Establishment of standards and procedures for airport civil engineering facilities

1. Outline of Research and Activities

FY	Event	Research			Reflection of result
		Design	Evaluation / Rehabilitation	Earthquake	
2001			Semi flexible pavement, Recycled asphalt mixture		Revision of guidelines as needed
2002	Opening of NARITA international airport runway B		High strength rigid pavement, Large stone asphalt mixture		
2003			Precast RC pavement		
2004			Roughness evaluation		
2005	Opening of CHUBU CENTRAIR international airport	Pavement on pier	Stability of groove		
2006	Noto hanto earthquake	Performance based design of pavement	Thin overlay on rigid pavement, Thermal infrared survey	Performance based design of airport, Support for re-opening of Noto Airport	
2007	Opening of KANSAI international airport runway B	Thermal stress of rigid pavement		Large scale liquefaction experiment	
2008		PCN calculation method	Adhesion strength between asphalt mixture layers		Establishment of new guidelines
2009		Parameter analysis of mechanistic pavement design			
2010	Opening of TOKYO international airport runway D, Tohoku earthquake			Sendai airport damage survey	Revision of guidelines
2011			Cooling time of asphalt pavement construction	Detecting method for cavity under pavement	Revision of guidelines
2012					Revision of guidelines
2013					Revision of guidelines
2014	Airport concession begins		Maximum construction thickness of asphalt concrete layer		Revision of guidelines
2015		New design coverage and aircraft load classification	Stripping of asphalt concrete		Revision of guidelines
2016	Kumamoto earthquakes		Curing period of groove	Kumamoto airport damage survey	Revision of guidelines
2017			Rutting calculation, Roughness index	Manual for earthquake	Revision of guidelines
2018			Evaluation of oil in asphalt concrete, Analysis of thin asphalt concrete section		
2019			Evaluation of asphalt binder		Establishment of new guidelines
2020			Dimension of groove		Establishment of new manual for earthquake

◆**Standardization of performance of the airport pavement design method**

[Background and Issues]

The design method for airport pavement in Japan was originally based on the specification-type design method, in which design conditions such as traffic volume and aircraft load are grouped into categories and the pavement thickness is determined according to the chart. Although this method has the advantage of simplifying the design process, it is difficult to design pavement that deviates from the general design conditions.

[Research Outline and Results Implementation]

The Civil Aviation Bureau's "Guidelines for Airport Pavement Design," prepared by NILIM, is based on performance specifications. The required performance, performance specifications, and performance verification items are organized accordingly, and a theoretical design method for determining the pavement thickness by calculating the stress and strain in the pavement is introduced as a performance verification method in addition to the empirical design method used in the past.

◆**Advancement of airport pavement evaluation methods and repair techniques**

[Background and Issues]

Many of the evaluation methods for airport pavement in terms of bearing capacity, materials, and pavement surface are based on methods used for road pavement, and there is a need for new evaluation methods that focus on the performance required specifically for airport pavement and the damage that affects airport operations. In addition, rehabilitation of airport pavement is often performed late at night, and since the late-night work hours are decreasing year by year due to the expansion of airport operation hours, a shorter construction time and a simple, reliable repair method are needed.

[Research Outline and Results Implementation]

The Civil Aviation Bureau's "Guidelines for Airport Pavement Rehabilitation," prepared by NILIM, introduces the use of infrared thermography for easy detection of delamination of flexible airport pavement, high-strength precast RC pavement as a rehabilitation method for rigid airport pavement, and a concrete thin-layer overlay method for rigid airport pavement. New evaluation methods, construction methods, and material specifications are introduced based on the needs of airport authorities.

◆**Earthquake countermeasures**

[Background and Issues]

In order for airports to function as hubs for emergency cargo transport immediately after an earthquake, it is necessary to promote seismic strengthening of runways and other facilities, as well as promptly inspect and repair airport pavement after the earthquake, and quickly restore service. The seismic reinforcement of runways and other facilities has encountered issues that have not been clearly defined, such as the degree of deformation allowed on the runway surface in the event of liquefaction of the foundation ground. In addition, many airport authorities do not have sufficient expertise in pavement damage caused by earthquakes, which poses a risk of not being able to conduct prompt inspections or determine emergency restoration methods in a flexible manner according to the extent of damage and the equipment available.

