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EXPERIMENTAL STUDY OF RUNOFF DRAINAGE FOR FLEXIBLE PAVEMENT

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ABSTRACT
Good water drainage is one of the most important things to consider when designing highway. Inadequate drainage facilities can lead to premature deterioration of the pavement and the development of adverse safety conditions such as cracks and rut. It is common, therefore, for a sizable portion of highway construction budgets to be devoted to drainage facilities. In essence, the general function of a highway drainage system is to remove rain water from the road and the highway right-of-way. This paper presents a study of the vertical drainage properties and the deterioration trends in water seeping of the pavement by testing the laboratory pavement section models with 2% slope which is very important in the selection of a suitable pavement surface layer and the base of the pavement. It has been concluded that by increasing number of days, when the pavement being saturated, the more amount of the water will runoff and the time of ending runoff increased by 77.78% after 138 days of study. The rut depth appeared after 2816 of wheel repetitions and recorded a 83.87% of rut depth increase after 109 days of load repetitions under different rain intensities with three durations of time.

INTRODUCTION
Drainage is very essential in design of roads since it affects the road's serviceability and life time. Drainage design involves providing facilities that collect, transport and remove runoff water from road pavement ***(Zumrawi, 2016)***

Poor drainage is often the main cause of road damages and problems with long term road serviceability ***(Onoyan-usina et al., 2013)***

Providing adequate drainage to a pavement system has been considered as an important design consideration to prevent premature failures due to water related problems such as pumping action, loss of support, and rutting, among others. Most water in pavements is due to rainfall infiltration into unsaturated pavement layers, through joints, cracks, shoulder edges, and various other defects, especially in older deteriorated pavements. Water also seep upward from a high groundwater table due to capillary suction or vapor movements, or it may flow laterally from the pavement edges and side ditches***(Rokade et al., 2012)*** **.**

Water in the pavement structure has long been recognized as a primary cause of distress. Within the past more than 25 years drainage of pavements has received an increasing amount of consideration. The mechanics of moisture distress are somewhat different for Portland cement concrete pavements and asphalt concrete (flexible) pavements; however the basic theory form hydraulic drainage and pipe flow are the same regardless of the pavement type **(FHWA, 2002)**.

Water has a number of unhelpful characteristics which impact on highway performance. It is a lubricant reducing the effectiveness of tire grip on the carriageway wearing surface which can increase stopping distances. Road surfacing materials are traditionally designed to be effectively impermeable, and only a small amount of rainwater should percolate into the pavement layers. It is important that any such water is able to drain through underlying pavement layers and away from the formation ***(Mukherjee, 2014)***.

Drainage quality is an important parameter which affects the highway pavement performance. The excessive water content in the pavement base, sub-base, and sub-grade soils can cause early distress and lead to a structural or functional failure of pavement ***(TIZA, 2016)***.

The selection of a suitable pavement surface layer and the base of the pavement are first made by studying the vertical drainage properties and the deterioration trends in permeability caused by clogging materials. The resistance of rutting for pavement structure is evaluated through the use of large-scale laboratory wheel tracking tests to provide an estimate of the structural capacity of the pavement structure. Based on these three criteria, a recommended design of the porous asphalt pavement is proposed for car parks and roads. ***(ONG and FWA, 2005)***.

MATERIALS AND METHODS

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

Steel Box: Steel container with external dimensions of (150 cm length), (80 cm) width and (135 cm) depth is constructed by the researcher to simulate the pavement layers (subgrade, sub base, crushed gravel base, binder and asphalt surface layers) according to typical cross sections for second carriageway Karbala-Alekhathaer, Al-Kshatriya Bridge Approaches, Al-dewanyah – Daghara highways that which constructed by Ministry of Construction and Housing / State Corporation For Roads and Bridges in Iraq. The steel plate thickness is 4 mm which was used to manufacture each part of the box. Figure 1 clarifies external dimensions for steel box.

Figure 1: The Steel Box of the Simulation Model.

The steel box contains openings 4 mm in diameter randomly distributed on the four sides of the box. . The object is to allow the water absorbed by the layers to be discharged out shown in Figure 2, four iron pipes as in Figure 3 were welded above the edge side of the steel container in order to install the distribution water pipe over it and steel base in order to make a suitable cross slope for steel box.

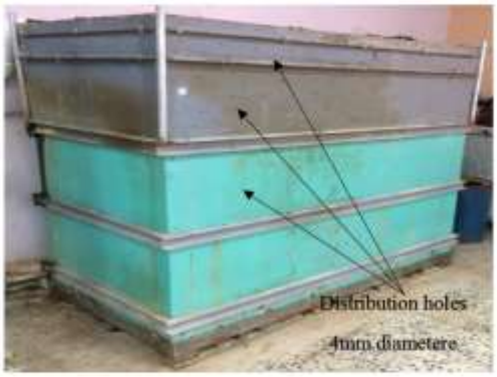


Figure 2: Holes Distributed Around the Steel Box.

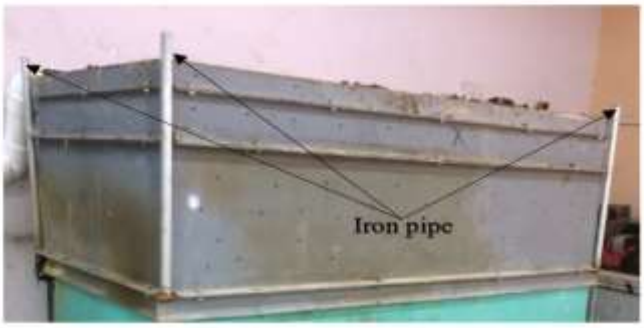


Figure 3: Iron Pipe Used to Install the Distribution Water Pipe.

Distribution of Water Pipe: is a system of water pipes with 150 cm length and 80 cm width. It is used as a water sprinkler, consisting of 12 iron pipe, with a pipe diameter of (1/2") and a pipe length of 70 cm, connected to an iron structure and 150 cm height above steel box top by the iron pipe and installed over the steel box by screws. This system has 2 mm diameter holes distributed systematically along the circular tube and at a distance of 3 cm to one hole and another, to simulate the rainfall over the highway in the model as shown in Figure 4.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.

