DEVELOPMENT OF A NEW POROUS CONCRETE BLOCK PAVEMENT FOR MOTORWAYS -WHISPER BLOCK PAVEMENT-

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ABSTRACT

Recently, road pavements with water-permeable surfaces have been increasingly used. These porous pavements are adopted from various reasons, such as to ensure the driving safety in rainy weather, to reduce the traffic noise, to recharge ground-water, and to alleviate the heat island phenomena in urban city centers. This study aims to develop a new porous concrete block pavement adaptable for heavier traffic motorways, since concrete block pavements have long been primarily used for walkways and lighter traffic motorways.
In indoor experiments, the durability of various porous concrete blocks against raveling, freezing, thawing, and their surface friction properties were assessed. After examining various sizes of blocks with some different laying patterns, a concrete block having a relatively large size (980 x 980 x 150 mm) was found to be suitable for motorway pavements. A small area in a testing field was paved with these blocks and various tests were conducted by repeatedly running a heavy vehicle on it. The newly developed porous block is thought to be applicable as a surface paving material for motorways.

1. INTRODUCTION

Interlocking blocks were introduced in Japan in the 1970s, while thin concrete plates had been used for a long time before. But these concrete block pavements have been used exclusively for walkways. On the other hand, the Portland cement concrete pavement had been used for motorways, but it has been losing its share after the 1960s. Nowadays, the share of concrete pavements in Japan is only 6% [1].

There are various reasons why the concrete pavement is not so much adopted in Japan. The major reasons are thought to be as follow [1]:

(1) The initial cost is higher than an asphalt pavement;
(2) The construction speed is relatively slow;
(3) It can not be opened to the public during the curing period; and

(4) The rehabilitation is not easy once it is deteriorated.

But the evaluation towards concrete pavement is changing, because of the depletion of crude oil resources and also from the requirements for a longer life span of the infrastructure.

In this research, we had thought that the porous concrete block pavements might overcome the above mentioned drawbacks of the conventional concrete pavements and aimed to develop a new porous concrete block pavement adaptable for heavy-load field, such as motorways, and apron and/or turning circle in airfields. The reasons for considering the use of porous concrete block pavements are as follow:

(1) There are various attempts to introduce the life-cycle cost assessment even in the pavement field, and the concrete pavements can compete against the asphalt pavements if we considered the total life cycle cost;
(2) The mechanized methods might speed-up the construction;
(3) The precast concrete pavement or concrete block pavements do not require any curing period for its surface materials; and
(4) Simply replacing the deteriorated blocks with brand-new blocks easily restores the block pavements.

2. OBJECTIVES

The specific targets in the study are as follows:

2.1 Adoption to Heavy-Load Fields

Concrete block pavements have been exclusively used for lighter-load fields such as walkways or light traffic roads in Japan. In this research, the present target is to develop a new porous concrete block pavement applicable to motorways with heavier traffic, but the future target might include other heavy-load fields such as aprons or turning circles in airfields, and pavements in the ports.

2.2 Applying Porous Concrete for the Surface Material

In order to ensure the driving safety during rainy weather, to reduce the traffic noise, and to alleviate the thermal load which causes the heat island phenomena, the surface layer of the pavement and the base course should be porous and water-permeable. These requirements are also important to compete against the porous asphalt pavements that are much adopted nowadays especially in the metropolitan areas and in the expressways.

2.3 Using Various Waste Material from Various Industries

Environmental awareness is one of the very important issues in the infrastructure construction, and now the right-of-way is expected as the space to "entomb" the various waste materials from various kinds of industries. In the study, the usage of the oxidized

slag, the LD steel slag, and some other materials will be examined as materials for making the blocks or in the base course or in the subgrade.

2.4 Considering Mechanized Construction Methods

For use in heavy-load fields, the block should be much thicker and heavier, and it would be difficult to manually spread those blocks. A mechanized construction method should solve this problem, and it will also help to reduce the construction period.

2.5 Establishing the Design Method

Any new paving technologies can not be widely used without establishing rational design standards. So, the development of the new porous concrete block pavement should include the examination of the design methods. The design methods should not just follow the conventional asphalt pavement's empirical design method, but it is ideal to develop a more rational design procedure specifically for the new block.

3. DEVELOPMENT OF A NEW CONCRETE BLOCK

3.1 Block Thickness

From literature, thickness of the concrete blocks (or precast concrete plates) in the heavy-load fields were found to be within the range of 80 [2] to 150 mm [3]. In this research, the tentative thickness of the block was decided as 120, 150, and 180 mm, and various concrete blocks were made for the indoor experiments, changing their thickness and joint shapes. The basic size of each block was taken as 300 x 150 x t (mm), here, t is the thickness of a block.

