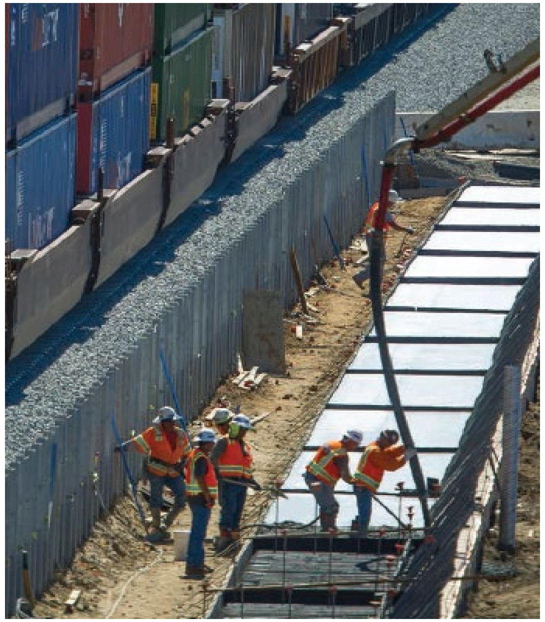
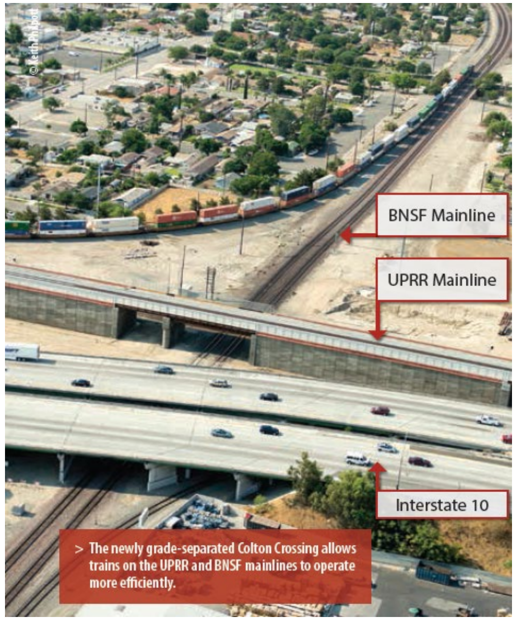
Evaluation and Performance of Lightweight Material Supporting Rail Systems

Steven F. Bartlett, Ph.D., P.E.
University of Utah





> The newly grade-separated Colton Crossing allows trains on the UPRR and BNSF mainlines to operate more efficiently.

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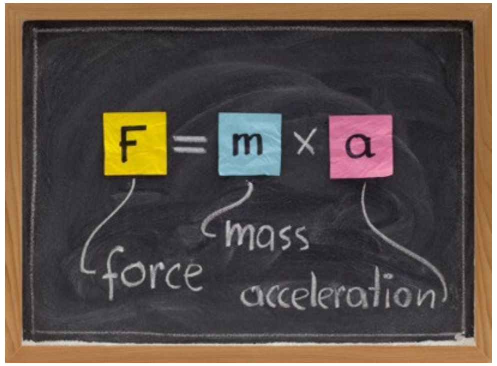
Introduction – Lightweight Materials Advantages

- Low inertial forces



  - small m (mass) produces small F_i
- High strength to weight ratio
- Energy Loss
  - Compressible → Increased Damping
- Manufactured materials with low variability in mechanical properties

Material Properties – EPS and Cellular Concrete

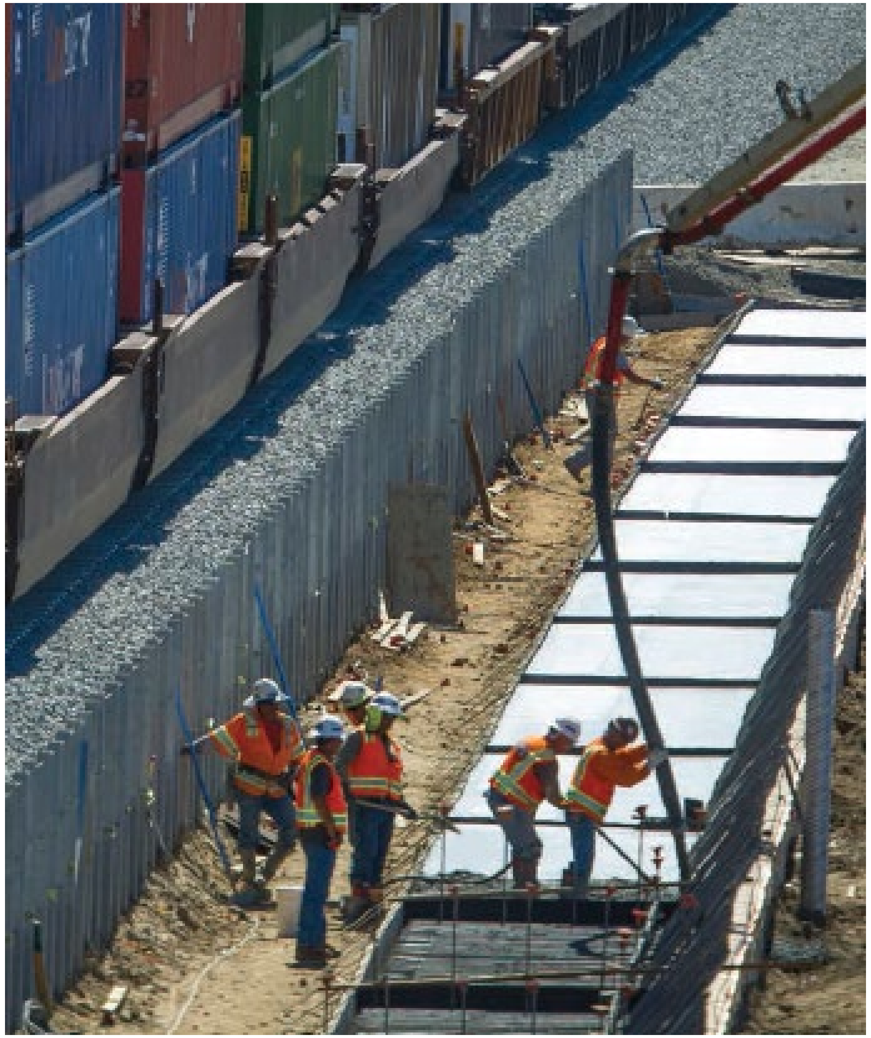
EPS

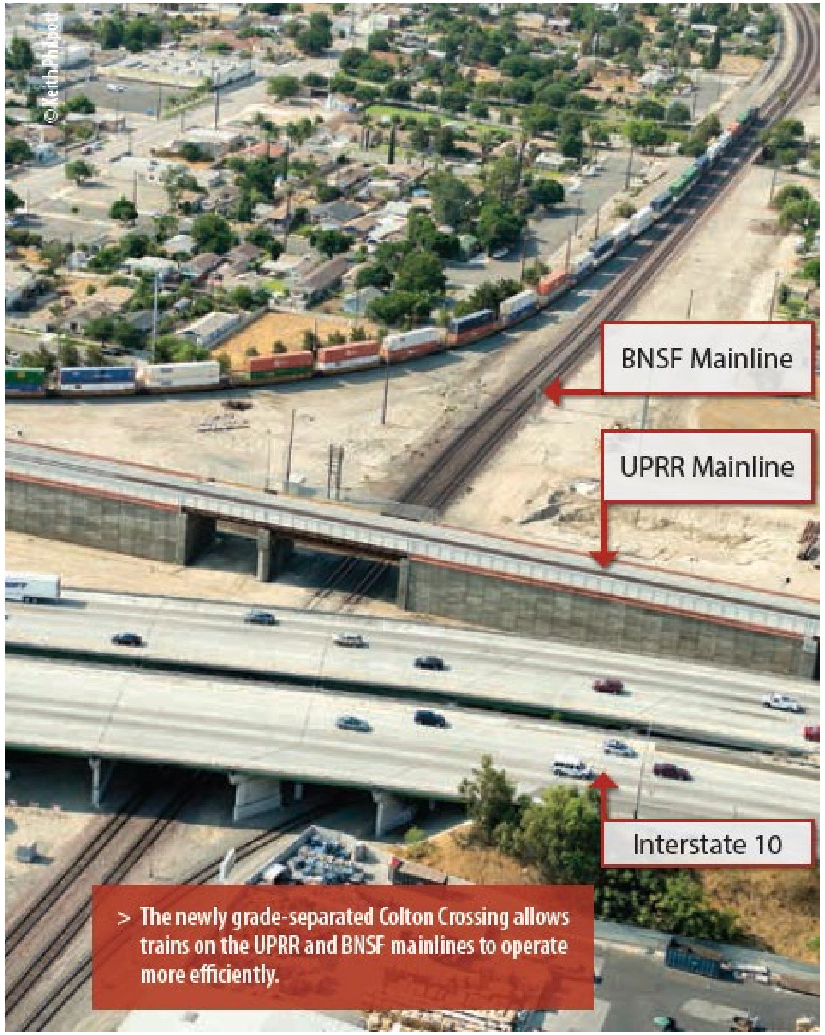
- Weight
  - 0.7 to 2.85 pcf
- Compressive Strength
  - 5 to 60 psi (10% strain)
  - 2.2 to 18.6 psi (1% strain)
    - Elastic Range
- Young's Modulus
  - 220 to 1,860 psi

