Evaluation of Porous Concrete Pavements in Japan

Yoshiki MURATA[1], Tatsuo NISHIZAWA[2], Katsuro KOKUBU[3]

Abstract

Porous concrete pavements were applied on a trial basis at three points on prefectural roads in Fukui, Japan. The objective was to verify their durability and serviceability as well as their behavior in snow and cold regions. Investigations were made continuously to check their serviceability and durability with lasting performance. The major parameters investigated included pavement smoothness, skid resistance, rutting and difference in elevation at the joint. Such parameters as permeability and low noise level were unique to porous concrete pavements.

This paper describes the results of a follow-up survey during the three-year period since the commencement of service. The surface properties, in-situ permeability and noise level of the porous concrete pavements remained nearly unchanged from the conditions upon completion although deterioration was observed in some sections. Thus, porous concrete pavements were determined to be fully applicable to snow and cold regions.

Introduction

In recent road pavement work, porous pavement materials with continuous voids have been used because there is a strong demand for vehicle safety and the preservation of the environment around the road. To meet the social demand for highly durable and long-lived pavements, expectations are placed on porous concrete pavements.

The Committee on Pavement of Japan Cement Association has been developing porous concrete pavements since 1997. Porous concrete was short of ensuring a strength exceeding 4.5 MPa as ordinary concrete. We showed that it has recently become possible to enable porous concrete to achieve the goal by using either organic or inorganic high strength admixtures and superplasticizers.

We have been constructing porous pavements on actual roads on a trial basis since 1999 to confirm whether porous concrete pavements function satisfactorily as roadway pavements. We have also been making follow-up researches to check the serviceability and durability with lasting performance of porous concrete pavements. The major parameters investigated included pavement smoothness, skid resistance, rutting and difference in elevation at the joint. Such parameters as permeability and

[1] 4-17-33 Toshima, Kita-ku, Tokyo, Japan Cement Association, 117-0003, email:yoshiki-murata@jcassoc.or.jp

[2] Professor, Civil Engineering Course, Doctor of Engineering, Kitacyujo, Tsubata, Kahoku-gun, Ishikawa, Ishikawa National College of Technology, 929-0392, email:nishi@ishikawa-nct.ac.jp / tatsunishi@aol.com

[3] Professor, Civil and Environmental Eng. Course, Faculty of Urban Environmental Sciences, Doctor of Engineering, Minami-Osawa 1-1, Hachioji, Tokyo, Tokyo Metropolitan University, 192-0397 email:kokubu@ecomp.metro-u.ac.jp

low noise level were unique to porous concrete pavements. This paper presents the results of follow-up researches conducted on prefectural roads in Fukui in the Hokuriku district for three years after the commencement of service. The objective was to verify the applicability of porous concrete pavements to snow and cold regions.

Pavement Outline

Plan of pavement. To verify the applicability and durability with lasting performance of porous concrete pavements in snow and cold regions, such pavements were applied on opposing lanes in three different routes in Fukui prefecture in November 1999. The pavements were installed in the Ryoke-Kawawada route (Imadate below), Saraya-Ohno route (Ohno below) and Imajo-Sugizu route (Imajo below) on ordinary prefectural roads in a heavy snowfall area. The length was 80 m (two 40-m sections) in Imadate and 50 m each at the other sites. Imadate and Ohno each carried a traffic volume of 350 large vehicles a day on lanes in opposing directions, and Imajo 163 vehicles (1999 survey results). Figure 1 shows a plan of pavements in Imadate.

