# UNPAVED AIRFIELDS, LOW STRENGTH CONCRETE, AND RAILROADS: AN APT UPDATE FROM ERDC

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# FACILITIES

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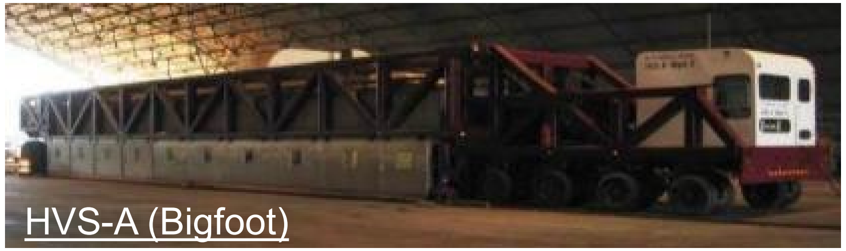
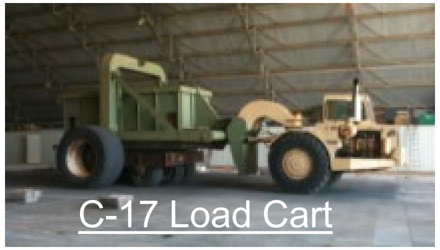
Hangar 2 Pavement Testing Facility
127,000 ft$^2$ of covered testing area


HVS-A (Bigfoot)


HVS-T (Titan)


C-17 Load Cart


Load Cart


Low-volume road track


Pavement Box Testing


Outdoor Testing Facility


“Snake Pit”

# US ARMY ERDC-HEAVY VEHICLE SIMULATOR

## HVS-A (Bigfoot)

- Length: 119 ft
- Width: 16 ft
- Mass: 227,000 lbs
- Testing length: 40 ft
- Wander: 5 ft
- Load: 10,000 – 100,000 lbs
- Speed: 4 – 10 mph
- Environmental
  23°F - 109°F

# US ARMY ERDC-HEAVY VEHICLE SIMULATOR

## HVS-T (Titan)

– Wheel load: 9,000 – 120,000 lbs.

– Testing length: 65 ft

– Wander: 6 ft

– Laser profiler

– Environmental chamber
    20° F – 110° F

– Carriage
    Highway
    Aircraft
    Rail

# US ARMY ERDC-LOAD CART

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## Single-wheel load cart

- Wheel load: Up to 45,000 lbs
- C-17
- C-130
- F-15

- Daily production – 1,500 passes per day

# UNPAVED LANDING ZONE (FDR)

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# PRIMARY OBJECTIVE

- Cargo aircraft may be required to operate on unpaved or aggregate-surface airfields
  - Generally designed for limited operations
  - May have relatively low-strength surface materials
  - May experience significant rutting damage

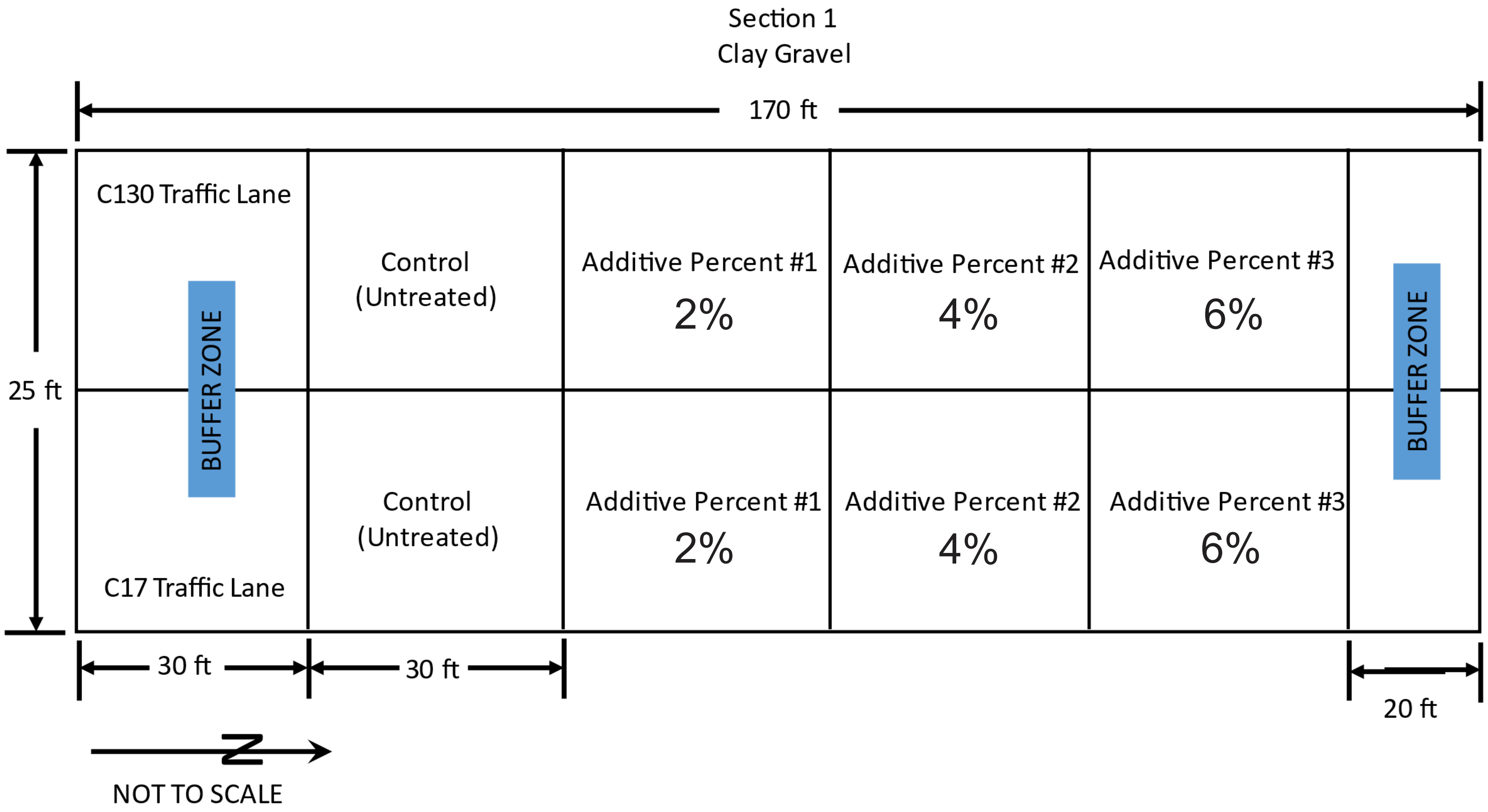
- Techniques to extend operational capabilities are needed
  - Full-depth reclamation may be one solution
  - Minimize required equipment
  - Unknown performance

- Determine performance of an aggregate surfaced LZ reconstructed with an FDR technique to support development of performance models.

## Loading Conditions for Auxillary Airfields:

C-130:
Wheel load = 39,375 lb
Tire = 100 psi

C-17:
Wheel load = 38,500 lb
Tire = 142 psi



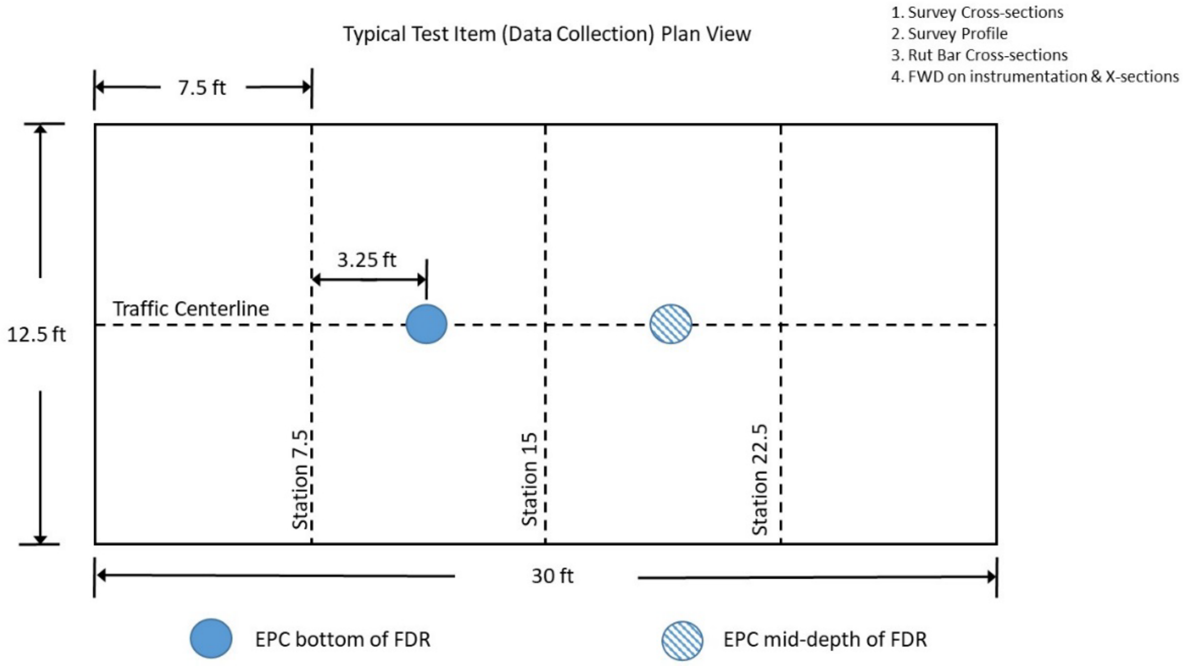
# CONSTRUCTION PHOTOS


# FDR Surface Course

- **C-17 Avg. Thickness**
  - Control → 11.7 in.
  - AP1 → 11.3 in.
  - AP2 → 11.9 in.
  - AP3 → 11.6 in.
- **C-130 Avg. Thickness**
  - Control → 11.7 in.
  - AP1 → 11.3 in.
  - AP2 → 11.4 in.
  - AP3 → 11.1 in.

- **C-17 EPC Depths**
- AP1
  - Mid Depth → 7.2 in.
  - Full Depth → 11.3 in.
- AP2
  - Mid Depth → 7.2 in.
  - Full Depth → 12.9 in.
- AP3
  - Mid Depth → 7.2 in.
  - Full Depth → 10.9 in.

- **C-130 EPC Depths**
- AP1
  - Mid Depth → 5.8 in.
  - Full Depth → 11.4 in.
- AP2
  - Mid Depth → 5.1 in.
  - Full Depth → 11.9 in.
- AP3
  - Mid Depth → 5.8 in.
  - Full Depth →10.9 in.



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# C-17 As-built Properties:

## Pre-traffic testing

Lab Values:

AP1:
Max Dry = 133.5 pcf
Optimum MC% = 5.9%

AP2:
Max Dry = 134.3 pcf
Optimum MC% = 6.2%

AP3:
Max Dry = 136.4 pcf
Optimum MC% = 6.0%

| Property | Control | AP1 | AP2 | AP3 |
|---|---|---|---|---|
| **Max. Dry Density @ OMC** | **128.1 pcf @ 6.3%** | **133.5 pcf @ 5.9%** | **134.3 pcf @ 6.2%** | **136.4 pcf @ 6.0%** |
| Wet Density (pcf) | 132.5 ± 3.8 | 120.2 ± 3.3 | 118.1 ± 1.2 | 117.0 ± 3.2 |
| Dry Density (pcf) | 121.5 ± 3.6 | 111.5 ± 3.2 | 109.7 ± 1.5 | 108.9 ± 3.3 |
| Nuclear Moisture Content (%) | 9.0 ± 0.3 | 7.8 ± 0.1 | 7.7±0.5 | 7.4 ± 0.3 |
| Oven-Dried Moisture (%) | 6.75 | 7.93 | 7.79 | 7.85 |
| CBR (DCP) | 21 ± 0.1 | 38 ± 3.8 | 57 ± 9.4 | 68 ± 7.4 |
| Thickness (in.) | 11.7 ± 0.2 | 11.3 ± 0.4 | 11.9 ± 0.1 | 11.6 ± 0.3 |
| **SP Base Course (114 pcf @12.2%)** | | | | |
| Wet Density (pcf) | 116.5 ± 0.9 | 118.0 ± 0.2 | 116.20 ± 1.5 | 117.1 ± 0.2 |
| Dry Density (pcf) | 112.4 ± 1.0 | 113.3 ± 0.2 | 110.2 ± 1.9 | 111.9 ± 0.1 |
| Nuclear Moisture Content (%) | 3.6 ± 0.1 | 4.2 ± 0.1 | 5.5 ± 0.5 | 4.7 ± 0.3 |
| CBR (DCP) | 35 ± 1.7 | 30 ± 1.8 | 35 ± 2.1 | 39 ± 6.9 |
| Thickness (in.) | 25.2 ± 0.4 | 25.2 ± 0.5 | 25.4 ± 0.4 | 26.4 ± 0.5 |

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# C-130 As-built Properties:

## Pre-traffic testing

Lab Values:

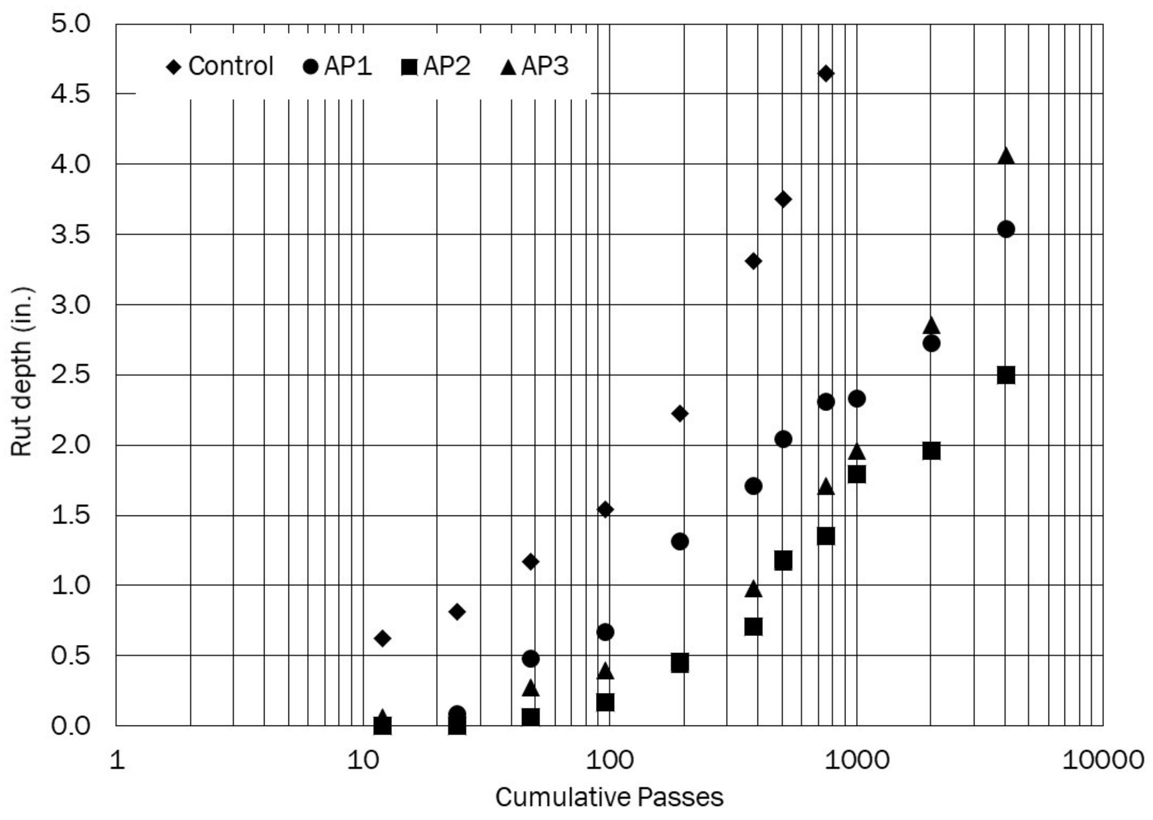
AP1:
Max Dry = 133.5 pcf
Optimum MC% = 5.9%

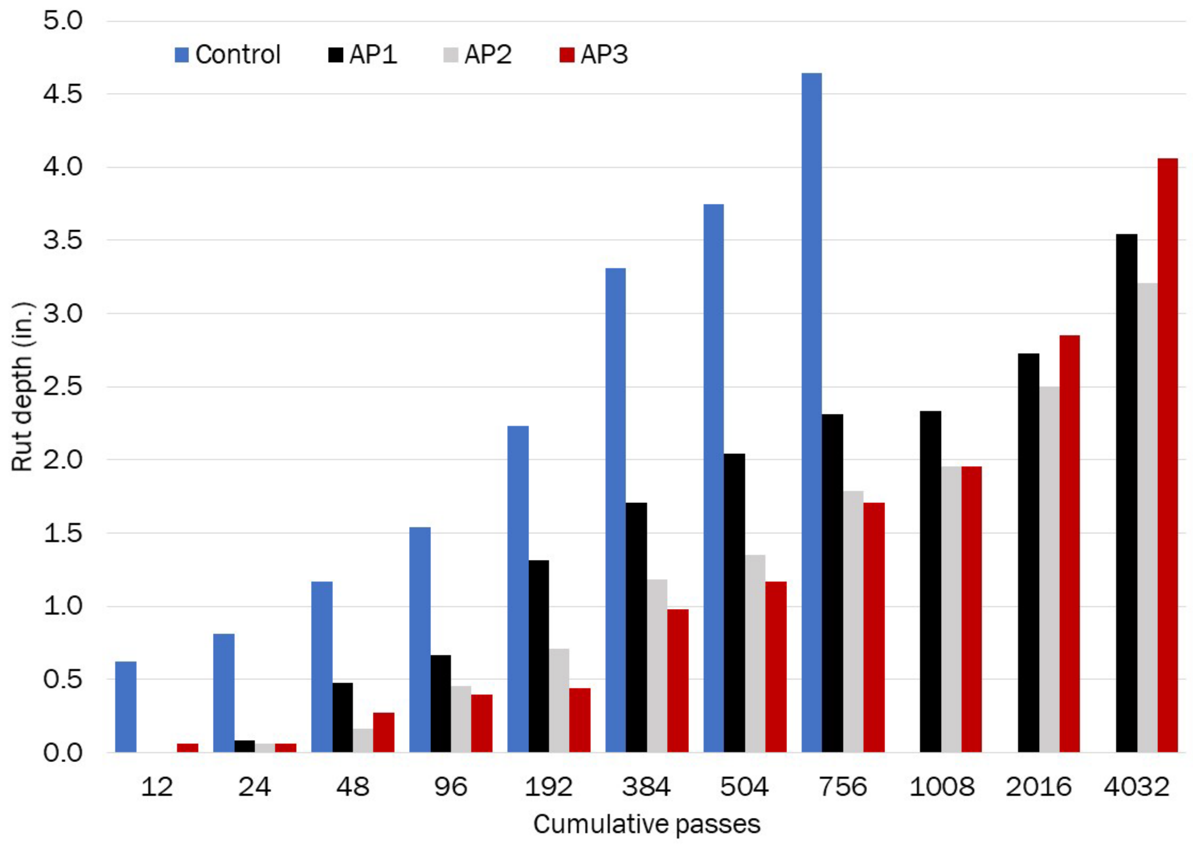
AP2:
Max Dry = 134.3 pcf
Optimum MC% = 6.2%

AP3:
Max Dry = 136.4 pcf
Optimum MC% = 6.0%

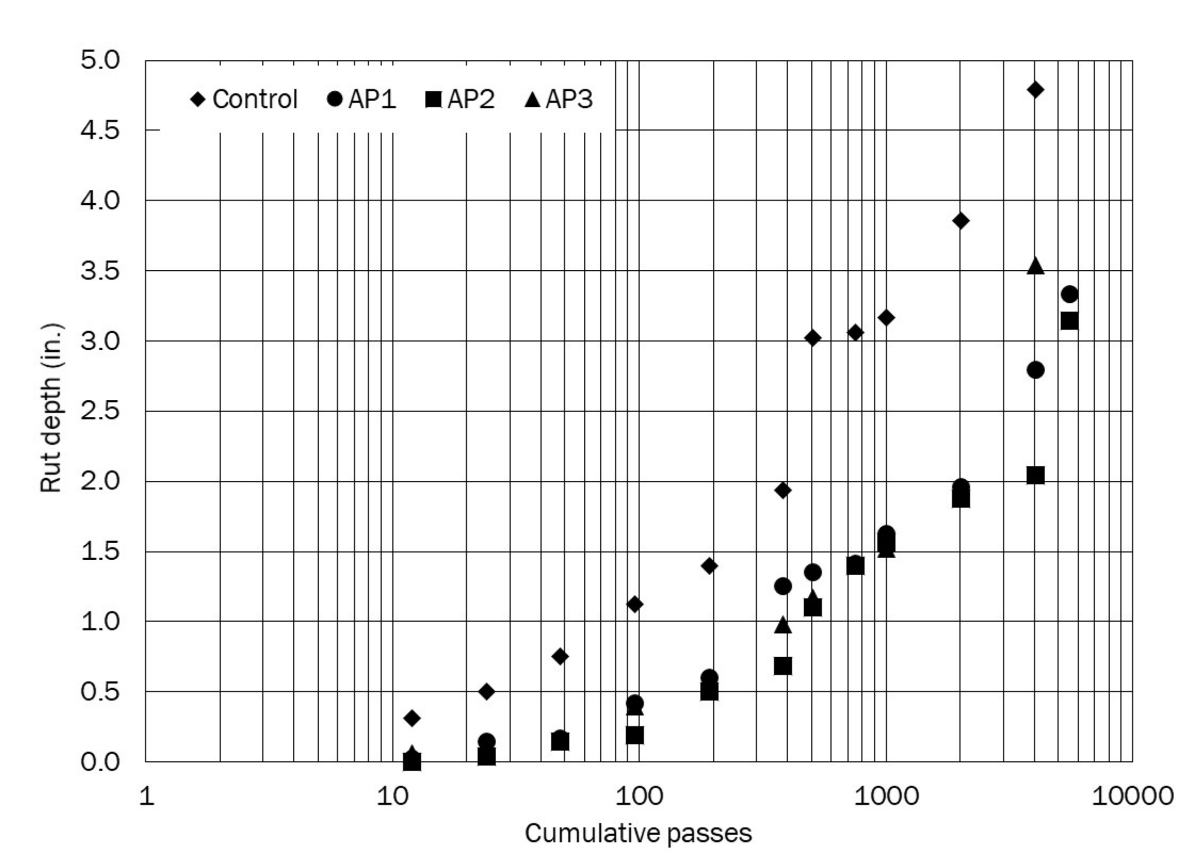
| Property | Control | AP1 | AP2 | AP3 |
|---|---|---|---|---|
| **Max. Dry Density @ OMC** | **128.1 pcf @ 6.3%** | **133.5 pcf @ 5.9%** | **134.3 pcf @ 6.2%** | **136.4 pcf @ 6.0%** |
| Wet Density (pcf) | 139.0 ± 2.3 | 121.6 ± 1.8 | 117.3 ± 3.2 | 115.0 ± 1.6 |
| Dry Density (pcf) | 127.0 ± 1.8 | 111.5 ± 2.0 | 107.5 ± 2.2 | 105.1 ± 1.1 |
| Nuclear Moisture Content (%) | 9.5 ± 0.4 | 9.1 ± 0.5 | 9.1 ± 0.8 | 9.6 ± 0.2 |
| Oven-Dried Moisture (%) | 8.5 | 8.5 | 8.3 | 8.1 |
| CBR (DCP) | 25 ± 2.4 | 37 ± 4.3 | 40 ± 3.7 | 51 ± 4.1 |
| Thickness (in.) | 11.7 ± 0.2 | 11.3 ± .3 | 11.4 ± 0.2 | 11.1 ± 0.3 |
| **SP Base Course (114 pcf @12.2%)** | | | | |
| Wet Density (pcf) | 118.1 ± 0.7 | 120.4 ± 1.1 | 119.7 ± 0.4 | 117.8 ± 0.5 |
| Dry Density (pcf) | 113.5 ± 0.6 | 115.3 ± 1.1 | 114.8 ± 0.4 | 113.2 ± 0.6 |
| Nuclear Moisture Content (%) | 4.1 ± 0.2 | 4.4 ± 0.1 | 4.3 ± 0.1 | 4.2 ± 0.2 |
| CBR (DCP) | 33 ± 3.6 | 39 ± 1.9 | 49 ± 0.5 | 41 ± 5.7 |
| Thickness (in.) | 25.4 ± 0.6 | 25.9 ± 0.5 | 25.2 ± 0.9 | 26.2 ± 0.5 |