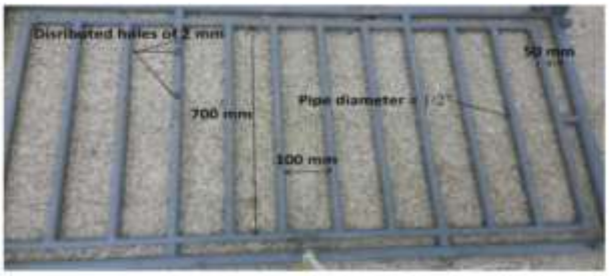


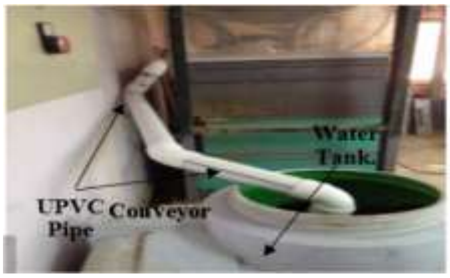
Figure 4: Water Distribution Network for Rainfall Simulation.

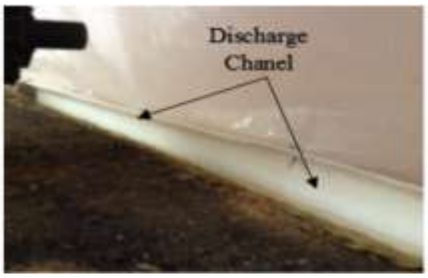
Water Pump: An electrical water pump is used which is joined to the water tank to draw water from the water tank to the distribution water pipe by plastic water pipe, the intensity of the water pump is 30 l/min. and with a power of 550W.

Water Tank: In this research, a cylindrical water tank made of plastic with a storage capacity of 500 liters of water for use in the experiment. The water tank is connected to the electrical water pump from the bottom and it contained a slot of 3/4" at the top which receives flux water by the plastic pipe of 3/4" with 1.5m length from the model which is connected to the channel shown in Figure 5.

Figure 5: Water Tank.

Drainage System Daring system consist of discharge channel that which used to collect water from the surface of pavement and water conveyor pipe with diameter 3" (7.35cm) to transfer water from the discharge channel and directed it into the water tank is constructed by the researcher. This system is made of UPVC material. Finger 6 explain the drainage system.





(A) *(B)*

Finger 6: A) Conveyor Pipe, B) Discharge Chanel.

Wheel Track: A framework of iron rectangular with 200 cm long and a 200 cm high has been manufactured. This frame contains ball bearing to facilitate the wheel movement. The wheel is constructed by rubber tire with 250 mm diameter and 80 mm width and the contact area between the surface of the pavement and the tire is 17.7 cm^2 (2.454 in^2). The caoutchouc tire is moved by three phase's motor 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 (150kg) to attain (95psi) maximum tier pressure according to (***IRAQIHIGHWAYDESIGENMANUAL***, 2005) have been used. The loads are placed above the iron plate of the wheel as shown in Figure 7

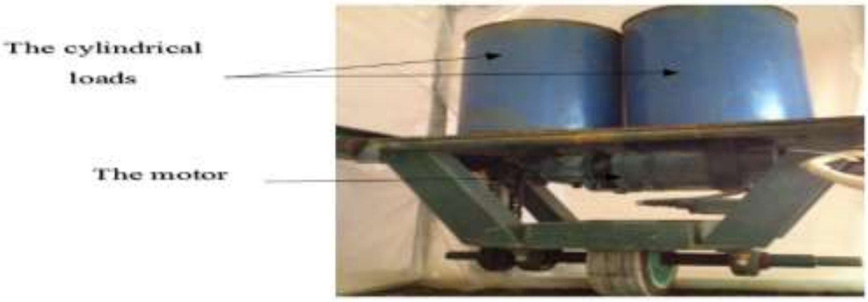


Figure 7: The ufactured simulated wheel track

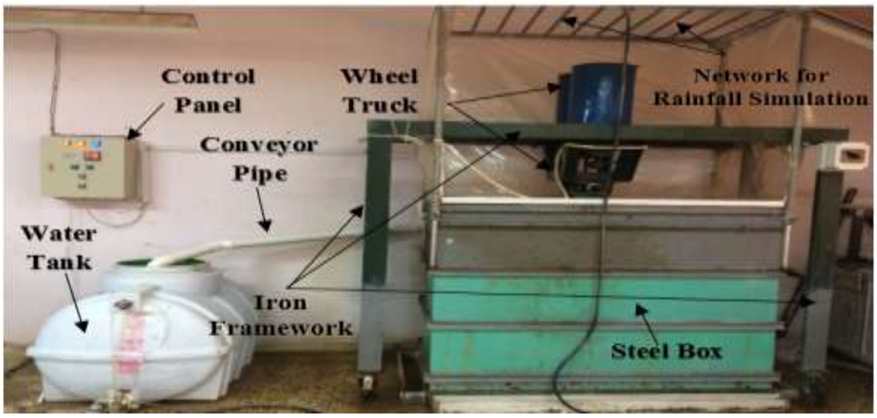
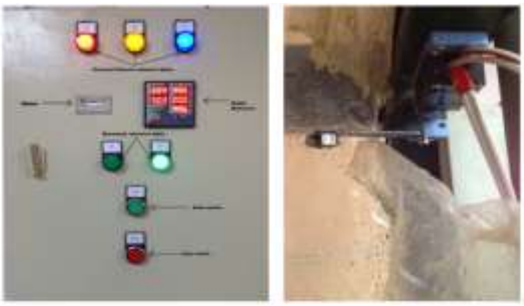


Figure 8: Prototype Laboratory Simulation Model

Control Panel: An electrical control panel is constructed by the researcher. It is used to control the movement of wheel load back and forth by placing two limit switch at the ends of an iron framework. This panel provides information about the number of repeated wheel load pass by processing a meter that calculates the number of times of passage and also know the amount of Ampere and the frequency of each electrical phase of the measurements by using a digital multimeter and also contains reference lights to know the direction of movement to the right and left. Figure 9 depict the control panel and limit switch.



(A) (B)
Figure 9 A) Control Panel, B) Limit Switch.

Pick of Rain Intensity: For this research, three genders of rainfall intensity were selected: low intensity rain with 30mm/min., intermediate intensity rain with 60mm/min. and high intensity rain with 90mm/min., and both of them have been studied for short and long term.

Tow quarter 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, 60 and 90 minutes. The long-term intensity rain embarked at the same time of the short term raining but continued for 138 days. 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 elaborated.

Starting the Test: The test initiate with turning on the water pump and opening the faucet to the required water intensity which was previously selected, then the water pump drag the water from the water tanker in which its amount of water was studied 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. 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 performance changes on the asphalt wearing layer pending the rain and under the influence of wheel track loading are registered.

