EVALUATION METHODS OF ROAD SURFACE PERFORMANCE IN JAPAN

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ABSTRACT

Since the design guides for pavement works were revised to performance-based in Japan, various pavement technologies such as cool pavement, which can cool down the maximum temperature of road surface from 60 degree C to 50 degree C, have been developed in Japan. In order to evaluate these technologies, several evaluations have been also developed. In this paper, skid resistance and water permeability are picked up, and present status of the evaluation methods for these functions are introduced. Dynamic Friction (DF) Tester was originally developed in Japan, and has been adopted as the ASTM test method. Water permeability is necessary to improve the traffic safety in rainy days, especially in expressways.

INTRODUCTION

In Japan, the design guides for pavement were revised[1)] in 2001 from the former specification-based standards that specified the materials and structures of pavement into performance-based rules that can flexibly adapt to technological innovation. In the former one, the owners decided the kind of asphalt mix, and the performance requirements for each kind of mix (such as Marshall stability) were prescribed in the Manual for Design and Construction of Asphalt Pavement which was old design guides. The constructors then produced and applied asphalt mixes that satisfied the regulations in the Manual.

On the other hand, in the current performance-based rules, the owners do not decide the kind of asphalt mix but specify the required performance for the road surface through identifying the functions and needs of the surface of the road. The constructors then select and use materials that meet the required performances. Because it is necessary to check whether the constructed road surface satisfies the performance requirements, there must be prescribed performance indices and evaluation methods.

The technical standards were revised because the functions required for pavement have become increasingly diverse as society has developed. The design guides were revised to performance-based rules to increase the freedom of designing pavement and selecting materials, respond to diverse needs, and encourage further technological innovation. For example, cool pavement (solar radiation reflective pavement etc.), which reduces the highest temperature of the pavement surface from 60°C to 50°C, was developed and has been implemented in Japan. To encourage such developments, various performance evaluation methods are being investigated in Japan.

This paper outlines and discusses methods for evaluating skid resistance and water permeability and describes the results of studies.

SKID RESISTANCE

Background

Because skid resistance has great influence on the braking distance, it has great relation to safety for driving a vehicle and is one of the most important performance requirements for road surface. It involves friction force acting between the pavement surface and tire rubber. Also, it involves very complicated phenomena in which various factors act to generate comprehensive friction. However, it is such an important factor, so an evaluation method needs to be established.

Overview of its Evaluation Method

In Japan, skid resistance is measured using Friction Measurement Vehicle, Skid Resistance Tester Based on Rotating Disc (Dynamic Friction Tester : DF Tester) , or the British Pendulum Tester. The first one is normally used on expressways in Japan. The second one, which was developed in Japan, is easy to measure and can determine the dynamic friction coefficient at various traveling speeds. It has been standardized as an ASTM standard testing method and has been approved as an effective measuring system for calculating skid resistance of the International Friction Index (IFI) [2-4]. This chapter outlines the method and reports on studies performed to develop the evaluation method.

Investigation of the evaluation method using DF Tester

Overview of the skid resistance evaluation method using DF Tester

The configuration of DF Tester is shown in Figure 1. Three pieces of tire rubber are installed on a disk that rotates horizontally up to a speed of 90 km/h, at which the disk is detached from the motor and allowed to rotate freely while a load of W is applied. The rotation speeds of the rubber pieces are monitored to determine the dynamic friction coefficient of the road surface. Water is continuously sprayed from when the rotation speed of the disk reaches 60 to 70 km/h until the end of the measurement.

