Response of Permeable Pavement under Wheel Truck to Rainfall Runoff and its Effects (Laboratory Model)

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Abstract. Good water drainage from different sources is one of the most important factors that must be considered when designing subways and highways. The research aims to study and analyze the effect of heavy, medium, and low rainfall, select suitable materials to drain rainwater from the surface and vertical drains, and evaluate the rutting that appeared on the compacted surface asphalt layer. The methodology of this research includes the laboratory model (prototype model). A laboratory model consisting of typical structure layers of flexible pavement was used in this research with a 2% slope for degradations and changes in the volumetric properties and permeability of the surface and binder layers of the highway section. A wheel truck was manufactured and used for a continuous go-and-forth with the influence of three different rain intensities to identify and simulate the actual situation of highways and roads. The rainfall duration of 30 mm/min rainfall intensity was 90 minutes, and the rain intensity of 60 mm/min had a rainfall duration of 60 minutes. For the rainfall intensity of 90 mm/min, the time of rainfall was equal to 30 minutes. The results obtained from the laboratory simulation model (box model) indicated that the average quantity of infiltrated water produced by the 30mm/min rainfall intensity in the pavement structure is 36.4 % greater than the average infiltration of this water from the 60mm/min intensity and 52% higher than the 90mm/min intensity of rain. The time of surface drainage ending and the ending time of vertical drainage increases when the rain duration is long, even if the rain intensity is low. The rut depth appeared after 2816 wheel load repetitions to increase this depth by 96% after 127 days of load passage under three different rainfall intensities of a different time. The tensile strength was significantly reduced by 17.25%. The TSR values indicate that the mixtures of the surface and binder layers have good resistance to moisture damage.

Keywords: Flexible pavement; vertical drainage; laboratory model; rut depth; rainfall intensities; tensile strength ratio.

1. INTRODUCTION

Drainage is essential in the design of roads since it affects the road's serviceability and lifetime. Drainage design involves providing facilities that collect, transport, and remove runoff water from road pavement [1]. Poor drainage is often the main cause of road damage and long-term road serviceability problems [2]. Providing adequate drainage to a pavement system has been considered an important design consideration to prevent premature failures due to water-related problems such as pumping action, loss of support, and rutting. 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 seeps 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 [3]. Water in the pavement structure has long been recognized as a primary cause of distress. The mechanics of moisture distress are somewhat different for Portland cement concrete pavements and asphalt concrete (flexible) pavements; however, the basic theory from hydraulic drainage and pipe flow is the same regardless of the pavement type [4]. The selection of a suitable pavement surface layer and the pavement base 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 [5]. The pavement layer thicknesses used in the current study are illustrated in Figure 1.

2. MODEL PREPARATION

The essential phase of this study is the laboratory simulation model. The details for the preparation and manufacture of the model are explained below.

2.1 Steel Box

Steel container with external dimensions of (150 cm length), (80 cm) width and (135 cm) depth is constructed by the researchers to simulate the pavement layers (subgrade, subbase, 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. 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. Four iron pipes were welded above the edge side of the steel container to install the distribution water pipe over it and the steel base to make a suitable cross slope for the steel box.

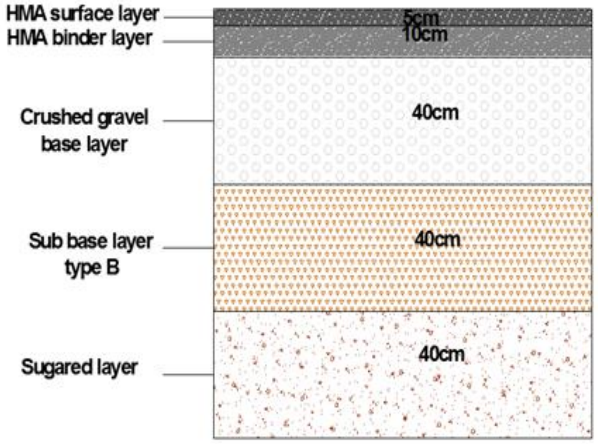

Figure 1: Typical cross-section of the used pavement layer thicknesses.

