Airport Pavement Behavior, Performance and Management System

Chia-Pei Chou
National Taiwan University
An airport pavement network requires a huge financial investment and sound engineering management to maintain a satisfactory and safe level of service for its sustainability.

An airport pavement network consists of multiple runways, taxiways, and large area of apron.
A comprehensive airport pavement management system (PMS) includes:

- Complete database
- Periodical performance inspections,
- Reliable traffic and environmental data collection,
- Reasonable maintenance decision criteria,
- Sound maintenance techniques, and
- Continuous research feedback mechanism
1. PCC SLAB MOVEMENT
Sensors layout

Slab Thickness: 41 cm (16in)
Optical Fiber Sensors in PCC slabs
Spec. of Optical Fiber Sensors

- Length: 50cm
- Resolution: $2 \times 10^{-3}$mm
- Range:
  - Expansion: 1% (5mm)
  - Shrinkage: 0.5% (2.5mm)
- Temperature limit:
  - Sensor: -50°C to +110°C
  - Data transmission part: -40°C to +80°C
Pouring
Crack Occurred
Joint saw cut

Raw Data

Crack Occurred
Pouring
Joint saw cut

D1
D2
D3
D4
D5 (8 AM)
Joint opening prediction model

• Cold season (Jan~Mar, Oct~Dec)
  \[ L'_{S7} = 1.58 - 0.047 \times DL_3 \quad R^2 = 0.903 \]

• Hot season (Apr~Sep)
  \[ L'_{S7} = 0.819 - 0.005 \times DL_3 - 0.013 \times AVG_{48} \quad R^2 = 0.811 \]

• \( L'_{S7} \) = prediction value of optical fiber sensors length change (mm)
• \( DL_3 \) = air temp. 3-hour before measuring (°C)
• \( AVG_{48} \) = 48-hour average air temp. before measuring (°C)
Joint opening prediction model

- Mean error is 5.8%
Major findings

- Slab movement reaction is **3 hours** later than air temperature.
- **In winter, slab has more freedom than summer.**
  - Slab was constructed/saw cut in January results in smallest move. annually.
  - The measured max. movement is around 0.90 mm and the max. joint opening is about 1.2 mm for 16 in slab.
  - Slab has **tension in winter** and **compression in summer**.
- The calculated **max. compressive stress** is around 3000 psi
2. SLAB STRESSES

Warp Stress
Thermal Stress
A/C Loading Stress
Sensors

Optical fiber sensor $\times 7$

Dowel-bar strain gage $\times 16$

H-bar strain gage $\times 42$

Temperature sensor $\times 14$

Position gage $\times 20$

Moisture sensor $\times 3$
Temperature Weekly Distribution

Rainy Days

Slab thickness: 41cm

<table>
<thead>
<tr>
<th>Slab</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6T11</td>
<td>2.5cm</td>
</tr>
<tr>
<td>T6T12</td>
<td>8cm</td>
</tr>
<tr>
<td>T6T13</td>
<td>13cm</td>
</tr>
<tr>
<td>T6T14</td>
<td>19cm</td>
</tr>
<tr>
<td>T6T15</td>
<td>27cm</td>
</tr>
<tr>
<td>T6T16</td>
<td>33cm</td>
</tr>
<tr>
<td>T6T17</td>
<td>38cm</td>
</tr>
</tbody>
</table>

Graph showing temperature distribution over time with different line colors for each slab.

Legend:
- Blue: T6T11
- Pink: T6T12
- Black: T6T13
- Purple: T6T14
- Red: T6T15
- Orange: T6T16
- Teal: T6T17
- Light Blue: Air temperature

Temperature range from 15°C to 50°C.

Dates: 10/5 to 10/11
Temperature Daily Gradient

- Temperature gradient: $\Delta_{\text{temp.}} / \Delta_{\text{depth}}$
- Max.: $0.031 ^\circ\text{C}/\text{mm}$ (2 p.m.)
- Min.: $-0.011 ^\circ\text{C}/\text{mm}$ (5 a.m.)

