Performance of Permeable Asphalt Pavements in Traffic Roads after Five years

T. Ayabe , K. Kubo
Public Works Research Institute, Tsukuba, Ibaraki, Japan

ABSTRACT: Recently urban floods frequently occur caused by localized torrential rain. Therefore the Designated Urban River Inundation Prevention Act was enacted in June 2003, whereby roadways in designated areas must be equipped with means for controlling rainwater runoff. Permeable pavement is a likely candidate, but it has rarely been applied to roadways. Therefore, its durability and sustainability in runoff control performance have not been validated enough. Thus, to confirm the applicability of permeable pavement to roadways, its durability and performance were examined in this study through experiments on test pavement within the Pavement Test Field of Public Works Research Institute (hereafter, PWRI) and on actual roadways. The results for test pavement at PWRI showed that the installation of a drainage pipe on the subgrade upper surface or an increase in the base course thickness was effective for retaining pavement durability even in the case of subgrade comprising cohesive soils. In addition, the results of observing test pavement constructed on actual roadways showed that pavement durability was retained in five years after the test pavement sections were opened to traffic. However, rainwater runoff control was not retained at some test pavement sections.

KEY WORDS: Permeable pavement, flood control, pavement

1 INTRODUCTION

Localized torrential rainfall in urban areas has been increasing due to global warming and heat island effect. In urban areas, where the ground surface is mostly covered with impermeable artificial structures such as buildings and paved roadways, rainwater generally flows directly into rivers and sewers, causing inundation and flood damage. Therefore, the Designated Urban River Inundation Prevention Act was enacted in June 2003, which stipulates that roadways in designated areas must implement countermeasures for controlling rainwater runoff. One effective measure is to apply permeable asphalt pavement (hereafter referred to as “permeable pavement”), which absorbs and stores rainwater in the pavement body. However, as there are only a few cases of applying permeable pavement to roadways, its durability and runoff control performance have not yet been fully validated. Thus, the objective of this study is to ensure the applicability of permeable pavement to roadways. This paper reports on the results of our experiments on full-size test pavements both at the test facility of PWRI and on actual roadways.

2 PRESENT SITUATION OF PERMEABLE PAVEMENT IN JAPAN

Permeable pavement was firstly used in Japan in 1970s for sidewalks for the purpose of growing street trees. As of 2001, the total sidewalk area covered with permeable pavement in Tokyo was 2.82 million m^2. Permeable pavement is generally used for sidewalks throughout Japan, particularly in urban areas.

As for roadways, permeable pavement has also been applied to some light traffic routes. In Niigata City, for instance, it is employed as a standard when the subgrade properties meet the required conditions.[2)] Nonetheless, permeable pavement is very rarely applied to heavy traffic routes at present.

3 PROBLEMS WITH PERMEABLE PAVEMENT ON ROADWAYS

One of the problems related to permeable pavement on roadways is the possibility of early distress due to vehicle load, which acts iteratively on the base course and subgrade and eventually lowers the bearing capacity, particularly when water-soaked. Consequently, permeable pavement has rarely been applied to heavy traffic routes, which are prone to frequent repeated loading, or to roadways where the subgrade comprises cohesive soils. Thus, it has not been possible to properly validate pavement durability. In the areas designated by the Designated Urban River Inundation Prevention Act, measures for controlling rainwater runoff, such as the use of permeable pavement, must be taken for roadways regardless of ground conditions and traffic volume. Therefore, a design method for permeable pavement applicable to heavy traffic routes and cohesive soils needs to be established. In addition, as few quantitative studies have been conducted on the performance of permeable pavement in controlling rainwater runoff, such performance also needs to be confirmed, and a method for quantifying rainwater runoff must be established.

In this study, laboratory experiments were conducted on permeable pavement to examine the impact of subgrade soil properties on pavement durability, rainwater storage capacity, and the required permeability of the materials used. Based on the results of the laboratory experiments, field experiments were conducted on test pavement prepared both within the grounds of PWRI and on actual roadways in order to validate pavement durability and performance in controlling rainwater runoff.

4 FINDINGS OBTAINED FROM LABORATORY EXPPERIMENTS

So far, the laboratory experiments conducted at PWRI have yielded the following findings regarding the durability and the performance of rainwater runoff control of permeable pavement.