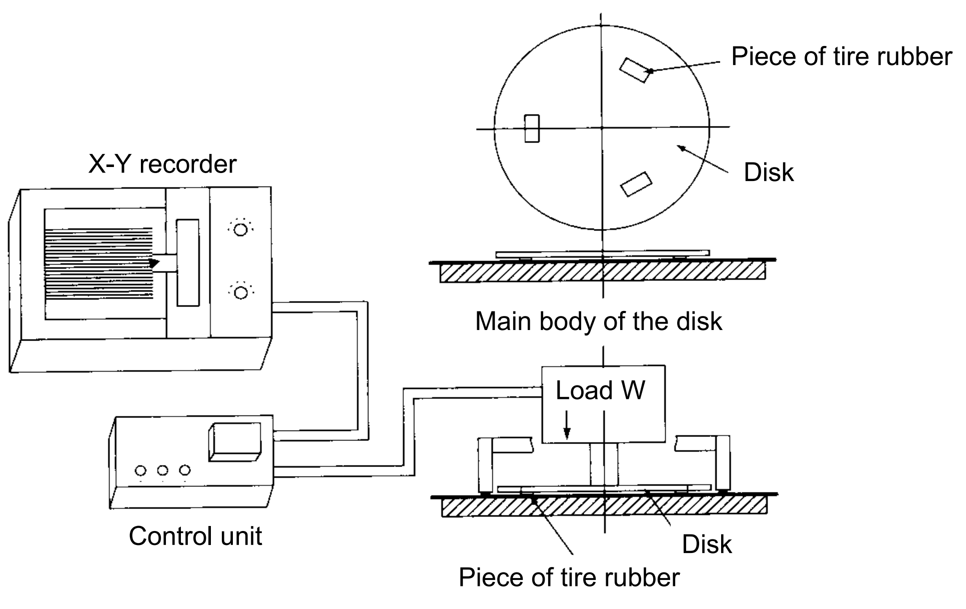

Figure 1: Concept of DF Tester5)

Investigation of the relationship with braking force coefficient determined using Friction Measurement Vehicle

When Friction Measurement Vehicle is used to measure braking force coefficient, a large system is required and it is difficult to perform indoors, but its method gives friction values very similar to the actual skid resistances between a travelling vehicle and the road surface[6]. The relationship was investigated between the rolling skid number (RSN) determined by DF Tester and the measurement by Friction Measurement Vehicle (braking force coefficient).

Road surfaces measured were dense graded asphalt concrete pavement, porous asphalt pavement, cement concrete pavement and polished road surfaces. The polished road surfaces were experimentally prepared by polishing the road surface of dense graded asphalt concrete until braking force coefficient became 0.3 and 0.4. It was considered that there would be some differences among each DF Tester, and five DF Testers (Type A-E) were selected for the test to investigate the relationship with braking force coefficient using one Friction Measurement Vehicle. The measuring speeds were 20, 40, 60 and 80 km/h.

The relationships of all data (all road surfaces, measuring speeds and DF Testers) are shown in Figure 2. Different symbols are used for each DF Tester.

