GeoVirginia 2015
Williamsburg
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Geotechnical Engineering at Kennedy Space Center

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Geotechnical Engineering at Kennedy Space Center

- Stability of the Transporter on the Crawlerway
- Crawlerway Surfacing
- Vehicle Assembly Building Foundations
- Slope Protection at Launch Pads


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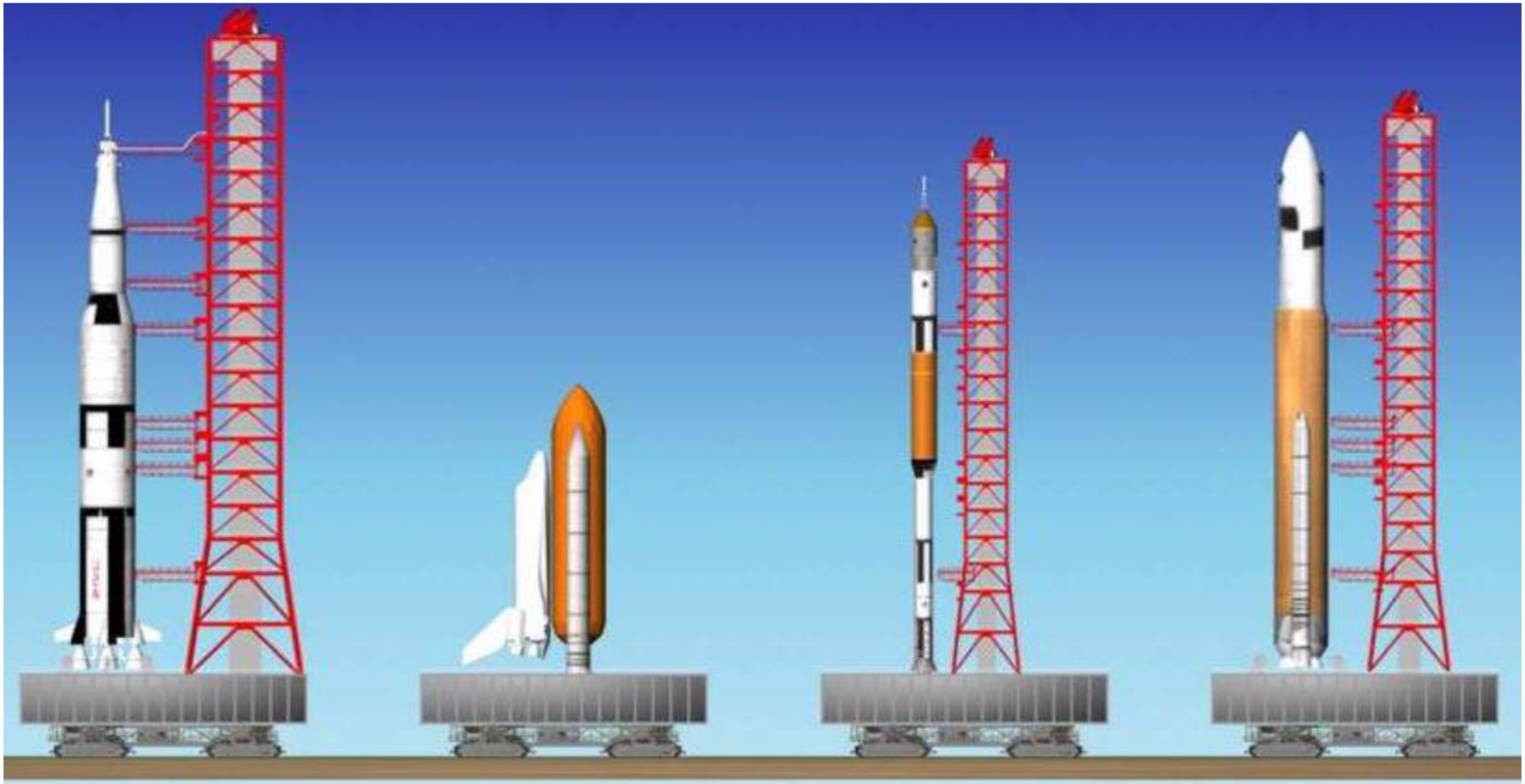
Transporter Stability on Crawlerway

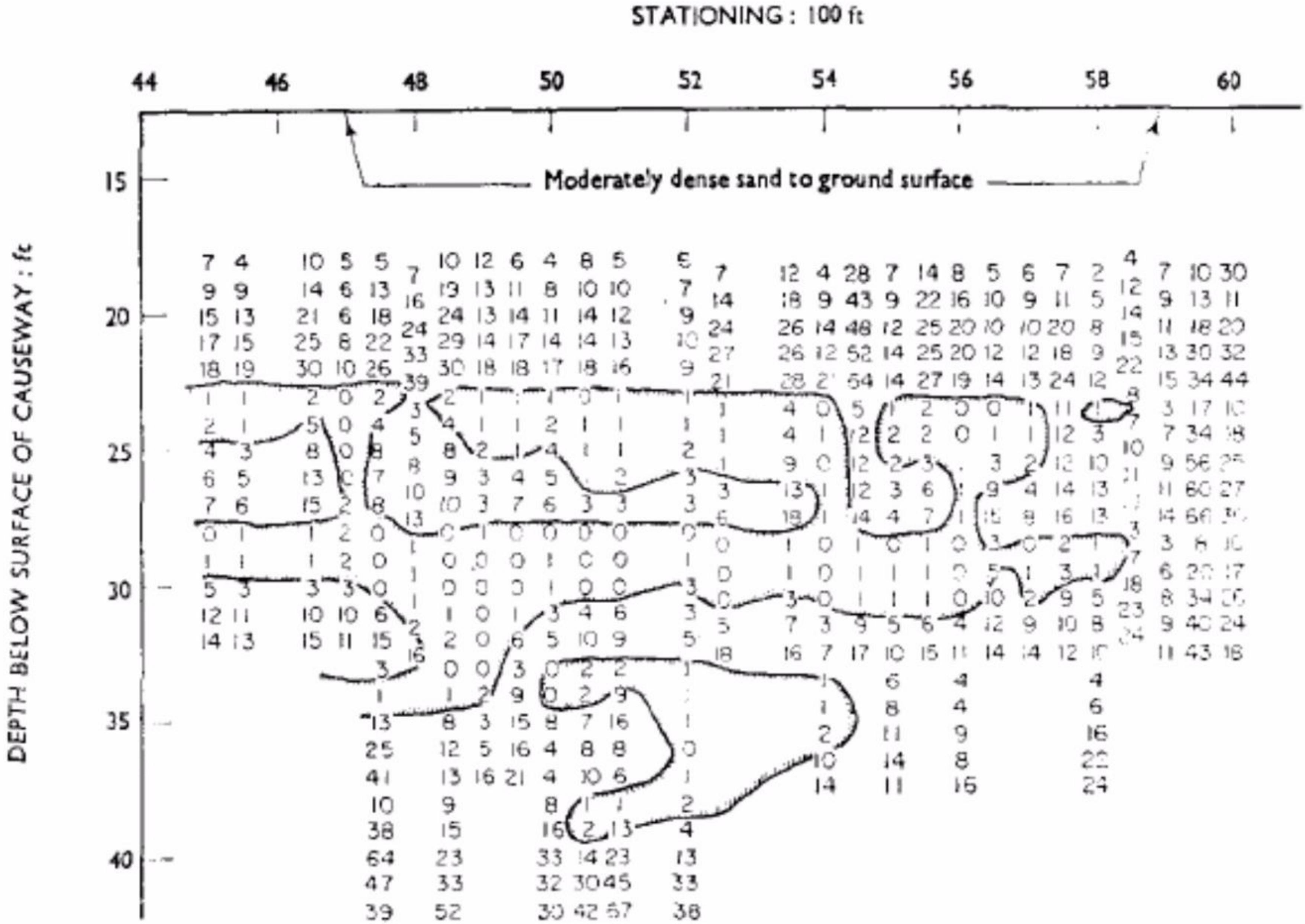
Loads Imposed on Crawlerway



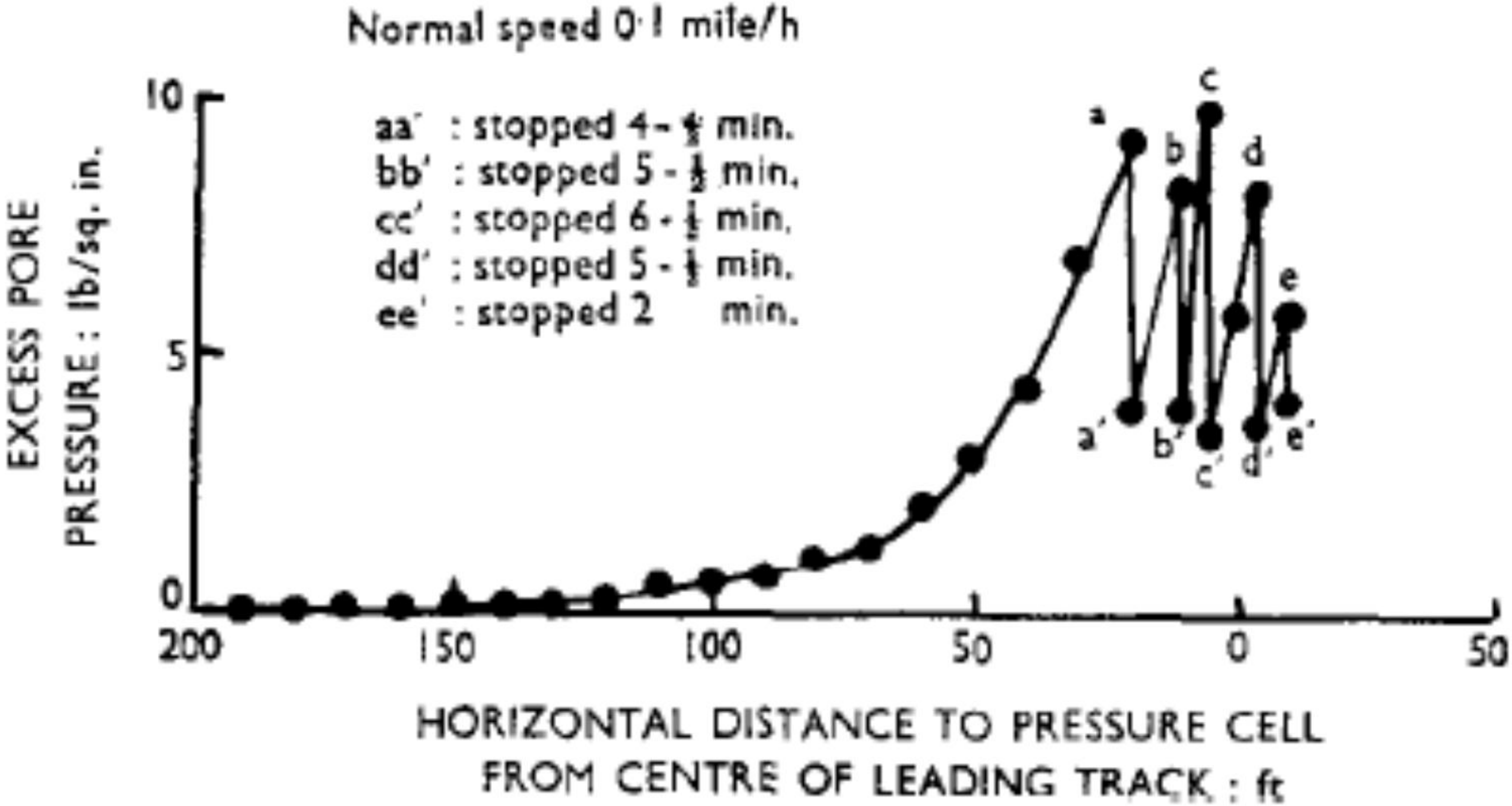
1960s Apollo	Space Shuttle	Proposed Ares I	Proposed Ares V
18 million lbs	18 million lbs	<18 million lbs	25 million lbs

Study Area:
Poor Conditions, Historical Data Available

Study Area:
Loose Zones under Crawlerway B (Peck 1969)



Pore Water Pressure Response in Loose Zone as Partially Loaded Transporter Approaches