[Research Outline and Results Implementation]

In order to clarify the effect of liquefaction of the foundation ground on the runway and other facilities, a liquefaction experiment was conducted on the reclaimed land at Ishikari Bay New Port, where a full-scale test pavement was built and explosives placed underground were detonated to generate liquefaction. The test results were used as a reference in the drafting process. In addition, referring to past earthquake damage at airports, a manual summarizing post-earthquake inspection and emergency rehabilitation was added to the Civil Aviation Bureau's "Airport Pavement Maintenance Manual (Draft)."

2. Main Research Results

◆Airport pavement design methods to be performance prescriptive

- Runway D of the Tokyo International Airport, which started service in 2010, consists of a reclaimed section and a pier section. The pier section requires an asphalt mixture on the concrete slab, and it is necessary that rainwater penetrating the pavement surface does not reach the concrete slab. Therefore, as shown in Figure-1, a flexible pavement consisting of a coated waterproof layer, a watertight SMA (stone mastic asphalt mixture), a drainage asphalt mixture, and a dense-graded asphalt mixture, in that order, was constructed on the concrete slab, and full-scale loading tests were conducted to verify the watertightness of the asphalt mixture. The pavement thicknesses shown in Figure-1 were verified by conducting full-scale driving load tests.
- In the theoretical design method for flexible airport pavement, the cumulative fatigue (the ratio of the number of loading cycles to the allowable loading cycles calculated from the magnitude of strain generated in the pavement by aircraft loading) is introduced to determine the pavement thickness where the cumulative fatigue on the underside of the asphalt mixture and on the subgrade does not exceed 1.0, as shown in Figure-2. For this purpose, it was necessary to establish fatigue failure criteria for the asphalt mixture and subgrade, which were calibrated from the pavement thicknesses used so far. Figure-3 shows the transverse distribution of the cumulative fatigue degree calculated for runways used by various types of aircraft. Since the position of the landing gear and the magnitude of the landing gear load differ depending on the aircraft, the magnitude of the cumulative fatigue degree and the position of the maximum fatigue degree are different for each aircraft, and the design can take into account the actual running configuration of the aircraft.
- In the theoretical design method for rigid airport pavement, the cumulative fatigue is introduced in the same way as for flexible airport pavement to determine the pavement thickness at which the cumulative fatigue on the underside of the concrete slab does not exceed 1.0. The stresses to be considered are load stress and thermal stress. While the load stress can be calculated by structural analysis, it is necessary to formulate the thermal stress generated by the temperature change of the concrete slab. Figure-4 shows the relationship between the temperature difference between the top and bottom of the slab and the thermal stress in the long-term observation results from the rigid pavement test. Although it has been known for some time that the thermal stress is proportional to the temperature difference between the top and bottom of the slab, the coefficient of proportionality was not known for the thermal stress of a thick concrete slab like those at airports.