2.2 Distribution of Water Pipe

The distribution of water pipe, which was manufactured from 12 iron pipes with 1/2" inch and 70 cm length, is connected to the frame as a water network with 150 cm length and 80 cm width, and 150 cm height from the top of the steel box 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. A slot on the long side of the water network is connected with a plastic pipe to the water pump, letting the water flow from the water tank to the water network.

2.3 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 the plastic water pipe. The intensity of the water pump is 30 l/min with a power of 550W.

2.4 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 experiments. The water tank is connected to the electrical water pump from the bottom and contains a slot of 3/4" at the top, which receives flux water by the plastic pipe of 3/4" with a 1.5m length from the model connected to the channel.

2.5 Drainage System

The drainage system consists of the discharge channel, which collects water from the pavement's surface, and a water conveyor pipe with a diameter of 3" (7.35 cm) to transfer water from the discharge channel and direct it into the water tank. This system was constructed by the researchers and made from UPVC material.

2.6 Wheel Track

A framework of iron rectangular with a 200 cm length and a 200 cm height has been manufactured. This frame contains a ball bearing to facilitate the wheel movement. The wheel is constructed by a rubber tire with 250 mm diameter and 80 mm width; the contact area between the pavement's surface and the tire is 17.7 cm^2 (2.454 in^2). To simulate the tires of the vehicles, in fact, and all dependable tests of rutting used, this material in the wheels used in this test for asphalt mixtures and to provide the wheel with these specifications in the local market when manufactured. The rubber tire is moved by a three-phase motor connected to the rubber by toothed wheels and fixed under an iron plate used to carry the loads. Two metal cylinders were filled with a concrete mix for load application to obtain the required weight (150 kg) to attain (95 psi) maximum tire pressure. The loads are placed above the iron plate of the wheel, as shown in Figure 2.

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Figure 2: Prototype laboratory simulation model.

2.7 Control Panel

The researchers construct an electrical control panel. It is used to control the movement of the wheel load back and forth by placing two limit switches at the ends of an iron framework. This panel provides information about the number of repeated wheel load passages by processing a meter that calculates the number of times of passages and also knows the amount of the electrical current and frequency of each electrical phase of measurements by using a digital multimeter. The panel also contains reference lights to see the direction of movement to the right and left.

3. LABORATORY TEST PROCEDURES

3.1 Pick of Rain Intensity

For this study, three types of rainfall intensity were selected: low-intensity rain with 30mm/min., and intermediate intensity rain with 60mm/min. High-intensity rain with 90mm/min. The amount of rain intensity depends on the amount of water flowing through the water pump. A long-term duration was used for low rainfall intensity. As for intermediate and high-value rainfall intensities, middle-term and short-term duration of rain were used. To choose the studied rain intensity, the hydrant of the water pump has been opened at the desired degree then water is outgoing from the tanker and moved on the plastic pipe to the water distribution network (which simulates the rainfall).

3.2 Starting the Test

In this study, the test is applied during the days of rain (wet days), and the presence of wheel load, and this test is also done on days in which there is no rain (dry days) but the wheel load exists. On wet days, the test was initiated by turning on the water pump and opening the faucet to the required water intensity previously calculated. The water pump drags the water from the water tanker, and its amount of water was studied before starting the test. The water starts to flow through the plastic pipe to arrive at the water distribution network to simulate the rainfall in the pavement. In the meantime, the wheel track, which is loaded with two cylindrical loads of 30kg for each cylinder, is run along the pavement through the test time.

The test is carried out on dry days by passing the wheel truck along with the pavement surface layer for 120 minutes per day without rain (dry days). 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 toward a side slope channel set on the pavement's cross slope and returns to the water tanker through the drainage system. Table 1 illustrates how to number the testing days according to the test date.

3.3 Time ending of the Surface Drainage Runoff

Surface drainage runoff is the lazy fleeing of the water on the pavement's surface to the channel executed on one side of the pavement during the testing. The pavement was sloped with a cross slope equal to 2%.

3.4 Vertical Drainage Time

The vertical drainage time is when the heaped-up water on the surface is absorbed through the surface layer. This time is calculated after the ending of the rainfall on the asphalt, then starting the timer to calculate the time until the total accumulated water on the surface layer is absorbed through the asphalt pavement layer.