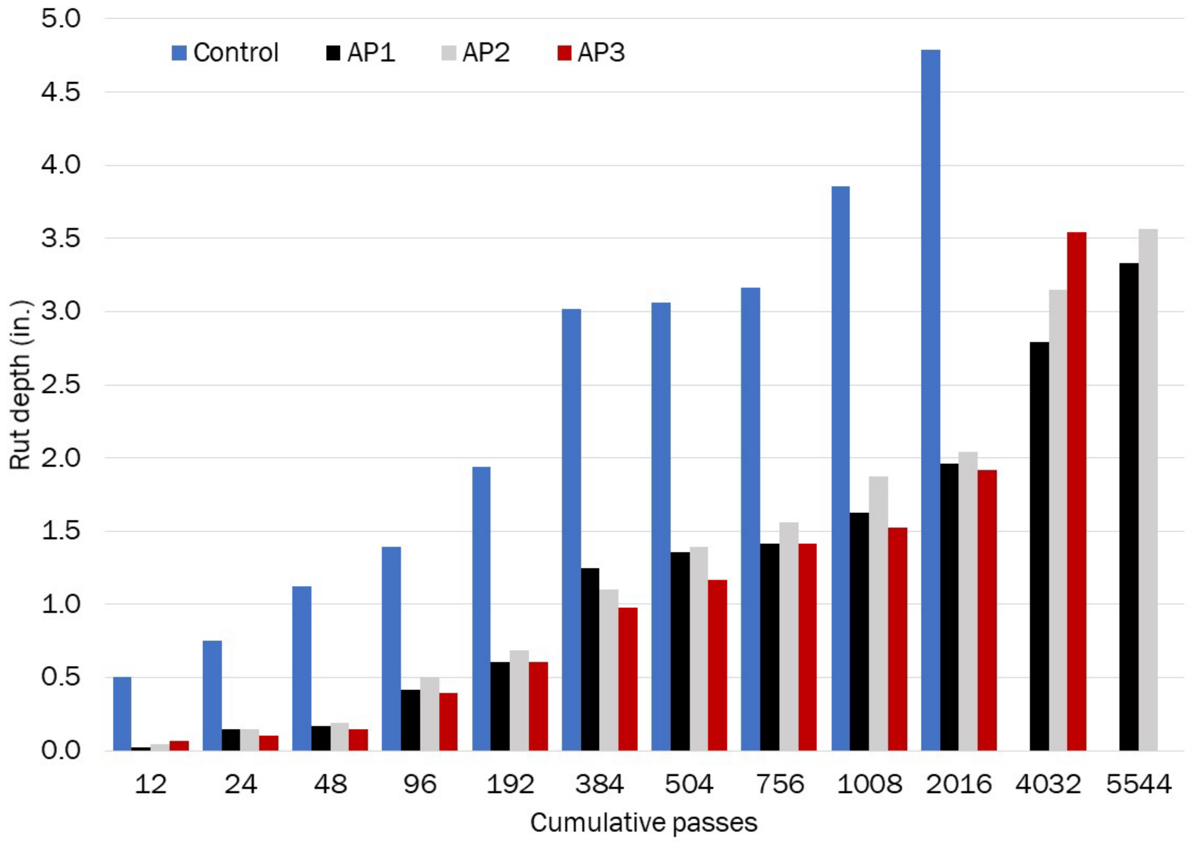
# C-17 RUT DEPTH WITH TRAFFIC



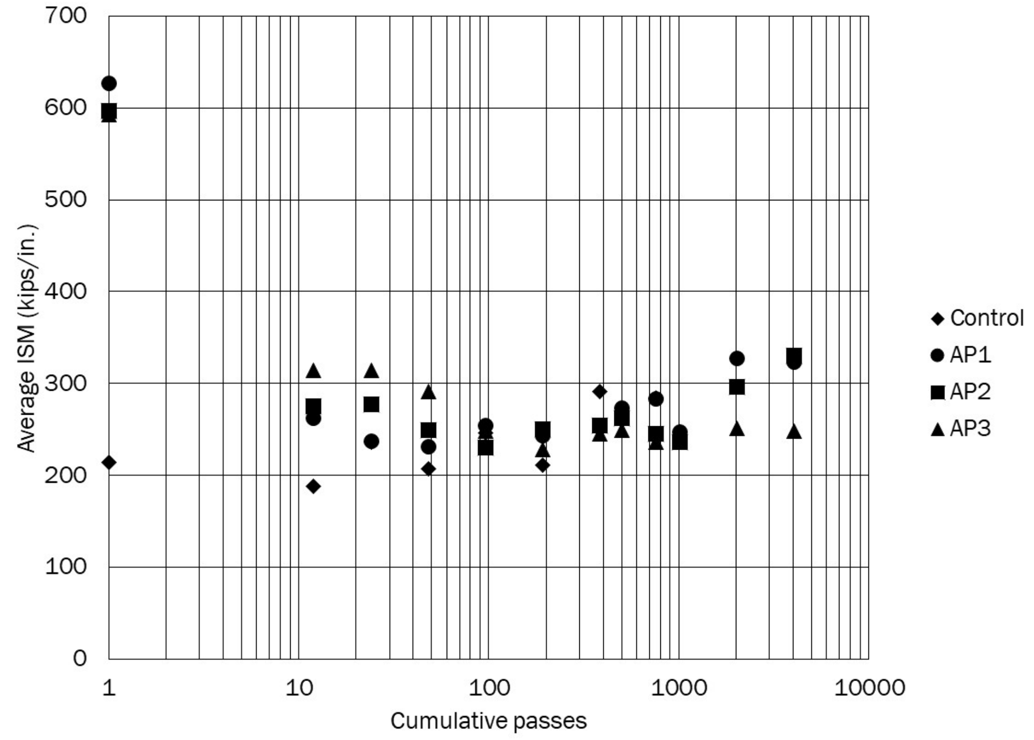
# C-130 RUT DEPTH WITH TRAFFIC



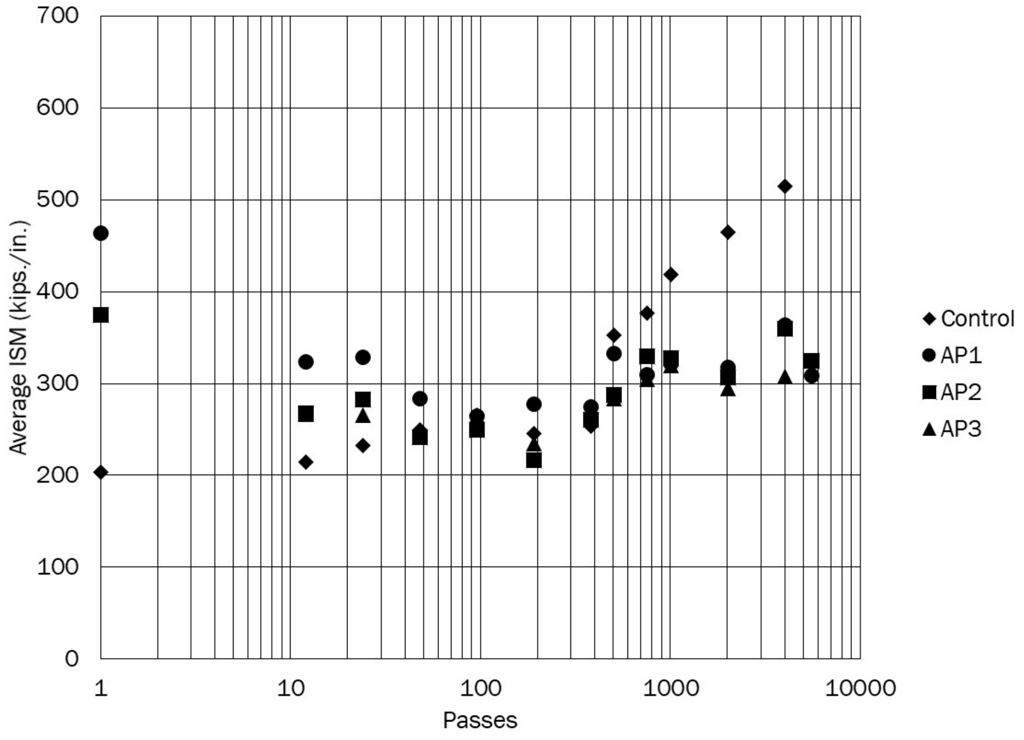



# IMPULSE STIFFNESS WITH TRAFFIC

## C-17 traffic

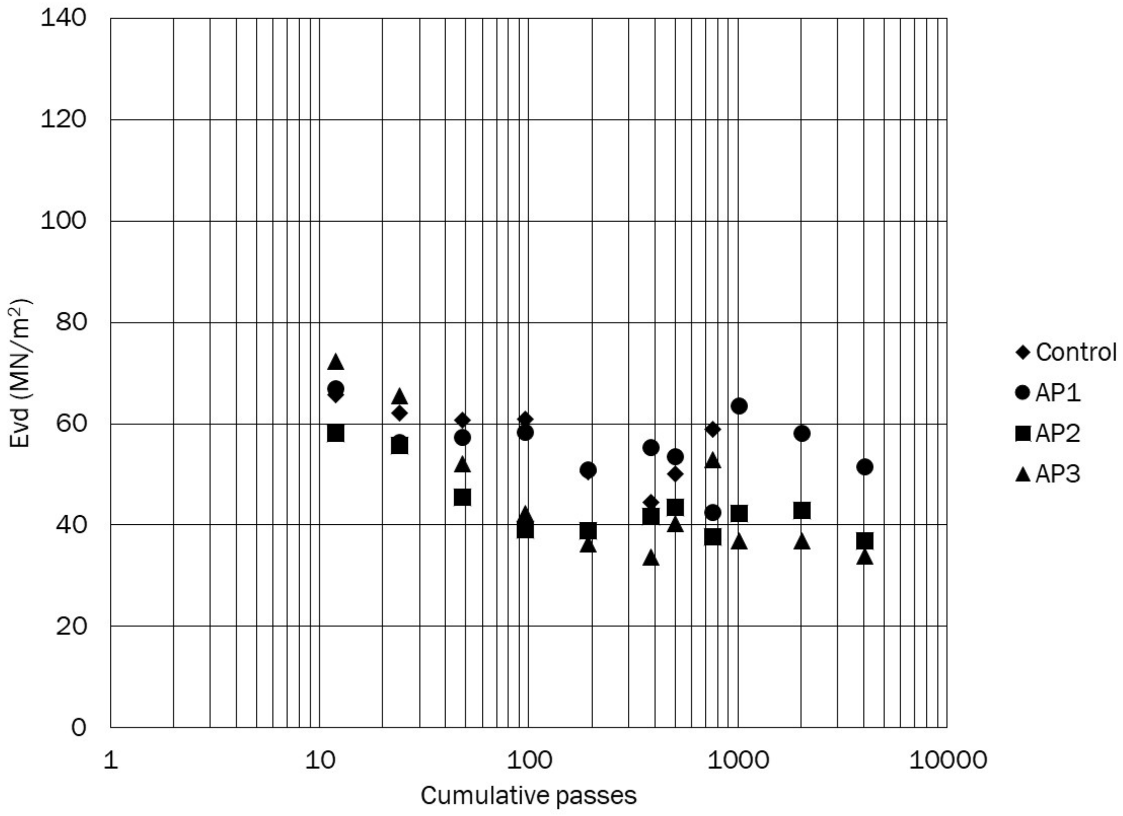



## C-130 traffic

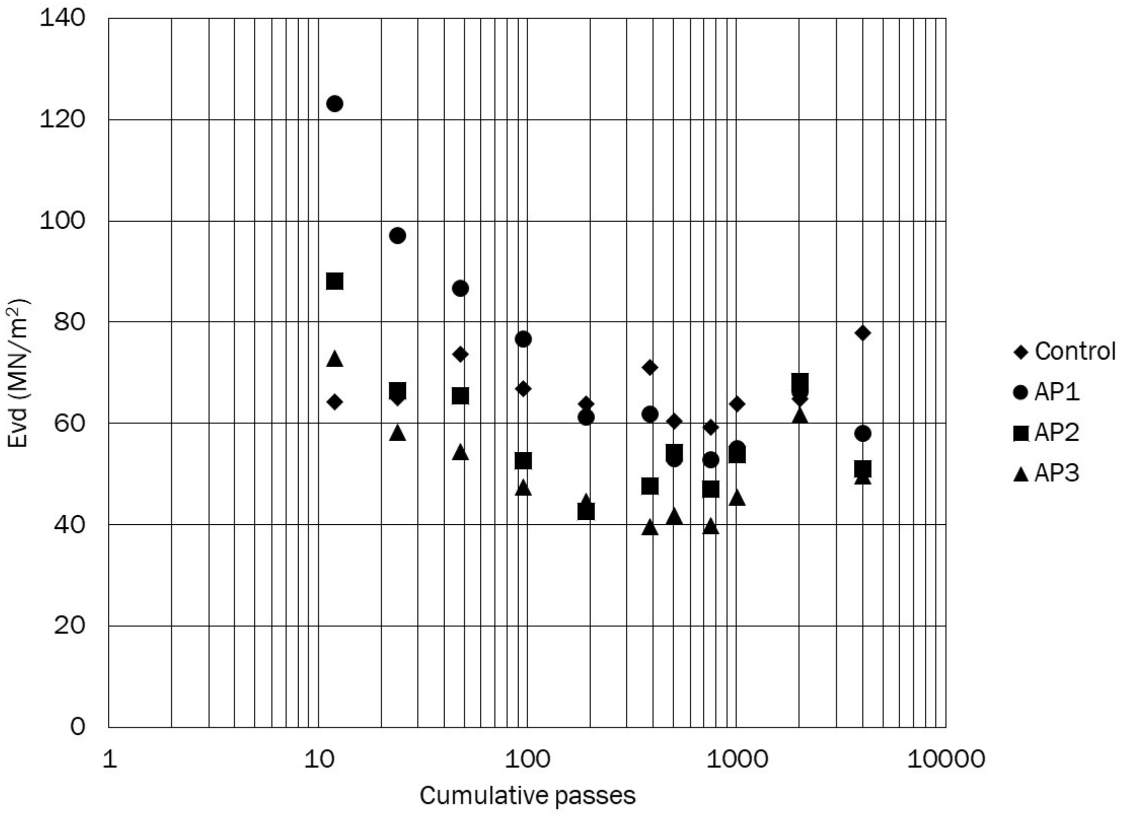


# LWD RESPONSE WITH TRAFFIC

C-17 traffic

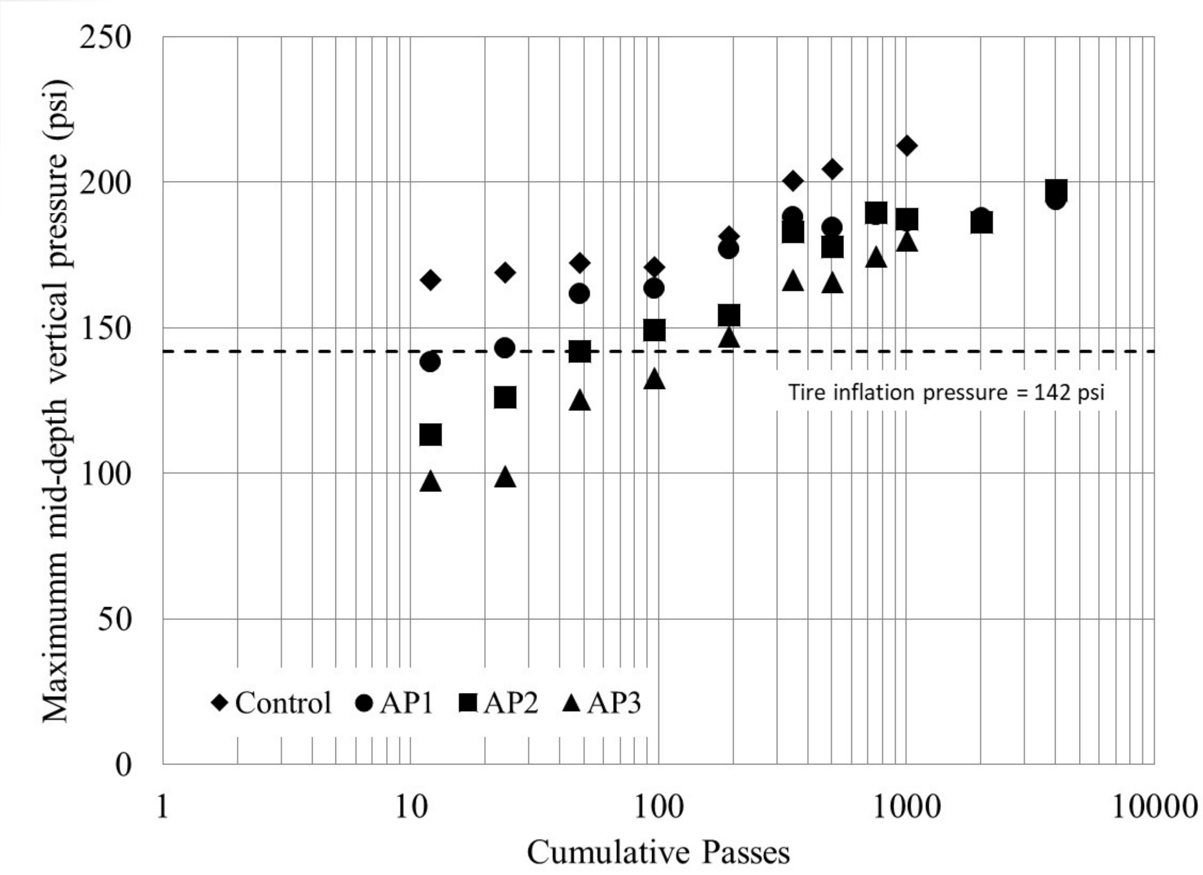



C-130 traffic

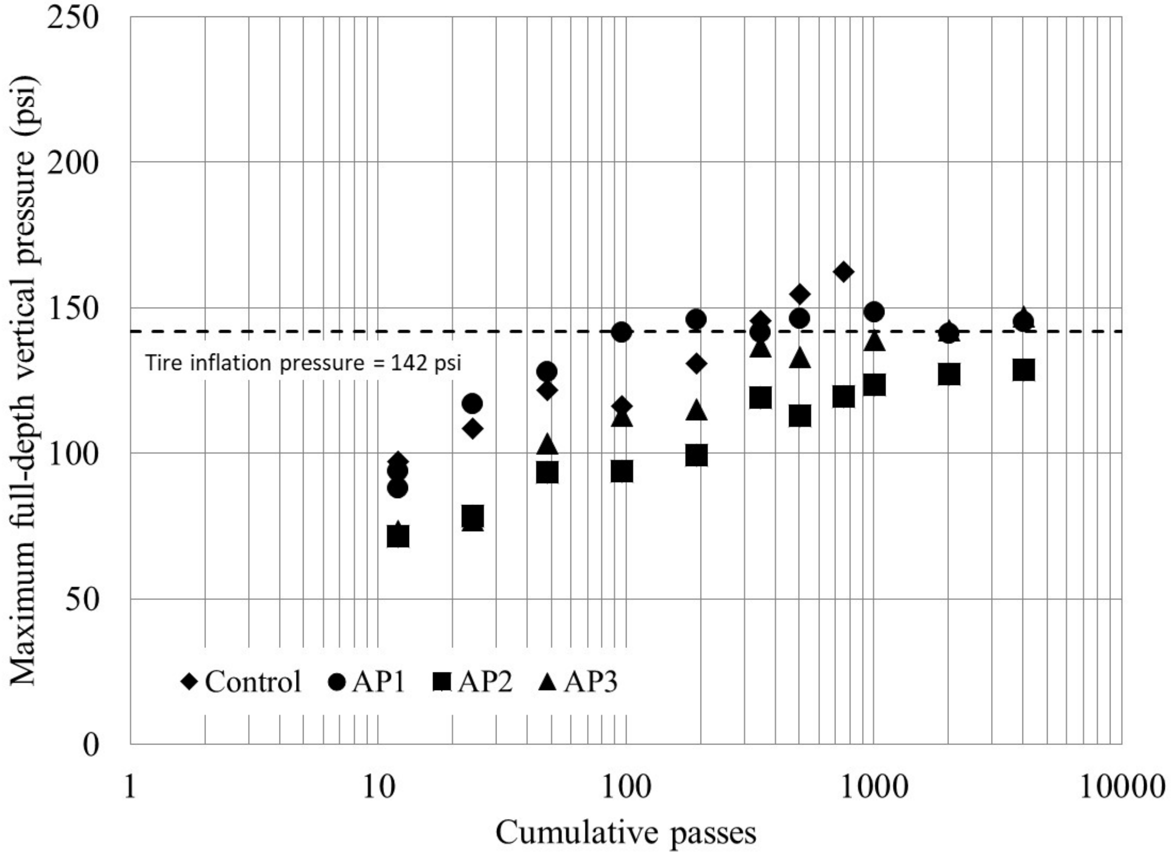


# C-17 EARTH PRESSURE CELL DATA

Mid-Depth EPC

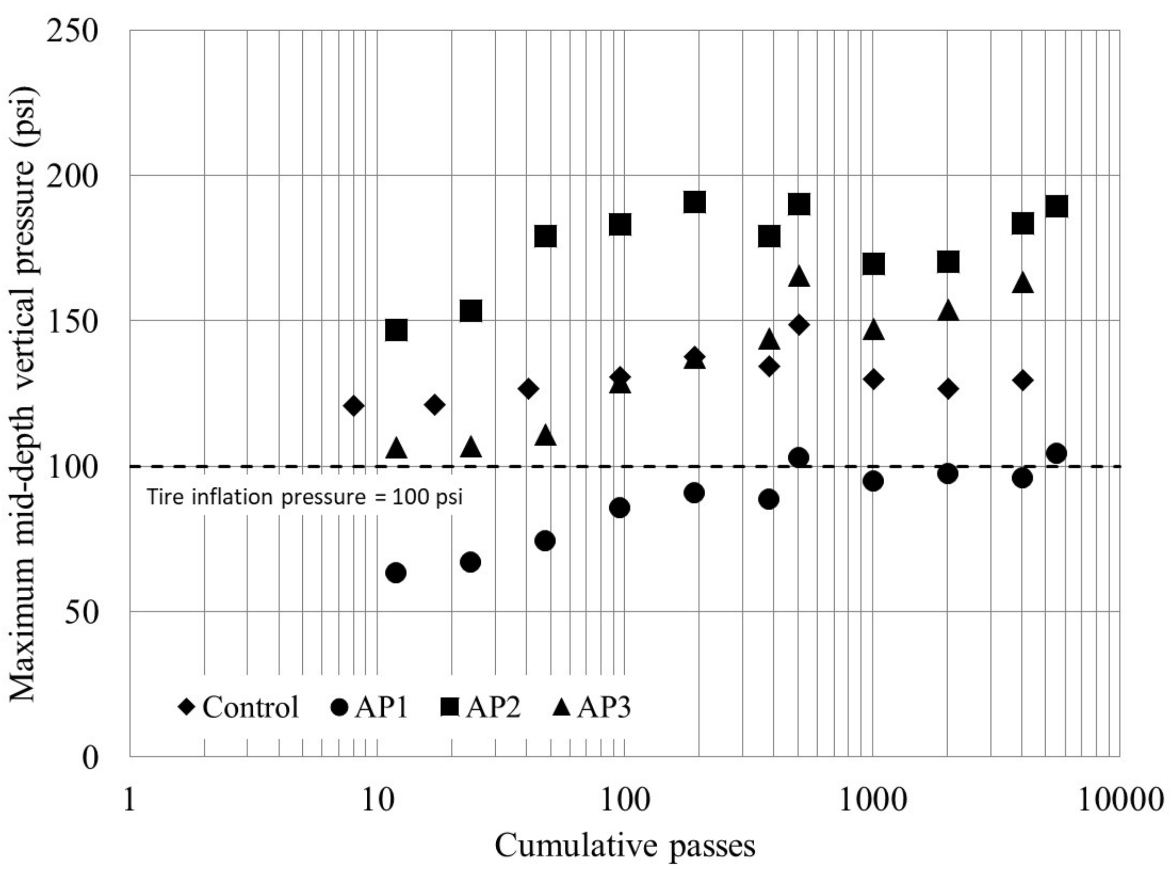



Full-Depth EPC

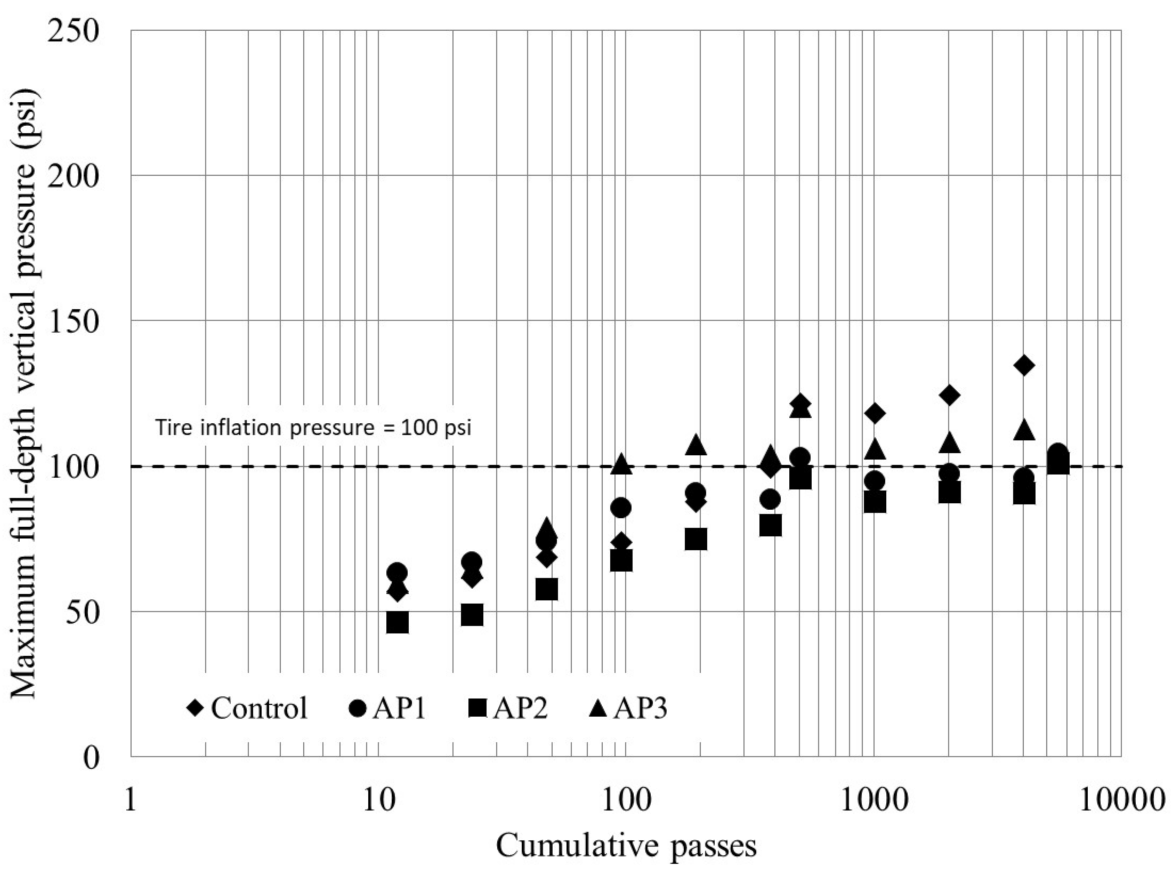


# C-130 EARTH PRESSURE CELL DATA

Mid-Depth EPC




Full-Depth EPC



# INITIAL OBSERVATIONS

- Construction – time limited
  - Thickness variability
  - Density concerns

- Cement content variability

- EPC data
  - Non-uniform contact area

- Initial performance data suggest this is a viable technique to extend operations in a remote location
  - Limited materials
  - Limited equipment
  - Troop construction

- Forensics ongoing / leverage response data to enhance performance models