LCC

- Weight
  - 20 to 45 pcf
    - Typical constructed values
- Compressive Strength
  - 50 to 400 psi
- Young's Modulus
  - 220 to 275 ksi

Grade Separation for Union Pacific Mainline

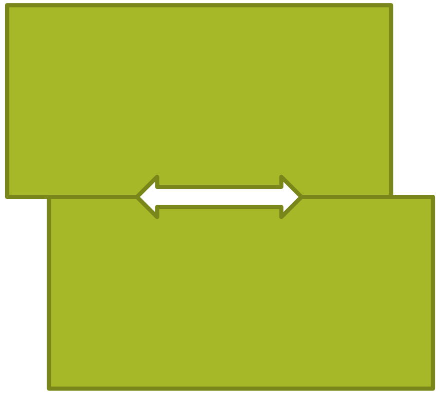




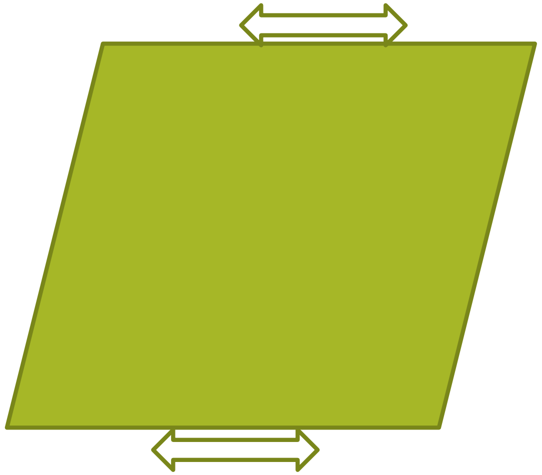
> The newly grade-separated Colton Crossing allows trains on the UPRR and BNSF mainlines to operate more efficiently.

©Keith Philpott

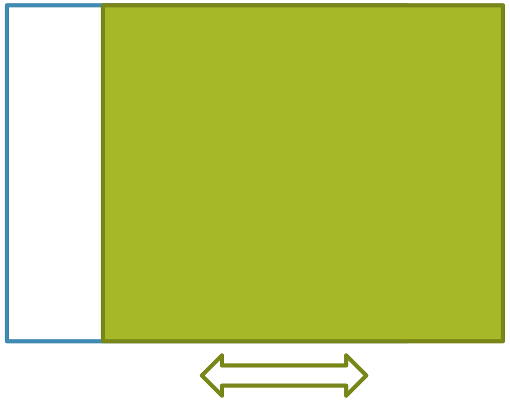
Modes of Seismic Excitation / Failure



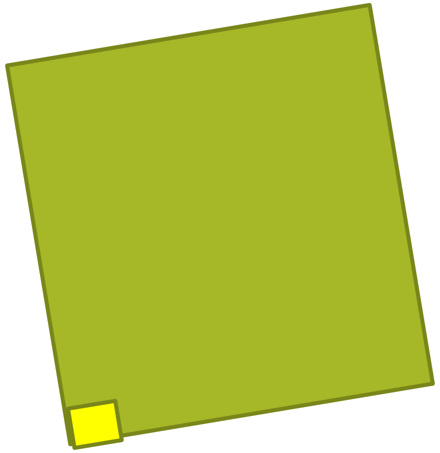
Interlayer Shear / Sliding



Horizontal Sway and Overstressing

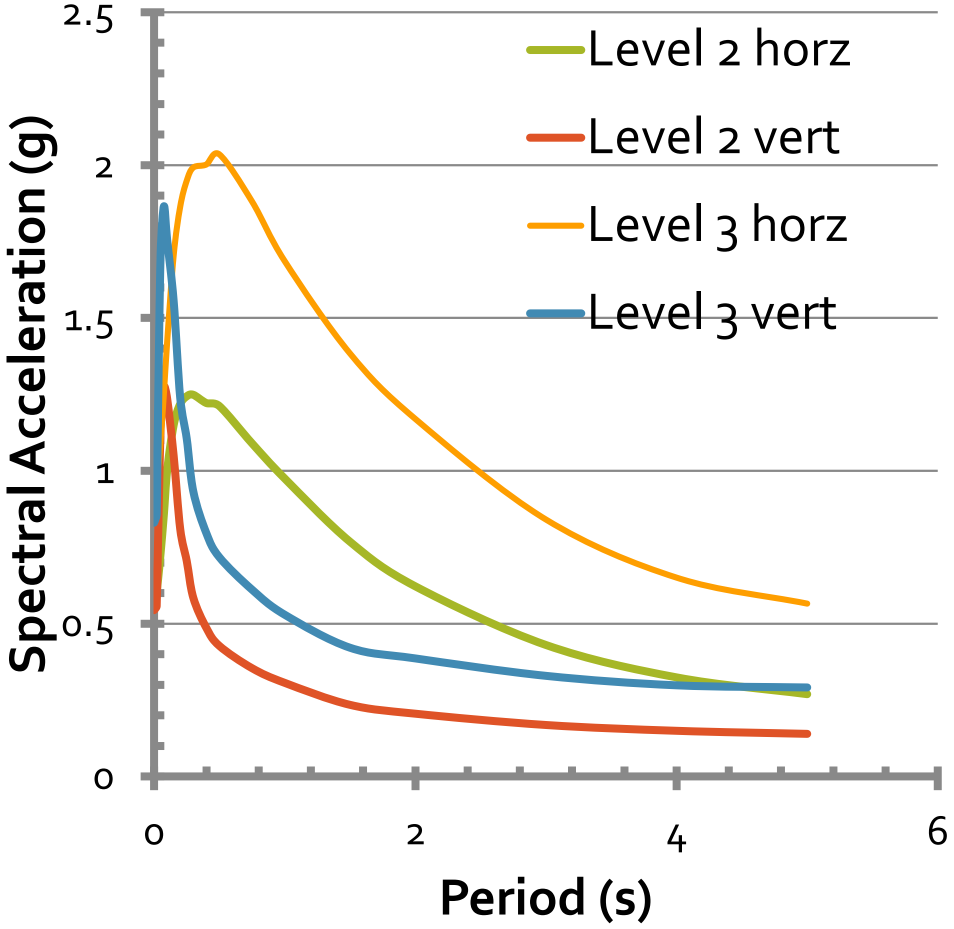


Basal Sliding



Rocking and Uplift

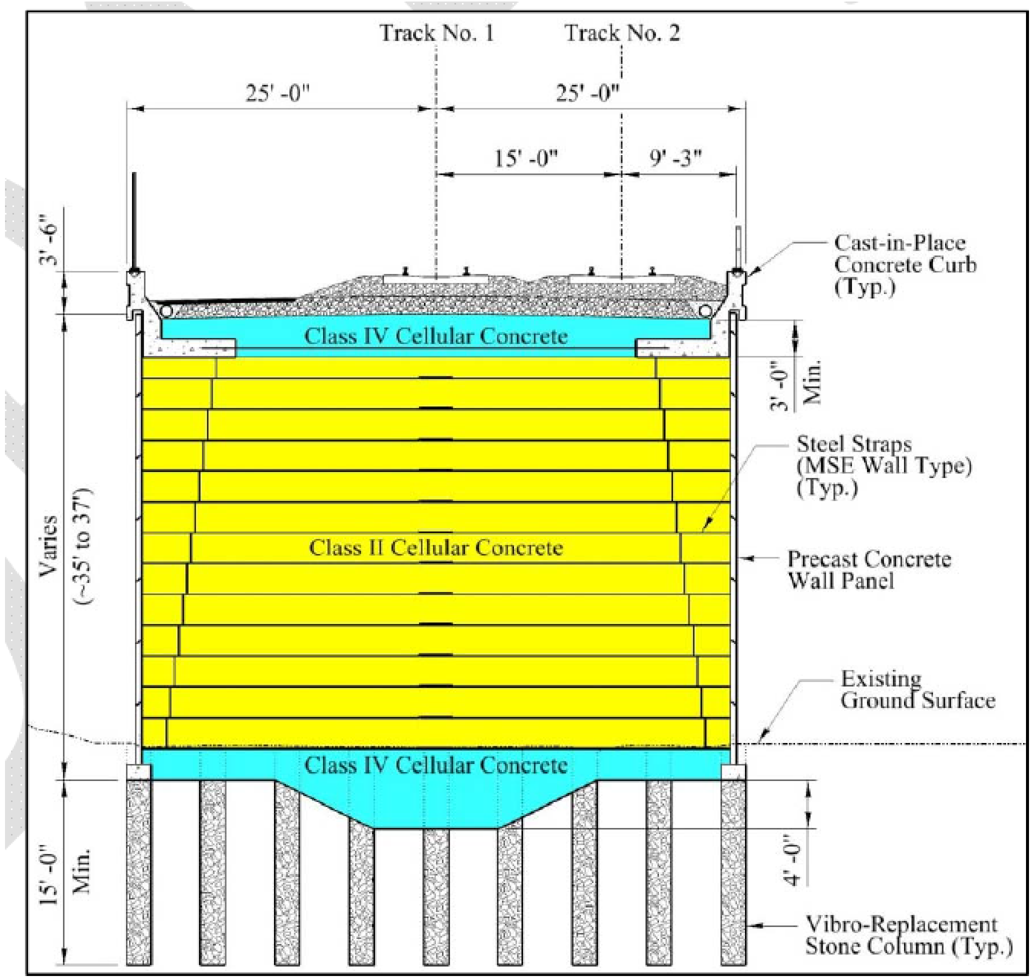
Design Considerations – Spectral Accelerations



1. Level 1 – The embankment structure should remain intact with no permanent deformation (i.e. the seismic loads must remain within the elastic range of the stress-strain curve of the embankment).
2. Level 2 – The embankment structure should be repairable, with only minor permanent deformation.
3. Level 3 – The embankment structure must not collapse after experiencing permanent deformations.

