Design and Construction of the Cold-Lay Foamed Asphalt Mixture at Kyogoku Project

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Abstract: The upper reservoir of the Kyogoku Hydroelectric Power Plant is a pool-type reservoir and the application of the asphalt facing to the entire inner surface of this reservoir is planned. Because of the location of the construction site in one of the coldest heavy snow regions in Japan, limiting the feasible period for construction work, the selection of a highly efficient construction method was essential. Hokkaido Electric Power, therefore, selected a cold-lay foamed asphalt mixture for the base layer of the asphalt facing because of its versatility to allow laying at normal temperature and the work is currently in progress. This paper reports on the design and construction of the cold-lay foamed asphalt mixture for the project as well as the properties of this mixture after construction.

KEY WORDS: Asphalt facing, base layer, cold-lay foamed asphalt mixture, Yamanaka-type soil hardness meter, re-expansion of asphalt cover

1 INTRODUCTION

Hokkaido Electric Power Co., Inc. (HEPCO) is currently constructing the pure pumped storage-type Kyogoku Hydroelectric Power Plant (maximum output of 600,000 kW, maximum utilizable flow of 190.5 m^3/s and effective head of 369.0 m). The four sides of its square-shaped upper reservoir are approximately 440 m in length with rounded corners. Three sides are embanked using excavated materials. It is planned to construct asphalt facing to cover the entire inner surface of approximately 180,000 m^2. Table 1, Figure 1 and Figure 2 show the specific data, plan and standard cross-section of this pool-type reservoir respectively.

Table1: Specific data of the upper reservoir

Item		Data, etc.	
Type of dam		Rockfill dam with asphalt facing	
Maximum height		22.6 m	
Crest length		1,140.9 m	
Total volume		$1,539\times10^3$ m^3	
Asphalt laying area		178×10^3 m^2	
Available depth		45.0 m	
Reservoir area		0.16 km2	
Maximum water level	Minimum water level	EL.890.0 m	EL.845.0 m
Gross storage capacity	Effective storage capacity	$4,400\times10^3$ m^3	$4,120\times10^3$ m^3

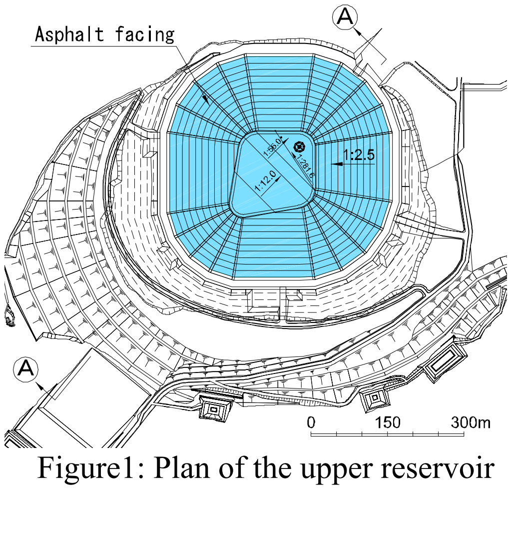


Figure1: Plan of the upper reservoir

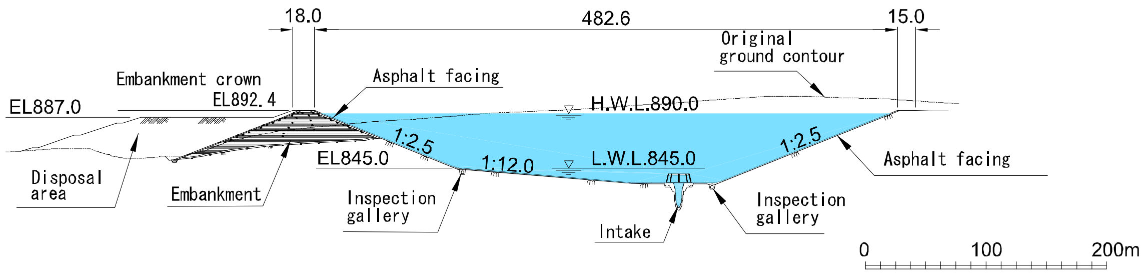
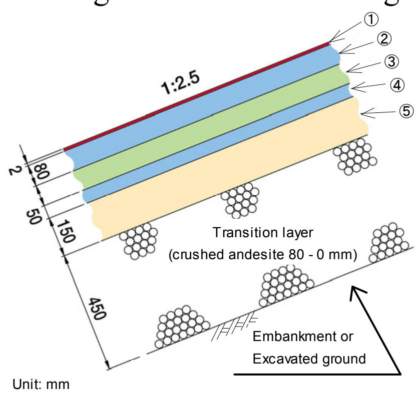


