LABORATORY VERIFICATION OF PERFORMANCE OF PIER DECK PAVEMENT FOR NEW RUNWAY D AT TOKYO HANEDA INTERNATIONAL AIRPORT

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ABSTRACT

The fourth runway at Tokyo Haneda International Airport is planned to be in part an asphalt pavement on a pier deck. The pavement consists of asphalt mixture layers of three different types: a dense graded, a drainable and a stone mastic asphalt mixture. Their performances were studied in various laboratory tests, and the following results were obtained.

1) A dense graded asphalt mixture with polymer-modified asphalt has sufficient durability when subjected to repeated loading and with respect to the segregation of the mixture.
2) Adhesion between the asphalt mixture layer and the concrete slab is verified after repeated wheel-track loading, even under submerged conditions.
3) The three asphalt mixtures composing the surface and binder courses on the concrete slab have sufficient fatigue resistance.

KEY WORDS

pier deck, asphalt mixture, laboratory test, durability, adhesion

INTRODUCTION

In Tokyo Haneda International Airport, which plays an important role in the domestic air service network, recently increasing demand for air transportation is to be met by construction of a new fourth runway, Runway D. Since this runway is to be partly located over the mouth of the Tama River, a pier structure is to be adopted for about 1,100m of the runway length. Such a structure has never been used for airport facilities before, so performance has been specified for all components including the pavement and there is a requirement to verify performance in detail.

The required performance of the pavement was determined in consideration of design life, management plan and traffic and climatic conditions, as shown in **Table 1**. Although cracking, rutting and roughness are the indices used to judge the need for repair of airport asphalt pavements, cracking and rutting are the main focus of this study because the pavement structure will be built on a pier deck. In addition, since various problems are caused if rain permeates the pavement, exfoliation between layers and watertightness are also considered as part of the required performance.

Table 1 Required performance for asphalt pavement on pier structure

Item	Required performance
Rutting	Minimal rutting under repeated aircraft loading
Exfoliation between layers	No exfoliation
Watertightness	Pavement structure sufficiently watertight
Watertightness under aircraft loading	Pavement structure sufficiently watertight under repeated aircraft loading
Fatigue failure	No fatigue failure under repeated aircraft loading

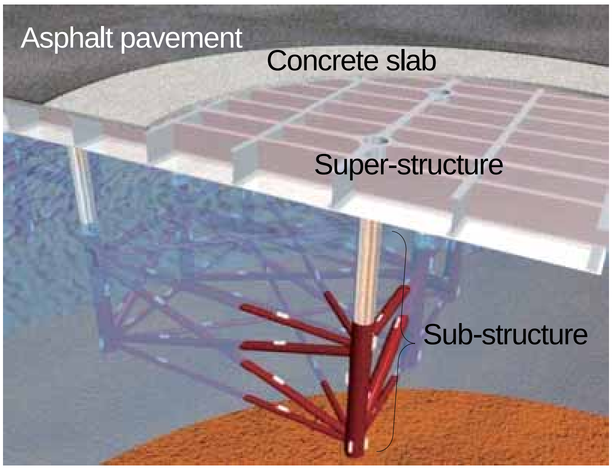

Figure 1 Jacket structure

The pier deck on which the asphalt pavement is laid consists of a concrete slab supported by a jacket structure that consists of piles, a steel pipe truss substructure and a steel beam superstructure. As shown in **Figure 1**, one standard jacket structure is 63m long and 45m wide, supported with six piles (longitudinal and transverse spacing are 31.5m and 15m, respectively). The concrete slab has a thickness of 420mm and the asphalt pavement is 200mm thick, consisting of asphalt mixtures laid in four lifts of 50mm each. The upper and lower surface courses consist of a dense graded asphalt mixture, the upper binder course is a drainable asphalt mixture and the lower binder course consists of a stone mastic asphalt mixture.

To verify the performance of this asphalt pavement, a series of laboratory tests was implemented.

ASPHALT MIXTURES AND COMBINATIONS

The materials evaluated in the laboratory tests were of the three types described above: a dense graded asphalt mixture, a drainable asphalt mixture and a stone mastic asphalt mixture. Polymer-modified asphalt (type II) was used in all cases. The composition of the mixtures is described below.

1) Dense Graded Asphalt Mixture (DGA)
The maximum particle size of the aggregate was 13mm and the particle size distribution was within the limits for surface course mixtures as described in the specifications for airport public works[1)]. Polymer-modified asphalt (type II) was used to obtain a dynamic stability of 2,500 times/mm or more in a wheel-tracking test.
2) Drainable Asphalt Mixture (DA)
The maximum particle size of the aggregate was 13mm and the same polymer-modified asphalt (type II) was used. The mixture was designed according to the drainable pavement design guide [2)] with a target air void of about 20%.
3) Stone Mastic Asphalt Mixture (SMA)
The maximum particle size of the aggregate was 13mm and the target particle size distribution was defined as about 27% passing a 2.36mm sieve. The polymer-modified asphalt (type II) was used and fibers measuring 1,200μm in length and 145μm in diameter were added. The mixture was designed to aim at a permeability coefficient of 1.0×10^{-7}cm/s or less.