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

4. RESULTS AND DISCUSSION

4.1 For Low Rain Intensity

This step presents the study result of the vertical drainage runoff and the surface drainage runoff for low-intensity rain (30mm/min.) with a time duration of 90 minutes during the study period.
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 [6]:

$$Q = KCIA \tag{1}$$

Where: Q = the peak runoff rate (m3/s).
K = Conversion factor equal to (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 the paved area [6]. The mean value of C was taken when calculating the peak runoff rate in this study.
I= the average rainfall intensity (mm/hr.) for a duration equal to the time of concentration and the recurrence interval recurrence chosen for the design.
A = drainage area (hectares).

Figure 3 depicts the results of the ending time of surface drainage runoff after continuous 90 minutes of rainfall for (30 mm/min.) rain intensity.

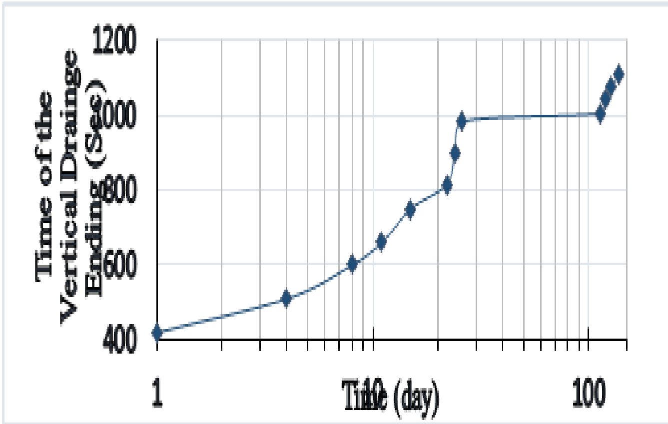

Figure 3: Relationship between surface drainage runoff ending time and the low rain intensity time.

The ending time of vertical drainage was registered after 90 minutes of rainfall. When the rain falling ended, the time that the accumulated water on the surface was absorbed through the asphalt pavement layer was recorded. Figure 4 shows that the vertical drainage increases with time increase, so for the first day of the rain test and for this period, the vertical drainage ended after 420 seconds, and its ending time increased to 1110 seconds because the clogging material penetrated the pavement and sealed 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, delays the vertical drainage of the water.

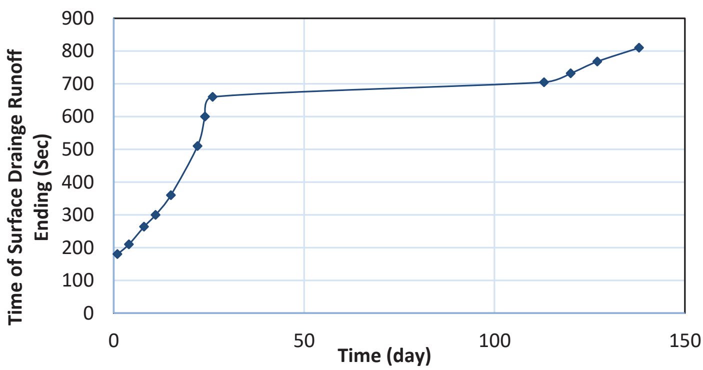

Figure 4: Relationship between the vertical drainage ending time and the low rain intensity time.

4.2 For Intermediate Rainfall Intensity and Middle Duration

This stage of examination test exemplifies the resulting study of the quantity of absorbed water, time ending of the surface drainage runoff, and vertical drainage time for the intermediate intensity of rain (60 mm/min.) as selected formerly.

Figure 5 illustrates that the time of ending the surface drainage runoff increases with the time of the test increase until it reaches its maximum value in this test, which is 564 seconds on day number 109 of the study. Sixty seconds were needed to run off after 12 days of rain falling. The pavement becomes saturated by increasing the number of days and after continuous rainfalls. Furthermore, the clogging material penetrates the pavement and seals the voids of the pavement, so the water seeping is decreased, and fewer amounts of water are absorbed [7]. While more water runs off toward the channel, the time of ending surface drainage runoff is increased. The other factor is that the rutting caused by track loading made the water movement difficult to drain to the channel, so a delay occurred in the time of ending drainage.