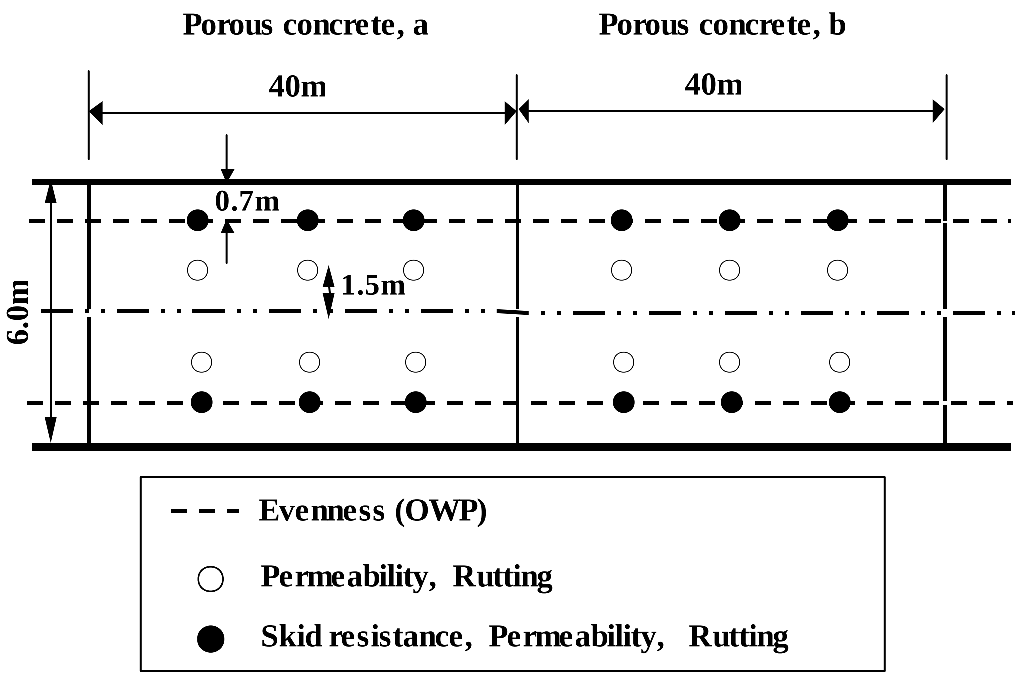

Figure 1.Plan of pavements

Pavement cross section. Figure 2 shows the cross section of pavement. The cross section of pavement had an impermeable asphalt cushion course and a drain pipe for transporting storm water through the porous concrete to the gutter.

The thickness of concrete plate was set at 20 cm based on the design of cross section of ordinary concrete pavements without any wire fabric or roller compacted concrete pavements while assuming a design pavement service life of 20 years, design flexural strength of concrete of 4.5 N/mm^2 and design daily traffic volume of less than 250 vehicles in one direction. It was confirmed in laboratory tests that the fatigue properties of porous concrete were equivalent to those of ordinary concrete.

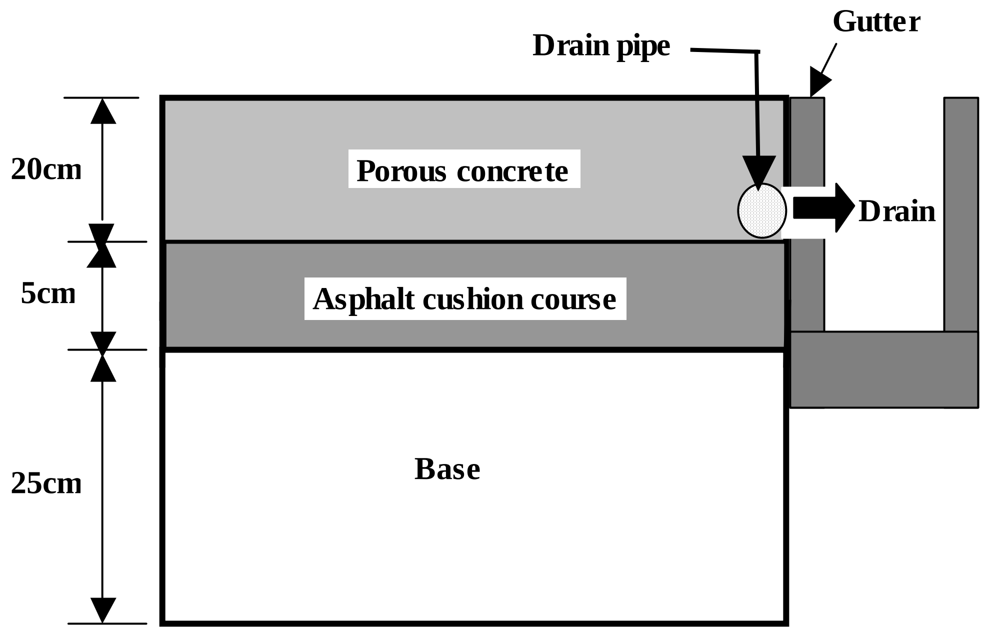

Figure 2.Pavement cross section

Type and mix proportion of porous concrete. Two types of porous concrete that were found most applicable to roadway pavements in laboratory tests were selected. Type *a* incorporated an inorganic special admixture to help develop greater strength, and type *b* was mixed with polymers. The desired percentage of voids was set at 15 to 20% for both types. Mix proportions are listed in Table 1.

Table 1.Mix proportions of porous concrete

Type	Maximum size of coarse aggregate (mm)	Water cemen -titious material ratio	Content of material (kg/m^3)				
			Water	Cement or cemen -titious	Fine aggregate	Coarse aggregate	Special admixture
a	13	0.225	78	346※1	173	1516	—
b	13	0.143	40	280※2	120	1500	80※3

※1 Ordinaly portland cement and cementitious

※2 High-early-strength portland cement ※3 Polymer

Joint structure. Only expansion joints were considered but no vertical construction joints were considered because the lengths of pavements were small, 40 to 50 m. No joints were reinforced as on roller compacted concrete pavements.

