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Design and construction of asphalt facing in cold heavy snow region

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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. This reservoir is located in one of the coldest regions in Japan and also has much snowfall. Because of the limited period available for civil engineering work, it is important to do the work efficiently. Therefore, Hokkaido Electric Power selected the cold-lay foamed asphalt mixture for the base layer of the asphalt facing because of its characteristics 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.

1 INTRODUCTION

Hokkaido Electric Power 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, Figures 1 and 2 show the specific data, plan and standard cross-section of this pool-type reservoir respectively.

The levelling macadam layer using a coarse graded asphalt mixture has been traditionally 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, term of the construction work is restricted between late May and mid-October, making the selection of a highly efficient construction method essential. Hokkaido Electric Power took notice of the foamed asphalt mixture used for the upper base layer of roads and decided to adopt an improved mixture

Table 1. Specific data of the upper reservoir.

Item	Data
Type of dam	Rockfill dam with asphalt facing
Total Crest length	1464.1 m
Total area of asphalt facing	178,000 m^2
Available depth	45.0 m
Reservoir area	0.16 km^2
Maximum water level	EL. 890.0 m
Minimum water level	EL. 845.0 m
Gross storage capacity	4,400,000 m^3
Effective storage capacity	4,120,000 m^3

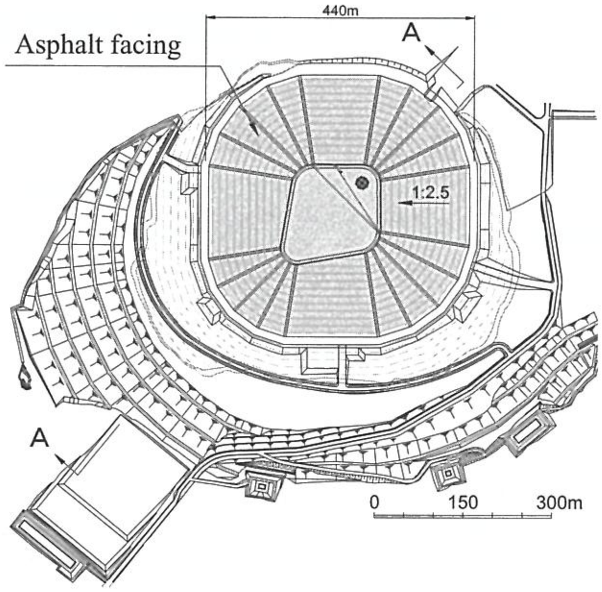


Figure 1. Plan of the upper reservoir.

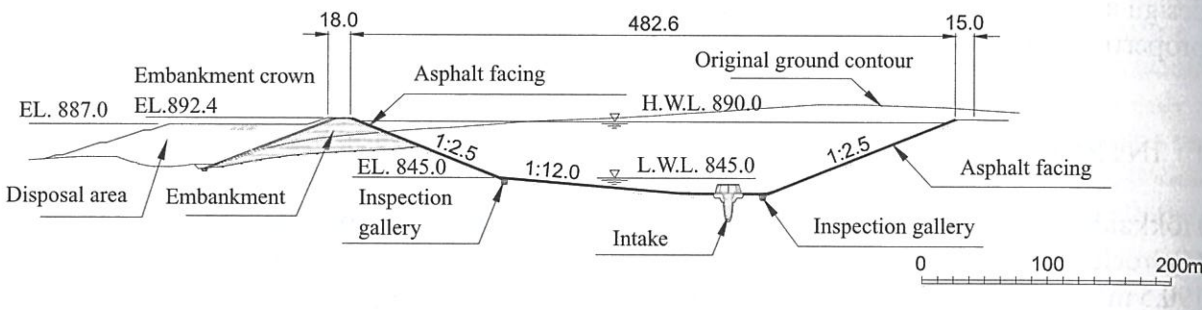
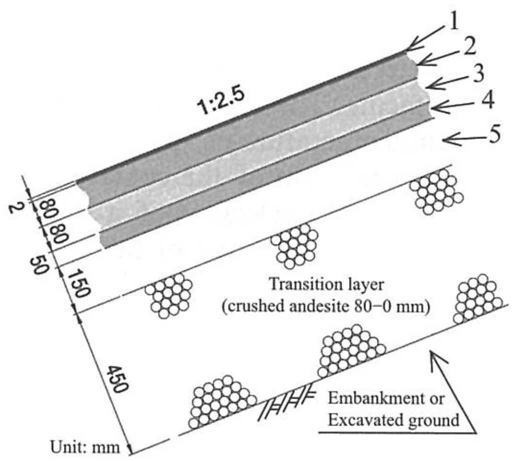