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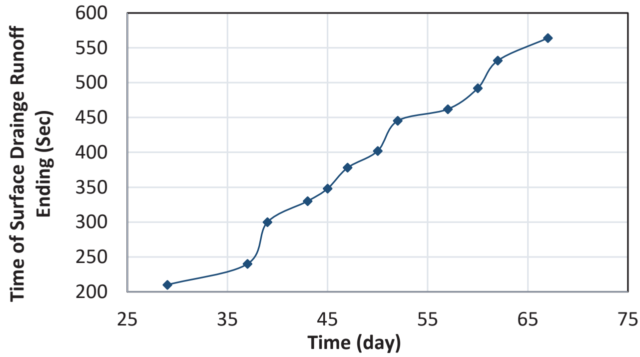

Figure 5: Relationship between the surface drainage runoff ending time and the intermediate rain intensity time.

The ending time of vertical drainage was registered after 60 minutes when the rain falling will run out and at the time that the heaped-up water on the surface was absorbed through the pavement layer. Figure 6 illustrates the relationship between the time of ending vertical drainage and 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 the test, but the time increased to a record 600 seconds in the second month. The clogging material penetrates the pavement and seals the voids on the pavement. When the wheel track is passed on the pavement surface, it causes an accumulation of water on the pavement, which in turn delays the vertical drainage of the water.

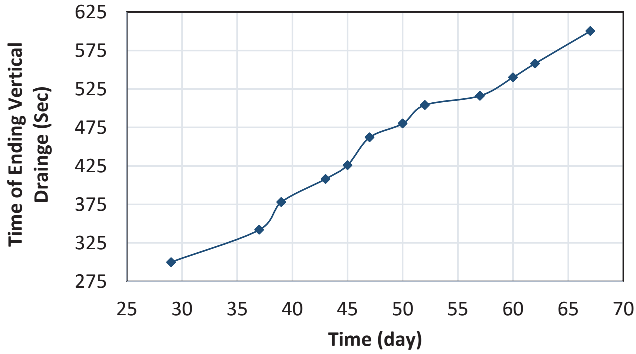

Figure 6: Relationship between the vertical drainage ending time and the intermediate rain intensity time.

4.3 For High Rain Intensity

This stage of examination test exemplifies the resulting study of the quantity of absorbed water, time ending of the surface drainage runoff, and vertical drainage time for the high intensity of rain (90 mm/min.) as selected formerly. Figure 7 shows the relationship between the surface drainage runoff with increasing time for rain intensity (90 mm/min.). This figure illustrates that the time of ending the surface drainage runoff increases by increasing time and reaches its maximum value, which is 564 seconds, while it needs 30 seconds to run off after 12 days of rain falling.

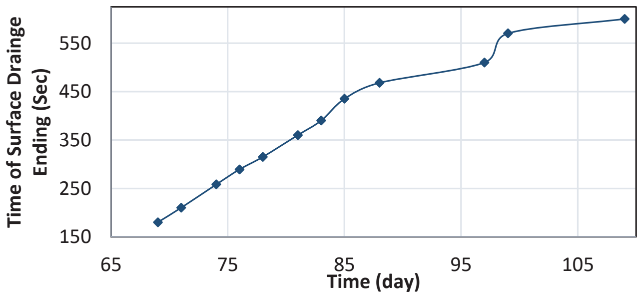

Figure 7: Relationship between the surface drainage runoff ending time and the high rain intensity time.

Increasing the number of days and after continuous rain falls, the pavement becomes saturated. Moreover, the clogging material penetrates the pavement and seals the voids of the pavement, so the water seeping is decreased, and fewer amounts of water are absorbed. More water runs off toward the channel, increasing the time of ending surface drainage runoff. The other factor is that the rutting caused by track loading made the water movement difficult to drain to the channel, so a delay occurred when the drainage was ended. The ending time of vertical drainage was registered after two different times; when the rain falling will run out and at the time that the heaped-up water on the surface was absorbed through the pavement layer. Figure 8 illustrates the relationship between ending vertical drainage and starting the test for high rain intensity (90mm/min.). The pavement needed seconds to complete the vertical drainage in the first month of the test, but the time increased to a record 248 seconds in the final month. The clogging material penetrates the pavement and seals the voids on the pavement. When the wheel track is passed on the pavement surface, it causes an accumulation of water on the pavement, which delays the vertical drainage of the water.

