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Ten Years Performance of a Water-Resistant Airport Runway Constructed on Reclaimed Ground

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Abstract: With limited land availability and increased awareness of environmental issues, Japan has had to construct many airports on reclaimed land in recent years. Such sites generally have a higher ground–water table than elsewhere, leading to frequent moisture-related damages in airport pavements. In response to this situation, a number of countermeasures to improve pavement design in terms of structure and materials were developed based on laboratory tests and a study of experimental pavements: properly reducing the design CBR of the subgrade, using asphalt-stabilized material for the base, and installing a drainage system around the pavement. These improvements were implemented in the construction of runway C at Tokyo Haneda International Airport. Through a 10-yearservice, the pavement was continuously monitored in terms of loading capacity and surface conditions (cracking, rutting, and roughness). The results were reported and analyzed in this paper, indicating that the above countermeasures effectively suppress moisture-induced damages and achieve a water-resistant airport pavement.

***Key words**: Airport runway; High water table; Reclaimed ground; Ten years performance.*

Introduction

As a consequence of limited land availability and gradually increased awareness of environmental issues, many new airport projects in Japan have to make use of land reclaimed from the sea, such as Tokyo Haneda International Airport and Kansai International Airport. However, the ground-water table is generally higher in the case of reclaimed land than at inland airport. If pavements are not properly designed, they will suffer from the moisture-induced damages [1-3]. For this reason, improved design methods for structure and materials are required for airport pavements constructed on reclaimed land to provide satisfactory performance over the service period.

In past years, considerable efforts have been put into preventing moisture-induced deterioration in asphalt pavements. For example, Fwa suggested that drainage analysis should be done as part of the pavement design process, and an efficient drainage system to quickly remove water should be considered in pavement construction and maintenance [4]. Elfino and Davidson recommended that a subgrade fill might be considered in cases where the in-situ ground had a high water table and that an economical fill height could be determined by utilizing the relationship between deformation and water content according to the Shell criteria [5]. In addition, the drainage characteristics of the base and subbase were highlighted as an important design consideration in the Association of State Highway and Transportation Officials (AASHTO) 1993 design method [6]. More studies can be found on improving the resistance of asphalt mixtures against moisture, such as using hydrated lime or other liquid anti-stripping additives [7-11].

With the aim of designing a water-resistant airport pavement, this research project involved a comprehensive series of laboratory tests and field pavement trials. The results obtained were then successfully applied to the construction of runway C at Tokyo Haneda International Airport. The performance of this runway has been continuously monitored for a period of 10 years.

Structure and Materials Design

This study commenced with laboratory tests aimed at improving the water resistance of asphalt mixtures and base course materials. Experimental pavements were then constructed to select the most appropriate water-resistant pavement structure. Based on the results of this work, a systematic method of pavement structure design including improving materials that can get high water resistance was developed. It was eventually applied to the construction of runway C at Tokyo Haneda International Airport located on a man-made island with a high ground water-table.

Laboratory Tests

Submerged wheel tracking tests were used to evaluate the moisture resistance of asphalt mixtures. Specimens consisted of an asphalt concrete (AC) layer and a 100-*mm* thick cement stabilized layer. Two thicknesses of AC layer were studied: 50 and 100*mm*. In half of the specimens with a 50-*mm* thick AC layer, 50% of the mineral filler was replaced by hydrated lime aimed to enhance anti-stripping ability. Straight asphalt with a penetration of 60-80 as commonly used for airport pavements in Japan was adopted. Prior to testing,

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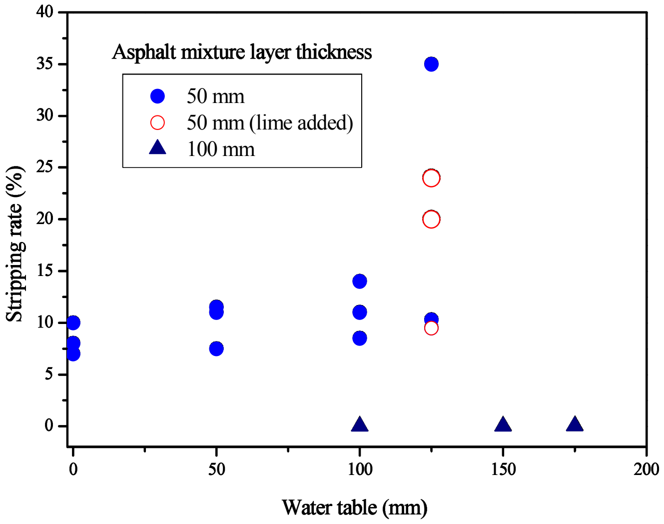


Fig.1. Stripping Rate of Asphalt Mixtures at Different Water Levels.