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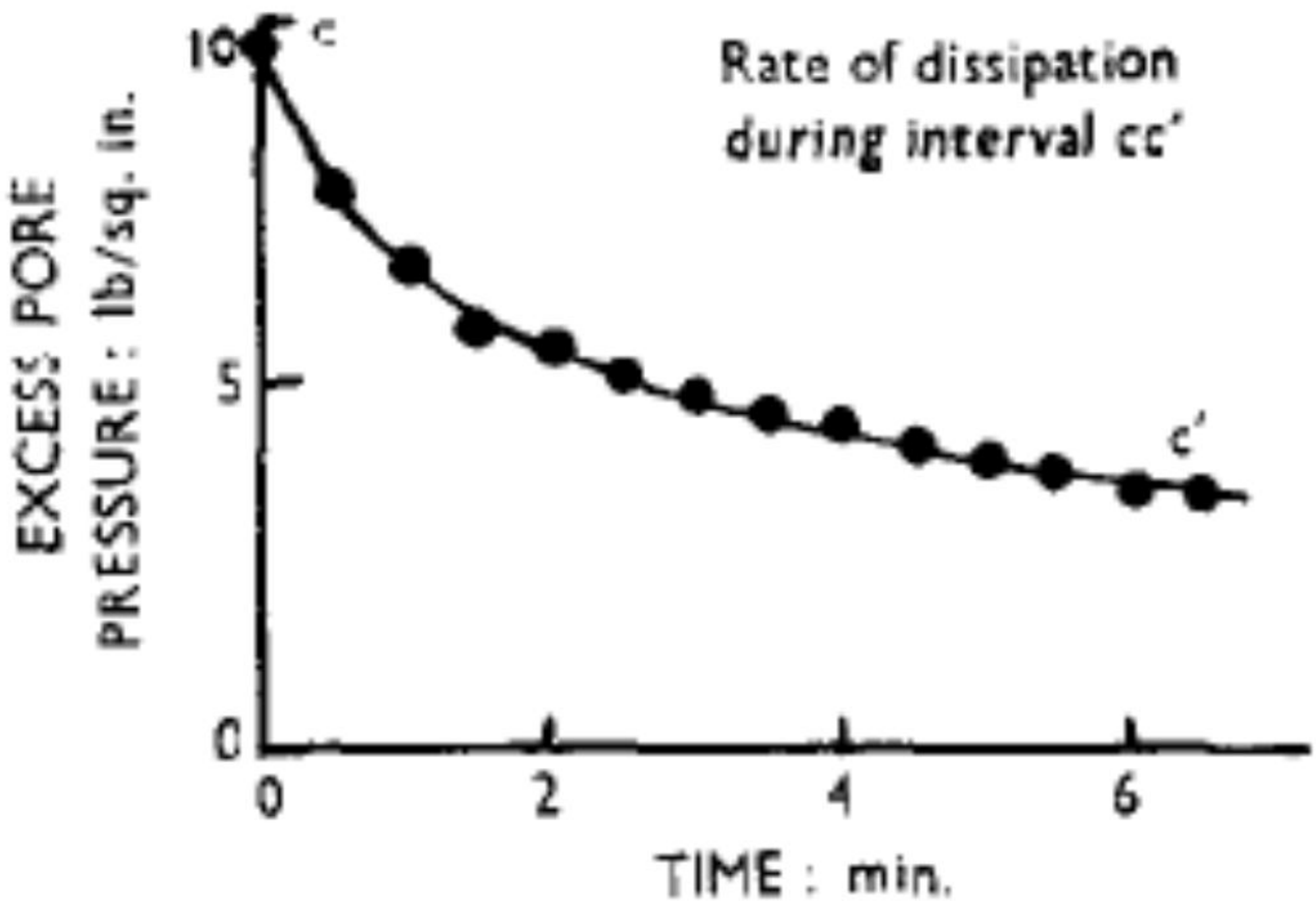
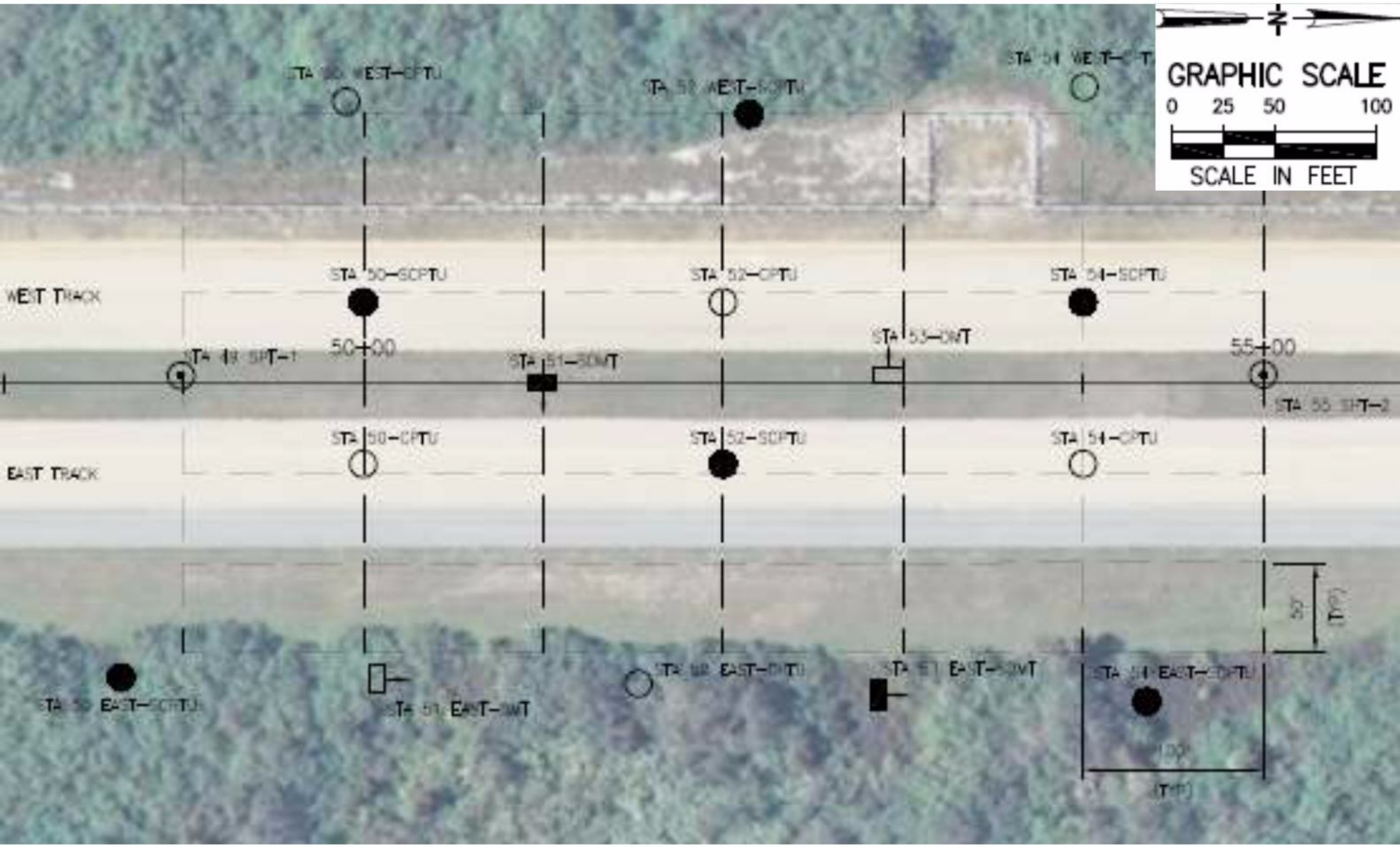
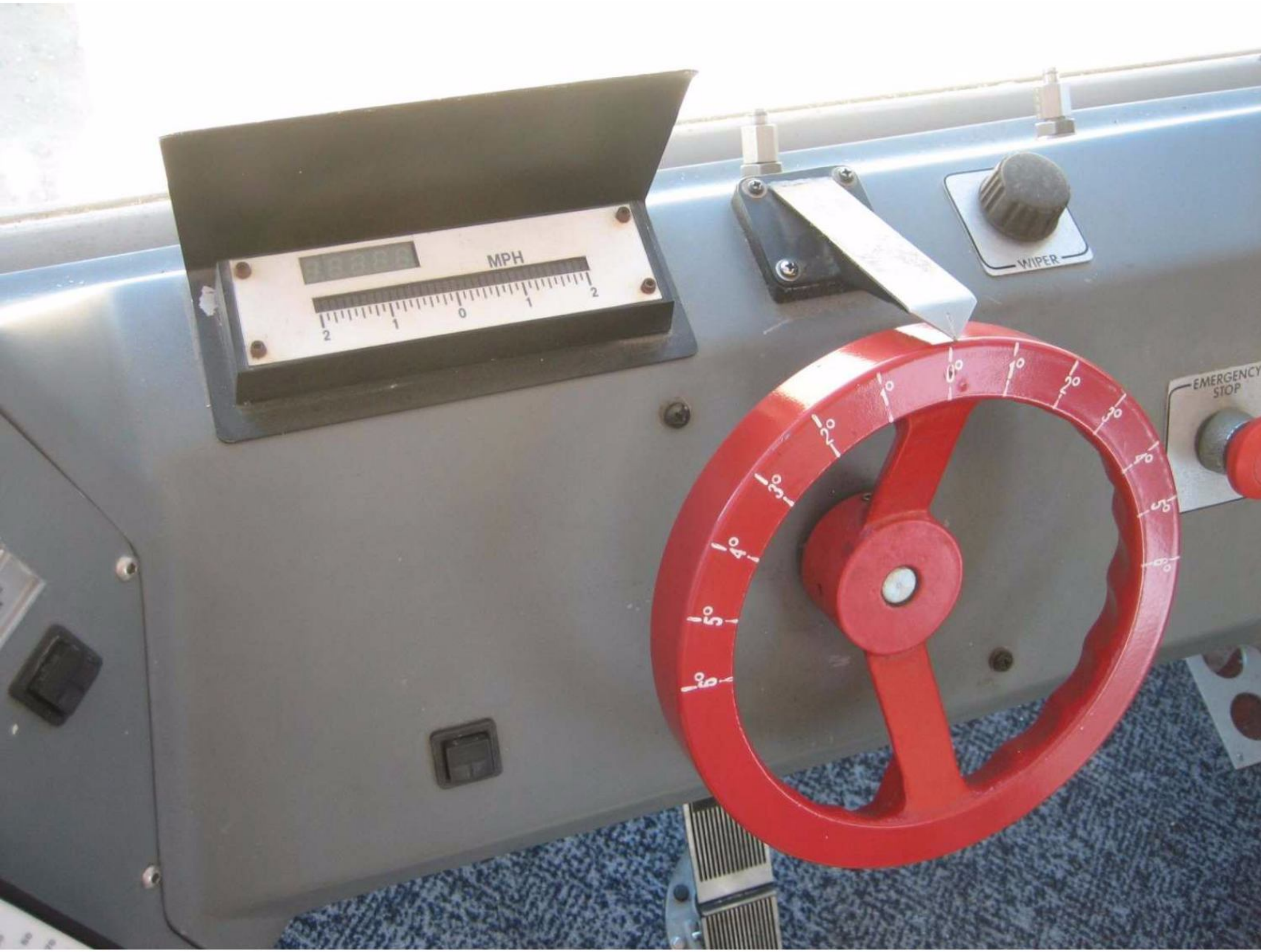


