THE AIR FORCE RESEARCH LABORATORY

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

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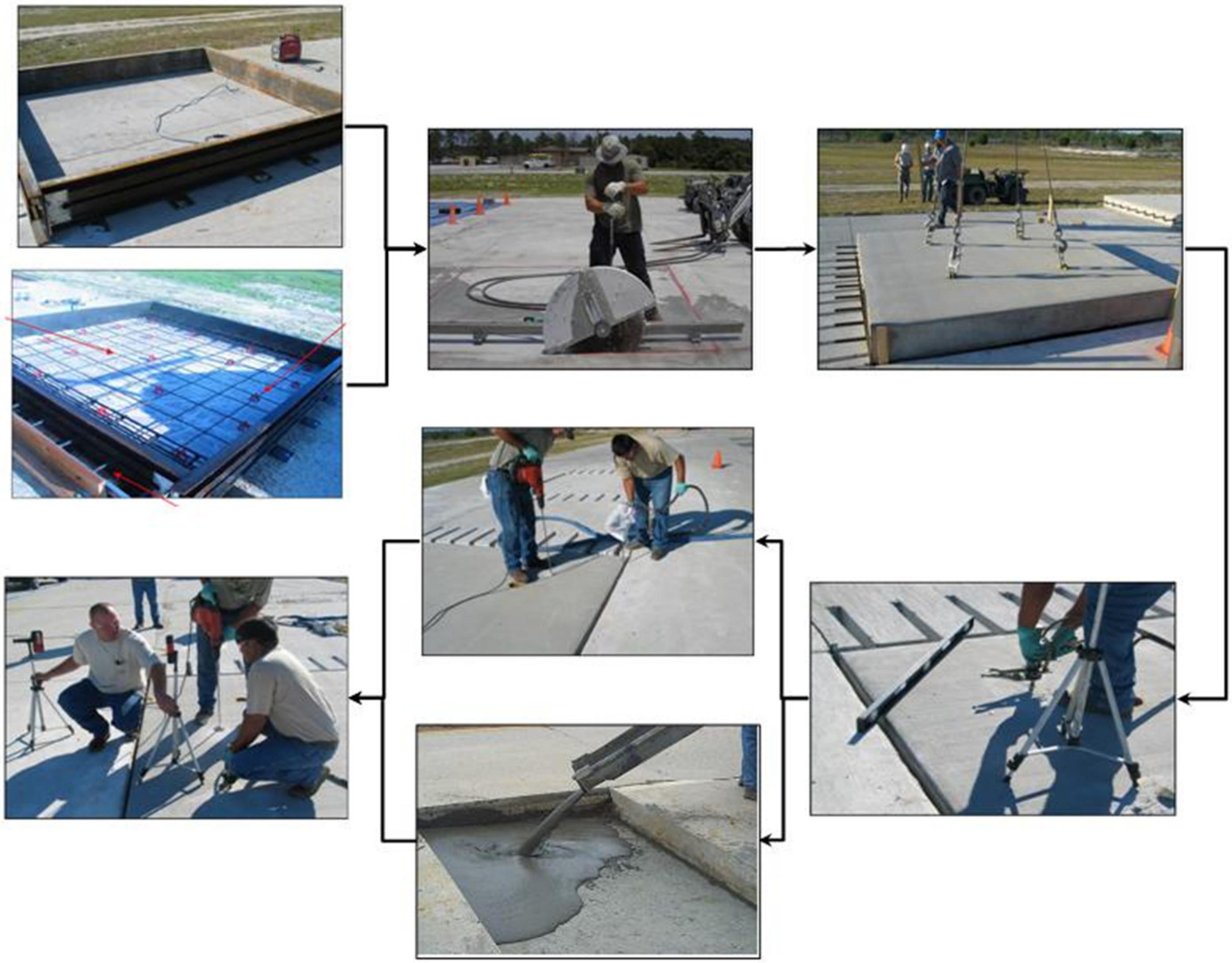
Objectives

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

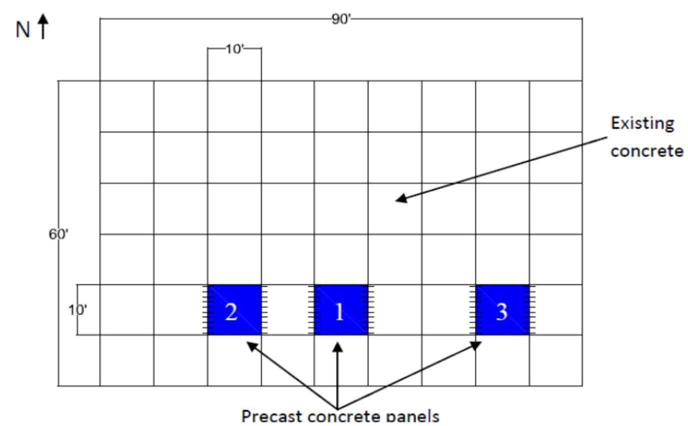
- Analysis of Load Transfer Efficiency *(LTE_{δ}, LTE_{σ} , and LT_{FAA})*
- Analysis of Joint Stiffness
- Analysis of Deformation Energy Dissipated to the Pavement Foundation
- Analysis of Performance based on FE Response Analysis
  - Thermal Stresses
  - Load Induced Stresses (C-17 Aircraft)
  - Performance Index based on Failure Criteria

Construction and Installation Process



Test Sections

Variant	Pre-cast Panel ID.	Joint Orientation	Bonding Agent	Installation Method	HWD Direction
1	#1	East	HDP Foam	Direct Injection	East to West
2	#1	West	HDP Foam	Direct Injection	East to West
3	#2	East	HDP Foam	Deep Injection	East to West
4	#2	West	HDP Foam	Deep Injection	East to West
5	#3	East	Flowable Fill	Conventional	West to East
6	#3	West	Flowable Fill	Conventional	West to East
7	#3	East	Flowable Fill	Conventional	East to West
8	#3	West	Flowable Fill	Conventional	East to West



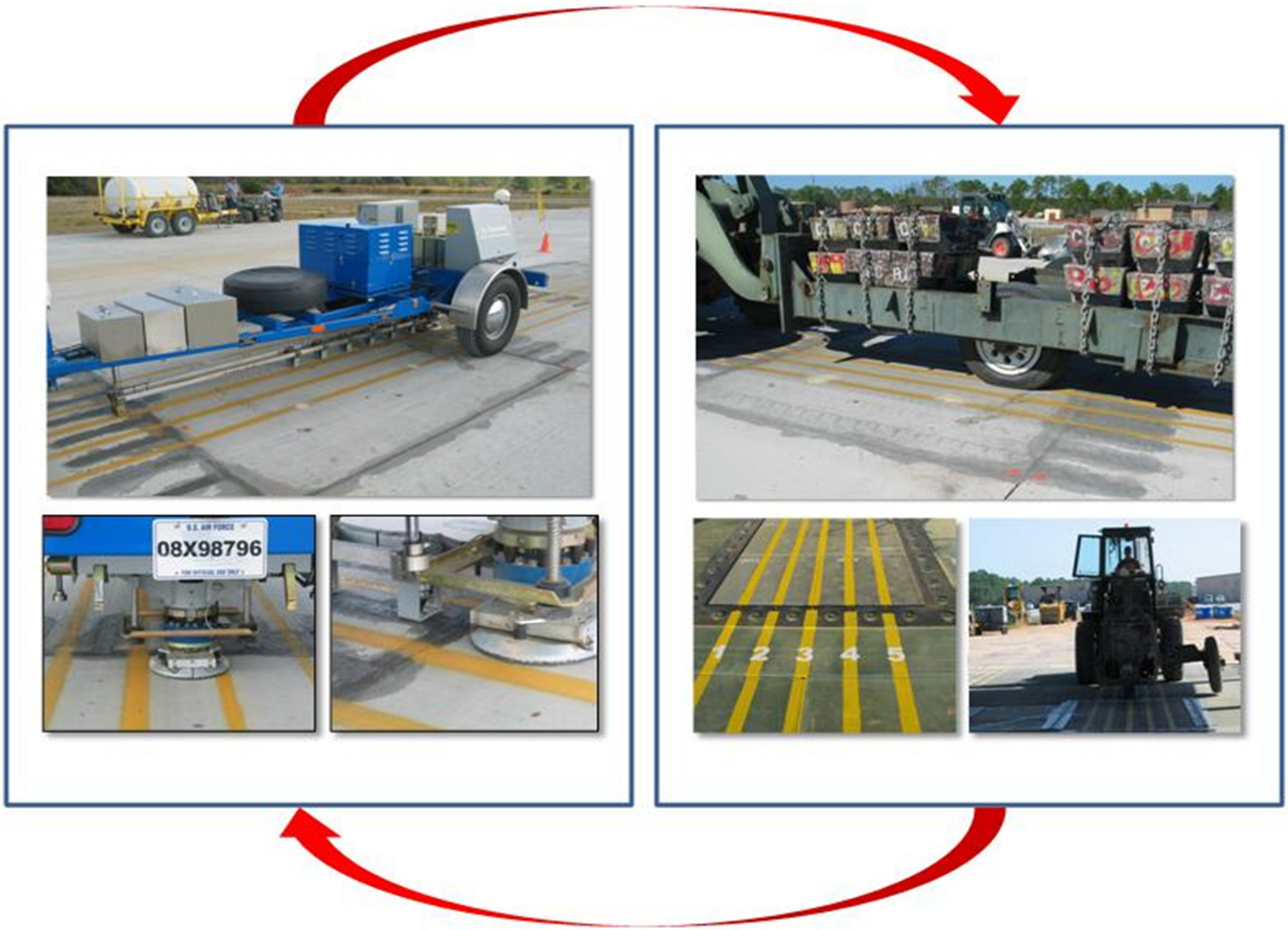
HWD Testing for Performance Analysis

HWD Mid-Slab Loading

- *Back-Calculation of the PCC Modulus*
- *Determination of Flexural Strength (S_c)*

HWD Edge Loading at Different Load Repetitions

- *Determination of Load Transfer Efficiency as a Function of Number of Load Applications*
- *Analysis of Joint Stiffness*
- *Analysis of Deformation Energy*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1 2 3 4 5

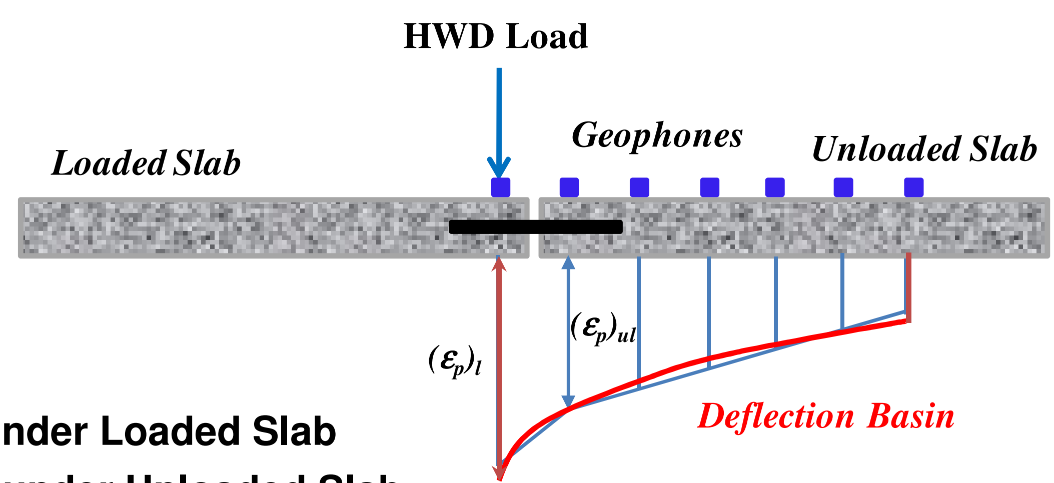
Load Transfer in Rigid Pavements

Definition:

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

$$LTE_\delta = \frac{d_u}{d_l} \times 100 \qquad LTE_\sigma = \frac{\sigma_u}{\sigma_l} \times 100$$

$$LT = \frac{LTE_\sigma}{1 + LTE_\sigma} \qquad l = \sqrt[4]{\frac{Eh^3}{12k(1-\upsilon^2)}}$$



d_l, σ_l= Deflection and Vertical Stress under Loaded Slab

d_u, σ_u= Deflection and Vertical Stress under Unloaded Slab

l = Radius of Relative Stiffness

LTE_σ= Stress Based Load transfer Efficiency

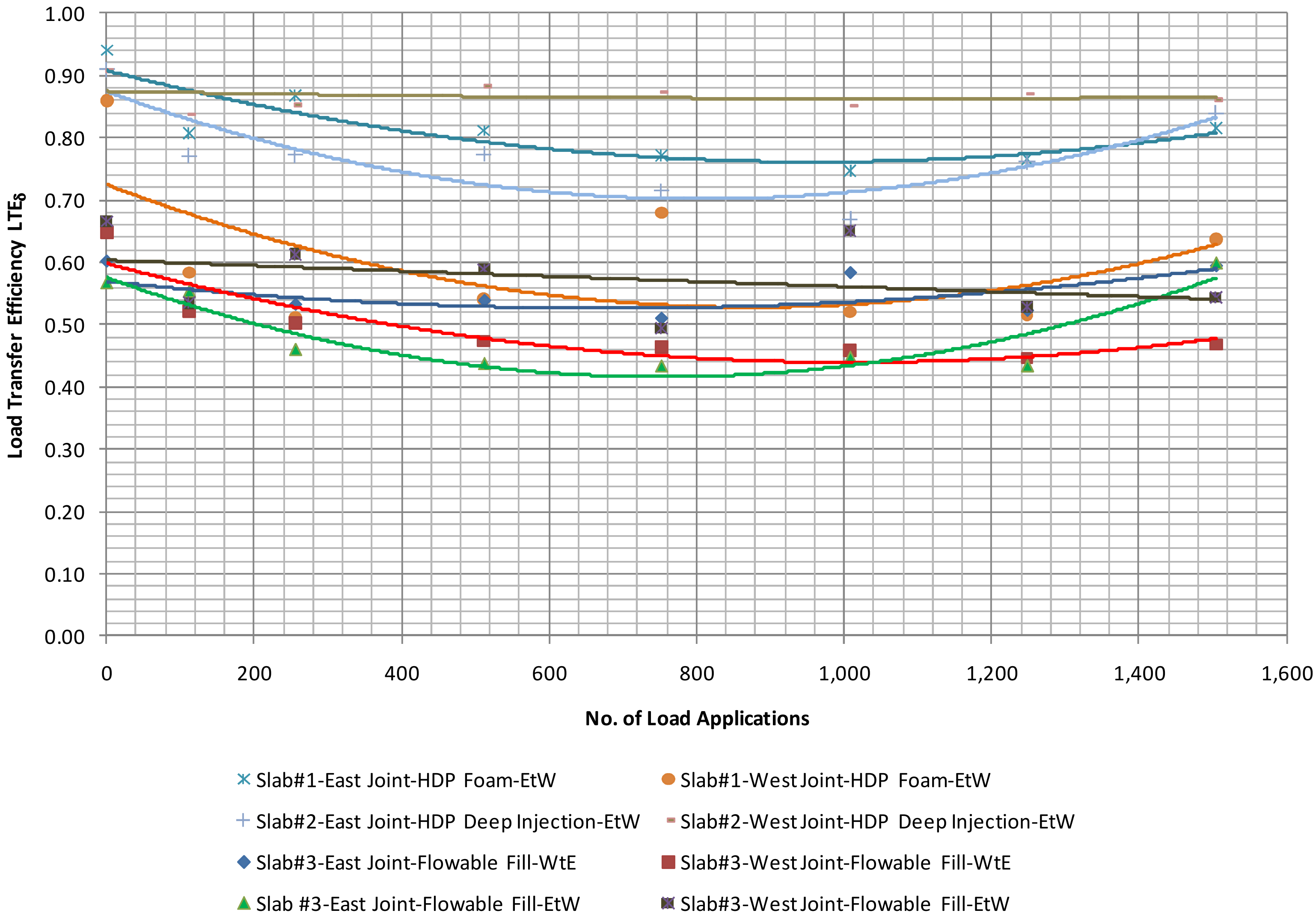
LTE_δ= Deflection Based Load transfer Efficiency

LT= FAA criteria for Load Transfer Efficiency

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

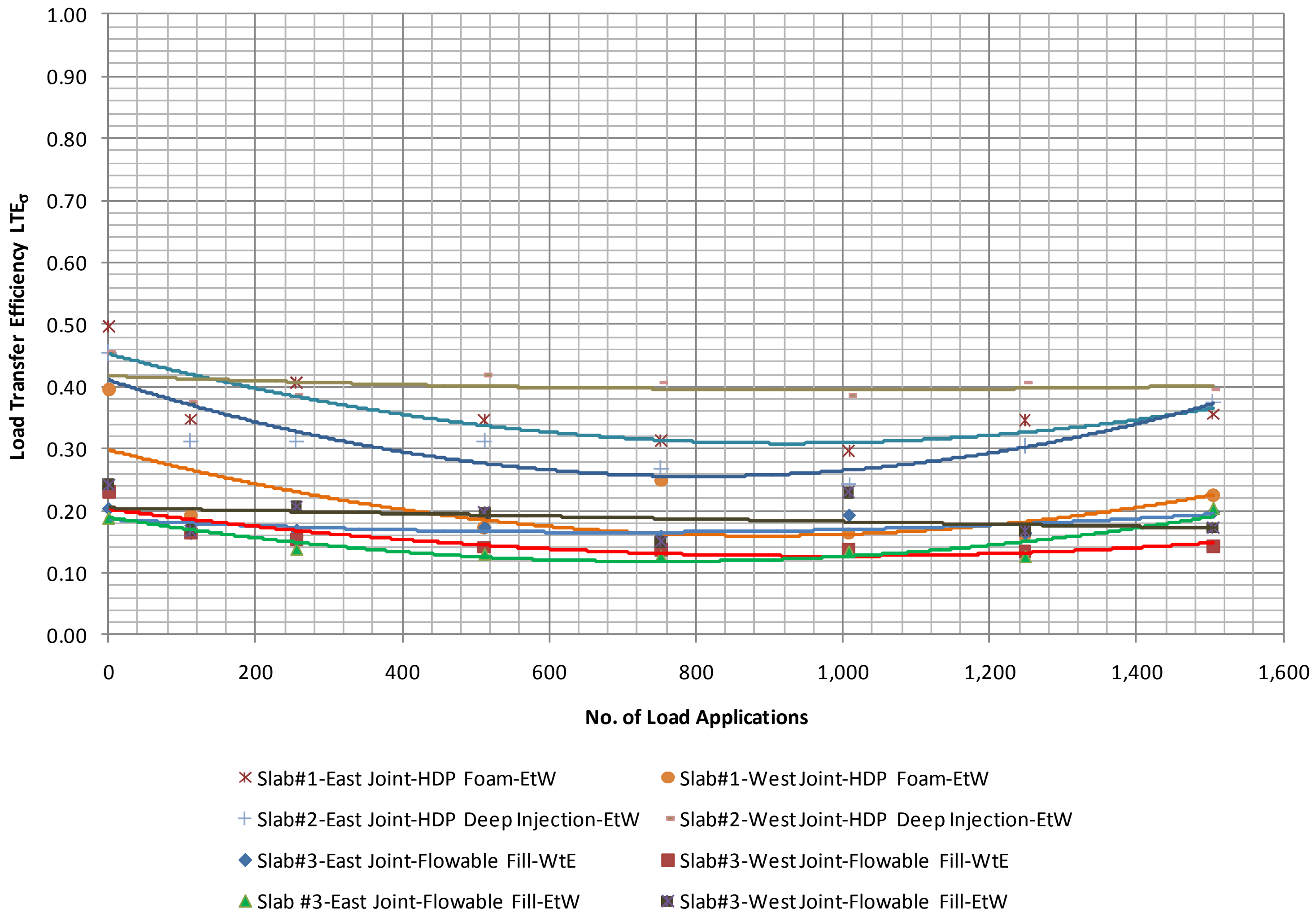
Load Transfer Efficiency Based on Deflections (LTE_δ)

