PERFORMANCE EVALUATION OF PRE-CAST SLABS FOR CONTINGENCY RIGID AIRFIELD PAVEMENT DAMAGE REPAIR

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Objectives

Mechanistic Characterization of pre-cast panels installed using different **Leveling Materials** and different **Installation Techniques** through:

- Analysis of Load Transfer Efficiency \( (LTE_\delta, LTE_\sigma, \text{ and } LT_{FAA}) \)
- Analysis of Joint Stiffness
- Analysis of Deformation Energy Dissipated to the Pavement Foundation
- Analysis of Performance based on FE Response Analysis
  - Thermal Stresses
  - Load Induced Stresses (C-17 Aircraft)
  - Performance Index based on Failure Criteria
Construction and Installation Process
## Test Sections

<table>
<thead>
<tr>
<th>Variant</th>
<th>Pre-cast Panel ID.</th>
<th>Joint Orientation</th>
<th>Bonding Agent</th>
<th>Installation Method</th>
<th>HWD Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>#1</td>
<td>East</td>
<td>HDP Foam</td>
<td>Direct Injection</td>
<td>East to West</td>
</tr>
<tr>
<td>2</td>
<td>#1</td>
<td>West</td>
<td>HDP Foam</td>
<td>Direct Injection</td>
<td>East to West</td>
</tr>
<tr>
<td>3</td>
<td>#2</td>
<td>East</td>
<td>HDP Foam</td>
<td>Deep Injection</td>
<td>East to West</td>
</tr>
<tr>
<td>4</td>
<td>#2</td>
<td>West</td>
<td>HDP Foam</td>
<td>Deep Injection</td>
<td>East to West</td>
</tr>
<tr>
<td>5</td>
<td>#3</td>
<td>East</td>
<td>Flowable Fill</td>
<td>Conventional</td>
<td>West to East</td>
</tr>
<tr>
<td>6</td>
<td>#3</td>
<td>West</td>
<td>Flowable Fill</td>
<td>Conventional</td>
<td>West to East</td>
</tr>
<tr>
<td>7</td>
<td>#3</td>
<td>East</td>
<td>Flowable Fill</td>
<td>Conventional</td>
<td>East to West</td>
</tr>
<tr>
<td>8</td>
<td>#3</td>
<td>West</td>
<td>Flowable Fill</td>
<td>Conventional</td>
<td>East to West</td>
</tr>
</tbody>
</table>

![Diagram of test sections](image-url)
HWD Testing for Performance Analysis

- HWD Mid-Slab Loading
- Back-Calculation of the PCC Modulus
- Determination of Flexural Strength ($S_c$)
- Analysis of Joint Stiffness
- Analysis of Deformation Energy
- HWD Edge Loading at Different Load Repetitions
- Determination of Load Transfer Efficiency as a Function of Number of Load Applications
**Definition:**

"Load Transfer" is a term used to describe the transfer (or distribution) of load across discontinuities such as joints or cracks (AASHTO, 1993).

\[
LTE_\delta = \frac{d_u}{d_l} \times 100 \\
LTE_\sigma = \frac{\sigma_u}{\sigma_l} \times 100 \\
LT = \frac{LTE_\sigma}{1 + LTE_\sigma} \\
l = \sqrt[3]{\frac{Eh}{12k(1-\nu^2)}}
\]

- \(d_l, \sigma_l\) = Deflection and Vertical Stress under Loaded Slab
- \(d_u, \sigma_u\) = Deflection and Vertical Stress under Unloaded Slab
- \(l\) = Radius of Relative Stiffness
- \(LTE_\sigma\) = Stress Based Load transfer Efficiency
- \(LTE_\delta\) = Deflection Based Load transfer Efficiency
- \(LT\) = FAA criteria for Load Transfer Efficiency

\[
LTE_\delta = \left[1206\left(\frac{a}{l}\right) + 377\right]LTE_\sigma^2 - 393\left(\frac{a}{l}\right)LTE_\sigma^3 \\
1 + 689\left(\frac{a}{l}\right)LTE_\sigma + 370 - 154\left(\frac{a}{l}\right)LTE_\sigma^2
\]
Load Transfer Efficiency Based on Deflections (LTE$_{\delta}$)