4.1 Findings Regarding Pavement Durability

1) In case that a subgrade is comprised of cohesive soils, deformation due to cyclic loading progresses more rapidly when the subgrade is water-soaked.
2) When a subgrade is comprised of cohesive soils, it is recommended to increase the pavement thickness to reduce the stress on the subgrade surface, or the durability of the pavement would be dropped drastically.

4.2 Findings Regarding Performance of Rainwater Runoff Control

1) Rainwater that infiltrates into the pavement body is stored within the voids of pavement materials at a ratio of 0.5% of the cubic volume in the case of granular base course materials, and 1.5% in the case of asphalt mixtures.
2) When the void content of porous asphalt mixture is 20%, the content of isolated void, which does not contribute to store water, would be about 6%. In case of 15% void content base material, the isolated void content would be about 3%. In the calculation to evaluate the performance of rainwater runoff control for each pavement structure, it must be considered that this isolated voids does not contribute to water control.
3) Although granular base course materials possess sufficient permeability, the materials can become insufficient (overly compacted) if the water content is not appropriately controlled during compaction.

5 VALIDATIONS BY TEST PAVEMENT PREPARED ON THE GROUNDS OF PWRI

5.1 Outline of Experiments

To identify how the difference in vertical pavement configuration and rainwater drainage mechanism affect pavement durability, an accelerated loading test was conducted using four full-size permeable pavement sections prepared at the Pavement Test Field at the Public Works Research Institute (PWRI). The Pavement Test Field is used for evaluating pavement durability by driving heavily loaded vehicles on full-scale pavement applied to a test track of 628 m in total length (Photo 1). Trucks of the most commonly used type in Japan were modified for use as heavily loaded vehicles to be driven by unmanned operation assisted by GPS (Photo 2). Four heavily loaded vehicles were operated simultaneously to drive at a speed of 40 km/h. The axle loads of each vehicle are set to 49kN (front axle) and 127kN (rear axle).

Photo 1 : Pavement Test Field

Photo 2 : Loading vehicle

Cross sections of the permeable pavement applied to the test track are shown in Figure 1. Four test pavement sections, each measuring 15 m in length and 5 m in width with varying vertical configuration, were prepared. The base course thickness of Section B was made 10 cm thicker than that of Section A in order to confirm the effect of increasing the pavement thickness. For Sections C and D, a drainage pipe was installed on the subgrade upper surface, through which rainwater that had infiltrated and was stored temporarily in the pavement body could be drained to the outside. For Section D, permeability stabilization was applied to form a vertical layer covering the full depth of the lateral side of the pavement body, so that the rainwater could be drained more effectively than at Section C. The subgrade comprised cohesive soils (Kanto loam). In this test, the void content of porous asphalt mixture is set to 20%, and that of base course is about 15%.

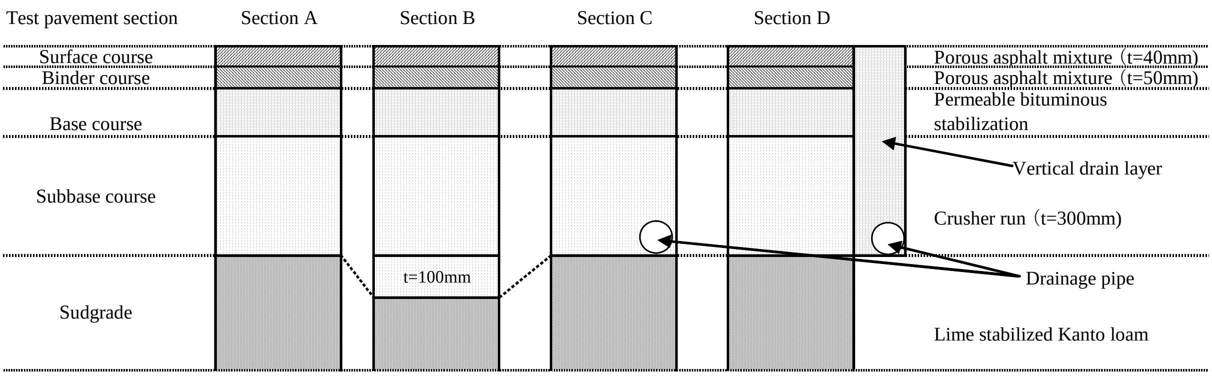


Figure 1 : Cross sections of full-size test pavement on the test track

5.2 Results of the Experiments

Figure 2 shows the progress of deflection immediately underneath the loading plate measured using FWD (hereafter referred to as “D_0 deflection”). The increase of D_0 deflection was moderate in Sections B, C, and D, while that in Section A progressed greatly. Likewise, the rut depth progressed more greatly and the pavement distress occurred earlier in Section A compared with the other three sections, as shown in Figure 3.

