**Zohrah GHAFOURI FARD[1], Mohammad Mehdi KHABIRI[2],
Pouya AFKHAMI MEYBODI[3]**

AN INNOVATIVE METHOD IN MEASURING PERMEABILITY AND EVAPORATION PARAMETERS IN POROUS PAVEMENTS WITH EMPHASIS ON ITS EFFECTS ON INCREASING URBAN TRANSPORT SAFETY

Summary. Today, the increasing development of urbanization and climate change and its resulting issues, including the occurrence of urban floods, is one of the important issues facing city managers. One of these problems that seriously affect lives today is the occurrence of floods and the inundation of urban thoroughfares. Among the problems of floods in urban areas are the disruption of the urban transportation system, reduced transportation safety, inundation of thoroughfares, and consequently, the poor appearance of urban roads. One of the successful strategies in controlling urban runoff is the use of porous pavements in urban thoroughfares. The two capabilities of permeability and evaporation of a porous pavement lead to reduced runoff and a resultant lack of occurrence of inundation of thoroughfares; therefore, accurate measurement of these two

---

[1] Faculty of Civil Engineering, Department of Roads and Transportation, Yazd University, Yazd, Iran. Email: zohreh.ghafori76@gmail.com. ORCID: https://orcid.org/0000-0002-9084-982X
[2] Faculty of Civil Engineering, Department of Roads and Transportation, Yazd University, Yazd, Iran. Email: mkhabiri@yazd.ac.ir. ORCID: https://orcid.org/0000-0003-3434-7603
[3] Faculty of Civil Engineering, Department of Roads and Transportation, Yazd University, Yazd, Iran. Email: pooya.afkhamy@gmail.com. ORCID: https://orcid.org/0000-0001-5497-9291

parameters is of special importance. This study aims to introduce two devices for measuring the permeability and evaporation of porous asphalt with an innovative method that can measure the permeability and evaporation of asphalt and porous concrete with appropriate accuracy.

Keywords: porous pavement, safety, urban transport measuring permeability, measuring evaporation

1. INTRODUCTION

Today, with the growth of population and urban development, climate change and the occurrence of floods, urban runoff control has become a serious problem in the field of urban management [1]. The occurrence of floods and the subsequent inundation of urban thoroughfares, in addition to disrupting urban transportation and reducing road safety, which is the most important feature of the road [2-7], has a negative psychological effect on lives in terms of visual beauty. Because the thoroughfares are very influential on the beauty of the urban texture and the moods of people, thus, the control and management of urban runoff are of special importance. The problems of traditional pavement have forced pavement scientists to adopt new strategies for using new pavements, including porous pavements in the pavement industry. This is because the porous pavement, which is presently used as a procedure in urban roads with low traffic volume and parking lots, is one of the methods of urban runoff control [8, 9].

Porous pavement is the best runoff management innovative alternative method for surface wastewater management because usually impermeable pavements allow water to flow along the surface and drain into the drainage basin or trenches along the roads or parking lots. However, porous pavement allows liquids to penetrate. The advantages of this pavement include runoff control, noise reduction, improved road safety for drivers and pedestrians due to the reduction of water spray and slippery phenomenon during rains and the potential to reduce frost due to proper drainage [10, 11]. In general, porous pavement includes porous asphalt and porous concrete. Porous asphalt is the same as ordinary asphalt but has less fine-grained and more uniform granulation than ordinary asphalt; thus, the percentage of empty space in this asphalt is more than that of ordinary asphalt [12, 13]. The initial idea of porous asphalt was to reduce the height and intensity of runoff on the pavement of airports, and thus, reduce the phenomenon of slippery water and aircraft slip [14], which was then used to increase safety and reduce landslides on suburban roads [15]. But today, this type of asphalt is known as one of the best materials for reducing floods and urban runoff [8, 16]. Porous concrete is a special type of high porosity concrete that has been used in the temperate regions of the United States since the 1970s and has gained worldwide usage since the 1980s. High permeability and its potential to reduce runoff led the Environmental Protection Agency to define porous concrete as one of the best methods for flood management [17, 18].

Two important features of porous pavement, which distinguish this pavement from the conventional pavement and reduce runoff, are permeability and evaporation [19-21]. The permeability of porous pavement to water from snow and rain allows them to penetrate the underlying layers of the porous pavement and prevents water from accumulating on the pavement surface [11]. On the other hand, porous pavement with the evaporation mechanism, especially when the lower layers are not very permeable, expels runoff and prevents flooding.

In fact, the high capacity of permeable pavements in holding water in the road body (up to 51 liters per square meter), and connecting it through the pores with the surface, leads to

a higher evaporation rate than impermeable surfaces [22]. Therefore, accurate measurement of these two porous pavement properties is of particular importance. In this research, the application of two devices for measuring the permeability and evaporation of porous asphalt with an innovative method has been investigated, and it should be noted that these two devices can also be used to measure the permeability and evaporation of porous concrete pavement as well.

2. LITERATURE REVIEW

During and after rains, phenomena such as slippery water, light reflection from the wet surface of the road and flooding of roads can cause accidents and reduce the safety of urban transportation; therefore, currently, attention to increasing road safety in rainy conditions by using the appropriate pavement, including porous pavement for roads has increased [23, 24]. Of course, the permeability and evaporation properties of porous pavements lead to reduced flooding of passages and consequently increase the coefficient of friction and slip resistance [25, 26]. Hence, measuring these two parameters is very crucial.

