J. Materials, Conc. Struct , Pavements, JSCE, No.634／V-45, 403-411, 1999 November

AIRCRAFT RESPONSE BASED AIRPORT PAVEMENT ROUGHNESS EVALUATION

Yoshitaka HACHIYA[1], Jianjun YIN[2], Osamu TAKAHASHI[3] and Kenji HIMENO[4]

[1] Member of JSCE, Dr. Eng., Chief, Runways Laboratory, Port and Harbor Research Institute, Ministry of Transport
(1-1, Nagase 3, Yokosuka 239-0826, Japan)
[2] Dr. Eng., STA Fellow, Runways Laboratory, Port and Harbor Research Institute, Ministry of Transport
[3] Member of JSCE, Dr. Eng., Senior Research Engineer, Port and Harbor Research Institute, Ministry of Transport
[4] Fellow of JSCE, Dr. Eng., Professor, Chuo University (1-13-27, Kasuga, Bunkyo-ku, Tokyo 112-8551, Japan)

Airport pavement roughness is studied including both the subjective evaluation and digital simulation. Pilots' subjective evaluation on surface characteristics is clarified by questionnaires, which indicates that the roughness is one of the most highly influential factors on riding quality and safety. The response of aircraft motion to the longitudinal profiles of airport pavements when departing on runways and taxiing on taxiways was simulated using the program TAXI. The results indicate that the aircraft response varies not only with the surface characteristics (i.e., the amplitudes and wavelengths of the profile), but also with aircraft speed. Finally, roughness criteria for runways and taxiways are proposed.

Key Words: pavement roughness, evaluation, aircraft response, vertical acceleration, simulation, criteria

1. INTRODUCTION

Recently, construction sites for airports have shifted to the softer ground, such as land reclaimed from the sea and high fill in mountainous areas. In addition, new aircraft with six-wheel landing gears have also appeared and larger aircraft are planned today. These could change the requirements for the airport pavements. On the other hand, the principle for the current method of airport pavement design has not changed for several decades and cannot take these items into account. Thus, a new design method is now required that can address the basic requirement for airport pavement, i.e., to continually provide well-conditioned surfaces for aircraft.

One possible candidate is the new concrete pavement design method issued by the Japan Society of Civil Engineers [1)], where the pavement structure is determined to fulfill various requirement to it. In the method, the requirements are defined as the serviceability consisting of foundation deformation, flexural cracks in the concrete slab, riding quality and the safety in operation. Of these four serviceability components, this paper focuses on riding quality (i.e., pilots' ease of operation and passengers' comfort), because it is the dominant factor in evaluating airport pavement in the pilot's subjective judgement, as shown later. However, the roughness of airport pavements, which governs the riding quality, is generally studied on the basis of research performed for road pavements [2), 3), 4)]. Other studies have recently been conducted that focus on airport pavement. In U.S.A., Gervais proposed the Boeing approach for runway roughness measurement, quantification and application [5)]. Gerardi analyzed the effect of runway roughness on aircraft operations [6)]. Moreover, Himeno et al. investigated the characteristics of pavement surface profile on airport runways [7), 8)]. However, the effect of pavement roughness on aircraft response was not clearly illustrated in their studies.

Similar research, that is, surface profile evaluation by analyzing the power spectral density was conducted in the Airport Pavement Committee of the Japan Society of Civil Engineers [9)]. The committee also reports the vertical accelerations at certain positions in aircraft with AIDS (Aircraft Integrated Data System) when they run on runways, and compares those at various airports. However, the committee does not show any criteria on runway roughness.

No digital simulation for analyzing the influence of pavement roughness on aircraft response was found in the literature until the 1970's when the U.S. Air Force Flight Dynamics Laboratory (AFFDL) developed the computer code TAXI [10]. The validity of this analysis was verified by tests using actual aircraft on many occasions, such as B-52 aircraft operating at U-TAPAO Air Base, Thailand during the Vietnam War. This was followed by validation tests with many fighter, cargo and bomber aircraft. Consequently, a great deal of confidence exists in using TAXI to predict aircraft dynamic response [11]. The program TAXI was used in this study to clarify the effect of pavement roughness on aircraft response.