2008 Field Testing at Study Area: SPT, CPT, DMT



2008 Dilatometer Tests

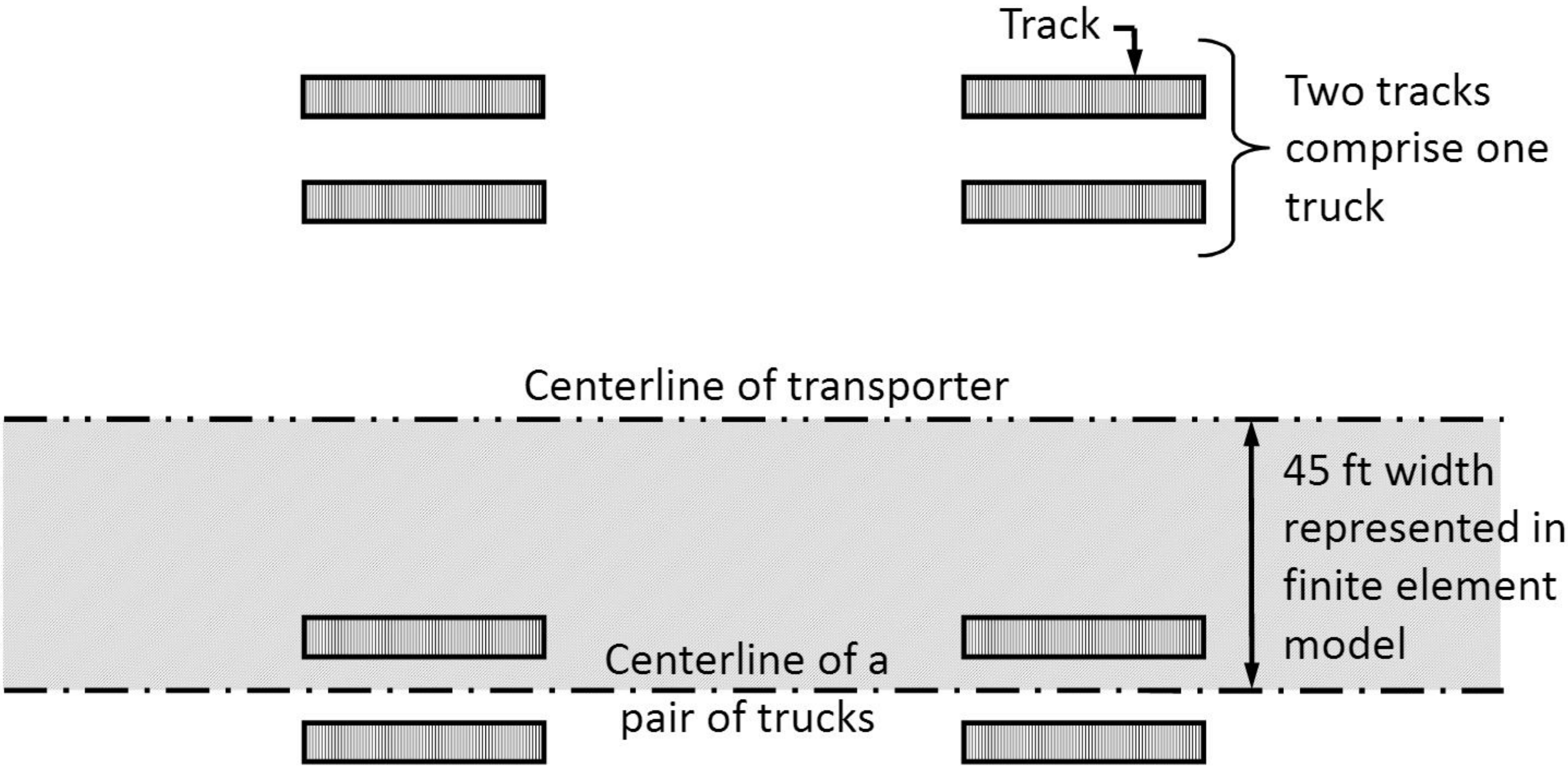

MPH
2 1 0 1 2
WIPER
EMERGENCY STOP


JB-23
TRUNKING 1
TRUNKING 2

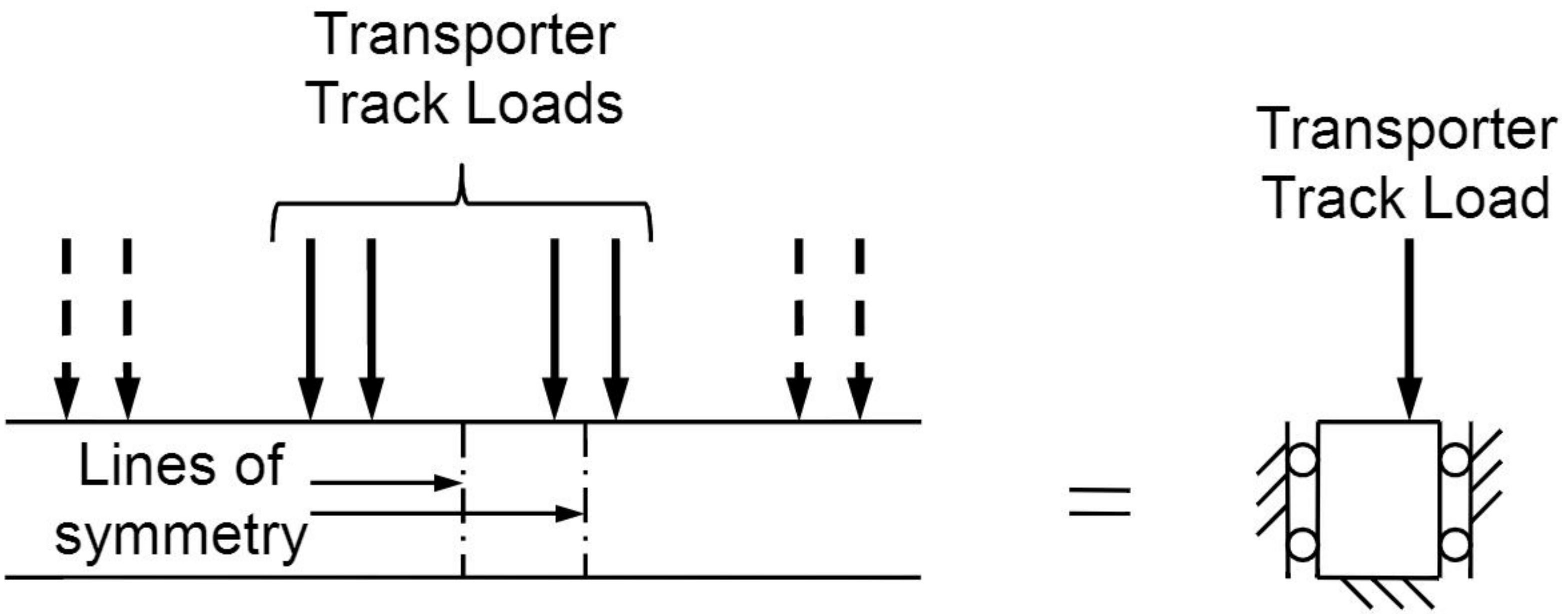

ZONE
ALCO
ALCO
ALCO
ALCO
ALCO
ALCO
ALCO
ALCO


C-OUT
1C2
1C2 B

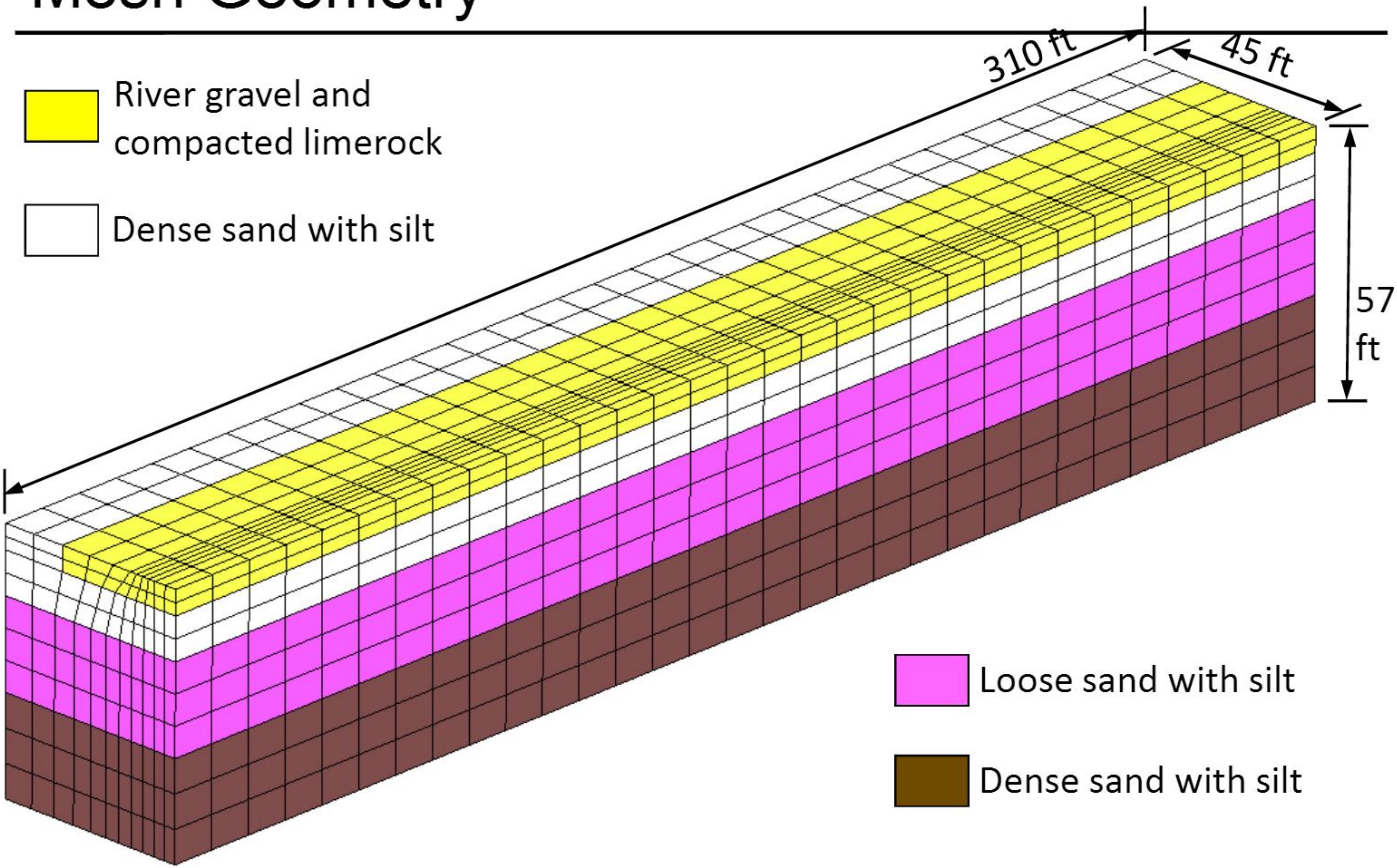
Plan View of Transporter Tracks



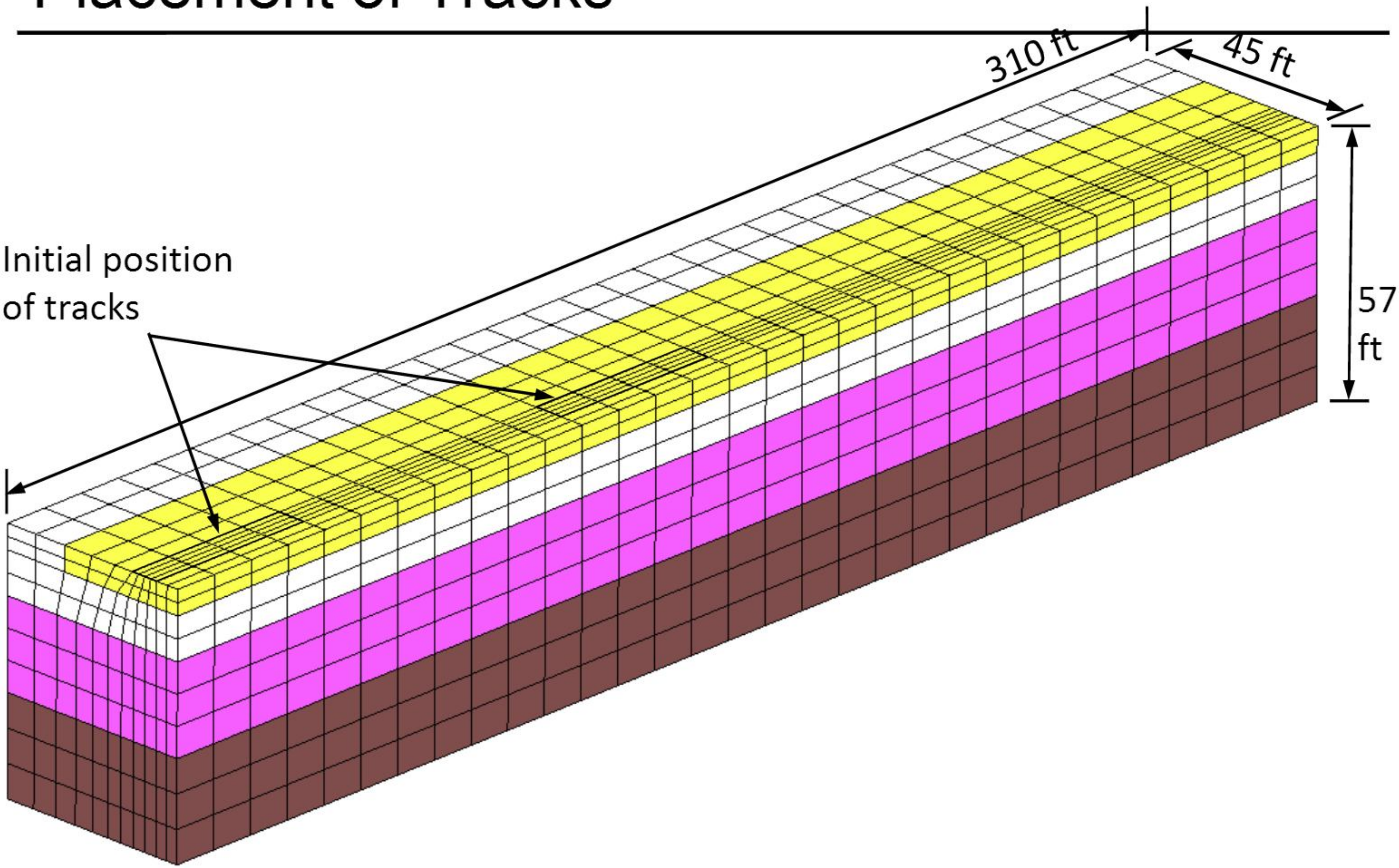
Symmetry


Transporter
Track Loads
Lines of
symmetry
Transporter
Track Load

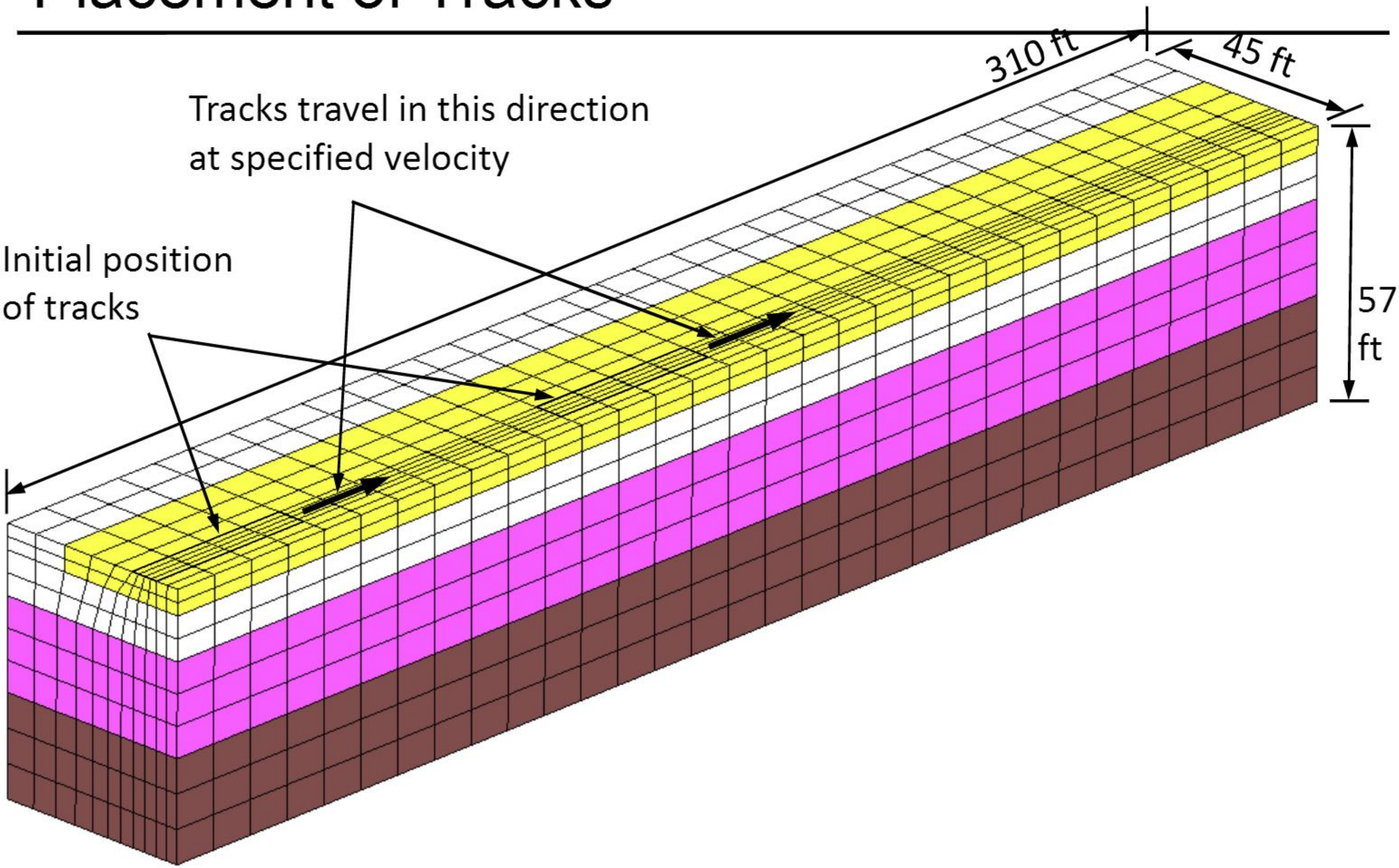
Mesh Geometry



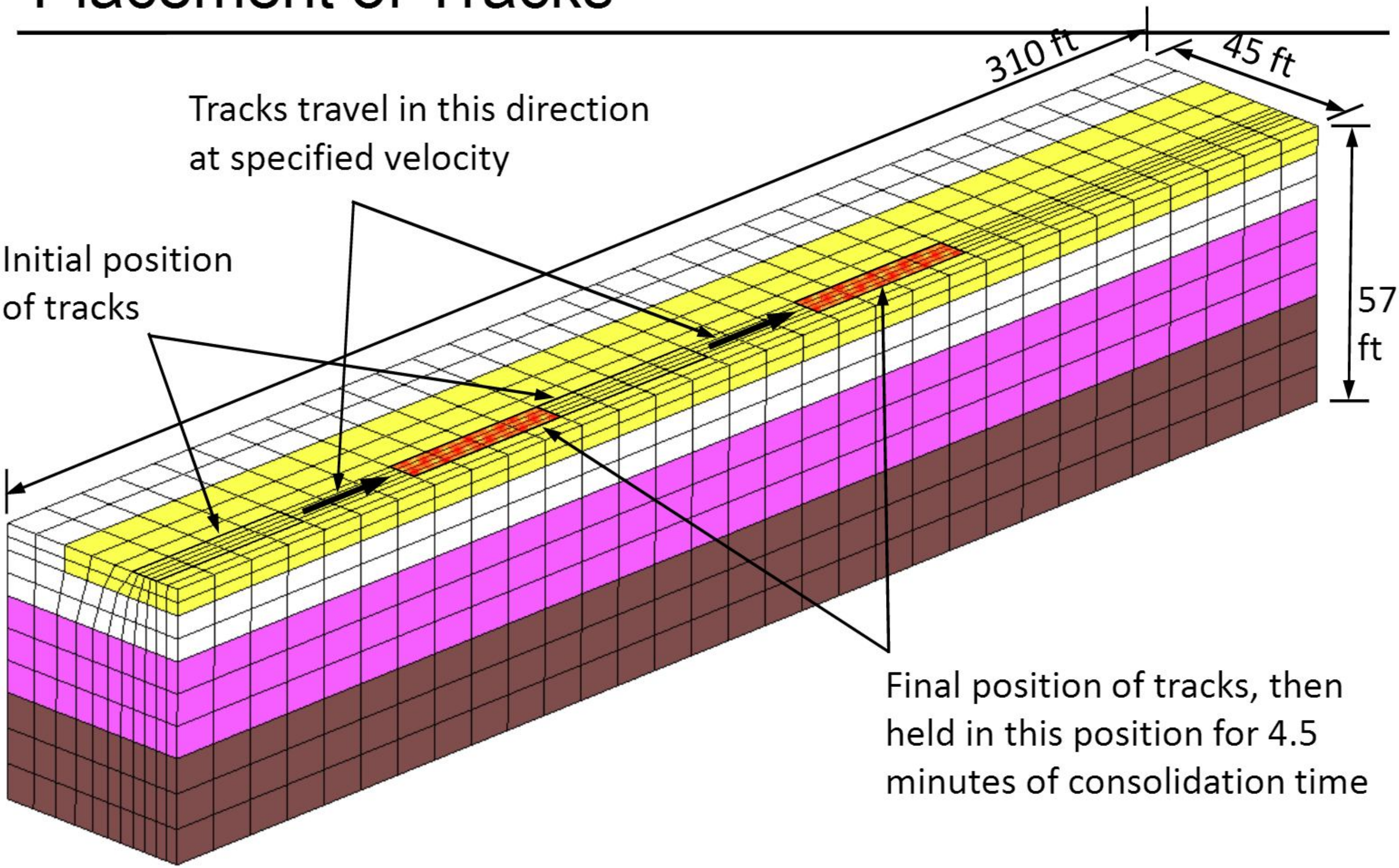
Placement of Tracks



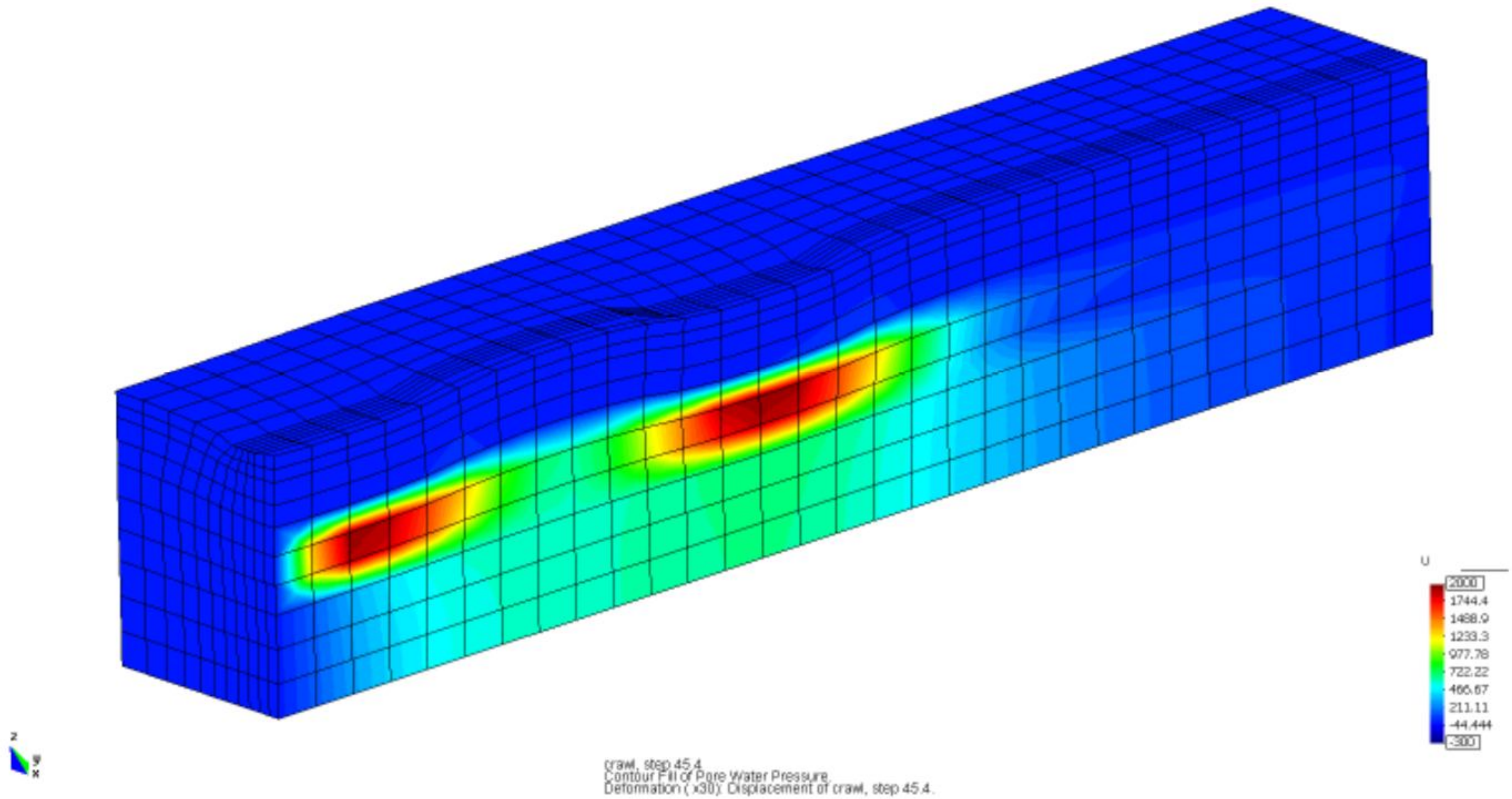
Placement of Tracks