Generally, regarding the measurement of porous asphalt permeability, there are two methods: the falling head and the constant head, and the existing devices measure the permeability rate of porous asphalt based on these two methods. In the falling head test, changes in the head and flow rate over time are determined. The falling head is recorded over time using the regression analysis, the specific flow rate is obtained using Equation 1 [27]. In relation 1, V is a special flow and dh is the change of head during dt.

$$V = \frac{dh}{dt} \tag{1}$$

The permeability coefficient (K) and the non-Darcy parameter (i) can also be obtained with the logarithm of the modified Darcy relation according to Formula 2, which in the logarithmic diagram of m, the slope of the line is obtained and also by placing i=1, k is also obtained. For each sample, the experiment is repeated several times to obtain accurate answers [27].

$$\log v = \log k + m \log i \tag{2}$$

In the constant head method, unlike the falling head method, the water height in the experiment is constant and the test starts when the balance between input and output flow is achieved. In this method, the permeability coefficient of (K) and the non-Darcy parameter (i) can be calculated from Equations 3 and 4 [27].

$$V_\Upsilon = K_\Upsilon i^m \tag{3}$$

$$V_\backslash = K_\backslash i^m \tag{4}$$

So far, several devices have been designed to determine the degree of laboratory permeability, including the asphalt pavement water permeability testing device with application number 201821952532.5 in 2019, the asphalt mixture permeability measuring device with application number 202020886465.2 in 2020, the asphalt concrete internal permeability testing machine with application number 201920590581.7 in 2020, the asphalt pavement water

permeability testing machine and water permeability testing method with application number 201810499181.5 in 2018, the asphalt concrete permeability testing device and method with application number 202011082049.8 in 2020 and the permeability devices mentioned in the By-Laws Documentation and Technical Basics Instructions for the Design, Execution and Maintenance of Porous Asphalt (Issue No. 384-2), including the Laboratory Permeability Instrument of the Army Engineers Group, the Florida Department of Transportation, the University of Science and Technology [27]. All of the abovementioned devices measure the permeability of porous asphalt by passing a volume of water through the pores of the porous asphalt using a falling head or a constant head, while in reality, porous asphalt must be able to absorb raindrops quickly and prevent the creation of runoff in the passages [28], not to pass a volume of water by itself; it is, therefore, important to build a device that can measure the permeability of water droplets in porous asphalt. In this regard, in 2020, a device called the permeability measurement of permeable asphalt mixture was introduced with application number 201921353588.3 (Figure 1), which with the help of a water distribution box located exactly on the surface of the asphalt sample, the volume of water from the built-in holes at the bottom of the distribution box to measure the permeability of asphalt with water droplets. Although with the introduction of this device, the defect of volumetric passage of water through porous asphalt to measure permeability was eliminated, however, this device had defects such as limited rainfall distribution box distance and asphalt surface and creating water particle pressure due to short distance from the sample surface and reporting unreal infiltration, impossibility of measuring the permeability of porous asphalt samples with different dimensions and shapes and the lack of ease of operation and repair of it.
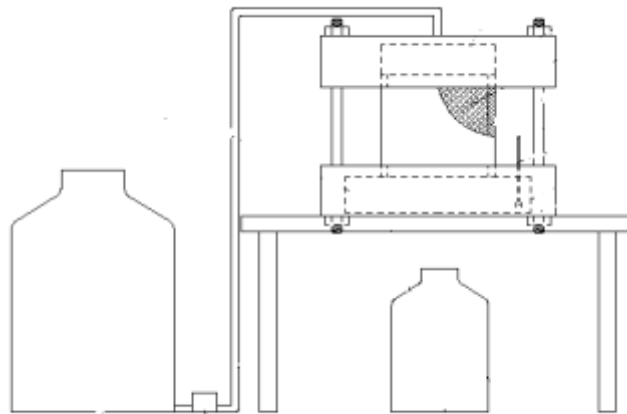

Fig. 1. Permeability measuring device of permeable asphalt mixture

In addition, Ma and his colleagues in a study titled "the effect of pore clogging on the permeability of porous asphalt pavement", used a device capable of measuring the permeability of porous asphalt by passing water droplets. This device, which can measure horizontal permeability by passing water droplets through porous asphalt, has two water collection tanks around the sample that collect drained water from porous asphalt (Figure 2). By measuring the volume of water and the time of water flow and also having the cross section of the reservoir, the value of the permeability coefficient is calculated using Equation 5 [29]. It should be noted that this device does not have the ability to measure the vertical permeability of porous asphalt, while the main application of porous asphalt is due to the permeability in the vertical direction

and horizontal permeability due to the limited thickness of the asphalt, and also, its low value compared to vertical permeability [30] has little practical application.