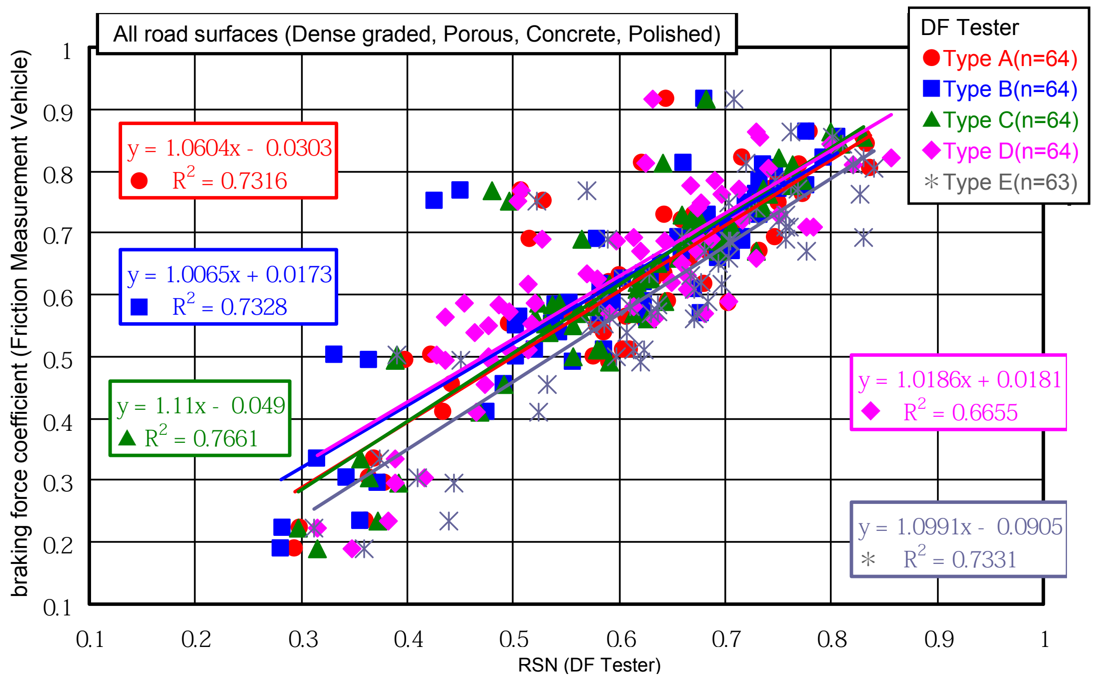

Figure 2: Braking force coefficient and RSN

Figure 2 shows a high correlation between braking force coefficient determined using Friction Measurement Vehicle and RSN determined by each DF Tester. The slope of the curve was almost Y = X, confirming that the evaluation method using DF Tester is valid. The relationship between braking force coefficient and RSN was checked separately for each kind of road surface, revealing high correlations for all surfaces.

However, this figure includes data which doesn't show clear correlation and it was assumed to be caused by different speeds. Therefore we reconfirmed result by each measuring speed. The result was shown in figure 3.

As is shown in figure 3, correlation coefficient at 20km/h was very small, and there found some differences in each DF Tester, especially at 80km/h.The data at 20 km/h were obtained immediately before the disk stopped and may have been affected by the rubber pieces being caught by the unevenness of the road surface. The data at 80 km/h were obtained immediately after the disk was detached from the motor and dropped and may have been affected by the bounce of the disk. However, Within the range of V = 40 to 60 km/h, there was a close correlation between braking force coefficient and RSN.

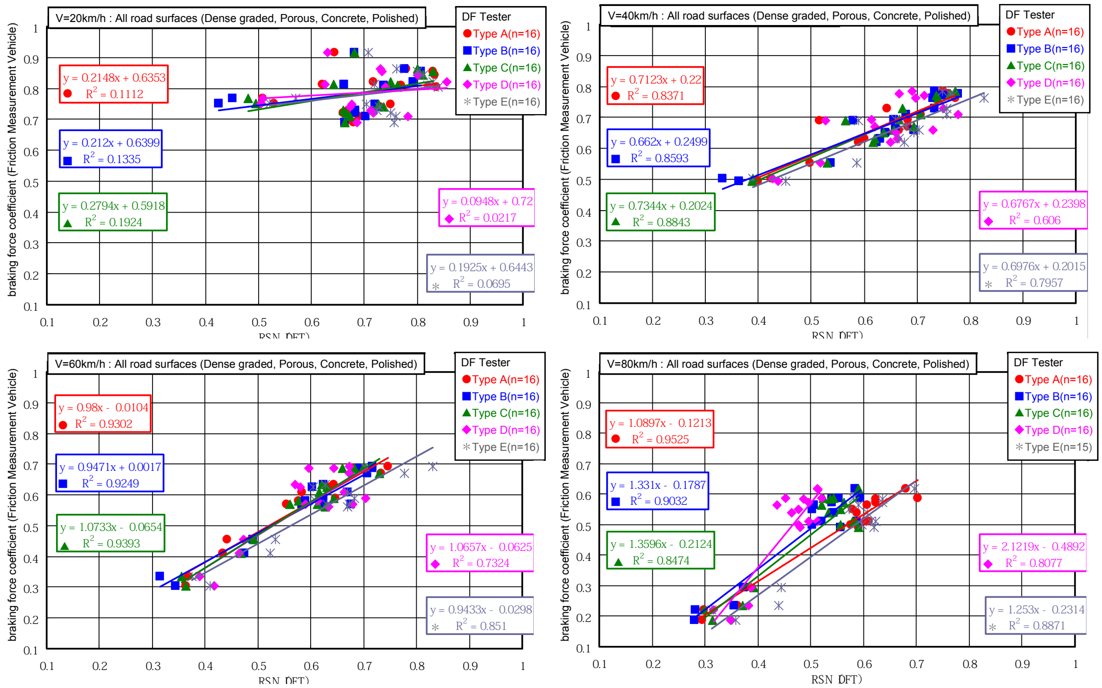

Figure3: Braking force coefficient and RSN for each measuring speed

Investigation of the limits of using rubber pieces

The rubber pieces installed on DF Testers are worn down by repeated testing. It is described that rubber pieces shall be replaced due to waves after twelve runs in ASTM standard "ASTM E-1911-98 Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester". However it is considered that the degree of its abrasion depends on texture of road surface and material of pavement. The limits of using the rubber pieces were investigated.