The spacing of joints in type *a* was set to be 4 m, shorter than the joint spacing on roller compacted concrete pavements to minimize joint width because no joints were reinforced and because type *a* was sensitive to changes in outdoor temperature. For type *b*, the joint spacing was set at 20 m, half the total length of pavement, because type *b* was polymer concrete with higher deformability.

Construction outline. Concrete was placed using asphalt pavers with high compaction capacity. Saw cut joints were provided two days after concrete placement. Concrete was cured for seven days. For curing type *a*, vinyl sheeting and mat were used to prevent water dissipation. Type *b* was subjected to atmospheric curing to promote the hardening of polymer.

Test outline. Test items and frequency are listed in Table 2. The tests were conducted according to a pavement testing manual prepared by Japan Road Association except flexural strength tests and noise measurement. To measure the noise, the tire/road noise measurement method was used and measurement was made as defined in "Acoustics - Measurement of noise emitted by accelerating road vehicles - Engineering method" in JIS D 1024 (JIS method). The measurement points in Imadate are shown in Figure 1.

Table 2.Major test items and frequency

Test item	Termes
Flexural strength (JIS A 1106)	7, 28days
Evenness (3m Profilometer)	0, 1, 3, 5 years
Skid resistance (DFT)	
Permeability	
Rutting (Cross profilometer)	
Crack	
Noise reduction (identified by JIS D 1024 and tire/road noise measurement)	
Permeability restoration	2, 3years

Results of test

Results of test upon construction completion. Some of the results of the test conducted upon completion of construction are listed in Table 3. The flexural strength of concrete exceeded 80 % (3.67 to 4.62 MPa) of the design strength (4.5 MPa) at seven days. It was found that the pavement could be placed into service after curing for seven days. The percentage of voids in specimens was 17 to 19%.

The smoothness upon construction completion was at 1.75 to 1.93 mm. The smoothness achieved the performance levels (under 2.4 mm) specified in the "technical standards for pavement structure".

The in-situ permeability upon construction completion was at 1,169 to 1,341 ml/15sec. The in-situ permeability achieved the performance levels (over 1,000 ml/15sec) specified in the "technical standards for pavement structure".

As a result of the measurement defined in "Acoustics - Measurement of noise emitted by accelerating road vehicles - Engineering method" in JIS D 1024", the noise level on porous concrete pavements was found to be 3 to 4 dB lower than on dense asphalt pavements adjacent to respective test pavements. As a result of the measurement defined in tire/road noise measurement, the noise level on porous concrete pavements was found to be 0.7 to 2.5 dB lower than on dense asphalt pavements adjacent to respective test pavements.

Table 3.Major results of testing upon construction completion

Construction site	Type	Flexural strength (N/mm^2)		Permeability (ml/15sec)	Skid resistance (40km/h)
		7days	28days		
Ohno	a	4.62	5.00	1,341	0.81
Imadate	a	4.12	4.65	1,169	0.68
	b	3.67	4.78	1,196	0.82
Imajo	a	4.20	4.69	1,302	0.73
Performance standards		—	4.5 over	1,000 over	—

Construction site	Type	Evenness (mm)	Noise reduction (dB) ※1		Noise reduction (dB) ※2	
			Dense asphalt concrete	Porous concrete	Dense asphalt concrete	Porous concrete
Ohno	a	1.93	76.2	73.2	97.2	96.5
Imadate	a	1.75	75.7	71.6	95.1	93.5
	b	1.83		72.2		92.6
Imajo	a	1.87	74.1	71.2	95.2	94.4
Performance standards		2.4 below	—	—	—	—

※ 1 Results of measurement defined in "Acoustics - Measurement of noise emitted by accelerating road vehicles - Engineering method" in JIS D 1024

※ 2 Results of measurement defined in tire/road noise measurement

Smoothness. The results of smoothness tests are shown in Figure 3. The pavement surface was slightly smoother at Ohno than at other sites. Smoothness, however, generally remained nearly unchanged after the commencement of service. This means that neither winter tires nor snow plows damaged the road surface in the first three years after pavement construction. Thus, smoothness upon completion of construction work was maintained.