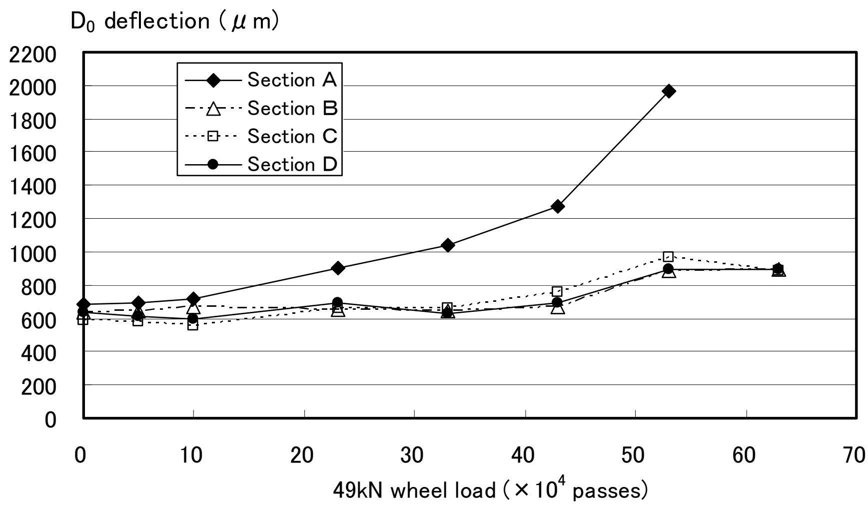


Figure 2 : Progress of D_0 deflection

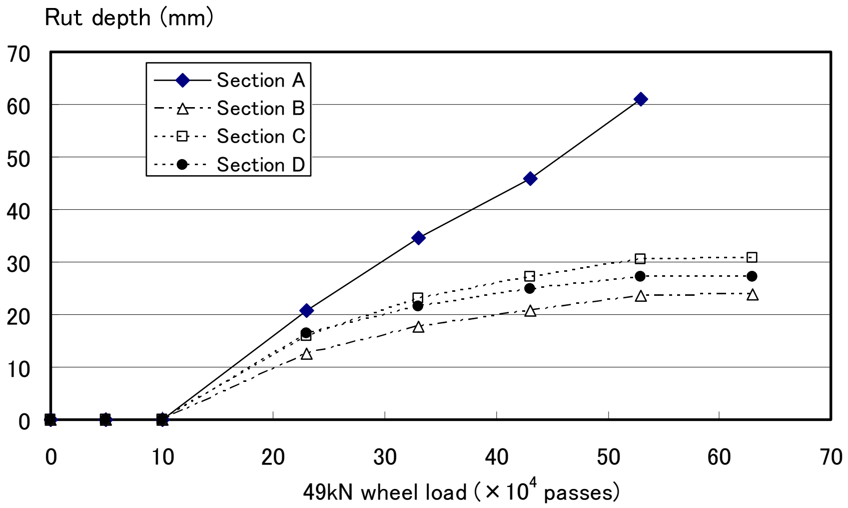


Figure 3 : Progress of rut depth

The cause for the earlier distress in Section A was investigated by cutting open the pavement body. A view of the open-cut cross section is shown in Photo 3, and the results of measuring the respective pavement layers are shown in Figure 4. The asphalt mixture layers were found to have deformed downward along the pavement ruts. The deformation even reached the subgrade, pushing base course materials into the subgrade. These phenomena are considered to be due to reduced bearing capacity of the subgrade that was water-soaked for a long time.