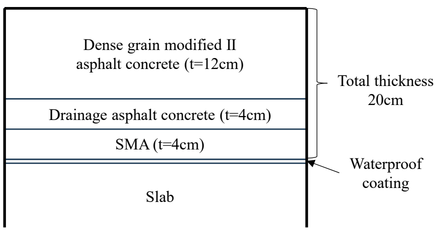

Figure-1 Pier section of Runway D at Tokyo International Airport

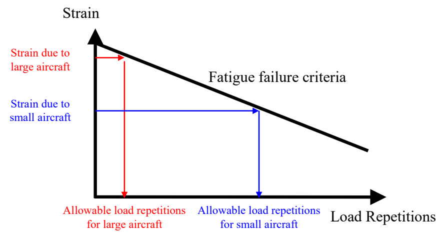

Figure-2 Conceptual diagram of theoretical design method

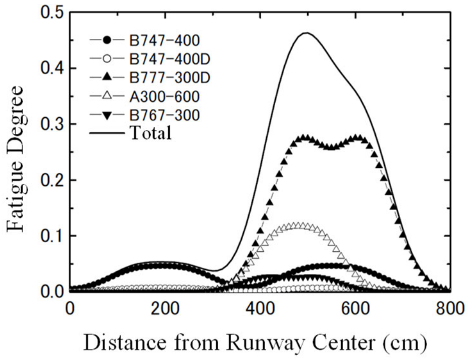

Figure-3 Distribution of cumulative fatigue degree in transverse direction

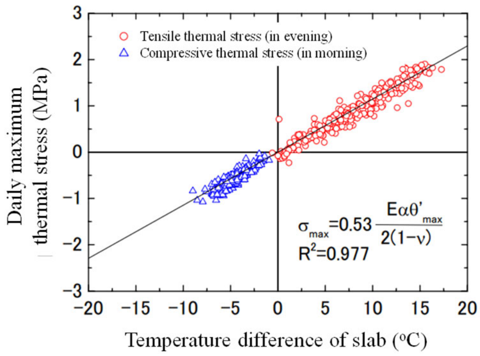

Figure-4 Thermal stress of rigid pavement

◆Advancement of airport pavement evaluation methods and repair techniques

- Airport pavement rehabilitation work is often performed at night when airport operations are stopped. Therefore, when rigid pavement is constructed, the facility must be temporarily closed day and night. Research was conducted on a construction method that enables the facility to be opened to traffic the next day by installing factory-made high-strength RC precast slabs. In the research, a new "cotter joint" was adopted as the joint between the slabs, and after verifying the load transfer performance, it was put into practical use.
- The only way to correct the slope of the existing rigid pavement was to remove and replace the existing concrete slab. Therefore, research was conducted on a method for applying a thin concrete overlay over the existing rigid pavement. In the research, the minimum overlay thickness was confirmed, the required adhesion strength between the existing pavement and the overlay layer was verified, and the surface treatment methods (water jet and shot blasting together, and shot blasting and adhesive together) to obtain the required adhesion strength were verified and put into practical use.
- In order to easily detect delamination between the layers of the airport asphalt mixture, infrared thermography, which is used to detect delamination of building tiles, was introduced. Since the scanning of the airport pavement was conducted late at night, it was expected that the temperature drop in the delaminated area would be very small. However, field tests confirmed that a commercially available infrared thermal camera can detect the temperature drop caused by delamination during a relatively warm season.
- The cracking resistance of existing flexible pavement has conventionally been evaluated based on the needle penetration and softening point of the asphalt binder for straight asphalt. Therefore, to evaluate both straight asphalt and modified asphalt, a method using $G^*\sin\delta$ through a DSR test was introduced, and a reference value was obtained for crack resistance evaluation.