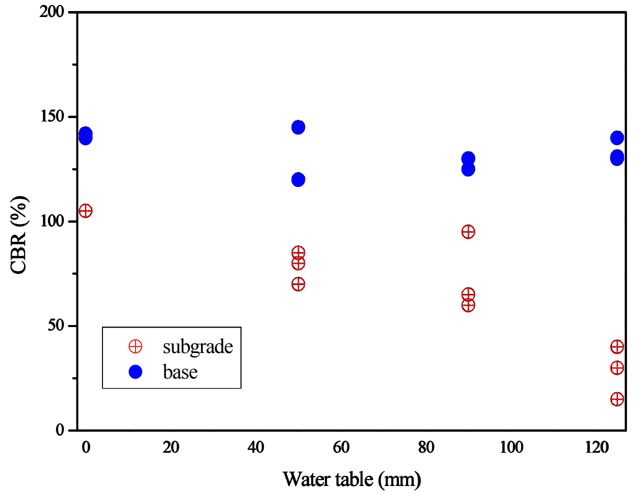


Fig. 2. CBR of Subgrade and Base Materials at Different Water Levels.

the specimen in each case was soaked in a water bath at 60°C up to a predetermined level (ranging from the bottom of the specimen to the top) for a curing time of 1 hour. A wheel load with a pressure of 0.63*MPa* ran repeatedly at the middle of the specimen surface with the test terminating at 25,000 cycles. As shown in Fig. 1, the use of hydrated lime as a portion of mineral filler did not have a significant effect on improving the water resistance of the specimens though it did contribute to the reduced variation among the test results. A notable effect was that little stripping occurred when the AC layer thickness was increased from 50 to 100*mm*. This verified that moisture damage could be significantly suppressed by suitably increasing the AC layer thickness.

California bearing ratio (CBR) tests were used to evaluate the water resistance of the subgrade and base materials. In this study, subgrade materials were natural sand and crushed stone mixed in a ratio of 1:4, while the base materials were crushed stone stabilized by adding cement at a proportion of 1.5% by weight. After soaked in 20°C water at a specific level ranging from the bottom of the specimen to the top (completely immersed), specimens were removed and tested using the standard CBR procedure. The results are presented in Fig. 2. It can be seen that the CBR value of subgrade materials rapidly decreased with the increase of the water level. For completely immersed specimens, the CBR value was only about 20% of that measured under dry conditions. This demonstrated that moisture had a tremendous effect on the strength of the normally used subgrade materials. In contrast, the cement-stabilized base materials lost little strength after water conditioned even when completely immersed. Therefore, it can be concluded that cement-stabilized materials were superior to resist water intrusion.

Experimental Pavements Study

The study continued with the construction of experimental pavements. Pavement design followed the standard CBR method to meet a design traffic volume of 3,000 coverages by a standard aircraft load (Boeing 747) [12]. The design CBR of the subgrade under dry conditions was 9%. Four sections of pavements were built, as shown in Fig. 3, of which Section C had the conventional structure comprising of mechanically stabilized stone (cement stabilized aggregate) as the base course and crushed stone as the subbase. Asphalt-stabilized materials were used as the base course for the other sections as well as for the subbase in Section B. Sections A and D had almost the same structure and materials except that the natural crushed stone was replaced by recycled crushed stone (stone from recycled asphalt pavement) in the subbase of Section D. In all experimental sections, the subgrade consisted of 2*m* of sand under which another sand layer was laid.

The bearing capacity of the experimental pavement sections was measured by the falling weight deflectometer (FWD) with a load of 200*kN* under the following five groundwater conditions:

- ➢ Not-submerged
- ➢ Submerged to mid-depth of subgrade
- ➢ Submerged to top of subgrade
- ➢ Submerged to top of subbase
- ➢ Submerged to top of base course

The used falling weight deflectometer (FWD) as shown in Fig. 4 is capable of applying the load up to 250*kN*, which is mounted with seven deflection sensors at locations ranging from the load center (0.0*m*) to 2.50*m* distant from the center. The test results are presented in Fig. 5. It can be seen that deflections tended to increase as the water level increased regardless of the pavement structure, with a more significant increase in Section C. Among the four sections, Sections C and D exhibited much greater deflection than Sections A and B. Sections A and B always showed similar deflection and the increase in deflection slowed after the water level reached the base layer. It was believed that the higher water resistance in Sections A and B could primarily be attributed to the use of asphalt-stabilized natural crushed stone as a base material. Sections C and D exhibited similar deflection before the water level exceeded the top of the subgrade, but thereafter the deflection of Section C rapidly increased, whereas it slowed in Section D. This difference was mainly attributed to the different base layers used in the two sections, that is, the mechanically stabilized crushed stone used in Section C was more sensitive to water than the asphalt-stabilized materials used in Section D. When comparing