During the test, the water drains and moves toward a channel which was set on the cross slope of the pavement, and returns back to the water tanker through the drainage system and pours on the top of the tanker. Table 1 illustrate how to numbering the days of testing according the date of the test.

Table (1): Test Day Number According to the Date for a Study Period of 138 Days.

Intensity mm/min	Time of Test (minute)	Date of Test	Test Day Number	Accumulation Number of Days
30	90	19/3/2017	1	1
30	90	22/3/2017	2	4
30	90	26/3/2017	3	8
30	90	29/3/2017	4	11
30	90	02/4/2017	5	15
30	90	09/4/2017	6	22
30	90	11/4/2017	7	24

30	90	13/4/2017	8	26
60	60	16/4/2017	9	29
60	60	24/4/2017	10	37
60	60	26/4/2017	11	39
60	60	30/4/2017	12	43
60	60	02/5/2017	13	45
60	60	04/5/2017	14	47
60	60	07/5/2017	15	50
60	60	09/5/2017	16	52
60	60	11/5/2017	17	57
60	60	14/5/2017	18	60
60	60	16/5/2017	19	62
60	60	21/5/2017	20	67
90	30	23/5/2017	21	69
90	30	25/5/2017	22	71
90	30	28/5/2017	23	74
90	30	30/5/2017	24	76
90	30	1/6/2017	25	78
90	30	4/6/2017	26	81
90	30	6/6/2017	27	83
90	30	8/6/2017	28	85
90	30	11/6/2017	29	88
90	30	20/6/2017	30	97
90	30	22/6/2017	31	99
90	30	2/7/2017	32	109
30	90	6/7/2017	33	113
30	90	13/7/2017	34	120
30	90	20/7/2017	35	127
30	90	31/7/2017	36	138

Time ending of the Surface Drainage Runoff: Surface drainage runoff is the lazy fleeing of the water on the surface of the pavement to the channel that executed on the one side of the pavement during the testing. After discontinuation the water flow, the time until the end of water runoff on the pavement surface is calculated.

Vertical Drainage Time The vertical drainage time is the time during which the heaped up water on the surface is absorbed through the surface layer. This time is calculated after ending of the rain intensity on the model then starting the timer to calculate the time until the full accumulated water on the surface layer is absorbed through asphalt pavement layer.

RESULTS

The test result for high rain intensity

This step appears the study result of the quantity of absorbed water, time ending of the surface drainage runoff and vertical drainage time for low intensity rain (30mm/min.) during the study period.

Surface Drainage Runoff Result

The time of completing the surface drainage runoff is calculated after ending the test then the ending time in which the water runoff to the channel is calculated in seconds.

Use the rational method to determine the peak runoff rate of water which falls upon the pavement area according to ***(Johnson and Chang, 1984)***:

Q = KCiA…………………………………. (2)

Where: Q = the peak runoff rate (m^3/s)

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K = (0.00275)
C = a dimensionless runoff coefficient representing characteristics of the watershed. For relatively small watersheds such as those dealt with in the surface drainage of highway pavements, the value of the C ranges (0.7-0.9) for paved area***(Johnson and Chang, 1984).***
i = the average rainfall intensity, (mm/hr.) for a duration equal to the time of concentration and for the recurrence interval recurrence chosen for design.
A = drainage area (hectares).

Table2: shows the results of time of completing the surface drainage runoff after continuously 90minute raining fall.

Date of Test	Test Day Number	Days Numbering	Time of the Surface Drainage Runoff Ending (Sec.)	Q(Discharge) mm³/Sec
19/3/2017	1	1	180	534600
22/3/2017	2	4	210	534600
26/3/2017	3	8	264	534600
29/3/2017	4	11	300	534600
02/4/2017	5	15	360	534600
09/4/2017	6	22	510	534600
11/4/2017	7	24	600	534600
13/4/2017	8	26	660	534600
6/7/2017	33	113	705	534600
13/7/2017	34	120	732	534600
20/7/2017	35	127	768	534600
31/7/2017	36	138	810	534600

Table 3 shows the results of time of completing the surface drainage runoff after continuously two hours rain fall. Figure 10 shows that the surface drainage runoff increases when time increases, and it records 180 seconds time to end the surface drainage runoff at the first day of the test for this rain intensity but 810 seconds is needed to end the surface drainage runoff after 138 days. By increasing number of days and when the pavement layers being saturated resulted of continuous rain falling, and because of other factors such as: the clogging material, as mentioned earlier, which penetrated into the pavement layer with minimal disturbance made to the unbound aggregate, the water seeping is decreased and less amount of water is absorbed. This in turn resulted in more runoff, so the water on the pavement will need more time to runoff.

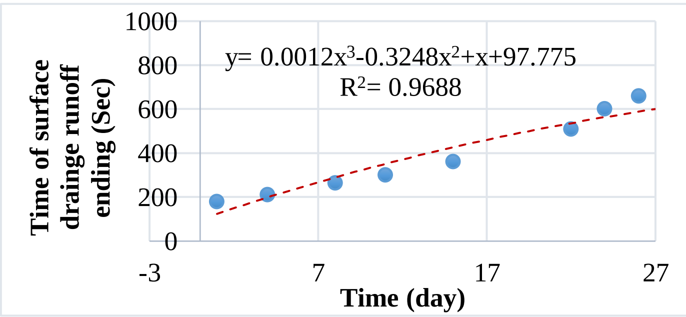

Figure 10: The relationship between the time of surface drainage runoff ending and the time for low rain intensity.

The wheel track passing on the pavement surface is the second factor that effect on the time of surface runoff; it causes rut on the pavement and this in turn made the movement of the water on the pavement to the channel to be difficult because of the depression appearance on the pavement leading to delay the surface drainage runoff.

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Vertical Drainage

The ending time of vertical drainage was registered after 90 minutes rain fall time. When the rain falling ended, the time that the accumulated water on the surface absorbed through the asphalt pavement layer was recorded. Table 3 illustrates the results that were recorded after 90 minutes rainfall.

Table 3: Test result for time of the vertical drainage ending for low rain intensity.

Date of Test	Test Day Number	Days Numbering	Time of the Vertical Drainage Ending (Sec.)
19/3/2017	1	1	420
22/3/2017	2	4	510
26/3/2017	3	8	600
29/3/2017	4	11	660
02/4/2017	5	15	750
09/4/2017	6	22	816
11/4/2017	7	24	900
13/4/2017	8	26	984
6/7/2017	33	113	1005.6
13/7/2017	34	120	1044
20/7/2017	35	127	1073.4
31/7/2017	36	138	1110

Figure 11 shows that the vertical drainage increases with time increases, so, as presented in Table 3, for the first day of rain test and for this time period the vertical drainage was ended after 420 seconds and after 138 days its ending time increases to 1110 seconds, because the clogging material penetrated to the pavement and seal the voids in the pavement and when the wheel track is passed on the pavement surface it caused accumulation of water on the pavement, this in turn delays the vertical drainage of the water.

