A Study about the Environmental Safeguard that Utilized Permeable Pavement

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ABSTRACT: Recently, it has been important for the road administrator to pay attention to the natural environment in road projects. In Aichi Prefecture, an international exposition was held in 2005. An access road to the exposition ground through the area to be conserved its ecosystem. Permeable asphalt pavements were chosen for this road. In this study, we conducted in-situ air permeability tests in order to confirm the performance of permeability of the pavements on the access road with age. In addition, we examined the subgrade soil under the pavement to verify inhabitation of soil microbes. As a result, we obtained the following :
(1)Four years after the construction of the road, the average test result was 1049 ml/15 sec. (91% of ones done at the time of right after construction.) (2)Under the permeable asphalt pavements, whereas the number of aerobic heterotrophic soil microbes was higher than one under the non-permeable pavements adjacent to the study road, the number of anaerobic heterotrophic soil microbes was lower. From the test results, it can be confirmed that: (a)The function of the permeability of this pavement has been kept even after four years after construction. (b)The function of the permeability of this pavement can also secure preferable environment within the subgrade soils to microbes, which indicates the possibility to mitigate the burden on soil environment. In conclusion, when constructing a road, it is one of the effective alternatives to apply the permeable asphalt pavement for mitigating a negative impact on the environment.

KEY WORDS: Permeability, water, nature, ecosystem, a soil microbe.

1 INTRODUCTION

In recent years, global environmental problems and protection of the natural environment have grown in the public consciousness. Social infrastructure projects, including for roads, must adopt policies that consider the restoration and conservation of the natural environment, improvements to the water cycle, recycling of construction by-products, and so on.

The 2005 World Expo in Aichi Prefecture was staged with the theme of Nature's Wisdom. In advance of the Expo, a number of strategies and guidelines to consider the natural environment. Please refer to the following URL for the details of the Expo.

http://www.gispri.or.jp/english/expo/index.html

In this study, we investigated the changes in environmental performance with age of the permeable asphalt pavement. This permeable pavement, which was used for an access road to the 2005 World Expo site, allows rainwater to infiltrate through the pavement and into the subgrade.

2 ENVIRONMENTAL CONSIDERATIONS IN CONSTRUCTION OF THE ROAD UNDER STUDY

2.1 Overview of the Study Road

The road under study was constructed to provide access to the “Seto Area (Satoyama Trail Zone)” of the Expo site and was opened in March 2005, just before opening of the Expo. The road was used by shuttle buses during the Expo.

In constructing the access road to the Expo site through Satoyama, a natural conservation area, negative impacts on the environment needed to be minimized. Therefore, a number of environmental conservation measures, including the use of permeable pavement, were adopted.

2.2 Environmental Conservation Measures (Other than Use of Permeable Pavement)

2.2.1 Habita Conservation for Wildlife

When constructing the main road, the flora and fauna in the area were surveyed in order to identify strategies that might mitigate the negative impacts on them. Rare species within the road construction site and areas that might be affected by the construction works were temporarily transplanted or relocated to safe areas in advance of construction.

Figure 1: Transplanting rare species to a temporary refuge

2.2.2 Renegotiating Road Slopes

After construction of the road, plants were established on road slopes in order to restore the vegetation to as close to its original state as possible. To restore the vegetation to resemble what originally existed, a mixture of species from the plant community surrounding the construction area was used for planting.

Erosion control fences were also built on the slopes to prevent surface soil from being washed away by rainfall and runoff. The fences were made of wood collected from cleared vegetation.

Figure 2: Tree planting by local children

2.3 Overview of the Permeable Pavement Built on the Road Under Study

For this access road to the Expo site through Satoyama, a natural conservation area, a permeable pavement that allows rainwater to permeate into the ground beneath the pavement was chosen to mitigate the negative impacts upon the Satoyama area. The pavement design procedure was outlined as follows.

2.3.1 Outline of the approach to pavement design

- TA method was adopted for the design. (CBR = 12%, TA = 17)
  It is reference in Clause 2.3.2 about TA method.
- A modified open-graded asphalt with high binder content (with maximum particle size of 13 mm) was used for the surface course, as for normal drained pavement, and crusher run was used for the base course.
- A filter course was provided to help distribute the water evenly through the pavement structure before reaching the subgrade (Fig. 3). It's strength as a pavement body was not considered.