3.2 Indoor Loading Tests

Various sizes of blocks were paved in a test pit (2.0 m x 2.0 m square shape) of the laboratory with different laying patterns, and loading tests were conducted to get the load vs. surface deflection relations and the load vs. strain (in each layer) relations as a pilot study. The outline of indoor loading tests is shown in Table 1.

3.3 Design Method

Various design methods had been adopted for the concrete block and/or precast pavements. These design methods are classified into two categories: empirical ones and theoretical ones. The typical empirical design method adopts TA design method for an ordinary asphalt pavement.

Through analyzing the pilot study results, a design method based on the multi layer elastic theory [4, 5] was examined. The ELSA (Elastic Layers System Analysis) [6], a free software for analyzing multi layer elastic theory, was used to analyze the test results.

Table 1 Outline of the Tested Block Pavements in the Pilot Study

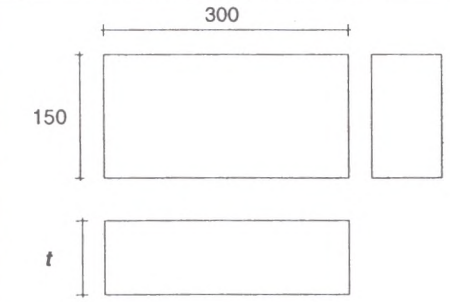
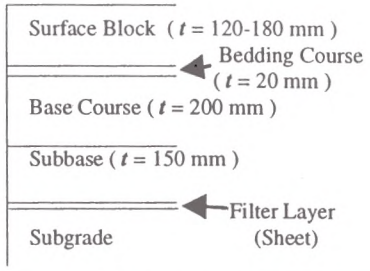
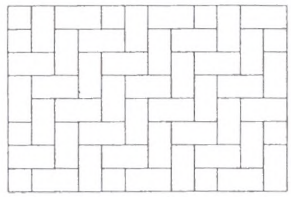
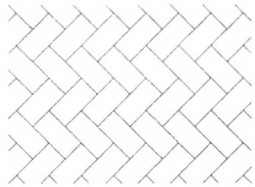
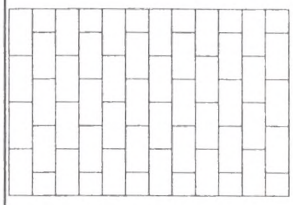
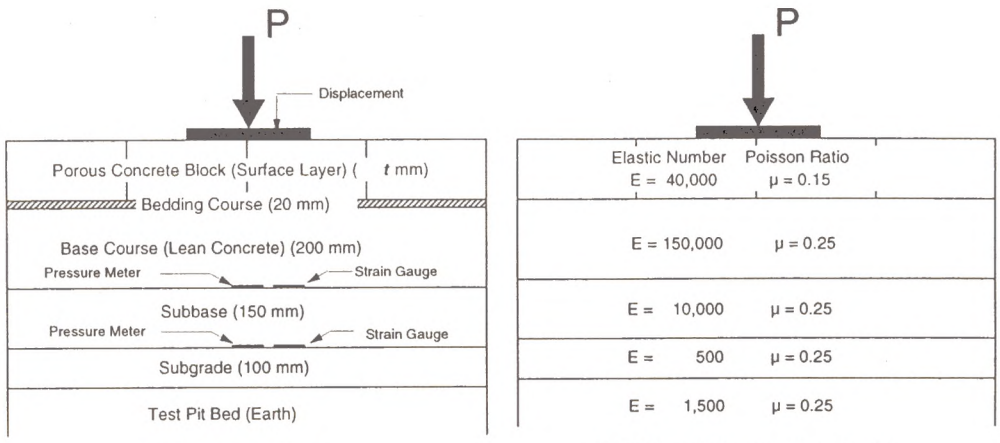
Pavement Structure	Basic Shape of the Block		Layer Structure		
					
Thickness *t* (mm)	120		150		180
Joint Shape	Round Shape		 Wedge (V) Shape		
Laying Pattern	Herringbone Bond (90°)		Herringbone Bond (45°)		Stretcher Bond
					
Concrete Mixture and Its Properties	Used Wasted Material (Replace Sand or Crashed Stone)		Crushed Wasted China	Glass Cullet	Steel Slag
	W/C Ratio		25 %		
	Wasted Material (kg/m^3)		1252	1318	1134
	Fine Sand (kg/m^3)		0	414	0
	Crushed Stone (kg/m^3)		348	0	378
	Bending Strength (N/mm^2)		4.5	4.2	4.2
	Coefficient of Permeability (cm/s)		1×10^{-1}	2×10^{-2}	2×10^{-2}

Table 2 shows a comparison between the measured results and the analysis of the results. The analyzed values were drawn from iteration through changing each layer's elastic number by trial-and-error. These displacement, stress and strain showed more or less the same values. The schematics of the loading test and the assumed material properties in the multi layer elastic analysis are shown in Figure 1.