In this study, pilots' subjective evaluation of airport pavements was first quantified by summarizing their answers to a questionnaire. Next, the current specifications for pavements were reviewed to clarify how pavement roughness is taken into consideration, and to discuss measuring equipment and the evaluation method. A digital simulation of the aircraft dynamic response to the roughness is presented, and, finally, a criteria for pavement roughness evaluation is proposed.

2. PILOTS' SUBJECTIVE EVALUATION OF AIRPORT PAVEMENTS

Pilots were asked to complete a questionnaire to study the subjective relationship between aircraft riding quality and airport pavements.

(1) Questionnaires to pilots

The questionnaires were answered by 84 pilots from the three major domestic airlines. The flight experience of the pilots in descending order was 10,000 - 15,000 hours, 5,000 - 10,000 hours, more than 15,000 hours and less than 5,000 hours. Half of the pilots had flight experience in the 10,000 - 15,000 hour bracket. The majority of aircraft operated by the pilots was large jet aircraft; that is, 70 % were B-767 and A-300, and 20 % were B-747 and B-777, with the rest being smaller jet aircraft.

The questionnaire addressed the influence of the airport pavement surface characteristics on both the riding quality and the safety of operation. The pilots were required to rank the influence of the surface characteristics on a five tier scale, with the minimum as 1 and the maximum as 5. The nine surface characteristics described below were picked up. The pilots were asked to evaluate the influence of these characteristics in terms of both the facilities and aircraft speed.

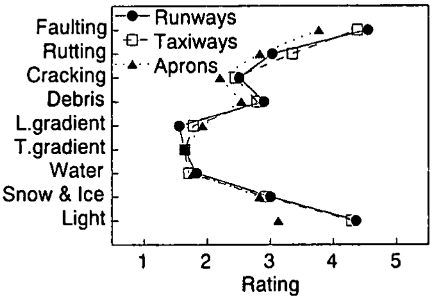


Fig. 1 Influence of surface characteristics on riding quality

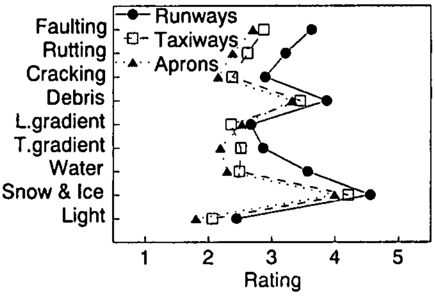


Fig. 2 Influence of surface characteristics on safety in operation

1) faulting
2) rutting
3) cracking
4) scattered debris
5) longitudinal gradient
6) transverse gradient
7) water film
8) snow and ice
9) airport lighting

(2) Summary of answers

The influence of the surface characteristics on the riding quality was not greatly different in the facilities. On the contrary, that on the safety in operation was ranked as the maximum in the runways. This difference in the influence was attributed to the difference in aircraft speed. The pilots subjectively judged that the surface characteristics had a greater influence on the riding quality at the higher aircraft speed.

The influence of each surface characteristic on the riding quality is shown in **Fig. 1**. Of these items, the longitudinal surface profile, i.e., faulting and embedded airport lights, had a greater relative influence on the riding quality. This influence is greater in both the runways and the taxiways than in the aprons.

The influence of the surface characteristics on the safety of aircraft operation is summarized in **Fig. 2**. In this case, snow and ice and scattered debris had greater influence; that is, the pilots were concerned about skid resistance and damage to tires and engines. This influence was greatest in the runways.

Studies on the skid resistance of airport pavements have been conducted, and some research results were already available [12]. In addition, debris scattered on the pavement might be studied without great difficulty because it generally results from cracking on the surface. Thus, the influence of the longitudinal surface profile, i.e., roughness, on riding quality was studied.

3. CURRENT SPECIFICATIONS ON PAVEMENT ROUGHNESS

For safe aircraft operation, standards for the pavement surface conditions (e.g., longitudinal gradient, gradient change) are specified by ICAO (International Civil Aviation Organization) and many agencies. Even for pavements constructed in accordance with this specification, the surface characteristics would change with time due to the repetition of traffic loading, ground settlement, and other factors. This deterioration could influence the riding quality of aircraft.