- The materials used for the binder course, base course, and filter course were evaluated to allow for strength reduction due to infiltration of rainwater in the design.

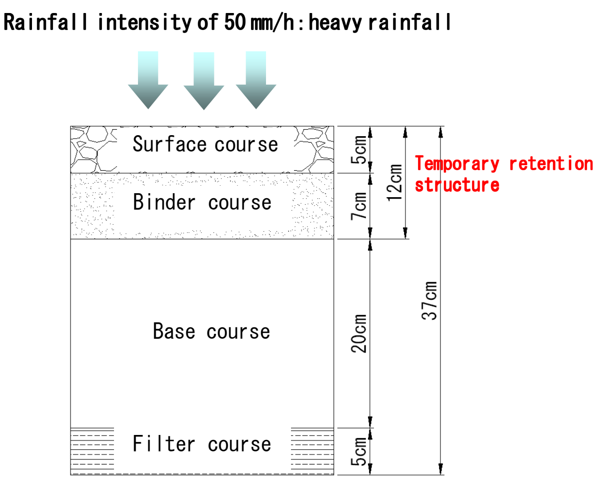

Figure 3: Cross section showing the structure of the pavement

2.3.2 TA method

TA method is one of asphalt pavement design methods to determine thickness of each course so as not to fall below target TA(thickness of layer equivalency, that is, thickness necessary for all layers from base course to surface course using hot asphalt mix for surface and binder courses) in accordance to design CBR of subgrade and design traffic.

Thickness of layer equivalency is calculated by multiplying coefficient of layer equivalency, that is, how many centimeters in thickness of asphalt mix for surface and binder courses 1 cm in thickness of pavement structural layers(pavement material) except asphalt mix for surface and binder courses is equivalent to.

3 ENVIRONMENTAL IMPACT STUDIES

As environment impact studies, we investigated In-situ permeability study and Test for soil microorganisms by soil sampling. Figure 4 show measurement locations.