Table 2 Comparison between Test Results and Analysis

	Displacement (mm) (Loading Position)			Stress σ_z (kgf/cm^2)		Strain ε_r (μm)	
	Concrete Block Surface	Base Course Surface	Subgrade Surface	Base Course Surface	Subgrade Surface	Base Course Surface	Subgrade Surface
Measured	0.25	0.3	0.8	0.5	0.2	45	30
Analyzed	0.26	0.31	1.1	0.52	0.22	45	70



(a) Loading Test (b) Elastic Layer Analysis

Figure 1 Pavement Structure in the Pilot Tests and the Analyses

The multi layer elastic theory was deemed to be adaptable for designing concrete block pavements in the pilot study. While one of our initial objectives was to develop a simple nomogram based design chart [7] applicable for concrete blocks, the decided size for the block, after the pilot study, was rather bigger. Therefore, further examination such as the use of FEM analysis [3] or other theoretical evaluation methods will be required to be able to establish a rational design method.

3.4 Block Size and Shape

From the results of the pilot study, in terms of the stress distribution, the 150 mm thick pavement seemed to have an advantage over the 120 mm thick one. On the other hand, there was not a big difference between 150 mm and 180 mm thick pavements in terms of the stress distribution. Based on these results, 150 mm was chosen as the ideal thickness for the pavement block under heavy load conditions.

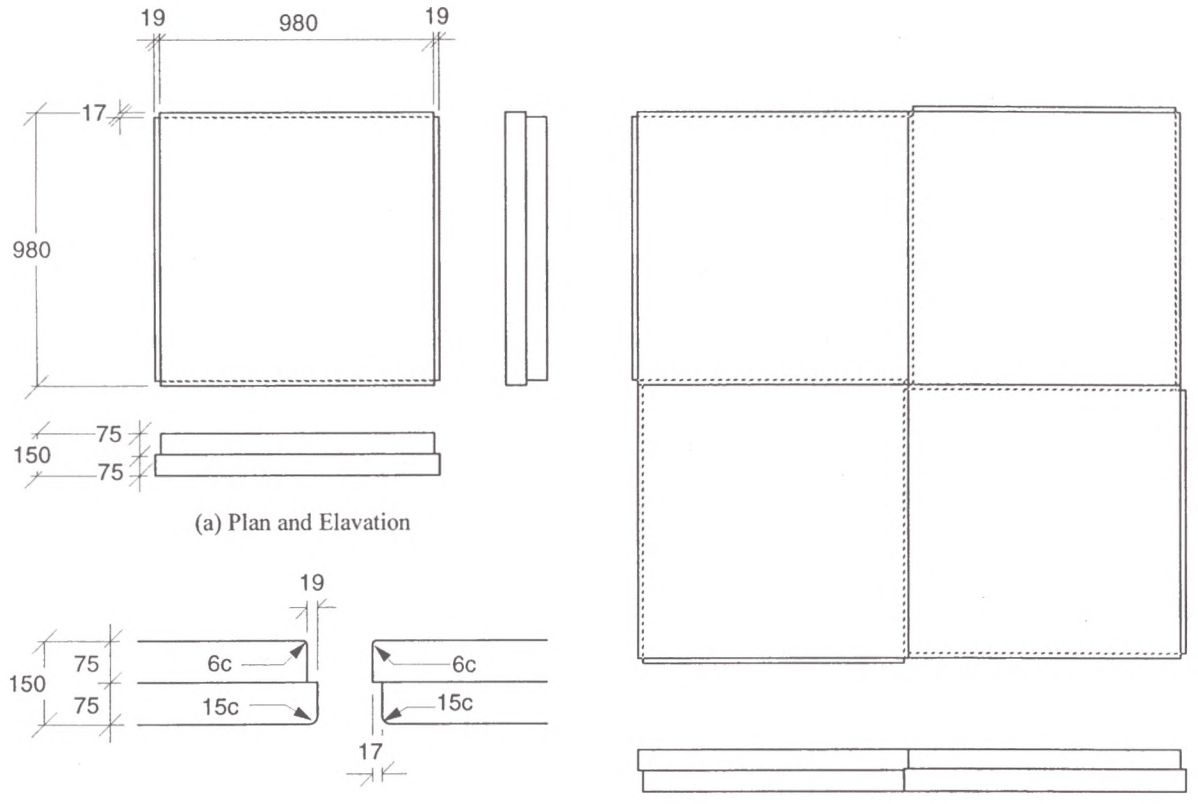
Initially, the shape of the block was planned to be rectangular with a 300 mm by 150-mm size. However, manual handling of a 150-mm block is too difficult because of its weight. Hence, some special block laying methods were examined, by using a special attachment, the group of the blocks would be laid together using a machine. Finally, a concrete block having a relatively large size (980 x 980 x 150 mm) was found to be suitable for motorway pavements, specially, in terms of construction efficiency. Figure 2 shows the size and shape of a newly developed porous concrete block in this research. Every edge of the block was designed to have a 'step' to transmit the load to the adjacent block.