AREMA (2010)

Typical Cross Section



(1) 8.5-foot wide concrete ties with ballasted track section [12 inches ballast/18 inches sub ballast],

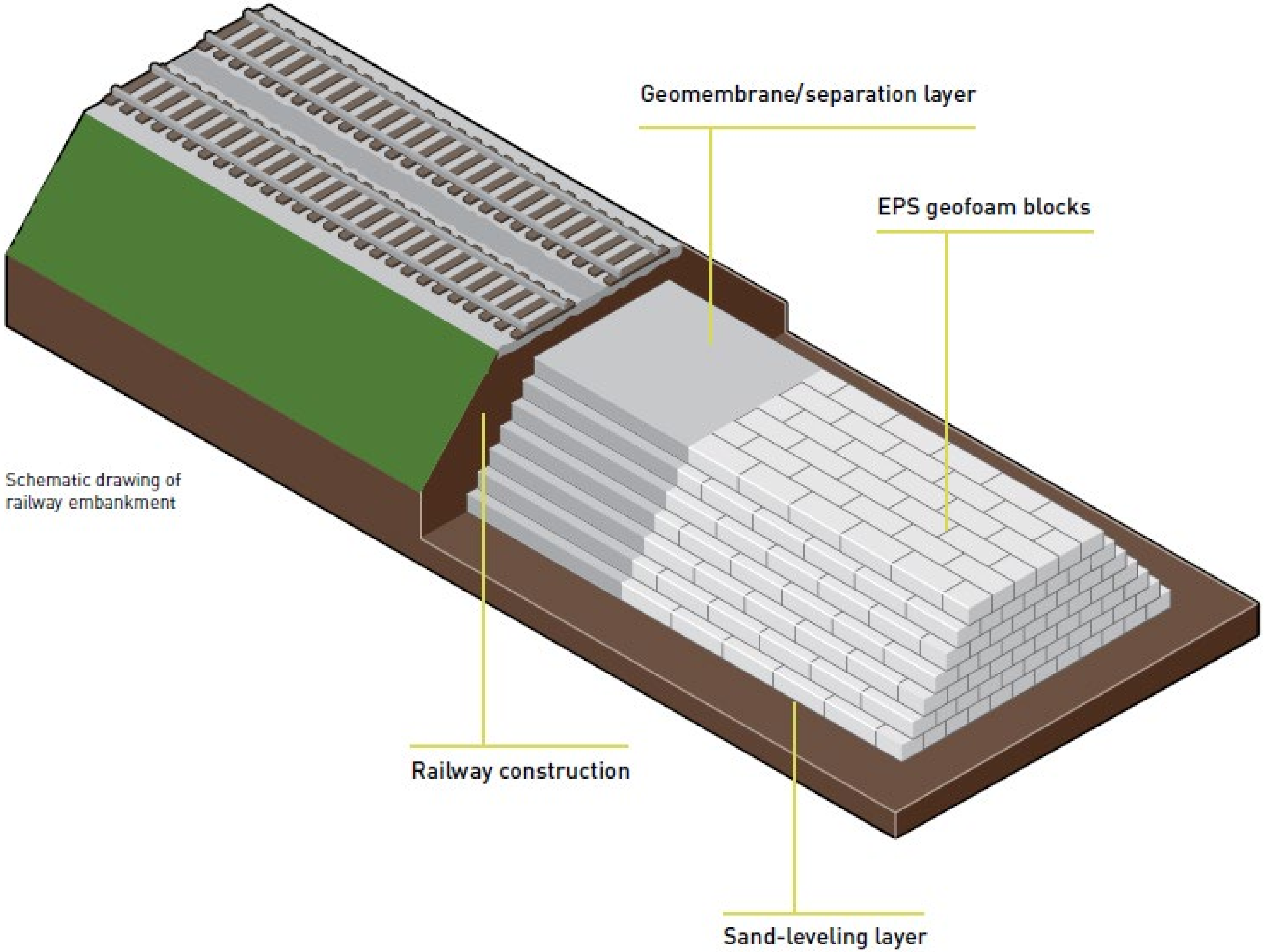
(2) 3-foot thick upper layer of Class IV cellular concrete,

(3) variable thickness of Class II cellular concrete,

(4) 2.5-foot thick Class IV layer of cellular concrete with a 4-foot deep shear key embedded in the foundation soils (at higher embankment sections),

(5) vibro-replacement stone columns approximately 15 ft deep in the foundation soils.

Geofoam Rail Embankments – Conceptual Drawing



Schematic drawing of
railway embankment

Design Considerations – Design Time Histories

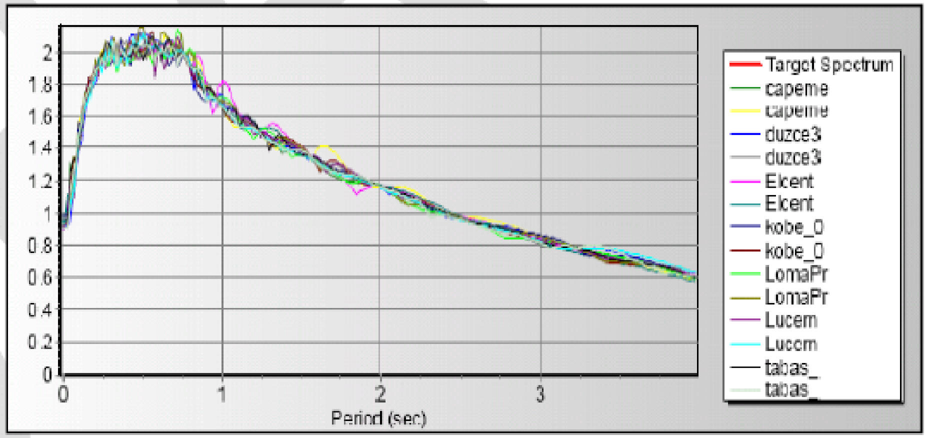


Figure 4. Spectrally matched time histories for Level 3 horizontal response spectra.