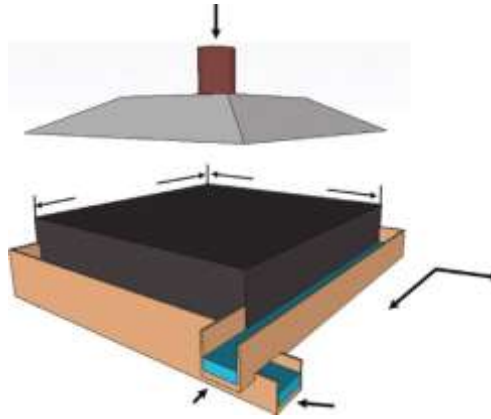$$n = v.s^{-1}.t^{-1} \tag{5}$$

Fig. 2. Horizontal asphalt permeability measuring device [29]

As mentioned, in addition to the permeability of porous asphalt, the evaporation properties of this type of asphalt have a significant effect on reducing the subsurface moisture of the pavement and reducing runoff [31]. Lee et al. in a study titled "Experimental study of evaporation rate in permeable pavements", measured the evaporation rate of porous pavements in the traditional way. In the study, the samples were placed in a container with a certain amount of water in the open at the same time, and after at least one day by calculating the difference between the weight of the container with the sample and water before the test and the weight of the container with the sample and the remaining water after one day, they obtained the amount of evaporated water and divided the amount of evaporated water by the time to obtain the evaporation rate [32]. In the traditional method of measuring evaporation, this test cannot be performed in the case of rain and snow. On the other hand, if one of the sample containers becomes problematic, then the whole test is canceled and must be performed again. In addition, a large number of containers are needed to perform the experiment, and most importantly, if another researcher performs this experiment in another place with different climatic conditions, the results cannot be comparable to the previous researcher, as environmental conditions are different. In 2017, a device for measuring the evaporation of permeable concrete was developed and patented. This device consists of two containers that are suspended on a fixed rod. The first container (which has holes at the bottom) is aggregate and a sample of porous concrete and the second container is full of sand. Pour the amount of water on top of the first container and after a while, water seeps from the bottom of it (Figure 3).

When the water has drained from the bottom of the first container and the material inside is wet, start recording the force using the loading equipment and note the amount of force applied by the loading device at this time as f_0 and considering 24 hours as the time period, the amount of force applied by the loading device is recorded as ... , f_2 , f after every 24 hours, then the evaporation of the first 24 hours is calculated with Equation 6 [33].

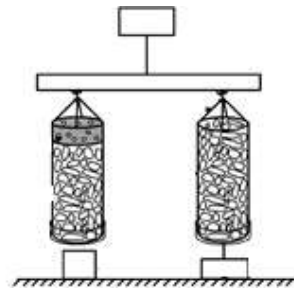$$E = \frac{F_i - F_{i-1}}{A * \rho} \tag{6}$$

Fig. 3. Porous concrete evaporation measuring device [33]

Aboufoul et al. in a study stated that water evaporation from porous asphalt is related to the vacancy topology, and measured the rate of evaporation using computed tomography (CT) scans with a device shown in Figure 4. This device includes a transparent container made of plastic with a thickness of 5 mm with internal dimensions of $80 * 25 * 40$ cubic meters, was used to hold the asphalt sample from all sides, except the upper part, which is open for evaporation. The sample was placed on a digital scale with an accuracy of 0.05 g to record the decrease in mass during evaporation at 5-minute intervals. During the test, the sample is placed in a fully insulated temperature control chamber at $2\pm40°C$, and the relative humidity inside the chamber is monitored by $2\pm10\%$ using a hygrometer sensor. Further, a full HD digital camera was also used to monitor the evaporation process with a resolution of 5 minutes [34]. Although this device can accurately measure the amount of evaporation, however, working with a porous asphalt evaporator with X-ray computed tomography scans is difficult.
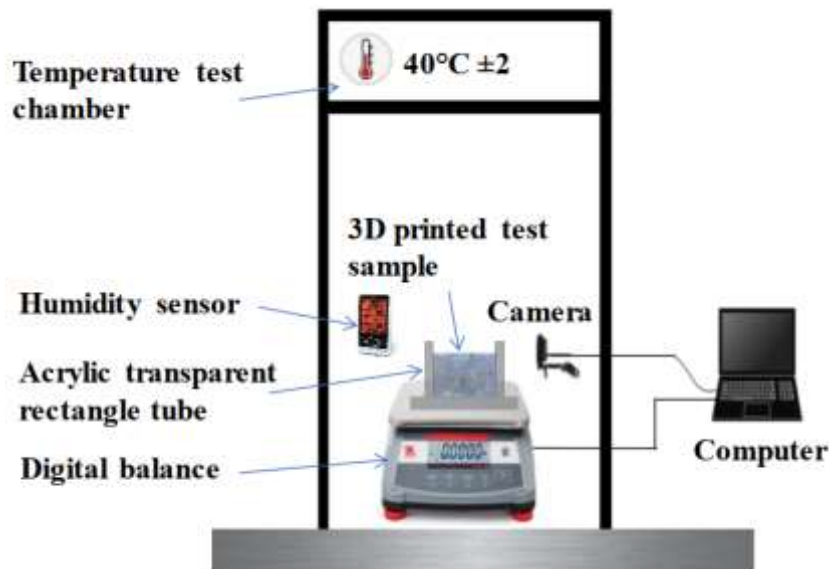

Fig. 4. Evaporation measuring device with computed tomography X-ray scans [34]

As mentioned, several devices have been proposed to measure the permeability and evaporation of porous asphalt; however, despite their advantages, each of them has also disadvantages. Therefore, this study aims to introduce a device for measuring the permeability of porous asphalt with a rain simulator and a device for measuring the evaporation of porous asphalt, which eliminates the disadvantages of previous devices.