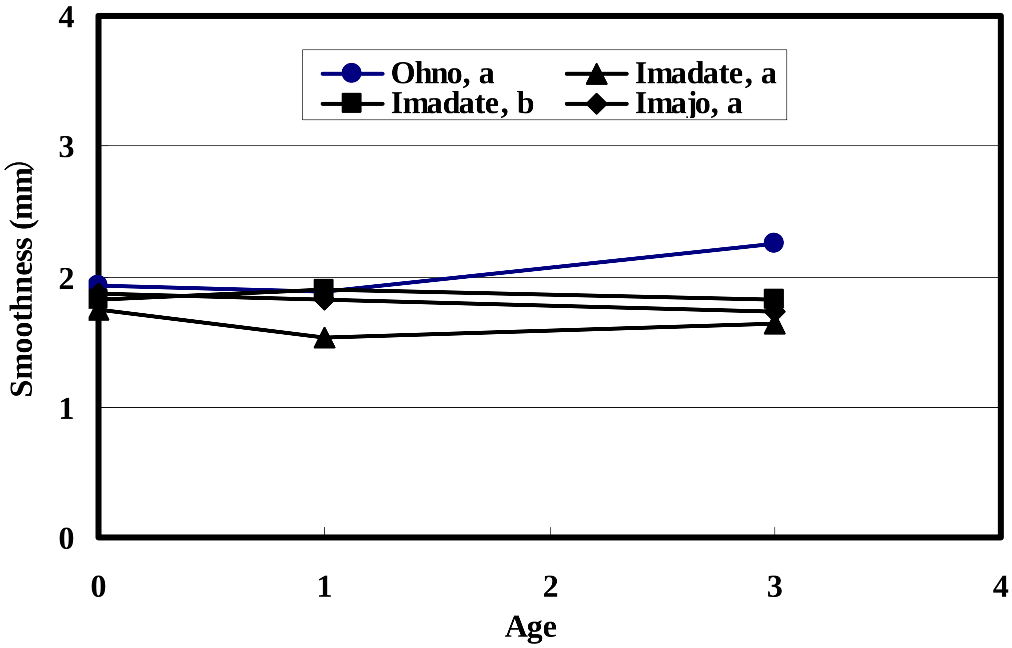

Figure 3. Smoothness

Skid resistance. Figure 4 shows the results of skid resistance tests using Dynamic Friction Tester (DF Tester) at a vehicle speed of 60 km/hr. Skid resistance was great at 0.7 to 0.8 upon construction completion in all cases. At the points with great skid resistance upon completion or within one year of completion, moderate roughness of surface texture induced locally by construction may have been detected by the tester as frictional resistance. Skid resistance was slightly greater one year after construction completion than upon completion at Imadate. Skid resistance was 0.5 to 0.6 at all sites three years after completion. The "road maintenance and repair guidelines" stipulates that roads should be repaired when the skid resistance coefficient reaches 0.25 while a skid resistance test vehicle is traveling at a speed of 60 km/hr. "Safety assessment of road surface" shows a significant correlation between DF Tester and a skid resistance test vehicle. A skid resistance coefficient of 0.25 corresponds to a DF Tester measurement of 0.28. It is assumed that the standard is satisfied until three years pass after the commencement of service.