# LOW STRENGTH CONCRETE

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# PRIMARY OBJECTIVE

- P-8 Poseidon aircraft (military equivalent of Boeing 737-800 airframe) present a unique structural challenge for military airfield pavements.
  - High landing gear loads
  - High tire pressures
  - Relatively close tire spacing on a dual-wheel gear

- Loading conditions unlike those evaluated in historical investigations at ERDC
  - Cargo aircraft (heavy load and low tire pressure)
  - Fighter aircraft (lighter load and high tire pressure)
  - Generally evaluated for long-term (design life conditions)

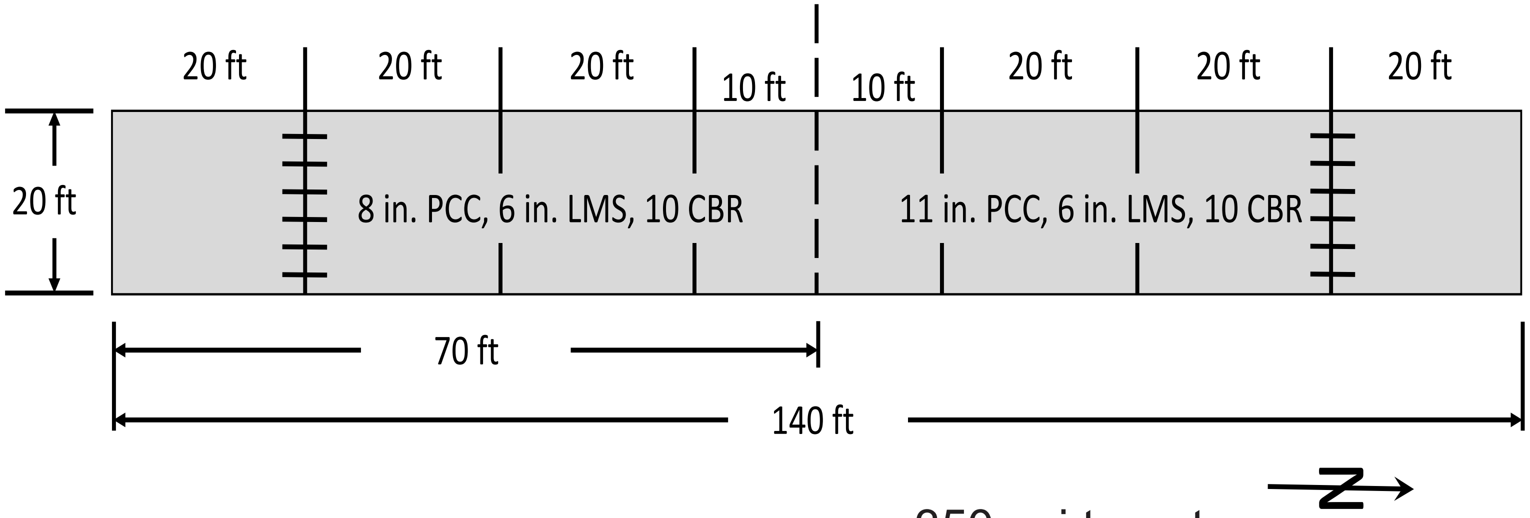
- <u>Determine performance of two relatively thin jointed plain concrete sections under simulated aircraft traffic.</u>

# APPROACH

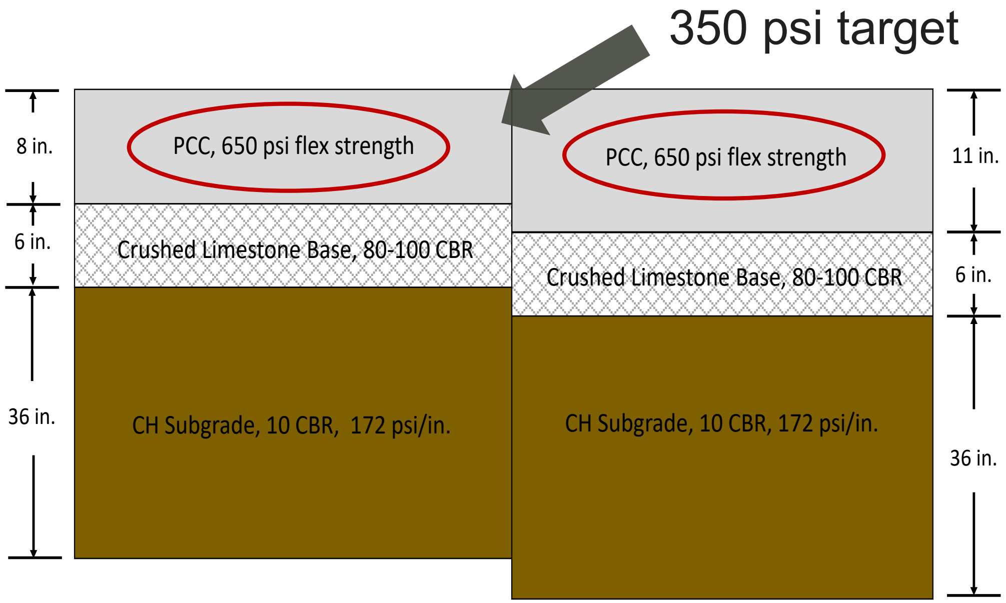
- Leverage previously trafficked PCC test section that met currently specified flexural strength requirements.
- Reconstruct section utilizing a substandard flexural strength PCC mixture
  - Limited high quality local materials
  - Unskilled labor force
  - Substandard mixture production facilities
- Inform risk by performing a direct comparison between normal strength PCC and reduced strength PCC.