![Temperature gradient graph](chart.png)
Shape Changes

Stresses Condition

Tensile Strain

TOP

Comp. Strain

2 PM

5 AM

Tension

Compression

Strain (10^-6)

Time (hr)

00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00

theoretical strain
measured strain
actually restrained strain
Warping and Curling Stresses

At midday, bottom has larger tension stress due to higher temp.

Max. tension stress at bottom
winter: 150psi
summer: 80 psi
Aircraft Loading Testing Analysis

Weigh-in-motion
Max. tension stress due to loading $\approx 50$ psi
B777-300

Strain $\times 10^{-6}$

Time (sec)

6H71
FEM model

Static stress/Dynamic stress is around 1.28
Max. Slab Stresses

A/C loading → Stress due to loading
Temp gradient at midday + Warping Stress
Temp seasonal changing + Thermal Stress

Max. design stress → Fatigue analysis
3. ROUGHNESS
Rough pavement will...

- Induce excess vibrations at aircrafts
- Affect pilots’ ability to read instruments accurately while taking off and landing
- Cause metal fatigue problems of aircraft
- Result in increasing pavement loading and accelerating pavement deterioration
Research Objectives

- Explore the relationship between an aircraft’s vertical acceleration, as well as gear loading, and pavement profile wave lengths.

- Develop airport pavement roughness evaluation indices:
  - Airport Pavement Roughness Index APRI2
Simulated Aircrafts

- Simulated Aircraft Model
- Other Model in APRAs
- Other Common/Important Model

Gross Weight (Kg) vs. Wheel Base (m)

- B747-400
- B747-200
- MD-11
- DC-8
- Cessna Citation I
- B777-200
- A340-200
- A300-600
- DC-10-10
- B757-200
- B767-300
- A380-800
- MD-90
- A320-200
- B737-800
- B707
- B767-200
- B727-200
- L-1011
- B737-200
Concept of new evaluation method

Airport Pavement Roughness Index 2

Aircraft
- types
- main wheel location
- Takeoff, landing, taxi speeds

HHT (Hilbert-Huang Transform)
- Runway profile real time wavelength analysis

APRI

Matrix of aircraft speed-wave index
By using APRAs

APRI2 : specific index for every airport
Case Study: Airport A

Centerline profile

Touchdown area
Evaluation with APRI 2

Centerline roughness

APRI Threshold
Case Study: Airport A
4. SKID RESISTANCE ANALYSIS
Aircraft Overruns

- Around the world, there is an average of one overrun accident every 8.5 days
- Over 50% result in the loss of the aircraft
- Over 10% result in fatalities
- In 2007, 50% of all aviation fatalities were due to aircraft overruns
• 2006.12.24, Indonesia Air B737: landing overrun

• 2007.9.17, Tai Air MD82, landed in heavy rain and had overrun
2007.7.19, Brazil TAM Air A320, landed on wet runway and had overrun

Skid Resistance?

Runway Safety Area?
Runway Skid Resistance

- **Resistance Force between Pavement and Tires**
- **Defined as** Friction Coefficient
- **Factors Affecting Skid Resistance**
  - Pavement Type, Surface Texture
  - Aircraft Type, Speed, Tire Pressure, Tire Texture
  - Temperature, Rainfall
Skid Resistance Measurement Specifications

◆ Specifications
  ➢ FAA AC150 5320-12C
  ➢ ICAO Airport Services Manual Part2
  ➢ Taiwan CAA Specification

◆ Major Contents
  ➢ Water Film: 1mm
  ➢ Speed: 65 or 95 km/h
  ➢ Measuring frequency and location
  ➢ Maintenance Strategy
  ➢ Frequency of maintenance
# Frequencies of Measurement and Rubber Removal