Figure-5 Construction of high-strength RC precast pavement

Figure-6 Existing pavement surface treatment by shot blasting

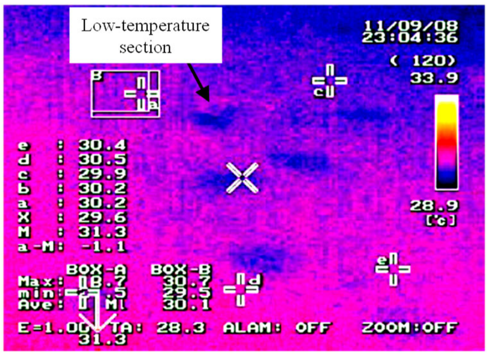

Figure-7 Infrared thermal image of pavement surface

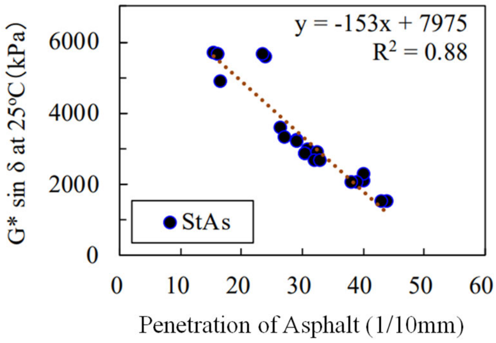

Figure-8 G*sinδ and needle penetration by DSR test

◆Earthquake countermeasures

- A full-scale liquefaction experiment was conducted at a reclaimed site in Ishikari Bay New Port to understand the effects of liquefaction of the foundation soil on the deformation and bearing capacity of the runway and other facilities to be constructed to withstand earthquakes. In the experiment, liquefaction was induced by increasing the excess pore water pressure through the use of explosives installed in the foundation ground, and the amount of pavement settlement and pavement bearing capacity to be recovered were measured, as shown in Figure-9. The results of the experiment were used to draft seismic design guidelines for airport civil engineering facilities.
- Based on the results of past surveys of airport pavement during earthquakes, such as the survey conducted at Sendai Airport, which was damaged by the Tohoku Region Pacific Ocean Earthquake, an inspection and emergency restoration manual was prepared, focusing on "local subsidence due to liquefaction of the foundation soil" and "cracks with steps" that could hinder the resumption of airport service after the earthquake. In particular, for "local settlement due to liquefaction of the foundation," since cavities can occur under the pavement, the "normalized deflection" and "deflection time difference" shown in Figure-11 are plotted in the upper left corner of the figure as an indicator to easily estimate cavities from the FWD (pavement bearing capacity measurement device) measurements. The upper left of the plot in Figure-11 indicates the higher the likelihood of a cavity. In addition, for emergency rehabilitation immediately after an earthquake, some points can be omitted as described, giving priority to the speed and ease of material procurement, without sticking to the pavement specifications applicable under normal conditions.

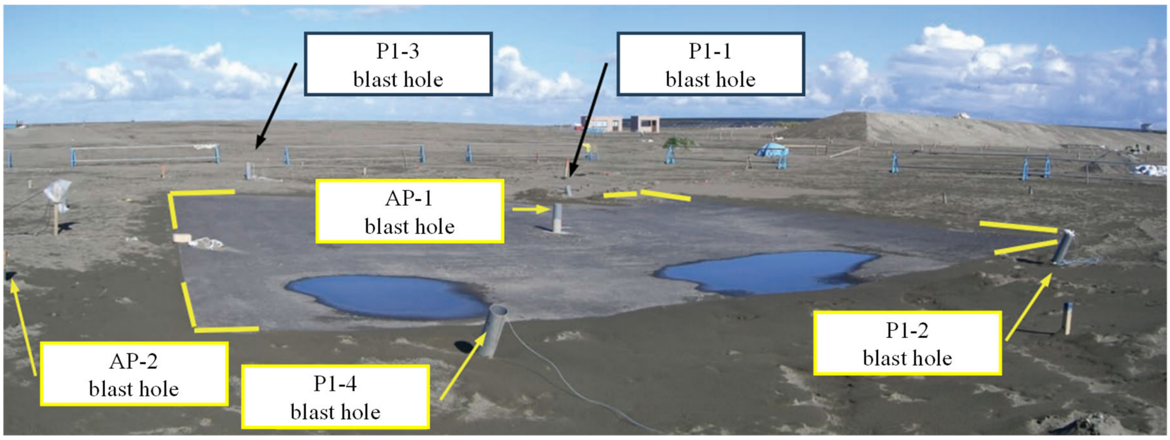

Figure-9 Test pavement after liquefaction in a full-scale liquefaction experiment