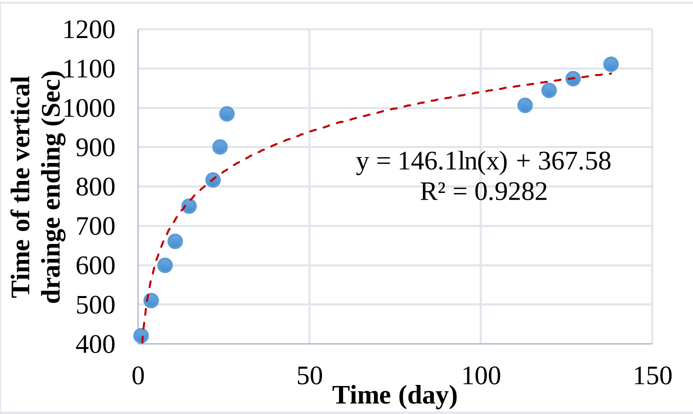

Figure 11: The relationship between time of the vertical drainage ending and the time for low rain intensity.

The Test Result for Intermediate Rainfall Intensity

This step exemplify the result study of quantity of absorbed water, time ending of the surface drainage runoff and vertical drainage time for intermediate intensity of rain (60 mm/min.) as selected formerly.

Surface Drainage Runoff Results

Table 4 depict the results of ending time of surface drainage runoff after continuously 60 minute raining fall for (60mm/min.) rain intensity.

Figure 12 shows the relationship between the surface drainage runoff with increasing time for rain intensity (60mm/min.) 60 minutes.

Table 4: Test result for time of the surface drainage runoff ending for intermediate rain intensity.

Date of Test	Test Day Number	Days Numbering	Time of the Surface Drainage Runoff Ending (Sec)	Q(Discharge) mm³/Sec
16/4/2017	9	29	210	950400
24/4/2017	10	37	240	950400
26/4/2017	11	39	300	950400
30/4/2017	12	43	330	950400
02/5/2017	13	45	348	950400
04/5/2017	14	47	378	950400
07/5/2017	15	50	402	950400
09/5/2017	16	52	445.2	950400
11/5/2017	17	57	462	950400
14/5/2017	18	60	492	950400
16/5/2017	19	62	531.6	950400
21/5/2017	9	67	564	950400

Figure 12 illustrates that the time of ending the surface drainage runoff increases with increasing the time of test until it reaches its maximum value in this test, which is 564 Seconds at day's number 109 in of study, as shown in Table 4. While it was need 60 seconds to run off after 12 days of rain falling. By increasing number of days and after continuously rain falling, the pavement becomes saturated, furthermore the clogging material permits to the pavement and seals the voids of the pavement so the water seeping is decreased and fewer amounts of water is absorbed. While more amount of the water runs off toward the channel, so the time of ending surface drainage runoff is increased. The other factor is that the rutting that is caused by track loading made the movement of the water difficult to drainage to the channel so a delay is occurred in the time of ending drainage.

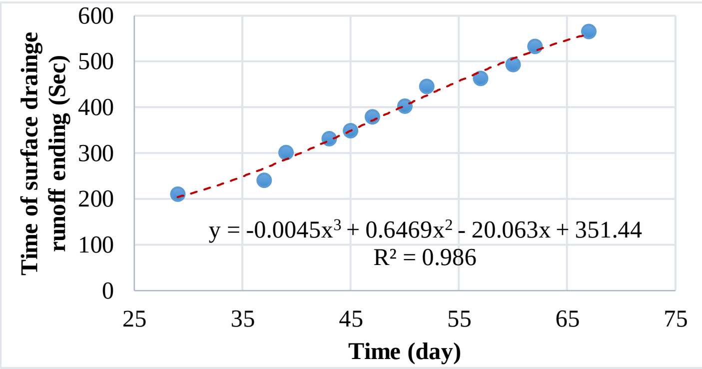

Figure 12: The relationship between the time of surface drainage runoff ending and the time for intermediate rain intensity.

Vertical Drainage

The ending time of vertical drainage was registered after60 minutes; when the rain falling run out and at the time that the heaped up water in the surface absorbed through the pavement layer. Table 5 and Figure 14 show the results that were recorded after 60 minutes rainfall.

Table 5 : Test result for time of the vertical drainage ending for (60mm/min.) rain intensity for 60 minutes.

Date of Test	Test Day Number	Days Numbering	Time of the Vertical Drainage Ending (Sec)
16/4/2017	**9**	**29**	**300**
24/4/2017	**10**	**37**	**342**
26/4/2017	**11**	**39**	**378**
30/4/2017	**12**	**43**	**408**
02/5/2017	**13**	**45**	**426**

04/5/2017	**14**	**47**	**462**
07/5/2017	**15**	**50**	**480**
09/5/2017	**16**	**52**	**504**
11/5/2017	**17**	**57**	**516**
14/5/2017	**18**	**60**	**540**
16/5/2017	**19**	**62**	**558**
21/5/2017	**9**	**67**	**600**

Figure 13 illustrates the relationship between the time of ending vertical drainage and the time of starting the test for intermediate intensity rain (60mm/min.) 60 minutes. The pavement needed 300 seconds to end the vertical drainage at 29 days of test but it increases the time increase to record 600 seconds at second month of test. The clogging material penetrates to the pavement and seals the voids on the pavement and when the wheel track is passed on the pavement surface it caused accumulation of water on the pavement which in turn delays the vertical drainage of the water.

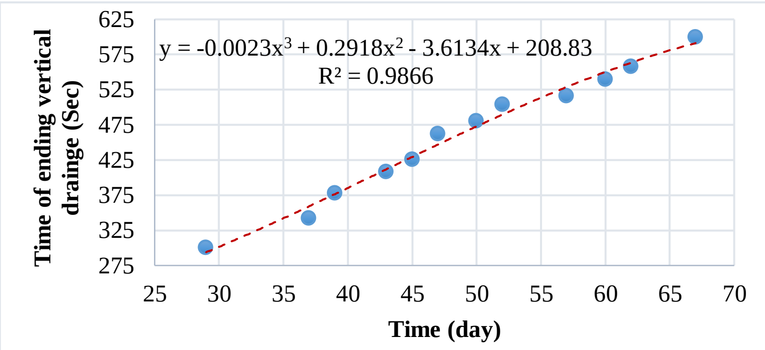

Figure 13: The relationship between Time of the vertical drainage ending (Sec) and the time (day) for rain intensity (60mm/min.) for60 minutes.