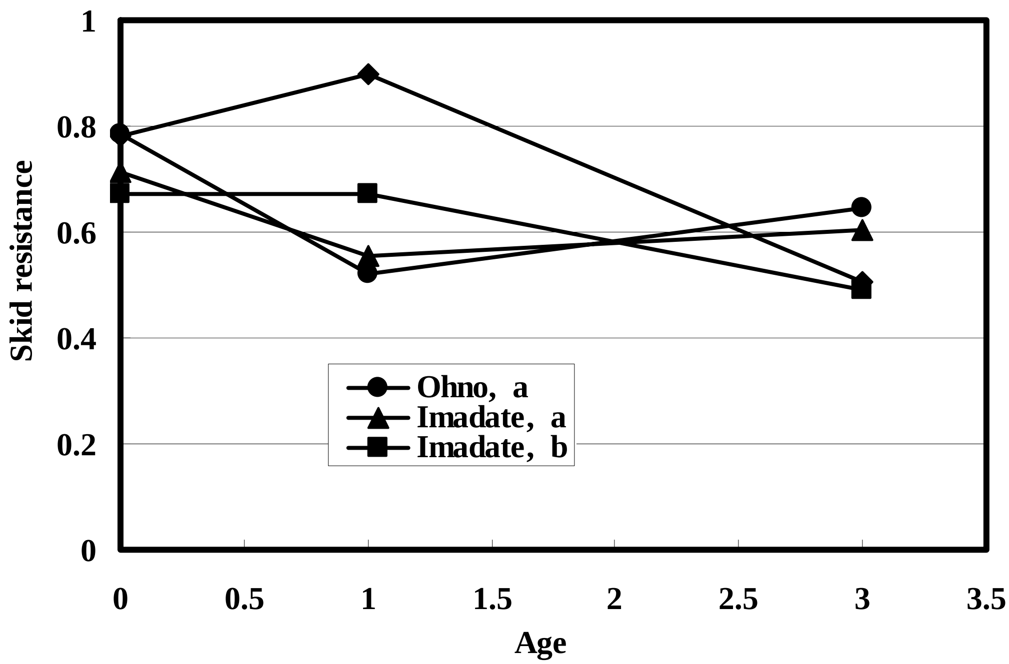

Figure 4. Skid resistance

In-situ permeability. The results of in-situ permeability test at Imadate are shown in Figure 5. No outstanding deterioration was observed either in type *a* or *b* for three years after the pavements were placed into service. Sufficient permeability was maintained.

The results at Ohno and Imajo are shown in Figure 6. Permeability started deteriorating right after the construction. The pavements became nearly impermeable in one to two years after the commencement of service. The passage of agricultural vehicles may have been a cause. Voids may have been filled with soils because there was a borrow pit in the vicinity.

Permeability was restored at the site. The equipment used for restoration was the one developed to jet high pressure water to clear permeable asphalt pavements of soils that filled the voids (jetting pressure: 5 MPa, rate of jetting: 0.34 m^3/min). Permeability at the site was restored to approximately 40 % of that upon completion of construction, much higher than before restoration. The jetting pressure of the equipment for asphalt pavements is fixed at 5 MPa. Further restoration of permeability is expected to be possible on concrete pavements by applying greater jetting pressure.

Rutting. Rutting was only 0.7 to 3.1 mm after three years since the commencement of service. Thus, no problems occurred during the three-year period.

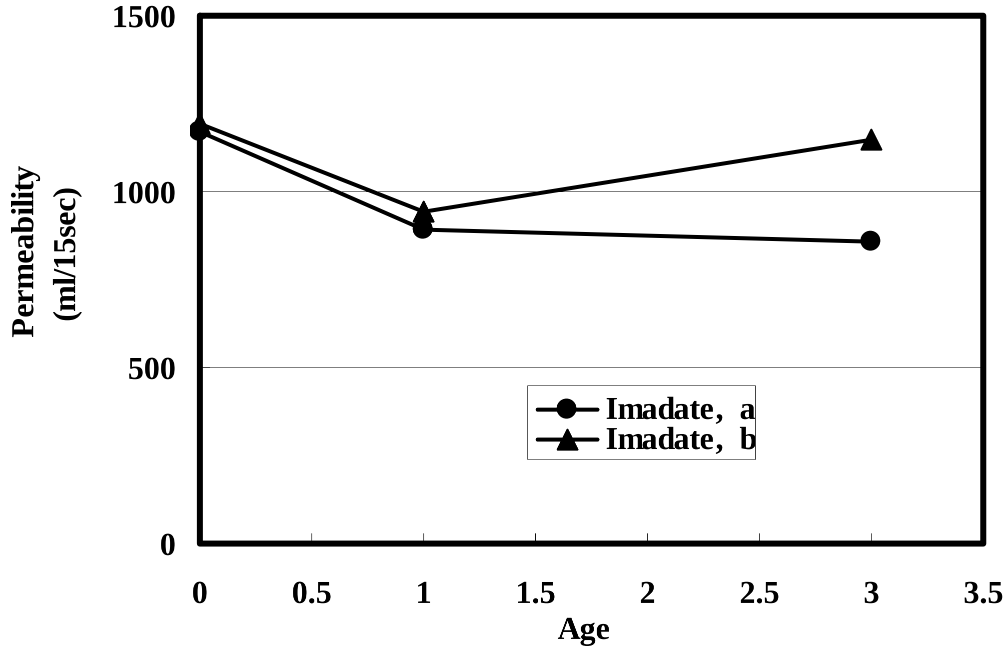

Figure 5. In-situ permeability (Imadate)