Photo 3 : View of open-cut cross section

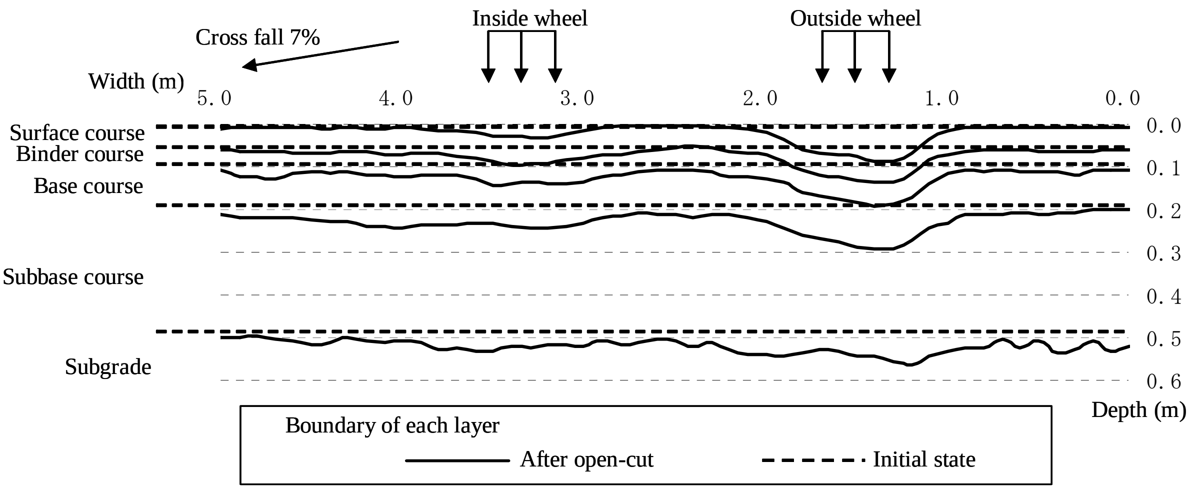


Figure 4 : Measurement results for open-cut cross section

The experiments yielded the following results: Section A with no measures for controlling rainwater runoff presented distress earlier than the other sections. In Sections C and D with a drainage pipe installed on the subgrade upper surface, pavement durability was presumably retained because the rainwater drained away from the pavement body through the drainage pipe. In Section B with an extra-thick base course, pavement durability was presumably retained due to the mitigation of stress acting on the subgrade upper surface. Thus, the installation of a drainage pipe and extra thickness of the base course suppressed the reduction of pavement durability even when the subgrade comprised cohesive soils.

6 VALIDATION USING TEST PAVEMENT APPLIED TO ACTUAL ROADWAYS

6.1 Outline of the Test Pavement

Permeable pavement was applied to actual roadways to confirm its durability and performance of rainwater runoff control. The test pavement was constructed mainly on heavy traffic routes at ten different places in Japan.

The features of the respective test pavement sections are outlined in Table 1, and their cross-sectional layer properties and dimensions are summarized in Figure 5. The rainwater drainage mechanisms used, Types P and S, are shown in Figure 6.

As of 2008, forth to fifth years had already elapsed since the test pavement sections were constructed.

Table 1 : Outline of test pavement sections on actual roadways

Test pavement section	Traffic volume (Vehicle passage per day and direction)	Subgrade soil	Type of rainwater drainage mechanism	Date when the test pavement entered service
A	3,000 or over	Cohesive soil	S	Dec-03
B	1,000 to less than 3,000	Conglomeratic soil	S+P	Oct-04
C	3,000 or over	Sandy soil (cement stabilization applied)	S	Mar-04
D	3,000 or over	Sandy soil	P	Jan-05
E	1,000 to less than 3,000	Soft rock	S	Mar-04
F	1,000 to less than 3,000	Sandy soil	S	Aug-04
G	1,000 to less than 3,000	Cohesive soil	S+P	Mar-04
H	1,000 to less than 3,000	Cohesive soil (cement stabilization applied)	S	Mar-05
I	1,000 to less than 3,000	Sandy soil (cement stabilization applied)	S	Mar-04
J	Less than 100	Silty soil	S+P	Mar-04

Test pavement section		A	B	C	D	E	F	G	H	I	J
Porous asphalt mixture	Surface course	5	5	5	5	5	5	5	5	5	5
Porous asphalt mixture	Intermediate course	5	0	5	5	5	0	0	0	0	0
Porous asphalt mixture	Binder course	5	5	5	5	5	5	5	5	5	0
Permeable bituminous stabilization	Base course	15	8	15	8	10	8	10～24	10、5	20、15、10	7
Crusher run	Subbase course	40、50	15～28	40	30,37	30	27	40	20、35	23、28,33	20、45
	Subgrade										(cm)