The Test Result for High Intensity Rain

This step exemplify the result study of quantity of absorbed water, time ending of the surface drainage runoff and vertical drainage time for high intensity of rain (90 mm/min.) as selected formerly.

Surface Drainage Runoff Results

Table 6 depict the results of ending time of surface drainage runoff after continuously 30 minute raining fall for (90 mm/min.) rain intensity.

Figure 15 shows the relationship between the surface drainage runoff with increasing time for rain intensity (90 mm/min.).

Table 6: Test result for time of the surface drainage runoff ending for (90mm/min.).

Date of Test	Test Day Number	Days Numbering	Time of the Surface Drainage Runoff Ending (Sec)	Q(Discharge) mm³/Sec
23/5/2017	21	69	210	1425600
25/5/2017	22	71	240	1425600
28/5/2017	23	74	300	1425600
30/5/2017	24	76	330	1425600
1/6/2017	25	78	348	1425600
4/6/2017	26	81	378	1425600
6/6/2017	27	83	402	1425600
8/6/2017	28	85	445.2	1425600
11/6/2017	29	88	462	1425600
20/6/2017	30	97	492	1425600

22/6/2017	31	99	531.6	1425600
2/7/2017	32	109	564	1425600

Figure 14 illustrates that the time of ending the surface drainage runoff increases by increasing time and reached to its maximum value, which is 564Seconds, as illustrate in Table 6. While it was need 30 seconds to run off after 12 days of rain falling. By increasing number of days and after continuously rain falling, the pavement becomes saturated, moreover the clogging material penetrates to the pavement and seals the voids of the pavement so the water seeping is decreased and fewer amounts of water is absorbed. While more amount of the water runs off toward the channel, so the time of ending surface drainage runoff is increased. The other factor is that the rutting that is caused by track loading made the movement of the water difficult to drainage to the channel so a delay is occurred in the time of ending drainage

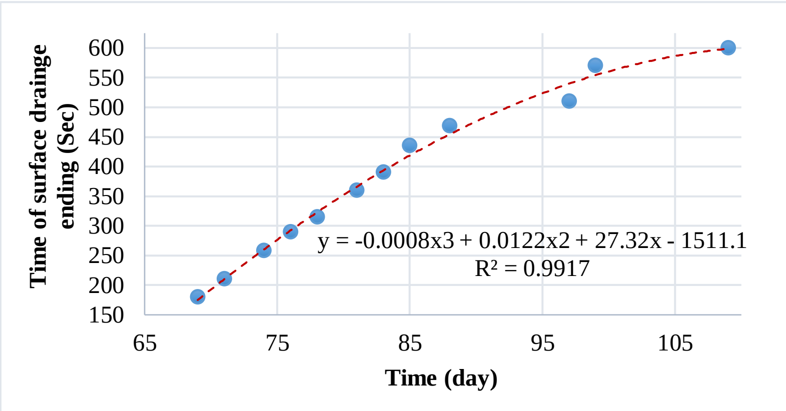

Figure14: The relationship between the time of surface drainage runoff ending (Sec) and the time (day) for rain intensity (90mm/min.).

Vertical Drainage

The ending time of vertical drainage was registered after two different times; when the rain falling run out and at the time that the heaped up water in the surface absorbed through the pavement layer. Table 7 and Figure 15 show the results that were recorded after 60 minutes rainfall.

Table 7: Test result for time of the vertical drainage ending for high rain intensity.

Date of Test	Test Day Number	Days Numbering	Time of the Vertical Drainage Ending (Sec)
23/5/2017	21	69	60
25/5/2017	22	71	75
28/5/2017	23	74	105
30/5/2017	24	76	120
1/6/2017	25	78	150
4/6/2017	26	81	172.8
6/6/2017	27	83	180
8/6/2017	28	85	198
11/6/2017	29	88	222
20/6/2017	30	97	246
22/6/2017	31	99	285.6
2/7/2017	32	109	300

Figure 15 illustrates the relationship between the time of ending vertical drainage and the time of starting the test for high intensity rain (90mm/min.). The pavement needed seconds to end the vertical drainage at the first month of test but it increases the time increase to record 248 seconds at final month of test. The clogging material penetrates to the pavement and seals the voids on the pavement and when the wheel track is passed on the pavement surface it caused accumulation of water on the pavement which in turn delays the vertical drainage of the water.

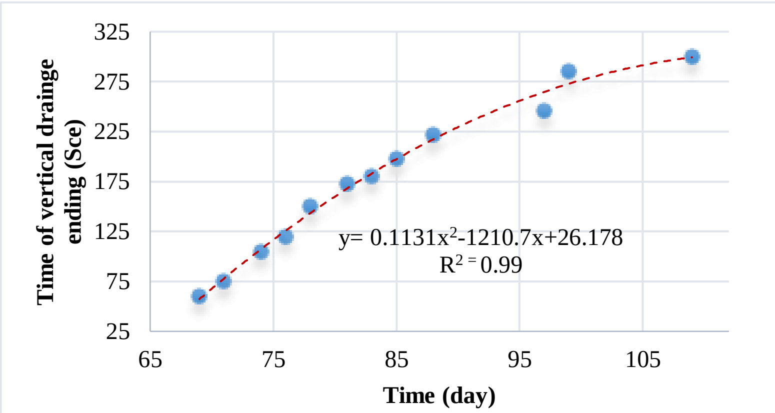

Figure 15: The relationship between Time of the vertical drainage ending and the time for high rain intensity

Table 8: Results of time of absorbed accumulated water in rut place for low rain intensity.

Time of Test (minute)	Date of test	Test Day Number	Days Numbering	Time of Absorbed Accumulated Water in Rut Place (sec.)	Rut depth (mm)
90	19/3/2017	1	1	0	0
90	22/3/2017	2	4	0	0
90	26/3/2017	3	8	0	0
90	29/3/2017	4	11	510	0.5
90	02/4/2017	5	15	570	0.5
90	09/4/2017	6	22	690	0.5
90	11/4/2017	7	24	800	1
90	13/4/2017	8	26	850	1
90	6/7/2017	33	113	950	13.5
90	13/7/2017	34	120	1000	14.22
90	20/7/2017	35	127	1025	15.12
90	31/7/2017	36	138	1100	15.5

Table 9: Results of time of absorbed accumulated water in rut place for Intermediate rain intensity.