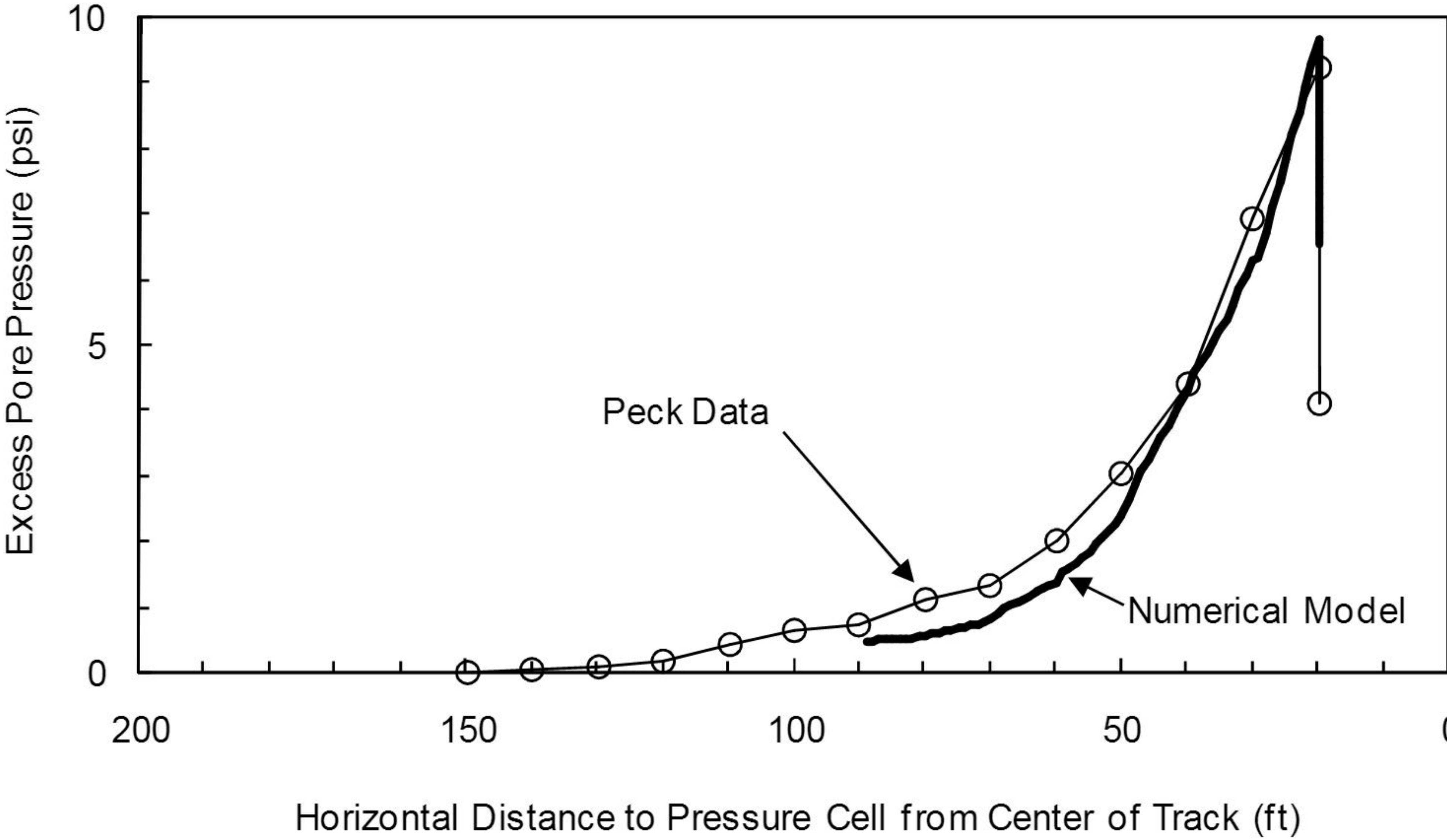
Placement of Tracks



Animation of Deformations and Excess Pore Water Pressures



Excess Pore Water Pressures



Settlement and Lateral Movement

- Calculated settlement = 3.96 inches, versus estimated settlement of 4.1 inches from 1967 Apollo field test
- Calculated maximum lateral movement = 1.04 inches, versus observed maximum lateral movement of ¾ to 1½ inches

Overall, the numerical model is in good agreement with the observed response from the 1967 field test for the Apollo program.

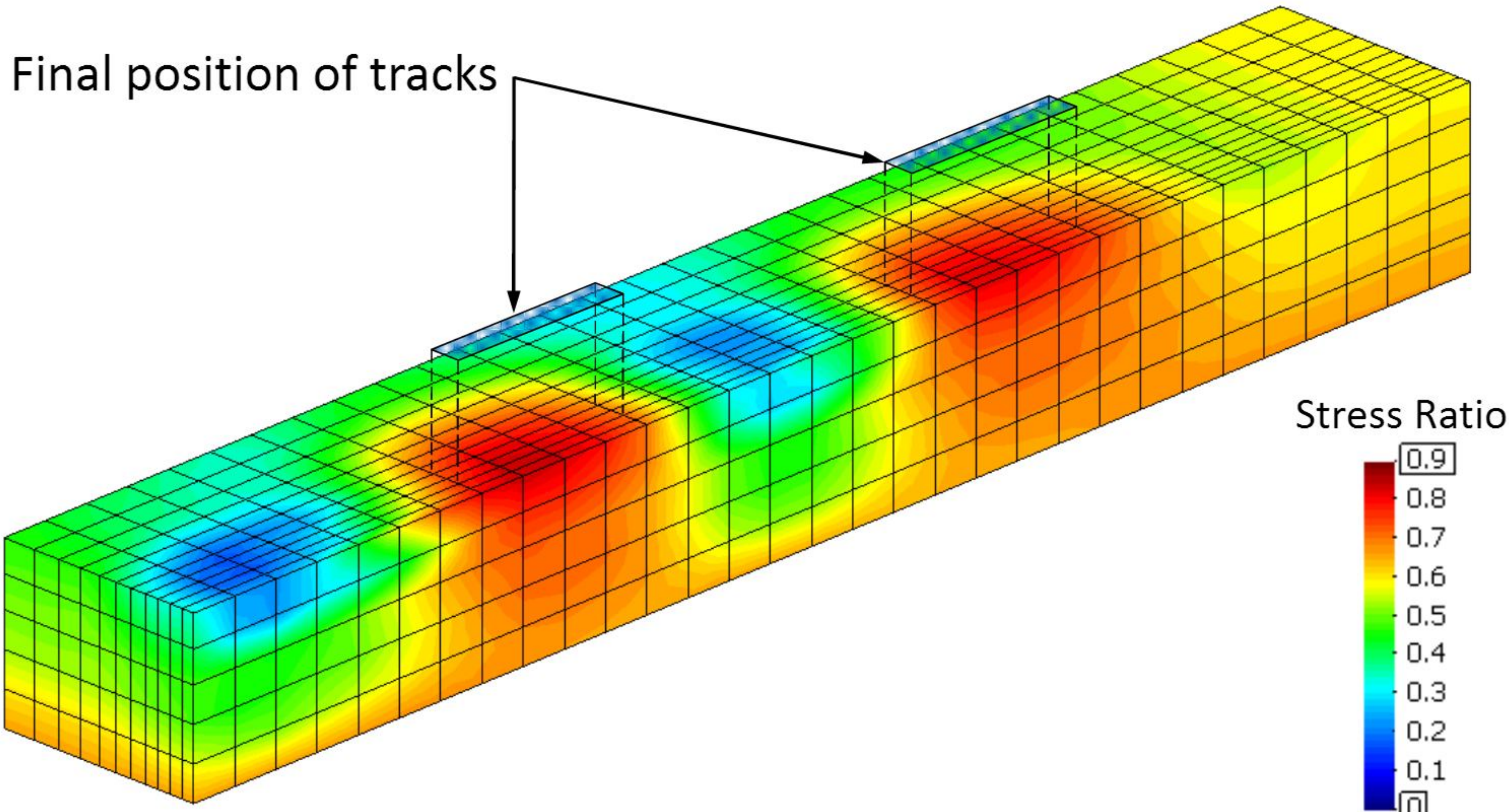
2008 Site Investigation Showed Improved Conditions Compared to 1960s