Figure 5 : Cross sections of test pavement on actual roadways

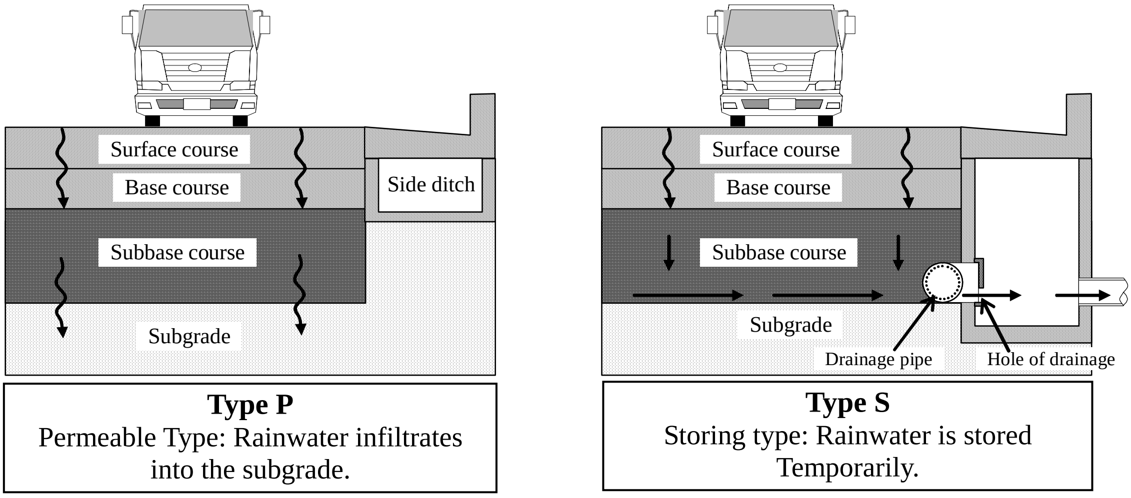


Figure 6 : Conceptual drawing of rainwater drainage mechanism of Types P and S

Photo 4 : Water sprinkler car

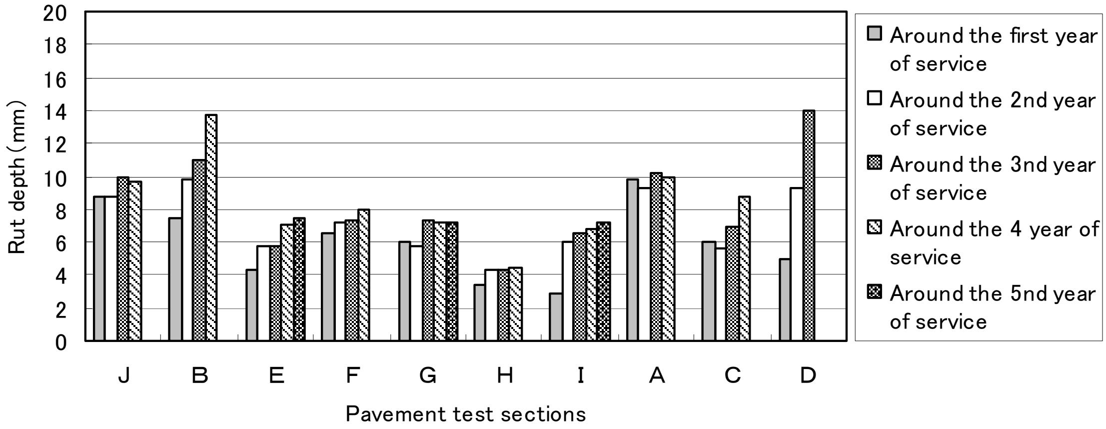
6.2 Follow-up Observations

The follow-up observations were conducted once every year after the start of service. The rut depth and D_0 deflection were measured to inspect the pavement durability. Watering experiments were conducted to inspect the capability to control rainwater runoff. In the watering experiments, the water sprinkler car shown in Photo 4 was used to sprinkle water, and the amount of runoff from the drainage pipe which was set on the upper surface of the subgrade was measured. In addition, the natural rainfall was measured throughout the year to measure the amount of runoff from the drainage pipe on the upper surface of the subgrade like the watering experiments.

6.3 Results of Follow-up Observations (Pavement durability)

The progress of rut depth is shown in Figure 7. Rut depth is around 15 mm or shallower for all test pavement sections. No conspicuous progress in rut depth due to the start of service has been observed. With respect to other investigation as well, no conspicuous progress due to the start of service has been observed, nor have reduced subgrade bearing capacity or signs of cavity generation inside the pavement body been detected. Furthermore, no remarkable increase in D_0 deflection has been observed by the measurements using FWD conducted so far.

