Study on Improving Functional Durability of Drainage Pavement in Snowy Cold Regions

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ABSTRACT: In Japan, Drainage pavements are highly regarded for the effectiveness of improving the running safety of vehicles and reducing road traffic noise. Therefore, these pavements have shown a drastic increase in number since around 1995. In snowy cold regions, however, traveling of vehicles with tire chains and snow removal in winter result in raveling and popping-out of aggregate and clogging of voids with chippings from pavements and hence in early degradation of noise reducing and draining functions. An attempt has been made to set the void ratio of the pavement at a lower value (about 17%) than that in ordinary areas (about 20%) in order to improve resistance to raveling fly-out of aggregate, but this has resulted in early clogging of voids and early degradation of noise reducing and draining functions. Under these circumstances, we developed new polymer modified asphalt for snowy cold regions to improve the durability of the noise reducing and draining functions of the pavement in such regions. This modified asphalt is as soft as 106 (1/10mm) in penetration and as low as -43℃ in Fraass brittle point as compared with pavement whose void ratio was set at a value (about 23%), which is equal to or higher than that adopted in ordinary areas (about 20%) by using this modified asphalt was applied to trial construction. This study reports on the verification results on the effect of improving the functional durability.

KEY WORDS: Porous, asphalt, void, performance, snowy cold region.

1 INTRODUCTION

1.1 Drainage Pavements in Japan

In Japan, the construction of the drainage pavement has been widely used since it was employed for practical use on Ring Road 7 in Tokyo in 1987. This drainage pavement has become the mainstream of the surface layer materials for the highly specified roads. In the national highways directly managed by the Ministry of Land, Infrastructure, Transport and Tourism, this type of pavements was employed in over 50km^2 in 2006 (Japan Road Association, 2006). This means that about 25% of the entire surface areas of the roads directly managed by the ministry have been replaced using this drainage pavement.

In snowy cold regions, however, snow removal in winter results in raveling and popping-out of aggregate and clogging of voids with chippings from pavements and hence in early degradation of functions of the drainage pavements. On the national highways of Hokkaido which is a typical snowy cold district in Japan, the standard void ratio of the drainage pavement has been set to 17% since 2002. This is to improve the durability by reducing the void ratio by 3 % compared with the void ratio of 20%, which is the standard design on Japan’s main island Honshu. In addition, the low temperature Cantabro loss rate is set to below 20% to prevent raveling and popping-out of aggregate by shocks caused when vehicles are using tire chains. Recently, damage of the drainage pavement has become conspicuous, and many damaged places are repaired by patching etc. In addition, the noise reduction and water permeation functions tend to deteriorate quickly. Therefore, it is highly indispensable to develop the drainage pavements that feature high durability and a long lasting noise reducing effect.

1.2 Development Target

We focused our attention on an asphalt to be used for drainage pavement that would increase the void ratio and durability of the drainage pavement. We developed a new type of asphalt with the aim of restraining raveling and popping-out of aggregate of pavement with high void ratio and to improve the durability of the water permeation and noise reduction functions by using a type of asphalt which has a higher flexibility at low temperatures than normal asphalt.

2 NEW POLYMER MODIFIED ASPHALT

The newly developed asphalt (hereinafter referred to as the “Developed asphalt”) aims at improving the durability of the porous asphalt during cold seasons, particularly the flexibility at low temperature. Table 1 shows the property test result of the developed asphalt. In addition, in order to compare the asphalt properties, test results are shown for the polymer modified asphalt type H for cold regions (hereinafter referred to as the “Cold region asphalt”) and for the polymer modified asphalt type H for general regions (hereinafter referred to as the “General region asphalt”). Comparing with the cold region asphalt and the general region asphalt, the developed asphalt has as high penetration as 106 (1/10mm) and Fraass brittle point which is 4-8 $^{\circ}$C lower, although the softening point is approximately the same level at 94.5°C. The test specimen did not break at -20°C, thus retaining a large flexibility at low temperatures.

Table 1: Properties of developed asphalt

Test Item		Developed As	Existing modified asphalt type H	
			General region As	Cold region As
Penetration	1/10mm	106	65	77
Softening point	℃	94.5	111.0	104.5
Fraass brittle point	℃	−43	−35	−39
BBR (−20℃) Work load	$\times 10^{-3}$ MPa	Unbroken*	383	953
BBR (−20℃) Stiffness	MPa	Unbroken*	240	14

*:Measurement was impossible because the deformation was too large.