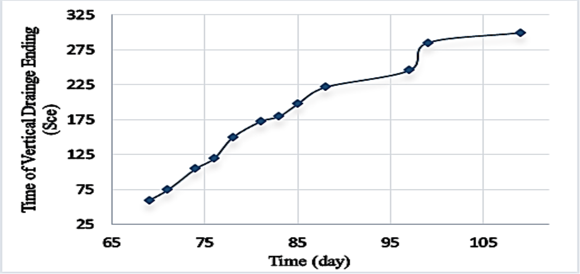

Figure 8: Relationship between the vertical drainage ending time and the high rain intensity time.

4.4 Time of Absorbed Accumulated Water in Rut Place

Figures 9 to 11 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 for the three rainfall durations, respectively. The time absorbed water accumulates in the rut depth increases by increasing time and the rut depth. So, 590 seconds of the average time of absorbed accumulated water in the rut place were needed when the rut depth was 0.5 mm and increased slowly by 60 seconds after ending the rain intensity (30 mm/sec) for 90 minutes duration and bypassing 2288-wheel repetition. So, it reached its maximum time of 1100 seconds when the recorded rut depth was 15.5 mm.

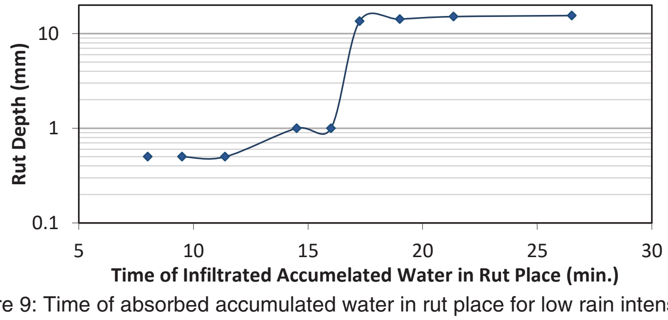

Figure 9: Time of absorbed accumulated water in rut place for low rain intensity.

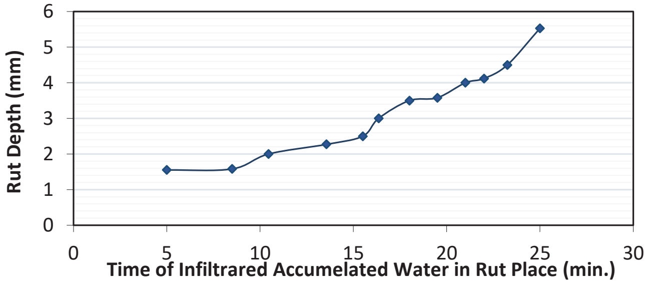

Figure 10: Time of absorbed accumulated water in rut place for intermediate rain intensity.

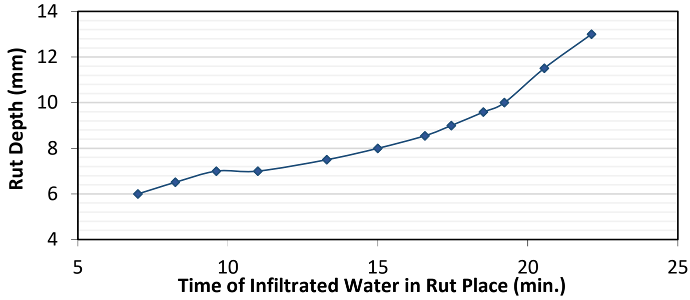

Figure 11: Time of absorbed accumulated water in rut place for high rain intensity.

4.5 Core Test Results

Five deep cores were extracted from the compacted asphalt pavement layer according to the [8] with a diameter of 10cm and with a height equal to 5cm and 10cm for surface and binder layers, respectively. The results of the rainfall laboratory tests are compared with those taken from cores before the rainfall simulation. The core samples were distributed in the form of three samples along the path of the wheel truck in the center of the pavement layer and two samples on both sides of the pavement layer to ensure the proper and correct sampling process. These samples are needed to calculate a number of the important physical properties of the asphalt pavement layers, which are related to the subject of this study, such as permeability, air voids, and moisture sensitivity.

