guidelines.

Table 4 and Fig.12 show the results for the amount of absorbed water through the pavement layer during long term and short term period for the chosen low rain intensity.

The amount of the in letter was calculated before beginning the test, and then after two or one hour rain fall and at the end of the test. Then the difference between the amount of water before starting the test and amount of water after ending the test is referred to the amount of absorbed water by pavement layer.

Table 4. Test result for amount of absorbed water for (58ml/min.) rain intensity for two hours

Date of Test	Days Numbering	Amount of Absorbed Water (letters)	Time of Vertical Drainage Ending(Sec)
26/04/2016	10	55.5	180
27/04/2016	11	50.5	180
28/04/2016	12	45.5	180
03/07/2016	78	5.5	247
18/07/2016	93	5.5	248
24/07/2016	99	10.5	250
25/07/2016	100	5.5	250
28/07/2016	103	5.5	253

Fig.12 shows the relationship between the amount of absorbed water and the time for continuously two hours rain under track loading for low intensity of rain (58 ml/min.). This Figure shows that the amount of water that is absorbed through the pavement layer decreases with increase in the time. For the first test day of this rain intensity the amount of water was 55.5 letters and then decreases to reach 5.5 letters after 78 days of test. The amount of absorbed water reached its highest point at the first day of test.

When leaving the model without testing, the amount of water increases, because the pavement layers need to absorb more quantity of the water to be saturated, and after saturation it absorbs less water quantity.

The water seepage decreases rapidly by increasing clogging materials of fine particles deposited on the surface of the pavement which result in passing the wheel track loading and the wear of the pavement surface and clogging materials of salts and fine sands and other adulterant materials of the water, so the amount of absorbed water decreases.

Fig.12 The Relationship Between The Amount of Absorbed Water and The Time for Rain Intensity (58ml/min.) for Two Hours.

Fig.13 shows the relationship between amount of absorbed water and time of vertical drainage ending for (58 ml/min.) rain intensity for two hours. By passing the days, the amount of water absorbed will decrease. The clogging materials and other distress that appear on the pavement causes the accumulation of water on the surface which needs more time to evaporate and seep so the time of vertical drainage ending increases.

Fig.13. The Relationship Between Amount of Absorbed Water and Time of Vertical Drainage Ending for (58 ml/min.) Rain Intensity for Two Hours.

Table 5 and Fig.14 show the result of amount of absorbed water for one hour rain intensity for low intensity rain.

Table 5. Test result for amount of absorbed water for (58ml/min.) rain intensity for one hour

Date of Test	Days Numbering	Amount of Absorbed Water (letters)	Time of Vertical Drainage Ending (Sec)
28/04/2016	12	25.5	180
04/05/2016	18	35.5	188
05/05/2016	19	30.5	189
26/07/2016	101	2.5	253
27/07/2016	102	2.5	253

Fig.14 shows that the amount of absorbed water decreases with increase in test days and reaches to its lowest value 2.5 letters at the ending day of the test as shown in Table 5. At the first test day of this rain intensity the amount of absorbed water was 25.5 letters but after leaving it for six days it increases 10 letters to reach 35.5 letters. So after leaving the pavement without rain fall the amount of absorbed water increases.

Fig.14 The Relationship Between The Amount of Absorbed Water and The Time for Rain Intensity (58ml/min.) for One Hour

Fig.15 shows the relationship between amount of absorbed water and time of vertical drainage ending for (58 ml/min.) rain intensity for one hour.

Fig.15. The Relationship Between Amount of Absorbed Water and Time of Vertical Drainage Ending for (58 ml/min.) Rain Intensity for One Hour.

Pavement saturation and the clogging material affects the amount of absorbed water. By increasing time, it causes a decrease in absorbing water, the amount of absorbed water in the high rain intensity and for long duration of rain fall is less than that for low intensity rain for short term rain fall. In addition, if there was continuous rain fall for two different intensities of rain with its two different durations of time, saturation pavement and clogging materials have greater effect on absorbing water.

9 Rutting result

The wheel passes 240 repetition of passage in one hour and 480 repetition of passage in two hours with 0.2 m/Sec under rain intensity for the required period of time. In the analysis of potential rutting, the rut depth appears after 960 wheel repetition, as in Table 6 and increases slightly 0.5 after 2640 of wheel passing and increases randomly, then produced 22.5 mm rut depth after 11040 wheel repetition of passages. The test results plotted in Fig.16 show the relationship between the number of load passages and rut depth for the pavement of two different rain intensities. Initially the rut is slowly developed in more than 10 mm until it reaches around 5760 wheel repetition pass.

Table 6. Rutting depth result

Inten sity ml/m in	Time of Test (minut e)	No. of wheel repeti tion	Rut dept h (mm)	Date of test	No. of days
116	60	240	0	17/04/2016	1
116	60	480	0	18/04/2016	2
58	120	960	0.5	26/04/2016	10
58	120	1440	1	27/04/2016	11
58	120	1920	1.5	28/04/2016	12
58	60	2160	2	28/04/2016	12
58	60	2400	2.5	04/05/2016	18
58	60	2640	3	05/05/2016	19
116	120	3600	5.5	09/05/2016	23
116	120	4080	6.5	10/05/2016	24
116	60	4320	7	12/05/2016	26
116	120	5280	9	17/05/2016	31
116	120	5760	10	24/05/2016	38
116	120	6240	12	26/05/2016	40
116	60	6480	14	31/05/2016	45
116	120	6960	14.5	15/06/2016	60
116	120	7440	15.5	19/06/2016	64
116	60	7680	16	26/06/2016	71
58	120	8160	17	03/07/2016	78
58	120	9120	19	18/07/2016	93
58	120	9600	20	24/07/2016	99
58	120	10080	20.5	25/07/2016	100
58	60	10320	21	26/07/2016	101
58	60	10560	21.5	27/07/2016	102
58	120	11040	22.5	28/07/2016	103

Fig.16. Rut Depth Results of Wheel Repetitions.

10 Conclusions

The following conclusions can be made from this study:

- 1) The amount of water of the absorbed water decreases from 50.5 letters on the first day of rain fall to 5.5 letters on the final day to collect 89% decrease after 71 days of testing for high rain

intensity. And decreases from 55.5 letters to 2.5 letters after 92 days rain fall to record 95 % decreasing for 58 ml/m rain intensity.

- 2) Although by increasing the clogging materials of fine particles that are deposited on the surface of the pavement that result of passing the wheel track loading and wear of the pavement surface, and other clogging materials such as salt in the water which penetrate to the pavement and seal the voids and affect its water seepage and causes decrease in the amount of absorbed water.
- 3) The rut depth appeared after 960 wheel repetitions which was 0.5 mm and increased to 19 mm after 9120 repeated wheel passing to record 97 % increase after 93 days of testing and rain fall under different rain intensity with two different time durations.

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