3 LAVORATORY EXAMINATIONS

3.1 Evaluation Method of the Asphalt Mixture

The developed asphalt was first evaluated by laboratory tests. The mixing design was normally used in cold regions. The mixture property was evaluated by the tests shown in Table 2. The maximum grain diameter of the porous asphalt mixture was 13 mm. The asphalt content obtained for the general area asphalt was considered as the standard. The mixture property was evaluated by substituting the binder. Table 3 shows the amount of asphalt and composite grain size of the aggregate.

Table 2: Evaluation item

Item	Evaluation test	Test conditions
Raveling Resistance	Cantabro test (Low temperature)	Temp.: −20°C Los Angeles macine (300turns)
Aggregate fretting resistance	Resistance test to raveling and popping-out of aggregate	Test temperature:60°C Air tire (for light trucks)
Resistance to plastic flow	Wheel tracking test	Temp.:60°C Solid Rubber Tire
Water resistance	Water immersion Marshall stability test	Temp.: 60°C Immersion time: 48 hours
Wear resistance	Raveling test (Reciprocating & chain)	Temp.:−20°C Cross chain

Table 3: Asphalt content and composite grain size

Target void ratio (%)	Asphalt content (%)	Each level of mesh (mm) accumulated passing percentage (%)				
		19	13.2	4.75	2.36	0.075
17	5.2	100	94.1	26.1	17.6	4.9
20	4.9	100	93.9	22.9	14.3	4.8
23	4.6	100	93.7	20.3	11.4	4.8

3.2 Evaluation Results

3.2.1 Raveling resistance at low temperature

The result of the low temperature Cantabro Test shows that the Cantabro loss rate of the developed asphalt was 5 % or less even though the void ratio was 23 %. Therefore, it was confirmed that the developed asphalt showed high raveling resistance at low temperatures compared with the general region asphalt and the cold region asphalt.

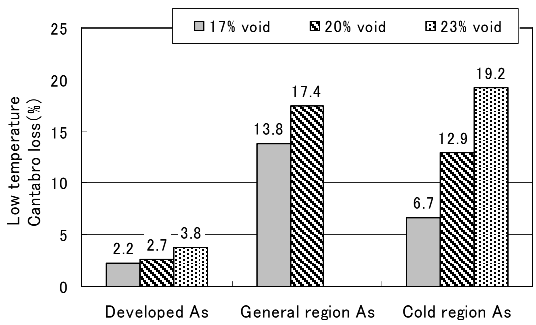

Figure 1: Cantabro test result

3.2.2 Aggregate fretting resistance

The raveling and popping-out of the drainage pavement will occur at intersections of busy streets and parking lots of an express ways by shear stress which is generated between steered tire and pavement. The Aggregate Fretting Test by Pressed Tire was executed to evaluate the resistance to raveling and popping-out of aggregate. This test was developed in Japan to simulate the raveling phenomenon (Japan Road Association, 2008)

Figure 2 shows the test results of four kinds of asphalt; the developed asphalt with the void ratios of 20% and 23%, and the general region asphalt with a void ratio of 17%, and the cold region asphalt with the void ratio of 20 %. As for the developed asphalt with the void ratio of 20%, the flying-loss rate was 2% or less, showing a fine result compared with the others. In addition, the loss rate was about 5% in the case of the developed asphalt with the void ratio of 23%, showing that the developed asphalt has good resistance to raveling fly-out of aggregate compared to the general region asphalt and the cold region asphalt with the void ratio of 20 %.