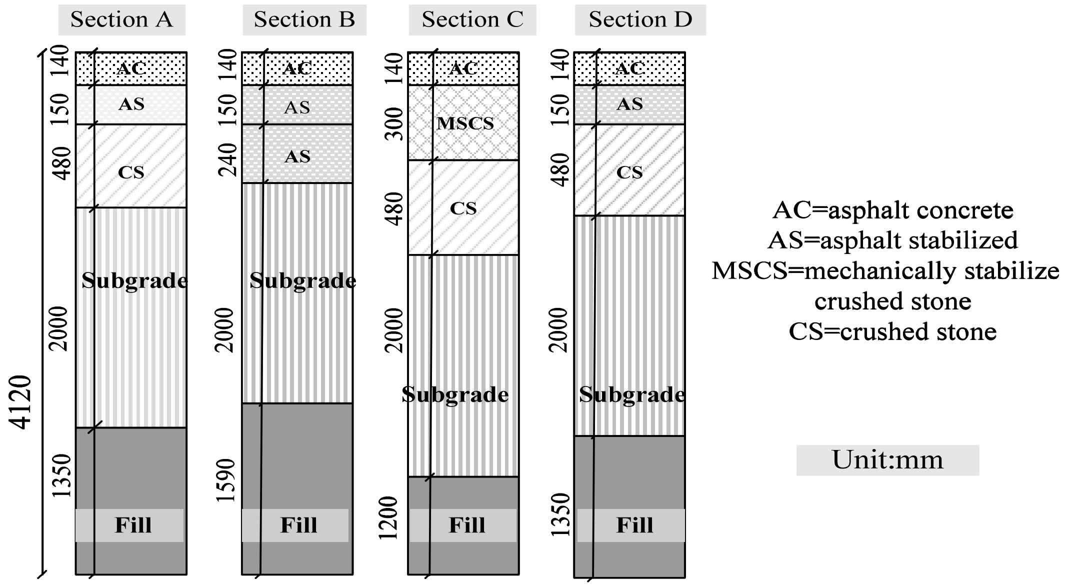


Fig. 3. Schematic Graph of Experimental Pavement Structure.

Fig. 4. FWD (Falling Weight Deflectometer).

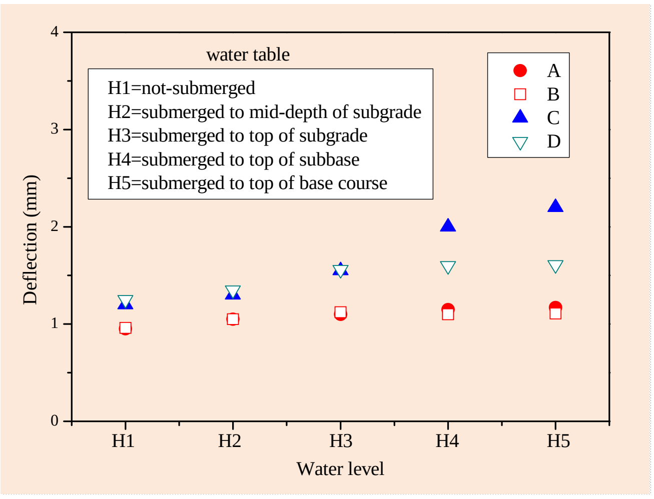


Fig. 5. Maximum Deflection of Experimental Pavements after Temperature Correction.

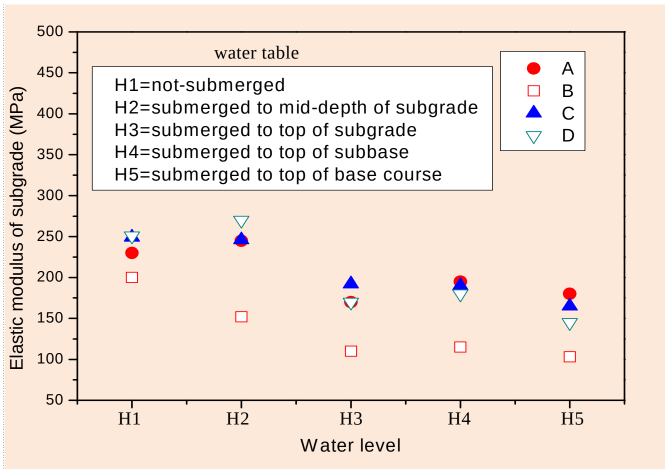
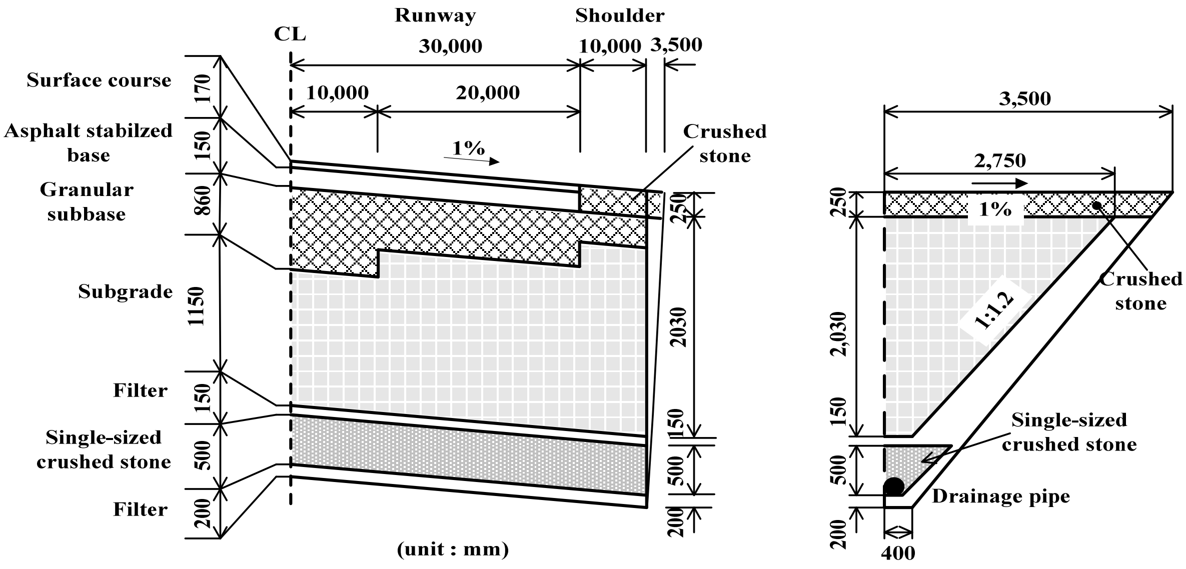