4 PROPERTIES OF THE NEWLY DEVELOPED BLOCK PAVEMENT

4.1 Pavement Structure and Material Properties

A pavement structure was designed applying the newly developed porous concrete block. Some types of slug and wasted Portland cement concrete and asphalt concrete

material were used in the subgrade and subbase course. For the surface of the porous concrete blocks, oxidized steel slug from the electric ferro-furnace industries was selected as wasted material mixture. The oxidized steel slug is heavy (the specific gravity under oven dry conditions was 3.70 g/cm^3) and hard (the hardness ranged between 600 to 1300 HV).



(a) Plan and Elavation

(b) Detail of Edge Desgin

(c) Laying Pattern

Figure 2 Schematics of the Developed Porous Concrete Block Pavement

The 3.5-m wide and 11.0-m long area in a testing field was paved with these blocks and various tests were conducted by repeatedly running a heavy vehicle on it. Table 3 shows the test results as well as the pavement structure design and the material properties.

4.2 FWD and Plate Bearing Test Results

Loading test using FWD and plate bearing test were conducted to the above mentioned pavement structure. Back calculations had applied on the FWD test results to get the material properties such as elastic number or Poisson ratio of each layers, but the results were deemed to be unrealistic. The back calculation methods should be re-examined. The plate bearing test results have not been well examined at this moment. The decided block size was much bigger than in the pilot test, the design method should be re-examined. The multi layer elastic theory is thought to be no more feasible, since the block size is bigger than ordinal concrete block pavements, and other methods such as FEM analysis might be introduced.

Table 3 Properties of the Developed Block Pavement (Design and Test Results)

Subgrade	Present Design CBR	1.0 %					
	Mixtures for Improvement	105.0 kgf/m^3 (Soil Hardening Mixture and Oxidized Steel Slug)					
	Design CBR	15.5 kgf/cm^2					
	Unconfined Compression	5.3 kgf/cm^2					
	Plate Bearing Strength (σ_3)	20.4 kgf/m^3					
Subbase	Design Mix Proportion	Wasted Concrete =70%, Wasted Asphalt Concrete =30%					
	Degree of Compaction	Density: 1.8 g/cm^3 (Standard Value = 1.859 g/cm^3)					
	Plate Bearing Test (K_{30})	25.6 kgf/m^3					
	In-situ Permeability Test	5.43 sec					
Base Course (Lean Concrete)	Design Mix Proportion (%)	LD Steel Slug (13-5) = 89.7, Slug = 4.6, Cement = 3.8, Water = 1.9					
	Design Compression Strength	40.0 kgf/cm^2 (Age: 3 days), 70.1 kgf/cm^2 (Age: 7 days)					
	In-situ Permeability Test	4.60 sec					
Bedding Course	Unit Content (Unit: kgf/m^3)	Crushed Stone (Size 7) = 1248, Cement = 624, Water = 131, Water Reducing Agent = 6.24					
Surface Concrete Block	Unit Content (Unit: kgf/m^3)	Oxidized Steel Slug = 2116, Cement = 506, Water = 126, Agent = 5.06					
	Bending Strength	Control Limit: 4.33 N/mm^2 (t = 150 mm), 5.09 N/mm^2 (t = 75 mm)					
	Abrasion Loss	Age 7 days =Less than 20 % (Design) 19.0 % (Control Limit)					
	Raveling Test	Age 14 days (-10℃) = less than 2 cm^2 (Design) 1.0 cm^2 (Control Limit)					
	In-situ Permeability Test	4.68 sec					
Test Results	Number of Vehicles Run	0	600	1200	1800	2400	Note
	Roughness	4.92	3.85	3.98	3.35	2.97	Standard Deviation
	Lateral Profile Measurement	0	0	0	0	0	Rutting Depth
	Skid Resistance (BPN)	71/72	75/75	72/76	69/75	68/76	OWP/BWP
	In-situ Permeability Test	4.7/4. 7	4.9/4.9	4.94.8	4.9/4.8	5.0/4.9	(Unit: sec) OWP/BWP

Note: 1) Roughness was measured with a 3m profilometer, and rutting was measured with a lateral profilometer.
2) 'In-situ permeability test' result shows the spent time to discharge 400cc water on the pavement surface.