km/h

The investigation involved repeatedly measuring several road surfaces (dense graded asphalt pavement, porous asphalt pavement, semi-flexible pavement, stone mastic pavement, solar radiation reflective pavement, water retaining pavement, and concrete pavement) using DF Testers. Measurements were continued until the RSN values sharply changed or the rubber pieces became so worn that they could no longer be used for measurements. In this test, Eight DF Testers were used.

Figure 4 plots the changes in rubber piece thickness. The abrasion speed of the rubber pieces differed depending on the kind of pavement. Particularly fast abrasion was observed on anti-skid pavements, such as heat-insulating pavement.

Figure 5 shows samples of changes in RSN and the rubber piece thickness during repeated measurement. These are dates on porous asphalt pavement and stone mastic pavement. As the figure shows, it is not found there is clear correlation between the changes in RSN and rubber piece thickness, and the other pavements also showed the same trend

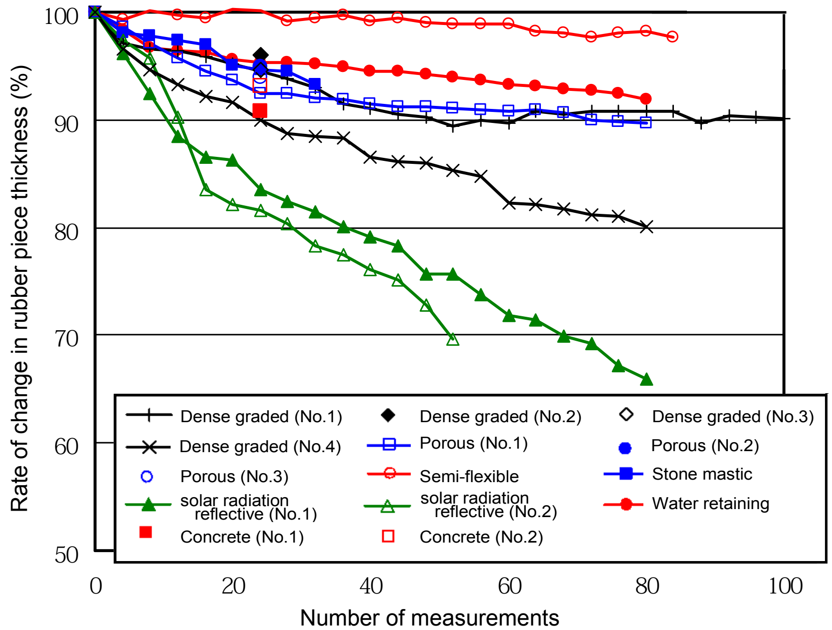

Figure4: Changes in rubber piece thickness

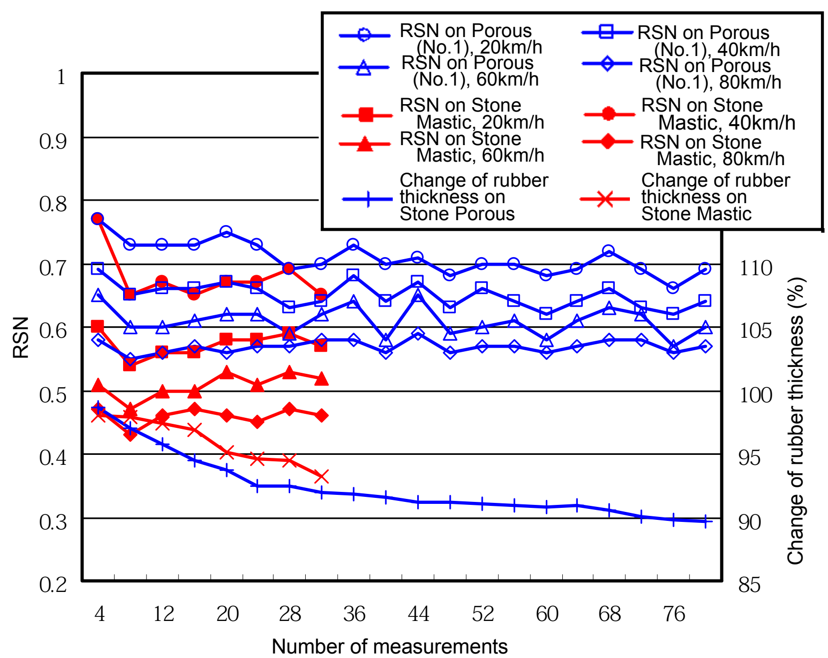

Figure5: Changes in rubber piece thickness and RSN during repeated measurements on porous asphalt (No.1) and stone mastic pavement