3. DEVICE INTRODUCTION

3.1. Porous asphalt permeability measuring device with rain simulator

This device has a one-meter frame, a shower head and a hose, a compartment full of aggregates with granulation of the base layer (without filler), which is open at the bottom of the container for the passage of water, and a net installed to hold the aggregates at the bottom, a container of specified volume and a stopwatch (Figure 5a, b). A one meter frame is made by connecting three pieces of polycarbonate talc with dimensions of 30 by 100 cm with the help of glue, and the headboard is mounted on a piece of polycarbonate talc with dimensions of 35 by 30 cm (Figure 5c) that is mounted on the frame. Then, with the help of a hose clamp, a hose of suitable length is connected from one end to the shower head and from the other end to the faucet. To make the container in which the aggregates are placed, the same polycarbonate talc parts can be used, so that for the edges of the container, polycarbonate parts with a length of 25 cm and a suitable height are used, and for the bottom of the dish, a plastic net is used, which is fastened to the walls of the dish with the help of glue. The height of the container, or in other words, the height of the talc parts of the container made of polycarbonate, depends on the purpose of the test. For example, if the purpose is to measure the exact penetration of porous asphalt by considering the base, use a container with a height of 15 cm that corresponds to the thickness of the base layer (Figure 5d) and if the purpose is to calculate the net penetration of porous asphalt, a height of 5 cm is sufficient. However, it should be noted that in addition to polycarbonate, other materials such as Plexiglas sheets or light metal sheets or any similar material that has the required strength could be used to make this device.
The method of testing with this device is that the sample is placed in a special place on a container full of aggregate under the shower, then the faucet is opened, and the amount of water should be adjusted so that the amount of water entering the sample and the amount of water leaving the sample be the same. Thus, water does not collect on the sample, and the incoming water completely penetrates. Then take a special container with a certain volume under the shower and measure and record the time it takes for the container to be filled with water with a stopwatch, and using Equations 7 and 8 (fluid continuity relations), the amount of flow and infiltration (speed of water passing through porous asphalt pores) can be calculated. The shower head, which is embedded in the frame at a certain distance from the sample, converts water into droplets and spreads the water droplets on the sample, making the permeability of the water droplets in the asphalt to be considered, which is more in line with reality. Furthermore, this device measures the permeability of porous asphalt by simulating rain and constant head. It should be noted that the appropriate distance of the head from the sample surface in this device causes raindrops to fall and penetrate the surface of the asphalt sample only under the effect of gravity. However, if the shower head is exactly on the surface of the sample and without a distance from it or within a short distance, water droplets enter the sample with high pressure and intensity and unreal infiltration is reported. Figure 6 shows a view of this device.

$$Q = \frac{V}{t} \tag{7}$$

$$K = \frac{Q}{A} \tag{8}$$

In relations 7 and 8:
Q = Flow in cubic meters per second;

V = Container volume in cubic meters;
t = Container filling time in seconds;
K = Penetration in meters per second;
A = Asphalt sample surface that passes water in square meters.

(A)   (B)

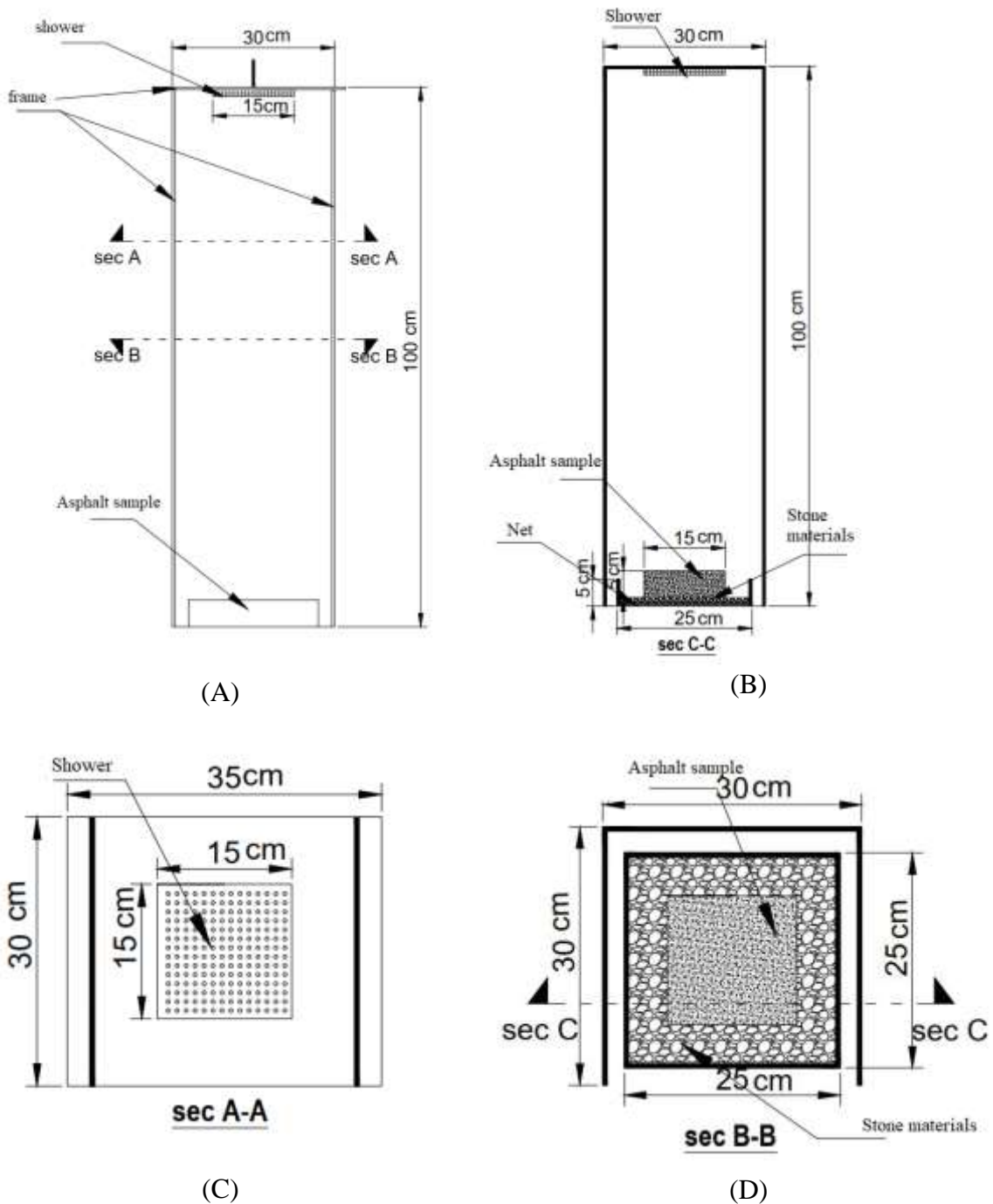(C)   (D)