- About a hundred passes of heavily loaded transporter
- 40+ years of aging

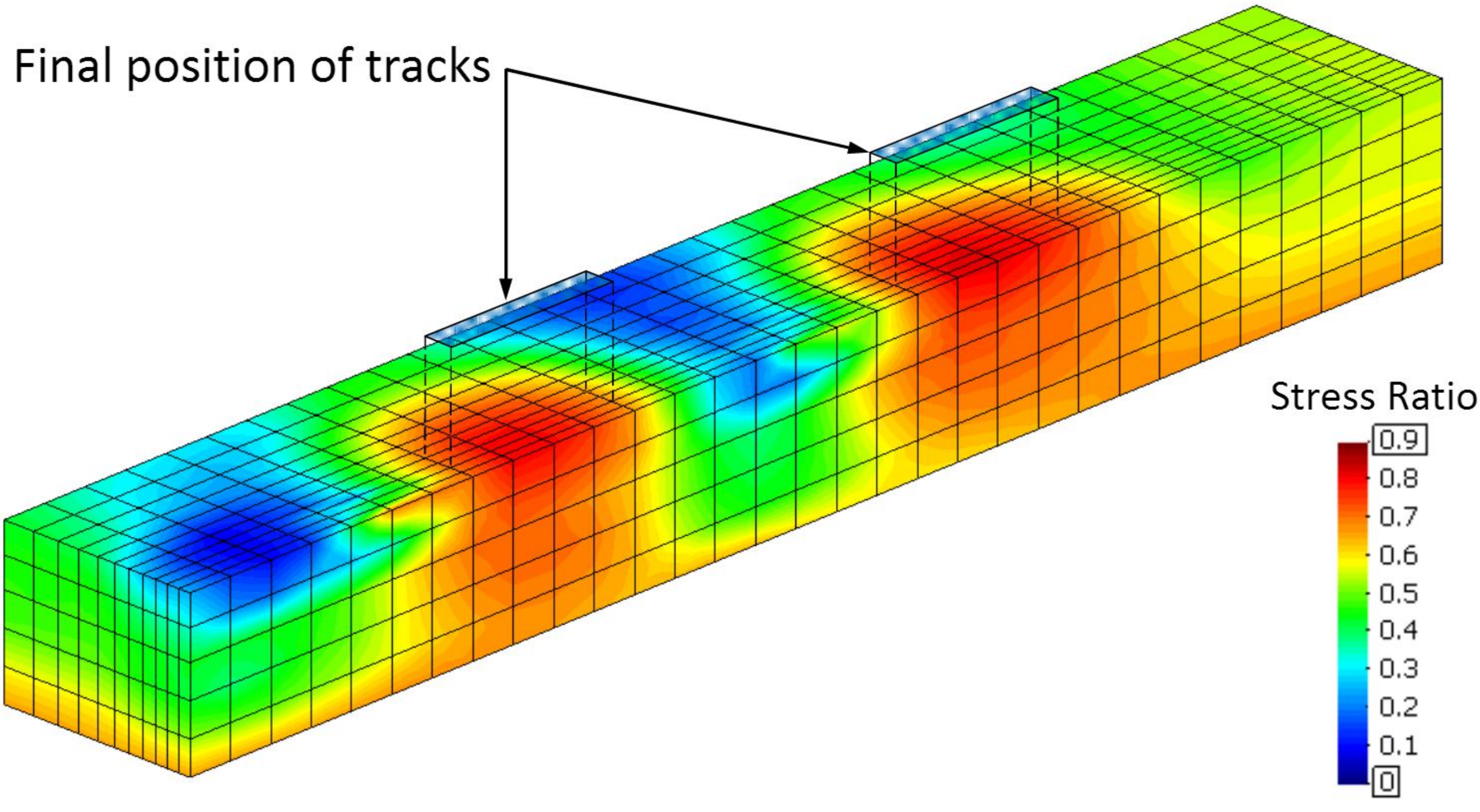
Ares V Settlement, Excess Pore Water Pressure, and Lateral Movement versus Transporter Speed

Transporter Speed (mph)	Excess Pore Water Pressure (psf)		Settlement (in.)	Lateral Movement (in.)
	Maximum	After 4.5 min.		
0.1	1,680	835	1.73	0.45
0.9	2,410	1,020	1.69	0.53
1.3	2,460	1,030	1.68	0.54

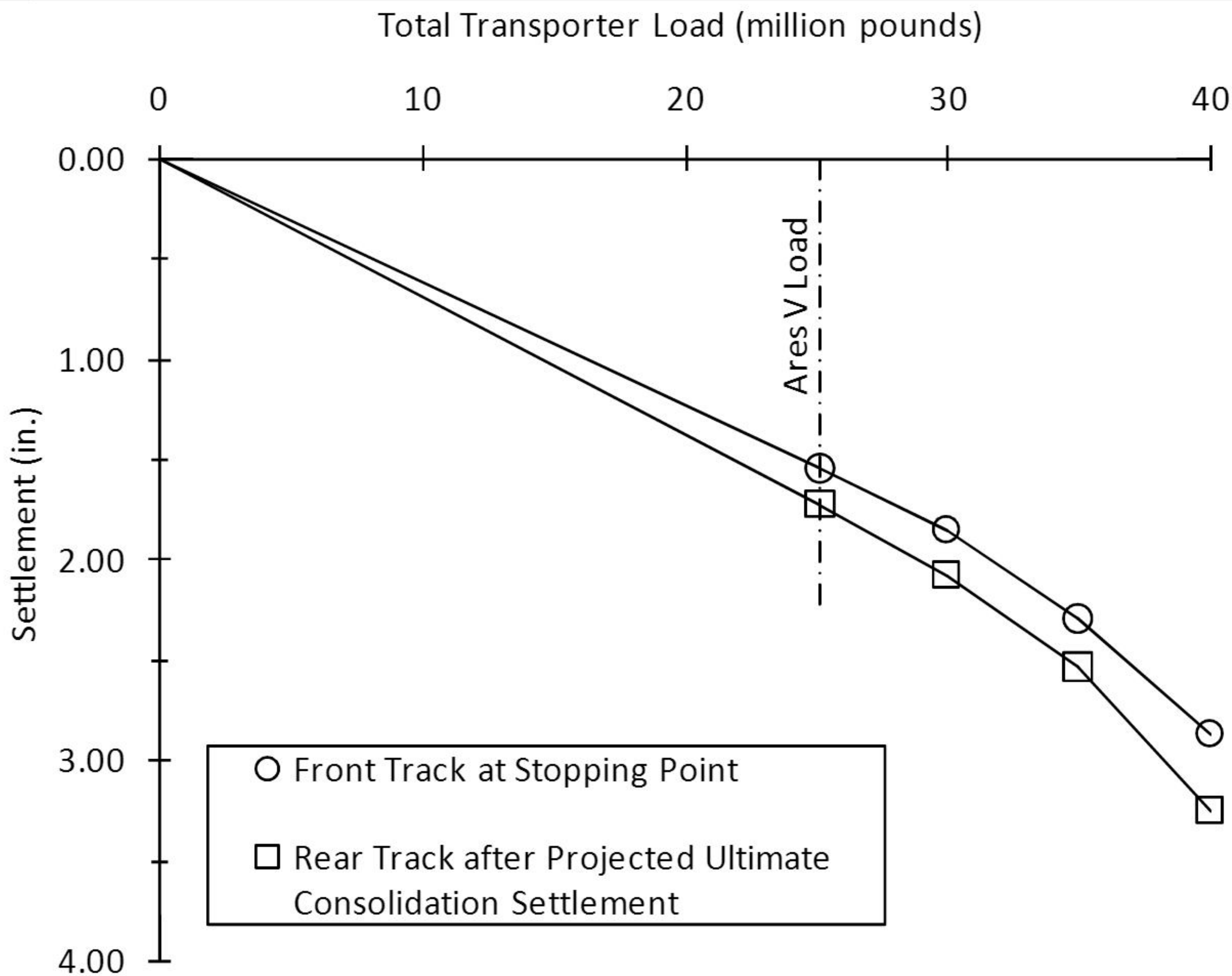
Degree of Shear Strength Mobilization at Depth 22 ft at Stopping Point for 1967 Apollo Field Test Load



Degree of Shear Strength Mobilization at Depth 22 ft at Stopping Point for Ares V