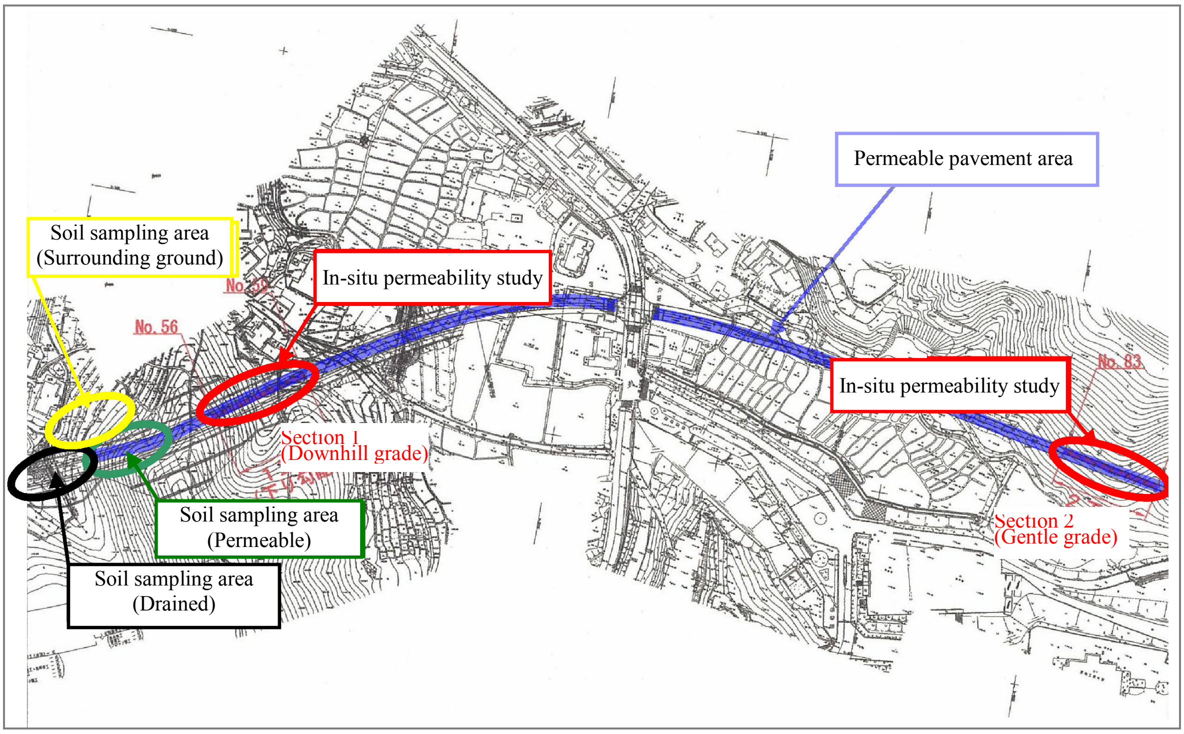

Figure 4: Measurement locations.

3.1 In-Situ Permeability Test

To investigate the changes in permeability of the pavement with age, we conducted in-situ permeability tests on the Satoyama access road immediately after construction and 1, 3, and 4 years after construction using the testing method specified in the “Pavement Test Handbook” published by the Japan Highway Association. (unit : mL/15 s, target permeability : 400 mL/15 s)

This method is summarized as follows.

3.1.1 Test method (Fig. 5, 6)

- Clean the pavement surface.
- Form a quantity of greasy clay into a 'snake' of about 1 cm diameter and 50 cm long. Affix it as a ring around the outer edge of the bottom of the base plate of the permeability test device (Fig. 6) to form a gasket or 'O-ring'. Press the test device down against the road surface firmly to ensure that there will be no water leakage through the clay gasket. Place a doughnut-shaped weight on the base plate to hold the device in place.
- Step 1: Place the mark "X1" at 100 mL from the top of the measuring cylinder, and place the mark "X2" at a position equivalent to 400 mL below the first mark.
- Step 2: Close the valve and fill the cylinder full of water.
- Step 3: Open the valve fully. Measure time for the water level in the cylindrical part to drop from the X1 level to the X2 level by a stop watch.
- Repeat steps 1 to 3 three times.