Figure2: Standard cross-section of the upper reservoir (A – A)

The levelling macadam layer using a coarse graded asphalt mixture has traditionally been used in Japan for the base layer of the asphalt facing. The Kyogoku project site experiences such severe weather conditions as a minimum temperature of -25°C and snow cover of approximately 5 m in thickness in winter. Therefore, the construction work is restricted to between late May and mid-October, making the selection of a highly efficient construction method essential. HEPCO took notice of the foamed asphalt mixture used for the upper base layer of roads and decided to adopt an improved mixture (cold-lay foamed asphalt mixture; hereinafter referred to as "FAM") for the base layer of the asphalt facing. Compared to a coarse graded asphalt mixture, FAM is less likely to be affected by the weather conditions during construction work, can be applied at normal temperature and does not require an asphalt finisher and other special machinery. In this project, the thick lift placing of a single 8-cm thick layer is used to form the upper impervious layer instead of the conventional double layer construction for the suppression of inter-layer blistering and cost reduction. This paper reports on the design and construction of FAM and the properties of FAM after construction. Figure 3 shows the configuration of the asphalt facing.



Name of layer and material used
① Protection layer asphalt mastic
② Upper impervious layer dence graded asphalt mixture
③ Intermediate drainage layer open graded asphalt mixture
④ Lower impervious layer dence graded asphalt mixture
⑤ Base layer foamed asphalt mixture (FAM)

Figure3: Configuration of asphalt facing

2 OUTLINE OF FAM

Figure 4 shows the fundamentals of the foamed asphalt and the manufacturing process of FAM. When water and air are blown into hot asphalt (around 150°C), foamed asphalt is created. The volume expands by 10 to 20 times and the resulting fall of the viscosity makes it possible to mix foamed asphalt and wet aggregates at normal temperature. Foamed asphalt does not completely cover coarse aggregates unlike a hot asphalt mixture but it adheres to fine aggregates and eventually combines with coarse aggregates after compaction. As FAM possesses the characteristics listed in Table 2, its use for the asphalt facing produces a great effect.

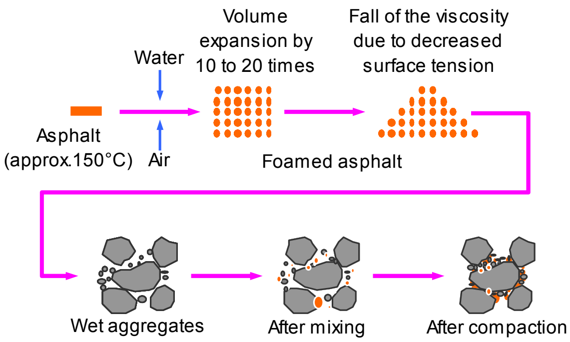


Figure4: Fundamentals of foamed asphalt and the manufacturing process of FAM

Table2: Characteristics of FAM

Characteristics	Description
Workability	Compared to a common hot asphalt mixture, there are noticeably fewer work restrictions, making rapid work execution possible (→shorter construction period).
Environmental impacts	The environmental impact (CO_2) can be reduced as FAM is produced at normal temperature.
Effective use of local materials	The effective use of local materials is possible.

3 PERFORMANCE REQUIREMENTS OF FAM FOR APPLICATION TO THE BASE LAYER

The base layer should meet such performance requirements as ① durability (protection of the transition layer), ② deformation performance (structural coherence from the asphalt facing to the embankment) and ③ flatness (base for the asphalt facing and adjustment of the unevenness to ensure the sufficient thickness of the lower impervious layer). The test results established in advance confirm that these performance requirements of the base layer will be met as long as the void of the FAM to be used for the base layer does not exceed 20%. Table 3 and Figure 5 show the specified mix proportion and specified gradation respectively. The aggregates used come from fresh and hard andesite which is produced by the excavation work of the upper reservoir and is crushed to the predetermined grain size. To produce FAM of uniform quality, slaked lime is added as it can improve the homogeneity of the asphalt. Photograph 1 shows the state of asphalt dispersion with or without slaked lime.