$$LTE_\delta = \frac{d_u}{d_l} \times 100$$



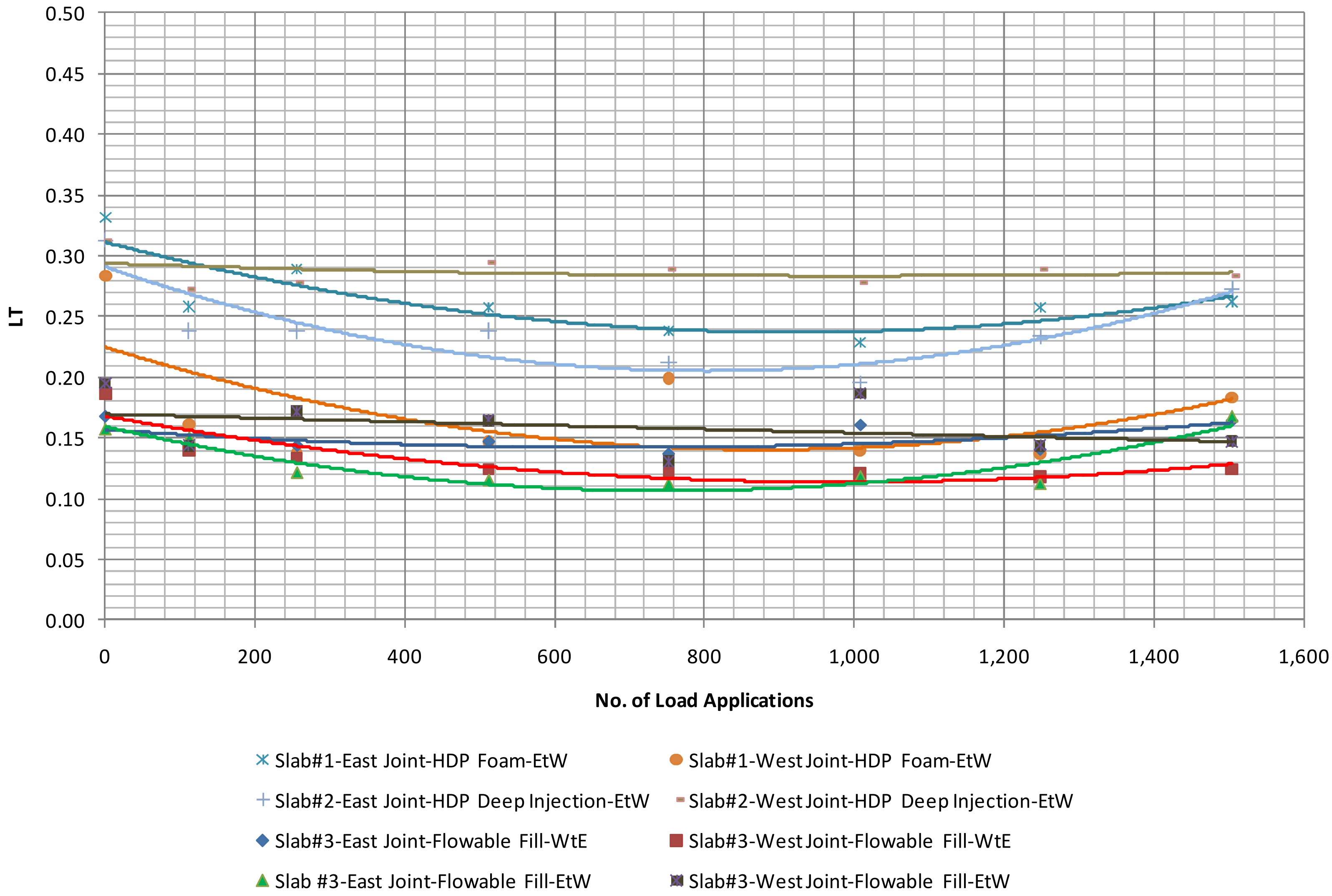
Load Transfer Efficiency Based on Stresses (LTE_σ)

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

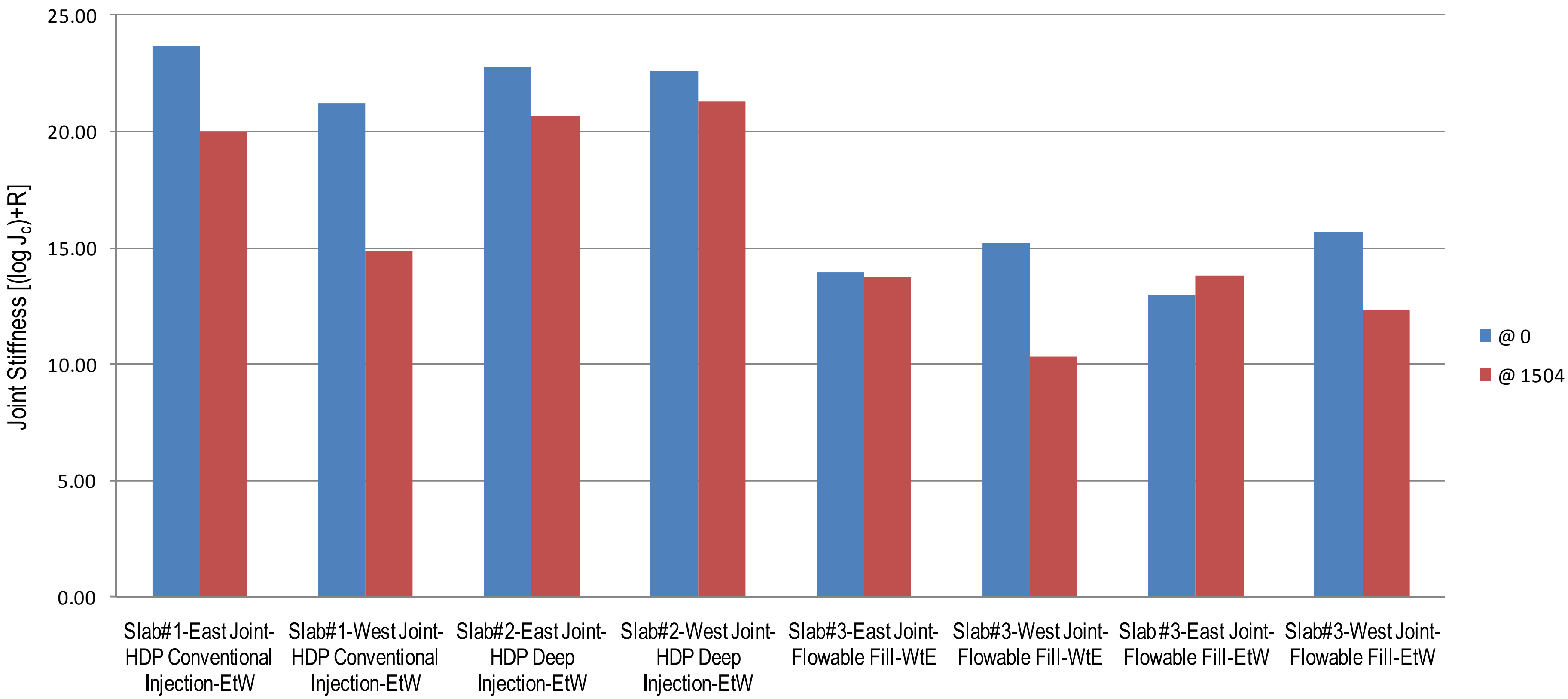


Load Transfer Based on FAA Design Criteria (LT)

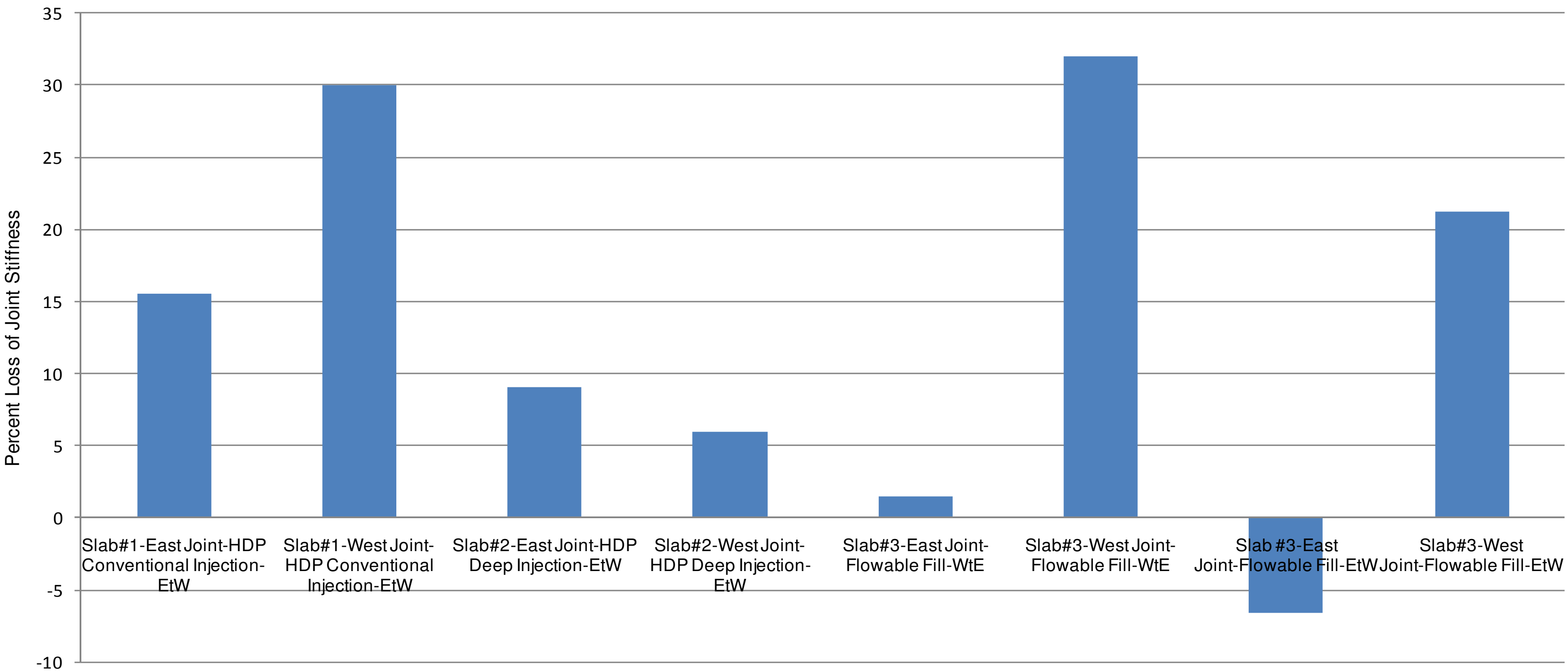
$$LT = \frac{LTE_\sigma}{1 + LTE_\sigma}$$



Initial and Terminal Joint Stiffness



Loss of Joint Stiffness after 1504 Load Repetition



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:

  $E=0.5k\varepsilon_p^{2}$

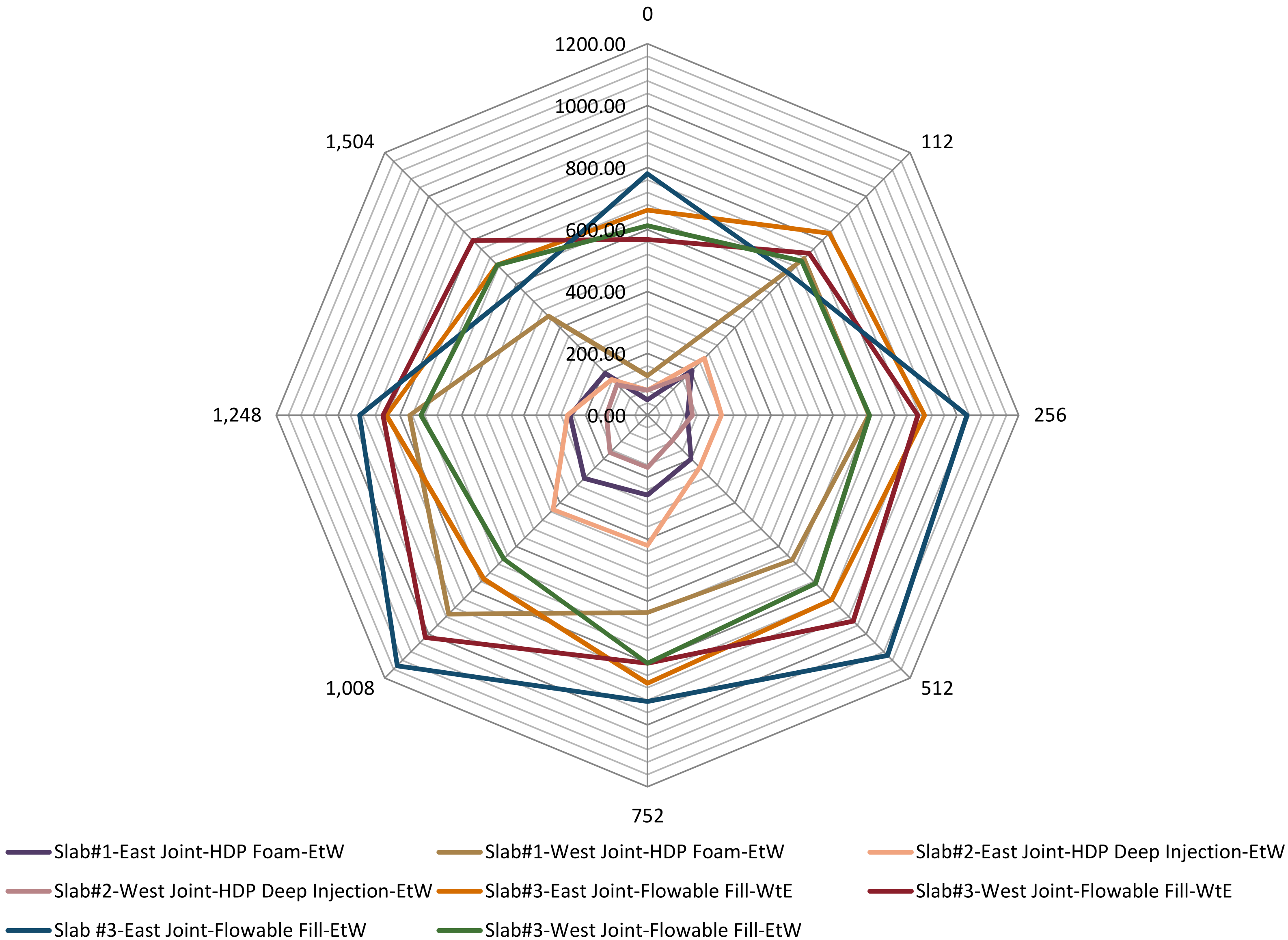
  – k=Modulus of Subgrade Reaction

  – ε_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

HWD Edge Loading at Different Times of the Day

Back-Calculation of the PCC Modulus

Determination of Directional Load Transfer Efficiency

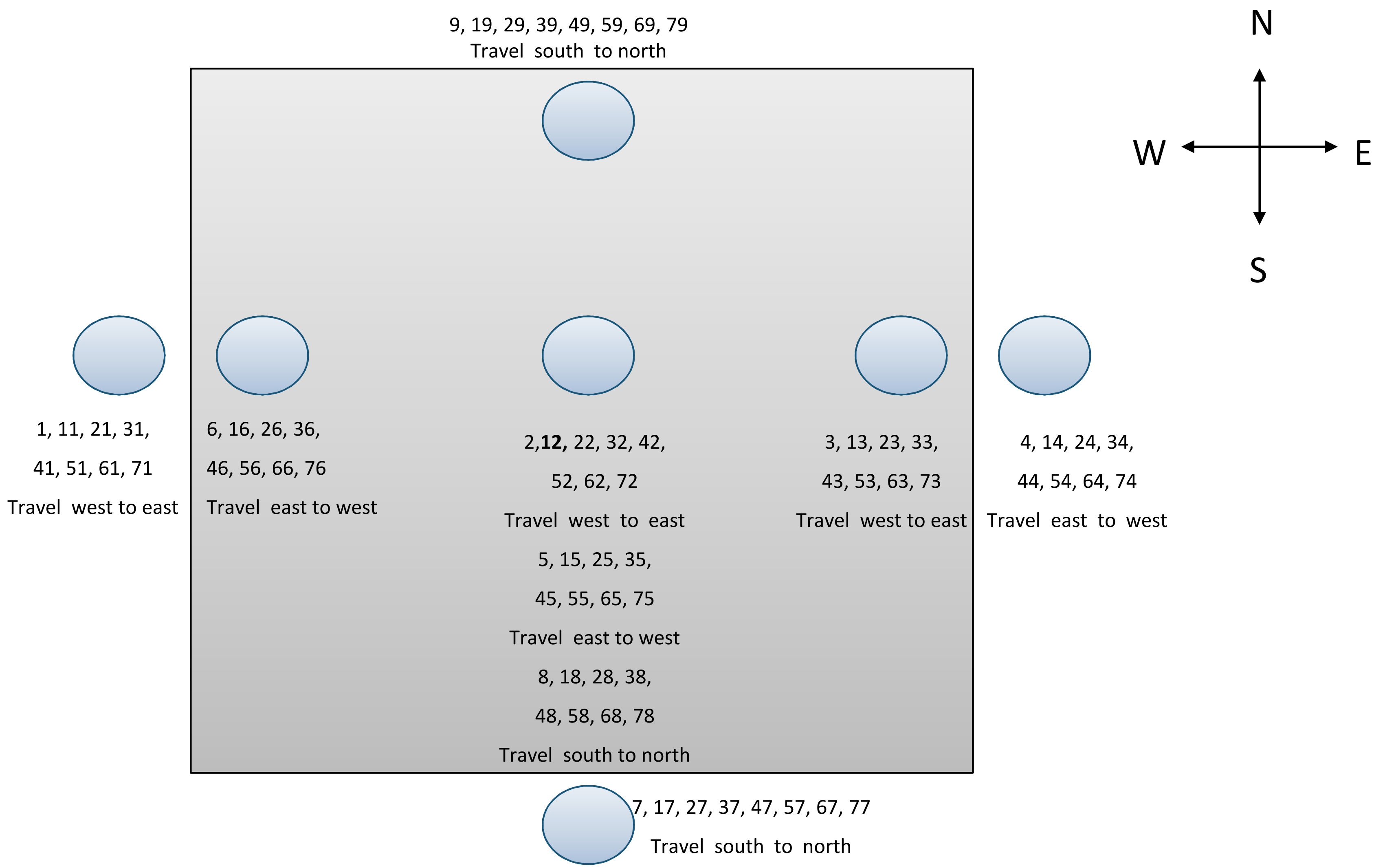
Determination of Flexural Strength (S_c)

Finite Element Modeling and Analysis of the Pre-Cast Slabs Subjected to C-17 Aircraft for Various Loading Positions

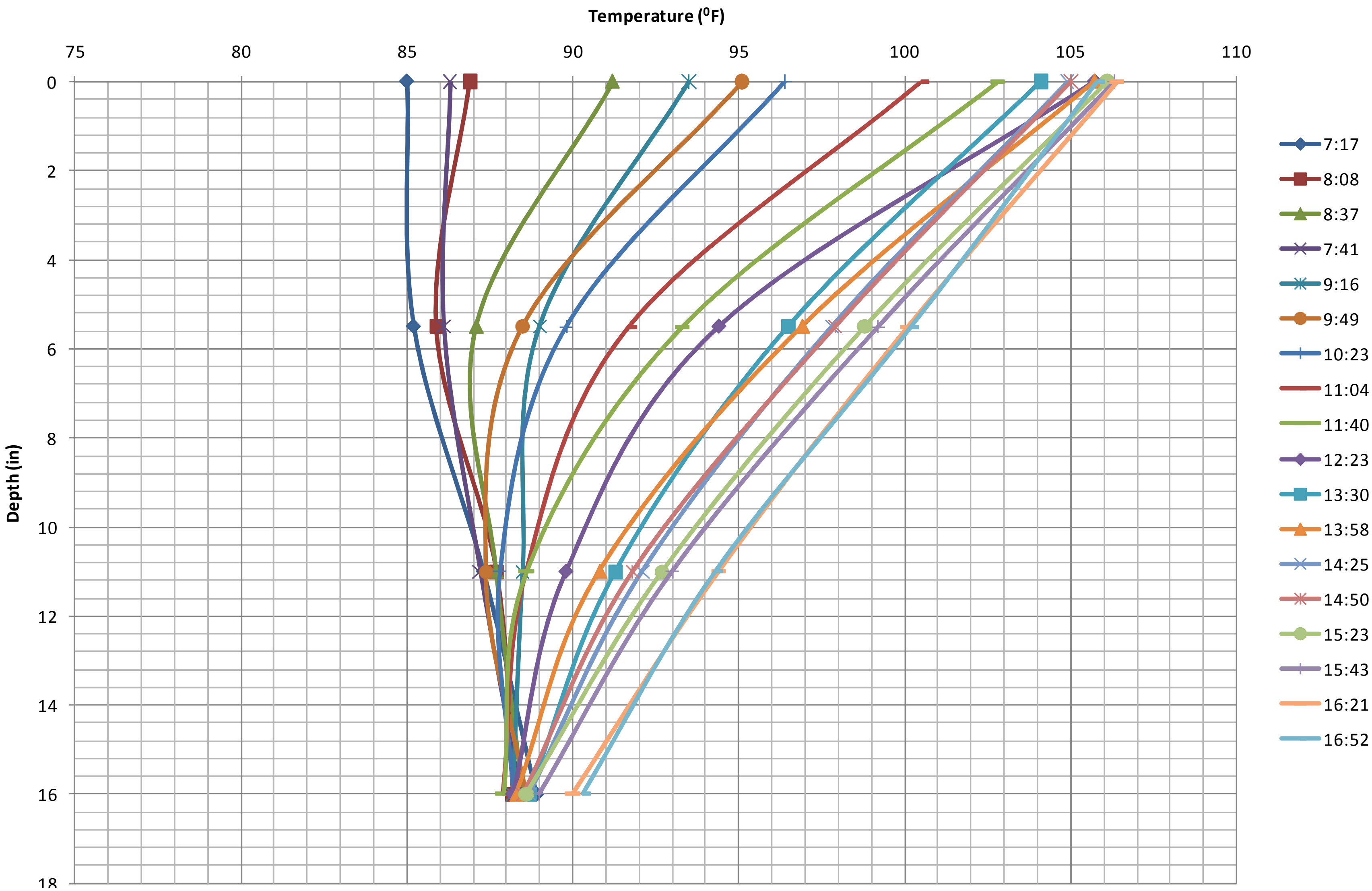
Determination of Critical Pavement Responses