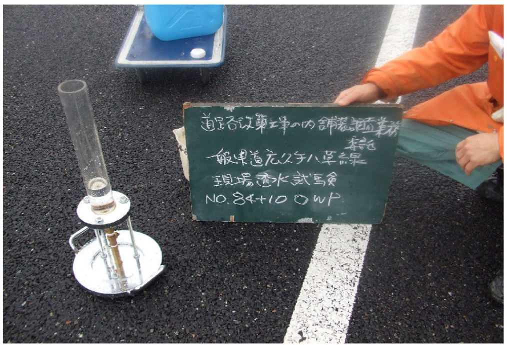

Figure 5: In-situ permeability test

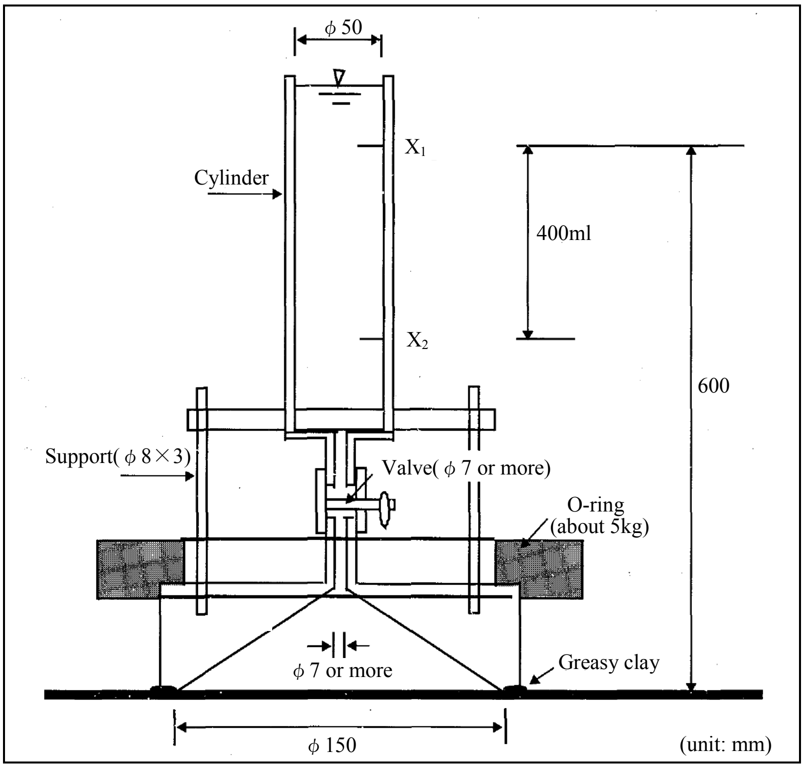

Figure 6: Cross-section of the standard in-situ permeability test device

3.1.2 Results

The in-situ permeability test results and permeability coefficients derived from the data by simple calculation are shown in Table 1. Figures 7 and 8 show the changes in in-situ permeability with age.

Four years after construction of the road (in February 2009), the average permeability from the 12 observation points was 1049 mL/15 s (690–1285 mL/15 s). These values were 91% (69–116%) of those measured immediately after construction. That is, the permeability of this pavement had declined by only 9% on average.

Even at the observation point from which the lowest permeability value was obtained (No. 57), the average permeability value from the outer wheel path (OWP) position and the between wheel path (BWP) position was approximately 800 mL/15 s. Although the permeability of this observation point had deteriorated in the 4 years since construction, the value satisfied the target permeability of 400 mL/15 s.

Table 1: In-situ permeability test results

			Immediately after construction	After 1 year	After 3 years	After 4 years	Feb 2009 /Mar 2005	After 4 years Permeability coefficient (cn／s)
			Mar 2005	Feb 2006	Feb 2008	Feb 2009		
Section 1	NO.55+10O	OWP	1091	652	498	753	69%	2.80E-01
	NO.55+10B	BWP	1200	1132	931	1107	92%	2.40E-01
	NO.56+10	OWP	1034	984	720	887	86%	3.30E-01
		BWP	1277	1250	1043	1187	93%	4.50E-01
	NO.57+10	OWP	594	909	676	690	116%	2.60E-01
		BWP	1132	723	866	1082	96%	4.10E-01
Section 2	NO.83+10	OWP	1364	1277	1073	1014	74%	3.80E-01
		BWP	1224	1304	1194	1285	105%	4.90E-01
	NO.84+10	OWP	1333	1304	1040	1089	82%	4.10E-01
		BWP	1224	1304	1181	1211	99%	4.60E-01
	NO85+10	OWP	1200	1304	975	1120	93%	4.20E-01
		BWP	1200	1250	1084	1164	97%	4.40E-01
Average			1156	1116	940	1049	91%	3.80E-01

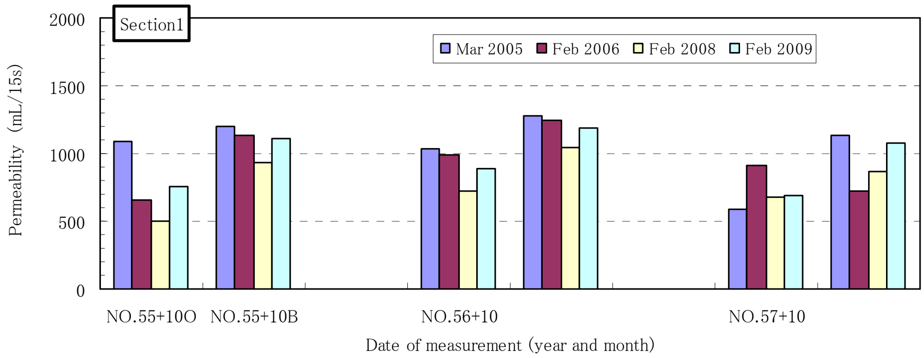

Figure 7: Changes in the in-situ permeability test results with age (Section 1)