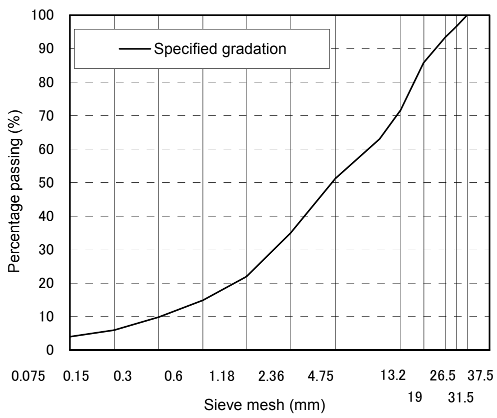
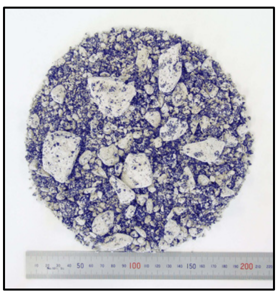


Figure5: Specified gradation

Table3: Specified mix proportion for FAM

Maximum grain size (mm)	Composition by weight (%)			Water content (%)	Water-asphalt ratio (W/As: %)
	Asphalt	Aggregate	Dispersibility improver		
40	4.5	94.5	1.0	7.0(OMC*)	2.0

* Optimum Moisture Content



With slaked lime

Without slaked lime
*Asphalt is coloured in blue.

Photograph1: State of asphalt dispersion

The asphalt and locally produced aggregates used for the manufacture of FAM underwent the quality control shown in Table 4 and Table 5 respectively and it has been confirmed that all of the test results so far satisfy the relevant standards. The binder test under the SHRP (Strategic Highway Research Program) shown in Table 6 was also conducted to establish the properties of the asphalt as these significantly affect the mechanical properties of FAM.

Table4: Quality control items for the asphalt

Control item	Unit	Reference value	Test method	Test frequency
Penetration (25°C)	1/10mm	More than 80 but less than 100	JIS* K 2207	Each lot
Softening point	℃	42.0~50.0		
Ductility (15°C)	cm	≥100		
Soluble toluene content	%	≥99.0		
Flash point	℃	≥260	JIS K 2265	
Mass loss on thin film oven	%	≤0.6	JIS K 2207	
Residual penetration on thin film oven	%	≥50		
Penetration ratio after heating	%	≤110		
Density (15°C)	g/cm³	≥1.000		

* Japanese Industrial Standards

Table5: Quality control items for locally produced aggregates

Control item	Unit	Reference value	Test method	Test frequency
Dry unit weight	g/cm³	≥2.45	JIS A 1109 JIS A 1110	Every 5,000 m³
Coefficient of water absorption	%	≤3.0		
Gradation	%	2.36mm : 30~40 37.5mm : 95~100	JIS A 1102	
Shape of coarse aggregate	%	≤10	Paving test guidebook**	
Abrasion loss*	%	≤30	JIS A 1121	Every 10,000 m³
Soundness (loss)*	%	≤12	JIS A 1122	
Clay content*	%	≤0.25	JIS A 1137	
Soft particles*	%	≤5	JIS A 1126	

* Items checked as the target value rather than the reference value for quality control
** published by Japanese Road Association

Table6: SHRP test items

Test item	Unit	Test Method	Test frequency
High temperature viscosity	cPs	HTV(High-Temperature Viscometer) test	Each lot (minimum: monthly)
G*/sinδ	kPa	DSR(Dynamic Shear Rheometer) test	
S value; m value	MPa	BBR(Bending Beam Rhemeter) test	
Mass loss	%	RTFOT(Rolling Thin Film Oven Test)	
Accelerated aging	-	PAV(Pressure Aging Vessel) test	

3.1 Durability (Frost Damage Resistance)

Because the construction site is located in a heavy snow area, the transition layer requires protection against the erosion due to avalanches or melting snow. A long-term exposure test using FAM specimens was conducted to evaluate the durability (frost damage resistance).

This exposure test was conducted with the conditions shown in Table 7 as the durability was expected to depend on different void and the presence of asphalt emulsion (sprayed for the protection of the base layer surface). The test commenced in March, 2002. Figure 6 shows the condition of the test.