Fig. 5. Different components of porous asphalt penetration measuring device with rain simulation

As mentioned, with this device, samples with different dimensions and shapes can be tested; however, a suitable shower head in accordance with the shape and size of the sample should be used so that the shape and area of the shower head are the same as the shape and area of the sample. The maps presented in this paper are assumed to be tested on a 15 cm by 15 cm cube sample. Also, because under the asphalt sample, there is a layer of stone materials with the characteristics and granulation of the base layer, it can be said that the performance of porous asphalt has been simulated in practice in the laboratory, which also applies the base effect on asphalt permeability and measures more real permeability. Hence, there is no need to perform an executive permeability test after the implementation of this type of asphalt, as this device has simulated the conditions of implementation in the laboratory.

Fig. 6. Porous asphalt penetration measuring device with rain simulation

3.2. Porous asphalt permeability measuring device with rain simulator

The porous asphalt evaporator is a device for accurately and conveniently measuring the amount of water evaporated by porous asphalt and comparing these values for different samples, including a fan mounted on the door of the device (Figure 7a) and a container with holes and holes in its walls and sealing foam (Figure 7b). The process of testing with an evaporator is to pour some aggregate with base granulation and a certain amount of water (500 g of water) into the device and place the asphalt sample on the aggregates so that the surface of the sample is completely along the holes created in the wall of the container (adjusting it is possible by increasing or decreasing the amount of aggregates below the sample). Cover the perimeter of the sample completely with foam so that there are no holes for air to pass through, as such, evaporation can only take place through the porous asphalt cavities (Figure 7c). After adjusting the humidity and temperature of the test environment and placing the hygrometer and thermometer inside the device, close the lid and weigh and record the whole device. Then put

the device in the right place and turn on the fan. By turning on the fan, airflow is created on the surface of the sample, which helps to evaporate quickly and prevents the accumulation of moisture on the surface of the sample and reduces the amount of evaporation after a while from the beginning of the test. After 24 hours, the whole device is weighed again and the evaporation value is calculated with relation 9. Figure 8 shows a view of this device.

$$E = m_1 - m_2 \tag{9}$$

In this relation:
E = The amount of evaporation in grams per day;
m_1 = The initial weight of the device along with water and sample in grams;
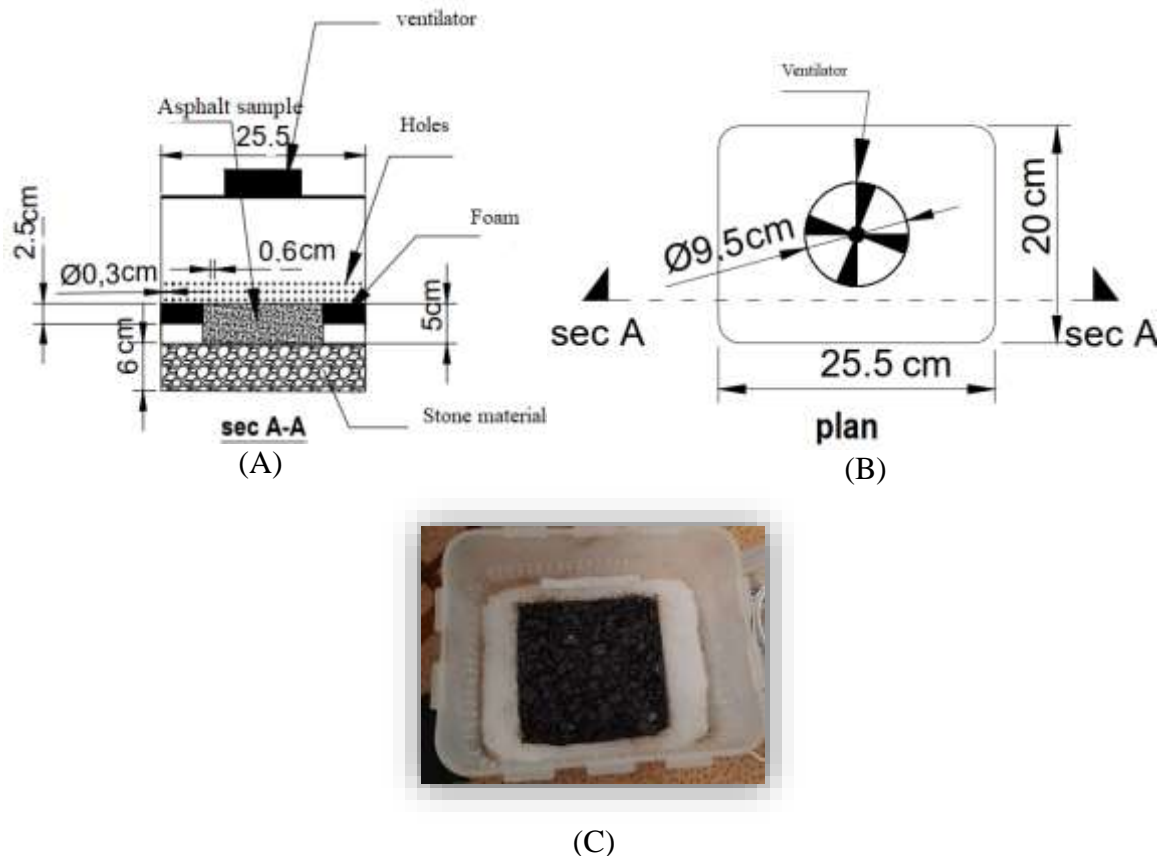m_2 = The secondary weight of the device remains with the water and the sample after 24 hours in grams.