Surface characteristics have been used as the design criteria for road asphalt pavement design. For example, in the CBR design method, on which the current airport asphalt pavement design method is based, the pavement structure is determined from the viewpoint of changes in the surface characteristics caused by repetitive traffic loading [13]. In the AASHTO pavement design method, passengers' subjective evaluation of the riding quality was quantified as PSI (Present Serviceability Index), which was also used as the design criteria. The pavement structure is determined so that PSI does not fall below the critical value [14].

On the contrary, neither aircraft riding quality nor the safety in aircraft operation was taken into consideration in the airport pavement design method [15]. Neither were they reflected on the airport pavement evaluation method. Instead, based on the engineers' subjective judgement, the PRI (Pavement Rehabilitation Index) which indicates the necessity for rehabilitation was developed as a rehabilitation criteria [4]. The index takes into account three types of distress in both asphalt and concrete pavements: cracking, rutting and roughness for asphalt pavements, and cracking, joint failure and faulting for concrete pavements. In addition, criteria are also established for each distress type, and the necessity of pavement rehabilitation is ranked into three classifications as follows.

Table 1 Criteria of rehabilitation necessity on roughness [4]

Facility	A	B	C
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

(unit: mm)

A: rehabilitation works are not necessary,
B: rehabilitation works are needed in the near future,
C: rehabilitation works are needed immediately.

The criteria vary in facilities, depending on the aircraft speed, as well as PRI. **Table 1** shows the criteria for roughness in asphalt pavements, which is one of the most important surface characteristics for riding quality.

In addition to the above mentioned criteria, the construction criteria was also determined. The pavement roughness must be kept within the range at the pavement construction; i.e., 2.4 mm of the standard deviation of the measured data by the use of 3 m profilometer [16].

For measuring the surface roughness to determine whether it satisfies the construction criteria and to judge the necessity for rehabilitation, a 3 m profilometer is generally used, as mentioned above. The result is the continuously measured relative difference in the surface elevation and is highly influenced by the length of the profilometer itself (3 m). The profilometer can certainly be used to check variations in the pavement construction, as it can evaluate the surface roughness where the wavelength is less than its length. However, surface roughness with a longer wavelength cannot be evaluated. In addition to the profilometer, a response type roughness measuring device has recently become available. Its effectiveness, however, is not established because the results strongly depend on the equipment [17].

Thus, roughness with a shorter wavelength caused by an airport light embedded in the pavement, for example, might be estimated by the use of 3 m profilometer, because its maximum diameter is 400 mm and its maximum height is 30 mm [18]. However, roughness with longer wavelength cannot be evaluated with a 3 m profilometer. Therefore, a study simulating the response of aircraft movement to the pavement surface was conducted to clarify the influence of such roughness on the riding quality. The precise surface profile might be obtained in several ways, such as the rod-and-level method, the contactless profile measuring method [19].

4. REVIEW ON SIMULATION PROGRAM TAXI

The program TAXI was used to simulate the aircraft dynamic response. The response of a representative aircraft (B-747) to pavement roughness when departing on a runway and taxiing on a taxiway with a constant velocity were simulated digitally with the program. The aircraft vertical accelerations at the center of gravity and the pilot station were selected as the indicators of the response, with the former providing an indictor for the passengers' comfort, and the latter indicating the pilot's ease in aircraft operation. A symmetrical longitudinal pavement profile was assumed because the pavement roughness along the longitudinal direction was the most important concern. This means that the profiles for the left and right main gears and the nose gear were simplified as one profile, and thus, roll cannot occur in the aircraft motions. A series of sinusoidal waves with a variety of wavelengths and amplitudes were introduced to represent the pavement roughness.

(1) Aircraft/pavement model

The aircraft/pavement model in TAXI is shown in **Fig. 3**. The model has an asymmetrical aircraft body supported by a nose, and right and left landing gear struts. Each landing gear strut is a nonlinear, oleo-pneumatic energy absorbing device, so it is idealized as a spring combined with a dash-pot. The tire at each gear is assumed to have point contact with the profile and is idealized as a linear spring. Moreover, three individual profiles were introduced to describe the paths of the three gears.