# TEST SECTION LAYOUT

## Plan view



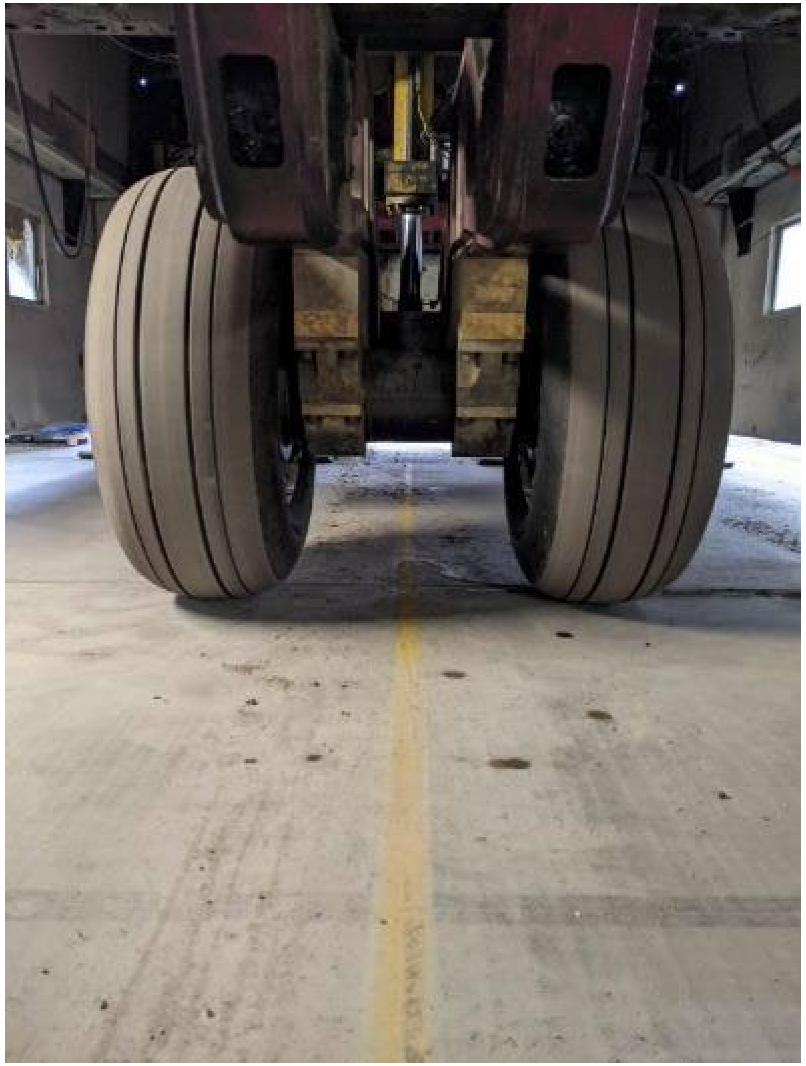

## Profile view



# CONSTRUCTION

# P-8 TEST GEAR CONFIGURATION

- 89,000 lb total load
- 220 psi inflation pressure
- Normally-distributed wander pattern
- Bi-directional traffic
- Load verified with mobile aircraft scales

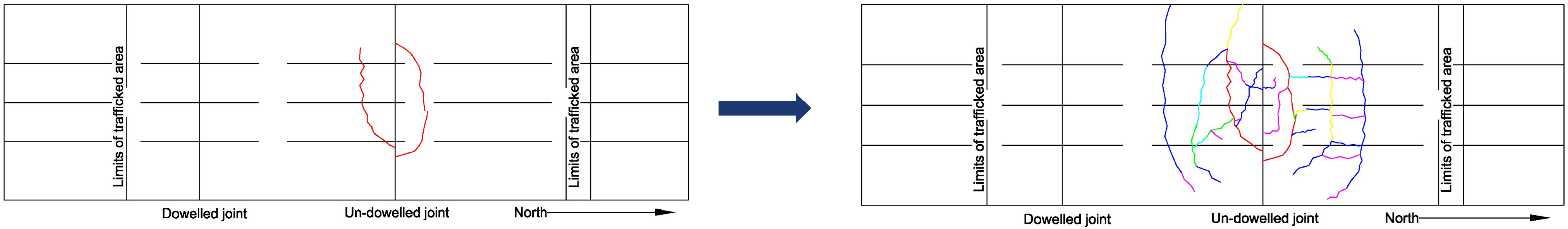


# FAILURE CRITERIA (ROLLINGS 1988)

- First Crack
  - Number of passes required to generate the absolute first crack in 50% of the loaded slabs
  - Two slabs were loaded for this experiment

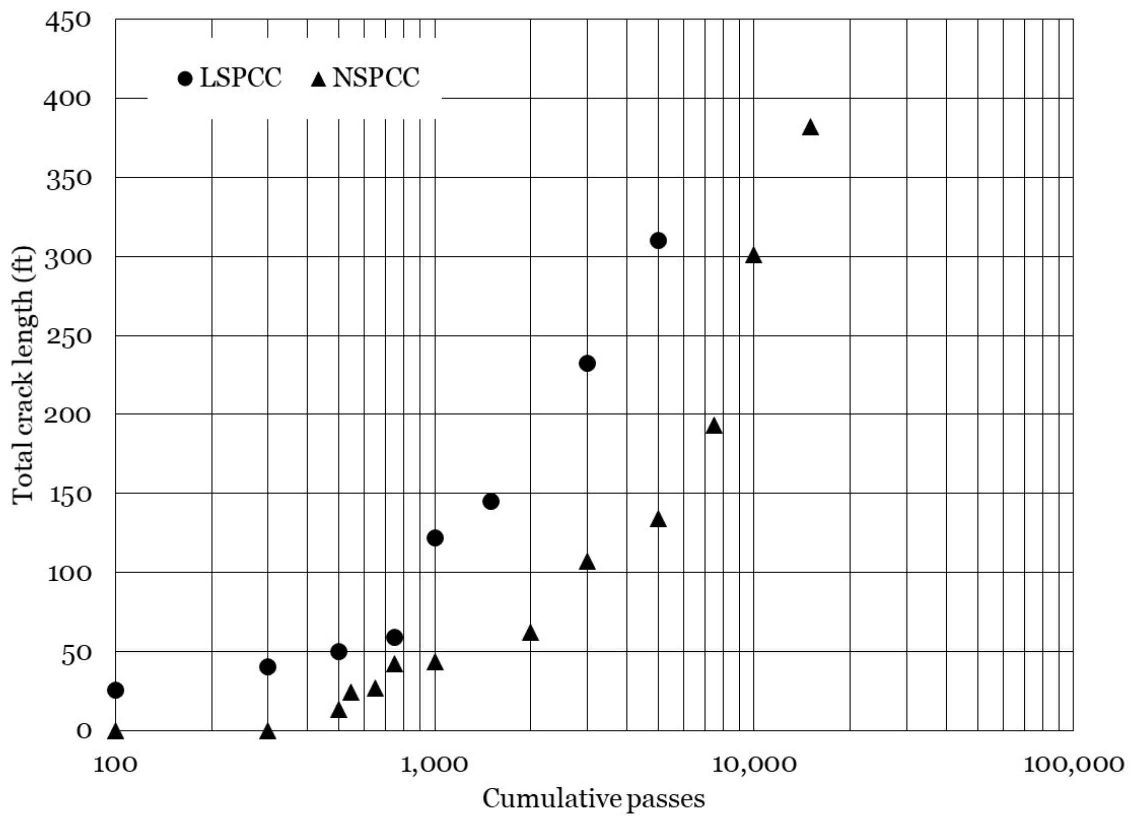
- Shattered Slab
  - Number of passes required to generate sufficient inter-connected cracks to divide a slab info four distinct pieces
  - One slab required to meet criteria

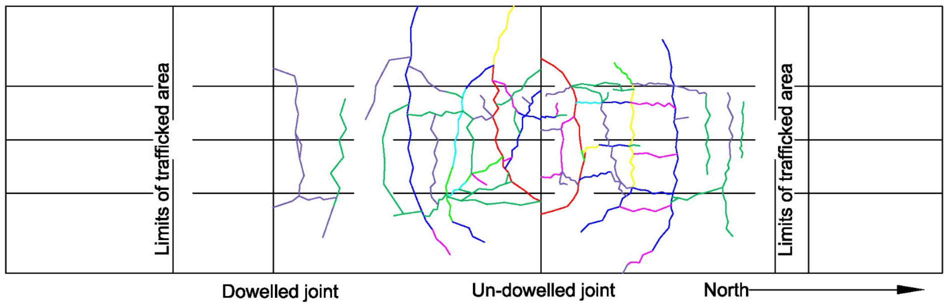
- Complete Failure
  - Number of passes required to generate sufficient inter-connected cracks to divide a slab into six or more distinct pieces



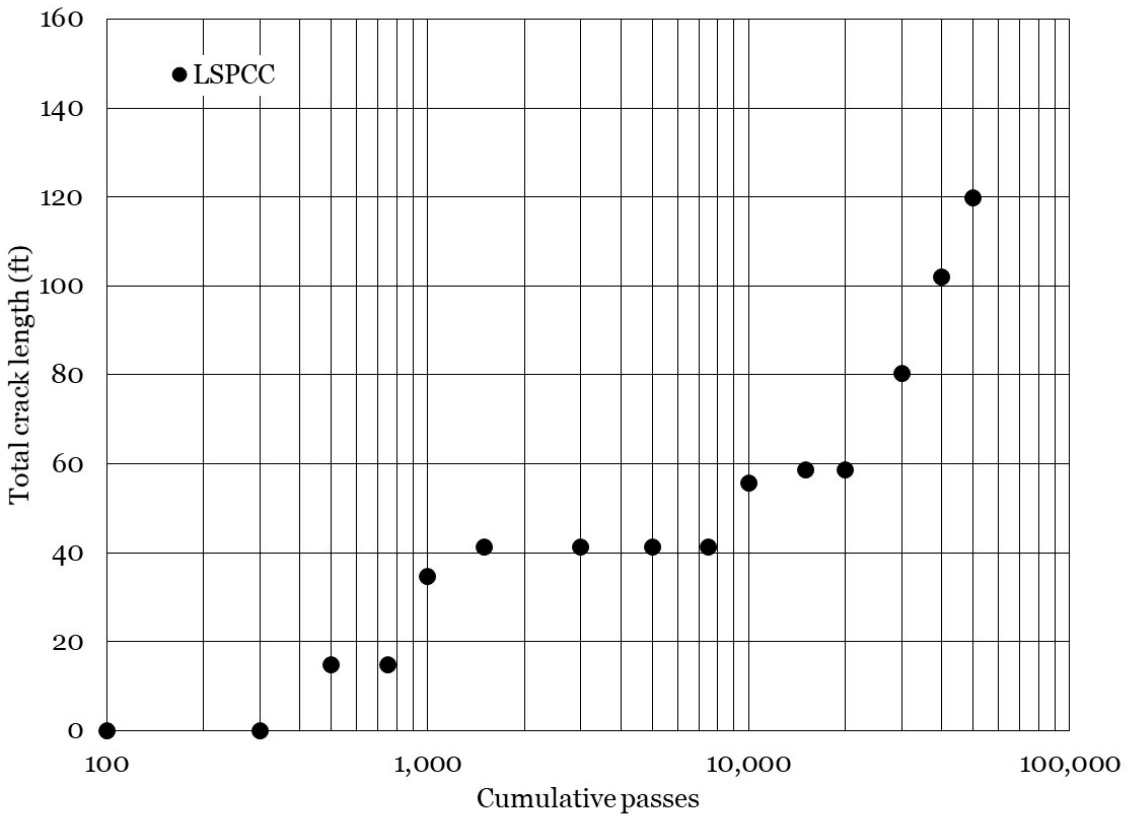
# CRACK DEVELOPMENT

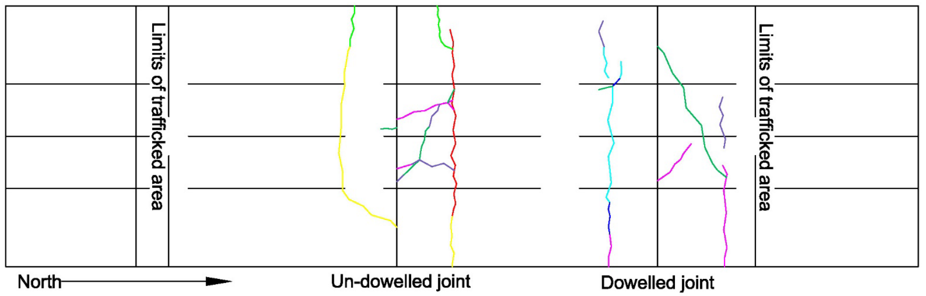
## 8-in. thick PCC




## 11-in. thick PCC



# SUMMARY OF SELECTED FAILURE CRITERIA

| 8-in.-thick PCC | | |
|---|---|---|
| **Criteria** | **NSPCC** | **LSPCC** |
| First crack | 400 | 85 |
| Shattered Slab | 2,500 | 850 |
| Complete Failure | 7,500 | 1,250 |

| 11-in.-thick PCC | | |
|---|---|---|
| **Criteria** | **NSPCC** | **LSPCC** |
| First crack | 50,000+ | 500 |
| Shattered Slab | 50,000+ | 45,000 |
| Complete Failure | 50,000+ | 50,000+ |

# COMPARISON TO APE EVALUATION IN PCASE

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## Results of APE evaluation (LSPCC 8 in. thick).