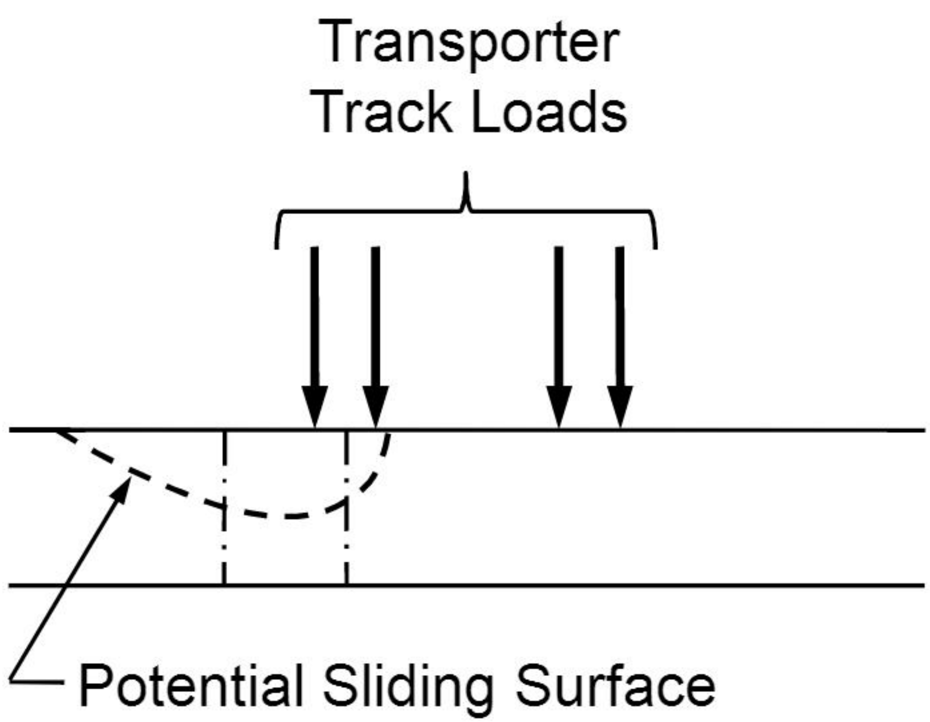


Prediction Analyses, Load vs Settlement

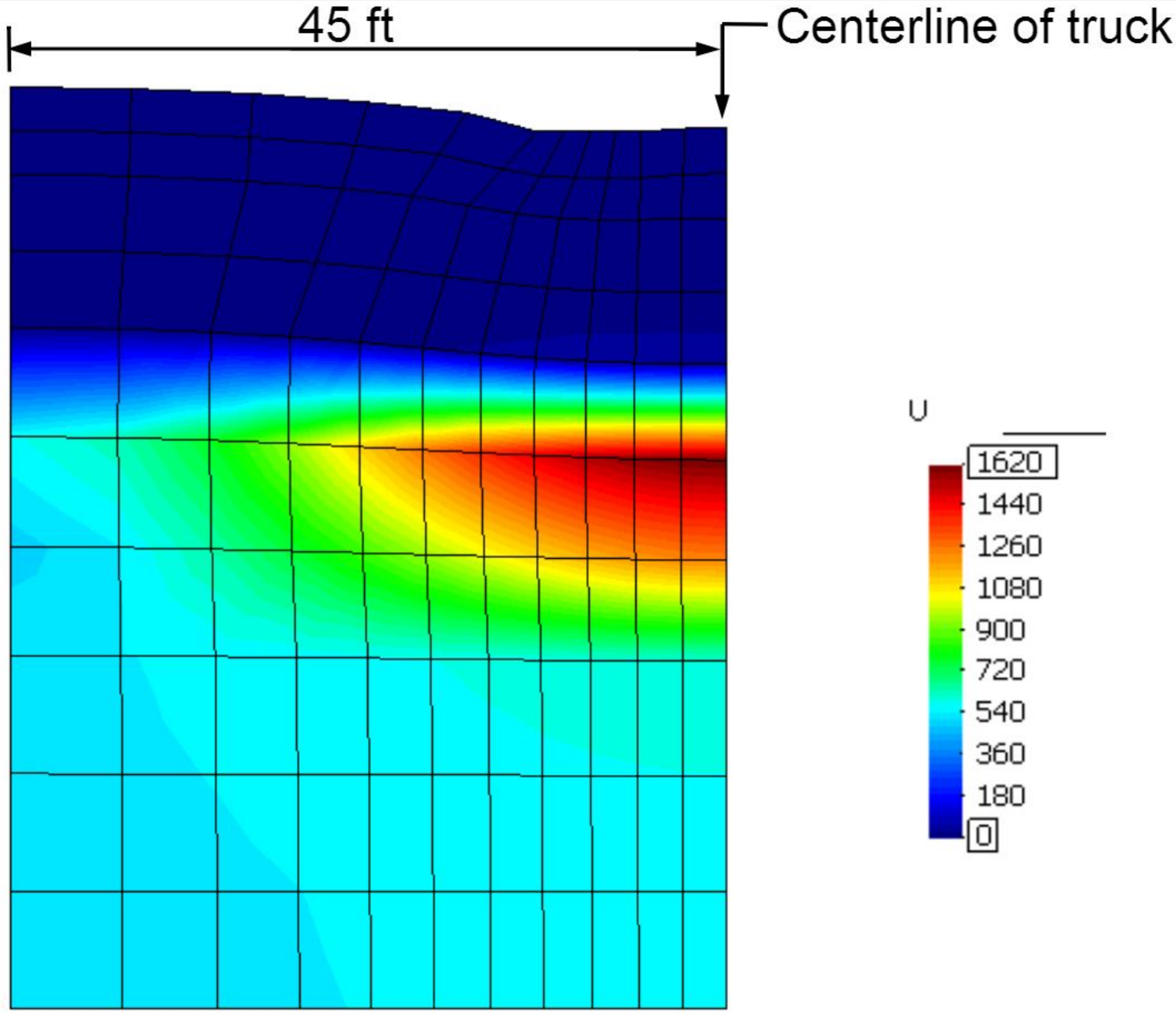


Impact of Boundary Conditions in Numerical Analyses on Potential Failure Modes

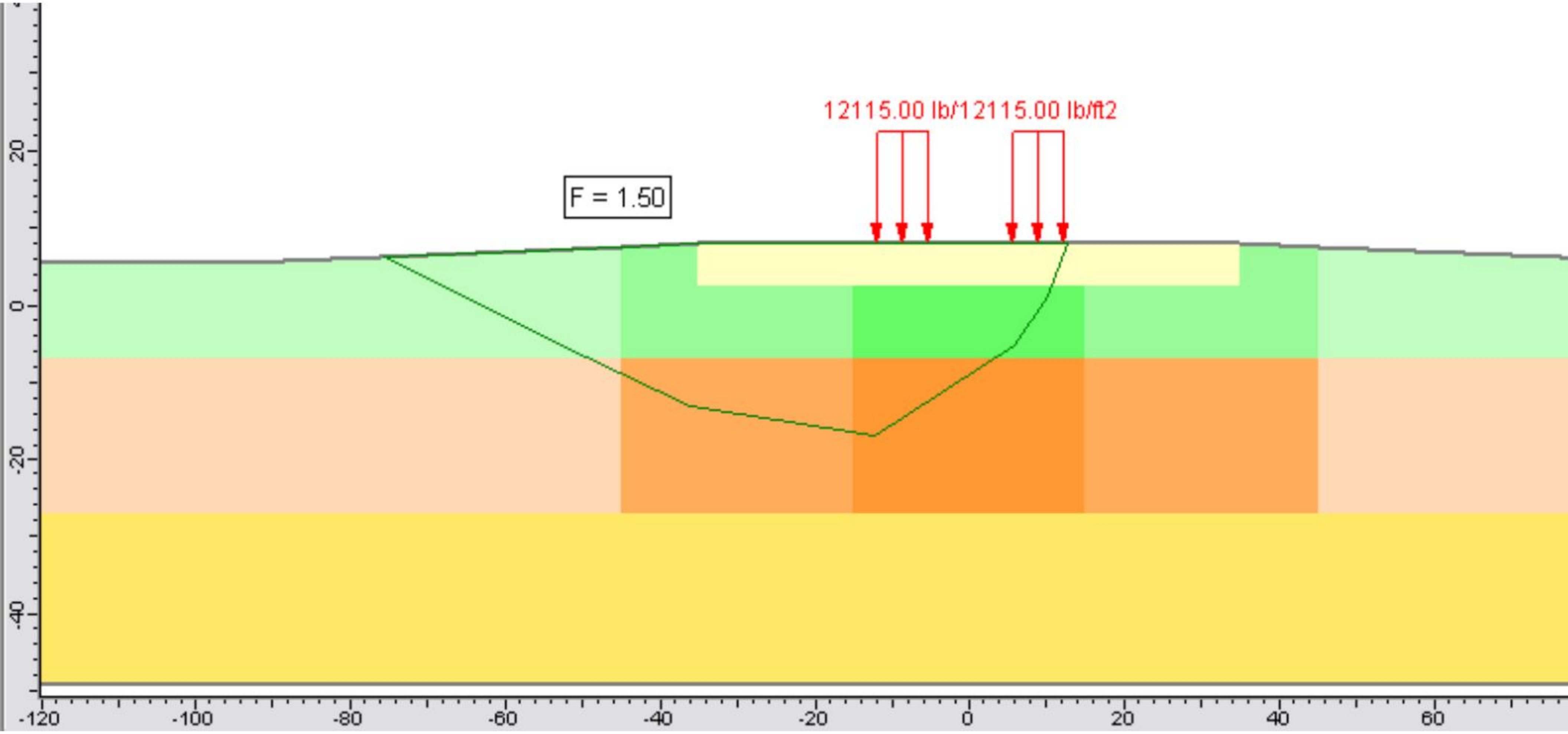
- Boundary conditions applied for numerical analyses prevent failure that extends beyond the model domain



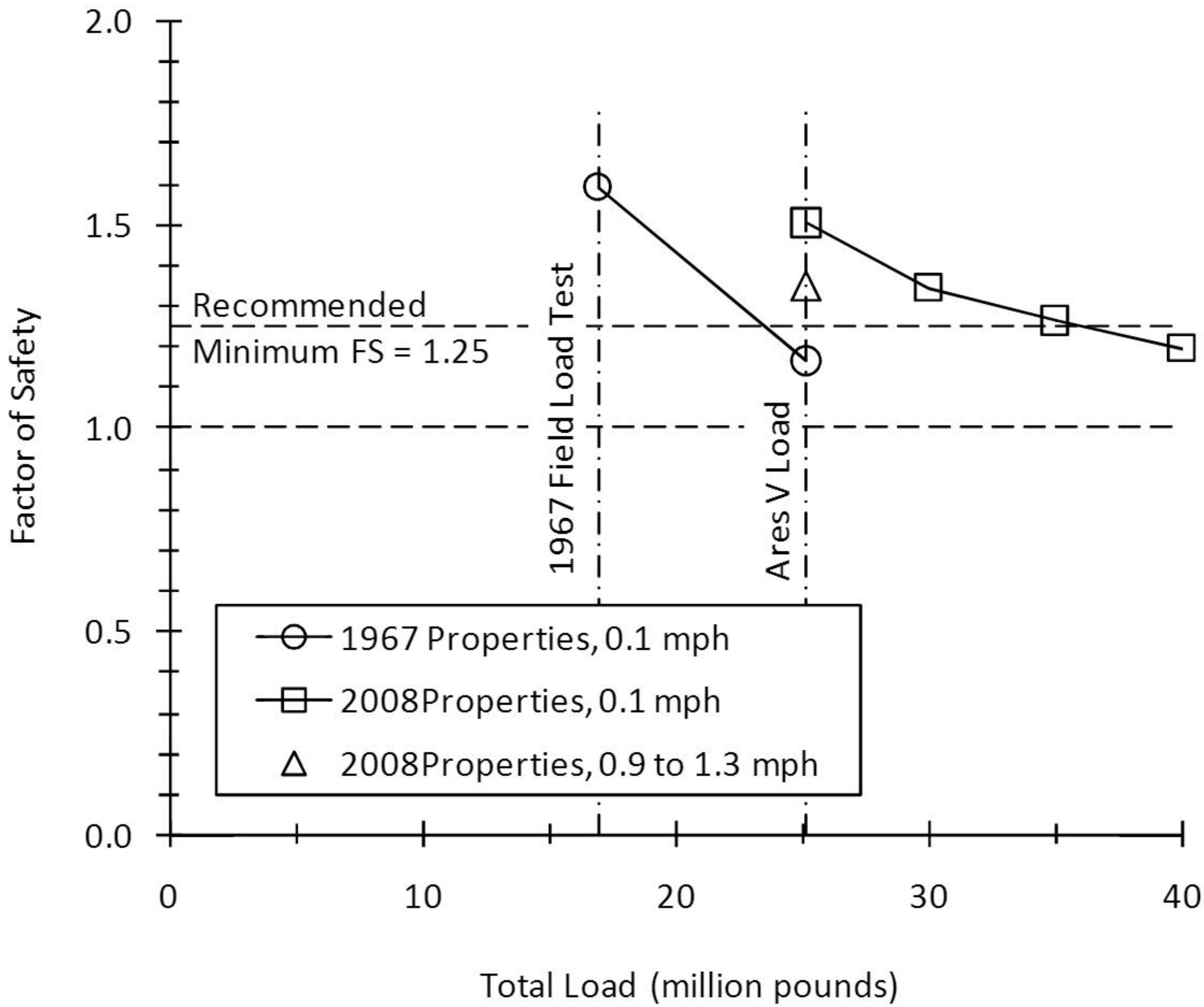
Link between Numerical Analyses and Limit Equilibrium Analyses: Excess Pore Water Pressure