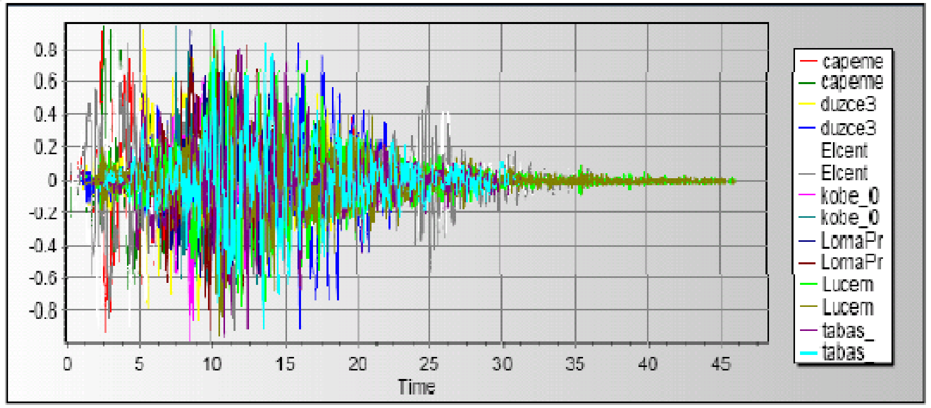
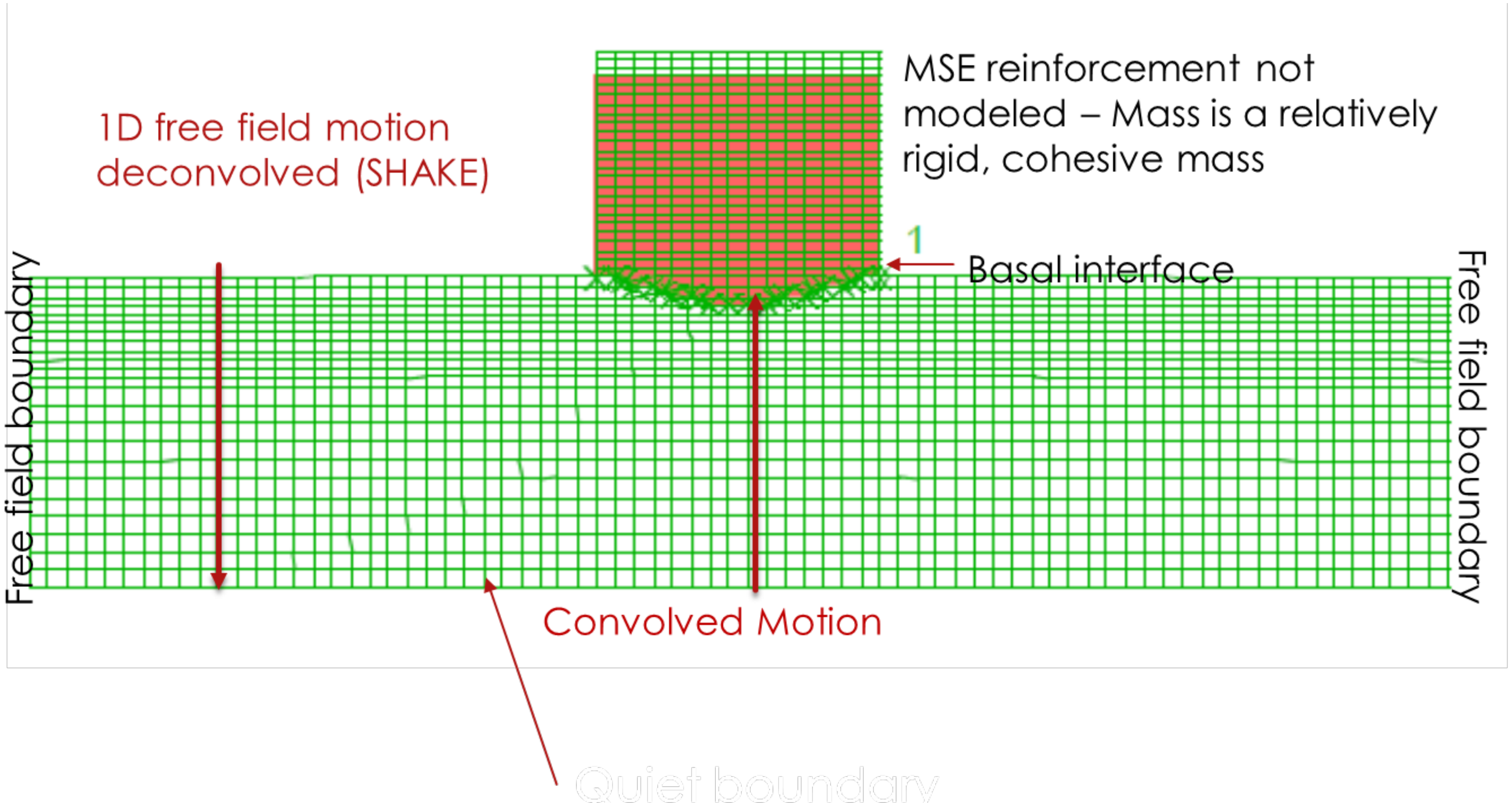


Figure 5. Comparison of spectrally-matched time histories with Level 3 target spectrum.

Design Considerations – Numerical Model



1D free field motion deconvolved (SHAKE)

MSE reinforcement not modeled – Mass is a relatively rigid, cohesive mass

Basal interface

Free field boundary

Free field boundary

Convolved Motion

Quiet boundary

Quiet boundary

Design Considerations – Colton Crossing Summary

- Evaluations suggest that the LDCC embankment remained in the elastic range for AREMA Level 1 and 2 earthquakes and will not exceed the peak shear strength under any of the AREMA Level 1, 2 and 3 earthquakes.

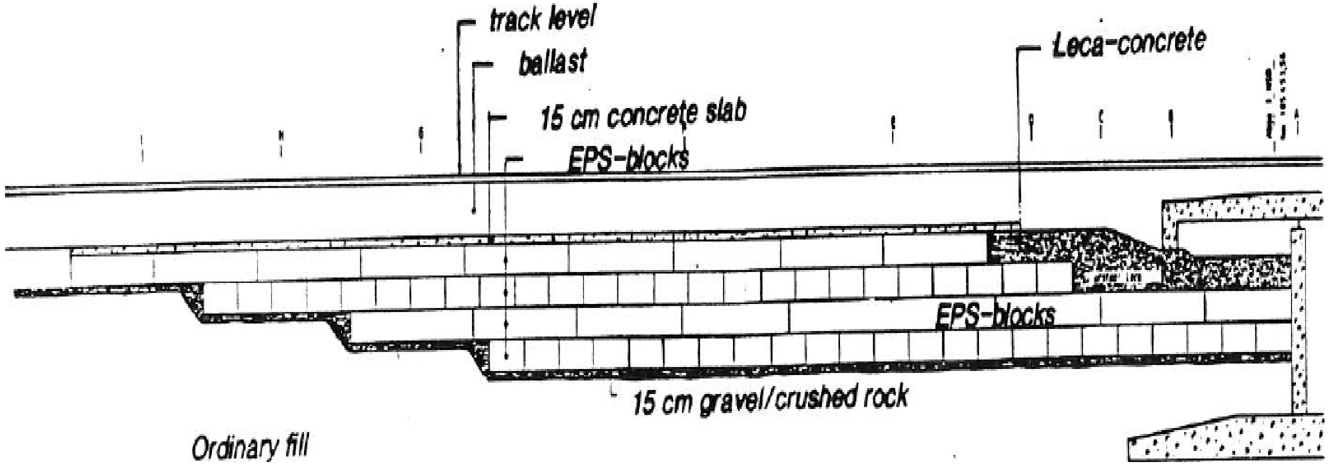
- Reinforcement of the LDCC mass is recommended to prevent the potential for minor cracking resulting from excitation.

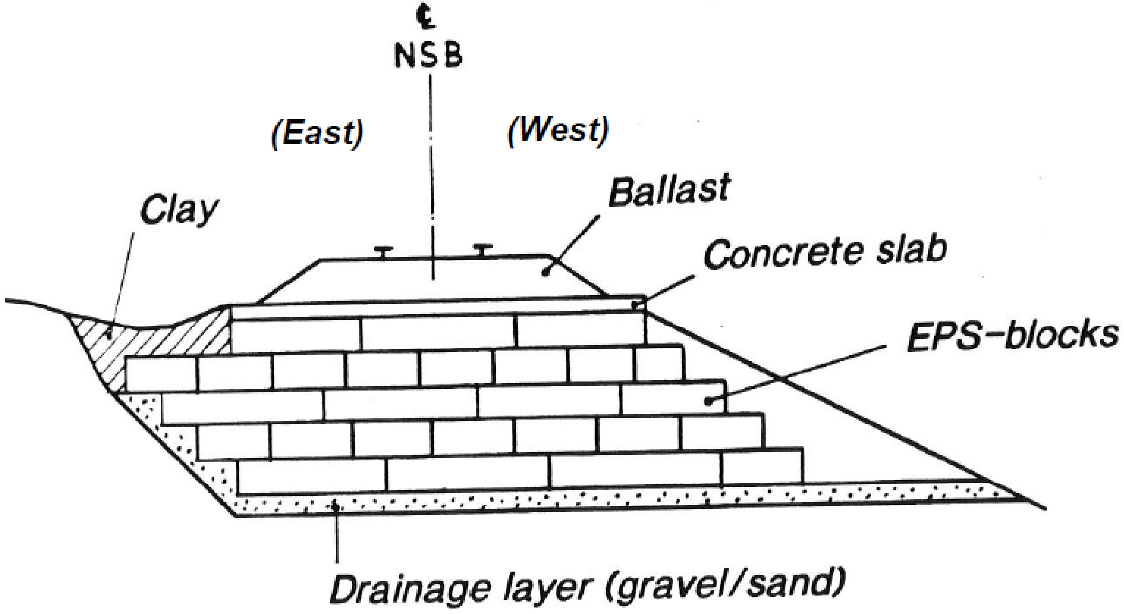
- Interlayer sliding and overstressing of LCC due to sway did not occur.
- Estimated basal sliding of the tallest section of the embankment is expected to range from 1 to 4 inches at the Level 2 earthquake, and from 4 to 7 inches at the Level 3 earthquake.

- The presence of basal shear key was integral to limit basal sliding for the AREMA Level 3 event. Higher strength LCC is also recommended near the top and base of the embankment.

- Rocking mode is not significant and any minor overstressing from such should be addressed by higher strength LCC in basal layer.