Table 2 illustrates the core test results conducted on the asphalt surface pavement layer after and before the experimental test. This table shows the effect of the wheel load and the rainfall, which affects the asphalt surface layer and has caused changes in the volume properties of this layer. The percentage of air voids (AV%) increased significantly at the end of the experimental test ending (after 138 days) by 1.2% of the asphalt surface layer. It is found that the percent air voids (AV %) increased from 4.91% after starting the experimental test to 5.10%, 6.73%, and 6.50% for core samples along the wheel path and in the first and third trimesters, respectively. The increase in air voids (AV %) resulted in an increase in the volume of the air voids (Va) in the pavement layer by 2.34% in the center position of the pavement and by 44.07% and 34.22% in the regions on both sides of the pavement layer. This led to an increase in the permeability of the layer from 2.52296E-05 m/sec before testing to 2.62521E-05 m/sec, 3.45838E-05m/sec and 3.34355E-05 m/sec in the areas located in the center and the first third and third trimester of the layer respectively. This result is compatible with the findings of the researchers [9].

Table 2: Core test results of the asphalt surface layer before and after the rainfall 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 the pavement	In the third trimester	
Bulk specific gravity (Gmb)	2.281	2.258	2.278	2.261	(ASTMD2726, 2010)
Bulk density Dmb (kg/m^3)	2274.80	2251.50	2271.72	2255.03	(ASTMD2726, 2010)
percent water absorbed	0.21	0.26	0.22	0.38	(ASTMD2726, 2010)
Theoretical Maximum Specific Gravity Gmm	2.40	2.42	2.40	2.41	(ASTMD2041, 2003)
Theoretical maximum Density Dmm (kg/m^3)	2393.04	2413.97	2394.03	2411.98	(ASTMD2041, 2003)
Percent Air Voids (AV %)	4.91%	6.73%	5.10%	6.50%	(ASTMD3203, 2005)
Volume determinations of the specimens cm^3).	392.69	384.8	360	370.8	(ASTMD3549, 2011)
Volume of the air voids Va (cm^3).	19.28	25.89	18.39	24.12	(AASHTOT283, 2006)
Hydraulic conductivity Ksat (cm/sec)	25.22E-05	34.58E-05	26.25E-05	33.43E-05	(ASTMPS129, 2001)

The results of the effect of falling rainfall on the surface course, which induces damage tests, are shown in Table 3. The results showed that the tensile strength was significantly reduced by 17.25% after the experimental test applied to the surface asphalt layer due to the rainwater effect and wheel load on the surface layer. However, the tensile strength ratio (TSR) indicates that the layer resistance to moisture is within the limits required for the specification, which states that this ratio is not less than 80% for the asphalt layers. The rut depths of the asphalt surface layer increase with decreasing tensile strength, which can be attributed to the fact that the aggregate structure is affected due to moisture damage and subsequent loss in tensile strength of the mixtures. The fatigue life of the mixtures decreases with decreasing tensile strength. The loss in stiffness justifies this trend and thereby initiating cracks and stripping. However, the tensile strength ratio (TSR) value indicates that the layer's resistance to moisture is within the limits required for the super pave specifications, which states that this ratio is not less than 80% for asphalt layers.

Table 3: Results of indirect tensile strength test of the surface course after 138 days of test (rainfall period).

Index Property	**Index Value Before the Test (Control)**	**Index Value after the test (condition) Test Method**			**Test Method**
		In the First Trimester	**In the Center of Pavement**	**In the Third Trimester**	
Tensile Strength St (kPa)	2165.605	1834.394	1796.178	1745.222	(AASHTOT283, 2006)
Tensile Strength Ratio (TSR)	-----------	84.70%	82.94%	80.58%	(AASHTOT283, 2006)

Table 4 illustrates the core test results for the asphalt binder layer before and after starting the test. This table shows that the percent of air voids (AV %) increased from 5.3093% after starting the test to 6.07%, 6.51%, and 6.85% for core samples along the wheel path and in the first and third trimesters. This increase, in turn, led to an increase in the volume of the air voids (Va) in the asphalt binder layer by 12.67% in the positions in the center of the layer and by 20.77% and 27.36% in the regions on both sides of the layer. This led to an increase in the permeability of the layer from 2.63941E-05m/sec before testing to 3.01772E-05m/sec, 3.23793E-05m/sec, and 3.41004E-05m/sec in the areas located in the center and the first third and third trimester respectively of the layer after conducting the test.