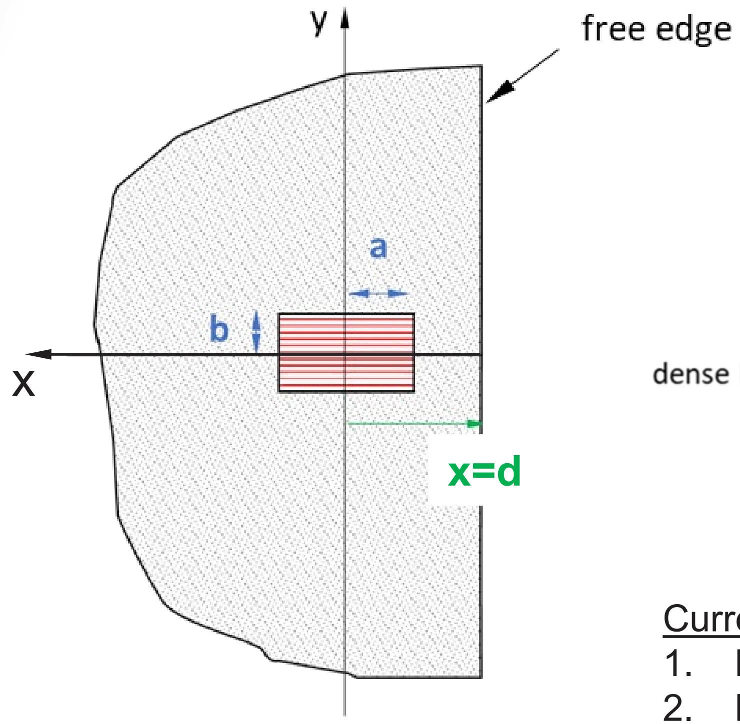
| PCASE Evaluation Inputs | | | | | | | |
|---|---|---|---|---|---|---|---|
| Layer | Material | T (in.) | k-value (pci) | Effective k (pci) | F.S. (psi) | Modulus (psi) | P.R. |
| PCC | PCC | 7.7 | NA | NA | 435 | 3,600,000 | 0.15 |
| Base | Unbound Crushed Stone | 6.1 | 0 | 234 | NA | NA | NA |
| Subgrade | Cohesive fill | NA | 174 | 174 | NA | NA | NA |
| | | | | | | | |
| | Results (passes) | | APE | Actual | % Decrease (APE from Actual) | | |
| | First crack | | 1 | 85 | 98.8 | | |
| | Shattered slab | | 13 | 850 | 98.5 | | |
| | Complete failure | | 104 | 1,250 | 91.7 | | |

## Results of APE evaluation (NSPCC 8 in. thick).

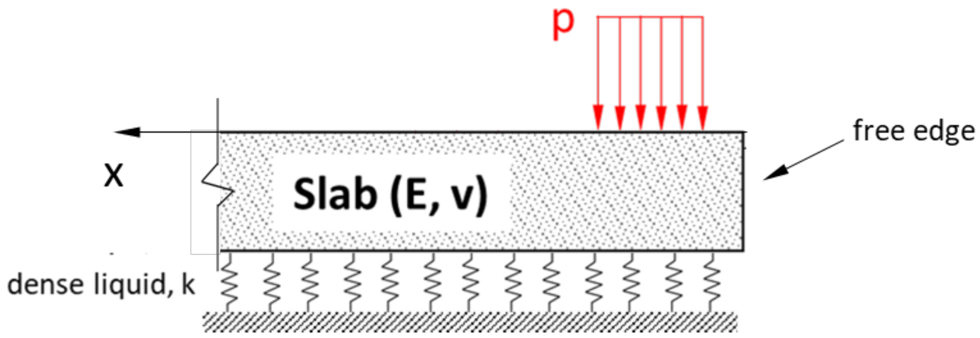
| PCASE Evaluation Inputs | | | | | | | |
|---|---|---|---|---|---|---|---|
| Layer | Material | T (in.) | k-value (pci) | Effective k (pci) | F.S. (psi) | Modulus (psi) | P.R. |
| PCC | PCC | 7.4 | NA | NA | 765 | 4,600,000 | 0.15 |
| Base | Unbound Crushed Stone | 6.1 | 0 | 234 | NA | NA | NA |
| Subgrade | Cohesive fill | NA | 174 | 174 | NA | NA | NA |
| | | | | | | | |
| | Results (passes) | | APE | Actual | % Decrease (APE from Actual) | | |
| | First crack | | 8 | 400 | 98.0 | | |
| | Shattered slab | | 84 | 2,500 | 96.6 | | |
| | Complete failure | | 677 | 7,500 | 91.0 | | |

# OVERVIEW OF CURRENT PCASE MODELS (1/2)

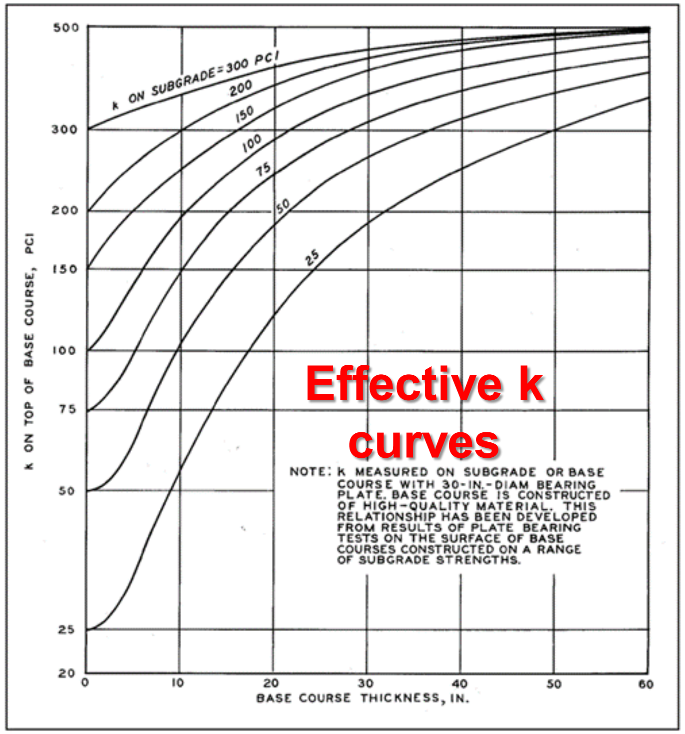
***BASED ON PICKETT ET AL. (1951)* SOLUTION FOR SEMI-INFINITE PLATE ON DENSE LIQUID FOUNDATION***




**Plan View**




**Profile View**




Current model assumptions:

1. Multi-slab system is reduced to single semi-infinite slab with discrete edge (x=d)
2. Load transfer effect imposed after free edge stress computation
3. Supported by dense liquid subgrade, where multiple layers beneath the slab are handled in one of two ways:
   - if aggregate layer, then "effective k" procedure is used;
   - if stabilized layer, then converted to equivalent thickness of PCC

* Pickett, G. (1951). Deflections, Moments, and Reactive Pressures for Concrete Pavements (No. 65). Kansas State College.

# OVERVIEW OF CURRENT PCASE MODELS (2/2)

***BASED ON LAYERED ELASTIC SOLUTION WITH EMPIRICAL ADJUSTMENT FOR LOAD TRANSFER MECHANISM***

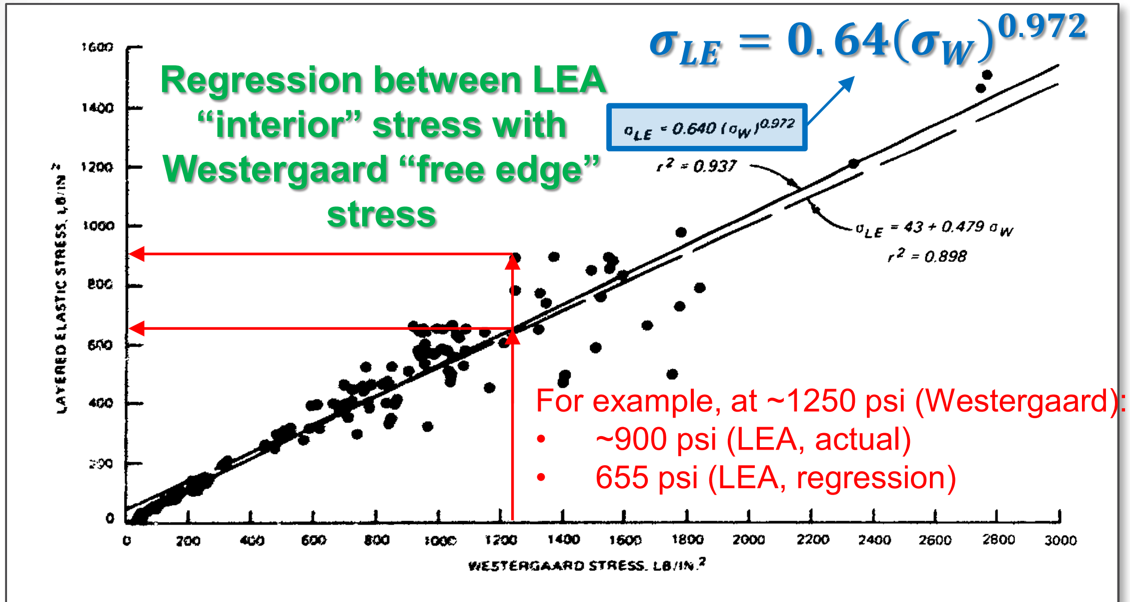



Figure 29. Relation between Westergaard and layered elastic calculated stresses

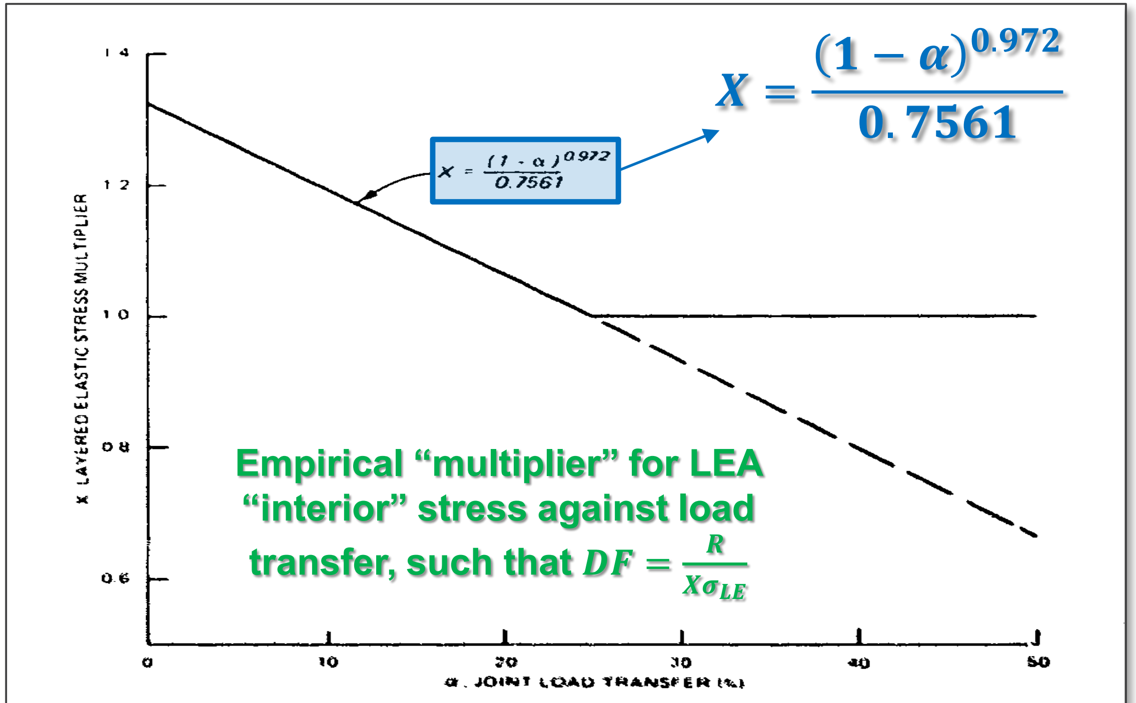



Figure 30. Multiplier for layered elastic stresses to account for load transfer

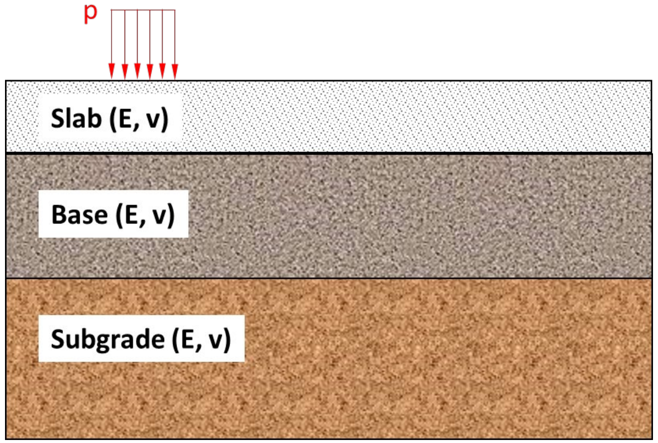
<u>Current model assumptions</u>:

1. Initial "interior" response in slab is computed using layered elastic theory
2. Load transfer effect imposed after LEA-computed interior stress computation using a "multiplier" regression equation produced from LEA computed stresses correlated to the "Westergaard edge stress" (see Rollings 1988*)

* Rollings, R. S. (1988). Design of overlays for rigid airport pavements (No. DOT/FAA/PM-87/19 FINAL REPO). Federal Aviation Administration, Program Engineering and Maintenance Service.