$$LTE_{\delta} = \frac{d_u}{d_t} \times 100$$
Load Transfer Efficiency Based on Stresses ($LTE_{\sigma}$)

$$LTE_{\sigma} = \frac{1206 \left( \frac{a}{l} \right) + 377 \left( LTE_{\sigma} \right)^2 - 393 \left( \frac{a}{l} \right) LTE_{\sigma}^3}{1 + 689 \left( \frac{a}{l} \right) LTE_{\sigma} + 370 - 154 \left( \frac{a}{l} \right) LTE_{\sigma}^2}$$

![Graph showing load transfer efficiency based on stresses.](image)
Load Transfer Based on FAA Design Criteria (LT)

\[ LT = \frac{LTE_\sigma}{1 + LTE_\sigma} \]
Initial and Terminal Joint Stiffness

Joint Stiffness \( [\log(J_c) + R] \)

@ 0
@ 1504
Loss of Joint Stiffness after 1504 Load Repetition

Percent Loss of Joint Stiffness

Slab#1-East Joint-HDP Conventional Injection-EtW
Slab#1-West Joint-HDP Conventional Injection-EtW
Slab#2-East Joint-HDP Deep Injection-EtW
Slab#2-West Joint-HDP Deep Injection-EtW
Slab#3-East Joint-Flowable Fill-WtE
Slab#3-West Joint-Flowable Fill-WtE
Slab#3-East Joint-Flowable Fill-EtW
Slab#3-West Joint-Flowable Fill-EtW
Differential Energy Concept

- The dissipated energy to the subgrade is assumed to be proportional to the energy of elastic deformation.

- Dissipated energy due to deformation of slab can be written as:
  \[ E = 0.5k \varepsilon_p^2 \]
  - \( k \) = Modulus of Subgrade Reaction
  - \( \varepsilon_p \) = Plastic deformation at the edge of the slab

- The differential energy is defined as the energy difference in the elastic subgrade deformation under the loaded slab (leave) and unloaded slab (approach):
  \[ DE = E_L - E_{UL} = \frac{1}{2} k(\varepsilon_p)_L^2 - \frac{1}{2} k(\varepsilon_p)_{UL}^2 \]

- Pavement systems with lower differential energy is expected to perform better in the field.
Differential Energy Concept
Effects of Environmental Conditions
Methodology

**HWD Testing for Temperature Analysis**

- **HWD Mid-Slab Loading at Different Times of the Day**
- **Back-Calculation of the PCC Modulus**
- **Determination of Flexural Strength \( S_c \)**
- **Finite Element Modeling and Analysis of the Pre-Cast Slabs Subjected to C-17 Aircraft for Various Loading Positions**
- **Determination of Critical Pavement Responses**
- **HWD Edge Loading at Different Times of the Day**
- **Determination of Directional Load Transfer Efficiency**
- **Determination of Design Factor (Stress/Strength) for each Permutation**
HWD TEST DROP SEQUENCE

9, 19, 29, 39, 49, 59, 69, 79
Travel south to north

6, 16, 26, 36, 46, 56, 66, 76
Travel east to west

2, 12, 22, 32, 42, 52, 62, 72
Travel west to east

3, 13, 23, 33, 43, 53, 63, 73
Travel west to east

1, 11, 21, 31, 41, 51, 61, 71
Travel west to east

6, 16, 26, 36, 46, 56, 66, 76
Travel east to west

2, 12, 22, 32, 42, 52, 62, 72
Travel west to east

3, 13, 23, 33, 43, 53, 63, 73
Travel west to east

7, 17, 27, 37, 47, 57, 67, 77
Travel south to north

8, 18, 28, 38, 48, 58, 68, 78
Travel south to north

4, 14, 24, 34, 44, 54, 64, 74
Travel east to west

5, 15, 25, 35, 45, 55, 65, 75
Travel east to west

8, 18, 28, 38, 48, 58, 68, 78
Travel south to north

7, 17, 27, 37, 47, 57, 67, 77
Travel south to north
Temperature Profile

Temperature (°F)

Depth (in)

7:17
8:08
8:37
7:41
9:16
9:49
10:23
11:04
11:40
12:23
13:30
13:58
14:25
14:50
15:23
15:43
16:21
16:52
Temperature Dependency of the Load Transfer Efficiency in Pre-Cast Panels

Day Time Superposition of Thermal and Load-induced Stresses for FWD Loading
• Load Transfer Efficiencies were calculated as a function of time of the day and the temperatures were logged at each interval.