Table 4: Core test results of the asphalt binder layer after and before the rainfall 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 the pavement**	**In the third trimester**	
Bulk specific gravity (Gmb)	2.279	2.259	2.266	2.253	(ASTMD2726, 2010)
Bulk density Dmb(kg/m^3)	2272.59	2253.01	2259.94	2247.46	(ASTMD2726, 2010)
Percent water absorbed	0.16	0.20	0.19	0.20	(ASTMD2726, 2010)
Theoretical Maximum Specific Gravity Gmm	2.407	2.417	2.413	2.420	(ASTMD2041, 2003)
Theoretical maximum Density Dmm (kg/m^3)	2400.01	2409.99	2406.00	2412.98	(ASTMD2041, 2003)
Percent Air Voids (AV %)	5.30	6.51	6.07	6.85	(ASTMD3203, 2005)
Volume determinations of the specimens (cm^3).	785.39	686.9	688.5	687.8	(ASTMD3549, 2011)
Volume of the air voids Va (cm^3).	41.62	44.74	41.79	47.18	(AASHTOT283, 2006)
Hydraulic conductivity Ksat (cm/sec)	26.39E-05	32.37E-05	30.17E-05	34.10E-05	(ASTMPS129, 2001)

Table 5 shows the results of the moisture sensitivity for the binder layer. This table shows that the tensile strength St has significantly decreased by 18.41% after the experimental test applied on the binder asphalt layer due to the effect of rainwater and the wheel load on the surface layer. However, the value of tensile strength ratio (TSR) indicates that the resistance of the layer to the moisture is within limits required for the Super pave specifications, which states that this ratio is not less than 80% for asphalt layers. The rut depths of the asphalt surface layer increase with decreasing tensile strength, which can be attributed to the fact that the aggregate structure is affected due to moisture damage and subsequent loss in tensile strength of the mixtures. The fatigue life of the mixtures decreases with decreasing tensile strength. The loss in stiffness justifies this trend and thereby initiating cracks and stripping. However, the tensile strength ratio (TSR) value indicates that the layer's resistance to moisture is within the limits required for the Super pave specifications, which states that this ratio is not less than 80% for asphalt layers.

Table 5: Results of indirect tensile strength test of the asphalt binder layer after 138 days of test (rainfall period).

Index Property	**Index Value before the test (control)**	**Index Value after the test (condition)**			**Test Method**
		In the first trimester	**In the center of the pavement**	**In the third trimester**	
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)

4.6 Effect of Rain Intensity and Duration of Rain Falling on the Drainage of the Pavement

The increase in rain intensity falling on the surface layer of the pavements leads to a decrease in the quantity of infiltrated water and the vertical drainage, which causes the increase in the time of vertical drainage ending when the rain duration is long, even if the intensity of rain is low, so the voids of pavement are filled with more water. Then more water causes more water runoff toward the channel of drainage. If rainfall intensity is greater than the permeation rate of the pavement, surface runoff takes place very quickly. While in the case of 30mm/min intensity rainfall, the surface runoff was less than the surface runoff in 60mm/min and 90mm/min intensities rainfall, respectively. The slope of 2% designed for the pavement resulted in reduced water depths, facilitating the runoff of the water. Rainfall duration is directly related to the volume of runoff because the vertical drainage rate of the surface decreases with increasing the intensity and duration of rainfall. The water starts infiltrating/ percolating to the water table, and if the rate of rainfall or the rate at which the water is reaching the ground exceeds the infiltration rate, it results in surface detention.

4.7 Effect of the Wheel Track Loading on the Drainage of the Pavement

The wheel track with 95 psi load and 0.2 m/s speed is repeated on the pavement on the days that do not contain any rain (dry conditions) and when the rain falls with different rainfall intensities and different rainfall duration for each rain intensity (wet condition). When the rut depth appears on the pavement, it causes an accumulation of water on the rut place, as shown in Figure 12, because the permeability of the wheel path area is less than the areas in the rest of the surface layer because of the impurities resulting from the passage of the wheel, which was explained previously. It makes the water movement toward the side channel difficult, so the time of ending the runoff is delayed. Ruts filled with water can cause vehicle hydroplaning and be hazardous because ruts tend to pull a vehicle towards the rutted path as it is steered across the rut [7]. A heavily rutted pavement should be investigated to determine the leading 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 leveled and overlaid.

Figure 12: Resulting rutting on the pavement.