The investigation showed that it is adequate to express the limit of using rubber pieces not by the number of measurements but by the degree of abrasion. Next, the effects of rubber piece thickness (abrasion) on RSN were investigated. The road surfaces used for the investigation were each one of dense graded asphalt pavement, porous asphalt pavement and concrete pavement, which are ordinary pavements in Japan. Nine DF Testers were tested both in the brand-new condition and in the second stage of abrasion at measuring speeds of 20, 40, 60 and 80 km/h.

The relationship between rubber piece thickness and RSN is shown in Figure 6. Figure 7 compares the mean abrasion of the rubber pieces measured at three different stages during measurement of dense graded asphalt concrete pavement.

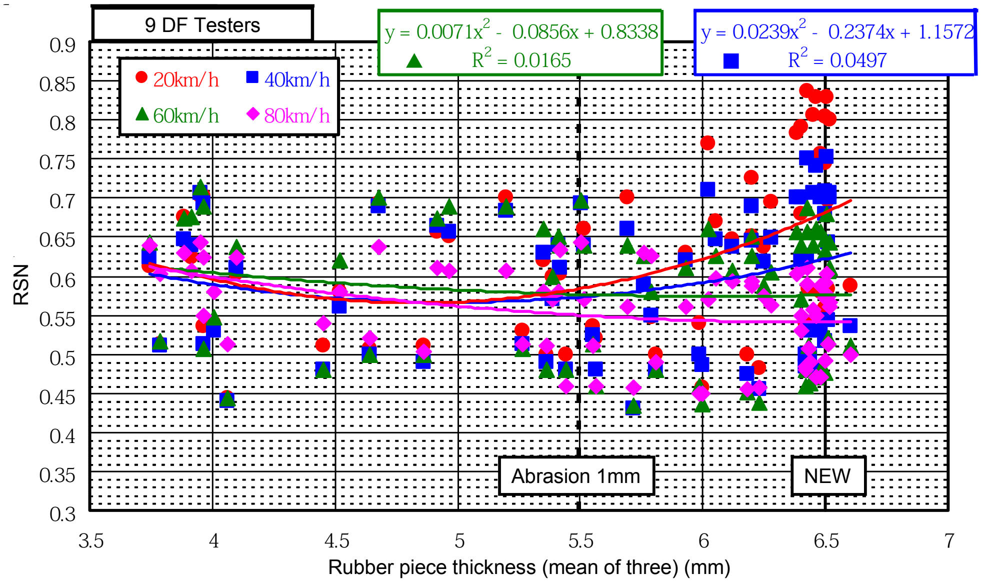

Figure 6: Rubber piece thickness and RSN (all kinds of pavement)