Thus, it was confirmed that pavement durability was well retained in fourth to fifth years of service.



Figre 7 : Progress of rut depth

6.4 Results of Follow-up Observations (Runoff control performance at an early of service)

Experiments involving watering the test pavement were conducted, and the results obtained at Section B are shown in Figure 8 as an example. Rainwater mostly ran off through the drainage pipe installed on the subgrade upper surface, and no surface runoff on the roadways was observed. The water began draining through the drainage pipe after a delay from the start of watering, and the peak runoff volume turned out to be lower than the watering intensity. The same trend was observed at other test pavement sections where a drainage pipe had been installed, thereby proving the effectiveness of rainwater runoff control.

Natural rainfall measurement was conducted, and the data obtained at Section A are shown in Figure 9 as an example. The rainfall peak was 39.0 mm/h observed at 4:40, whereas the runoff peak was 18.6 mm/h observed at 5:10, showing a 52% reduction in peak runoff volume from the peak rainwater volume. In addition, there was a delay of around 30 minutes in the peak runoff from the peak rainfall. The fact that the rainwater runs off after a delay and with a reduced volume from the peak rainfall helps mitigate the load to rivers and sewers, and so helps mitigate flooding in urban areas.

Thus, the results of watering experiments and the data on natural rainfall measurement proved the effective performance of permeable pavement in controlling rainwater runoff.

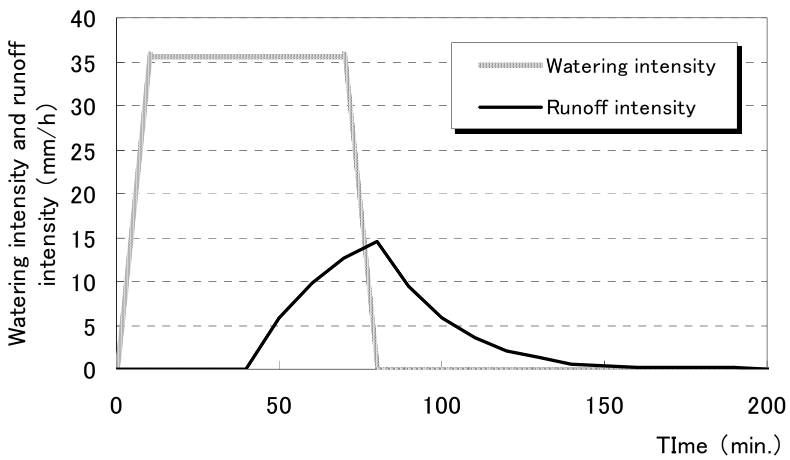


Figure 8 : Data on watering experiments measured at Section B

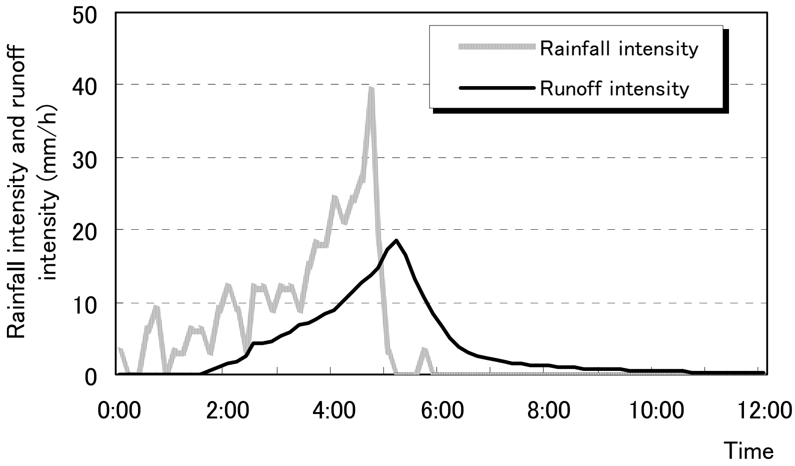


Figure 9 : Data on natural rainfall measured at Section A

6.5 Results of Follow-up Observations (Runoff control performance in the fourth to fifth years of service)

Figure 10 shows the results of watering experiments at Section B as an example. In a year after the road was opened to service, the peak runoff of 15 mm/h from the drainage pipe was measured, and the runoff from the drainage pipe then decreased in subsequent watering experiments. In the watering experiment conducted 50 months after the start of service, no runoff was measured from the drainage pipe.