# OVERVIEW OF THE PROPOSED MODEL

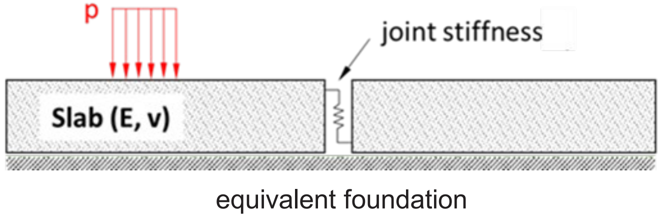
**Multilayered elastic system**




*Coupling effects of multilayered system with plate solution through Taylor-Maclaurin series*

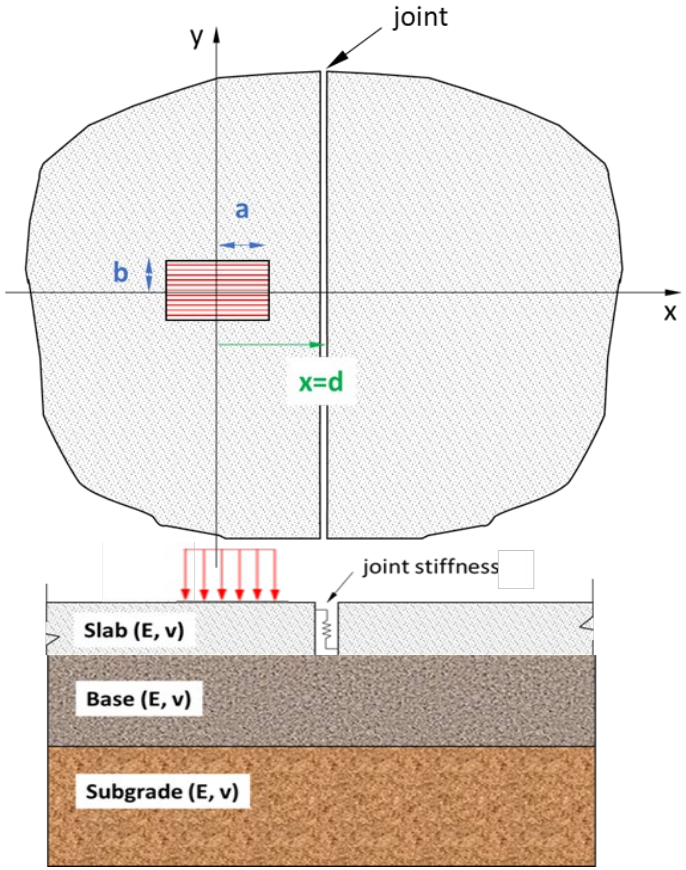
+

**Plate solution w/ elastic joint & equivalent foundation**




**resultant *equivalent* system**

=



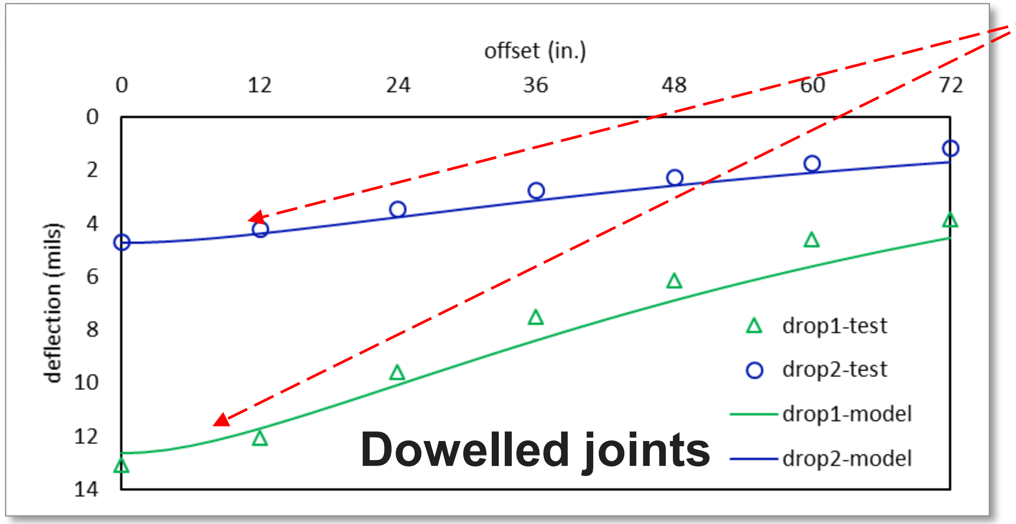

1. In cases of comparison with dense liquid solutions, proposed solution is *backwards compatible* to address and match these solutions.

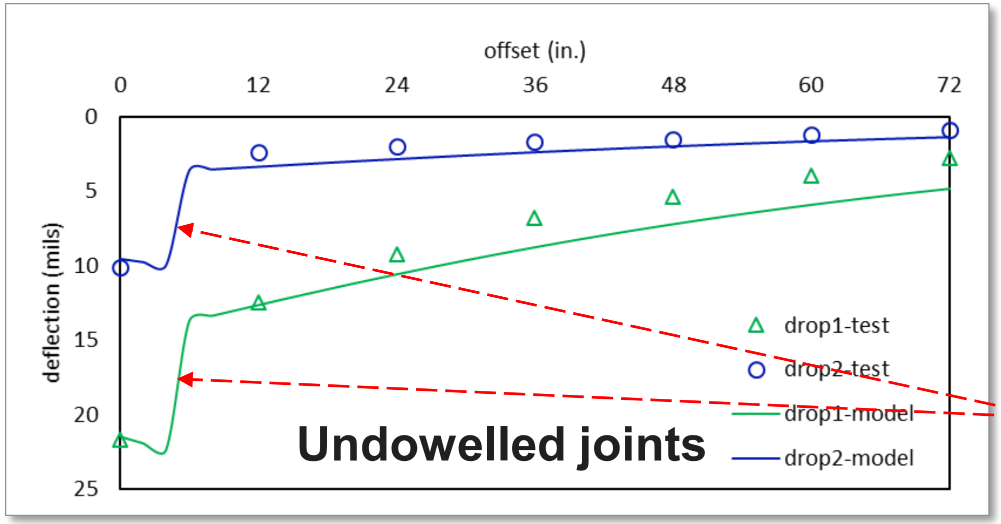
2. In cases of comparison with elastic solid or multilayered elastic solutions, *foundation produces equivalent response as the corresponding elastic solid or multilayered elastic solutions*.

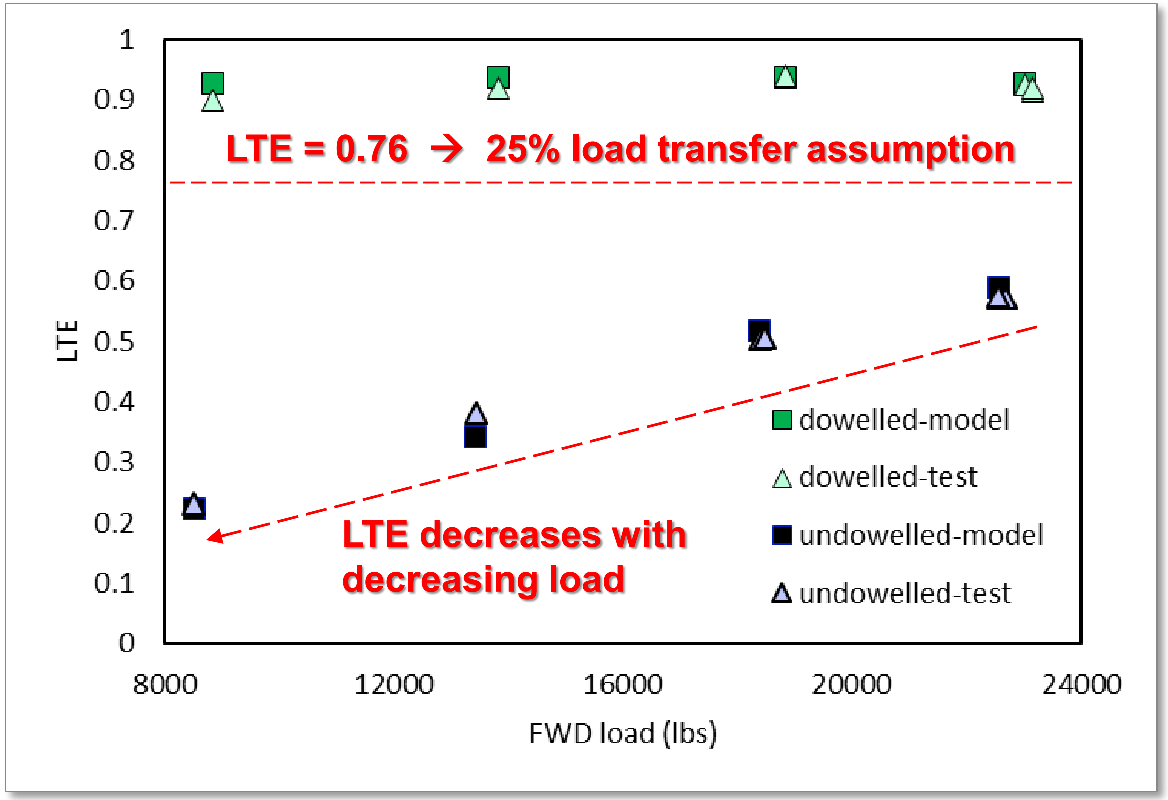
# COMPARISON TO FWD FIELD DATA

**P-8 RIGID PAVEMENT TEST SECTION – FWD TESTS ACROSS JOINT (BETWEEN SENSOR 1 AND 2), PASS 0**

**Shear and moment transfer at joint**




**Shear transfer only (with low shear stiffness value)**

# RAILROAD TEST SECTION

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# DESIGN ASSUMPTIONS

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UFC-4-860-1 (June 2022) RAILROAD DESIGN AND REHABILITATION

RAIL: 115 #
- Moment of inertia (I) = 65.6 in.$^4$
- Section modulus ($Z_b$) = 22.0 in.$^3$

TIE SPACING: 21 in.