Table7: Exposure test

Specimen size	As content	Void	Emulsion
30 x 30 x 15 cm	4.5%	15%; 20%	With; without

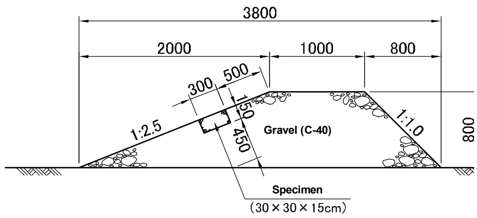


Figure6: Condition of the test

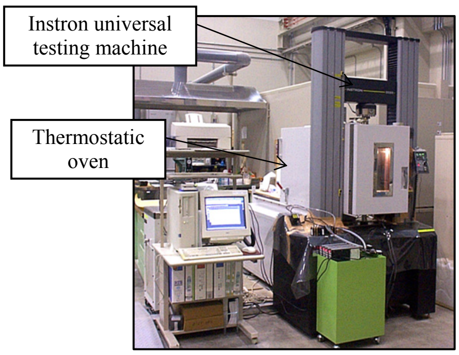
Visual observation of the specimens exposed for three and a half years could not identify any clear differences between the specimen of 15% void and that of 20% void. In the case of the specimen without emulsion, the fine grain content on the surface gradually decreased, exposing the coarse aggregates. The specimen with emulsion did not show such a tendency. These results seem to indicate that sufficient frost damage resistance can be secured with void of 20% or lower and that asphalt emulsion protects the surface of the base layer.

3.2 Deformation Performance

The specimens were made using FAM, based on the specified mix proportion. These were subject to an indirect tensile test to evaluate the deformation performance of FAM. The indirect tensile test uses an Instron universal testing machine as the loading device and applied a load diametrically to the cylindric specimen (80 mm in thickness and 150 mm in diameter) inside a thermostatic oven at a predetermined temperature. Based on the creep test results, the modulus of deformation was calculated. Photograph 2 shows the full view of the testing system while Table 8 and Figure 7 show the test conditions and test results respectively.

Table8: Test conditions

Making of specimen	Gyratory compactor
Indirect tensile test	Instron universal testing machine
Testing temperature	-15°C (minimum design temperature for the base layer)
Number of specimens used	17
Porosity of specimens	14.7 ~ 16.9% (average: 15.8%)



Photograph2: Full view of the testing system

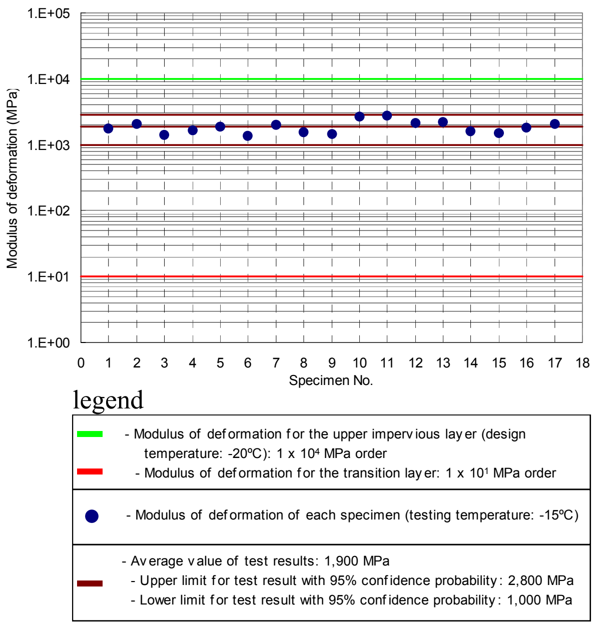
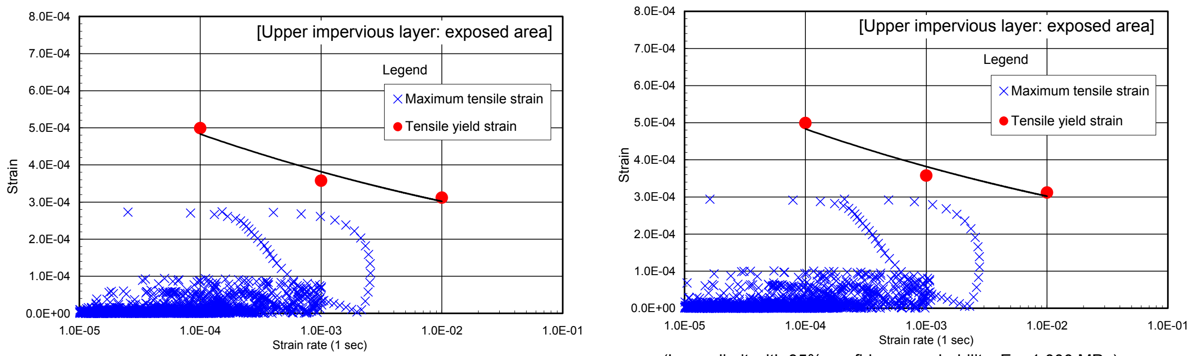