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15</td>
<td>12 Months</td>
<td>24 Months</td>
</tr>
<tr>
<td>16-30</td>
<td>6 Months</td>
<td>12 Months</td>
</tr>
<tr>
<td>31-90</td>
<td>3 Months</td>
<td>6 Months</td>
</tr>
<tr>
<td>91-150</td>
<td>1 Month</td>
<td>4 Months</td>
</tr>
<tr>
<td>151-210</td>
<td>2 Weeks</td>
<td>3 Months</td>
</tr>
<tr>
<td>&gt;210</td>
<td>1 Week</td>
<td>2 Months</td>
</tr>
</tbody>
</table>
Skid Resistance Measuring Equipment
Continuous Friction Measurement Equipment (CFME)

- Slip Mode
  - Grip Tester
  - Airport Surface Friction Tester
  - Runway Friction Tester
  - ........

- Yaw Mode
  - Mu-Meter
  - SCRIM
Grip Tester

- Slip Mode Friction Measuring Equipment
- Water Film: 1 mm
- Speed: 65 km/h
Case Studies of Skid Resistance Measurements

• Taiwan 16 Airports
• Pavement Types
  • Flex
  • Rigid
## 1. Flexible Pavement

### Overlay 2005.2

<table>
<thead>
<tr>
<th></th>
<th>1st 1/3</th>
<th>Mid. 1/3</th>
<th>Last 1/3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>0.75</td>
<td>0.84</td>
<td>0.79</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>0.78</td>
<td>0.84</td>
<td>0.81</td>
</tr>
</tbody>
</table>

### 2005.1

<table>
<thead>
<tr>
<th></th>
<th>1st 1/3</th>
<th>Mid. 1/3</th>
<th>Last 1/3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>0.52</td>
<td>0.77</td>
<td>0.77</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>0.52</td>
<td>0.78</td>
<td>0.79</td>
</tr>
</tbody>
</table>

---

**Diagram Note:**
- The circular red area indicates a specific segment of the overlay's condition.
- The graph on the right shows the overlay's performance with colors indicating different condition levels.

---

**Legend:**
- ■ 0.74新建門檻<=檢測值
- ■ 0.43最低門檻<=檢測值<0.74新建門檻
- ■ 檢測值<0.43最低門檻
- ■ 0.58新建門檻<=検測値<0.74新建門檻
- ■ 檢測値<0.58新建門檻

---

**Additional Observations:**
- The condition of the overlay shows an improvement compared to the previous data.
- The 2005.2 overlay has a higher overall score, indicating better performance in the mid and last sections.
Flexible Pavement Example

- Touch down Zone
- Other area

Touch Down O/L

Rubber Removal
### 2. Rigid Pavement (Grooved)

<table>
<thead>
<tr>
<th>R/W</th>
<th>1st 1/3</th>
<th>Mid. 1/3</th>
<th>Last 1/3</th>
<th>R/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.61</td>
<td>0.71</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.69</td>
<td>0.73</td>
<td>0.72</td>
<td>B</td>
</tr>
</tbody>
</table>

**2007.5**
Groove Quality Inspection
Grooving Spec.

- FAA and ICAO Spec.
  - Depth $a$: 6.0±1.6 mm
  - Width $b$: 6.0 ~ 7.6 mm
  - Spacing $c$: 35.0 ~ 38.0 mm
  - 60% and above must have depth over 6.0 mm

- Timing for Grooving:
  - Rigid: after curing for 28 days
  - Flexible: at least 30 days

- Grooving increases friction coefficient
Electric scooter consists of:
- Laser displacement sensor
- Accelerometer
- DMI system
- Data acquisition device

Installed at the center of the front axle

Measuring speed: 2 km/hr

Data collecting frequency: 800 Hz

Sampling distance interval: 1 mm
Raw Data

Groove width

Groove spacing, S

Groove depth, D
Field Experiment-runway A

Runway length: 3660m
Runway width: 60m
Grip Number: 0.7

6mm

Joint
groove

distance from the runway end (m) vs. depth (mm)
Field Experiment-Airport A

Depth

Width

FAA standard

Spacing
Field Experiment – Airport B

Unevenness

6mm

Shallow
Field Experiment-runway B

Depth

Width

Spacing
Groove configuration and skid resistance of Runway A and Runway B

- Groove depth (mm)
- Groove spacing (mm)
- GN value
- Cumulative %
Major Findings