Rail Systems on EPS Geofoam – NSB Rail Line – Skien, Norway





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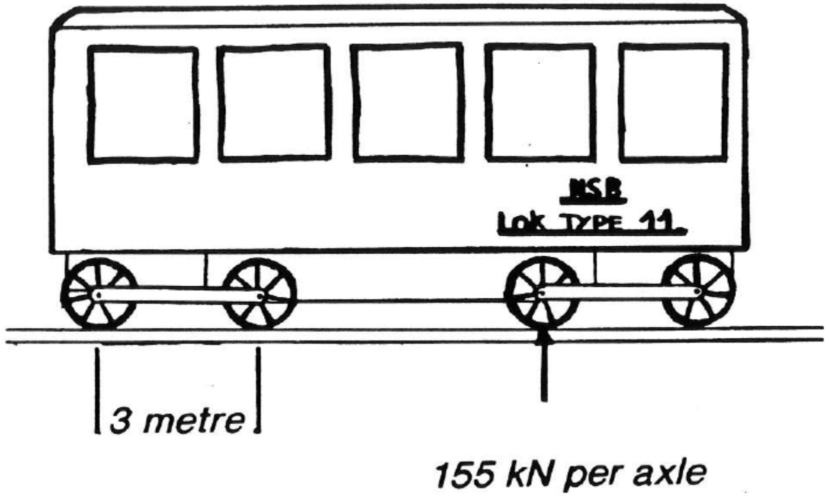
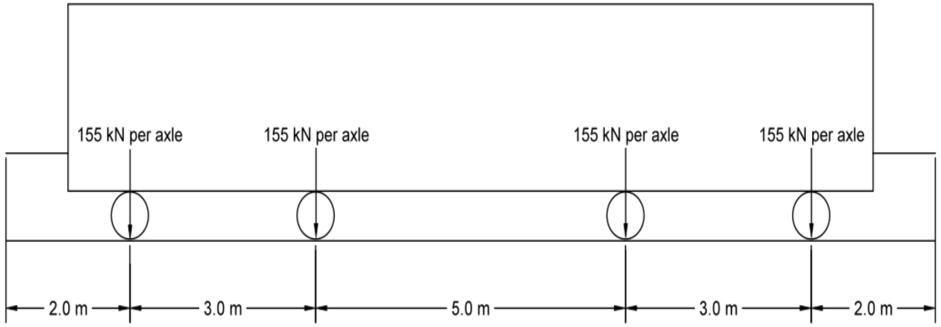
Modeling of Rail Systems on EPS Geofoam – NSB System Norway



34.8 kips / axle



Light Rail Systems on EPS Geofoam

Light rail EPS Embankment Construction in Netherlands – Milan Duskov

Overview

- Case Histories of Rail on EPS
- Numerical Modeling of Case Histories
- Deflection Monitoring
  - Commuter Rail
  - Light Rail
- Subsequent Ballast Testing

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Light Rail Embankments – Roper Yard – Salt Lake City

UTA –Light Rail – Salt Lake City, Utah

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Light Rail Embankments – Roper Yard – Salt Lake City

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UTA –Light Rail – Salt Lake City, Utah

Light Rail Embankments – Roper Yard – Salt Lake City

UTA –Light Rail – Salt Lake City, Utah

Commuter Rail Embankments – Draper, Utah

Front Runner – UTA – Corner Canyon – Draper Utah

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Modeling of Commuter Rail Embankments – Draper, Utah

Front Runner – UTA – Corner Canyon – Draper Utah

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Modeling of Rail Systems on EPS Geofoam – NSB System Norway

Vertical Deflections (mm) measured from train loads (Frydenlund et al., 1987).

Stationing	East Rail		West Rail	
	Bolt in concrete slab	Nail in Sleeper	Bolt in concrete slab	Nail in sleeper
185.411,0		-3		-3
185.416,0		-1		-4
185.421,5		-4		-5
185.424,5	0	-4	-3	-6
185.427,5	0	-4	-2	-5
185.437,0	-1	-5	-3	-7
185.443,0	-1	-2	-3	-5
185.446,5	-1	-3	-2?	-1
185.448,5		-2		-3
185.450,5 Bridge End	0	-1	0	-3
185.453,5 Bridge Axis	0	-1	0	-2

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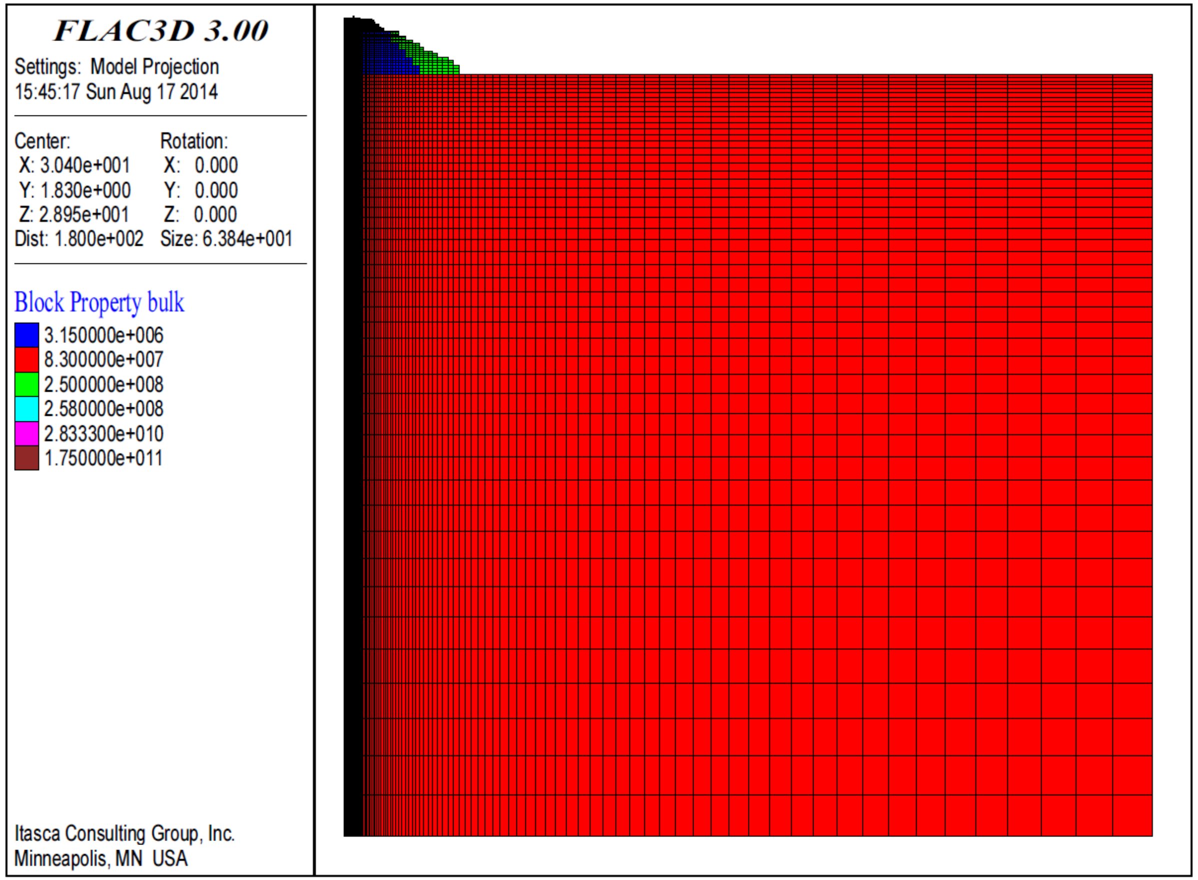
Modeling of Rail Systems on EPS Geofoam – NSB Norway



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Y: 1.830e+000	Y: 0.000
Z: 2.895e+001	Z: 0.000
Dist: 1.800e+002	Size: 6.384e+001

Block Property bulk

- 🟦 3.150000e+006
- 🟥 8.300000e+007
- 🟩 2.500000e+008
- 🟦 2.580000e+008
- 🟪 2.833300e+010
- 🟫 1.750000e+011