Figure7: Indirect tensile test results

The modulus of deformation of FAM is in the range of 1 ~ 3 x 10^3 MPa falling between the relevant modulus for the upper impervious layer and that for the transition layer.

Using the upper and lower limits with 95% confidence probability as the modulus of deformation for the base layer, the seismic safety of the asphalt facing was evaluated by means of dynamic analysis. This analysis found that the maximum tensile strain at the upper impervious layer occurred at the upper part of the cut boundary of the embankment provided that the water level was at its lowest. Because of the external exposure of this area, the satisfaction of the required safety factor (1.1) was checked and confirmed by comparison with the tensile yield strain under the design temperature of -20°C for the upper impervious layer in winter. Figure 8 shows the analysis results.



(Upper limit with 95% confidence probability: E = 2,800 MPa) (Lower limit with 95% confidence probability: E = 1,000 MPa)

Figure8: Safety evaluation results (upper impervious layer)

3.3 Flatness

The base layer functions as the foundation for the asphalt facing and the unevenness adjustment layer to ensure the sufficient thickness of the lower impervious layer. As such, it should have adequate trafficability for construction machinery. Evaluation of the trafficability was based on the residual deformation of the base layer after the running of a dump truck (vehicle delivering a mix) on the base layer constructed for the slope paving test in 2002 as shown in Figure 9. Two loading cases, i.e. with the maximum load and with no load, were used and the number of trips was set at 15 for both cases. The residual deformation was measured after every five trips. Table 9 shows the loading conditions for the dump truck. The test results appear to indicate the sufficient level of trafficability as the residual deformation with the maximum load (after 15 trips) was approximately 2 mm (Figure 10).

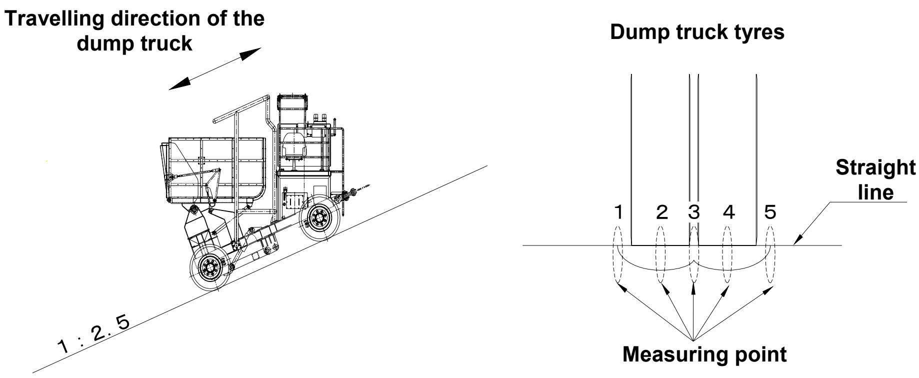


Figure9: Trafficability test

Table9: Loading conditions

Loading condition			Empty	Maximum load
Gross weight (tons)			7.7	17.7
Number of Wheels			Rear: 4; Front: 2	
Load	Rear	Gross weight (tons)	4.2	12.8
		Per wheel (tons)	1.05	3.2
	Front	Gross weight (tons)	2.9	3.7
		Per wheel (tons)	1.45	1.85
Travelling speed (m/min)			20	