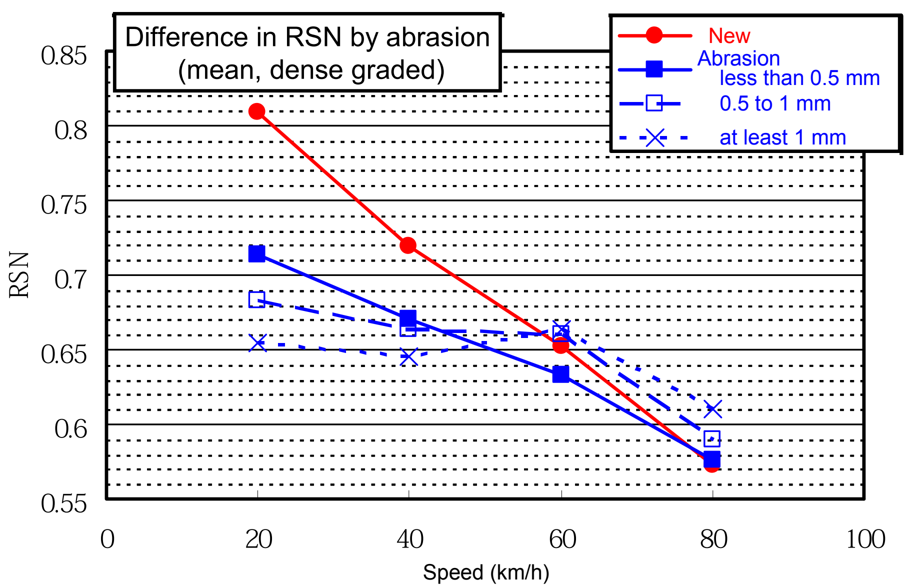

Figure7: Change in RSN by abrasion (dense graded asphalt pavement)

Figure 6 shows that the difference in RSN by measuring speed decreases as the rubber pieces were worn (abraded), which prevented evaluation of the speed dependency of RSN. As shown in Figure 7, this inability became notable at an abrasion of about 0.5 mm (rubber piece thickness: 6 mm). The same trend was observed also on porous asphalt pavement and concrete pavement. Therefore, it was concluded that rubber pieces should be recommended to be exchanged when they have abraded by 0.5 mm.

Investigation of the amount of water to be sprayed

Although ASTM does not prescribe the difference in water head for spraying water during measurements, it states that the flow should be kept at 3.6 L/min when the tank for supplying water is 0.6 m above the tester. Because it is difficult to measure the water membrane thickness while measuring RSN, it is necessary to determine the amount of water that is discharged during the measurement. Here, the runoff per unit time was measured by changing the elevation of the tank and the amount of water contained in the tank to change the difference in water head. One dynamic friction tester was investigated. The resultant relationship between discharge and RSN is shown in Figure 8.

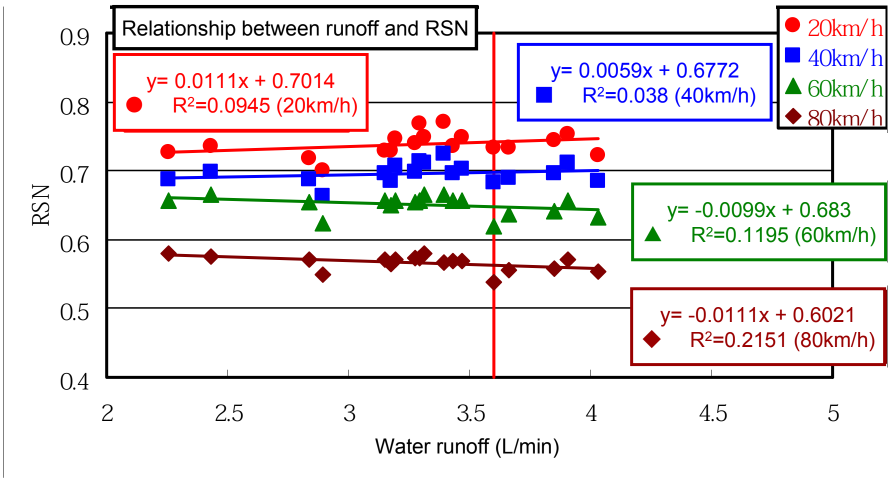

Figure8: Water runoff and RSN (dense graded asphalt pavement)

The investigation showed that water runoff from 2.2 to 4.0L/min in testing didn't have great influence on RSN. On the other hand, because the ASTM contains a statement on water runoff as mentioned above, the relationship between the difference in water head and water runoff should be investigated in advance and measurements should be conducted at a water head difference that gives a flow of 3.6 L/min.

WATER PERMEABILITY

Background

In Japan, porous asphalt pavement is increasingly used mainly on major roads to reduce traffic noise and ensure traffic safety by preventing water from splashing during rainfall. Porous asphalt pavement is a basic requirement particularly on expressways, but it is also increasingly used for pedestrian paths in cities for the protection and growth of roadside trees, to maintain slip resistance, and to reduce the amount of storm water and the load on drainage facilities [7]. Water permeability is an index of this performance.