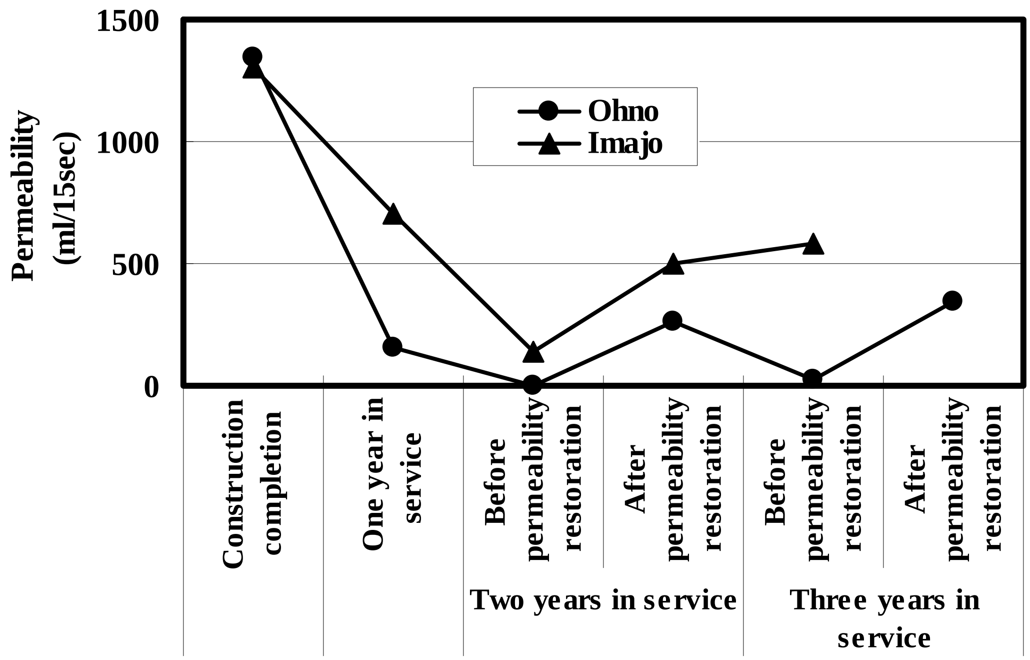

Figure 6. In-situ permeability (Ohno, Imajo)

Noise. The noise levels measured using a method defined in "Acoustics - Measurement of noise emitted by accelerating road vehicles - Engineering method" in JIS D 1024 (JIS method) are shown in Figure 7. The values three years after the commencement of service represent the results before permeability was restored. Measurements on adjacent dense asphalt pavements are also shown in the figure. Noise level was lower on porous pavements than on dense asphalt pavements except at Ohno. The variance was 3 to 4 dB upon completion of construction but decreased to approximately 1 dB three years after the commencement of service.

Figure 8 shows the relationship between in-situ permeability and noise level identified by the JIS method. The noise level was generally higher where permeability was lower although high noise level was obtained despite high permeability in such a place as at Imadate. This indicates that noise level increased after three years of service because of the deterioration of permeability as the voids were filled with soils.

To identify the frequency band in which noise level could be reduced, noise was analyzed in one-third octave bands (Figure 9). Noise generally is a combination of components in various frequency bands. In the analysis in one-third octave bands, noise level is calculated in respective one-third octave bands. As a result of an analysis, it was found that noise level was lower on porous concrete pavements than on dense asphalt concrete pavements in frequency bands higher than 800 Hz to 1000 Hz. Thus, porous concrete was found to be effective for reducing noise level in higher frequency bands.