The measured quality of the three asphalt mixtures as obtained in Marshall tests and other tests is shown in **Table 2**.

Table 2 Quality of asphalt mixtures

Test	Item	DGA	DA	SMA
Marshall	Optimum asphalt content (%)	5.5	4.8	6.8
	Density (g/cm^3)	2.394	2,017	2,370
	Air void (%)	3.7	20.3	2.7
	Degree of saturation (%)	77.5	31.7	85.6
	Stability (kN)	17.04	7.60	9.38
	Flow (1/100cm)	31.5	51	50
	Retained stability (%)	91.7	102.8	87.5
Cantabro	Loss (%)	-	2.5	-
Permeability	Coefficient of permeability (cm/s)	-	28.2×10^{-2}	-
Pressurized permeability	Coefficient of permeability (cm/s)	-	-	-

EVALUATION OF RUTTING RESISTANCE OF MIXTURES

In order to evaluate the rutting resistance of the asphalt mixtures, wheel-tracking tests and submerged wheel-tracking tests were carried out.

Wheel-tracking tests

The dense graded asphalt mixture used for the two surface courses was the main target of this test. In addition, the stone mastic asphalt mixture used as the lower binder course was tested, because it is subject to comparatively large tensile stresses during aircraft loading. The wheel-tracking tests were conducted according to the manual for pavement testing methods[3]. That is, a specimen measuring 300mm in width and length by 50mm in thickness was prepared. A wheel load of 686N was repeatedly applied to the specimen at a fixed speed in a temperature-controlled room at an ambient temperature of 60°C.

The test results are shown in **Table 3.** Here, the dynamic stability of the dense graded asphalt mixture satisfies the performance requirement of 2,500 times/mm or more. In addition, the required dynamic stability of the stone mastic asphalt mixture was also verified.

Table 3 Dynamic stability of asphalt mixtures

Mixture	Specimen No.			Average
	1	2	3	
DGA	10,500	10,500	15,750	12,300
SMA	5,250	6,300	7,875	6,480

(unit: cycles/mm)

Table 4 Exfoliation rate of asphalt mixtures

Mixture	Specimen No.			Average
	1	2	3	
DGA	0.70	0.33	0.22	0.42
SMA	2.43	1.59	1.54	1.85

(unit: %)

Submerged wheel-tracking tests

The stone mastic asphalt mixture used as the lower binder course, which is thought to be highly susceptible to stagnant water resulting from rain permeation, was subjected to submerged wheel-tracking tests. The dense graded asphalt mixture used for the surface course was also tested, since aircraft loading is applied directly to this layer.

The submerged wheel-tracking tests were carried out according to the method indicated in the manual for pavement testing methods (supplement)[4]. The specimens measured 300mm in width and length by 100mm in thickness. Their composition consisted of a 50mm thick asphalt mixture layer over a 50mm thick cement-treated base. In the tests, each specimen was placed in water with the level maintained at the bottom of the asphalt mixture layer. Wheel load was then repeatedly applied as above. The ambient temperature was similarly held at 60°C in these tests.

Table 4 shows the results. The exfoliation rate of the stone mastic asphalt was 1.85%, which is less than the 5% specified in reference 5), so resistance to exfoliation between asphalt and aggregate is fully with the requirements. This is also true for the dense graded asphalt mixture made with polymer-modified asphalt.

EVALUATION OF ADHESION BETWEEN ASPHALT MIXTURE AND CONCRETE SLAB

Special wheel-tracking tests and submerged wheel-tracking tests were carried out for the purpose of verifying adhesion between the asphalt mixture and the concrete slab. The stone mastic asphalt mixture, the material of the lower binder course, was the target of these tests.

Special wheel-tracking tests

In these special tests, the wheel load was applied to a specimen comprising the asphalt mixture on a concrete slab. The specimen size was the same as that used in the submerged wheel-tracking tests, being 300mm in width and length with a thickness of 100mm. In the process of preparing the specimen, the asphalt mixture was laid on the concrete slab after applying waterproofing material which met the requirements described in reference 6).

The loading wheel used in the tests, consisting of three connected solid tires, was able to apply a load of 2,058N over a width of 150mm. As the purpose of testing was to understand the adhesion properties of the asphalt mixture to the concrete slab after 20,000 cycles of repeated loading, the ambient temperature was reduced to 40°C from the 60°C commonly used in wheel-tracking tests. At various points during loading (0, 2,000, 4,000 and 20,000 cycles), the strength of adhesion between the asphalt mixture and the concrete slab was measured in accordance with reference 3) (except for the specified test temperature of 20°C).