(2) Analytical solution

The aircraft/pavement model was solved analytically in two simulation phases. First, the aircraft was idealized as a rigid body, and thus, no displacement within the body was possible. Second, the flexibility of the aircraft body was considered to reflect the bending motion of the fuselage and wings. The aircraft motion was simulated by combining the results from these two phases.

For the rigid body phase, the Lagrange method was used to determine the analytical solution due to the nonlinear property of the aircraft gears. This is expressed in Eq. (1).

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{q}_i} - \frac{\partial KE}{\partial q_i} + \frac{\partial PE}{\partial q_i} + \frac{\partial DE}{\partial \dot{q}_i} = 0 \qquad (1)$$

where,

KE - the kinetic energy,

PE - the potential energy,

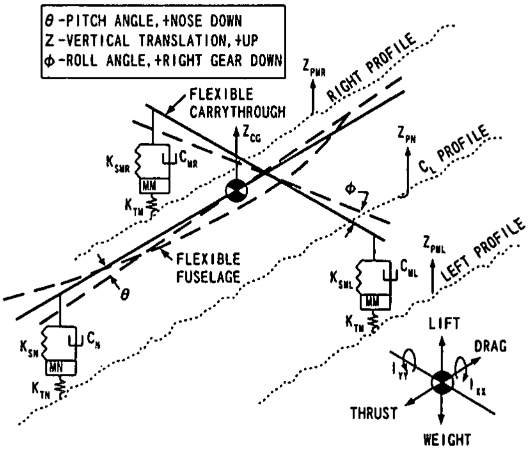


Fig. 3 Diagram used to develop mathematical model 11)

DE - the dissipated energy, and

$q_i, \dot{q}_i$ - the displacement and velocity of motion.

The analytical solution was then derived, as shown below.

a) Vertical acceleration at the gravity center

$$\ddot{Z}_{CG} = (F_{SML} + F_{SMR} + F_{SN} + L - Mg) / M \qquad (2)$$

where,

F_{SML}, F_{SMR}, F_{SN} - total strut force of the left and right landing gear and the nose gear,

L - lift force,

M - total mass of the aircraft,

g - acceleration of gravity.

b) Unsprung mass vertical acceleration of the landing gear

$$\ddot{Z}_{M} = (F_{TM} - F_{SM} - M_M g) / M_M \qquad (3)$$

where,

F_{TM} - vertical tire force of the landing gear,

F_{SM} - strut force of the landing gear,

M_M - mass of the landing gear.

c) Unsprung mass vertical acceleration of the nose gear

$$\ddot{Z}_{N} = (F_{TN} - F_{SN} - M_N g) / M_N \qquad (4)$$

where,

F_{TN} - vertical tire force of the nose gear,

F_{SN} - strut force of the nose gear,

M_N - mass of the nose gear.

d) Pitching acceleration

$$\ddot{\theta} = (F_{SML}A_{ML} + F_{SMR}A_{MR} - F_{SN}B_N - F_{TD}\varepsilon_1)/I_{YY} \qquad (5)$$

where,

F_{TD}, ε_1 - friction force of the tire and its moment arm,

A_{ML}, A_{MR}, B_N - moment arms of the left, right landing gear and the nose gear,

I_{YY} - pitching inertia.

e) Horizontal translation acceleration

$$\ddot{x} = (F_T - F_{TD} - F_{AD})/M \qquad (6)$$

where,

F_T, F_{AD} - thrust and aerodynamic drag forces.

In the flexible body simulation phase, the modal method was used to reflect the effects of the aircraft's flexibility on its motion, as shown in Eq. (7).

$$M_i\ddot{q}_i = \xi_{mli}F_{ML} + \xi_{mri}F_{MR} + \xi_{ni}F_{SN} - 2\zeta_i\omega_i M_i\dot{q}_i - \omega_i^2 M_i q_i \qquad (7)$$

where,

M_i - generalized mass,

$\xi_{mli}, \xi_{mri}, \xi_{ni}$ - model deflections at the left and right landing gear and the nose gear,

ω_i - model frequency,

ζ_i - structural damping factor,

$q_i, \dot{q}_i, \ddot{q}_i$ - generalized coordinates, and their first and second order of time derivatives,

i - the i th mode.