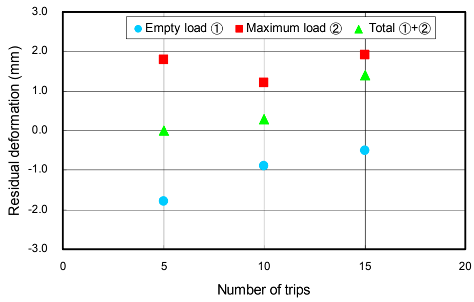


Figure10: Trafficability test results

4 CONSTRUCTION OF THE BASE LAYER

Figure 11 shows the flow of the construction of the base layer using FAM and the construction machinery to be used. As FAM is a normal temperature mixture, it can be laid by means of levelling by a bulldozer and compacting by a vibration roller as in the case of the transition layer unlike the case of a hot asphalt mixture. The daily rate of the base layer laying work using FAM by one party is approximately 2,000 m^2. The overall construction period is shorter than that of conventional levelling and macadam layer work (using a coarse graded asphalt mixture) as the work with FAM is less likely to be affected by the weather conditions (outside temperature and rain). Photograph 3 shows scenes of levelling by a bulldozer with a 3D-Machine Control system (21 ton class capable of automatically controlling the blade operation using 3D design data) and of compaction by a self-climbing vibration roller (14 ton class).

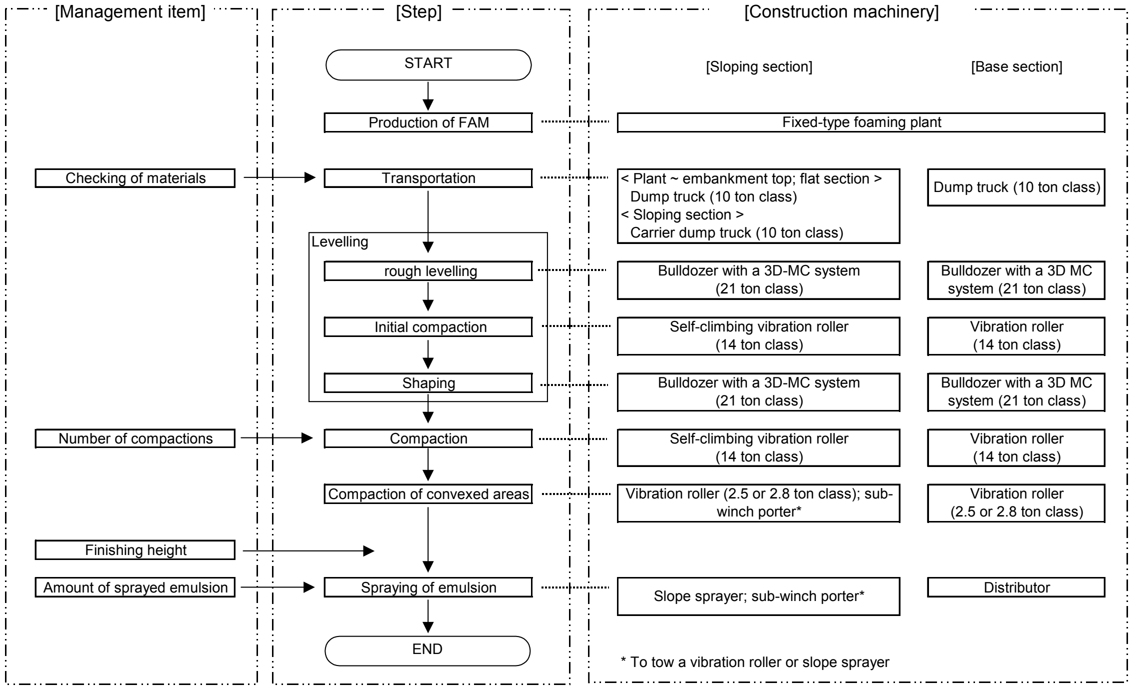


Figure11: Construction flow of the base layer and construction machinery to be used

(Levelling by a bulldozer with a 3D-MC system)

(Compaction by a self-climbing vibration roller)

Photograph3: Scenes of the construction work

Table10: Number of compaction operations

	Sloping section Bottom section
Number of Compaction Operations	4 passes with vibrated compaction

Table 10 shows the number of compaction operations for the base layer. The compacted surface will experience the unevenness (around 3 cm in size) caused by the caterpillar of the vibration roller (14 ton class), this unevenness is eradicated with the use of a smaller vibration roller (2.5 or 2.8 ton class) for finishing compaction. As the finished elevation is within ± 25 mm of the design elevation, the accuracy of the work is sufficient for the base layer.