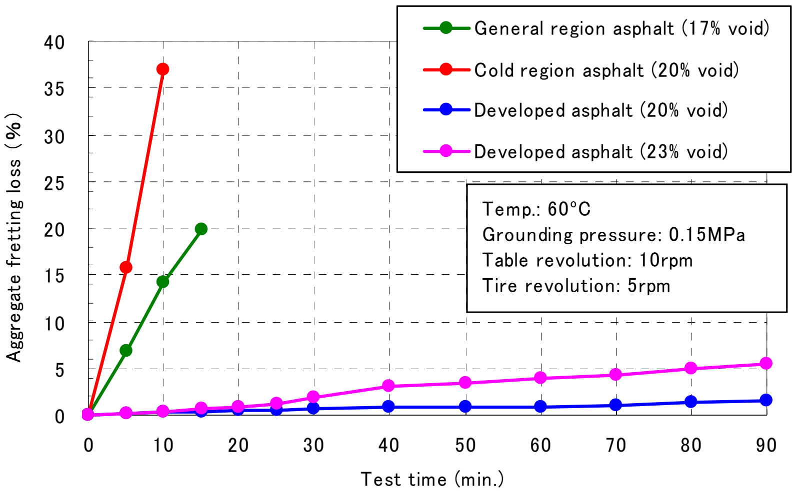

Figure 2: Aggregate fretting test result by pressed tire

3.2.3 Wear resistance

The wear resistance was evaluated by the Raveling Test. As shown in Figure 3, the amount of wear the developed asphalt was 1.09 cm^2 when the void ratio was 23%. This is high compared to the void ratio of 17% in the case of the general region asphalt, and the void ratio of 20 % in the case of the cold area asphalt.

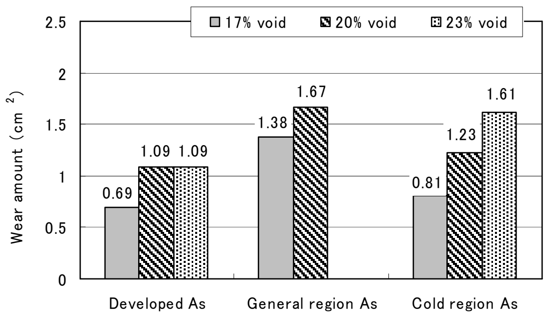

Figure 3: Raveling test result

3.2.4 Resistance to plastic flow

The evaluation of the resistance to plastic flow was carried out by the Wheel Tracking Test (Japan Road Association, 2007). In a Wheel tracking test, a solid tire weighing 686N is allowed to run in both ways for 60 minutes in a test room at a temperature of 60 ºC. The number of runs per 1 mm deformation is evaluated as the Dynamic Stability (DS, time/mm). The one having a greater DS is considered to have a greater resistance to plastic flow. Figure 4 shows the overview of the Wheel tracking test. The test results are shown in Table 4. The target value of the DS in snowy cold areas is set to 3,000 times/mm or more (Japan Highway Public Corporation, 1999). The DS of the mixture using the developed asphalt was 6,300 times/mm or more in the case of a void ratio of 23%. This shows that the developed asphalt has a high resistance to plastic flow.

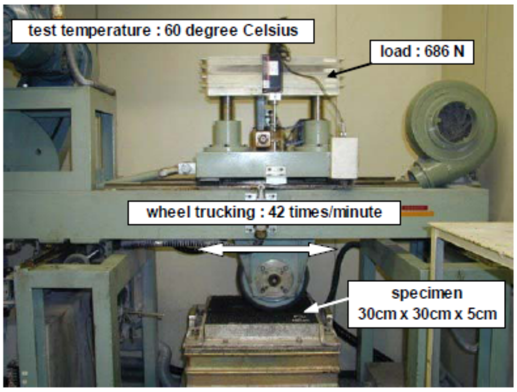

Figure 4: Wheel tracking test

Table 4: Dynamic Stability (DS) and Residual Stability (RS)

Item		Developed As			Modified asphalt type H				
					General region As		Cold region As		
Void	%	17	20	23	17	20	17	20	23
DS	Time/mm	12,600	10,500	7,000	12,600	10,500	10,500	7,870	5,300
RS	%	92.9	92.0	94.3	94.5	92.6	92.3	92.0	87.6

3.2.5 Water resistance

The water resistance was evaluated by the Marshall Stability Test. Table 4 shows the results of the residual stability. The Residual Stability (RS) of the developed asphalt was 90% or more. In comparison with the residual stability (87.6-94.5%) of the general region asphalt and the cold region asphalt, the developed asphalt has the same or greater water resistance.

4 EVALUATION OF APPLICATION TO AN ACTUAL ROAD

4.1 Summary and Comparison Condition

The test construction was carried out using this newly developed asphalt in the jurisdiction of Sapporo road office of the Hokkaido Regional Development Bureau. Porous asphalt mixtures with the void ratio of 20% and 23% were used.

Route 230 in Sapporo City, called the Ishiyama Street, is a main road in the urban area. Figure 5 shows the layout of the test construction site. In the construction site, there are elementary school and hospital facing the highway. The traffic volume there is as large as 49,000 units/day. Therefore maintaining driving safety and reducing traffic noise by means of the drainage function of the road surface is highly desired to create pleasant environment for the residents.