Investigation of methods for evaluating water permeability

Overview of the current evaluation method and issues

The current evaluation method involves measuring the amount of penetrated water by using an in-situ permeability tester (Figure 9). The tester is installed on the surface of the road to be measured, and water is poured into the cylinder up to almost the mouth. Then, the valve is opened at once, and the time taken for 400 mL of water to flow out from the water head of 600 mm is measured. This value is used to calculate the water permeability of the road, which is the amount of water that permeates in 15 seconds [8].

The main issue of this current method is the differences among testers used by test laboratories. Initially, there was only one manufacturer of permeability testers, but as the evaluation method spread, other manufacturers started to produce testers and there are now at least seven manufacturers of testers. Some manufacturers also produce more than one model. A survey of the main models showed differences in the inside diameter of the valve shown in Figure 9. There were also differences in the watertightness of the water sealer (Photograph 1). In order to establish a method of evaluating water permeability, these two issues have been investigated.

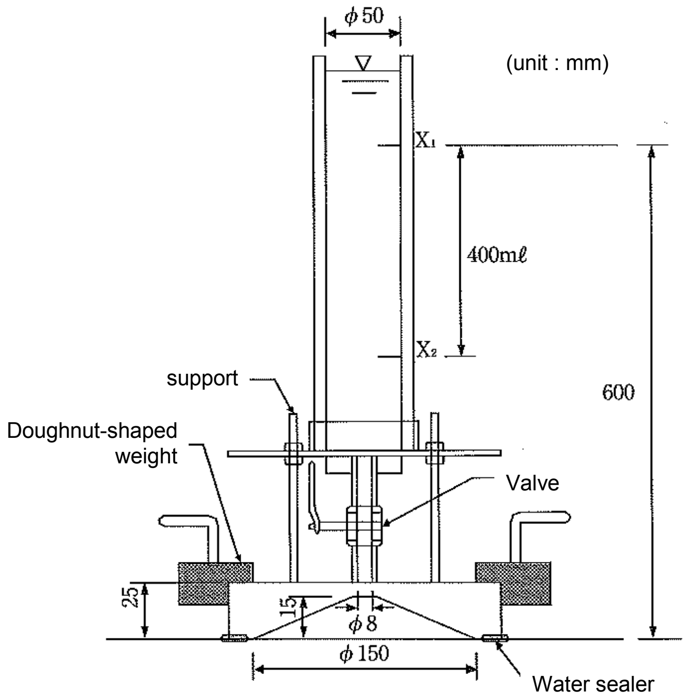

Figure 9: In-situ permeability tester

Figure 10: Incomplete watertightness of water sealer

Investigation on the inside diameter of the valve

The inside diameters of the valves of in-situ permeability testers sold in Japan were found to be φ 6.8, 8 and 10 mm. The difference was likely to be because the inside diameter of φ 8 mm is prescribed for the pipes connected to the valves but does not apply to the valves. The effects of the inside diameter of the valve on water permeability measurements were investigated by measuring the permeability of the same pavement using the same tester and changing the valve and water head. The results are shown in Figure 11.

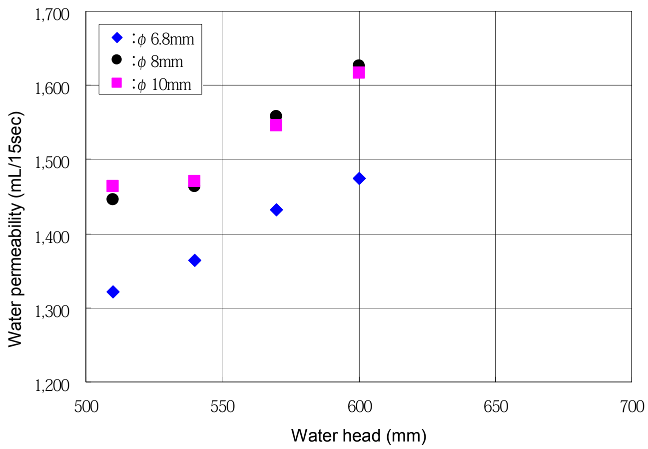

Figure 11: The inside diameter of the valve and permeability measurements

As shown in the figure, changes in water head did not affect water permeability if the inside diameter of the valves was φ 8 mm (the inside diameter of the connecting pipes) or larger. However, the permeability sharply dropped at the inside diameter of φ 6.8 mm. Therefore, care must be taken on the inside diameter of the valves to be used.