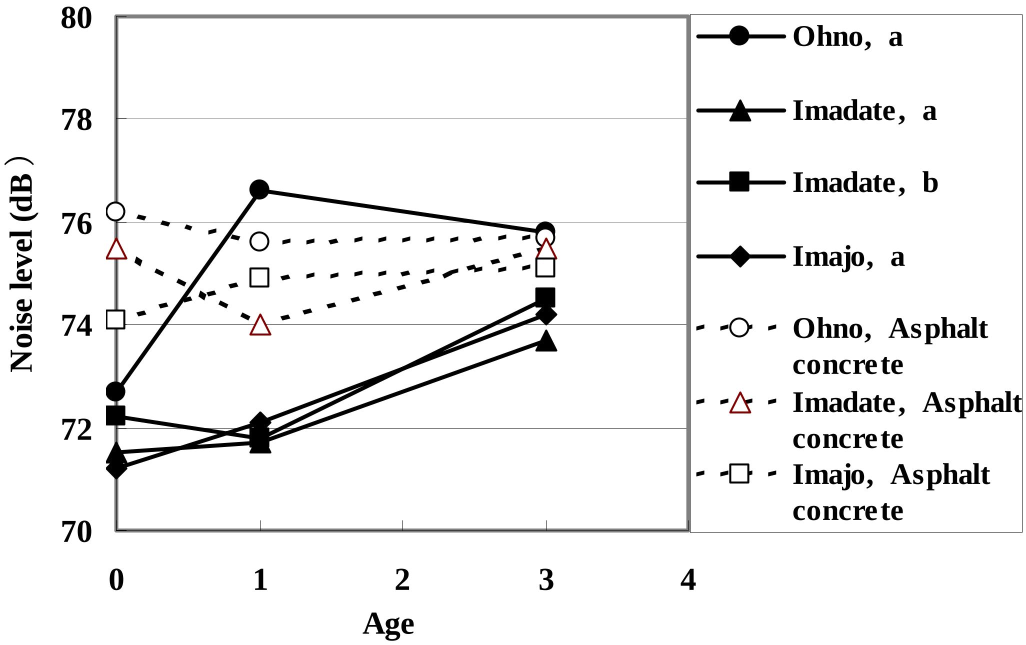

Figure 7. Noise levels identified by JIS method

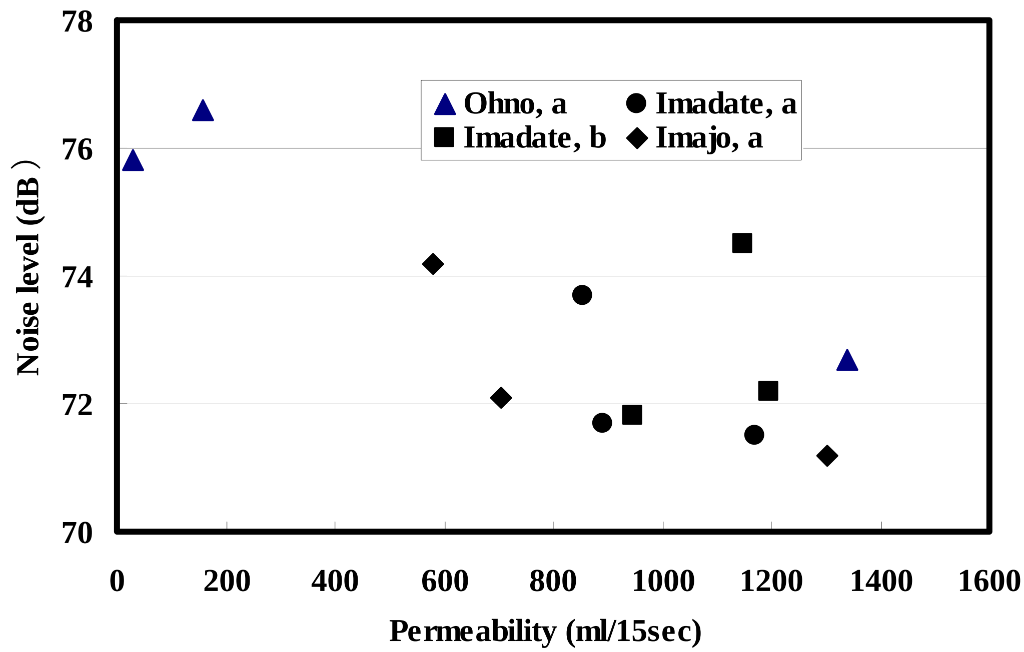

Figure 8. In-situ permeability and the measurement by JIS method

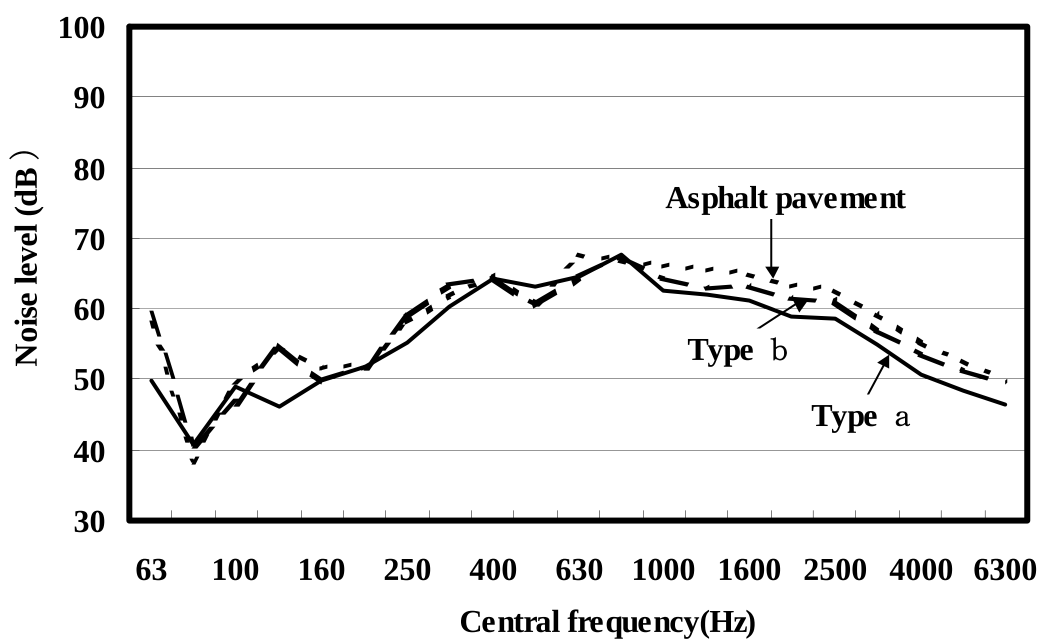

Figure 9. Results of noise analysis in one-third octave bands (Imadate)