Determination of Design Factor (Stress/Strength) for each Permutation

HWD TEST DROP SEQUENCE

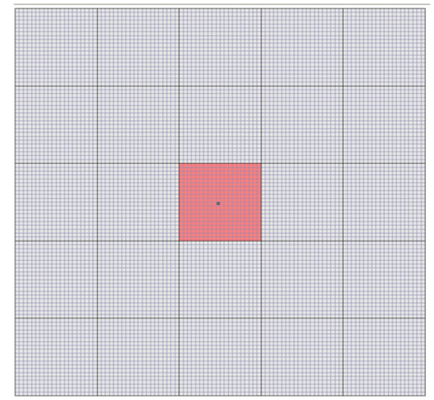


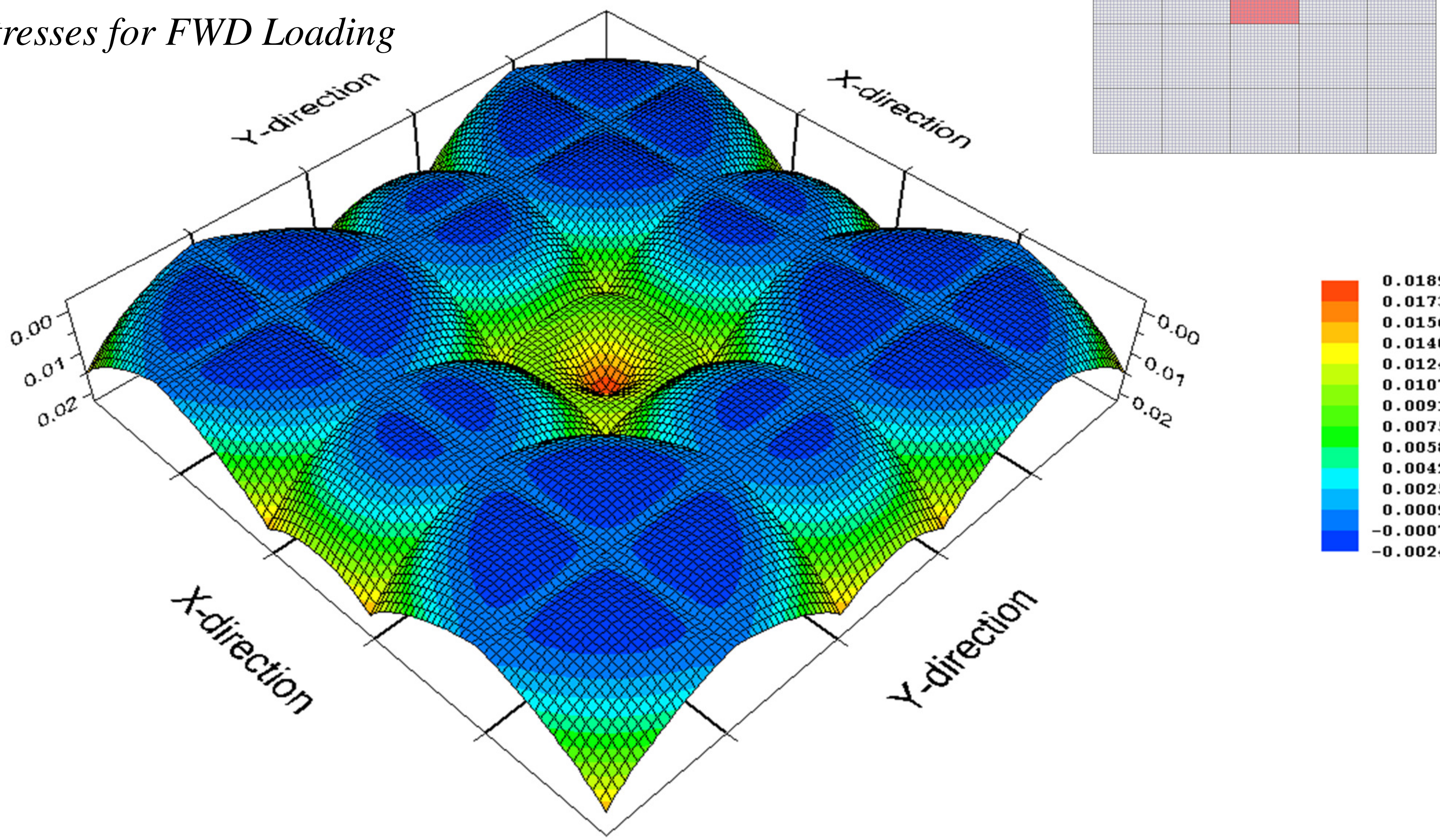
Temperature Profile



Temperature Dependency of the Load Transfer Efficiency in Pre-Cast Panels

Day Time Superposition of Thermal and Load-induced Stresses for FWD Loading



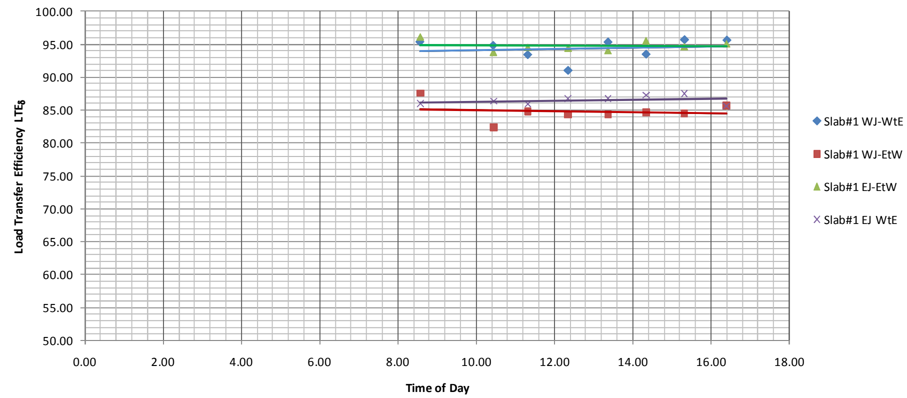


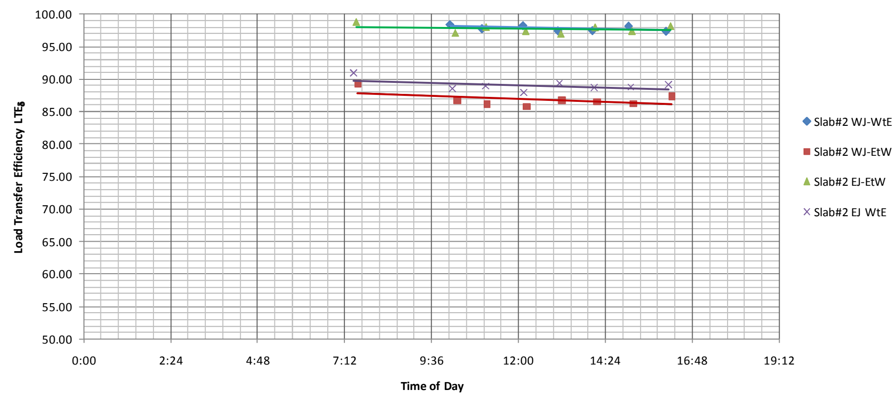
Temperature Dependency of the Load Transfer Efficiency in Pre-Cast Panels

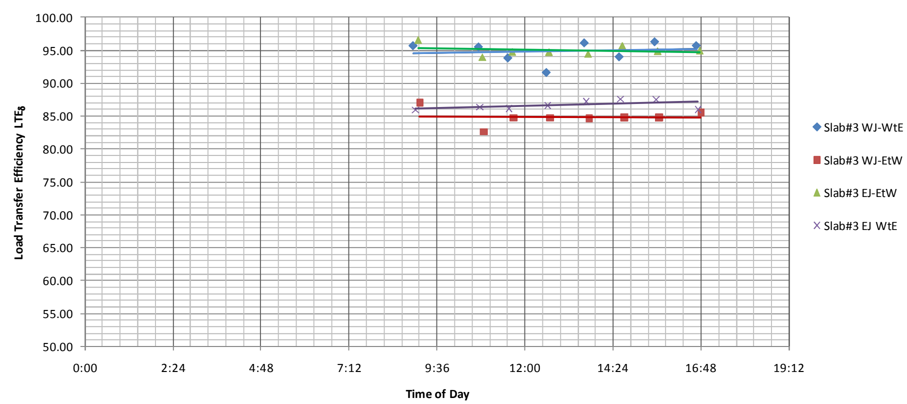
- Load Transfer Efficiencies were calculated as a function of time of the day and the temperatures were logged at each interval.

- Lowest recorded surface temperature was at 7:17 am as 85 ^{0}F and highest surface temperature was 107 ^{0}F at 13:57 pm.

- Load transfer efficiencies were relatively constant throughout the day.







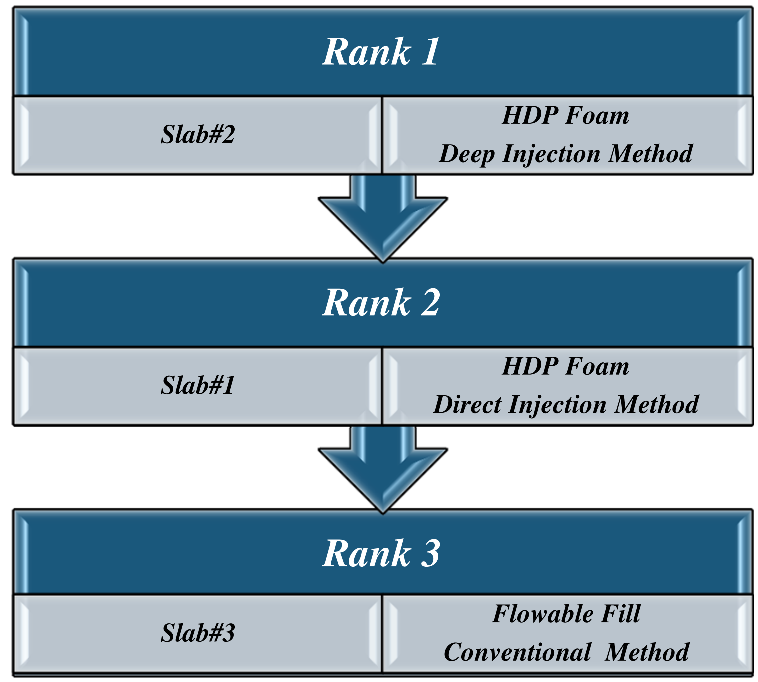
Summary

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

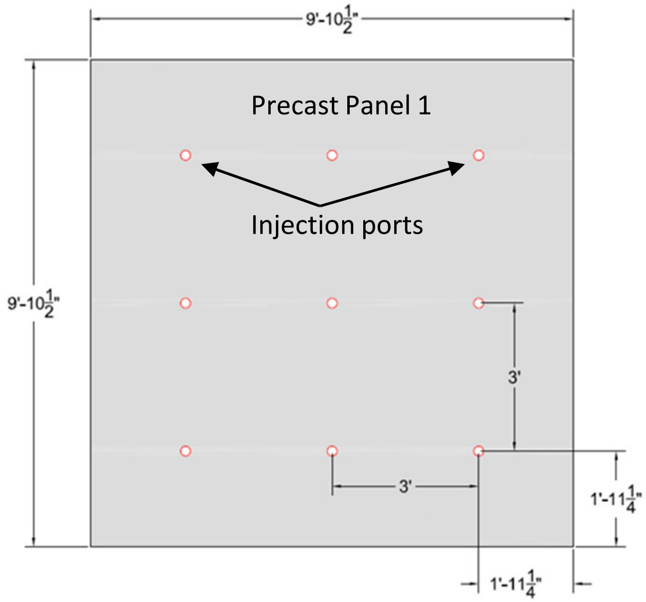
High Density Polyurethane (HDP) foam was used for leveling and installation of Slab#1 and Slab#2. Flowable fill was used for Slab#3

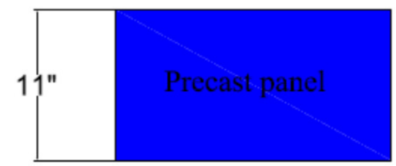
Performance of the repaired sections were assessed through analysis of:

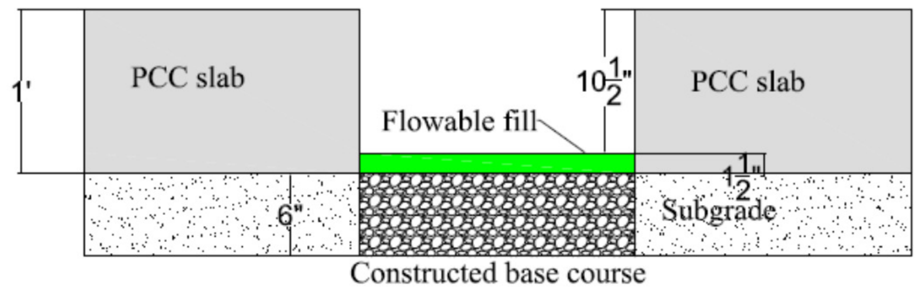
- Load Transfer Efficiency Based on Deflections (LTE_{δ})
- Load Transfer Efficiency Based on Stresses (LTE_{σ})
- Load Transfer Based on FAA Design Criteria (LT)
- Analysis of Joint Stiffness based on MEPDG criteria [log $(J_c)+R$]
- Analysis based on Dissipated Deformation Energy to Subgrade
- Analysis of Responses of Pre-Cast Panels using FE



Thank you!