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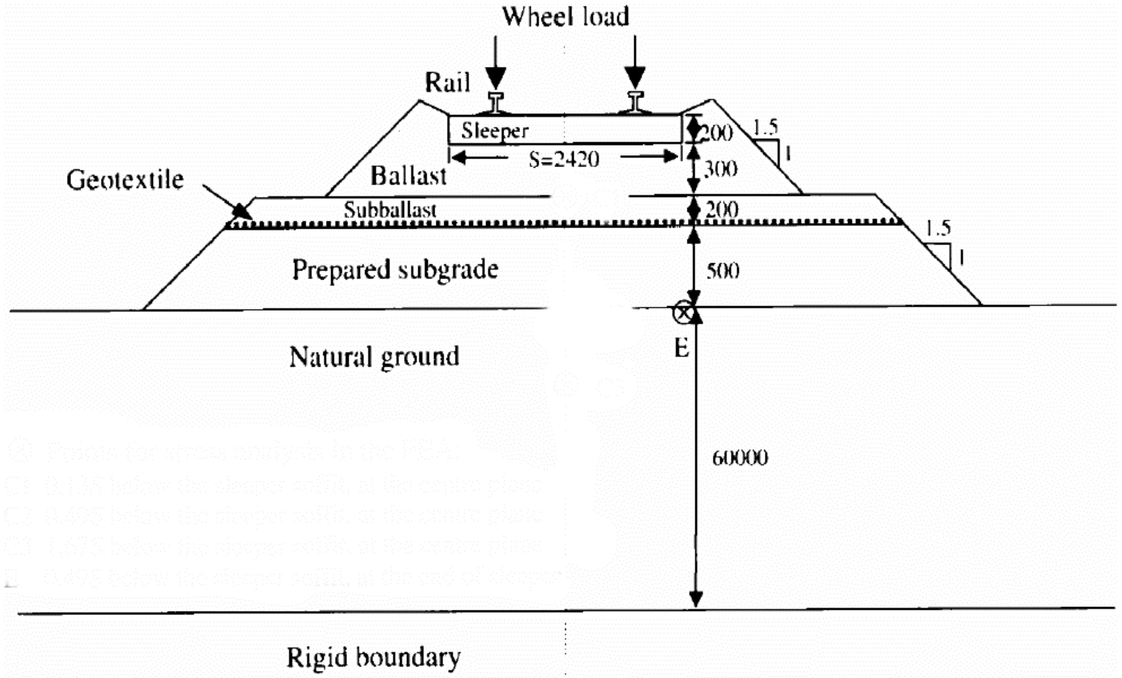
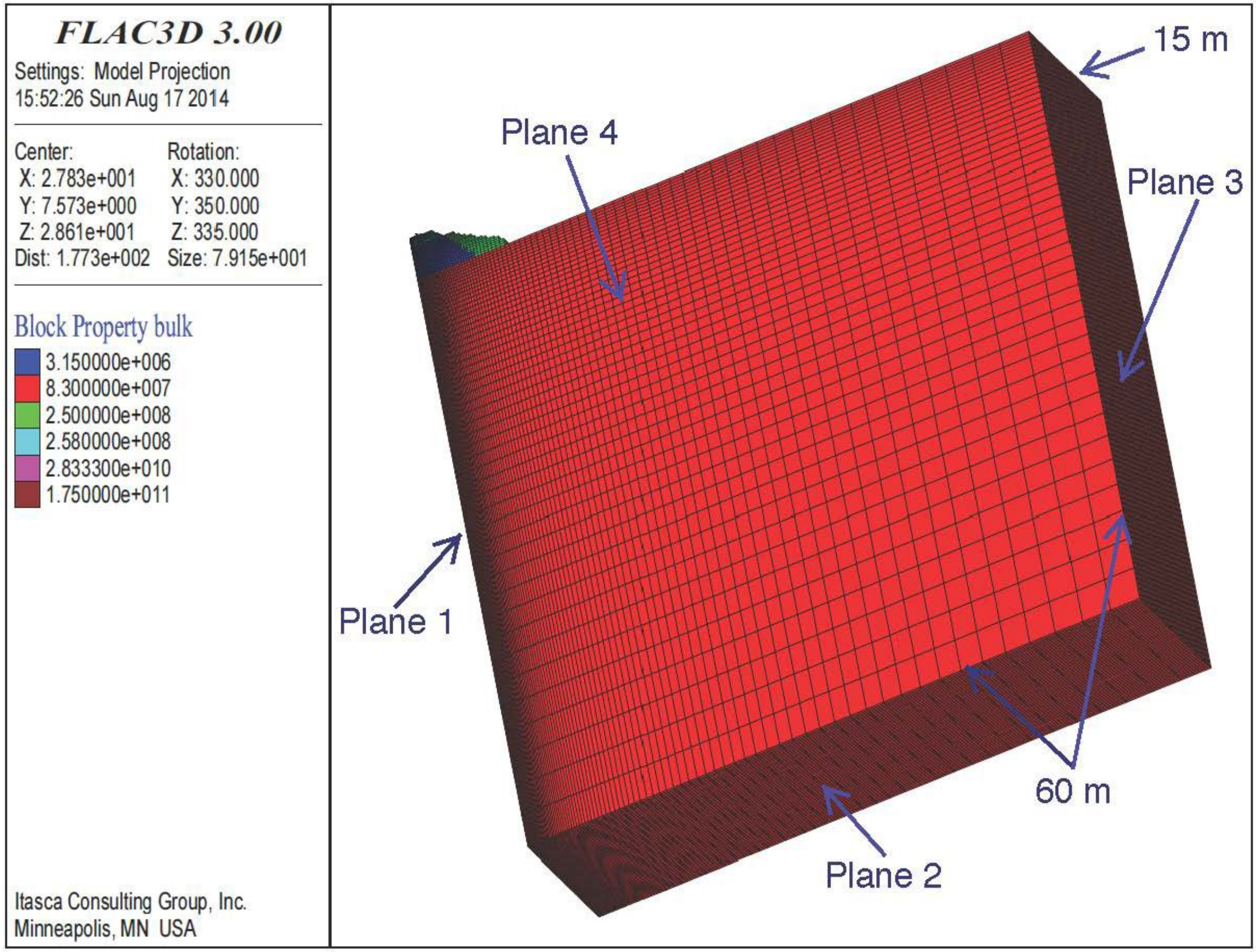


Modeling of Rail Systems on EPS Geofoam – NSB Norway



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Y: 350.000
Z: 335.000
Size: 7.915e+001

Block Property bulk

- 🟦 3.150000e+006
- 🟥 8.300000e+007
- 🟩 2.500000e+008
- 🟦 2.580000e+008
- 🟪 2.833300e+010
- 🟫 1.750000e+011

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3D model with symmetry

Modeling of Rail Systems on EPS Geofoam – NSB Norway

Description	E MPa	ν	Note
Rail	210000	0.3	78 mm wide, 153 mm deep
Sleeper (3D/2D)	31000/13000	0.3	242 mm wide, 200 mm deep
Ballast	130	0.3	
Concrete Slab	40000	0.2	
EPS29	7.5	0.103	
Drainage Layer	300	0.3	
Fill	300	0.3	
Sand (Natural Ground)	100	0.3	

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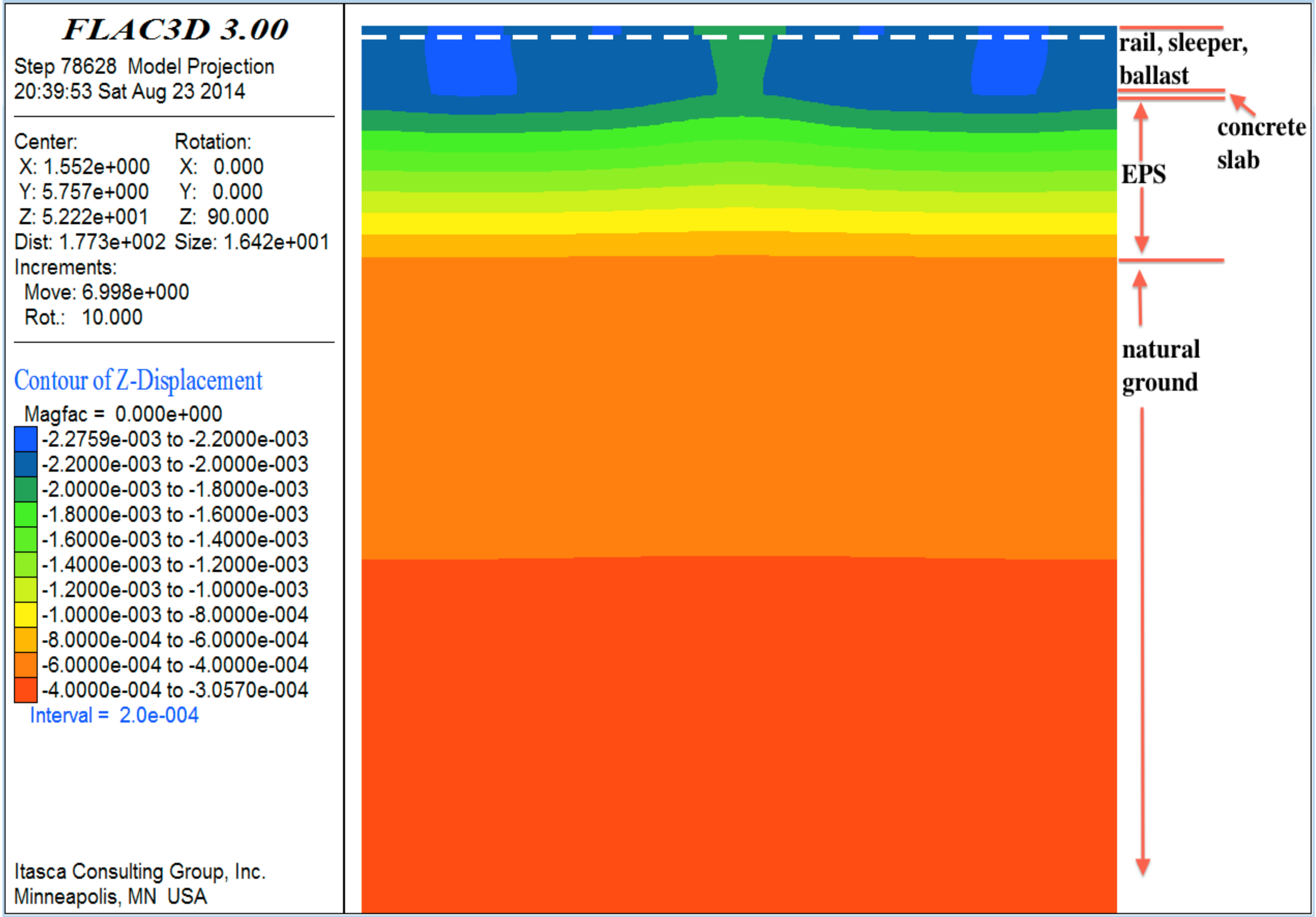
Deflection of Rail Systems on EPS Geofoam – NSB Norway