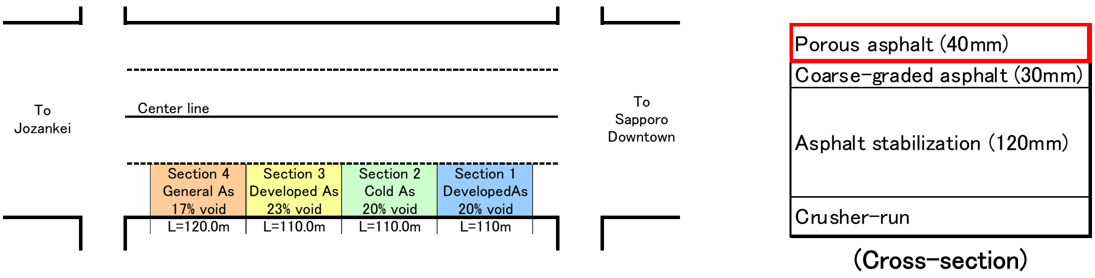

Figure 5: Assignment of paved sections at test construction site

Four kinds of porous asphalt mixture were used for the construction test. In the paved sections 1 and 3, where the developed asphalt was used to improve the durability of the water permeation function and noise reduction function, the target void ratio was set to 20% and 23%, respectively. In addition, for comparison purposes, the construction was also carried out for paved section 2, where the cold region asphalt was used with the target void ratio of 20 %, and for paved section 4, where the general region asphalt was used with a target void ratio of 17 %. The mixture used in section 4 was the standard mixture of drainage pavement normally used by Hokkaido Regional Development Bureau.

4.2 Construction Method

4.2.1 Test mixing and establishment test construction

In order to confirm the mixture property and choose the best construction method, the test construction was performed at the company's premise. As shown Table 5, rolling was done by three methods. Sufficient degree of compactness was obtained from all these methods. However, conspicuous difference was observed on the surface property (surface roughness). Therefore, it was decided to use a tire roller to reduce the roughness of the road surface as much as possible with consideration given to degradation of the functions caused by the raveling and popping-out of aggregate during cold periods. This was done to settle the aggregate.

It was decided that a macadam roller would be used for the initial rolling immediately after laying the materials. The rolling was performed at least three times. Concerning the second rolling, a tire roller was used. When the road surface temperature dropped down to below 90 ºC, this rolling was started. This rolling was performed at least five times.

Table 5: Texture depths at premises test construction site by Mini Texture Meter

Mixture type	Macadam roller 3 times Tire roller 5 times	Macadam roller 3 times Tandem roller 5 times	Macadam roller 3 times Tandem roller 5 times
Target void ratio 20%	1.09*	1.36over	HIGH**
Target void ratio 23%	1.19*	HIGH**	HIGH**

*Average of three places **Measurement Impossible

4.2.2 Brief description of the construction on an actual road

Ordinary construction equipment was chosen for this construction. HA60W made by Sumitomo Construction Machinery Co., ltd. was used as the asphalt finisher. R2-H1 made by Sakai Heavy Industries Co., ltd. was used as the macadam roller. TZ700 made by Sakai heavy industries, Co., ltd. was used as the tire roller. The existing dense graded asphalt pavement was removed by 4cm. Then, surface layer of 4cm thickness was made, using the four kinds of porous asphalt mixture, including two kinds for comparison purposes. Emulsion PKR-T which includes rubber was used as the tack coat. Table 6 shows the details of the mixtures.

Table 6: Properties of mixtures used for construction

Item	Section 1	Section 2	Section 3	Section 4	Standards
Asphalt type	Developed As	Cold region As	Developed As	General region As	−
Target void ratio (%)	20	20	23	17	−
Asphalt content (%)	5.0	5.0	4.8	5.1	−
Void ratio (%)	19.5	20.0	22.9	16.8	−
Marshall Stability (kN)	9.44	5.26	7.73	7.9	≧3.5
Flow value (1/100 cm)	39	25	37	37	20 to 40
Low temperature Cantabro loss rate (%)	1.3	11.5	1.4	11.1	＜20
Water permeation coefficient (cm/sec)	17.5×10^{-2}	18.9×10^{-2}	35.7×10^{-2}	9.9×10^{-2}	$\geqq 1\times10^{-2}$

4.3 Follow-up Inspection Results

4.3.1 Drainage function

Figure 6 shows the measurement results of the water permeation amount of the on-site test. At the paved sections 1, 2 and 4 where the target void ratio was set at 20% and 17%, voids were clogged on the pavement surface eight months after the construction. The water permeation amount was about 50ml/15sec, showing that the drainage function dropped quickly. On the other hand, the paved section 3 which had the target void ratio of 23 % retained the drainage function as high as 800ml/15sec, eight months after the construction. Moreover, 20 months after the construction, it retained the same water permeation function as the paved sections 1, 2 and 4 had eight months after the construction.