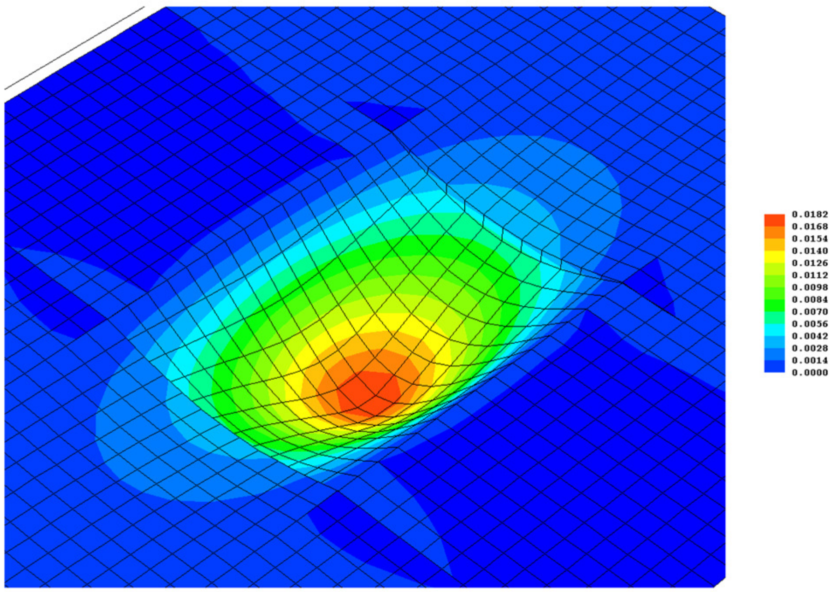




HDP Foam Injection

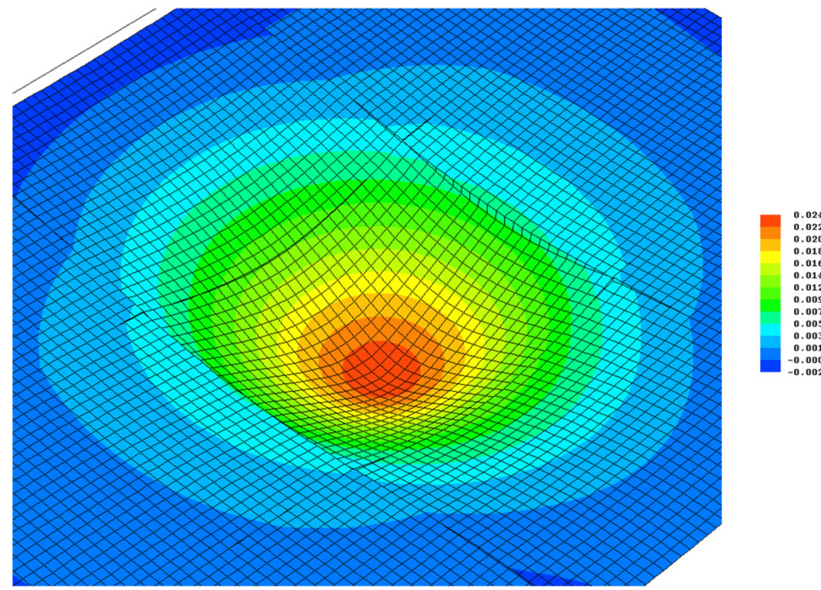
Flowable Fill Installation Detail

Impact of Transverse Load Transfer Efficiency on Mid-Slab Deflections under HWD



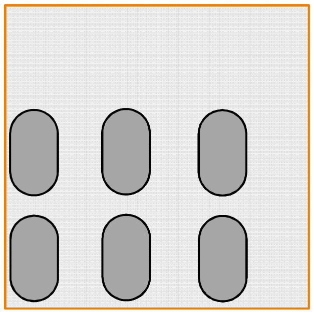
LTE_y=90%
LTE_x=100%

LTE_y=90%
LTE_x=90%



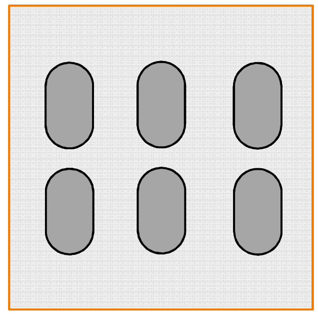
Loading Configurations for FE Response Calculations

1



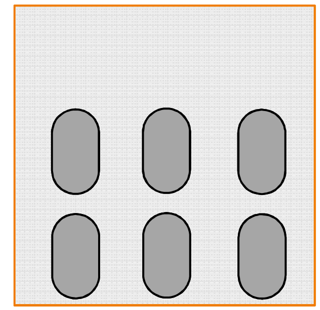
Corner Loading

2



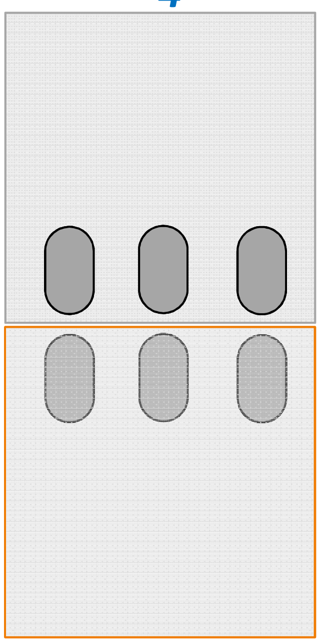
Mid-Slab Loading

3

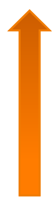


Edge Loading

4

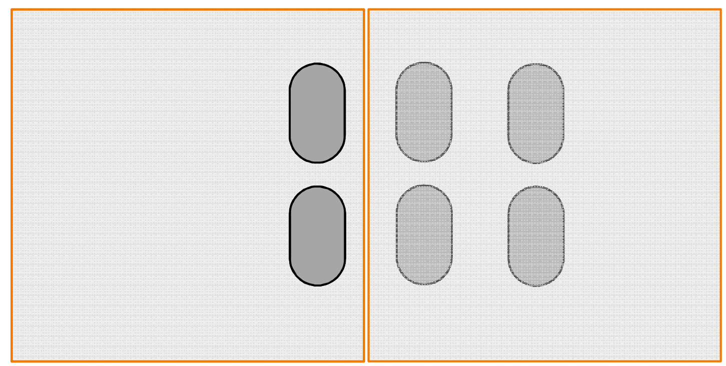


Landing in the direction of dowel bars

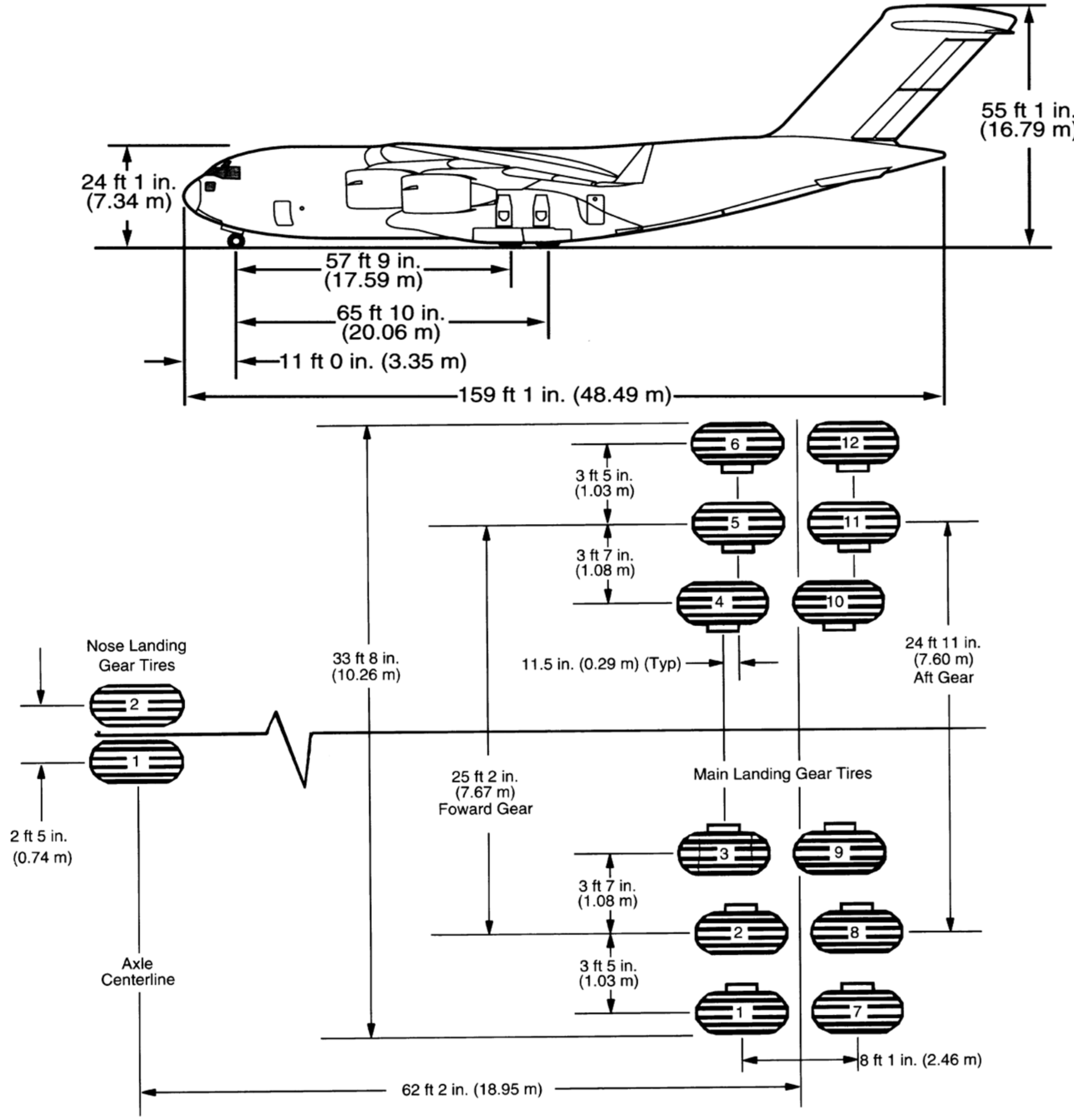


Direction of Landing

5



Landing perpendicular to the direction of dowel bars


24 ft 1 in.
(7.34 m)
55 ft 1 in.
(16.79 m)
57 ft 9 in.
(17.59 m)
65 ft 10 in.
(20.06 m)
11 ft 0 in. (3.35 m)
159 ft 1 in. (48.49 m)
Nose Landing
Gear Tires
2
1
2 ft 5 in.
(0.74 m)
Axle
Centerline
33 ft 8 in.
(10.26 m)
25 ft 2 in.
(7.67 m)
Foward Gear
3 ft 5 in.
(1.03 m)
3 ft 7 in.
(1.08 m)
11.5 in. (0.29 m) (Typ)
Main Landing Gear Tires
6
5
4
12
11
10
3
2
1
9
8
7
24 ft 11 in.
(7.60 m)
Aft Gear
8 ft 1 in. (2.46 m)
62 ft 2 in. (18.95 m)

Criteria for Different Runway Repair Strategies

- ***EXPEDIENT REPAIR***

  Expedient repairs are defined as airfield pavement repairs that create an initial operationally capable MOS/MOAS, based on projected mission aircraft requirements, in the most expeditious manner possible.