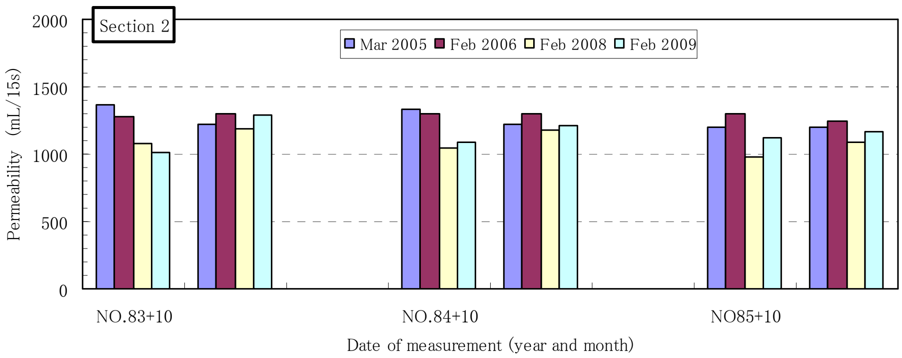

Figure 8: Changes in the in-situ permeability test results with age (Section 2)

3.1.3 Evaluation

The test results confirmed that the permeability performance of this pavement satisfied the target permeability value of 400 mL/15 s. Generally, pavement permeability is considered to deteriorate with age. However, the test results obtained over a period of 4 years from construction indicated that the permeability function of this pavement may have even improved slightly. This result may have been influenced by light rain early on the day of the test, but the rain would have had little influence on the permeability itself. Therefore, the test results indicate that the permeability function of this pavement persisted through the 4-year monitoring period after construction and maintained its required level of performance.

3.2 Reducing Impacts on Under Ground Ecosystems

We sampled soil from the subgrade under the permeable pavement and from under a nearby drained pavement on neighboring ground as well as on the Satoyama access road, and examined the population of two kinds of soil microbe, bacteria and fungi. We also measured the pH of the soil samples and performed C/N analysis by the dry combustion method according to the “Standard Method of Soil Analysis and Measurement” published by the Japanese Society of Soil Science and Plant Nutrition. C: soil carbon content; N: soil nitrogen content).

3.2.1 Test for soil microorganisms

- A given amount of each soil sample was measured. Each sample was mixed with sterile water so that the total weight was 10 times the weight of the sample. After ensuring the soil was dispersed in suspension, the sample was incubated.
- Aerobic heterotrophic soil microorganisms were cultured on nutrient agar media by the pour method according to "Sewage Examination Methods 8-1" published by Japan Sewage Works Association.
- Anaerobic heterotrophic soil microorganisms were cultured by the pour method on nutrient agar media using the GasPak method.
- Bacteria and actinomycetes were examined according to the "Soil Environment Analysis Method" published by the Japanese Society of Soil Science and Plant Nutrition. An inverted microscope (40–400×) was used to distinguish between bacteria and actinomycetes and count the population of each.
- Molds were examined according to the "Soil Environment Analysis Method."
- Denitrifying bacteria and nitrate-reducing bacteria were cultured on Giltay media in accordance with "Sewage Examination Methods 9-2" and counted by the Most Probable Number method (five-tube method). If the pH of the sample turned alkaline, nitrate-reducing bacteria were judged to be present; samples that produced bubbles in a Durham tube were determined to contain denitrifying bacteria.
- Sulfate-reducing bacteria were cultured on semisolid Postgate's E media according to "Sewage Examination Methods 12-1" and counted by the Most Probable Number method (five-tube method). If the medium turned black due to the formation of iron sulfide, the sample was judged positive for the presence of sulfate-reducing bacteria.

3.2.2 Results

The total numbers of soil microorganisms detected in the incubation tests are shown in Table 2. There were few sulfate-reducing bacteria and anaerobic heterotrophic soil microorganisms under the permeable pavement, which indicates that the pavement provides an aerobic environment within the subgrade soil.

Table 2: Incubation test results

Sampled area	Aerobic heterotrophic soil microorganisms	Anaerobic heterotrophic soil microorganisms	Bacteria	Actinomycetes	Molds	Nitrate-reducing bacteria	Denitrifying bacteria	Sulfate-reducing bacteria
Point 1.Permeable(stabilized)	1.04E+5	0	3.55E+4	2.49E+2	2.23E+1	1.93E+4	1.56E+3	0.70
Point 2.Drained(not stabilized)	1.27E+5	2.70E+4	1.93E+4	3.87E+4	2.02E+2	1.09E+4	1.03E+3	1.37E+3
Point 3.Surrounding ground 1 (depth:0.5m)	5.43E+5	2.76E+2	1.22E+5	1.23E+5	3.50E+3	9.47E+5	1.65E+3	1.06E+1
Point 4.Permeable(not stabilized)	1.56E+4	4.03E+1	8.23E+2	1.11E+4	1.80E+2	3.07E+1	2.50	4.74E+1
Point 5.Drained(stabilized)	7.70	0	0	0	0	3.90	0	2.30
Point 6.Surrounding ground 2 (depth:0.35m)	2.37E+6	3.40E+5	4.77E+5	4.53E+5	5.20E+3	8.50E+5	2.57E+4	1.27E+4