Time of Test (minute)	Date of test	Test Day Number	Days Numbering	Time of Absorbed Accumulated Water in Rut Place (min.)	Rut depth (mm)
60	16/4/2017	9	29	240	1.55
60	24/4/2017	10	37	240	1.58
60	26/4/2017	11	39	300	2
60	30/4/2017	12	43	300	2.27
60	02/5/2017	13	45	360	2.5
60	04/5/2017	14	47	420	3
60	07/5/2017	15	50	450	3.5
60	09/5/2017	16	52	460	3.58
60	11/5/2017	17	57	480	4

60	14/5/2017	18	60	480	4.12
60	16/5/2017	19	62	540	4.5
60	21/5/2017	20	67	560	5.53

Table 10: Results of time of absorbed accumulated water in rut place for high rain intensity.

Time of Test (minute)	Date of test	Test Day Number	Days Numbering	Time of Absorbed Accumulated Water in Rut Place (min.)	Rut depth (mm)
60	16/4/2017	21	29	50	6
60	24/4/2017	22	37	50	6.51
60	26/4/2017	23	39	90	7
60	30/4/2017	24	43	90	7
60	02/5/2017	25	45	120	7.5
60	04/5/2017	26	47	125	8
60	07/5/2017	27	50	180	8.55
60	09/5/2017	28	52	210	9
60	11/5/2017	29	57	240	9.59
60	14/5/2017	30	60	250	10
60	16/5/2017	31	62	280	11.51
60	21/5/2017	32	67	280	13

Tables 8, 9 & 10 shows the results of time of absorbed accumulated water in rut place after ending rain fall for the three types of rain intensity for 90,60 and 30 minutes .

Figure 16, 17 & 18 show the relationship between the time of absorbed water that accumulated at the rut depth place and the rut depth for the two different rain intensities. The time of absorbed water that accumulated in the rut depth increases by increasing time and by increasing the rut depth. So, 590 seconds the average time of absorbed accumulated water in rut place were needed when the rut depth was 0.5 millimeters and increased slowly by 60 seconds after ending the rain intensity (30mm/sec) for 90 minutes duration and by passing 2288 wheel repetition. So it reached its maximum time 1100 seconds. When the recorded rut depth was 15.5 millimeters.

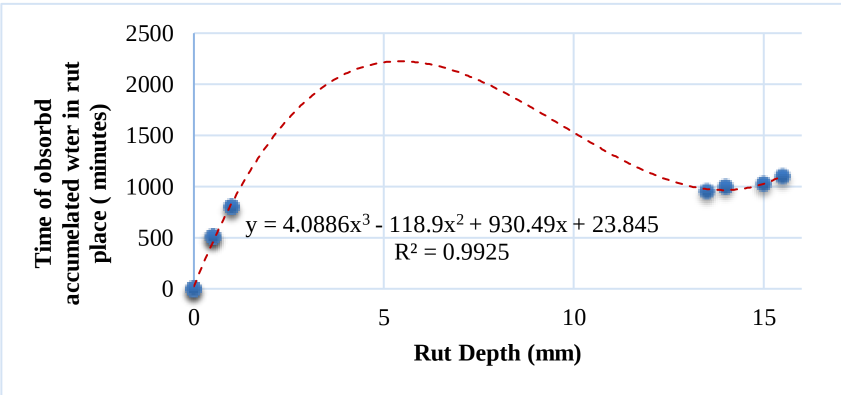

Figure 16: Results of time of absorbed accumulated water in rut place for low rain intensity.

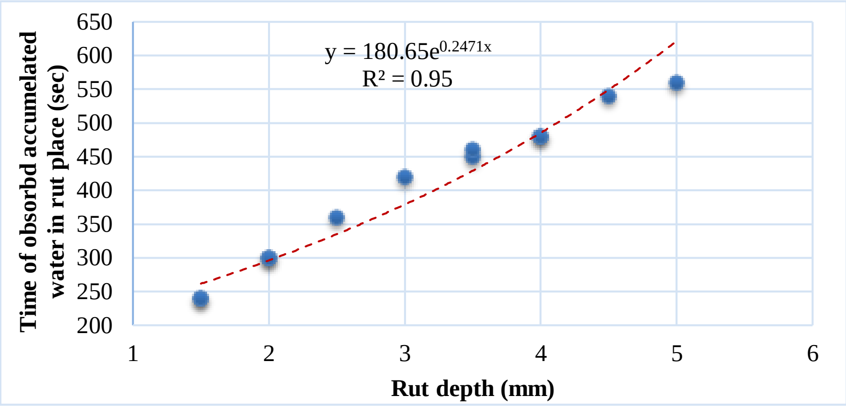

Figure17: Results of time of absorbed accumulated water in rut place for Intermediate rain intensity.

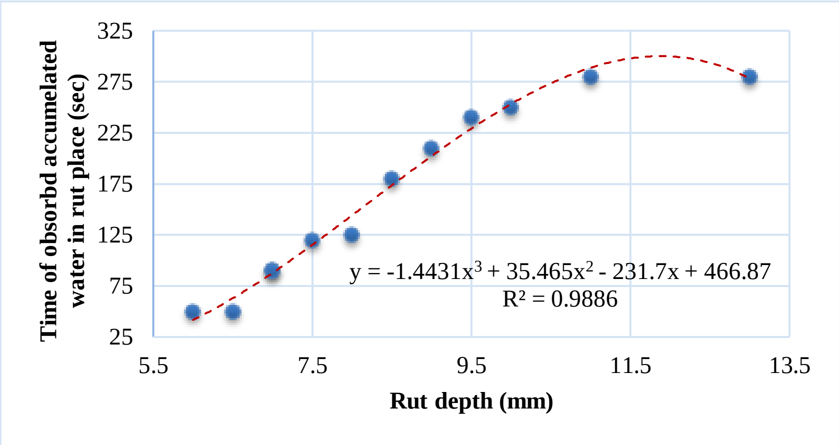

Figure18: Results of time of absorbed accumulated water in rut place for high rain intensity.

CORE TEST RESULTS

Five deep cores were extracted from the compacted asphalt pavement layer according to ***(ASTMD979, 2012)*** after the rainfall laboratory tests, These samples were distributed in the form of three samples along the path of wheel truck in the center of the pavement layer and two samples on both sides of the pavement layer in order to ensure the proper and correct sampling process as shown in Figures 19&20 to calculate a number of the important volumetric properties of the asphalt pavement layers, which are related to the subject of this study.