- Periodic skid resistance measurement is essential for maintaining runway safety
- Overlay of flex. pavement can improve the friction condition with
- Most of rubber removal techniques used in Taiwan cannot efficiently improve the skid resistance value
- Grooving increases skid resistance capability effectively
- The Automatic Grooving Measuring Techniques can efficiently inspect the grooving quality
5. PAVEMENT MANAGEMENT SYSTEM
Airport Pavement Management System (APMS)

• An APMS provides a consistent, objective, and systematic procedure for establishing facility policies, setting priorities and schedules, allocating resources, and budgeting for pavement maintenance and rehabilitation.

• It can also quantify information and provide specific recommendations for actions required to maintain a pavement network at an acceptable level of service while minimizing the cost of maintenance and rehabilitation.

• Source: Airport pavement management program, FAA AC 150/5380-7a (2006)
MANAGEMENT LEVELS

• **Network Level**
  • Decisions are made about short-term and long-term budget needs, the overall condition of the network, and the management of an entire pavement network.

• **Project Level**
  • Decisions are made about the most cost-effective M&R alternative for the pavements identified in the network analysis. At this level, each specified pavement should have a detailed condition survey, including nondestructive and/or destructive tests, pavement’s load-carrying capacity, roughness, and friction measurements may be useful.

  Source: Airport pavement management program, FAA AC 150/5380-7a (2006)
# Pavement performance survey

## Pavement condition
- **Pavement condition index (PCI)** based on pavement distress data surveyed by visual Inspection or automatic equipment

## Skid resistance
- **Continuous Friction Measurement Equipment (CFME)**

## Roughness
- **Laser Profiler**

## Structural bearing capacity evaluation
- **Falling weight deflectometer (FWD)**
- **Taking core and lab testing**

## Structure thickness
- **“As built” records**
- **Take core**
- **Ground penetrating radar (GPR)**
Pavement condition inspection
Runway skid resistance survey
Runway roughness survey

ARRB
Walking Profiler
Structural Bearing Capacity Evaluation

Falling (heavy) Weight Deflectometer (FWD/HWD)
Pavement distresses:
Runway 05L-23R

- Patching: 65%
- Sealant Damage: 21%
- Spalling: 10%
- C2: 2%
- A1: 1%
- A2: 1%
- A3: 1%
Pavement distresses:
Runway 06-24

- Long Crack: 6%
- A2, 3%
- A3, 1%
- Sealant Damage: 6%
- Spalling: 9%
- Pothole: 8%
- Patching: 66%
Pavement distresses: Taxiway

A1 (Longitudinal crack)
A2 (Transverse crack)
A3 (Corner break)
A4 ("D" crack)
B1 (Spalling)
B2 (Pumping)
B3 (Joint seal damage)
B4 (Blowup)
B5 (Faulting)
C1 (Polished aggregate)
C2 (Pothole)
C3 (Patching)
D1 (Longitudinal separation)
D2 (Lane-to-Shoulder separation)

WC, EC
North T/W
South T/W

0 1,000 2,000 3,000 4,000 5,000
Pavement distresses: Apron

- A1 (Longitudinal crack)
- A2 (Transverse crack)
- A3 (Corner break)
- A4 ("D" crack)
- B1 (Spalling)
- B2 (Pumping)
- B3 (Joint seal damage)
- B4 (Blowup)
- B5 (Faulting)
- C1 (Polished aggregate)
- C2 (Pothole)
- C3 (Patching)
- D1 (Longitudinal separation)
- D2 (Lane-to-Shoulder separation)