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 Y: 5.757e+000          Y:   0.000
 Z: 5.222e+001          Z:  90.000
Dist: 1.773e+002  Size: 1.642e+001
Increments:
  Move: 6.998e+000
  Rot.:   10.000

Contour of Z-Displacement
  Magfac =  0.000e+000
🟦 -2.2759e-003 to -2.2000e-003
🟦 -2.2000e-003 to -2.0000e-003
🟩 -2.0000e-003 to -1.8000e-003
🟩 -1.8000e-003 to -1.6000e-003
🟩 -1.6000e-003 to -1.4000e-003
🟩 -1.4000e-003 to -1.2000e-003
🟨 -1.2000e-003 to -1.0000e-003
🟨 -1.0000e-003 to -8.0000e-004
🟧 -8.0000e-004 to -6.0000e-004
🟧 -6.0000e-004 to -4.0000e-004
🟥 -4.0000e-004 to -3.0570e-004
   Interval =  2.0e-004

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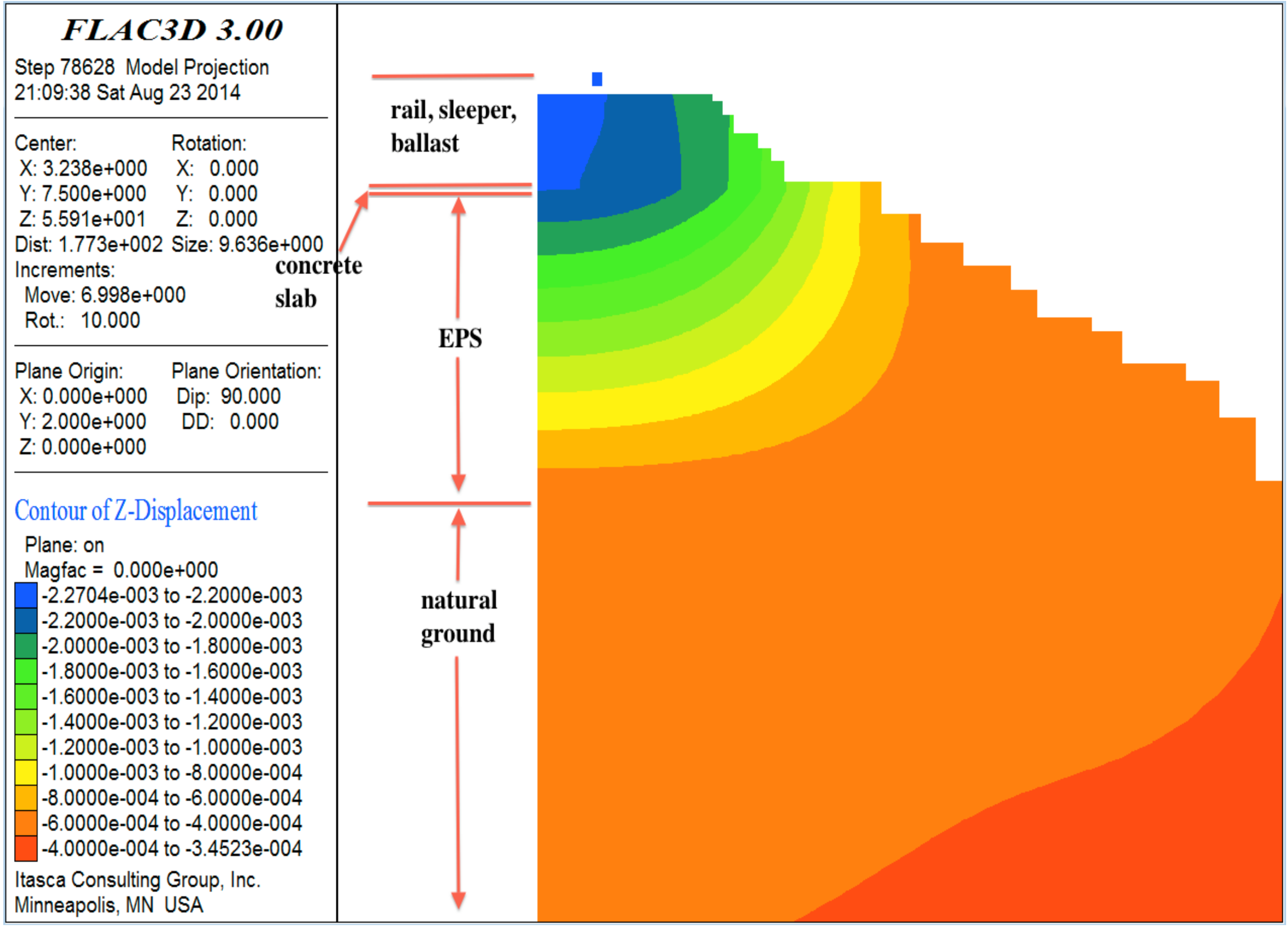
Modeling of Rail Systems on EPS Geofoam – NSB Norway



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Dist: 1.773e+002

Rotation:
X: 0.000
Y: 0.000
Z: 0.000
Size: 9.636e+000

Increments:
Move: 6.998e+000
Rot.: 10.000

Plane Origin:
X: 0.000e+000
Y: 2.000e+000
Z: 0.000e+000

Plane Orientation:
Dip: 90.000
DD: 0.000

Contour of Z-Displacement
Plane: on
Magfac = 0.000e+000
🟦 -2.2704e-003 to -2.2000e-003
🟦 -2.2000e-003 to -2.0000e-003
🟩 -2.0000e-003 to -1.8000e-003
🟩 -1.8000e-003 to -1.6000e-003
🟩 -1.6000e-003 to -1.4000e-003
🟩 -1.4000e-003 to -1.2000e-003
🟩 -1.2000e-003 to -1.0000e-003
🟨 -1.0000e-003 to -8.0000e-004
🟧 -8.0000e-004 to -6.0000e-004
🟧 -6.0000e-004 to -4.0000e-004
🟥 -4.0000e-004 to -3.4523e-004

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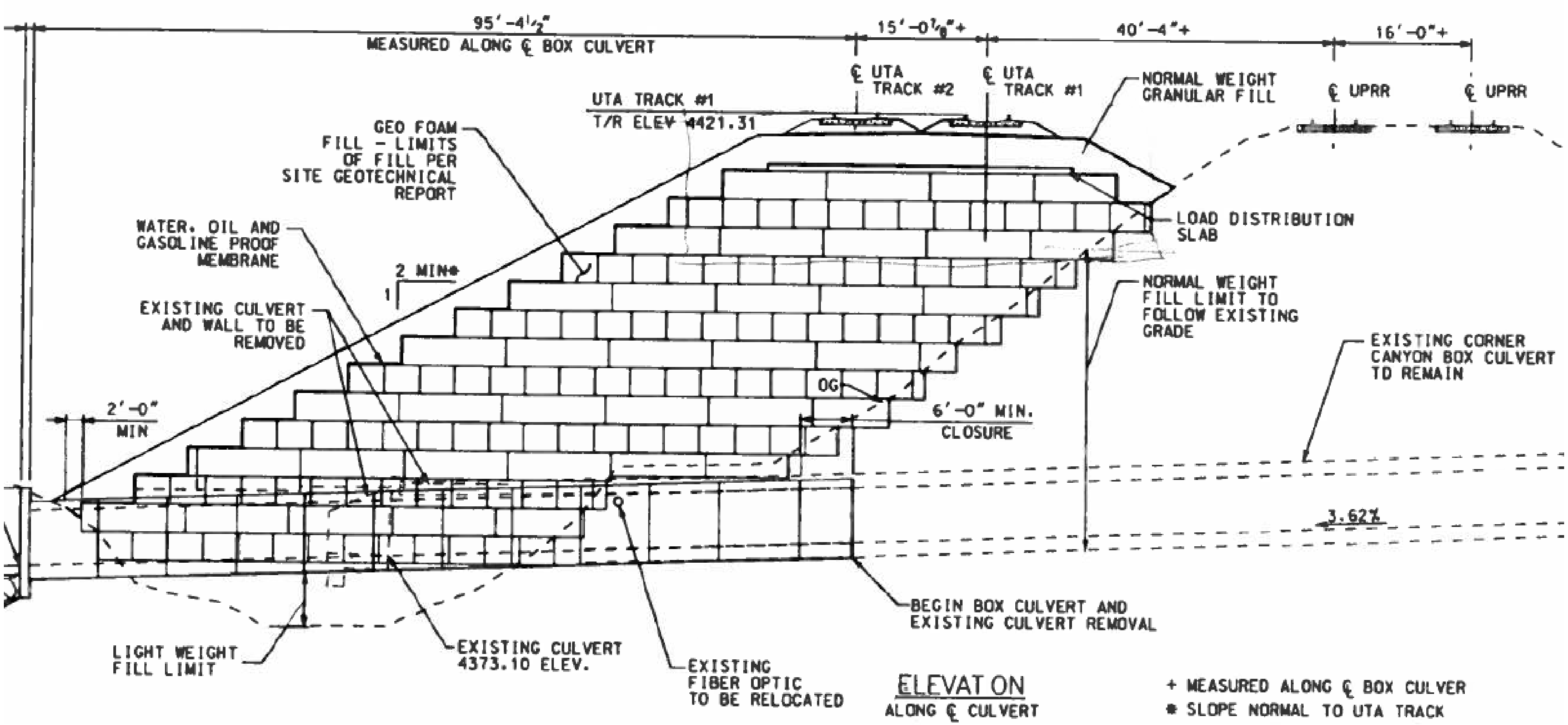
2.3 mm of deflection predicted by numerical model