WHEEL LOAD: 30,000 lb

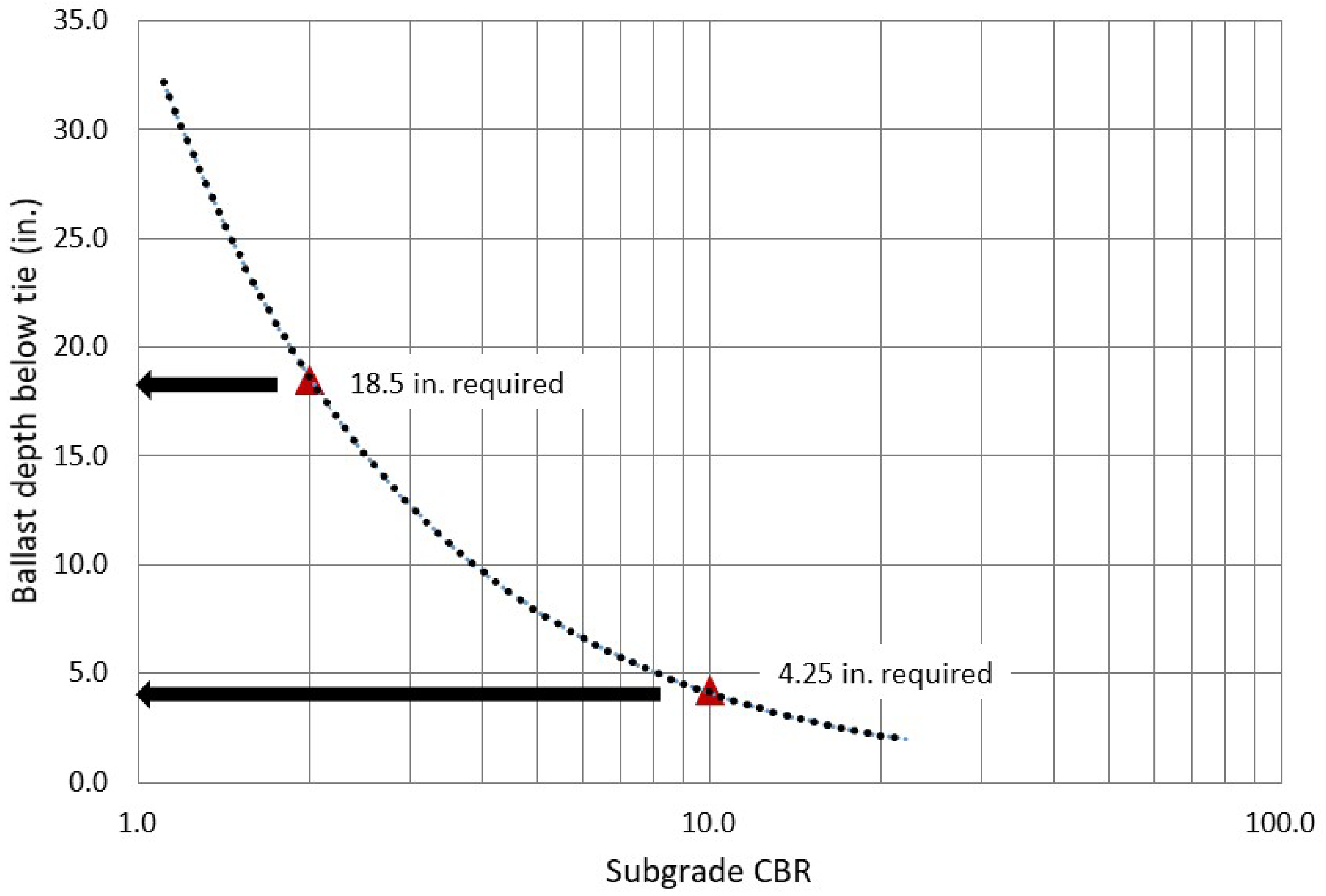
TRACK MODULUS (u) = 2,000

$$q_o = \frac{0.39 P_d C_d S}{X_1}$$ ← Maximum rail seat load

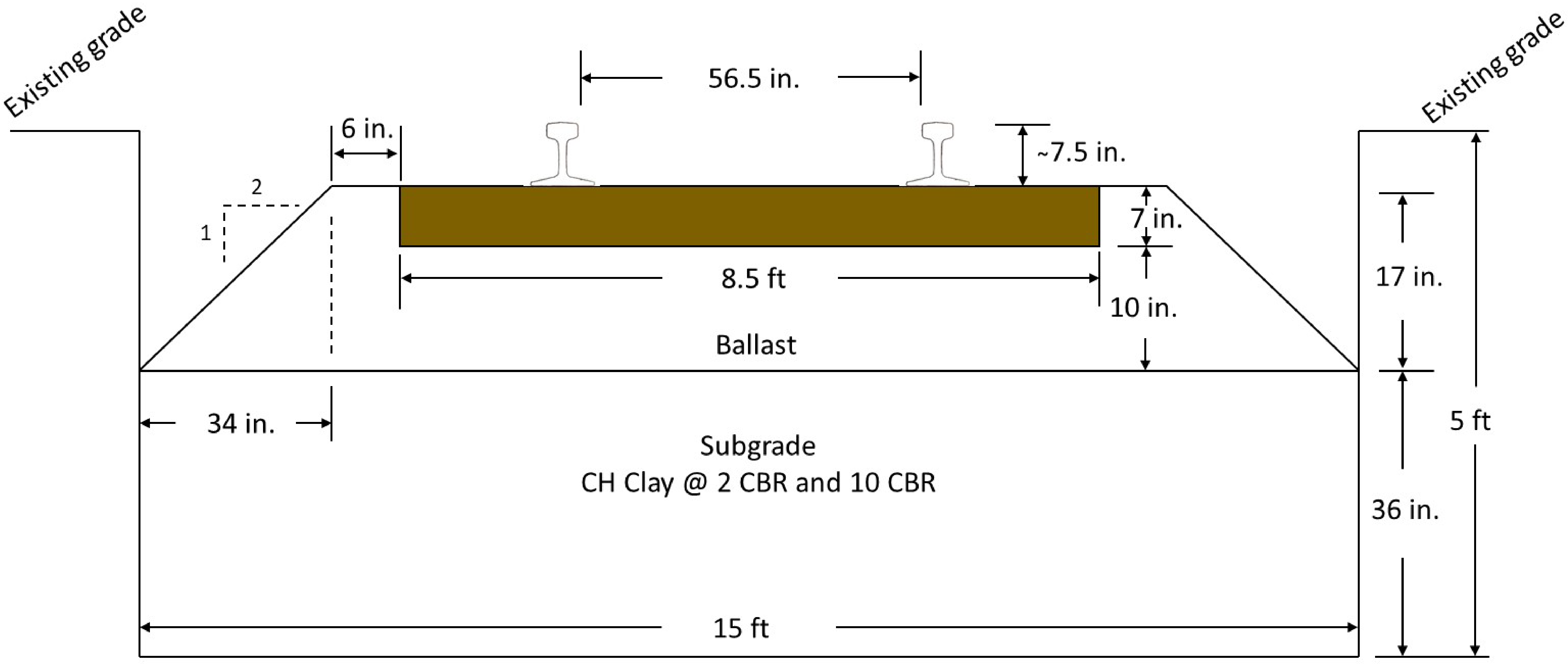
$X_1 \approx 34.9$
$C_d = 1.44$

$$p_m = \frac{q_o}{A_b}$$ ← Ballast surface stress

$$h = \frac{\left(50\frac{p_m}{p_c} - 10\right)^{0.74}}{2.54}$$ ← Ballast depth

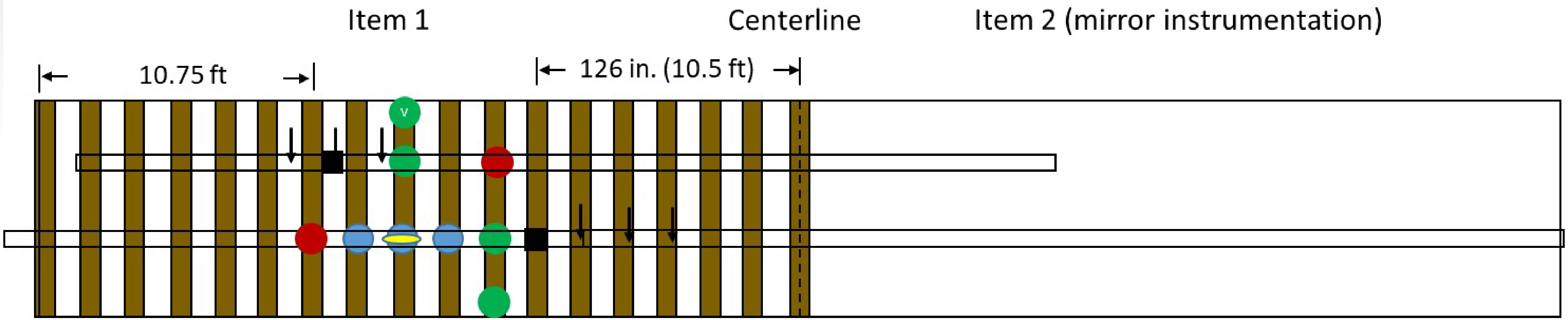


# CROSS SECTION




Not to scale

# INSTRUMENTATION PLAN VIEW

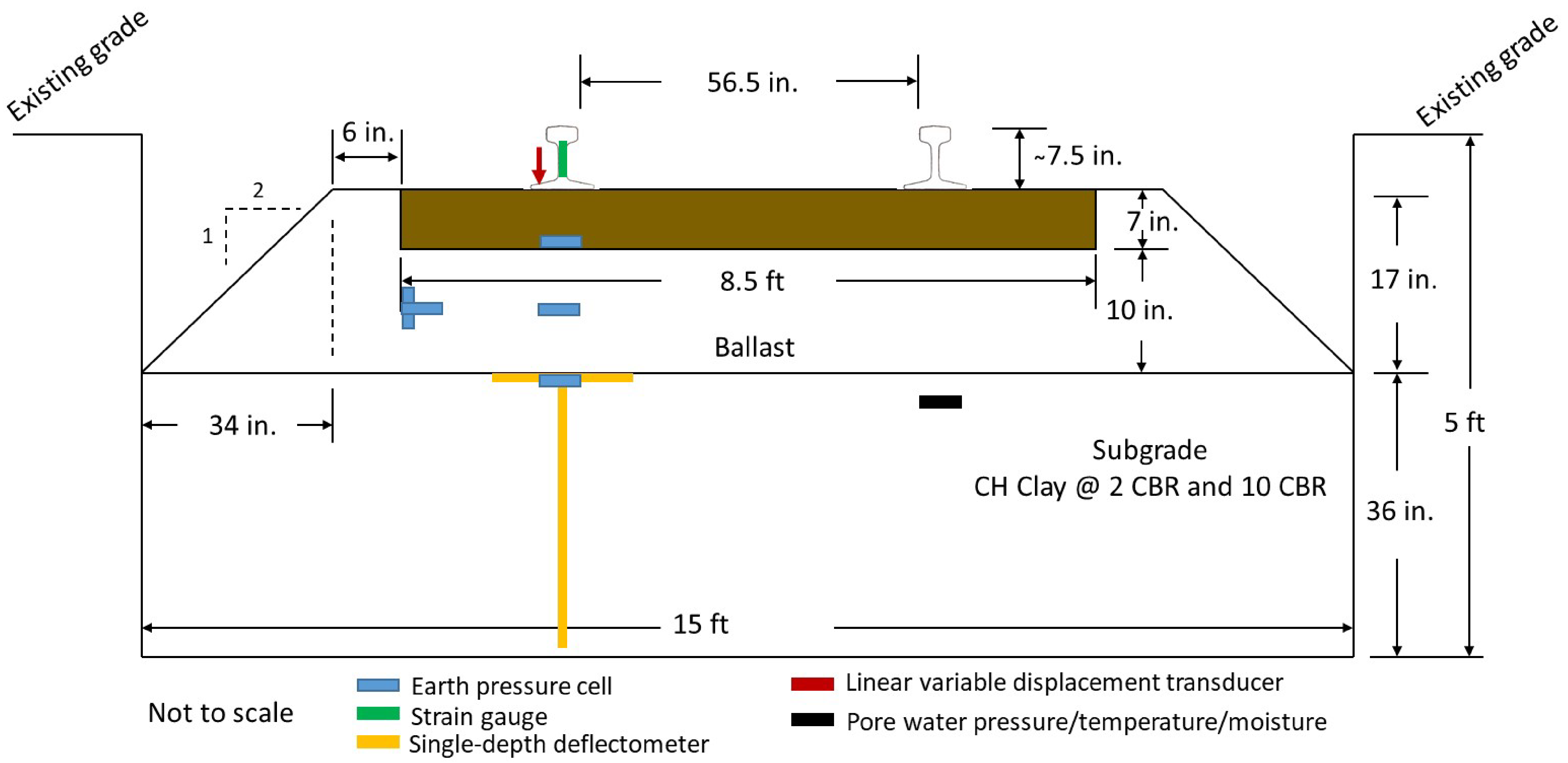



- Earth pressure cell in routed tie (3 per item)
- Earth pressure cell mid-depth ballast; V indicates vertical installed earth pressure cell (5 per item)
- Earth pressure cell subgrade (2 per item)
- Single-depth deflectometer subgrade (2 per item)
- LVDT cluster @ 21 in. spacing (6 LVDTs per item)
- Pore water pressure/moisture/temperature

Not to scale

North

# INSTRUMENTATION PROFILE



# CONSTRUCTION

## Quality Control:

-Field CBR tests

-Nuclear density/moisture content

-Grade/thickness control

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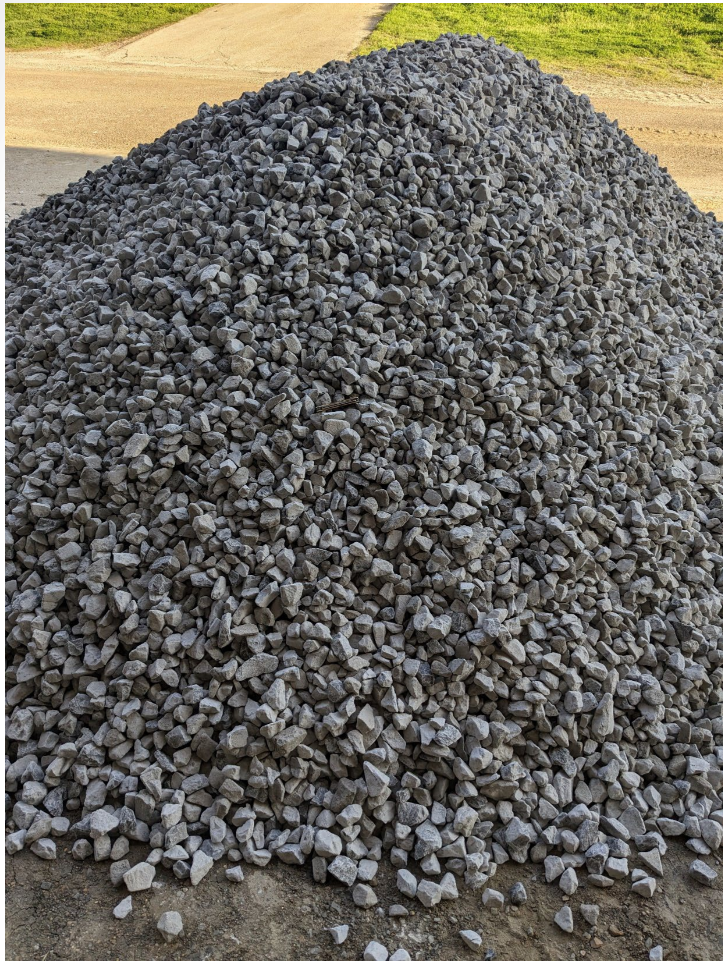

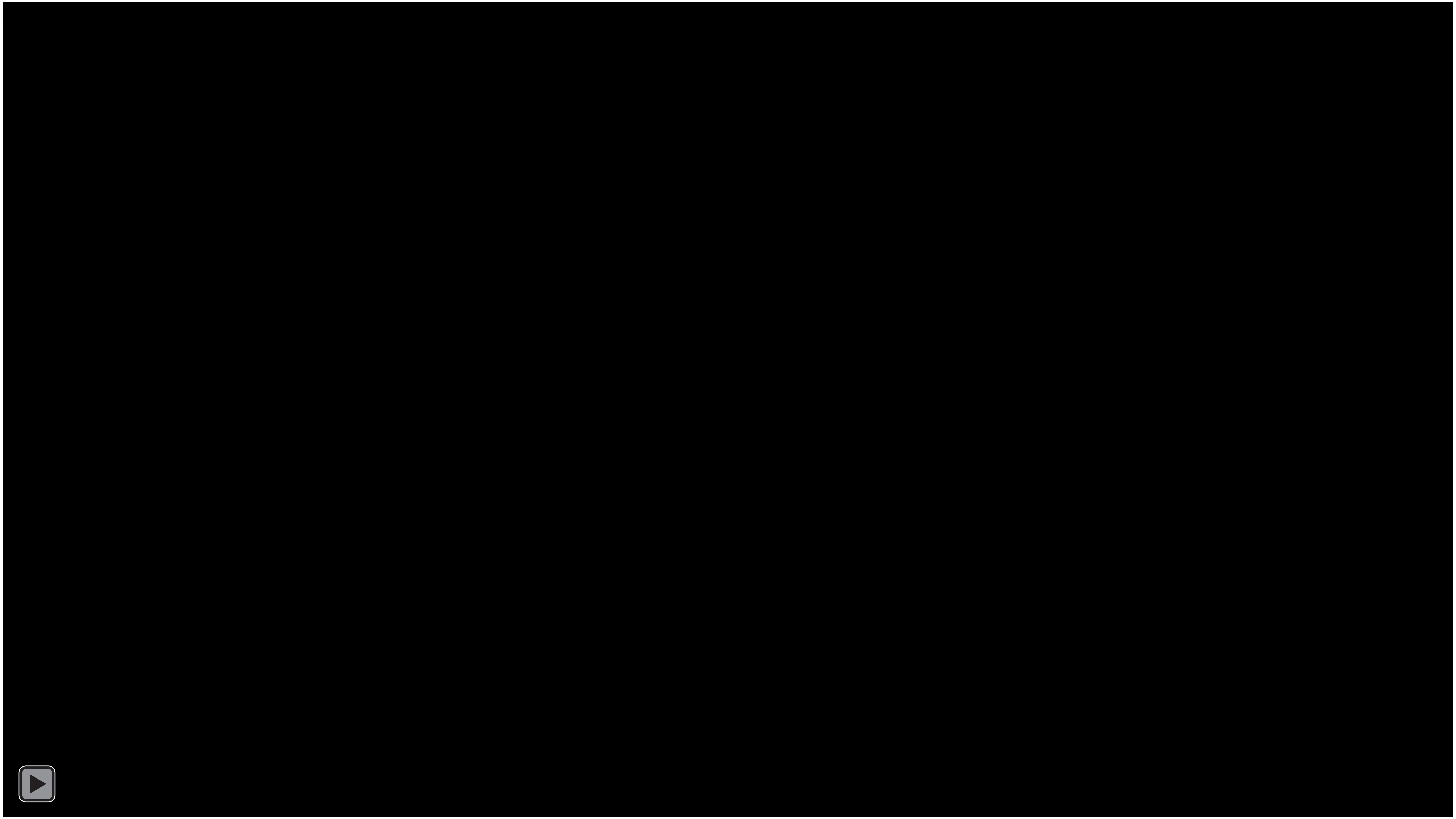

# CONNECT WITH US

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