From the results above, it was proven that the durability of the drainage function can be improved by setting the target void ratio as high as about 23 %.

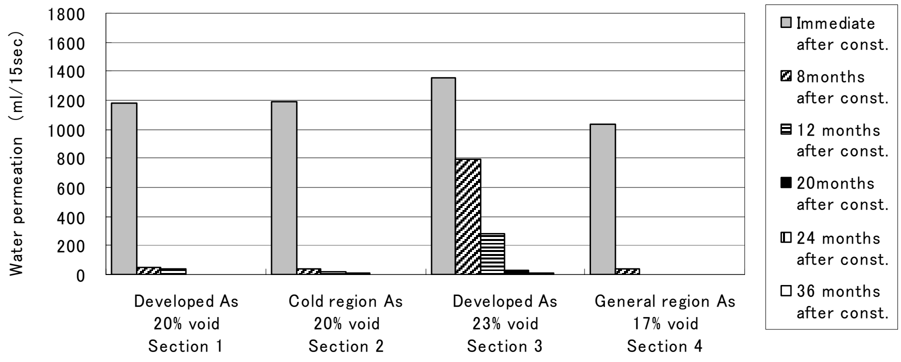

Figure 6: On-site measurement result of water permeation amount

4.3.2 Noise reduction function

The Road Acoustic Checker (RAC) designed to measure the noise, which occurs from a contact of two tires of a special tread pattern with the pavement surface (Kasahara, 2006). Figure 7 shows the tire/road noise measurement results by RAC. On the paved sections 1, 2 and 4, where the target void ratio was set to 20% and 17%, the road noise value 12 months after the construction increased 3 to 5 dB compared to that of immediately after the construction. This indicated that there was degradation of the noise reduction function in these sections. On the other hand, the noise level of paved section 3, which had the target void ratio of 23%, had only a 1 dB increase compared to that of immediately after the construction. This shows that the paved section 3 retained the same noise reduction function as it had immediately after the construction. In addition, the road noise values of paved section 3 immediately after the construction and 36 months after the construction were both about 1 to 2 dB respectively below those of paved sections 1, 2 and 4. Hence, it was confirmed that the noise reduction function in the initial service period can be increased and the durability of the functions can be enhanced by setting the target void ratio to as high as about 23 %.

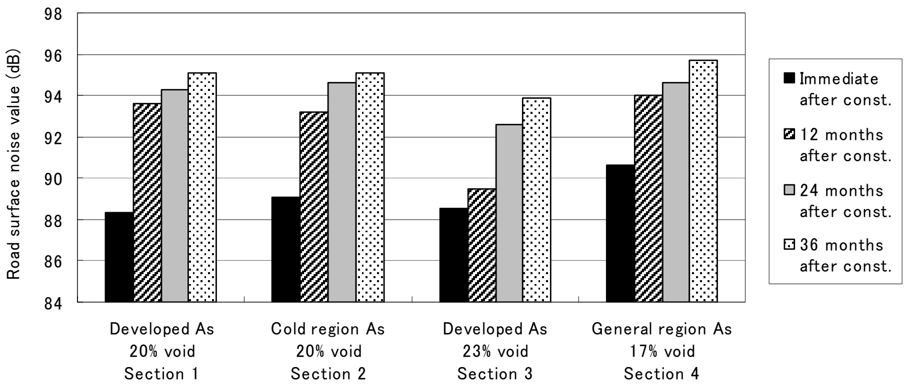

Figure 7: Tire/road noise level by RAC

4.3.3 Rut depth of pavement surface

Figure 8 shows the measurement result of the rut depth of pavement surface. In the initial service period (eight months after the construction), the rut depth of section 3, which had the target void ratio of 23%, differs by about 1 to 2 mm from that of sections 1, 2 and 4, which had a target void rates of 20 % and 17 %. However, the changes after this period were the same for all of the four sections. From this result, it can be concluded that the difference in void ratio does not have much effect on the rut depth of pavement surface.