5 PROPERTIES OF THE COMPLETED BASE LAYER

5.1 Slackness

The construction of the base layer using FAM for the upper reservoir commenced in September, 2005 and approximately 80,000 m^2 of the base layer has been completed as of October, 2009. As some sections of this base layer are exposed for a long time until the laying of the lower impervious layer, the completed base layer has been monitored for the purpose of checking its properties. This follow-up monitoring found that the base layer laid in autumn suffered the softening of FAM (this phenomenon is described as "slackness" hereinafter), primarily at the embankment top, after winter. The check of the specimens collected from an area of the slackness found that the slackness is confined to the surface. The embankment top area is the first area to experience the melting of snow in spring as shown in Photograph 4. This exposed area receives a constant supply of melted snow while the ambient temperature often drops below 0°C. The decrease of the adhesive strength between the asphalt and coarse aggregates by the cycle of freezing and melting causes this slackness.

Photograph4: Melting of snow at the base layer (Photograph taken on 8th May, 2006)

5.2 Measuring of the Slackness by the Yamanaka-Type Soil Hardness Meter

The slackness of the base layer was measured using the Yamanaka-Type Soil Hardness Meter to quantify the slackness. With this meter, a cone of 18 mm in diameter and 40 mm in height was vertically inserted into the soil to measure the non-penetration amount (0 ~ 40 mm; a larger value means greater hardness) to determine the level of the soil hardness. Photograph 5 and Photograph 6 show the meter and its actual use respectively. For this measuring operation, nine measured values were obtained at each point to calculate the average value. Figure 12 shows the measurement results.

Photograph5: Yamanaka-Type Soil Hardness Meter

Photograph6: Measuring of the hardness

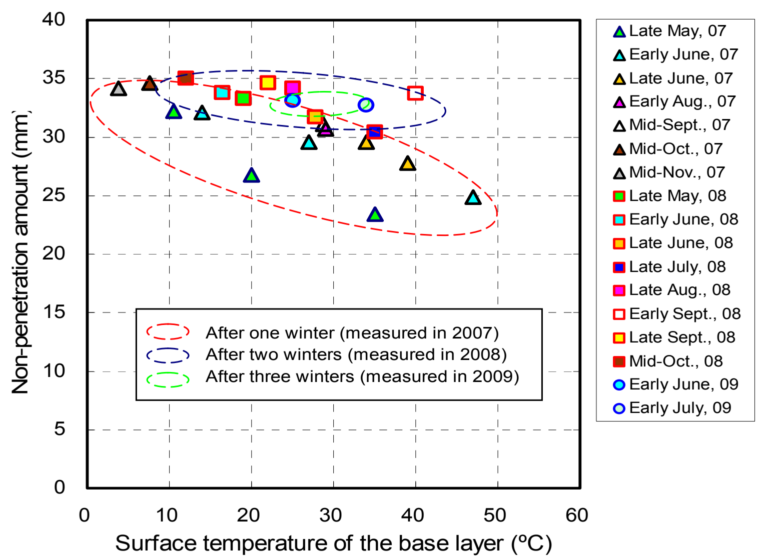


Figure12: Measurement results of the base layer laid in 2006

The following knowledge has been acquired from the measurement results using the said meter.

① The slackness of the base layer observed after the first winter tends to disappear (the non-penetration amount increases, suggesting harder) towards summer.

② The disappeared slackness does not reappear from the second winter onwards.

③ The non-penetration amount after the first winter is highly dependent on the temperature. It tends to become smaller when the surface temperature of the base layer rises and larger when the said temperature drops. This dependence on the temperature is less evident from the second winter onwards.

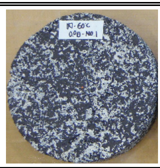
④ The slackness occurs within a 10 ~ 20 mm zone of the surface layer. As it disappears with the passing of time, it does not appear to progress any deeper.

The reason for the disappearance of the slackness may well be an increase of the adhesive strength of the coarse aggregates as a result of an increased contact area between the asphalt and aggregates, in turn caused by an increased surface area of asphalt in the base layer due to its growing viscosity facilitated by a higher ambient temperature (this phenomenon is described as "re-expansion of asphalt cover by temperature" hereinafter). The absence of the slackness in the first winter of the base layer laid in summer is presumably attributable to the sufficient re-expansion of the asphalt cover by temperature before the arrival of winter.