Fig. 6. Change of Elastic Modulus of Subgrade in Experimental Pavements.

Section A with Section D, Section A always deflected less than Section D irrespective of water level. The difference indicated that using recycled crushed stone in place of natural crushed stone in the subbase layer could compromise water resistance.

As found in the laboratory tests, the behavior of the subgrade was significantly affected by the presence of groundwater. The elastic modulus of the subgrade in the experimental sections was obtained by backcalculation from the deflections to quantify this phenomenon. Fig. 6 presents the elastic modulus of the subgrade under FWD loading for each section. It can be seen that the modulus decreased as the pavement became submerged in water. The modulus dropped by 20-50% as the groundwater rose up to the subgrade surface from the not-submerged condition. Correspondingly, it was reasonably concluded that the CBR of subgrade would drop at the same rate as it was strongly related to the modulus. Thus, the design of the pavement structure must either ensure the basis for using the not-submerged CBR value by stabilizing the subgrade



(a) pavement structure

(b) filtering system

Fig. 7. Pavement Structure Used for Runway C.

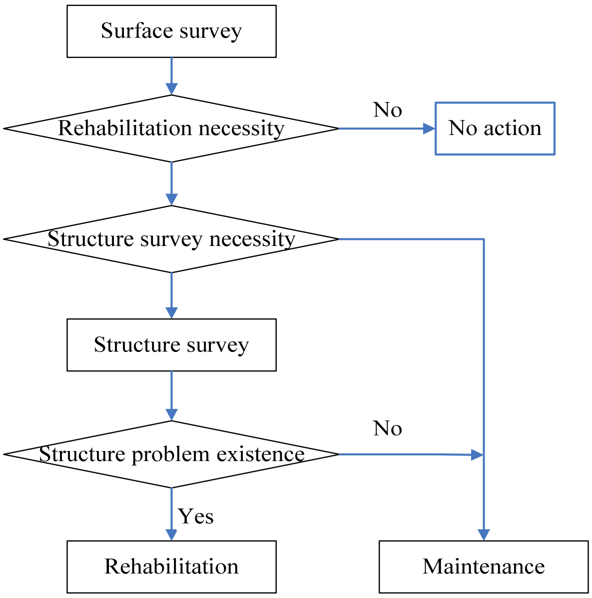


Fig. 8. Evaluation System for Airport Pavement Management.

or adopt the reduced strength exhibited in the submerged situation.

Water Resistant Pavement Structure

In accordance to the laboratory tests and experimental pavement study described above, a number of conclusions were drawn for designing a water resistant pavement.

- An increase in thickness of the AC layer was the most effective countermeasure to prevent stripping of the asphalt mixture layer.
- Cement stabilized material could achieve a higher strength when it was submerged in water.
- Pavement structure using asphalt stabilizer materials as the base course was more water-resistant than one using a granular base.
- To reflect the conditions experienced in practice, the reduced CBR obtained in the submerged conditions should be used rather than that measured under dry conditions.

Following these findings, the pavement structure for runway C was designed to meet an expected traffic volume of 40,000 coverages by a Boeing 747 over a 10-year service period [12, 13]. The results are presented in Fig. 7(a). Taking account of both economic and engineering viewpoints, the subgrade materials were not cement-stabilized; instead the CBR of the subgrade used was intentionally reduced using a value converted from its modulus back-calculated from the submerged condition. In contrast with a typical airport pavement structure (Section C in Fig. 3), the thickness of the AC layer was increased to 170*mm*, and asphalt-stabilized material was used as the base course. In addition, based on experience with a previous runway project, a filter system for lowering the water level was implemented around the pavement structure as shown in Fig. 7(b).