(3) Simulation procedures

Fig. 4 is a flow chart for the simulation procedures using TAXI. A three term Taylor series method with a constant time step (e.g., 0.001 second) was used. Results were obtained for each simulation step in consideration of the two-phased analytical solution.

a) Representative aircraft

The B-747 aircraft was selected as the representative aircraft. Its flexibility data is, however, unavailable fully from relevant literature. Because the structural parameters of aircraft class C in the literature of Sonnenburg (1976) and Spanger et al. (1997)$^{20), 21)}$ are similar to that of a B-747, the parameters of aircraft class C were used instead of those for a B-747.

b) Operating states

Two operating states were simulated:

1) Aircraft departing on the runway from an initial velocity of 55 km/h to takeoff, and
2) Aircraft taxiing on taxiway with a constant velocity of 33 km/h $^{22)}$.

In addition, a 31 m hypothetical section with a smooth surface was assumed in front of the pavement section to decrease the simulation errors.

c) Pavement roughness

A series of sinusoidal waves with a variety of wavelength and amplitude combinations, as shown in **Fig. 5**, were introduced to simulate the pavement roughness. They are:

1) Wavelength: 1.5, 3.1, 4.6, 6.1, 7.6, 9.1, 12, 15, 18, 24, 30, 46, 61, 76 and 91 m
2) Amplitude: 13, 25, 38 and 51 mm.

d) Representative value

The simulation results are a series of continuous vertical acceleration values along the longitudinal profile. To describe them quantitatively, the 85th percentile of these simulated aircraft vertical accelerations was subjectively selected as the representative value. This corresponds to the

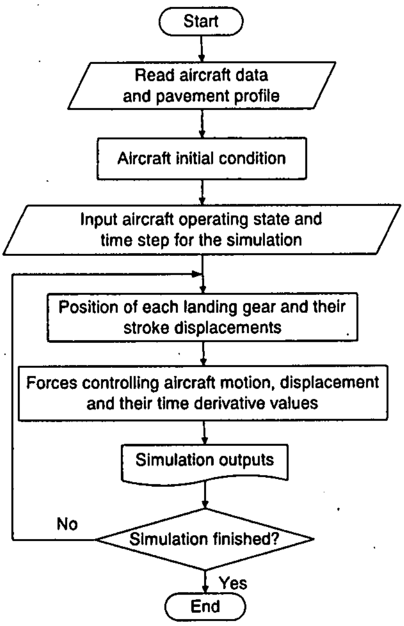


Fig. 4 Flow chart for simulation procedure

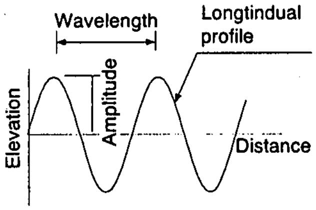
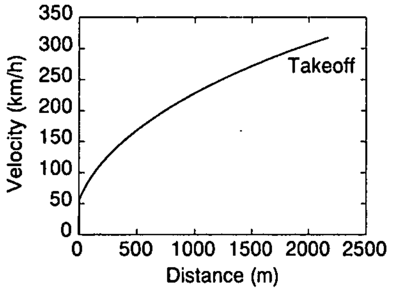
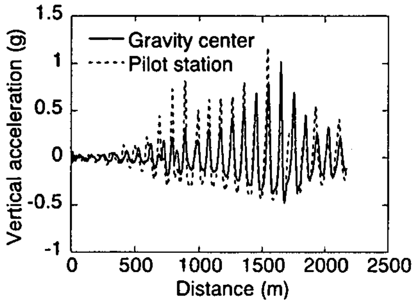


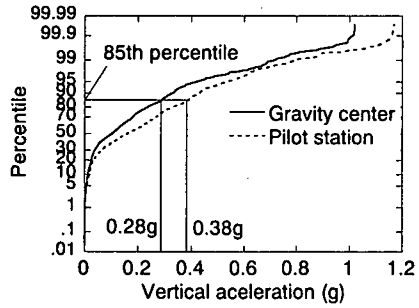
Fig. 5 Illustration of pavement roughness