Tables 11 & 12 illustrates the core test results was conducted on asphalt pavement layer after and before the test. This tables shows that the effect of the factors (wheel load and rainfall) that have been shed on the asphalt surface layer has caused changes in the volume properties of this layer and this change has continued to make changes in this properties for the asphalt binder layer also.

For example, the percentage of air voids (VA) we find that the percentage has increased significantly after the test, We find them higher in place on a wheel path in the center of the surface layer than the places located in the first trimester and the third trimester of the same layer and this is also the case in asphalt binder layer.

The results of this test shown in the same tables indicate that the (TSR) of the two layers and the places mentioned for each layer are within the limits for the Superpave requires a minimum TSR of 80 percent, which states that this ratio is not less than 80% for both asphalt layers .

Figure 19: Cores extraction

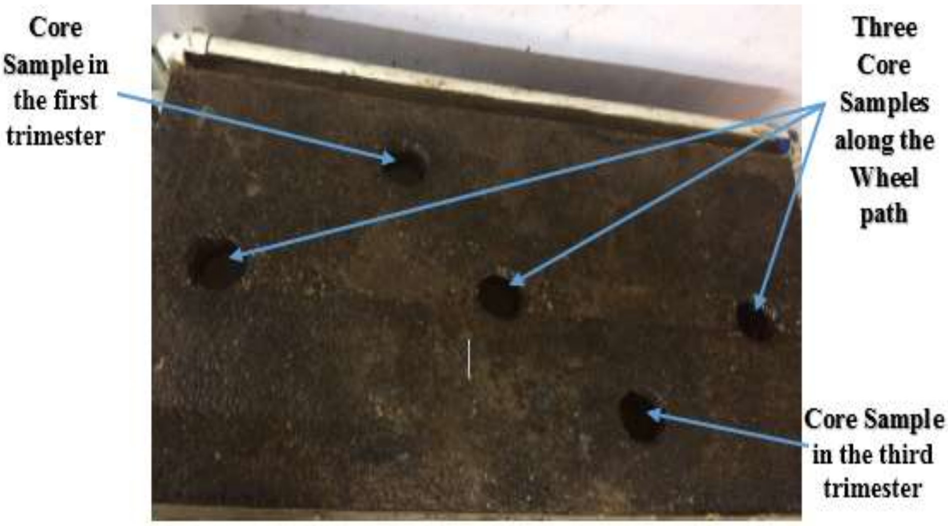

Figure 20: Distribution of core samples on pavement layer

Table 11: the core test results asphalt surface layer after and before the test.

Index Property	Index Value before the test (control)	Index Value after the test (condition)			Test Method
		In the first trimester	In the center of pavement	In the third trimester	
Bulk specific gravity (Gmb)	2.298	2.2769	2.2613	2.2726	(ASTMD2 726, 2010)
Bulk density Dmb (kg/m3)	2291.710	2270.388	2254.748	2266.038	(ASTMD2 726, 2010)
percent water absorbed	21.30%	26.72%	22.00%	38.45%	(ASTMD2 726, 2010)

Theoretical Maximum Specific Gravity Gmm	**2.415**	**2.408**	**2.401**	**2.405**	**(ASTMD2 041, 2003)**
Theoretical maximum Density Dmm (kg/m3)	**2407.996**	**2401.0168**	**2394.037**	**2398.0255**	**(ASTMD2 041, 2003)**
Percent Air Voids (AV %)	**4.844%**	**5.44%**	**5.81%**	**5.426%**	**(ASTMD3 203, 2005)**
Volume determinations of the specimens (cm³).	**363.3**	**381.6**	**362.7**	**369**	**(ASTMD3 549, 2011)**
Volume of the air voids Va (cm³).	**17.59**	**20.75**	**21.07287**	**20.02194**	**(AASHTO T283, 2006)**
Hydraulic conductivity Ksat (m/sec)	**2.52296E-05**	**2.83338E-05**	**3.02889E-05**	**2.82609E-05**	**(ASTM PS129)**
Tensile strength St (kPa)	**2165.605096**	**1834.39490**	**1745.2229**	**1796.17834**	**(AASHTO T283, 2006)**
Tensile Strength Ratio (TSR)	/	**84.70%**	**80.58%**	**82.94%**	**(AASHTO T283, 2006)**

Table 12: the core test results asphalt binder layer after and before the test.

Index Property	**Index Value before the test (control)**	**Index Value after the test (condition)**			**Test Method**
		In the first trimester	**Centre of pavement**	**In the third trimester**	
Bulk specific gravity (Gmb)	**2.288**	**2.268**	**2.259**	**2.269**	**(ASTMD 2726, 2010)**
Bulk density Dmb (kg/m3)	**2282.0789**	**2262.2627**	**2253.4026**	**2262.9023**	**(ASTMD 2726, 2010)**
percent water absorbed %	**17.012%**	**19.69%**	**19.11%**	**20.19%**	**(ASTMD 2726, 2010)**
Theoretical Maximum Specific Gravity Gmm	**2.407**	**2.409**	**2.4**	**2.408**	**(ASTMD 2041, 2003)**
Theoretical maximum Density Dmm (kg/m3)	**2400.0197**	**2402.0139**	**2393.04**	**2401.0168**	**(ASTMD 2041, 2003)**
Percent Air Voids (AV %)	**4.91%**	**5.81%**	**5.83%**	**5.75%**	**(ASTMD 3203, 2005)**
Volume determinations of the specimens (cm³).	**694.8**	**683.3**	**690.5**	**0.21**	**(ASTMD 3549, 2011)**
Volume of the air voids Va (cm³).	**34.11**	**39.69**	**40.25**	**39.32**	**(AASHT OT283, 2006)**

Hydraulic conductivity Ksat (m/sec)	**2.63941E-05**	**3.13632E-05**	**3.12712E-05**	**3.09369E-05**	**(ASTM PS129)**
Tensile strength St (kPa)	**1152.866**	**942.675**	**923.566**	**955.414**	**(AASHTOT283, 2006)**
Tensile Strength Ratio (TSR)	/	**81.76%**	**80.11%**	**82.87%**	**(AASHTOT283, 2006)**

Effect of Rain Intensity and Duration of Rain Falling on the Drainage of the Pavement
The increase in the amount of rain intensity falling on the surface layer of the flexible pavements has two effects, the first leading to a decrease in the amount of the vertical drainage so the voids of pavement is filled with more water, and then more of water causes more water runoff toward the channel of drainage and the second this increase leading to increase the percent of air voids in the pavements layers, resulting in problems in the layer of pavement.