• Lowest recorded surface temperature was at 7:17 am as 85°F and highest surface temperature was 107°F at 13:57 pm.

• Load transfer efficiencies were relatively constant throughout the day.
Summary

Three pre-cast PCC slab installation techniques were investigated in this research effort.

High Density Polyurethane (HDP) foam was used for leveling and installation of Slab#1 and Slab#2. Flowable fill was used for Slab#3.

Performance of the repaired sections were assessed through analysis of:

- Load Transfer Efficiency Based on Deflections (LTE$_δ$)
- Load Transfer Efficiency Based on Stresses (LTE$_σ$)
- Load Transfer Based on FAA Design Criteria (LT)
- Analysis of Joint Stiffness based on MEPDG criteria [log $(J_c)+R$]
- Analysis based on Dissipated Deformation Energy to Subgrade
- Analysis of Responses of Pre-Cast Panels using FE
Thank you!
Precast Panel 1

Injection ports

HDP Foam Injection

Flowable Fill Installation Detail
Impact of Transverse Load Transfer Efficiency on Mid-Slab Deflections under HWD

LTE_y = 90%  
LTE_x = 100%

LTE_y = 90%  
LTE_x = 100%
Loading Configurations for FE Response Calculations

1. Corner Loading

2. Mid-Slab Loading

3. Edge Loading

4. Direction of Landing

5. Landing perpendicular to the direction of dowel bars
Criteria for Different Runway Repair Strategies

• **EXPEDITENT REPAIR**
  Expedient repairs are defined as airfield pavement repairs that create an initial operationally capable MOS/MAOS, based on projected mission aircraft requirements, in the most expeditious manner possible.
  – **Criteria:** Criteria have been established for an expedient repair to provide an accessible and functional MOS/MAOS that will sustain 100 passes of C-17 with a gross weight of 227,707 kg (502 kips), or 100 passes of C-130 with a gross weight of 79,380 kg (175 kips).

• **SUSTAINMENT REPAIR**
  Repair efforts designed to upgrade expedient repairs for increased aircraft traffic are known as sustainment repairs.
  – **Criteria:** Sustainment repairs to an MOS/MAOS are expected to support 5,000 passes of C-17 with a gross weight of 227,707 kg (502 kips), or 5,000 passes of C-130 with a gross weight of 79,380 kg (175 kips).
Distribution of Vertical Stresses at the Top of the Subgrade (Day Time)
Distribution of Vertical Stresses at the Top of the Subgrade (Corner/Edge Loading for Slab#1)
Typical Day Time Curling

Top of the PCC Layer is *Warmer*
Bottom of the PCC Layer is *Cooler*

Typical Night Time Curling

Top of the PCC Layer is *Cooler*
Bottom of the PCC Layer is *Warmer*
Maximum Deflection under C-17 Landing Gear

Maximum Plastic Deformation (m)

- Slab#1
- Slab#2
- Slab#3
Airfield Pavement Failure Models

- Pavement Life is a function of the ratio between flexural strength and the bending stress used in the design (AC150/5320-6D)

\[
SCI = \frac{\left(\frac{S_c}{\sigma_v}\right)^{0.2967}}{0.002269} - F_s (0.3881 + F_{sc} 0.00039 \times SCI) \log COV
\]

\[
COV = 5000 \times 10^{0.07058}
\]

- \(COV=\) Coverage
- \(\sigma_v=\) Working stress in the design
- \(S_c=\) Flexural Strength \(S_c = 6.5 \sqrt{f_c}\)
- \(SCI=\) Structural Condition Index

\[
F_{sc} = \frac{0.392 - 0.3881 \times F_s}{0.0039 F_s}
\]
Design Factor $[\sigma_{v(\text{max})}/S_c]$