4.3 Thermal and Noise Property

One of the merits of adopting whatever concrete pavement is its thermal property. Because of its lighter color and higher specific heat, concrete pavement is thought to be able to alleviate the heat island phenomena in urban city centers. To confirm this point, temperature measurements were executed on the developed porous concrete block pavement and the ordinary asphalt pavement. Figure 3 shows the measurement results. The results show that the temperature of the porous concrete block pavement was cooler than the ordinary asphalt pavement, especially, at the inside and bottom of the block.

The noise levels generated on a concrete block pavement are found to be very similar to those generated on the smooth asphalt pavement [8]. As mentioned before, road pavements with water-permeable surfaces have been increasingly used because of their low noise property. To confirm the noise property of the developed porous concrete block, sound level measurements were conducted. The sound levels, which the tire made when the car was driven at various speeds, were measured. The results are shown in Table 4. The sound levels were found to be similar to those of the ordinary asphalt pavement.

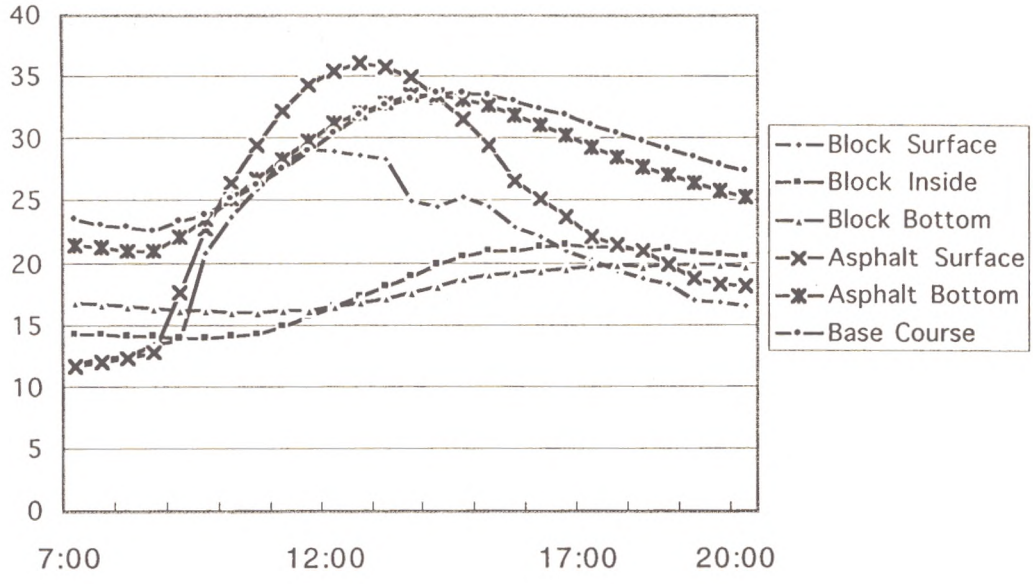


Figure 3 Temperature Measurement Result (Nov. 14, 1999)

Table 4 Sound Level (Tire Noise) Measurement Results

	Speed of the Car		
	20 km/h	30 km/h	40 km/h
Porous Concrete Block	69.3 dB	82.4 dB	86.7 dB
Asphalt Pavement	74.0 dB	82.0 dB	87.0 dB

5. CONCLUDING REMARKS

Followings are the some concluding remarks from the research:

• The porous concrete block pavement might overcome the drawbacks of the cast-in-place concrete pavement, and it should be promoted from the environmental and life cycle cost aspects.

• In this research, various porous concrete block pavements were assessed, and finally, a square shape block having 980 x 980 mm size was found to be suitable for pavements in heavier-load fields.

• Some measurements on the noise and thermal properties of the developed pavement were executed, and it was deemed to have advantages over the ordinary asphalt pavement.

• To confirm whether the developed porous concrete block pavement is feasible in heavier-load fields or not, it should be tested on the actual highway under heavy traffic condition.

• Further study would be required to establish the rational design method.

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