The obtained values of adhesive strength are summarized in **Table 5**. Although adhesive strength falls a little with wheel-track loading, the fall does not continue as the number of loading cycles increases. Strength is clearly better than the value of 0.59MPa specified in reference 6) with any number of cycles of loading. These results demonstrate that the pavement structure has adequate performance under aircraft loading; that is, there is sufficient adhesion between the asphalt mixture and the concrete slab.

Table 5 Adhesive strength in special wheel-tracking tests

Specimen No.	Before tracking	Unsubmerged			Submerged		
		No. of loading cycles			No. of loading cycles		
	0	2,000	4,000	20,000	2,000	4,000	20,000
1	1.15	1.02	1.26	0.97	1.15	1.40	1.09
	1.30	0.92	1.27	1.13	1.30	1.38	1.25
2	1.25	1.02	1.12	1.25	1.50	1.40	1.25
	1.27	1.02	1.25	1.38	1.40	1.30	1.15
3	1.66	1.25	1.02	1.09	1.27	1.25	0.99
	1.66	0.76	1.27	0.92	1.27	1.48	1.15
Average	1.38	1.00	1.20	1.12	1.32	1.37	1.15

(unit: MPa)

Special submerged wheel-tracking tests

Special submerged wheel-tracking tests were planned to evaluate adhesion between the asphalt mixture and the concrete slab if rain stagnates within the pavement. The water level was kept 40mm below the top surface of the specimen, the composition of which was the same as in the special wheel-tracking test. Other test conditions were same as those used in the special wheel-tracking test.

The test results are given in **Table 5**. Although adhesive strength does not change until 4,000 cycles of loading, there is a strength reduction, compared with the non-tracked state, of 10% or more by 20,000 cycles of loading. As the strength exceeds the standard value already mentioned (0.59MPa), adhesion is recognized as satisfactory even in the case of submersion.

EVALUATION OF FATIGUE RESISTANCE OF ASPHALT MIXTURE

In order to evaluate the fatigue resistance of asphalt mixtures making up the asphalt pavement laid over the concrete slab, bending fatigue tests were carried out. Here, the resilient modulus of each asphalt mixture was first measured, then the maximum value of strain caused by aircraft loading was calculated and finally the fatigue resistance at maximum strain was verified through a bending fatigue test. The asphalt mixtures used in this evaluation process were the three types already discussed: dense graded, drainable and stone mastic.

Resilient modulus

A repeated indirect tension test was conducted to measure the resilient modulus as the elastic modulus of each asphalt mixture. Two temperature conditions (-5°C, 20°C) were adopted in accordance with the procedure specified in the performance verification, while two loading frequencies (10Hz, 2Hz) were used in consideration of aircraft moving on a runway and taxiway, respectively. Although each loading waveform was a haversine wave, it consisted of 0.09s loading and 0.01s unloading in the case of 10Hz loading and 0.1s loading and 0.4s unloading in the case of 2Hz loading. Though the load corresponding to 50% of strength was applied to the specimen in the case of 2Hz loading, a smaller load, 10 to 15% of strength, was applied in the case of 10Hz loading. The specimens, measuring 100mm in diameter and 63.5mm in height, were prepared using a gyratory compactor.

The average value of resilient modulus (*Mr*) is shown in **Table 6**. Though the resilient modulus becomes quite low at the higher test temperature in the case of 2Hz loading, it differs little with temperature change under 10Hz loading. Among the three asphalt mixtures, the drainable asphalt has the minimum modulus, whereas stone mastic asphalt and dense graded asphalt have the maximum at 10Hz, 2Hz, respectively.

Table 6 Resilient modulus of asphalt mixtures

Mixture	Frequency (Hz)	Temperature (°C)	*Mr* (MPa)	Temperature (C)	*Mr* (MPa)
DGA	2	-5	19,000	20	9,800
	10	-5	7,200	20	6,500
DA	2	-5	6,700	20	2,700
	10	-5	5,700	20	4,600
SMA	2	-5	11,600	20	4,200
	10	-5	7,600	20	7,200

Calculation of maximum strain

The maximum strain of asphalt mixture layers as aircraft load is applied to the surface of a pavement laid on piers was calculated using three-dimensional finite element analysis. As a structural analysis model, the one jacket shown in **Figure 2** was assumed. To model the adhesion between the stone mastic asphalt mixture layer and the concrete slab, springs were inserted in the vertical direction and two horizontal directions. The steel beams were modeled by beam elements. The elastic moduli of the asphalt mixtures were based on the test results described above and standard values were used for other material properties. To calculate the maximum strain of asphalt mixture layers, various aircraft, including A380-800, B747-400D, B777-200ER and B767-300, were placed at various positions on the pavement structure.