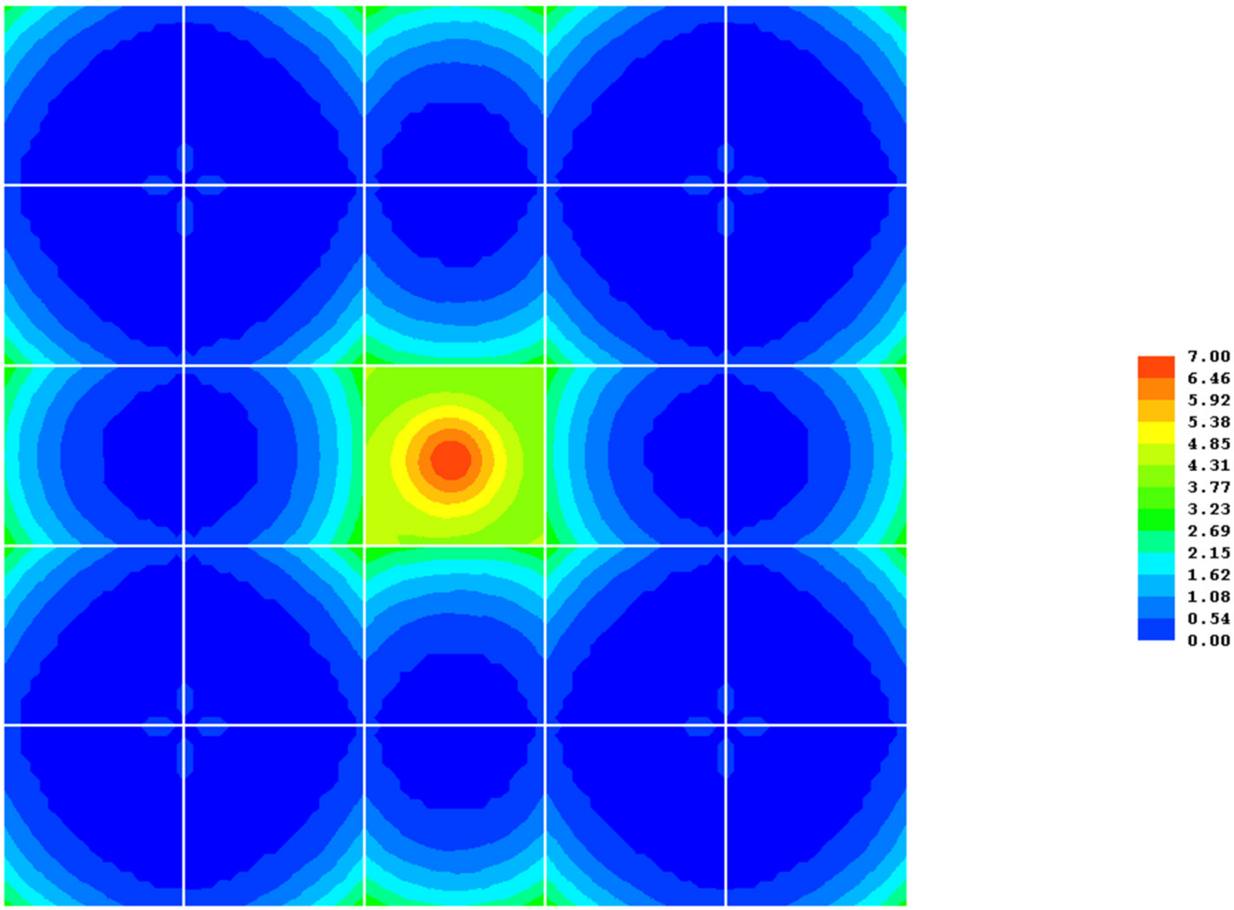
  - **Criteria:** Criteria have been established for an expedient repair to provide an accessible and functional MOS/MAOS that will sustain ***100 passes of C-17*** with a gross weight of 227,707 kg (502 kips), or ***100 passes of C-130*** with a gross weight of 79,380 kg (175 kips).

- ***SUSTAINMENT REPAIR***

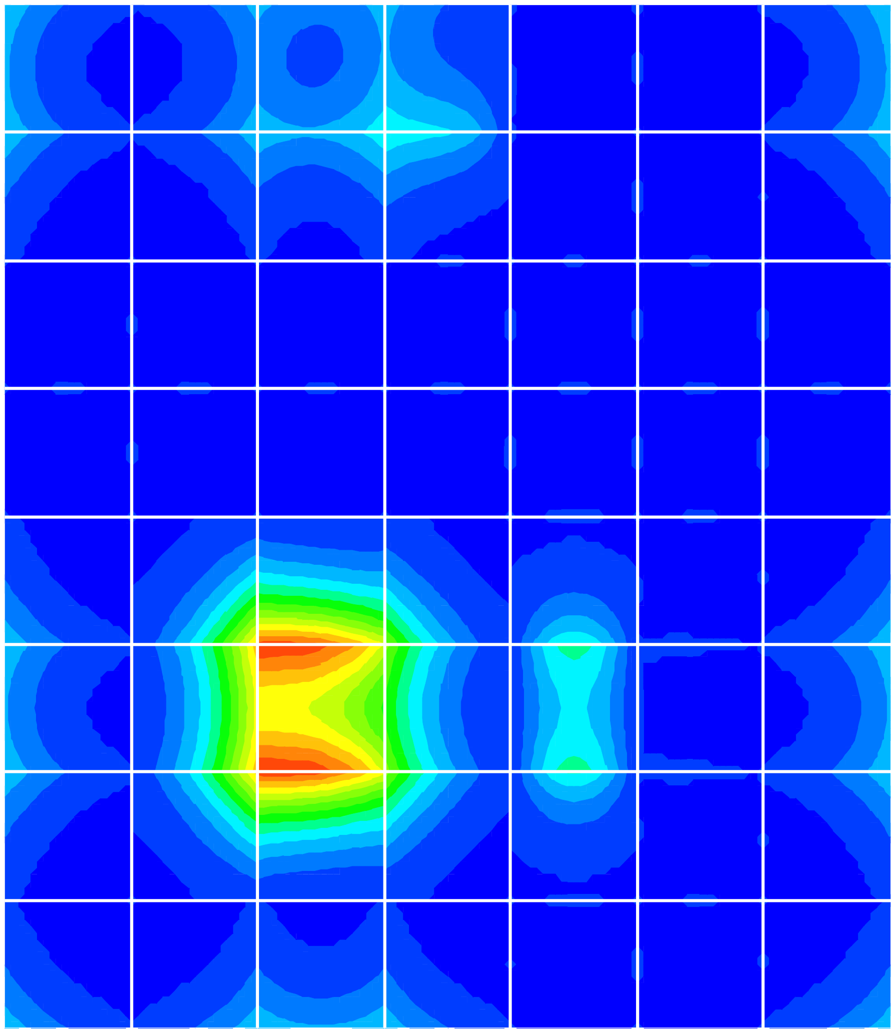
  Repair efforts designed to upgrade expedient repairs for increased aircraft traffic are known as sustainment repairs.

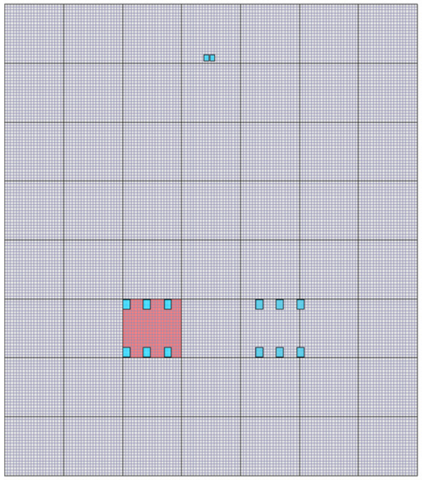
  - **Criteria:** Sustainment repairs to an MOS/MAOS are expected to support ***5,000 passes of C-17*** with a gross weight of 227,707 kg (502 kips), or ***5,000 passes of C-130*** with a gross weight of 79,380 kg (175 kips).

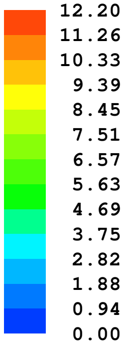
Distribution of Vertical Stresses at the Top of the Subgrade (Day Time)



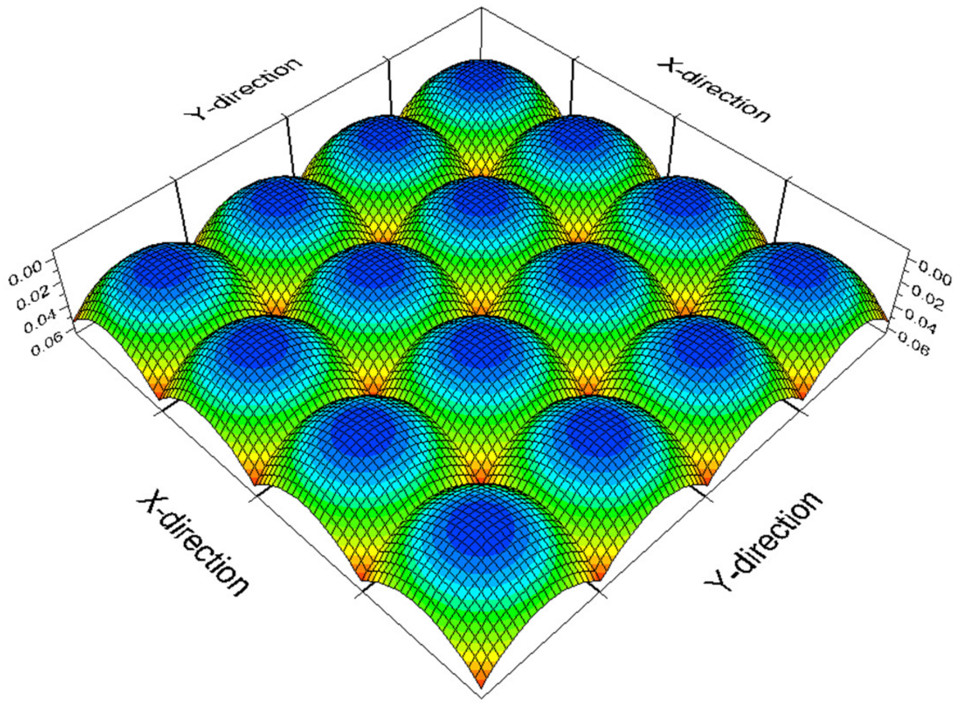
Distribution of Vertical Stresses at the Top of the Subgrade (Corner/Edge Loading for Slab#1)