(A)   (B)

(C)
Fig. 7. Different components of the porous asphalt evaporation measuring device

4. ADVANTAGES OF THE MEASURING DEVICES FOR EVAPORATION AND PERMEABILITY OF POROUS ASPHALT

As mentioned, these two devices have advantages that eliminate the disadvantages of the previous devices. A full description of the benefits of these two devices is provided in Table 1.

Fig. 8. Porous asphalt evaporation measuring device

Tab. 1.

Advantages of the devices for measuring the evaporation and permeability of porous asphalt

	Device name	
	Porous asphalt permeability measuring device with rain simulation	Porous asphalt evaporation measuring device
Advantages	• More accurate and realistic measurement of the permeability of porous asphalt by passing water droplets through the sample to calculate the permeability • Measuring the permeability of porous asphalt samples with different dimensions and shapes • No need to test the field penetration on fresh porous asphalt after application • Use of base materials to determine more accurate and real permeability • Ease of operation and repair of the device • Simplicity and cheapness of device parts • Limitation of precipitation distance and non-pressure of water particles due to short distance from the sample surface and report of unreal infiltration • Ability to easily adjust the volume of water entering the device with the help of a faucet and more accurate permeability measurement • Measuring the permeability of other porous materials including porous concrete	• Control of environmental conditions such as temperature and humidity • Testing for samples of different sizes and shapes • Ease and convenience of working with the device • Simplicity and cheapness of device parts • Measurement of evaporation of other porous materials, including porous concrete • Use of base materials to determine more accurate and realistic evaporation rates

5. THE TEST RESULTS

Table 2 and Figure 9 provide an example of the results of experiments performed by these two devices. These results are related to the samples of cubic porous asphalt with dimensions of 15 by 15 cm with different granulations presented in Table 3 and the percentage of bitumen is 3 to 4% (with a step of 0.5%).

Tab. 2.

Results of permeability and evaporation test using
the device for measuring the evaporation and permeability of porous asphalt

| 3.5		3	$d_{10}d_{10}$	Percentage of bitumen Granulation
Permeability	Evaporation	Permeability		
0.0031840	24.500	0.0032650	4.76	A
0.0022820	19.500	0.0023200	3.60	D
0.0017990	14.500	0.0018060	3.00	C
0.0016020	10.125	0.0016210	2.60	E
0.0014247	4.750	0.0014294	2.36	B
4		3.5		
Evaporation	Permeability	Evaporation		
23.70	0.0030690	24.000	4.76	A
18.50	0.0022580	19.000	3.60	D
13.55	0.0017840	14.050	3.00	C
9.00	0.0015720	9.500	2.60	E
4.00	0.0014247	4.375	2.36	B
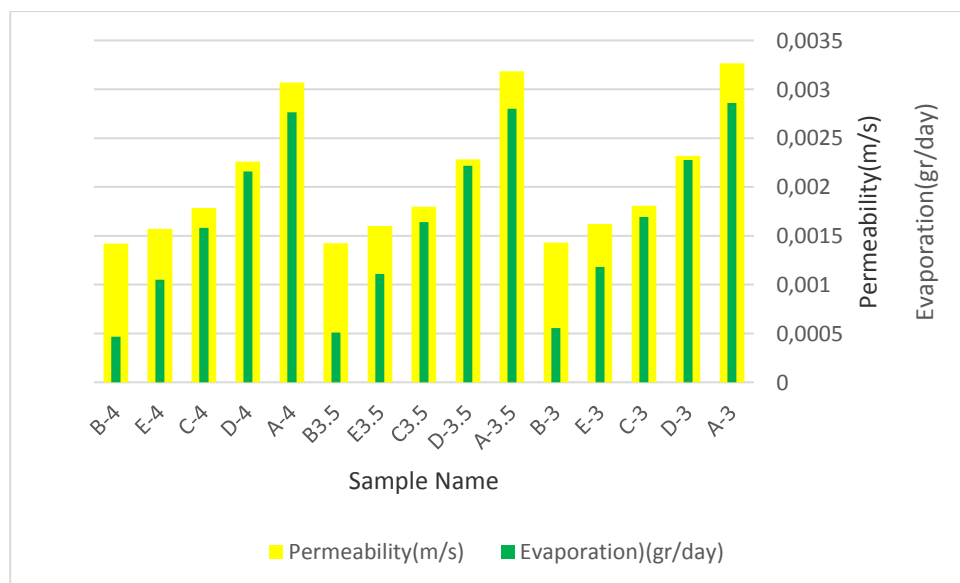
Fig. 9. Results of permeability test with the porous asphalt permeability measuring device with the rain simulator and evaporation measurement results with the porous asphalt evaporation measuring device