Figure 2. Standard cross-section of the upper reservoir (A-A).



Name of layer and material used
1 Protection layer Asphalt mastic
2 Upper impervious layer Dense graded asphalt mixture
3 Intermediate drainage layer Open graded asphalt mixture
4 Lower impervious layer Dense graded asphalt mixture
5 Base layer Foamed asphalt mixture (FAM)

Figure 3. Configuration of asphalt facing.

(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.

2 OUTLINE OF FAM

Figure 4 shows the fundamentals of the foamed asphalt and the manufacturing process of FAM. When water and air are sprayed 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.

3 PERFORMANCE REQUIREMENTS OF FAM FOR THE BASE LAYER

The base layer should meet such performance requirements as durability (protection of the transition layer), deformation performance (structural coherence from the asphalt facing to the embankment) and flatness (base for the asphalt facing and adjustment of the unevenness to ensure the sufficient thickness of the lower impervious layer). The results of the test 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 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.

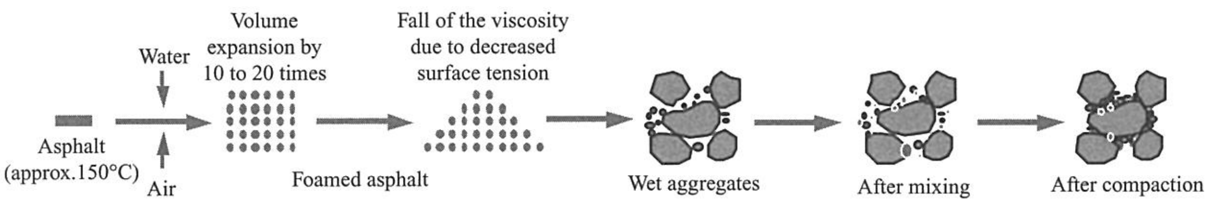


Figure 4. Fundamentals of foamed asphalt and the manufacturing process of FAM.

Table 2. 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

Table 3. Specification mix proportion for FAM.

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

*Optimum Moisture Content.

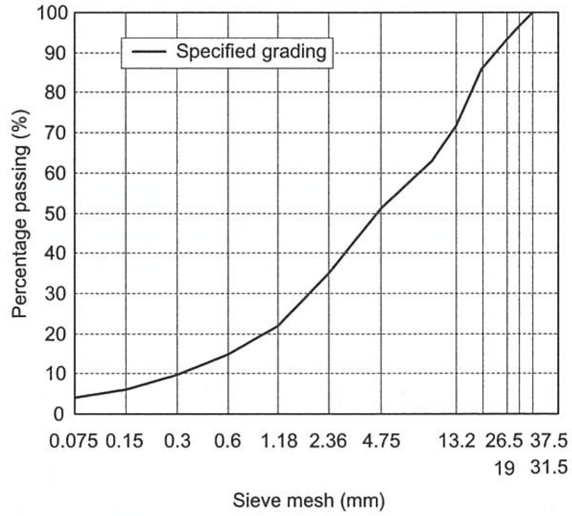


Figure 5. Specified gradation.

Table 4. Exposure test.