(a) Aircraft velocity along runway



(b) Simulated vertical acceleration

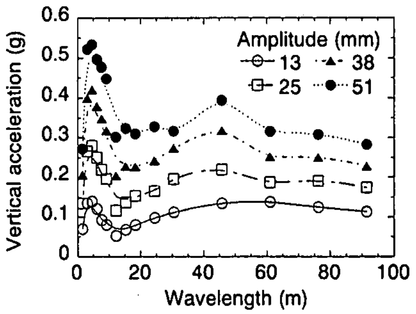


(c) Distribution of vertical acceleration

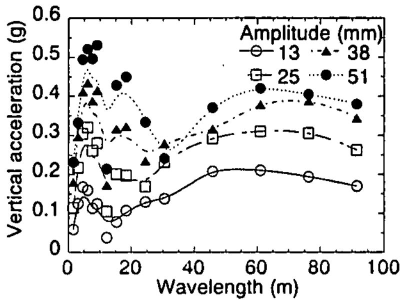
Fig. 6 Simulation example

acceleration under which the accumulated number of data is almost equal to that under one standard derivation, assuming that the data are normally distributed.

Fig. 6 shows one simulation example in which an aircraft departs on a runway with a roughness of a 91 m wavelength and a 51 mm amplitude. Accordingly, the 85th percentiles of 0.28 g and 0.38 g were obtained as the representative values of vertical acceleration at the gravity center and the pilot station, respectively, regardless of the difference in vertical acceleration direction.



(a) Vertical acceleration of center of gravity at departing



(b) Vertical acceleration of pilot station at departing

Fig. 7 Aircraft response on runway roughness

5. SIMULATION RESULTS

(1) Aircraft departing on runway

Fig. 7 shows the simulation results for aircraft departing on a runway. It can be found that:

1) Aircraft vertical acceleration at both the center of gravity and the pilot station increases with the amplitude of pavement roughness.

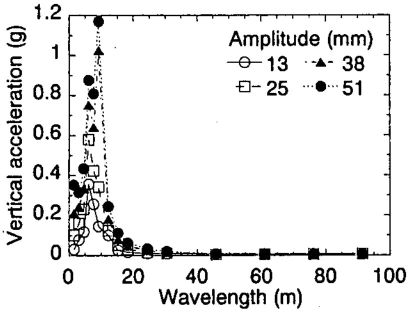
2) The aircraft response varies at different wavelengths. For the center of gravity location, the peak appears at wavelengths of 4.6 m and 46 m, whereas the peak for the pilot station case appears at wavelengths between 4.6 and 9.1 m and at 18 m and 61 m. The amplitude had little influence on these wavelengths at their peak acceleration and might be negligible.

(2) Aircraft taxiing on taxiway

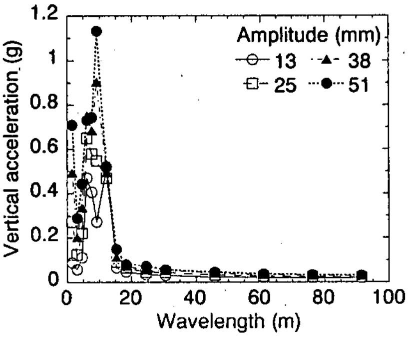
Fig. 8 shows the simulation results for an aircraft taxiing on the taxiway. It was found that:

1) Aircraft vertical acceleration at both the center of gravity and the pilot station increases with the amplitude of pavement roughness, which is a similar result to that of aircraft departing on runways.

2) For aircraft vertical acceleration at both the

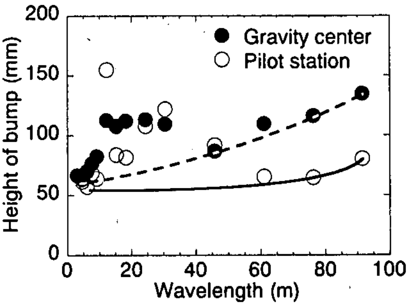


(a) Vertical acceleration of center of gravity at taxiing

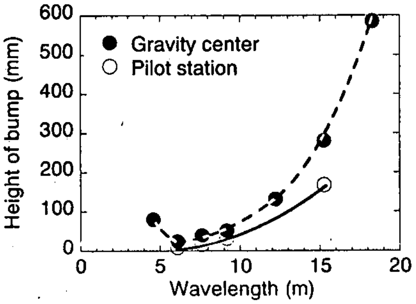


(b) Vertical acceleration of pilot station at taxiing

Fig. 8 Aircraft response on taxiway roughness



(a) Roughness criteria for runway



(b) Roughness criteria for taxiway

Fig. 9 Criteria for roughness evaluation

center of gravity and the pilot station, the peaks appear at wavelengths less than 12 m. Beyond that wavelength, the vertical acceleration becomes very small regardless of the amplitude.