Limit Equilibrium Analyses for Ares V Load



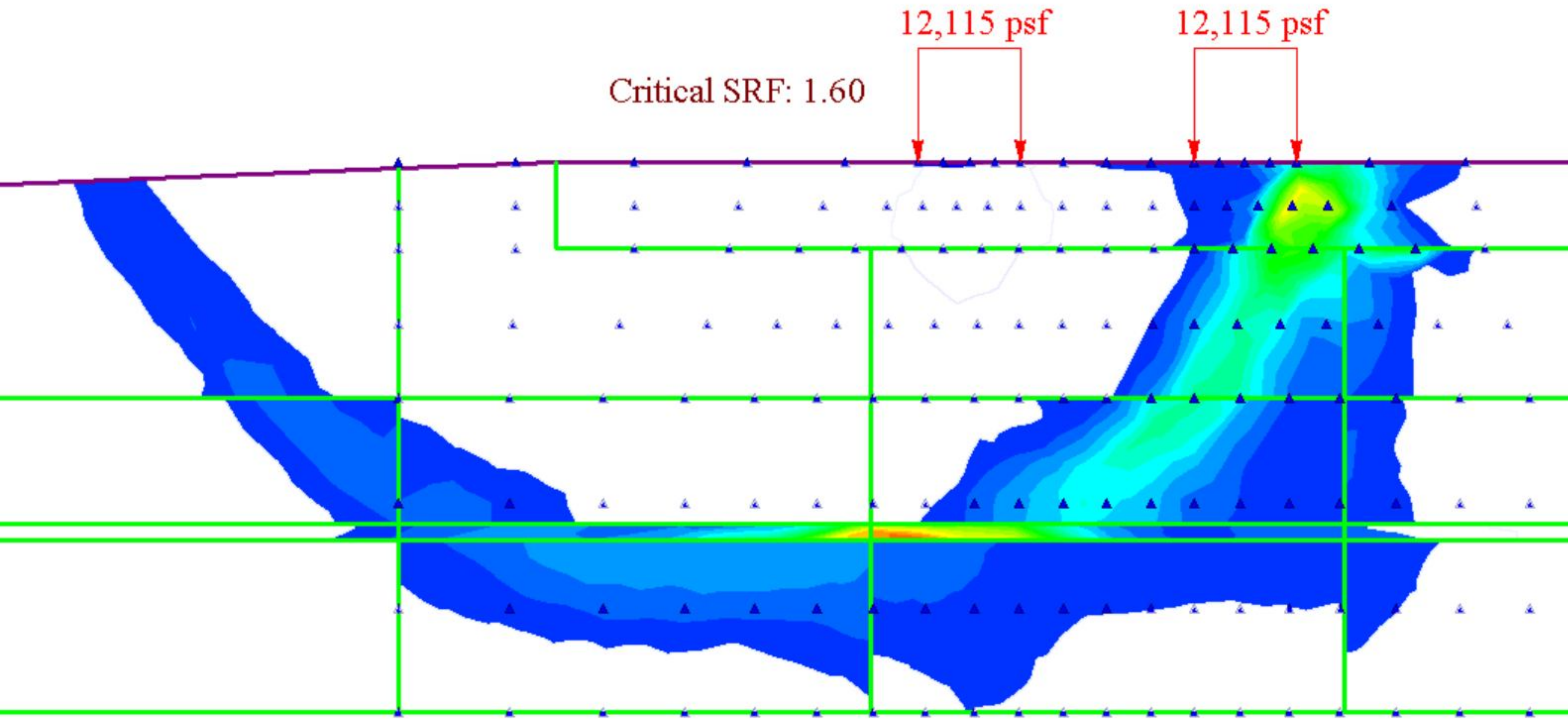
Factor of Safety vs Transporter Load



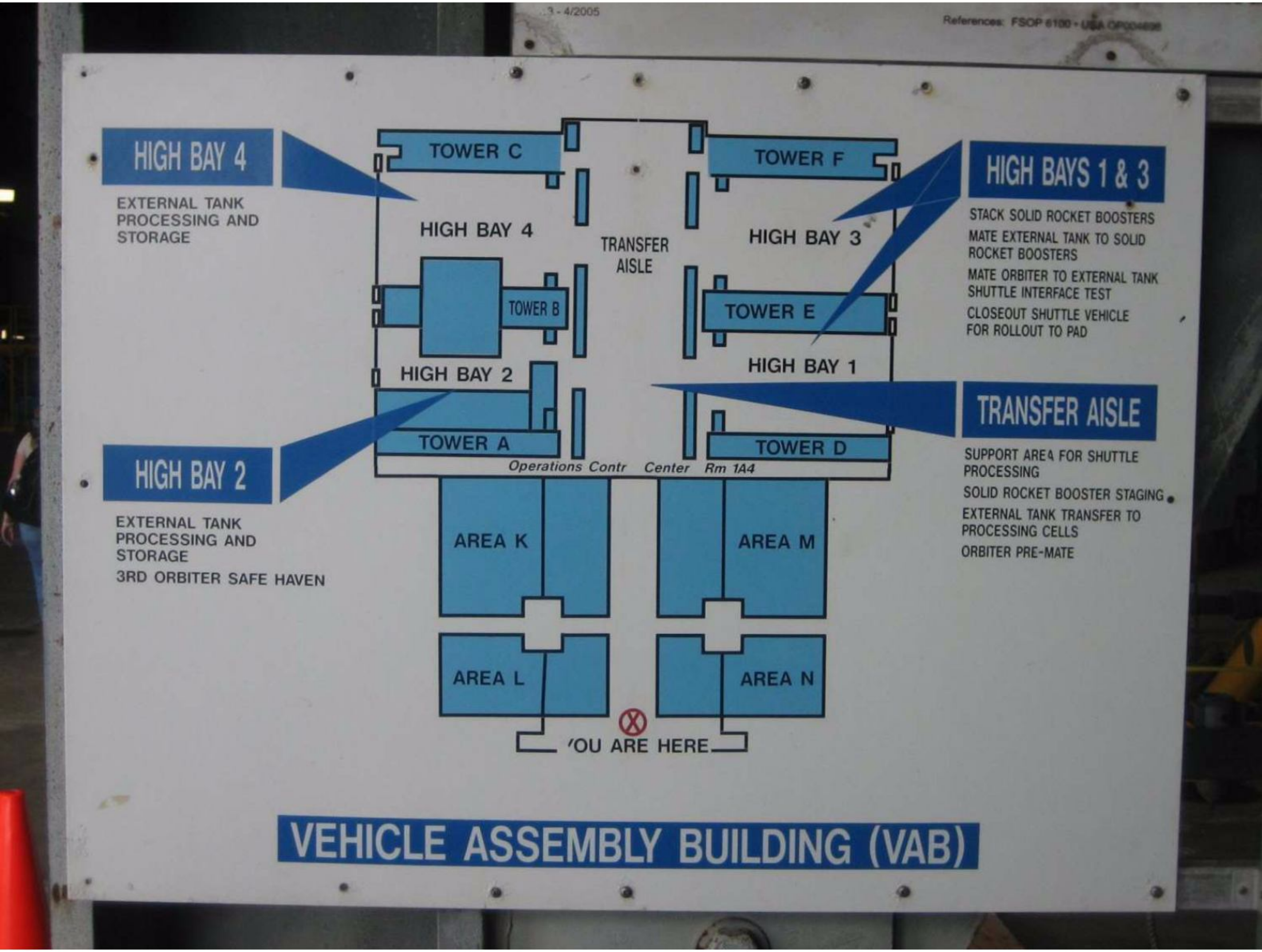
Justification for Minimum FS = 1.25

- Temporary loading
- Applied recommendations by Silva et al. (2008):
  - Well characterized site
  - High quality analyses
  - Therefore, this is a “Category I” project, and FS = 1.25 corresponds to probability of failure = 0.1 to 0.01%

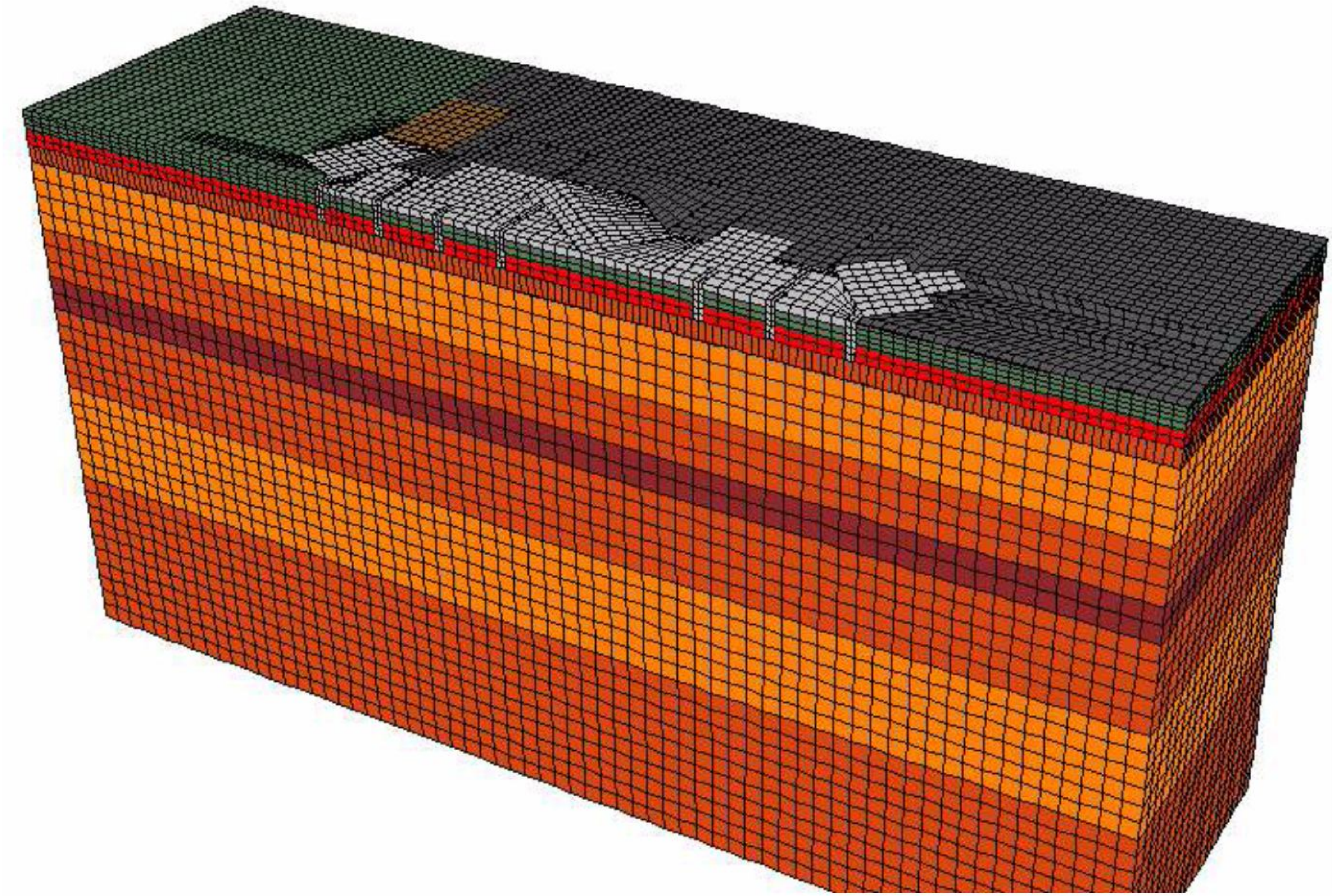
Numerical Analysis of Stability: One of Several Critical Areas Analyzed along Crawlerway A



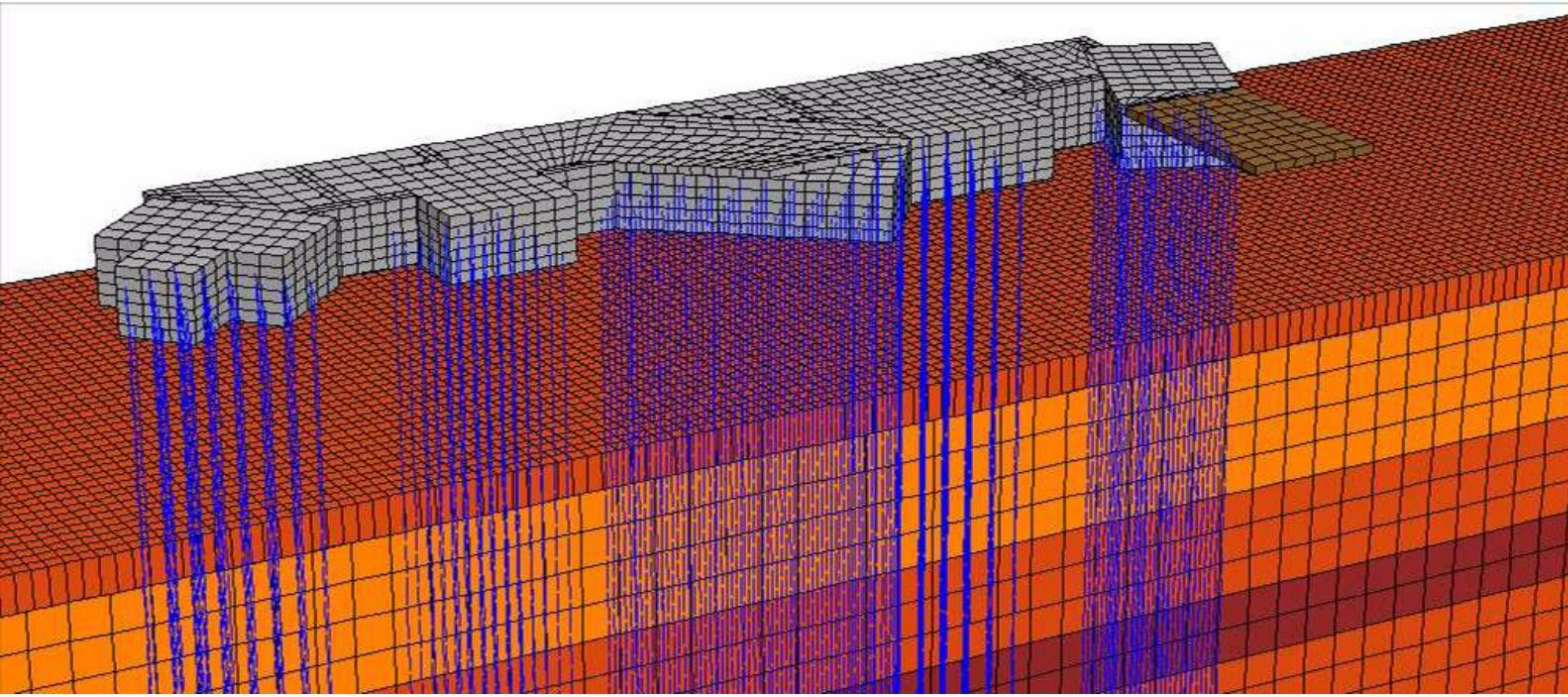
Vehicle Assembly Building (VAB) Foundations


HIGH BAY 4
EXTERNAL TANK PROCESSING AND STORAGE
HIGH BAY 2
EXTERNAL TANK PROCESSING AND STORAGE
3RD ORBITER SAFE HAVEN
TOWER C
TOWER F
HIGH BAY 4
TRANSFER AISLE
HIGH BAY 3
TOWER B
TOWER E
HIGH BAY 2
HIGH BAY 1
TOWER A
TOWER D
Operations Contr Center Rm 1A4
AREA K
AREA M
AREA L
AREA N
'OU ARE HERE
HIGH BAYS 1 & 3
STACK SOLID ROCKET BOOSTERS
MATE EXTERNAL TANK TO SOLID ROCKET BOOSTERS
MATE ORBITER TO EXTERNAL TANK SHUTTLE INTERFACE TEST
CLOSEOUT SHUTTLE VEHICLE FOR ROLLOUT TO PAD
TRANSFER AISLE
SUPPORT AREA FOR SHUTTLE PROCESSING
SOLID ROCKET BOOSTER STAGING
EXTERNAL TANK TRANSFER TO PROCESSING CELLS
ORBITER PRE-MATE
VEHICLE ASSEMBLY BUILDING (VAB)

Perspective View of Mesh, Showing Plane of Symmetry between High Bays 1 and 3



View of Plane of Symmetry at Centerline of High Bay 1 Showing Pile Caps and Piles