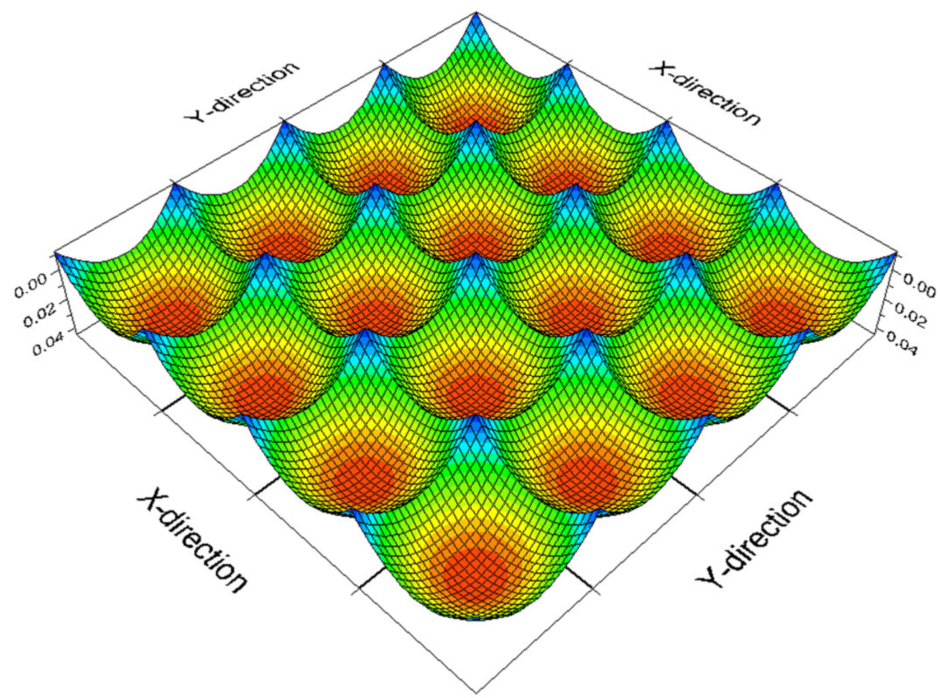


Typical Day Time Curling

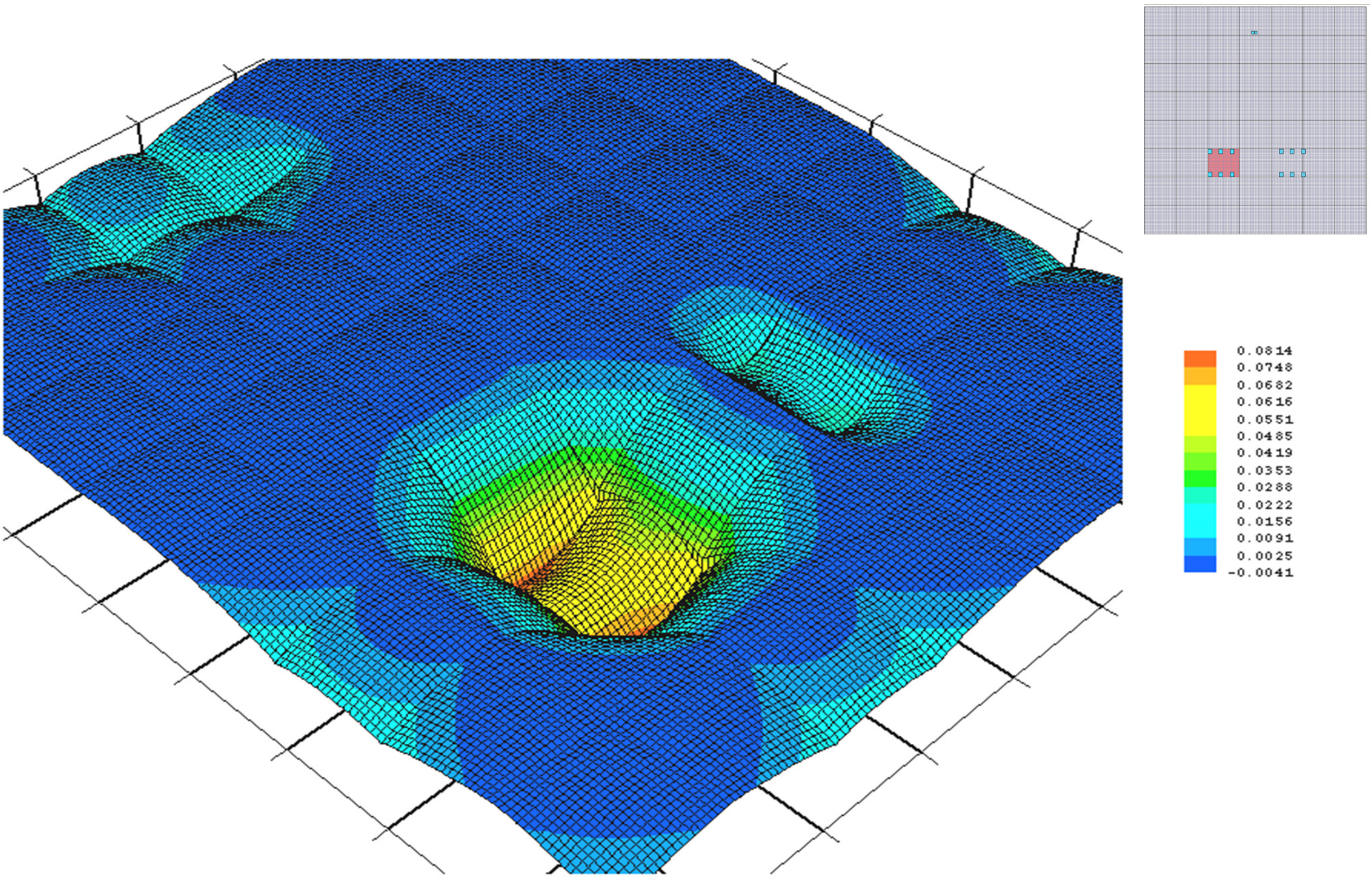


Top of the PCC Layer is *Warmer*
Bottom of the PCC Layer is *Cooler*

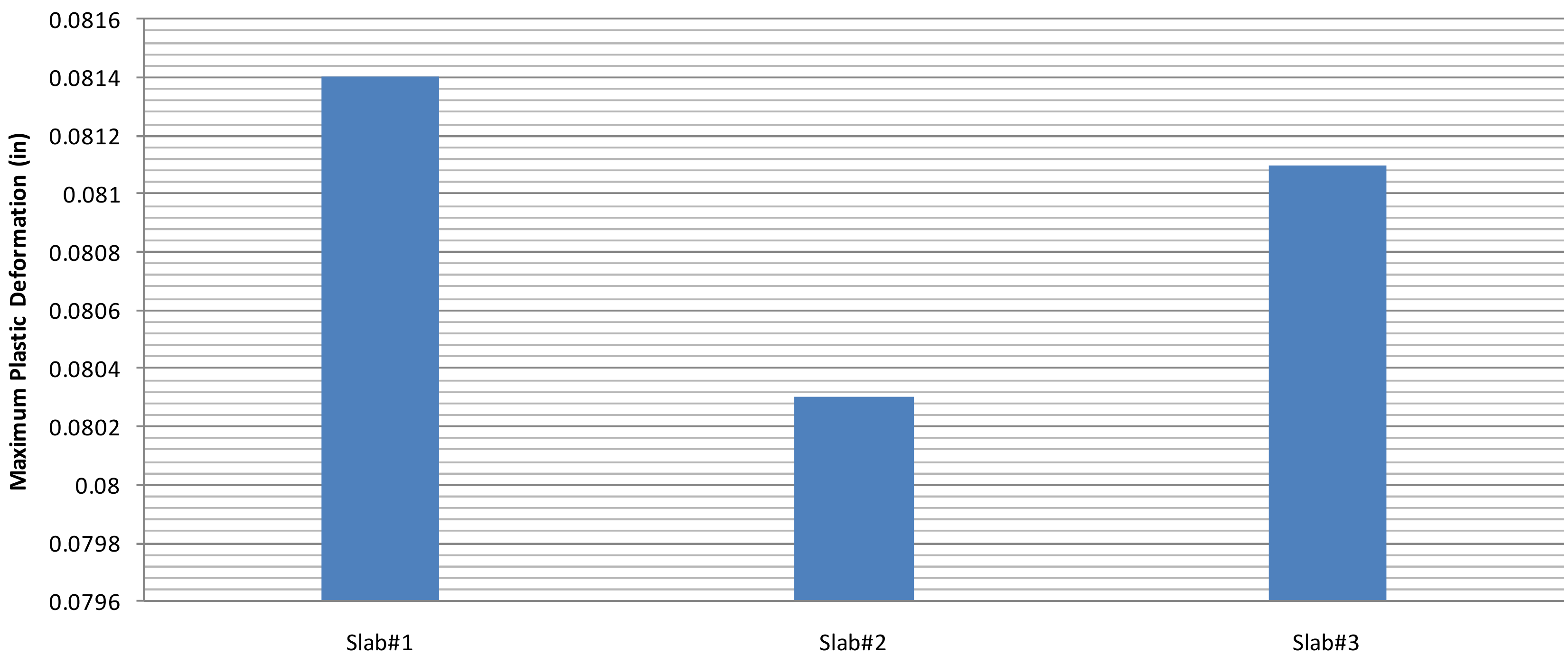
Typical Night Time Curling



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


0.0814
0.0748
0.0682
0.0616
0.0551
0.0485
0.0419
0.0353
0.0288
0.0222
0.0156
0.0091
0.0025
-0.0041

Maximum Deflection under C-17 Landing Gear



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)**

$$SCI = \frac{\left(\frac{S_c}{\sigma_v}\right) - 0.2967 - F_s(0.3881 + F_{SC}\,0.000039 \times SCI)\log COV}{0.002269}$$

$$COV = 5000 \times 10^{\frac{\left[\sqrt{\frac{S_C}{1.3\sigma_V}} - 1\right]}{0.07058}}$$

$$F_{SC} = \frac{0.392 - 0.3881 \times F_S}{0.0039 F_S}$$

- **COV= Coverage**
- **σ_v=Working stress in the design**
- **S_c=Flexural Strength** $S_c = 6.5\sqrt{f_c'}$
- **SCI=Structural Condition Index**

Design Factor [$\sigma_{v(max)}/S_c$]