Ten Years Performance of Runway C

Runway C is 3,000*m* long and opened to traffic in 1996. Straight asphalt (60-80) was used in the asphalt mixture. All materials used satisfied the specifications for airport pavements [13]. Since coming into operation, the runway had accepted regular traffic and was continuously monitored for a period of 10 years. During the first few years, all sections performed equally well. Most deterioration occurred in the latter five years and is analyzed in the following sections.

Method of Evaluating Airport Pavement Performance

Performance data collected during the monitoring of runway C were evaluated using the routine method schematically shown in Fig. 8, with surface and structure evaluation included [14].

Table 1. PRI Criteria for Rehabilitation Works.

Pavement Type	A	B	C
Runway	≥ 8.0	8.0-3.8	≤ 3.8
Taxiway	≥ 6.9	6.9-3.0	≤ 3.0
Apron	≥ 5.9	5.9-0.0	≤ 0.0

Table 2. CR, RD, and SV Criteria for Rehabilitation Works.

Distress type	Pavement type	A	B	C
CR (%)	Runway	≤ 0.1	0.1-6.5	≥ 6.5
	Taxiway	≤ 0.9	0.9-12.7	≥ 12.7
	Apron	≤ 1.9	1.9-17.0	≥ 17.0
RD (*mm*)	Runway	≤ 10	10-38	≥ 38
	Taxiway	≤ 17	17-57	≥ 57
	Apron	≤ 22	22-70	≥ 70
SV (*mm*)	Runway	≤ 0.26	0.26-3.64	≥ 3.64
	Taxiway	≤ 0.91	0.91-6.57	≥ 6.57
	Apron	≤ 1.50	1.50-8.63	≥ 8.63

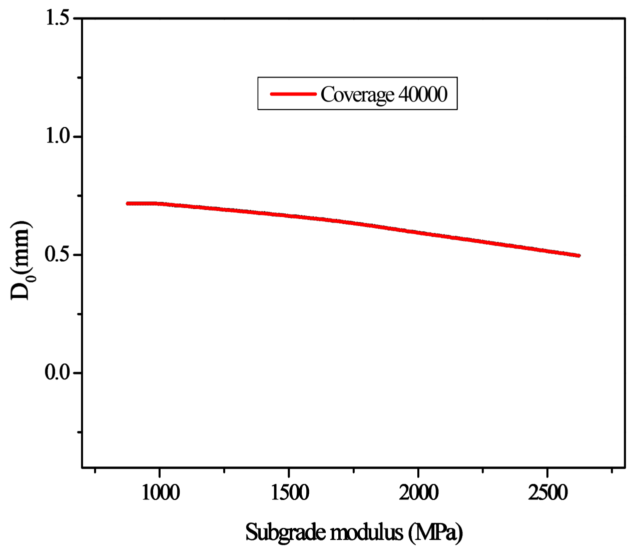


Fig. 9. Criteria for Maximum Deflection (D_0).

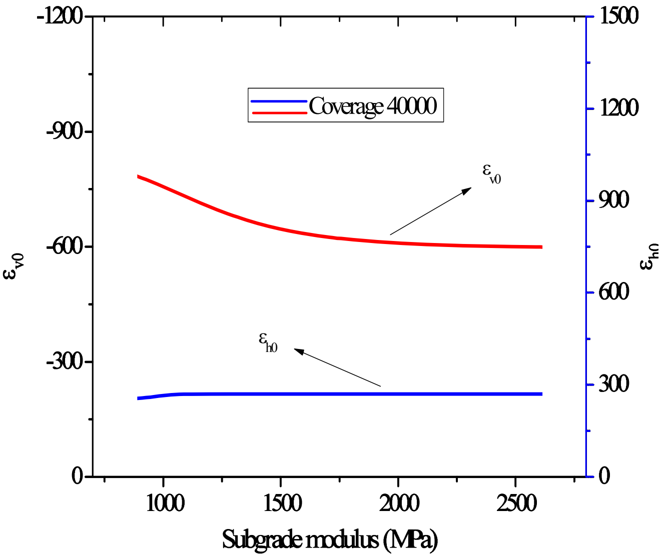


Fig. 10. Criteria for Tensile Strain (ε_{h0}) and Compression Strain (ε_{v0}).

Surface condition was usually evaluated by the pavement rehabilitation index (PRI). This was developed based on relating the engineers' subjective ratings with the objective measurements representing the pavement surface condition. PRI took the polynomial form including three variables representing rutting, cracking and roughness, as expressed by Eq. (1).

$$PRI=10-0.450CR-0.0511RD-0.655SV \quad (1)$$

where,
PRI = pavement rehabilitation index;
CR = cracking ratio, %, defined as the cracked area divided by the unit area;
RD = rutting, mm, the maximum rutting depth in the unit area; and
SV =standard deviation of roughness measured by 3*m* profilemeter.