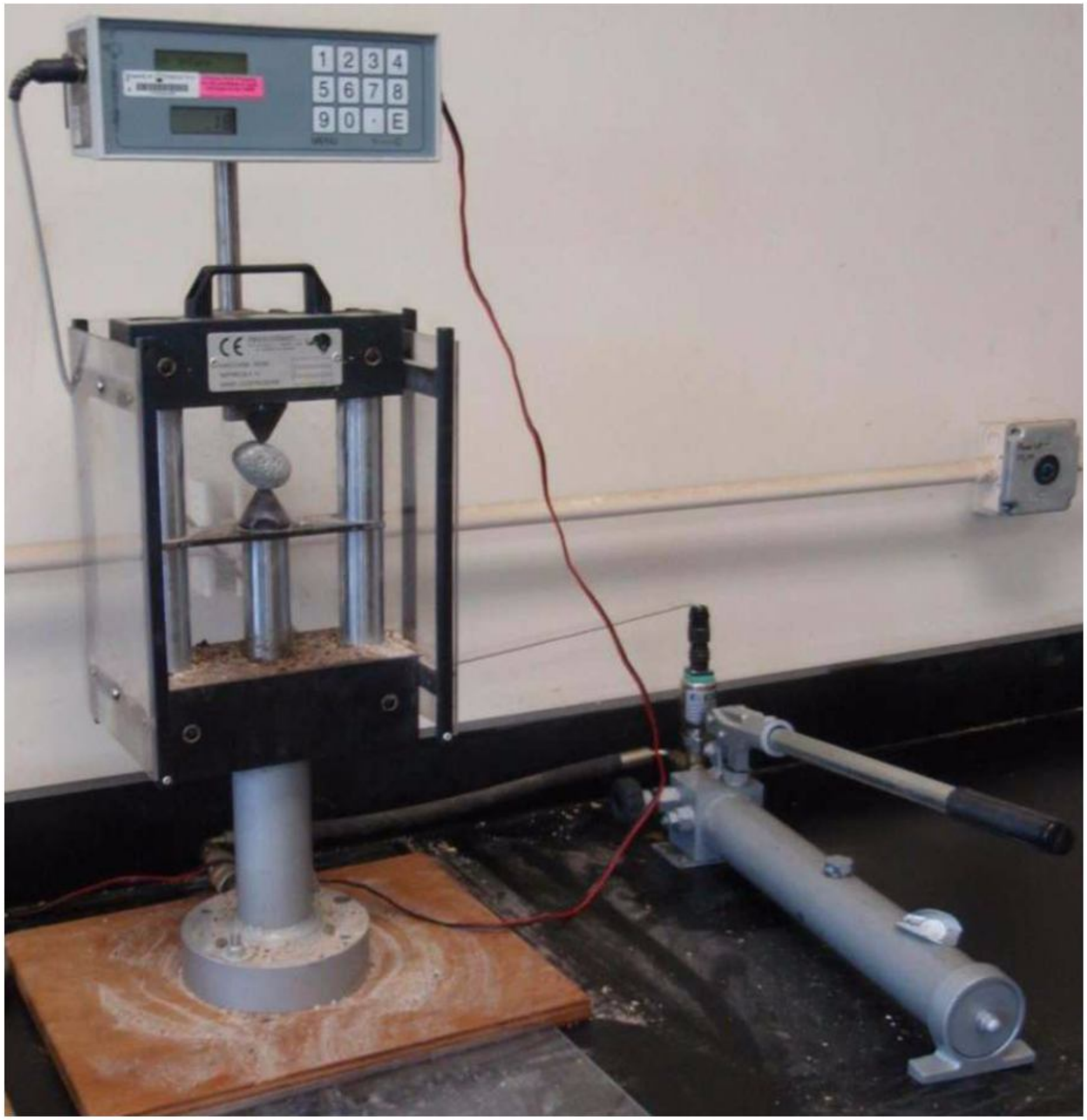


Findings and Recommendations from Analyses of VAB Foundations

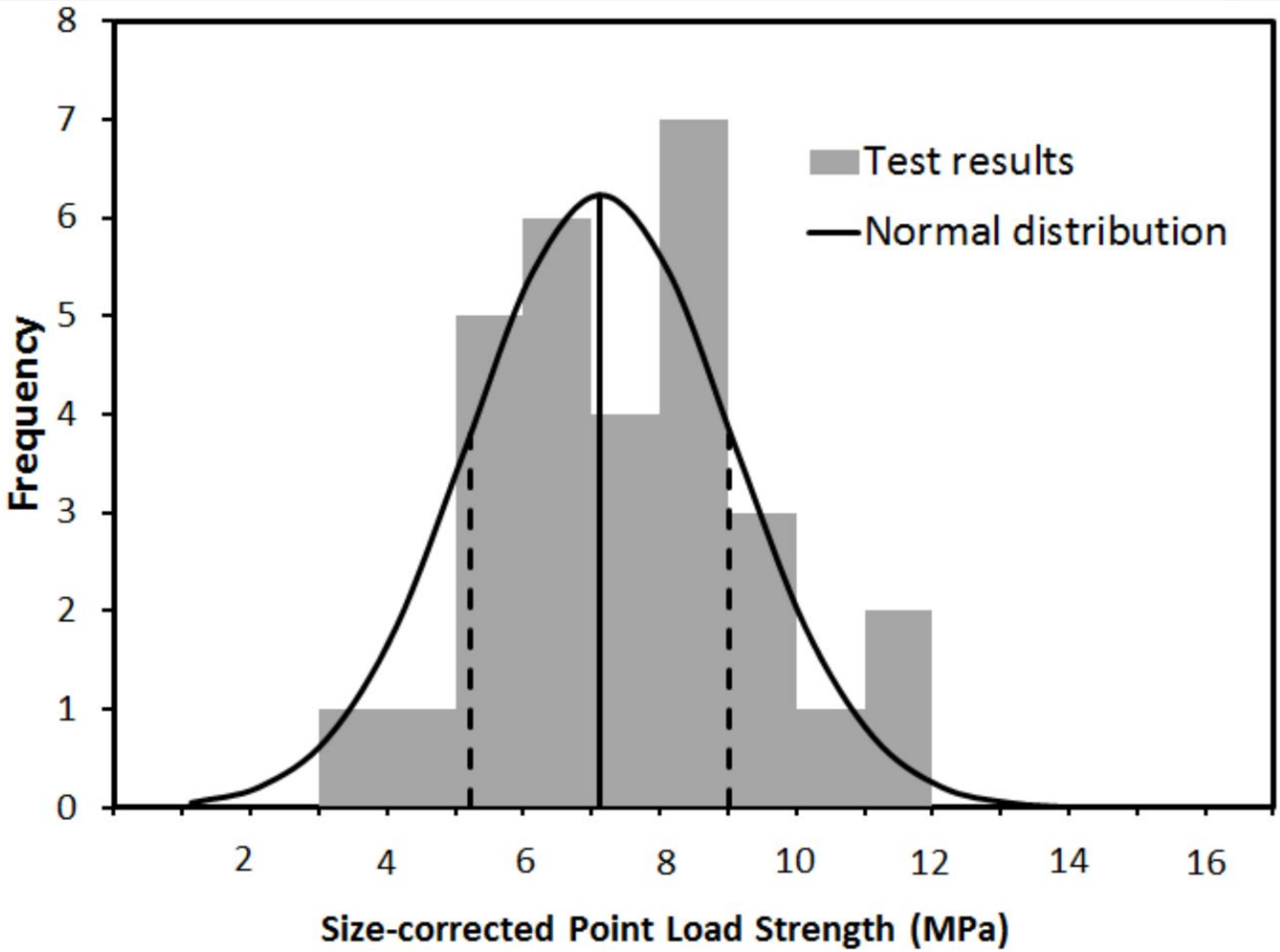
- Main VAB foundations will be OK under Ares V loads
- Pile-supported threshold will be overloaded
- Remediation options at threshold:
  - Reconfigure threshold to avoid direct loading of transporter on threshold pile cap
  - Install additional pile supports at threshold

Crawlerway Surface Treatment

Point Load Testing to Estimate Crushing Strength of Surface Gravel



Distribution of Point Load Strength Data



Used Principals of Statistical Inference to Establish Acceptance Criteria

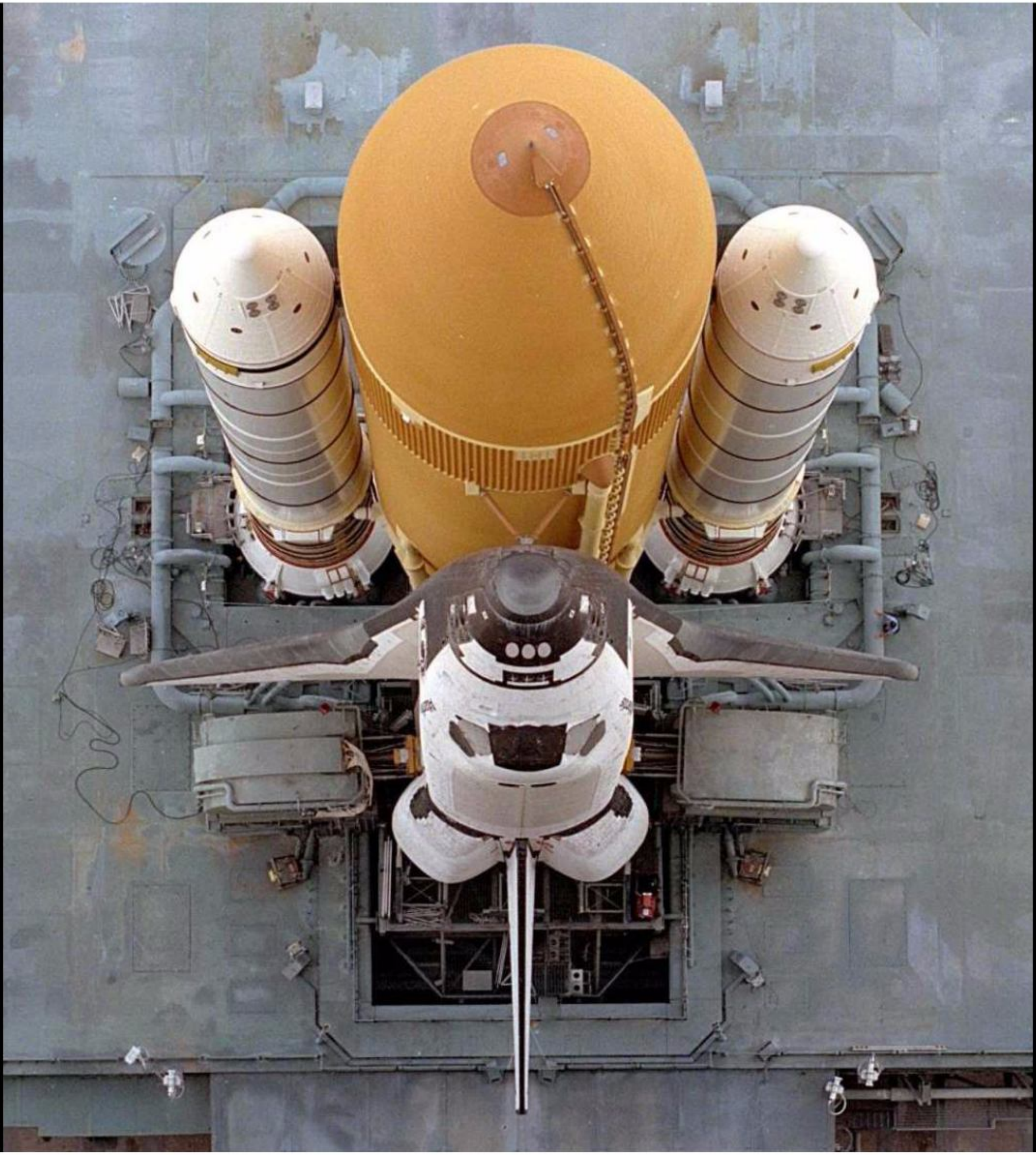
Check that the mean strength is high enough:

$$\bar{x}_n \geq \bar{x}_e - 1.65 s_e \sqrt{\frac{1}{n_n} + \frac{1}{n_e}} = 6.8\,\text{MPa}$$

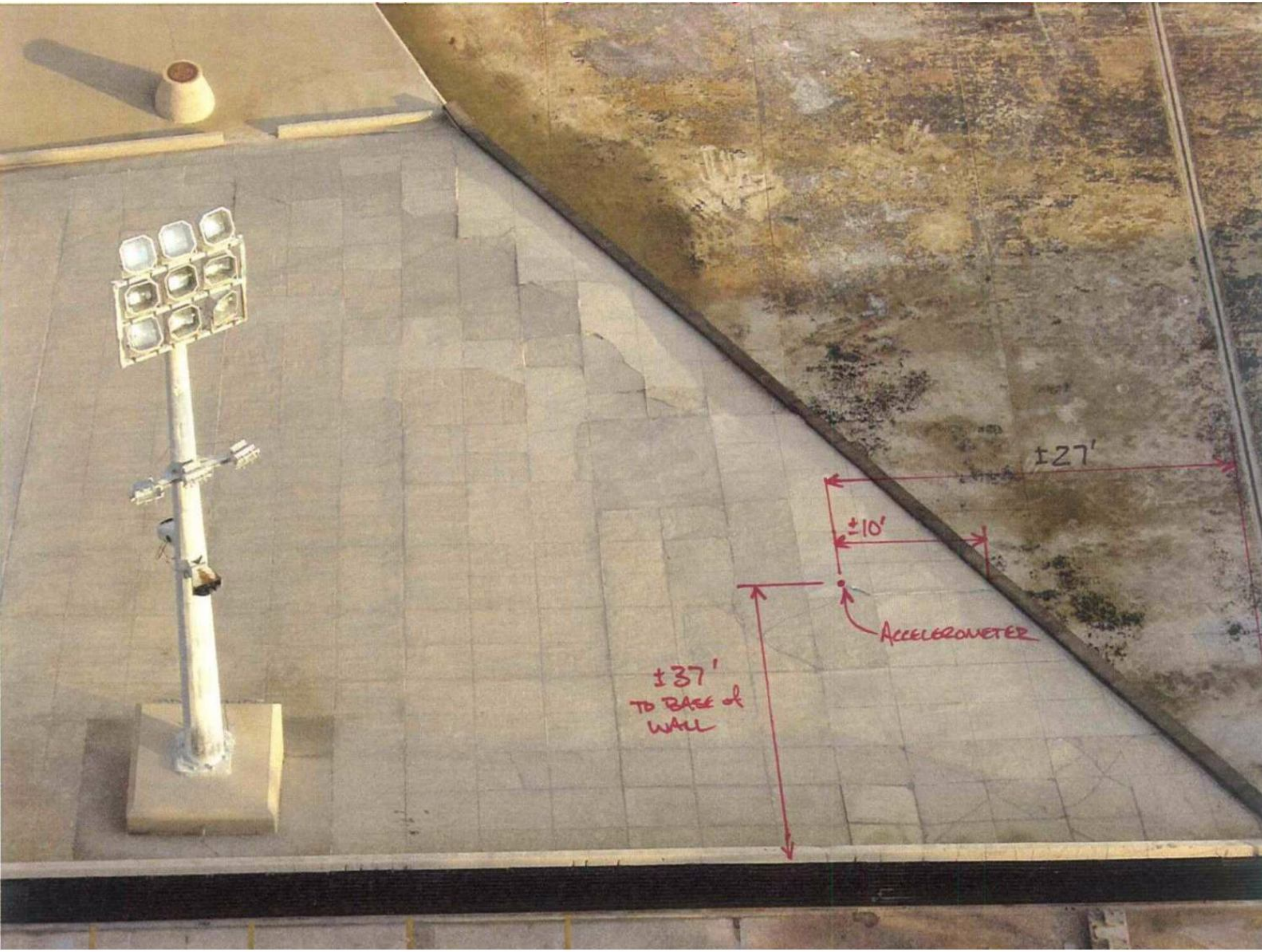
Check that the mean minus one std. dev. is high enough:

$$\bar{x}_n - s_n \geq \bar{x}_e - s_e - 1.65 s_e \sqrt{\frac{1}{n_n} + \frac{1}{n_e}} = 4.7\,\text{MPa}$$

Slope Protection at Launch Pads




Atlantis


±27'
±10'
ACCELEROMETER
±37' TO BASE of WALL

Analysis and Remediation

- Newmark displacement analysis to determine necessary stabilizing force
- Inclined helical anchors to provide the force

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- Crawlerway Surfacing
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Discovery