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STUDY ON POROUS CONCRETE USING ORDINARY PORTLAND CEMENT FOR EARLY TRAFFIC OPENING

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In Japan, the use of concrete pavements gradually decreased since the 1960s owing to the fact that they require some days to cure. However, recent research revealed that concrete pavements are effective for the Life Cycle Cost and the heat island phenomenon. A novel method of making concrete pavements, with which the traffic can be opened after only one-day curing, has been proposed in Japan. Furthermore, authors have developed porous concrete for road pavement, which can also cure in one day. This study proposes a new design method to reduce the production cost of porous concrete. To achieve this, the high early-strength Portland cement was replaced with ordinary Portland cement and coarse aggregate of various sizes with a single-sized coarse aggregate. Various tests revealed that the concrete prepared by the proposed design method satisfies the standard values of the bending strength and the permeability coefficient for concrete pavement for early traffic opening. Therefore, it is considered that the design method proposed herein is vital in reducing the cost of porous concrete pavements.

Keywords: Cost reduction, Pavement concrete, Single-sized coarse aggregate, Bending strength, Permeability coefficient.

1 INTRODUCTION

Asphalt pavements are widely used in Japan owing to their ease of construction at a low initial cost. On the other hand, concrete pavements were also used until the 1960s, when their applications started to decline gradually because they require some days to cure before the traffic could be opened. Figure 1 shows the transition of road pavement constructions in Japan (Japan Road Association 2012). The application of concrete pavements has reduced drastically since the 1980s. However, recent research revealed that concrete pavements are effective for the Life Cycle Cost and the heat island phenomenon. A novel method of making concrete pavements that cure for only one day has been proposed in Japan. Furthermore, authors have developed porous concretes for road pavements. Using the high-early-strength Portland cement has made the porous concrete to undergo the one-day curing. The purpose of this study is to develop a novel design method to reduce the cost of porous concrete. For the cost reduction, the high-early-strength

Portland cement was replaced with ordinary Portland cement, and the coarse aggregates of various sizes were replaced with those of a single size to aid the ease of design and production of the porous concrete. The effects of these changes on the porous concrete were investigated.

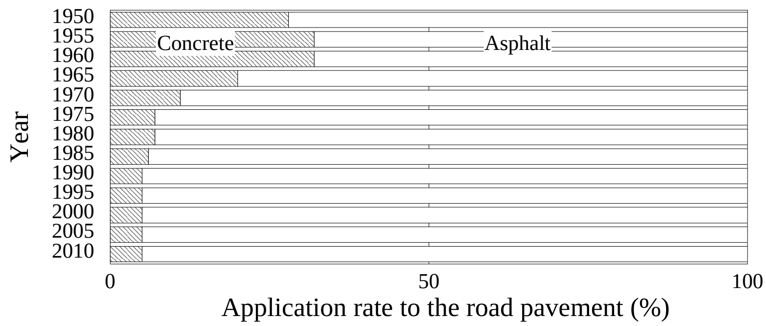


Figure 1. Transition of road pavement construction in Japan.

2 AUTHORS' PAST STUDY

The concrete developed in authors' previous study requires its performance to satisfy the standard for bending strength and the targeted permeability coefficient. The standard value of the bending strength after one-day curing is 3.5 N/mm^2 and the targeted permeability coefficient is 0.01 cm/s (Japan Road Association 2007, Japan Cement Association 2016). Table 1 lists the materials used in authors' previous study and Table 2 also shows the mixture proportion. With this mixing proportion, bending strength of 4.13 N/mm^2 and a permeability coefficient of 0.479 cm/s were obtained after the one-day curing. The concrete was used for a parking lot and trial construction of road pavements for heavy vehicles (Yamakado *et al.* 2018, Yamakado *et al.* 2019). Satisfactory results were recorded for the parking lot and the trial construction.

Table 1. Materials used in authors' past study.

Material	**Type**	**Particle size**
Cement	High-early-strength Portland cement (HPC)	-
Water	Tap water (W)	-
Fine aggregate	Crushed stone (S)	3–6 mm
Coarse aggregate	Crushed stone (G)	6–13 mm
Chemical admixture	Air entraining and high-range water reducing agent (AE)	-

Table 2. Mixture proportion used in authors' past study.

Unit weight (kg/m^3)				
W	**HPC**	**S**	**G**	**AE**
107	430	632	1191	1.505

3 COST OF CONVENTIONAL CONCRETE

Table 3 lists the prices of fresh concrete classified according to the types of cement used (Yamaguchi Pref. 2018). Fresh concretes made of ordinary Portland cement have low cost compared to those made with high-early-strength Portland cement. Consequently, the porous concrete prepared in our previous study was a bit costly as high-early-strength Portland cement was used, as shown in Table 1. Moreover, Table 4 shows the prices of crushed stones, which are the same regardless of the particle size.