As content	Void	Emulsion
4.5%	15%, 20%	With, without

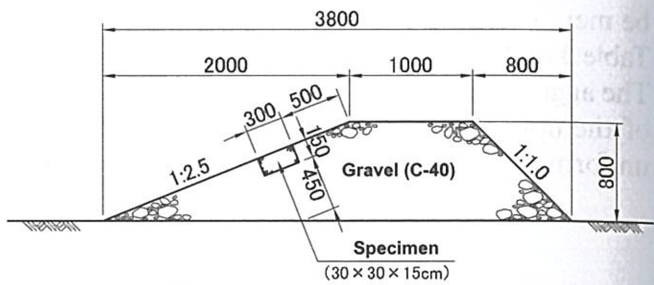


Figure 6. Condition of the test.

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).

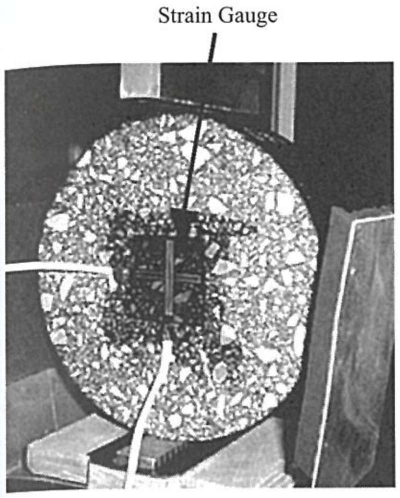
This exposure test was conducted with the conditions shown in Table 4 as the durability was expected to depend on different void and the presence of asphalt emulsion (sprayed for the protection of the base layer surface). The test commenced in March, 2002. Figure 6 shows the condition of the test.

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*

A gyratory compactor was used to make the specimens, 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 used an Instron universal testing machine as the loading device and applied a load diametrically to the cylindrical specimen (80 mm in thickness and 150 mm in diameter) inside a thermostatic oven at a predetermined temperature. Photograph 1 shows the specimen of the indirect tensile test. Based on the results of the creep test, the modulus of deformation was calculated. Figure 7 shows the test results (Takano et al. 2004).



Photograph 1. The specimen of indirect tensile test.

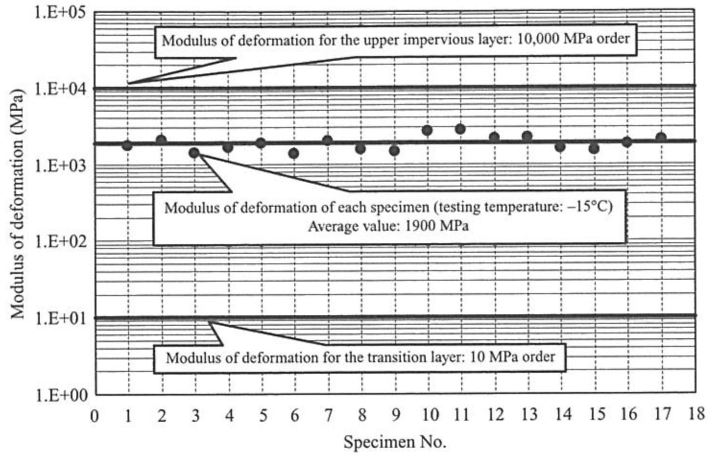


Figure 7. Indirect tensile test results.

Table 5. Conditions of dynamic analysis.

Model	
	Two-dimensional Finite Element Method
Seismic waves	
	Kaihoku-Brige Wave (1978.6.12)
	Minohgawa Dam Wave (1995.1.17)
Maximum horizontal acceleration	
	220 gal (Magnitude 6.5 at the nearest fault, considering the distance from the source)

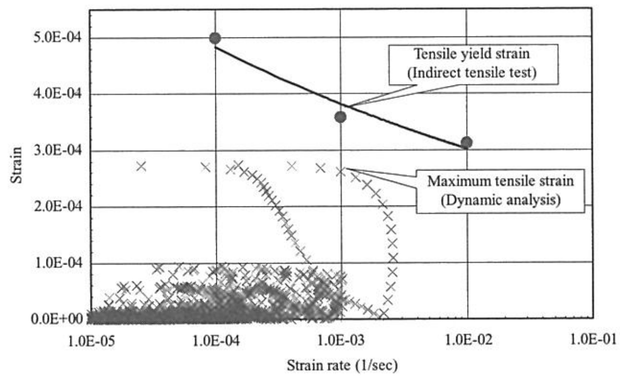


Figure 8. Safety evaluation result (upper impervious layer).