The PRI value scaled from 0 for very poor to 10 for excellent pavement condition. The necessity for rehabilitation works was evaluated by the categorized criteria given in Table 1. Categories A, B, and C, respectively, indicated that rehabilitation was not required; rehabilitation was required in the near future and rehabilitation was required immediately. Since runway pavements were usually used by aircraft operating at a high speed, a stricter criterion was specified than for taxiways and aprons.

In general, rutting, cracking, and unevenness together contributed to pavement surface deterioration. Under some rare conditions, however, deterioration mainly resulted from one or two of these distresses. In such cases, PRI alone could not give a reliable evaluation. Therefore, the criterion for each distress was also given, as shown in Table 2. Here, categories A, B, and C had the same meaning as those in Table 1.

The structural capacity of the airport pavement was evaluated by the FWD-based system incorporating three main indexes in terms of maximum deflection (D_m), vertical strain at the top of the subgrade (ε_v) and horizontal strain at the bottom of the AC layer (ε_h). D_m was directly measured by FWD tests, while ε_v and ε_h were calculated using the backcalculated modulus of each layer. The three indexes were then corrected to standard conditions (20°C and 10*Hz* loading frequency) and compared against criteria that were established

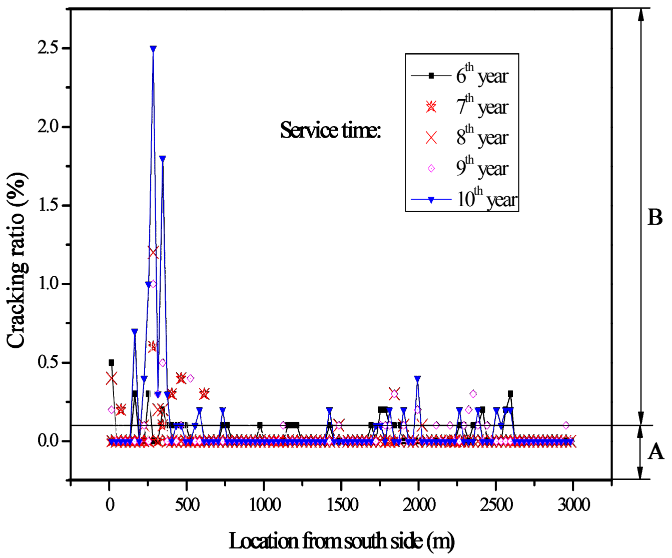


Fig. 11. Change in Cracking of Runway C in the Latter Half of Service Period.

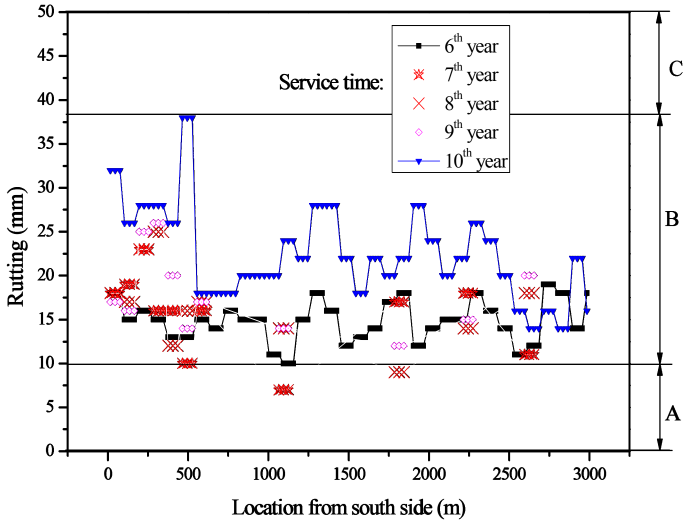


Fig. 12. Change in Rutting of Runway C in the Latter Half of Service Period.

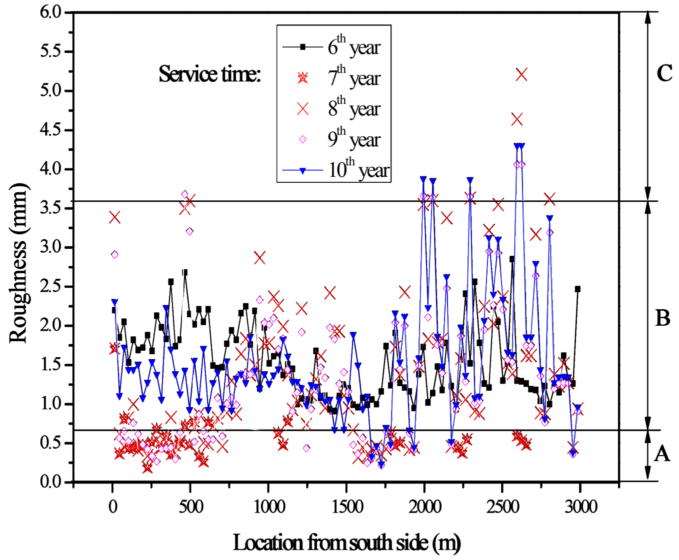


Fig. 13. Change in Roughness of Runway C in the Latter Half of Service Period.