For these reasons, it was crucial to change the type of cement to reduce the production cost of porous concrete. On the other hand, the particle size of the crushed stone does not affect the production cost of the porous concrete. However, the construction of porous concrete pavements is difficult compared to other concrete and asphalt pavements. Therefore, it is expected that using the single-sized crushed stone would enhance the ease of the preparation of the materials and the mixing proportion and would help in the construction of the porous concrete pavement while reducing production cost.

To reduce the cost and for easier work, we replaced the high-early-strength Portland cement with ordinary Portland cement and the coarse aggregate of various sizes with that of a single size.

Table 3. Prices examples of fresh concrete in Yamaguchi prefecture.

Cement	Strength (N/mm^2)	Slump (cm)	Price (JPY)
Ordinary Portland cement	30	8	16850 (160 USD)
High early strength Portland cement	30	8	17350 (165 USD)

Table 4. Price examples of crushed stones.

	Particle size (mm)	Price (JPY/ton)
Crushed stone	3–6	2300
	6–13	
	13–23	
	20–40	

4 EXPERIMENTAL OVERVIEW

4.1 Mixing Condition and Curing

Table 5 compares the materials used in our previous study with those used herein. Table 6 shows the mixture proportion employed herein. Density of the ordinary Portland cement was 3.15 g/cm^3 and that of the aggregate in the saturated surface-dry condition was 2.76 g/cm^3. The targeted porosity in Table 6 was set to satisfy the targeted permeability coefficient obtained in our previous study. Two types of specimen were prepared for tests; a cylindrical specimen (φ100 × 200 mm) for the permeability test and a prismatic specimen (150 × 150 × 530 mm) for the bending test. The specimens were cured using the aerial curing method to consider the actual construction field.

Table 5. Comparison of the materials used in the previous study and those used in this study.

Material	Past study	This study
Cement	HPC	Ordinary Portland cement (OPC)
Fine aggregate	Particle size: 3–6 mm	-
Coarse aggregate	Particle size: 6–13 mm	Particle size: 3–6 mm (G)

Table 6. Mixture proportion used in this study.

Unit weight (kg/m^3)				
W	**OPC**	**G**	**AE**	**Targeted porosity**
107	430	1673	1.505	15%

Moreover, applying aerial curing enabled us to investigate the influences of the season or air temperature during the casting and curing.

4.2 Constant-Head Permeability Test

The constant-head permeability test was performed on the cylindrical specimens (Figure 2(a)) to verify whether they satisfy the targeted permeability coefficient. The flow volume from the outflow port and the time were measured when the water level above the tester was kept constant. The permeability coefficient was calculated by Eq. (1).

$$k = \frac{Ql}{Aht} \tag{1}$$

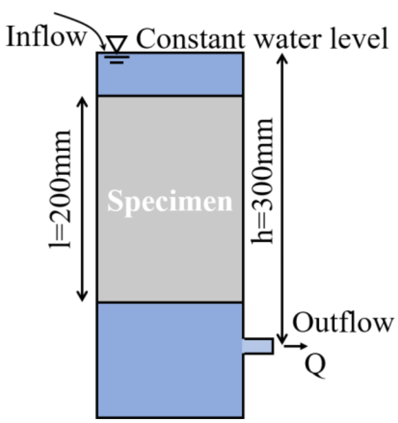
where k is the constant permeability coefficient, Q the flow volume, l the specimen height, A the specimen section area, h the water level difference, and t the measuring time

4.3 Bending Strength Test

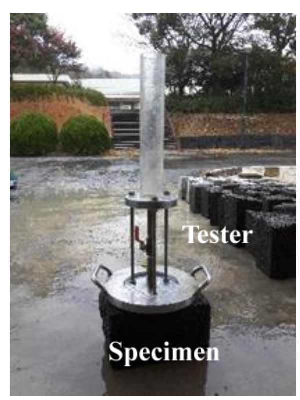
The bending test was performed, adhering to the Japanese Industrial Standards for concrete bending tests. The curing time (material age) of the samples for the bending test was set to 1, 3, and 28 days in the formwork. The bending strength of the specimens was compared with the standard value after one-day curing under the new mixing condition.

4.4 Falling-Head Permeability Test

This test was performed to find the relation between the permeability coefficient and the bending strength. Therefore, the broken specimens from the bending test were used. The conditions of this test using the tester and the specimen are shown in Figure 2(b). However, it should be noted that the permeability coefficient obtained from this test might not be the real value. The permeability coefficient obtained in Figure 2(a) was calculated from the flow in only the vertical direction, whereas that obtained in this test was derived from the flow in all directions. Therefore, the permeability coefficient in this test could be an overestimation. However, since the large or small relation of this coefficient could be evaluated, the coefficient was used only to derive the relationship with the bending strength.



(a) Diagram of constant-head permeability test.