North apron vs. South apron
Developing an APMS software
<table>
<thead>
<tr>
<th>Condition Category</th>
<th>PCI</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>85 ~ 100</td>
<td>15</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>70 ~ 85</td>
<td>15</td>
</tr>
<tr>
<td>Fair</td>
<td>55 ~ 70</td>
<td>15</td>
</tr>
<tr>
<td>Poor</td>
<td>40 ~ 55</td>
<td>15</td>
</tr>
<tr>
<td>Very poor</td>
<td>25 ~ 40</td>
<td>15</td>
</tr>
<tr>
<td>Serious</td>
<td>10 ~ 25</td>
<td>15</td>
</tr>
<tr>
<td>Failed</td>
<td>0 ~ 10</td>
<td>10</td>
</tr>
</tbody>
</table>
Pavement condition: PCI Sections in North field
Pavement condition: Section level
Pavement condition: PCI
Sample units in North field
Pavement condition: sample unit
<table>
<thead>
<tr>
<th>Condition Category</th>
<th>PCI</th>
<th>M&amp;R strategies</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>85 ~ 100</td>
<td>M&amp;R</td>
<td>Preventive maintenance, Joint and crack sealing, Load transfer, Slab stabilization, Drainage improvement</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>70 ~ 85</td>
<td>Routine Maintenance</td>
<td>Partial-depth repairs, Full-depth repairs, Patching, Diamond grinding, Crack and joint stitching</td>
</tr>
<tr>
<td>Fair</td>
<td>55 ~ 70</td>
<td>Rehabilitation</td>
<td>Overlays, Slab replacement</td>
</tr>
<tr>
<td>Poor</td>
<td>40 ~ 55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very poor</td>
<td>25 ~ 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serious</td>
<td>10 ~ 25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failed</td>
<td>0 ~ 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
M&R priorities

Level 1

Level 2

Level 3
Decision tree for pavement maintenance

Section

Pavement condition data

Level 1
Level 2
Level 3

Section PCI <50

YES

Section PCI <50

YES

Rehabilitation

YES

Level 1
Level 2
Level 3

SU PCI <50

YES

SU PCI <45

YES

Rehabilitation

YES

SU PCI <40

YES

Full depth slab repair

YES

SU PCI <55

YES

SU PCI <50

YES

SU PCI <45

YES

Full depth slab repair

YES

A
Deduct value of M&H Joint Sealing >12

Deduct value of M&H cracking >20

Deduct value of polished aggregate>20

Deduct value of pumping>20

Deduct value of pothole>8

Joint sealant replacing

Crack sealing

Grooving

Slab stabilization

Pothole patching

Do nothing
M&R Decisions

Routine Maintenance

- Crack Seal
- Sealant Repair
- Slab Stabilized
- Grooving
M&R Decisions
Rehabilitation

Rehabilitation
Full Depth Patch
Reconstruction
Performance prediction model

Runway

$y = -4E-11x^2 + 5E-06x + 93.295$

$R^2 = 0.938$

Accumulated aircraft movements (takeoff and landing)
Performance prediction model

Taxiway

$y = -4E-16x^3 + 4E-10x^2 - 0.0002x + 88.812$

$R^2 = 0.5373$

Accumulated aircraft movements (takeoff and landing)
Performance prediction model

Apron

\[ y = -2E-13x^3 + 3E-08x^2 - 0.0014x + 96.831 \]

\[ R^2 = 0.7546 \]
CONCLUSIONS

1. Knowing the stresses due to seasonal temperature variation, daily warping, and aircraft loading can give a better understanding of concrete slab pavement behavior, so as to have a more reliable runway, taxiway, and apron design.

2. Runway roughness evaluation is dramatically different from highway system. Surface profile decomposition, aircraft dynamic acceleration, runway pavement dynamic loadings, aircraft running speed and aircraft combination are all important factors of Airport Runway Roughness Index.
Conclusions (con’t)

3. Periodic skid resistance measurement is essential for maintenance runway safety, and grooving can indeed improve the skid resistance. However, an automatic technique of grooving quality inspection is not only necessary but also efficient for improving the runway safety.

4. Airport pavement system with reliable data collection, periodical performance inspection, and systemic maintenance techniques can assure a good level of service and its sustainability.
THANK YOU FOR YOUR ATTENTION