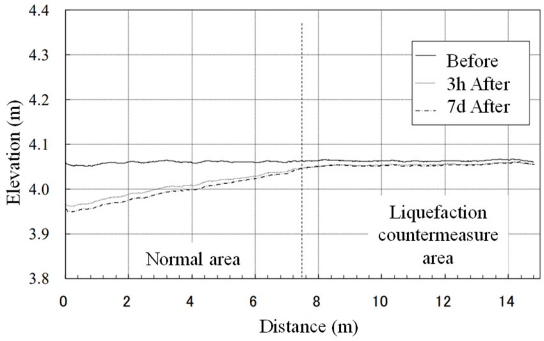

Figure-10 Pavement height in liquefaction experiment

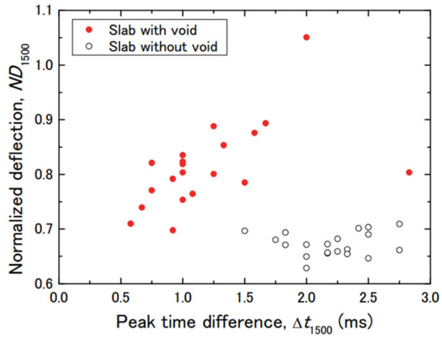

Figure-11 Normalized deflection and deflection peak time difference

3. List of Related Reports and Technical Documents

- Hachiya, Matsuzaki, Tsubokawa, Ito, Yamawaki, Tanaka and Yokoo: Application of Precast High Strength RC Slab Pavements in Airports, NILIM Technical Note No. 113, 2003
- Hachiya, Mizukami, Tsubokawa, Esaki, Noda, Nakamaru and Higashi: Study on Thin Bonded Concrete Overlay of Airport Concrete Pavement, NILIM Research Report No. 30, 2006
- Hachiya, Ezaki, Tsubokawa, Noguchi and Maekawa: Laboratory Verification on Performance of Pier Deck Pavements on Runway D at Tokyo International Airport, Journal of Japan Society of Civil Engineers, Pavement Engineering, Vol. 12, 2007
- Tsubokawa, Mizukami, Hachiya and Kameta: Study on Thermal Stress due to Daily Temperature Change of Airport Concrete Pavement, Journal of Japan Society of Civil Engineers, Pavement Engineering, Vol. 12, 2007
- Tsubokawa and Mizukami: Study on Infrared Thermographic Inspection of De-Bonding of Airport Asphalt Pavement, Journal of Japan Society of Civil Engineers, Pavement Engineering, Vol. 12, 2007
- Sugano et al.: Experimental Study on Countermeasures for Liquefaction subjected to Full-Scale Airport Facilities, Port and Airport Research Institute Technical Note No. 1195, 2009
- Tsubokawa, Mizukami, Hata and Maekawa: Report on Damages of Pavement at Sendai Airport due to 2011 Tohoku Region Pacific Coast Earthquake, NILIM Technical Note No. 680, 2012
- Kawamura, Tsubokawa and Kato: Detection Method of Voids under Concrete Slab by Using FWD, Journal of Japan Society of Civil Engineers, E1-Pavement Engineering, Vol. 73, No. 1, 2017

・ Kawamura and Tsubokawa: Crack Resistance Evaluation of Pavement Recovered Asphalt by DSR Test, Japan Society of Civil Engineers, 75th Annual Meeting, 2020

4. Future Prospects and Remaining Issues

◆Standardization of performance of the airport pavement design method

The empirical design method uses the “design aircraft load category,” in which aircraft are classified according to the size of the aircraft load, and the “design coverage,” which is a design traffic index calculated from the number of runs of each aircraft. However, there is no clear classification method for determining the size of the single-wheel load that constitutes the landing gear of an aircraft (one leg, two wheels, four wheels, or six wheels), and the calculation method for the design coverage does not accurately reflect the actual aircraft running configuration (running position distribution in the facility crossing direction). Therefore, it is necessary to clarify the classification method of the design aircraft load category and introduce a traffic volume indicator that can accurately reflect aircraft travel patterns.

◆Enhancement of airport pavement evaluation methods and repair techniques

When a localized sudden failure (e.g., pothole) of several tens of centimeters in diameter occurs on a flexible pavement runway, the runway is temporarily closed for emergency repair. Although it is desirable to repair the damage with a hot asphalt mixture, it is not always readily available, so airport authorities may use a cold asphalt mixture, which is always available. After repairing with the cold asphalt mixture, the runway is usually put back into service and then it is repaired with a hot asphalt mixture at night when airport operations are stopped. Therefore, the challenge is to establish cold asphalt mixture specifications suitable for emergency repair of runways.

The runway surface is provided with grooves 6 mm in width and 6 mm in depth to allow quick drainage of rainwater. However, as the grooves crumble and wear down due to aircraft travel, the coefficient of friction on the pavement surface decreases. Therefore, the problem is to clarify the effect of changing the groove dimensions on the coefficient of friction and groove collapse, and to find the groove dimensions that improve the durability and coefficient of friction.

◆Earthquake countermeasures

When local subsidence occurs due to liquefaction of the foundation soil, cavities may occur under the pavement, so a FWD (pavement bearing capacity measuring device) is generally used to conduct a detailed inspection of the pavement bearing capacity. However, since it may take time to procure a FWD, the issue is to enable the inspection using equipment that is easily procured near the airport, for the purpose of early reopening of service at the airport.