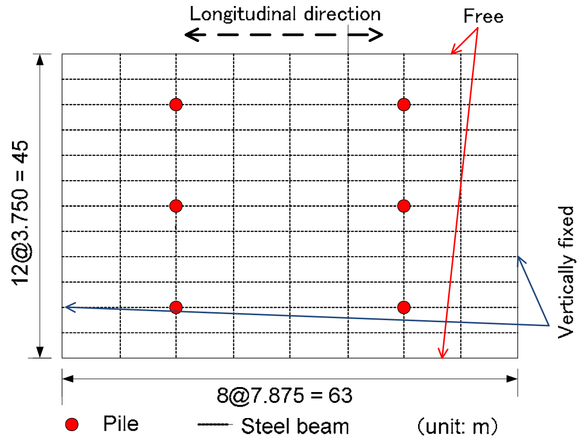

Figure 2 Structural analysis model (plan)

Table 7 Strain used for bending fatigue tests

Facility	Temperature (°C)	DGA	DA	SMA
Runway	-5	250	190	140
	20	230	190	150
Taxiway	-5	170	100	70
	20	200	190	200

(unit: 1×10^{-6})

Fatigue resistance

The fatigue resistance of the asphalt mixtures was verified through repeated bending fatigue tests using the maximum values of tensile strain obtained in the analysis described above. Specimens measuring 40mm in width and thickness, and 400mm in length, were cut from a sample of dimensions 150mm in width, 400mm in length and 50mm in thickness. The test was carried out by two-point loading using a two-point support system with a spacing of 100mm. The following test conditions were adopted:

- Loading frequency: 10Hz , 2Hz
- Temperature: -5°C, 20°C
- Loading waveform: sine curve
- Strain: shown in **Table 7** (at the bottom of the specimen)
- Maximum number of loading cycles: 200,000

As an example of the test results, those for the dense graded asphalt mixture at –5°C and 20°C are shown in **Figure 3**. No sign of possible fatigue failure is seen up to 200,000 cycles of loading. This is true for other conditions and for the other asphalt mixtures, so the fatigue resistance of the pavement structure is concluded to be sufficient.

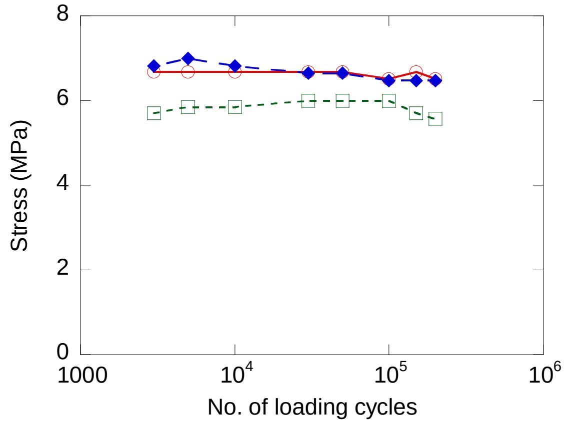

Figure 3 Example of fatigue test results (dense graded, -5°C, 10Hz)

CONCLUSIONS

A performance evaluation was carried out for an asphalt pavement on a concrete slab as planned for the pier portion of Runway D at Tokyo Haneda International Airport. The results of the evaluation are summarized as follows.

(1) In wheel-tracking tests and submerged wheel-tracking tests on a dense graded asphalt mixture with polymer-modified asphalt planned for use in the surface courses, dynamic stability was found to be 2,500 times/mm or more. It is concluded that its resistance to rutting is sufficient. Resistance to exfoliation is also sufficient.

(2) In special wheel-tracking tests and special submerged wheel-tracking tests, adhesion between the stone mastic asphalt concrete layer (planned as the lower binder course) and the concrete slab was found to satisfy the performance requirements. Adhesion between the two is concluded to be sufficient.

(3) In repeated bending tests up to a maximum of 200,000 cycles on the dense graded asphalt mixture, the drainable asphalt mixture, and the stone mastic asphalt mixture, no fatigue failures were observed. The fatigue resistance of all three asphalt mixtures is concluded to be sufficient.

REFERENCES

1) Civil Aviation Bureau, Ministry of Land, Infrastructure and Transport (ed.): Common Specifications for Airport Public Works, 2004.
2) Japan Road Association: Technical Guide for Drainable Pavements (Draft), 2001.
3) Japan Road Association: Manual for Pavement Testing Method, p.1,069, 1988.
4) Japan Road Association: Manual for Pavement Testing Method (Supplement), p.317, 1996.
5) Japan Highways (Eastern, Central and Western: Design Guide (Vol.1, Pavements), 2006.
6) Japan Road Association: Design and Construction Data on Waterproofing Layer for Reinforced Concrete Bridge Deck for Highway, 25p., 1987.