Photo 5 shows the result of the watering experiment conducted 50 months after the start of service. As most of the sprinkled water overflows or remains stagnant on the road surface, it was considered that the water does not permeate through the pavement surface. In addition, it was visually confirmed that earth and sand accumulated in voids of the road surface.

Thus, no runoff was measured from the drainage pipe in the watering experiment conducted 50 months after the start of service at Section B, because water permeation through the road surface was blocked by the clogging of voids of the pavement. Moreover, the clogging of voids similar to Section B occurred at Section F and G. In this test construction, it was confirmed that several places where the runoff control performance declined in the fourth to fifth years of service.

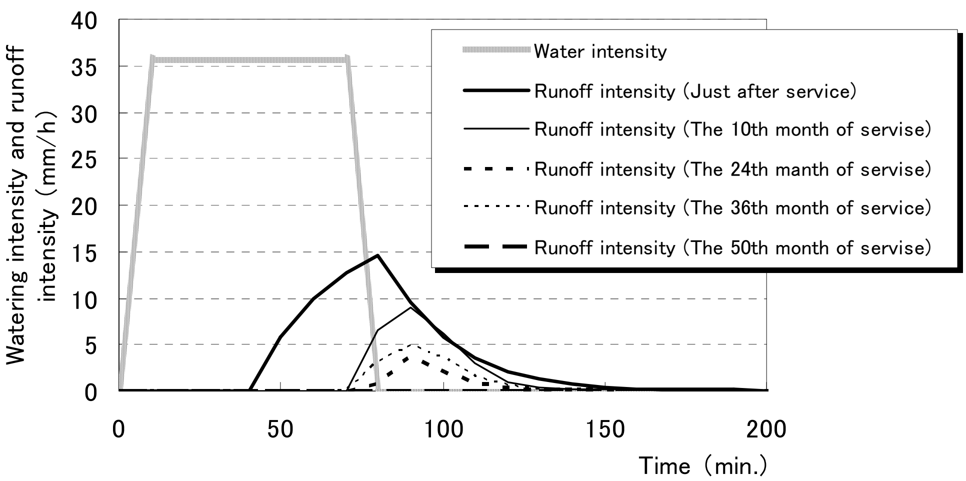


Figure 10 : Data on watering experiments measured at Section B

Photo 5 : Situation of the watering experiment after 50 months of service at Section B

7 CONCLUSIONS

In this study, we conducted laboratory experiments, full-size test pavement experiments on the test track, and test pavement experiments on actual roadways in order to confirm the applicability of permeable pavement to roadways. The following results were obtained:

1) The results of accelerated loading tests using heavily loaded vehicles showed that the test pavement section where no measures were taken showed distress at an early stage. This revealed that the lowering of pavement durability can be prevented by installing a drainage pipe or increasing the base course thickness even if the subgrade comprises cohesive soils.
2) The results of follow-up observations on the test pavement on actual roadways showed that pavement durability had hardly been affected in the forth to fifth years of service.
3) The runoff control performance of permeable pavement at an early stage of service was confirmed from the watering experiments results and the observation data of the natural rainfall. However, it was confirmed that the rainwater runoff control performance declined due to the clogging of voids at several sections in the fourth to fifth years of service.

REFERENCES

Horikoshi, S., Ohashi, K., Oshita, G., 2000, *Permeable Pavement in Niigata City*, 8th Hokuriku Road Pavement Conference, Japan

Kamada, O., Kubo, K., Nakamura , T., 2008, *A Study on Application of Permeable Pavement in Traffic Roads*, Proceedings of the 12th Road Engineering Association of Asia and Australasia, Philippine

Public Works Research Institute, 2006, *A Study on the Design Method of Permeable Pavement in Traffic Roads*, Technical Note of PWRI No.4008, Japan

Kawakami, A., Kubo, K., 2008, *Accelerated Loading Test on Durability of Cool Pavement in PWRI*, Proceedings of the 3rd International Conference on Accelerated Pavement Testing, Spain

Kubo, K., Ito, M., Ayabe, T., 2008, *A Study on Application of Permeable Asphalt Pavement in Traffic Roads*, Proceedings of the 6th International Conference on Road and Airfield Pavement Technology, Japan