5.3 Re-expansion of Asphalt Cover by temperature

To ascertain the re-expansion of the asphalt cover by temperature in the base layer, FAM specimens (80 mm in thickness and 150 mm in diameter) were created using a gyratory compactor and were observed under a microscope. These specimens were dried in an oven at 45°C, 60°C or 80°C after aeration for one week at a constant temperature (20°C). The changes of each specimen were observed after 12, 24 and 48 hours. Table 11 shows the observation results of the specimen dried at 60°C.

Table11: Macroscopic observation of specimen dried at 60°C

Drying temperature (°C)	Drying time (hours)			
	0	12	24	48
60				

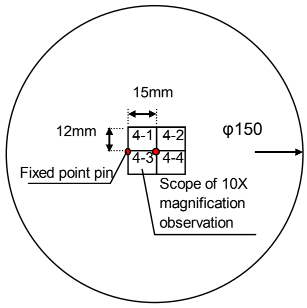
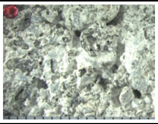
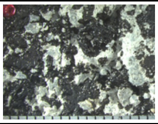
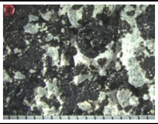
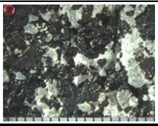


Figure13: Microscopic observation area

The microscopic observation area was set at the central area of the upper surface of each specimen as shown in Figure 13. With each specimen, four zones of 12 mm in length and 15 mm in width (4-1 ~ 4-4) were observed. The scale of magnification was 10 fold. Table 12 shows the microscopic observation results for the specimen dried at 60°C (within the scope of 4-4 for this specimen shown in Table 11). Figure 14 shows the rate of increase of the asphalt mortar area from the initial state (i.e. 0 drying hours) for each case of the drying temperature. The observation results confirm that the asphalt in FAM will begin to show the property of a viscous substance when it exceeds its softening point (around 45°C), expanding its surface area. Figure 15 shows the DSR test results described in Table 6. It was confirmed that the high temperature of asphalt reveals its viscosity more prominently. Therefore, the extent of asphalt cover re-expansion will be larger with a higher drying temperature.

Table12: Microscopic observation of specimen dried at 60°C

Drying temperature (°C)	Drying time (hours)			
	0	12	24	48
60				

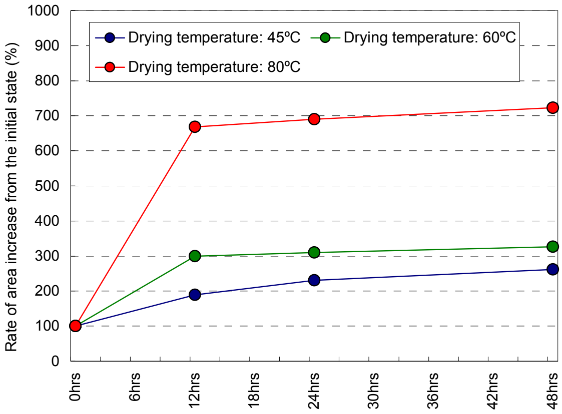


Figure14: Rate of increase of asphalt mortar area

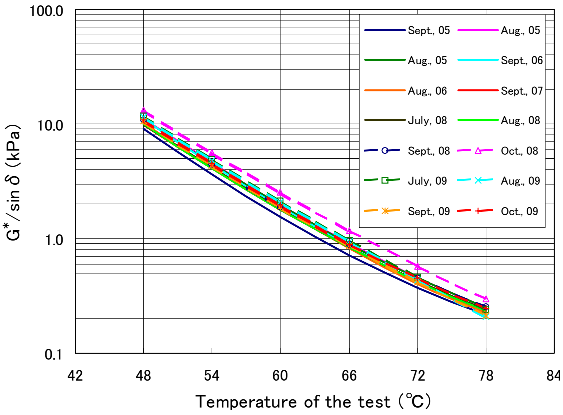


Figure15: DSR test results

6 CONCLUSION

This report compiles the design, field construction and post-construction properties of FAM used for the base layer of the asphalt facing. FAM has such positive effects as cost reduction and a shorter construction period. Even though it partially slackens after winter, the slackness is gradually eradicated through the re-expansion of the asphalt cover, proving its value as a material which sufficiently satisfies the required performance of the base layer. Laying of the impervious layer is planned to commence in 2010 in addition to the laying of the base layer and all possible measures will be taken to ensure proper quality control and schedule control as has been the case so far.

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