Cracking. Cracking was observed on type *a* at Imajo and on type *b* at Imadate. Cracking was observed at two points between vertical and horizontal joints in the early stages of service at Imajo (Figure 10). It is ascribable to poor curing during construction in a cold area.

In Imadate, a crack crossed the pavement transversely to the other end three years after the commencement of service (Figure 11). The crack width was 0.2 to 0.4 mm, small enough to allow the passage of vehicles. The crack occurred probably because joints were placed at spacings of long 20 m on type *b*, which was polymer concrete with higher extensibility than ordinary concrete. This means cracking can be prevented by modifying the design joint spacing.

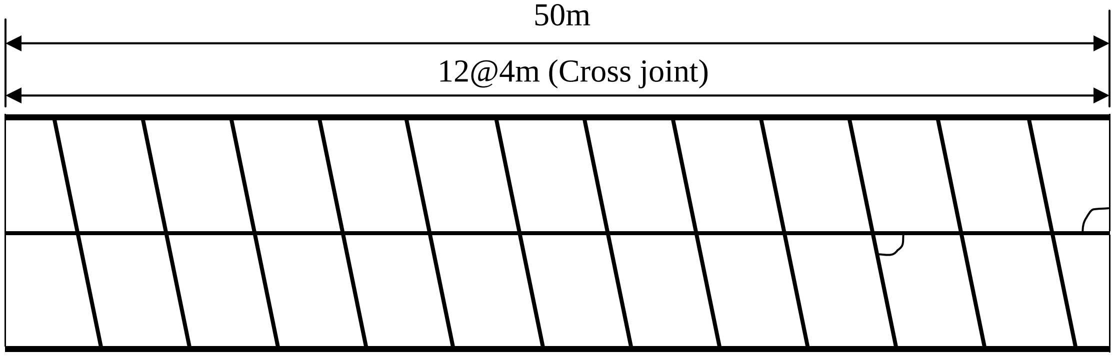

Figure 10. Cracking three years after the commencement of service (type *a* at Imajo)

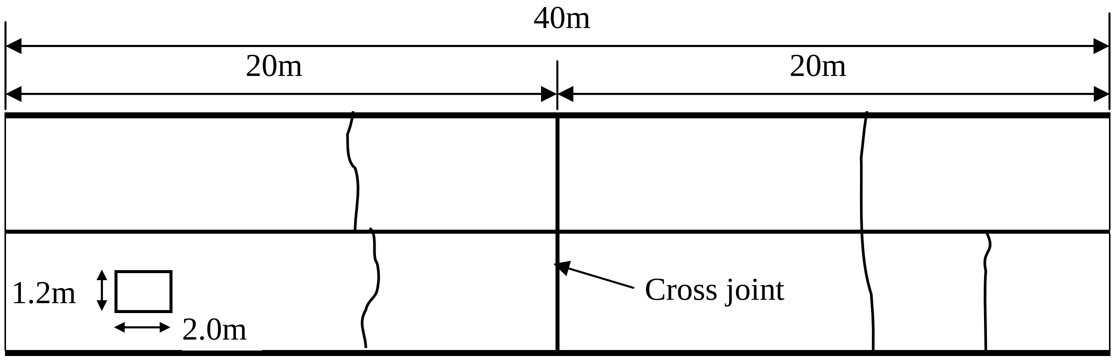

Figure 11. Cracking three years after the commencement of service (type *b* at Imadate)

Conclusions

The following findings were obtained concerning the porous concrete pavements constructed in Fukui Prefecture in 1999.

(1) The concrete pavements could be opened to traffic after seven days of curing even under winter construction conditions.

(2) The concrete pavements satisfied the technical standards for pavement structure.
(3) The concrete pavements were highly permeable and noise levels were low.
(4) Neither winter tires nor snow plows caused any damage to the pavements.

The surface properties, in-situ permeability and noise level of the porous concrete pavements remained nearly unchanged from the conditions upon completion of construction although deterioration was observed in some sections. Thus, porous concrete pavements were determined to be fully applicable to snow and cold regions.

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