The pH values of the soil samples from all observation points and the results of C/N analysis are shown in Table 3. Soil pH has a strong impact on biological activities, but the pH readings obtained from these observation points varied widely from 4.50 to 10.83. The values obtained from the C/N analysis were generally low, which indicated there was little organic matter present. In the samples from which C/N ratio could be obtained, the value was around 11, which can be considered to derive from microorganisms rather than soil organic matter.

Table 3: pH values and the results of C/N analysis

Sampled area	pH	C %	N %	C/N
point 1.Permeable (stabilized)	5.43	0.07	0.00	0.00
point 4.Permeable(not stabilized)	10.67	0.26	0.00	0.00
point 2.Drained(not stabilized)	7.80	0.12	0.00	0.00
point 5.Drained(stabilized)	10.83	0.05	0.00	0.00
point 3.Surrounding ground 1 (depth:0.5m)	4.50	0.16	0.02	10.72
point 6.Surrounding ground 2 (depth:0.35m)	5.13	0.61	0.05	11.68

3.2.3 Evaluation

(1) General Comments

The test results indicate that the permeability function of the permeable pavement causes less impact from isolation of the soil environment than drained pavement despite the fact that the soil is covered by a pavement in both cases. This result suggests that the permeability function of this pavement appropriately delivers required performance.

(2) Reducing the Isolation Impact on the Soil

The number and percentage of anaerobic microorganisms (total of anaerobic heterotrophic soil microorganisms and sulfate-reducing bacteria) were lower under the permeable pavement. This indicates that the soil maintained an aerobic environment. Generally, the rate of mineralization by microorganisms is greater in an aerobic environment than in an anaerobic environment. In addition, odors from hydrogen sulfide and ammonia will be produced in an anaerobic environment, whereas their production will be suppressed in an aerobic environment. We conclude that the permeable pavement, by promoting an aerobic environment rather than anaerobic environment, has a stronger self-purification function and reduced odors than the soil environment under drained pavements.

(3) Providing Organic Matter to the Soil by Permeability Function

The high pH readings obtained from observation points 4 and 5 indicate an unfavorable living environment for microorganisms. However, soil microorganisms were recognized under the permeable pavement (point 4). Although it is difficult to make a valid comparison because there is a difference in the T-C (total carbon) content between point 4 and point 5, the permeable pavement (point 4) appears to provide a better living environment for microorganisms than that under the drained pavement (point 5) through an ability to supply organic matter to the soil. We consider that the higher T-C value of point 4 resulted from the structural features of the permeable pavement. i.e., that organic matter could be provided to the soil even if the surface is covered by a pavement.

(4) Providing Organic Matter to the Soil Under the Road Surface

This may contradict what we discussed under (3) above, except for forest and grassland, in fact, organic matter places no burden on the soil under bare ground or road surface.
Considering the generally very low values of T-C and C/N ratio obtained from the test results, it was difficult to identify any negative environmental impact of this pavement in regard to organic matter mineralization by soil microorganisms. That is, the test results neither proved nor disproved the existence of soil microorganisms beneath the pavement. However, if we assume that there is a source of organic matter, a permeable pavement is likely to maintain aerobic soil conditions and therefore be superior in its ability to provide a better living environment for aerobic microorganisms.

4. CONCLUSION

The test results confirmed that the permeability function of this pavement has persisted for 4 years after construction. The permeability of the pavement provides a favorable environment within the subgrade for soil microorganisms, which indicates a reduced burden on the soil environment.
In conclusion, when constructing a road, it is imperative to assess impacts on the environment in the route selection process. When road construction in an environmentally sensitive area is unavoidable, the use of permeable pavement can be used to mitigate the negative impacts on the environment.