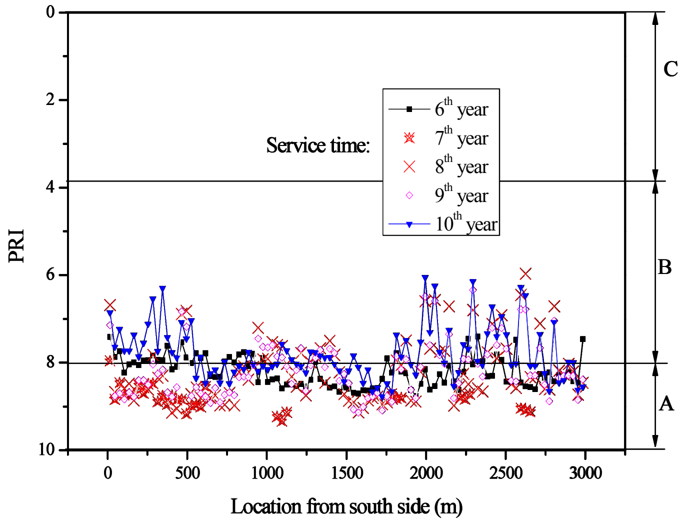


Fig. 14. Change in PRI of Runway C in the Latter Half of Service Period.

based on accelerated pavement tests [15]. Figs. 9 and 10 present the criteria used in this study [15, 16].

Discussion of Ten Years Performance of Runway C

Changes in Surface Condition

The surface condition of Runway C in terms of cracking, rutting, and roughness over the latter five years of the 10-year service period is, respectively, is presented in Figs. 11, 12, and 13. Based on these measurements, the PRI was calculated as shown in Fig. 14.

These monitored results showed that there was a general trend toward progressive deterioration of the surface condition with the time, as evidenced by the worsening of each index and the falling PRI. After five years of service, 68% of the runway fell into PRI category A, while the rest was rated in category B. Upon the completion of a 10-year design life, the percentage of sections evaluated as PRI category A fell to 47%, and other sections were still scored as B. Overall, runway C provided an acceptable surface condition for the full 10-year period since most sections were rated as PRI category A or B, so no immediate rehabilitation was required.

Different sections of runway C behaved differently. Sections from 0 to 500*m* (starting from the south end), were observed to have a higher rutting and cracking ratio, more evident with respect to cracking. The possible reason for this was an inefficient filter system, which resulted in a higher ground water table in this section and consequently led to more severe distresses. Roughness was evaluated poorer in sections from 1,800 to 2,800*m* as compared with other sections. This was perhaps attributed to the different settlements of the foundation.

In addition, attention should be paid to the larger rutting suffered by runway C since a rutting depth of 15*mm* or larger was often a concern in practice though this degree of rutting was not rated poor in this paper. The main reason for this was the instability of asphalt

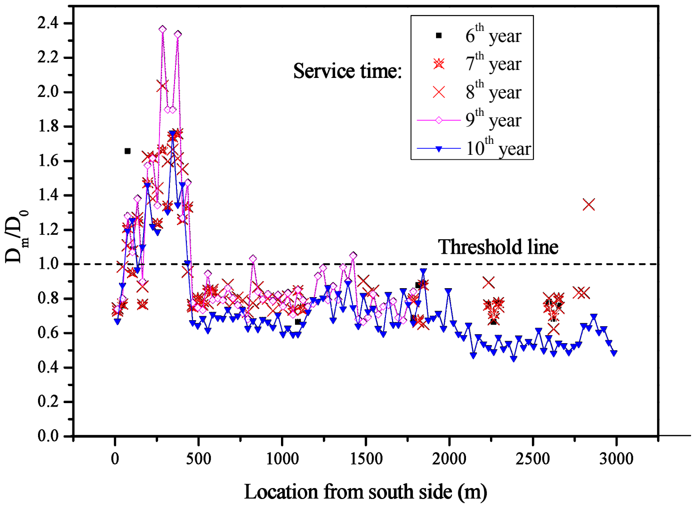


Fig. 15. Change in D_m of Runway C in the Latter Half of Service Period.