(3) Criteria for roughness evaluation

A vertical acceleration of 0.35 g for the aircraft dynamic response has already been used worldwide as the riding quality criterion for evaluating airport pavement roughness [5), 10), 11)]. Therefore, criteria for evaluating airport pavement roughness were assessed based on this criterion and the simulation results.

From **Fig. 7** and **Fig. 8**, the following facts can be observed in comparing the obtained results to the criterion.

1) For aircraft departing on a runway, amplitudes of pavement roughness over 38 mm are intolerable. Amplitudes of 25 mm or less are tolerable regardless of the wavelength of the pavement roughness.

2) For aircraft taxiing on taxiways, the peak aircraft vertical acceleration generally exceeds the vibration criteria of 0.35 g at wavelengths below 12 m regardless of the amplitude. The peak vertical acceleration on the taxiway at both the center of gravity and the pilot station are significantly higher than that for aircraft departing on a runway.

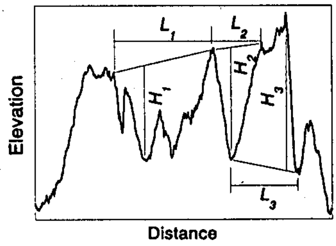


Fig. 10 Evaluation example (length L and height H of bump)

Fig. 9 shows the proposed evaluation criteria for runways (**Fig. 9 (a)**) and taxiways (**Fig. 9 (b)**), which are the envelopes over the simulation results at the center of gravity and pilot station, respectively. It can be found that criteria derived from the pilot station position is more strict than those from the gravity center position. The proposed criteria can be adopted to actual pavement profiles because the aircraft response to continuous sinusoidal waves is more critical than to single or multiple bumps. For the sinusoidal pavement profile shown in **Fig. 5**, the wavelength can be considered as the length between bumps, and the amplitude can be considered as half of the bump height. The procedure for applying the roughness evaluation criteria to an irregular pavement profile with single or multiple bumps is demonstrated in **Fig. 10**.

6. CONCLUDING REMARKS

The following conclusions on airport pavement roughness were obtained from this study:

1) From the viewpoint of a pilots' subjective judgement, the airport pavement surface characteristics influence both the riding quality and the safety in aircraft operations. The influence of the longitudinal profile is the greatest in the former, whereas that of skid resistance and the anxiety over aircraft damage is greater in the latter. The influence of surface characteristics depends greatly on the aircraft speed; i.e., the influence is greater on the runways than on the taxiways and the aprons.

2) The aircraft vertical acceleration increases with the amplitude of pavement roughness. The peak aircraft vertical acceleration appears at different wavelengths for runways and taxiways. For taxiways, the peak only appears at wavelengths less than 12 m, while, for runways, peaks not only appear at wavelengths shorter than 12 m, but also at longer wavelengths.

3) The surface roughness related with shorter wavelength is quantitatively evaluated by the use of the ordinary profilometer. On the other hand, that with longer wavelength might be evaluation by proposed criteria derived from the riding quality criteria of 0.35 g in aircraft dynamic response and the digital simulation.

4) The roughness evaluation criteria for runway and taxiway are different and those derived from the pilot station location are more strict than those from the gravity center position. The tolerable bump height is 50 mm for the wider range of wavelength in runways. On the contrary, the evenness at wavelength between 5 and 15 m is critical in taxiways; that is, only 10 mm is tolerable.