The modulus of deformation of FAM is in the range of 1000~3000 MPa, which is between the relevant modulus for the upper impervious layer and that for the transition layer.

The seismic safety of the asphalt facing was evaluated by means of dynamic analysis. Table 5 shows the conditions 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 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 results of the analysis.

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. Two loading cases, i.e. with the maximum load (17.7 ton) and with no load (7.7 ton), were used and the number of running was set at 15 for both cases. The results of the test appear to indicate the sufficient level of trafficability as the residual deformation with the maximum load was approximately 2 mm.

4 CONSTRUCTION OF THE BASE LAYER

Figure 9 shows the flow of the construction of the base layer of 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 2000 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).

The number of compaction operations for the base layer is 4 passes. The compacted surface will get the unevenness (around 3 cm in size) caused by the caterpillar of the vibration roller (14 ton class), and 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 commenced in September, 2005 and approximately 107,000 m^2 of the base layer has been completed as of September, 2010. 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 2. 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 (Seto et al. 2010).

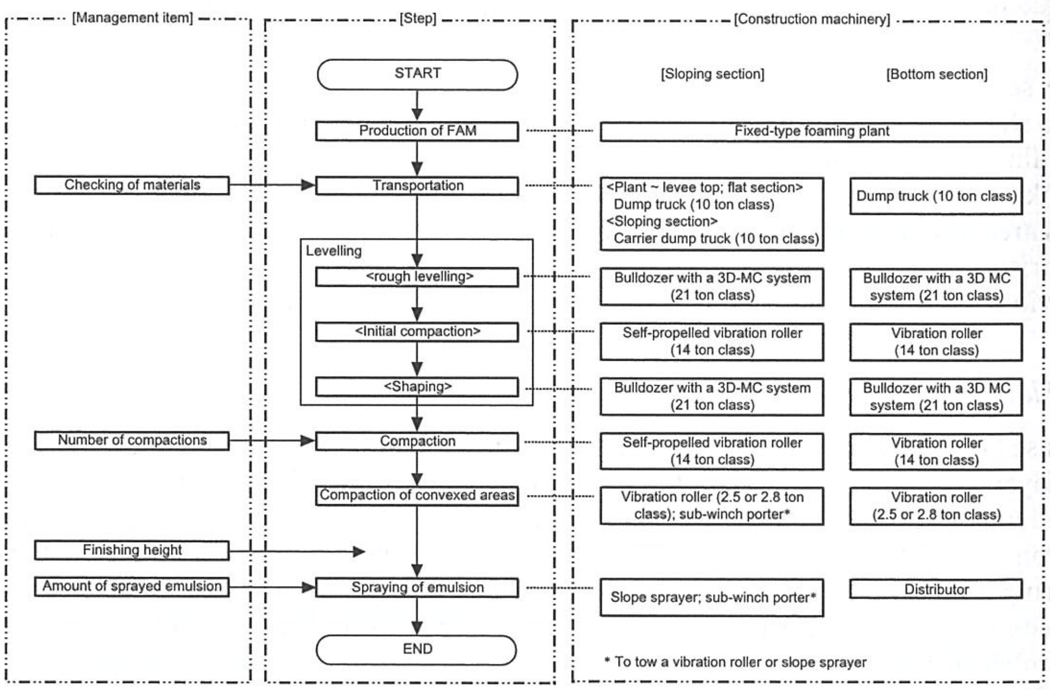


Figure 9. Construction flow of the base layer and construction machinery to be used.