Investigation on the watertightness of water sealers

Various kinds of water sealer are used for permeability testers, including those that are installed on the tester and putty to be applied to cut off water. Because the current evaluation method directly measures the amount of water that flows into pavement, differences in the watertightness of water sealers are likely to strongly affect permeability measurements. Therefore, the effects were investigated by measuring the water permeability of the same pavement using the same tester and water sealers consisting of: 1) rubber ring attached to the tester, 2) rubber ring + silicon mat, 3) silicon mat, and 4) putty. The results are shown in Figure 12.

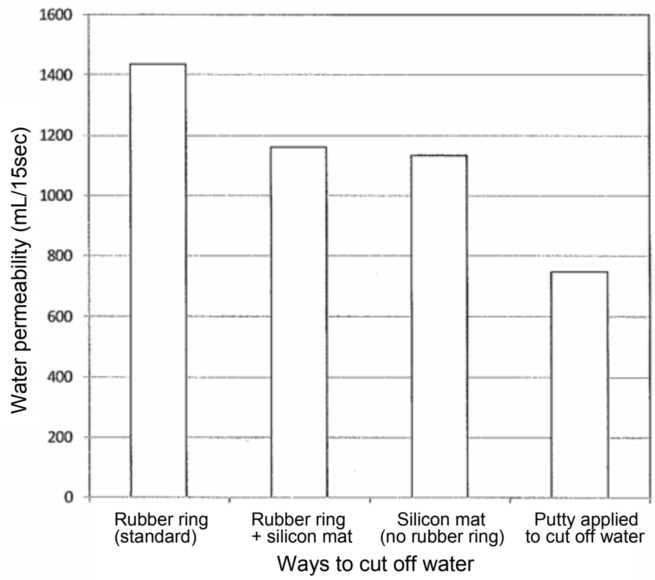

Figure 12: Water permeability using different water sealers

The test showed that putty was most watertight. Highly watertight materials such as putty need to be used to seal water in order to correctly evaluate the seepage of rainwater into pavement.

CONCLUSION

About the evaluation method of skid resistance, Friction Measurement Vehicle is normally used on expressways in Japan. This method gives friction values very similar to the actual skid resistances between a travelling vehicle and the road surface. However it requires a large system and it is difficult to perform indoors. On the other hand, the method of using DF Tester which developed in Japan and has been standardized as an ASTM standard testing method is easy to measure and can determine the dynamic friction coefficient at various travelling speeds.

In this paper, it was found out that there was a close correlation between RSN determined by DF Tester and the measurement by Friction Measurement Vehicle, especially within the range of V=40 to 60km/h. In addition, the limits of using rubber pieces which installed on a rotary disk of DF Tester was investigated. It is described that rubber pieces shall be replaced due to waves after twelve runs in ASTM standard. However it is considered that the degree of its abrasion depends on texture of road surface and material of pavement. It was found out that rubber pieces should be changed exchanged before they have abraded by 0.5mm. Furthermore, it was considered that the amount of water to be sprayed in testing had relationship to RSN, so the relationship between the amount of water to be sprayed and RSN was investigated. As a result, it was found out that the amount of water to be sprayed from 2.2 to 4.0L/min in testing didn't have great influence on RSN. Still, ASTM contains a statement on the amount of water to be sprayed, so the relationship between the difference in it and water head should be investigated in advance.

About water permeability, because porous asphalt pavement is increasingly used mainly on major roads to reduce traffic noise and ensure traffic safety by preventing water from splashing during rainfall, it has been necessary to evaluate its performance more appropriately than before.

In this paper, it was found out there were difference about the diameter of the valves though the inside diameter of the connecting pipes was standardized with φ8.0mm. Especially, if the diameter of the valves is φ6.8mm, it has great possibility to evaluate performance of water permeability unfairly. Also, it was found that it was possible that water leaks from road surface and the permeability tester. Therefore highly watertight materials need to be used between road surface and tester in order to correctly evaluate the seepage of rainwater into pavement.

The authors will continue to study methods of evaluating various performance indices, aiming to establish methods that can correctly assess the performance requirements for pavement, encourage further innovations of pavement-related technologies, and improve the effects and efficiency of paving works.

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