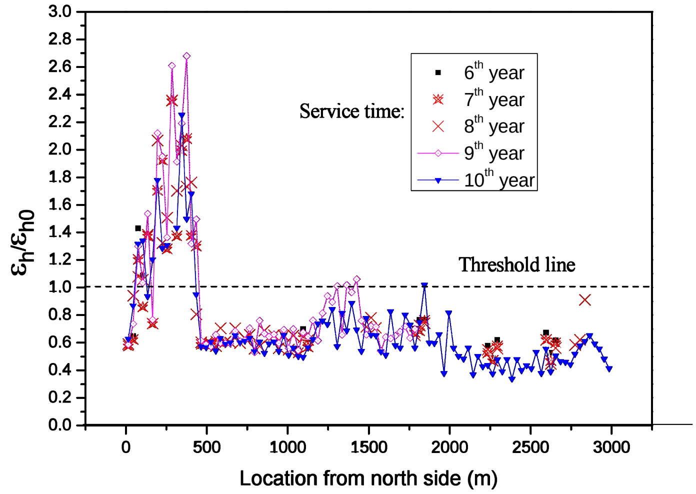


Fig. 16. Change in ε_h of Runway C in the Latter Half of Service Period.

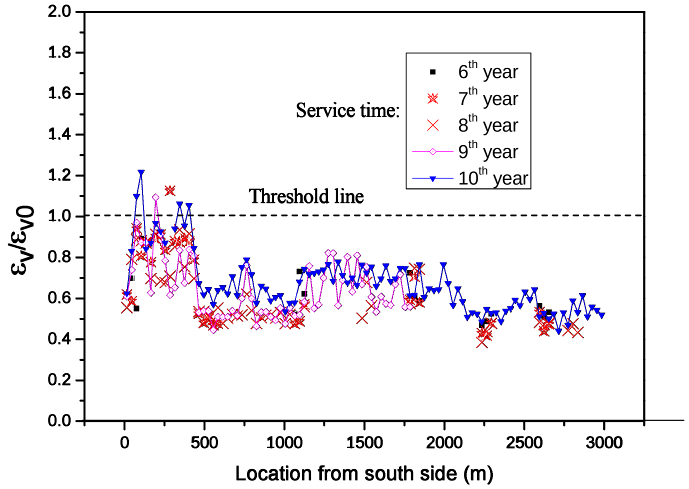


Fig. 17. Change in ε_v of Runway C in the Latter Half of Service Period.

concrete under heavy load. Hence, it was recommended that modified asphalt is used to replace straight asphalt.

Changes in Structural Bearing Capacity

The deflections used as a measure of the bearing capacity of the pavement structure were measured using the FWD with a load of 200*kN*. From the resulting deflection basin, the modulus of each layer was backcalculated. Then, the modulus of the AC layer and the maximum deflection (D_m) were corrected to the standard test conditions (20°C and 10*Hz*) with a routinely used procedure [15, 16]. This standardized AC layer modulus and the backcalculated modulus of the other layers were input into a multi-layered elastic theory based software "BISAR" to calculate the tensile strain at the bottom of the AC layer (ε_h) and the compressive strain at the top of the subgrade (ε_v). Finally, the obtained ε_v, ε_h and D_m values were compared with the criteria (D_0, ε_{h0} and ε_{v0}) as shown in Fig. 9 and Fig. 10. The results indicated the structural capacity of the evaluated pavement.

Figs. 15, 16, and 17 present D_m, ε_h and ε_v, respectively, where the ordinate represented the measured value divided by the criteria value. If this ratio was less than unity, it meant that the pavement was considered adequate to provide the required structural capacity.

As expected, the structural capacity of runway C progressively deteriorated from the 6th year to 10th year as judged from the increase in D_m/D_0, $\varepsilon_h/\varepsilon_{h0}$ and $\varepsilon_v/\varepsilon_{v0}$. As with the evaluation of surface condition, the section from 0 to 500*m* was poor in condition in regards to structure strength; this was also possibly due to the inefficient filter system. In this area, most sections recorded the D_m/D_0, $\varepsilon_h/\varepsilon_{h0}$, and $\varepsilon_v/\varepsilon_{v0}$ values over the threshold line. Other sections indicated a satisfactory structural capacity with a few sections between 1800 and 2600*m* exhibiting marginal D_m/D_0, $\varepsilon_h/\varepsilon_{h0}$ and $\varepsilon_v/\varepsilon_{v0}$ values near the threshold line. From these results, it was to conclude that the pavement structure used for runway C could sufficiently provide structural capacity over the 10-year service period if the filter system worked well.

Summary and Conclusions

The following conclusions can be drawn from this study:

1. Based on the results of the laboratory and experimental tests, a water resistant pavement structure was proposed. Differing from the traditional design for airport pavement structure, this pavement was designed using a subgrade CBR that was intentionally reduced to reflect the actual submerged condition in place of the normal dry condition. Further, the thickness of the AC layer was increased to 170*mm*, an asphalt-stabilized material layer was used as the base course and a filter system was put in place around the pavement structure.
2. The 10-year performance of runway C in Tokyo Haneda International Airport indicated that this newly established water resistant pavement structure could provide a satisfactory performance at high groundwater condition when the drainage system worked well.
3. It is recommended that, in the future, an appropriate modified asphalt binder be used in place of the straight asphalt used in this study to mitigate rutting damage.

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