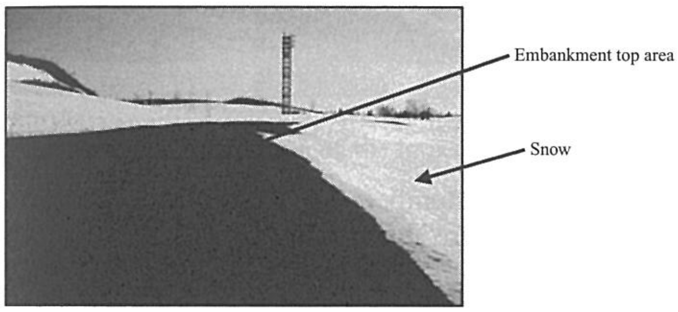
5.2 *Measuring of the slackness by the yamanaka-type soil hardness meter*

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 3 shows the meter. For this measuring operation, nine measured values were obtained at each point to calculate the average value. Figure 10 shows the results of the measurement.

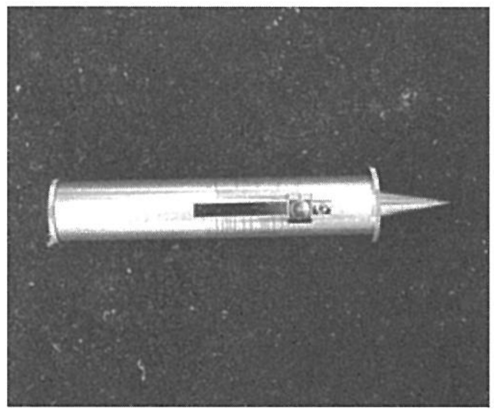
The following knowledge has been acquired from the results of the measurement using the said meter.

- The slackness of the base layer observed after the first winter tends to disappear (the non-penetration amount increase, suggesting harder) towards summer.
- The disappeared slackness does not reappear from the second winter onwards.
- 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.

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



Photograph 2. Melting of snow at the base layer.



Photograph 3. Yamanaka-Type Soil Hardness Meter.

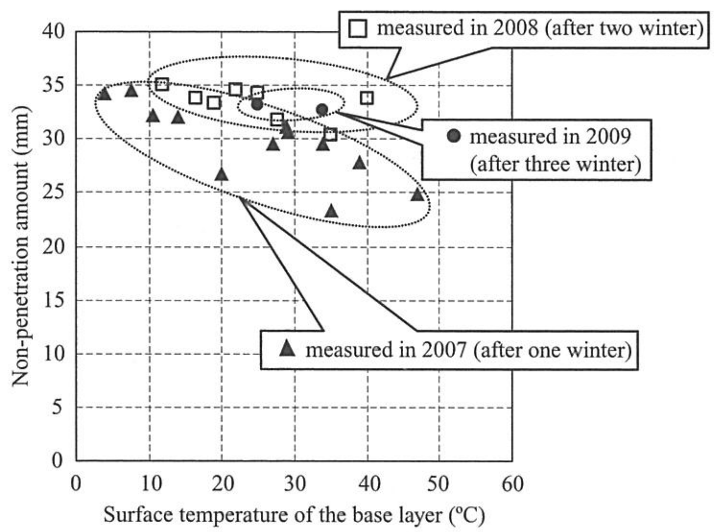
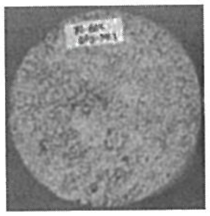
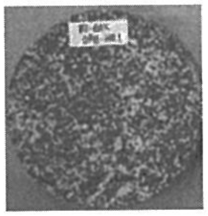
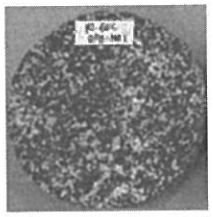
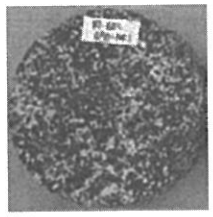


Figure 10. Measurement results of the base layer laid in 2006.

Table 6. Observation of specimen dried at 60°C.