If rainfall intensity was greater than the permeation rate of the pavement, the surface runoff takes place very quickly. While in case of low intensity rainfall, an opposite trend is found. Thus, high intensity rainfall yields higher runoff. The slope of 2% that was designed for the pavement resulted in reduced water depths, so facilitates the runoff of the water.

Rainfall duration is directly related to the volume of runoff due to the fact that the vertical drainage rate of the surface decreases with increasing the duration of rainfall, till it attains a constant rate.
The water starts infiltrating/ percolating to the water table and if the rate of the rainfall or the rate at which the water is reaching the ground exceeds the infiltration rate, it resulted in the surface detention.

4.14 Effect of the Wheel Track Loading on the Drainage of the Pavement
The wheel track with 95 psi load and 0.2m/s speed is repeated on the pavement under different rain intensities with different time durations.

When increasing number of days of test, the repetitions of the wheel track on the pavement cause a small rut depth 7 millimeters after 13992 wheel passes and medium rut depth 15.5 millimeters after 24816 wheel passes on the wheel path.

When the rut depth appeared on the pavement it causes accumulation of water on the rut place as shown in Figure 21 and it difficult the movement of the water toward the side channel so the time of ending the runoff is delayed.

Ruts filled with water can cause vehicle hydroplaning, and can be hazardous because ruts tend to pull a vehicle towards the rut path as it is steered across the rut.

A heavily rutted pavement should be investigated to determine the main cause (or causes) of failure (e.g. insufficient compaction, subgrade rutting, poor mix design or studded tire wear). Slight ruts can generally be left untreated. Pavement with deeper ruts should be levelled and overlaid.

Figure 21: Rutting place on the pavement

Other Distresses of the Pavement

The slight raveling occurred on the pavement because loss of fines ***(Pavement Surface Evaluation and Rating , 2002)*** resulting from passing of the wheel track and the continuous rain falling with high rain intensity and long duration of raining test for continuous 138 days and expressed as localized range (patchy areas, usually in the wheel paths) shown in Figure 22.

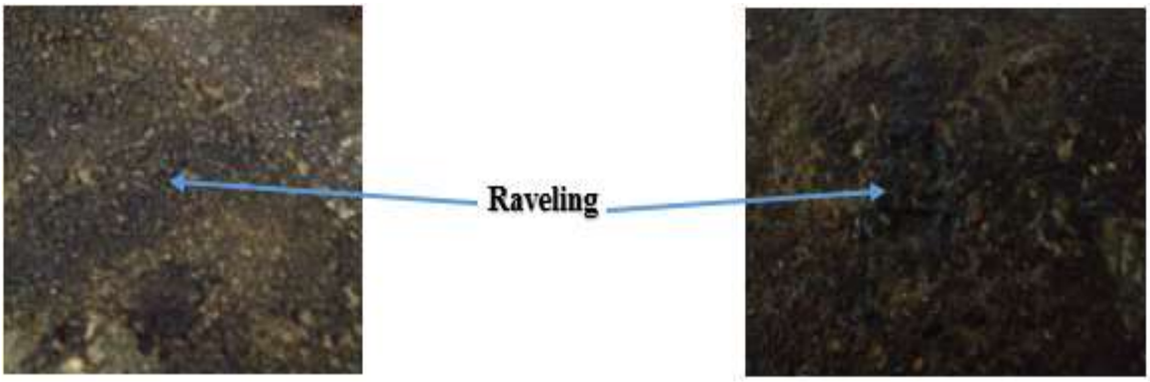

Figure22: Raveling that occurred on the surface of the pavement.

CONCLUSIONS

Depending on the results obtained from this study, the following conclusions can be made:

1. The quantity of water absorbed has decreased from 90 liters on the first day of test to 49.5 liters on the last day of the study period which indicates a 45% decrease after 138 days of testing for 30mm/min rain intensity. Also, it decreased from 60letters on day 29 of test which began with the second rain intensity to 20 letters after 67 days of the study period which equal to 66.67 % decrease for 60 mm/min rain intensity. And so it is decreased from 45letters on day 69 of test which is considered the first day of the third intensity of rain to 23.5 letters after 109 days of rain falling which equal to 47, 78 % decrease for 90 mm/min rain intensity.
2. The water infiltration decreases by the more days passed, as the pavement becomes saturated and need to absorb less amount of water than the first days of testing.
3. Increasing the clogging materials of fine particles that deposited on the surface of the pavement that results 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 effect on its permeability caused decreasing of the amount of absorbed water.
4. With the passage of time for the study period, when saturation with rainwater increased for pavement cross section layers, the more quantity of the water will runoff. The presence of clogging materials led to a decrease in the value of the permeability of the asphalt surface layer, which in turn increased the time of the surface drainage runoff ending. At the first day of study when the pavement cross section was

unsaturated and absorbed 90 letters after 90minuts of rain falling with 30mm/min rain intensity, the run off ended after 180 sec. from the ending of the raining time. While after 138 days when the quantity of absorbed water decreased to 49.5 letters for the same intensity rain, more quantity of water is runoff so it needs 810 sec. to end the runoff toward the channel of discharge. So the time increased by 77.78% after 138 days of study.

5. The rut depth appeared after 1056 of wheel repetitions which was 0.5 mm and increased to 13 mm after 5280 repeated wheel passing to record 80 % of increase after 109 days of the study period for rain falling under different rain intensities with different durations of time. The wheel passes 176 pass for 60 min. in one point on the pavement which simulates to vehicle passes at peak hour of traffic. The water will accumulate in rut place and needs more time to drainage or evaporate. This place makes the water movement difficult to drainage to the channel so a delay will occurred in the time of ending drainage and runoff.
6. The amount of increase in the percent air voids (AV %) of the asphalt surface layer, which is 1.2% greater than the amount of increase in the asphalt binder layer, which is equal to1.17%, and this is due to the effect of continuous rainfall with increased intensity of rain and the impact of traffic load on this layer.
7. The percent air voids (AV %) of the areas on the wheel truck path is less than in the areas located on both sides of the track for surface and binder courses.
8. Tensile Strength Ratio (TSR) of the regions on the wheel truck path is less than in the regions located on both sides of the track for each asphalt layers.
9. Wheel load and rain had little influence on asphalt binder layer, but they do affect the asphalt surface layer significantly.
10. The pavement slope of 2% with the selection of material for asphalt pavement which was designed and selected in chapter three is suitable for flexible pavement so it decreased the amount of infiltration water and increased in the amount of water that runoff toward the channel side of the pavement and caused the distresses and deterioration after long term of rain falling and more wheel load repetition.

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