Tab. 3.

Granulation of porous asphalt test samples

Percentage of passage					
Sieve (mm)	A Granulation	B Granulation	C Granulation	D Granulation	E Granulation
25.000	100.00	100.00	100.00	100.00	100.00
19.000	90.00	100.00	95.00	92.50	97.50
9.500	56.00	80.00	68.00	62.00	74.00
4.750	10.00	25.00	17.50	13.75	21.25
2.360	5.00	10.00	7.50	6.25	8.75
0.075	2.00	4.00	3.00	2.50	3.50

As noticed from Table 2 and Figure 9, the higher the grain size per cent of fixed bitumen, the greater the permeability and evaporation rate; So that granulation A, due to being a larger aggregate and having more cavities and porosity, has more fluid passage ducts than other granulations, and thus, has more permeability and evaporation. In addition, granulation B has less permeability and evaporation than other granulations due to its finer fineness, and consequently, cavities and porosity. On the other hand, with increasing the amount of bitumen due to the filling of some cavities with bitumen, the amount of permeability and evaporation decreases. Of course, it should be noted that from 3% bitumen to 4% bitumen, the amount of permeability reduction is not significant because increasing the amount of bitumen is small. Since the results of these two devices are consistent with previous research [34-36], then both devices have good performance in measuring the rate of permeability and evaporation.

6. CONCLUSION

Since permeability and evaporation are two important properties of porous asphalt to reduce runoff, measuring these two parameters is of particular importance. However, several devices have been proposed to measure these two parameters, each of which, despite its advantages, also has disadvantages. This study aims to introduce a porous asphalt permeability measuring device with a rain simulator and a patented porous asphalt evaporation measuring device that does not have the disadvantages of previous devices. These two devices can measure the permeability and evaporation of porous asphalt with more accuracy and ease for samples with different dimensions and shapes. Consequently, these devices can be used in road construction science research centers, porous asphalt road construction companies, concrete and asphalt laboratories in engineering colleges, and road and urban research centers that study porous asphalt to accurately measure the permeability and evaporation of porous asphalt.

References

1. Abass K., et al. 2022. "Rising incidence and risks of floods in urban Ghana: Is climate change to blame?". *Cities* v 121: 103495.

2. Diakakis M., N. Boufidis, J.M.S. Grau, E. Andreadakis, I. Stamos. 2020. "A systematic assessment of the effects of extreme flash floods on transportation infrastructure and circulation: The example of the 2017 Mandra flood". *Int. J. disaster risk Reduct.* 47: 101542.
3. Rebally A., C. Valeo, J. He, S. Saidi. 2021. "Flood Impact Assessments on Transportation Networks: A Review of Methods and Associated Temporal and Spatial Scales. Front. Sustain". *Cities* 3: 732181.
4. Sharafati M., M. Nightmare. 2018. "Tilihal on Traffic Crisis Management (Comparative Study)". *Golestan Management Knowledge Quarterly* 8(32): 53-82.
5. Suarez P., W. Anderson, V. Mahal, T.R. Lakshmanan. 2005. "Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area". *Transp. Res. Part D Transp. Environ.* 10(3): 231-244.
6. Alabbad Y., J. Mount, A.M. Campbell, I. Demir. 2021. "Assessment of transportation system disruption and accessibility to critical amenities during flooding: Iowa case study". *Sci. Total Environ.* 793: 148476.
7. Beljatynskij Andrey, Olegas Prentkovskis, Julij Krivenko. 2010. "The experimental study of shallow flows of liquid on the airport runways and automobile roads". *Transport* 25(4): 394-402.
8. Cheng Y.-Y., S.-L. Lo, C.-C. Ho, J.-Y. Lin, S. L. Yu. 2019. "Field testing of porous pavement performance on runoff and temperature control in Taipei City". *Water* 11(12): 2635.
9. Hu M., T. Sayama, X. Zhang, K. Tanaka, K. Takara, H. Yang. 2017. "Evaluation of low impact development approach for mitigating flood inundation at a watershed scale in China". *J. Environ. Manage* 193: 430-438.
10. Choi J., J. Choi, T.S. Park. 2021. "Comparative analysis of porous pavement mixtures through production inspection and accredited test results". *Journal of the Korean Asphalt Institute* 11(1).
11. Al-Busaltan S., M.A. Kadhim, B.K. Nile, G.A. Alshama. 2021. "Evaluating Porous Pavement for the Mitigation of Stormwater Impacts". In: *IOP Conference Series: Materials Science and Engineering* 1067(1): 12052.
12. Ma X., J. Jiang, Y. Zhao, H. Wang. 2021. "Characterization of the interconnected pore and its relationship to the directional permeability of porous asphalt mixture". *Constr. Build. Mater.* 269: 121233.
13. Adams M.C., T.H. Cahill. 2003. "Infiltration BMPs – Porous Asphalt Pavement and Beyond". In: *World Water & Environmental Resources Congress 2003*: 1-13.
14. Cahill T., M. Adams, C. Marm. 2003. "Porous asphalt: The right choice for porous pavements". *HMAT Hot Mix Asph. Technol.* 8(5).
15. Nicholls J.C. 1998. *Asphalt surfacings*. CRC Press.
16. Akhtar M.N., A.M. Al-Shamrani, M. Jameel, N.A. Khan, Z. Ibrahim, J.N. Akhtar. 2021. "Stability and permeability characteristics of porous asphalt pavement: An experimental case study". *Case Stud. Constr. Mater.* 15: e00591.
17. Zhang Y., H. Li, A. Abdelhady, J. Yang, H. Wang. 2021. "Effects of specimen shape and size on the permeability and mechanical properties of porous concrete". *Constr. Build. Mater.* 266: 121074.
18. Utomo A.B., L.F. Hidayatiningrum, B. Dhanardono. 2021. "Application of porous concrete to resolveflood on the roads". In: *IOP Conference Series: Earth and Environmental Science* 708(1): 12037.