Drying time (hours)			
0	12	24	48
			

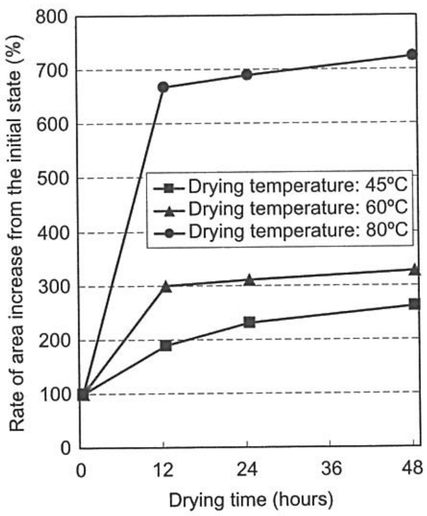


Figure 11. Rate of increase of asphalt mortar area.

to its growing viscosity facilitated by a higher ambient temperature (this phenomenon is described as "re-expansion of asphalt cover by temperature" hereinafter).

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. 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 6 shows the observation results of the specimen dried at 60°C. Figure 11 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. 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.

6 INFORMATION TECHNOLOGY CONSTRUCTION SYSTEMS

Information Technology (IT) construction system has been greatly increasing the efficiency and effectiveness of civil engineering work. The system enables one to have centralized management of an enormous amount of three-dimensional data.

An IT system using Real Time Kinematics Global Positioning System (RTK-GPS) and Total Station (TS) is used throughout the construction of the upper reservoir. The IT system

Photograph 4. Levelling by a bulldozer Withures a 3D-MC system.

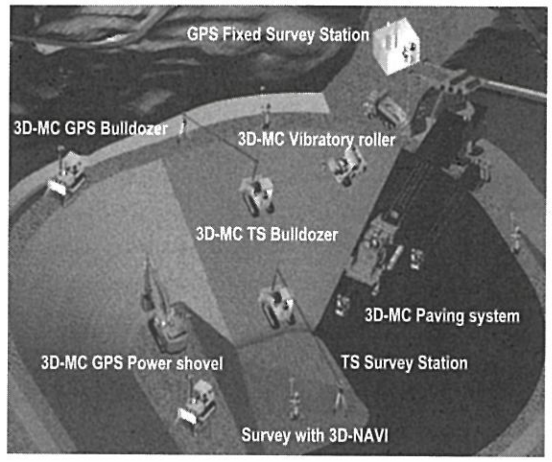
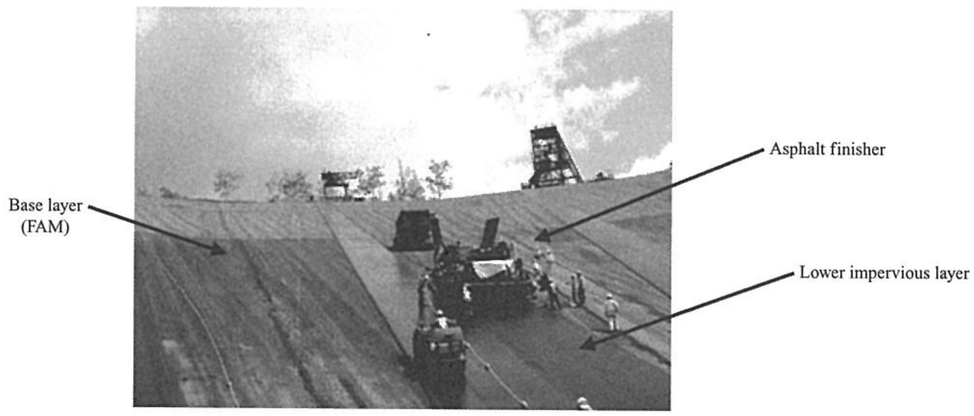


Figure 12. Civil engineering work with the IT system.



Photograph 5. Situation of the impervious layer.

greatly increased the construction efficiency. Photograph 4 shows scenes of levelling FAM by a bulldozer with a three-dimensional Machine Control (3D-MC) system, which is capable of automatically controlling the blade operation using three-dimensional design data. Figure 12 shows the civil engineering work with the IT system at the upper reservoir.

7 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. As shown in photograph 5, Laying of the impervious layer was commenced 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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