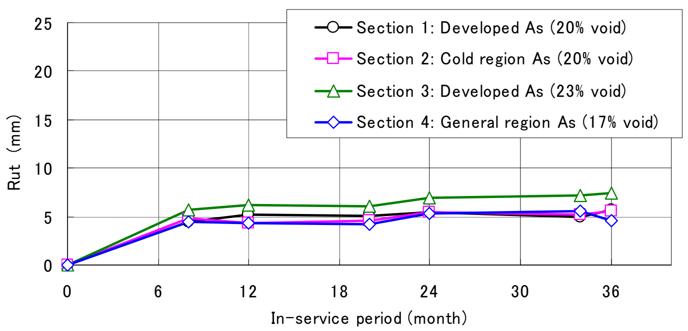

Figure8: Measurement result of rut depth

4.3.4 Skid resistance

The skid resistance was evaluated by Dynamic Friction Tester (DF Tester). In each paved sections, the dynamic friction coefficient of the road surface was measured by the DF Tester. The dynamic friction coefficient was measured from about one month after the construction until three years after the construction. Figure 9 shows the measurement result of the dynamic coefficient of friction equivalent to 60 km/h running. The sliding resistance was low in the initial period due to the asphalt film on the surface. However, it increased as the road was used further. The measurement result shows that the dynamic friction coefficient at each speed is almost the same regardless of the differences in the mixtures. From these results, it can be concluded that the differences in void ratio does not have much effect on the coefficient of skid resistance.

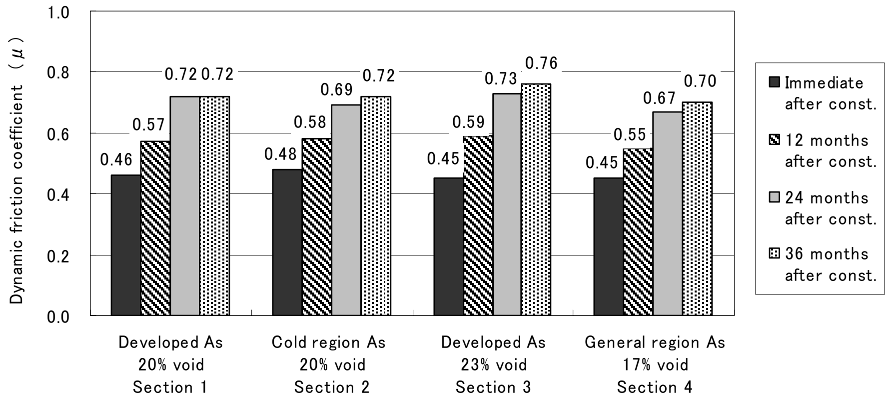

Figure 9: Measurement result of dynamic friction coefficient

5 SUMMARIES

The following are the follow-up inspection results:

- The paved section of the developed asphalt with a void ratio set to as high as 23 % showed large water permeation in the initial period. Twenty months later, however, it declined to such value that was only slightly different from the paved sections.
- As for the noise level of the road surface, the paved section of the developed asphalt with the void ratio set to as high as 23 % kept the considerable noise reduction function that it had during the initial period. It was confirmed that the noise reduction function can be retained.
- The rut greatly increased in the initial service period. After this period, however, there was little change. Therefore, it was confirmed that the difference in void ratio did not have much effect on the amount of crossing roughness.
- The value of the DF tester which evaluates the sliding resistance was low immediately after the construction on all paved sections. However the value gradually increased as time passed and this high value is still retained at present.

6 CONCLUSIONS

The Cantabro test which evaluates the raveling resistance, can be used as the quantitative evaluation method for the durability of the porous asphalt mixture in snowy and cold regions. However, in order to evaluate the durability of the actual road, a more appropriate quantitative evaluation method which reflects the actual servicing conditions needs to be established.

The paper reported the follow-up inspection of the test construction, and considered how the durability and functionality were affected by the drainage pavement which had a higher void ratio than the ordinary drainage pavement in cold regions. We are convinced that valuable data has been obtained by the follow-up inspections which lasted three years. We were able to find the possibility that the drainage pavements which have a higher void ratio than the conventional ratio can be applied in snowy cold regions by using the asphalt developed now. The currently performed construction is the first example of using the drainage pavement which has a high void ratio in snowy cold regions. We were able to confirm that the durability of the drainage function and noise reduction function can be effectively improved by employing a higher void ratio.

We are planning to carry out two additional constructions with this type of engineering at sites which have a smaller traffic volume than the site studied this time. We will continue to accumulate the follow-up inspection data of the drainage pavement construction sites in snowy cold regions and suggest drainage asphalt pavements suitable for snowy cold regions like Hokkaido.

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