19. Yang B., H. Li, H. Zhang, N. Xie, H. Zhou. 2019. "Laboratorial investigation on effects of microscopic void characteristics on properties of porous asphalt mixture". *Constr. Build. Mater.* 213: 434-446.

20. Jusić S., E. Hadžić, H. Milišić. 2019. "Stormwater management by green roof," *ACTA Sci. Agric* 3: 57-62.

21. Yang Q., F. Dai, S. Beecham. 2022. "The influence of evaporation from porous concrete on air temperature and humidity". *J. Environ. Manage* 306: 114472.

22. Suman S.K., R. Kumar. 2022. "Hydraulic Design of Reservoir in Permeable Pavement for Mitigating Urban Stormwater". *River Hydraulics*: 1-11.

23. Abdi A., S. Javadi, R. Sedghi. 2015. "Improving the safety of urban roads using porous asphalt". In: *15th International Conference on Transportation and Traffic Engineering*. Tehran.

24. Staniek M., P. Czech. 2016. "Self-correcting neural network in road pavement diagnostics". *Automation in Construction* 96: 75-87.

25. T. Ji, L. Xiao, F. Chen. 2020. "Parametric analysis of the drainage performance of porous asphalt pavement based on a 3D FEM method". *J. Mater. Civ. Eng.* 32(12): 4020383.

26. Afonso M.L., M. Dinis-Almeida, C.S. Fael. 2019. "Characterization of the skid resistance and mean texture depth in a permeable asphalt pavement". In: *IOP Conference Series: Materials Science and Egineering* 471(2): 22029.

27. "Regulations for the implementation and maintenance of porous asphalt of the country's management and program organization". Documents and technical bases of the project instructions. Journal No. 2-384. Tehran, Iran, 2015.

28. Hu J., Z. Qian, P. Liu, D. Wang, M. Oeser. 2020. "Investigation on the permeability of porous asphalt concrete based on microstructure analysis". *Int. J. Pavement Eng.* 21(13): 1683-1693.

29. Chen X., H. Wang, C. Li, W. Zhang, G. Xu. 2020. "Computational investigation on surface water distribution and permeability of porous asphalt pavement". *Int. J. Pavement Eng.*: 1-13.

30. Ranieri V., J. J. Sansalone, S. Shuler. 2010. "Relationships among gradation curve, clogging resistance, and pore-based indices of porous asphalt mixes". *Road Mater. pavement Des.* 11(no. sup1): 507-525.

31. Tziampou N., S.J. Coupe, L.A. Saudo-Fontaneda, A.P. Newman, D. Castro-Fresno. 2020. "Fluid transport within permeable pavement systems: A review of evaporation processes, moisture loss measurement and the current state of knowledge". *Constr. Build. Mater.* 243: 118179.

32. Li H., J. Harvey, Z. Ge. 2014. "Experimental investigation on evaporation rate for enhancing evaporative cooling effect of permeable pavement materials". *Constr. Build. Mater.* 65: 367-375.

33. CN107389497 Apparatus and method for determining evaporation rate of pervious concretepavement. Available at: https://patentscope.wipo.int/search/en/detail.jsf;jsessionid=A007E8C71AE30B1D33A64 34B71FB661F.wTDESCRIPTION.

34. Aboufoul M., N. Shokri, E. Saleh, C. Tuck, A. Garcia. 2019. "Dynamics of water evaporation from porous asphalt". *Constr. Build. Mater.* 202: 406-414.

35. Zhu J., T. Ma, Z. Lin, J. Xu, X. Qiu. 2021. "Evaluation of internal pore structure of porous asphalt concrete based on laboratory testing and discrete-element modeling". *Constr. Build. Mater.* 273: 121754.

36. Hassan N.A., M.Z.H. Mahmud, K.A. Ahmad, M.R. Hainin, R.P. Jaya, N. Mashros. 2016. "Air voids characterisation and permeability of porous asphalt gradations used in different countries". *ARPN J. Eng. Appl. Sci*. 11: 14043-14047.