REFERENCES

1) Japan Society of Civil Engineers: *Concrete Standard Specifications, Pavement Volume*, 168p.,1996 (in Japanese).
2) International Civil Aviation Organization: *International Standards and Recommended Practices on Aerodromes, Annex 14*, 159 p., 1990.
3) Civil Aviation Bureau, Ministry of Transport (CAB, MOT): *General Specification for Airport Civil Engineering Facilities*, 1993 (in Japanese).
4) CAB, MOT: *Guideline on Airport Pavement Rehabilitation*, 95p., 1984 (in Japanese).
5) Gervais, E. L.: Runway Roughness Measurement, Quantification and Application; The Boeing Approach, *Aircraft/Pavement Interaction; An Integrated System*, ASCE, pp. 121-131, 1991.
6) Gerardi, T.: The Effect of Runway Roughness on Aircraft Operations, *Aircraft/Pavement Technology: in the Midst of Change*, ASCE, pp.335-347, 1997.
7) Himeno,K., Akimoto, T., Kawamura,A. and Fukuhara, T.: Characteristics of Pavement Surface Profile on Airport Runways, *Journal of Japan Society of Civil Engineers (JSCE)*, pp.43-51, 1998 (in Japanese).
8) Akimoto, T., Kawamura, A., Kasahara, A., Himeno, K. and Hachiya, Y.: Characteristics of Pavement Surface Profile on Airport Runways, *Proceedings of the third International Symposium on Pavement Surface Characteristics*, New Zealand, pp.171-187, 1996.
9) Airport Pavement Committee, Japan Society of Civil Engineers: *Research on Pavements of New Tokyo International Airport*, 258p., 1985.
10) Gerardi, A. G.: Digital Simulation of Flexible Aircraft Response to Symmetrical and Asymmetrical Runway Roughness, *Technical report AFFDL-TR-77-37*, August 1977.
11) Gerardi, A. and Krueger, D.: The Effects of Runway Roughness on Aircraft Fatigue Life, *Aircraft/Pavement Interaction; An Integrated System*, ASCE, pp.77-95, 1991.
12) Hachiya, Y., Umeno, S. and Fujikura, T.: Skid Resistance of Airport Runways, *Journal of Pavement Engineering*, JSCE, Vol.1, pp.159-166, 1996 (in Japanese).
13) Horonjeff, R.: *Planning and Design of Airports*, Second Edition, 460p., 1975.
14) AASHTO: *Design of Pavement Structures*, 1993.
15) CAB, MOT: *Guideline on Airport Asphalt Pavement Design* , 78p., 1990 (in Japanese).
16) CAB, MOT: *Guideline on Inspections of Airport Civil Engineering Facility Constructions*, 1993 (in Japanese)
17) Hudson, W.R.: Road Roughness-Its Elements and Measurement, *Transportation Research Record*, No.836, pp.1-7, 1981.
18) Sato, K. and Hachiya, Y.: Field Tests of Airport Lighting Systems with Base and Conduit Units, *Technical Note of Port and Harbour Research Institute*, No.395,46p., 1981 (in Japanese).
19) Akimoto, T., Himeno,K., Kawamura,A. and Fukuhara, T.: Development of a New Data Acquisition System for Measureing Absolute Pavement Surface Profile, *Journal of JSCE*, pp.13-20, 1998 (in Japanese).
20) Sonnenburg, P. N.: Analysis of Airfield Runway Roughness Criteria, *Final Report of FAA-RD-75-110*, 1976.
21) Spanger, E. B., Gerardi, A. G. and Tomita, H.: Roughness Measurements of Airfield Pavements, *Road and Airport Pavement Response Monitoring Systems*, ASCE, pp.352-366, 1991.
22) International Civil Aviation Organization: *Aerodrom Design Manual, Part2*, 1970.

(Received February 15, 1999)

航空機の応答に基づく空港舗装の平坦性評価

八谷好高・殷　建軍・高橋　修・姫野賢治

空港舗装の平坦性について論じた．まず，空港舗装の表面性状に関する航空機パイロットの主観的評価について研究し，平坦性が乗心地に及ぼす影響が最も大きい項目の一つであることを明らかにした．次に，滑走路と誘導路上を走行するときの舗装縦断形状に対する航空機の応答に関する数値シミュレーションをプログラムTAXIを用いて実施した．その結果として，航空機の応答が振幅，波長といった舗装の表面性状だけではなく，航空機走行速度によって変化することを示し，最後に，空港滑走路と誘導路の平坦性に関する規準を提案した．