The slight raveling occurred on the pavement because of the loss of fines [10] due to decreased tensile strength (St). It increased the percent air voids (AV %) as shown in a result of the cores test, resulting from passing the wheel track. The continuous rain falling with high rain intensity and long duration of raining test for constant 138 days and expressed as a localized range (patchy areas, usually in the wheel paths).

5. CONCLUSIONS

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

- The quantity of water infiltrated decreased from 90 liters on the first day of the test to 41.5 liters on the last day of the study period after 138 days of testing, which indicates a 53.89% decrease after 138 days of testing for 30mm/min rain intensity. Also, it decreased from 60 liters on day 29 of the test, which began with the second rain intensity, to 20 letters after 67 days of the study period, equaling to 66.67 % decrease for 60 mm/min rain intensity. It decreased from 45 liters on day 69 of the test, considered the first day of the third intensity of rain, to 23.5 letters after 109 days of rain falling, equaling 47, 78 % decrease for 90 mm/min rain intensity.
- Increasing the clogging materials of fine particles and salt that are deposited on the surface of the pavement results in passing the wheel track loading of the pavement surface, and other clogging materials such as salt in the water which penetrates the pavement seals the voids, and effects on its infiltration causing decreasing of the amount of absorbed water.

- The time of vertical drainage ending increases when the rain duration is long, even with low intensity.
- The time of surface drainage runoff end has increased by 77.78% after 138 days of testing for 30mm/min rain intensity. Also, it increased by 62.76% from day 29 of the test, which began with the intermediate rain intensity and after 67 days of the study period for 60 mm/min rain intensity. It increased by 36.69% from day 69 of the test, which is considered the first day of the third intensity of rain and after 109 days of rain falling for 90 mm/min rain intensity.
- The average time of the surface drainage runoff ending the 30mm/min rainfall intensity is higher than the 60mm/min rainfall intensity average by 21.6% and 23.38 in the 90 mm/min rainfall intensity.
- The rut depth appeared after 2816-wheel repetition and 11 accumulation test days from the beginning. It appeared in the test on day number 4 from the test which was 0.5 mm in height and increased to 13 mm after 18480 repeated wheels passing to record 80 % of increase after 109 days of the study period on day number 32 from the test for rain falling under different rain intensities with varying durations of time. The wheel passes 176 passes for 60 min. At one point on the pavement, which simulates the vehicle passes at the peak hour of traffic. The water will accumulate in a rut place and needs more time to drain or evaporate. This place makes the water movement difficult to drain to the channel, so a delay will occur when drainage and runoff end.
- The average time of Infiltrated Accumulated Water in Rut Place on a wheel path for 30 mm/min rainfall intensity was more than 32% of this time for 60 mm/min rainfall intensity and 72% of this time for 90 mm/min. The intensity of rain.
- The rutting that occurred in the pavement layer of the laboratory model used in this study resulted from the deformation of this layer due to the influence of the factors that were applied during the study period, which in turn led to the generation of high-pour water pressure in the pavement layers, which is one of the factors that cause this distresses on the asphalt pavements. The rutting in the roads affects traffic safety and driving comfort. In dry conditions, rutting will act as a wheel path; the driver may need extra effort to get out from the rutted path if the rut depth is significant. Moreover, rutting is more hazardous in wet weather when water accumulates in the rutted path and leads to hydroplaning.
- Two deep cores were extracted from the compacted asphalt pavement layer before the rainfall laboratory tests, and five deep cores after the test compared physical properties, it was found 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.
- The percent air voids (AV %) of the areas on the wheel truck path is less than in the regions located on both sides of the track for surface and binder courses.
- The value of Tensile Strength Ratio (TSR) for the core samples extracting from the compacting asphalt surface layer in the laboratory model is 1.16% greater than it is value for the samples taken from the asphalt binder layer, although the loads applied on the surface layer directly and with the presence of rainfall. The TSR values indicate that the mixtures of the surface and binder layers performed well with good resistance to moisture damage, Although the reduction in tensile strength (St) by the rainwater and wheel load conditions.
- The pavement slope of 2% with the selection of material for asphalt pavement was designed and selected as suitable for flexible pavement, so it decreased the infiltration water. It increased the amount of water that runoff toward the channel side of the pavement and caused distress and deterioration after a long term of rain falling and more wheel load repetition.

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