(b) Falling-head permeability test.

Figure 2. Conditions of each permeability test in this study.

5 RESULTS AND DISCUSSION

5.1 Results of the Constant-Head Permeability Test

Figure 3 shows the results of the constant-head permeability test. The values in the figure are related to the porosity of the specimens. All the samples satisfy the targeted permeability coefficient, which is 0.01 cm/s, even at porosities less than 15%. Generally, because the strength of porous concretes increases as the porosity decreases, designing for smaller targeted porosities under this mix proportion could yield concrete with high strength and adequate permeability coefficient.

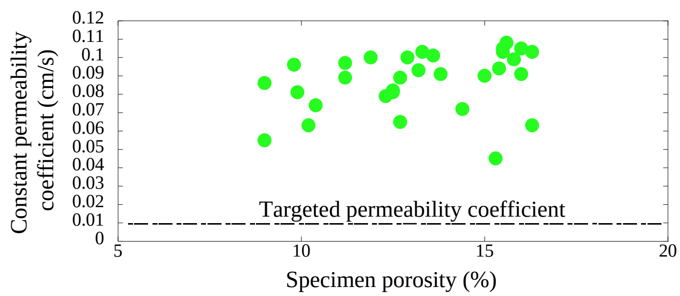


Figure 3. Constant permeability coefficient and specimen porosity relation.

5.2 Effects of Seasons or Air Temperature on the Bending Strength

Figure 4 shows the bending test results for the specimens cured in one day. The values in the figure are the average values for three specimens and are related to the atmospheric temperature during casting. All the obtained values satisfy the standard strength for one-day curing, which is 3.5 N/mm^2, hence, the porous concrete could be subjected to the early traffic opening as a one-day concrete pavement. The strengths at the air temperatures during the casting were 4.35, 3.53, and 3.60 N/mm^2 at 9.8 °C, 24.6 °C, and 31.2 °C, respectively. In general, the early-strength of concretes increases at higher air temperatures.

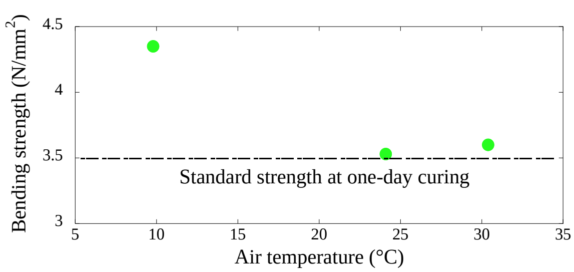


Figure 4. Bending strength and air temperature at the casting relation.

However, herein, the strength at the lowest air temperature was the highest. It shows the level of skill of the person making porous concretes contribute to their properties. The first specimens were prepared in May and the final specimens in December. The average temperature for the specimens prepared in May and December were 22 °C and 10 °C, respectively. The average strengths were high even though the air temperatures were low. This is because our level of skill in making specimens was improved when we made the specimens at 9.8 °C. It was found that although all the average strengths satisfied the standard strength for one-day curing, the reproducibility of specimens depended on our skill in making concrete samples.

5.3 Relationship between the Bending Strength and the Falling-Head Permeability Coefficient

Figure 5 shows the relationship between the bending strength and the permeability coefficient obtained from the falling-head permeability test. The bending strengths decrease with increasing permeability coefficients and increases with the passing material age period. Moreover, almost all the specimens cured for three days satisfied the Japan standard for bending strength of pavement concretes at 28 days (4.5 N/mm^2). These results show that the bending strength of the porous concretes was found to be dependent on the permeability coefficient and the age period.

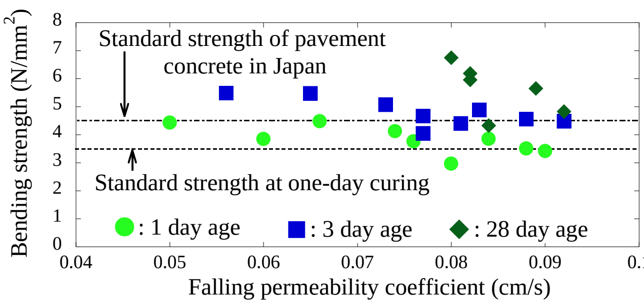


Figure 5. Bending strength and falling permeability coefficient.

6 CONCLUSIONS

In this study, the bending strength at early curing and the permeability coefficient of porous concrete prepared using ordinary Portland cement and single-sized coarse aggregate were investigated. From the obtained results, the following conclusions are drawn: (i) making porous concrete depends on the person's skill level; (ii) the bending strength and the permeability coefficient of the porous concrete prepared in this study satisfy the standard values; (iii) the bending strength after three days of age satisfies the design strength of pavement concrete at 28 days. Therefore, although the method employed in this study depends on the person's skill, it is effective for cost reduction and easy design of porous concrete.

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