Range of measurements was 2 to 3 mm under static loading by NSB personnel

Modeling of Rail Systems on EPS Geofoam – Commuter Rail Corner Canyon



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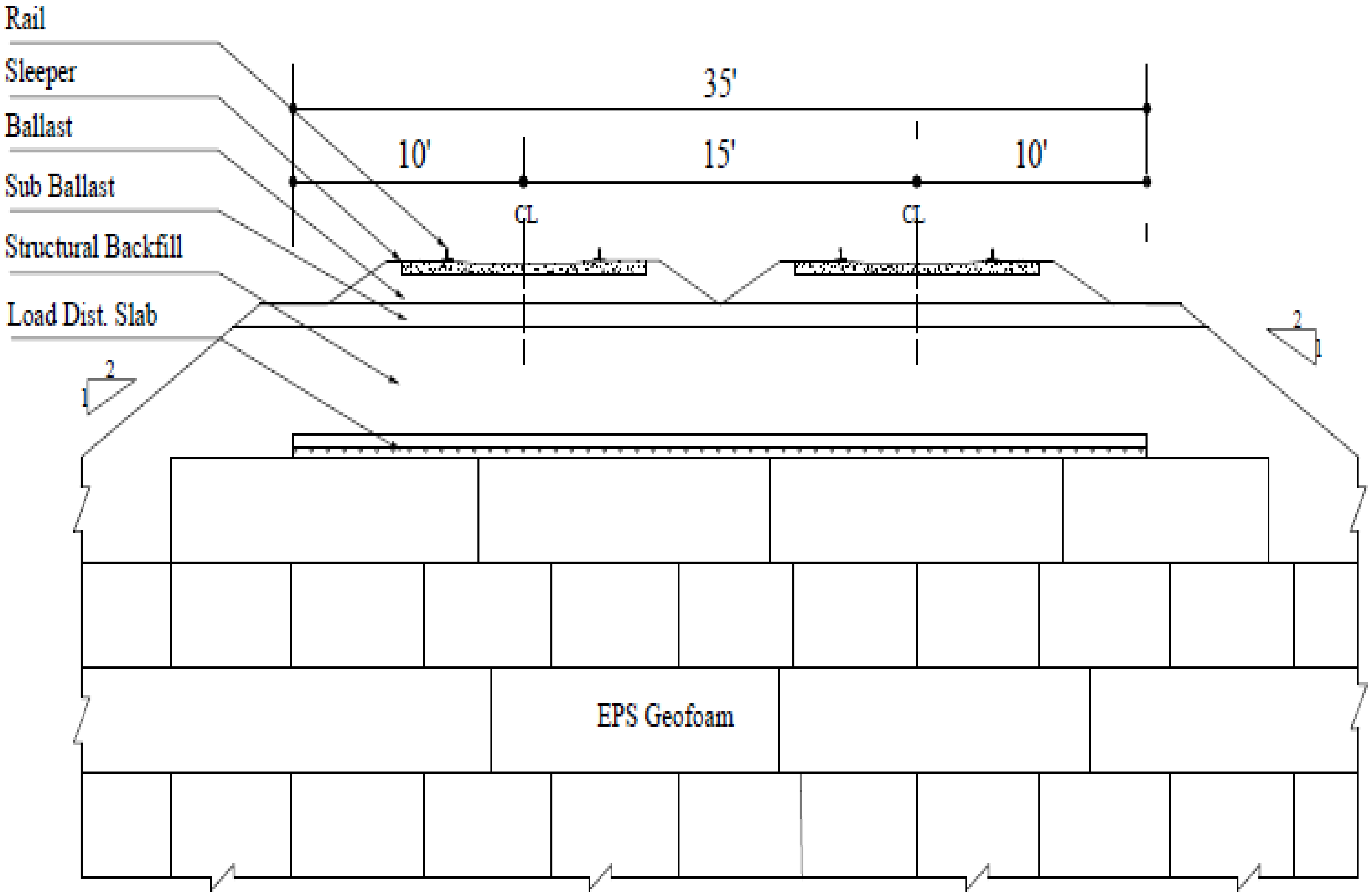
Modeling - Typical Section for Commuter Rail



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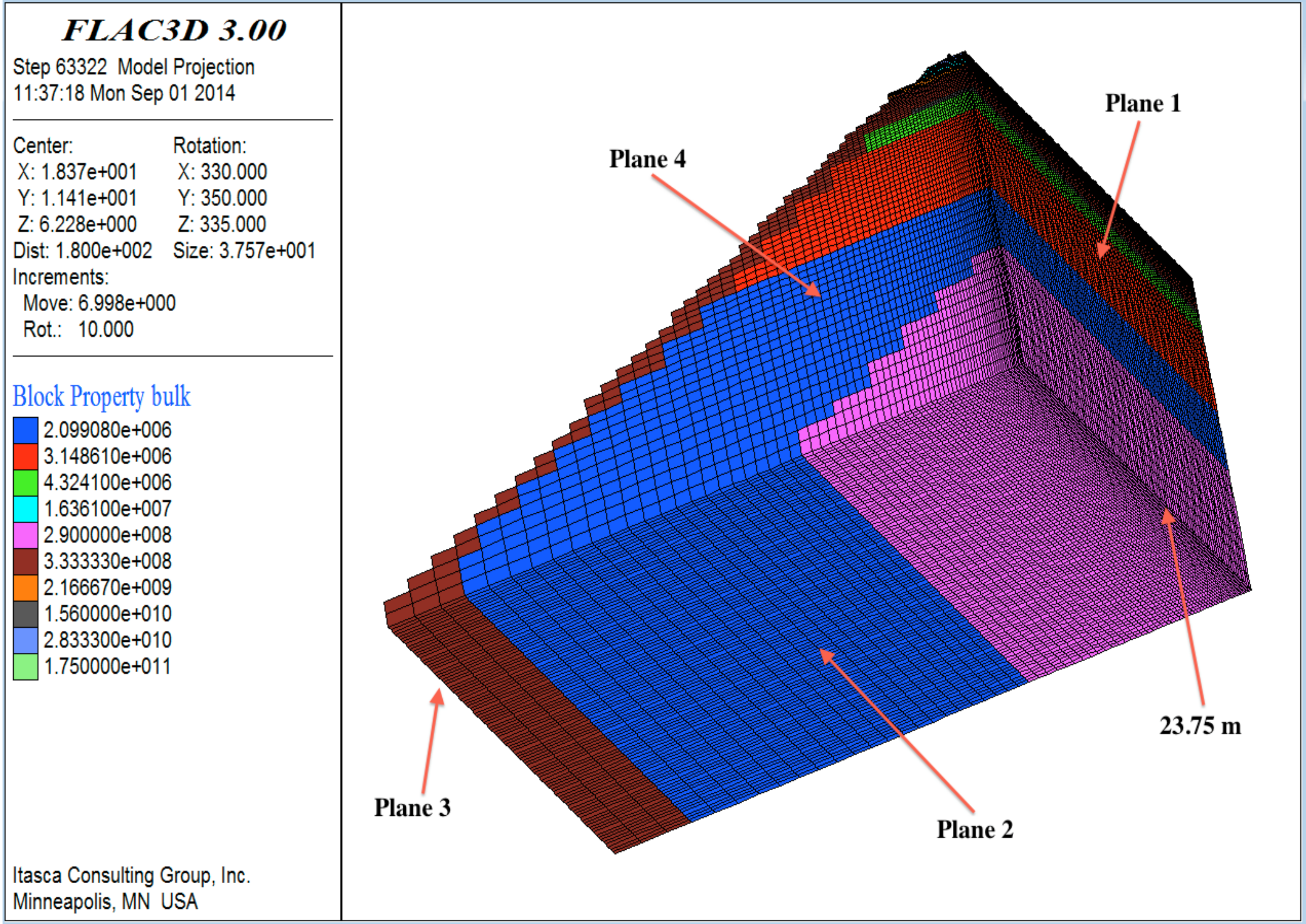
Modeling of Rail Systems on EPS Geofoam – Commuter Rail



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Z: 6.228e+000
Dist: 1.800e+002

Rotation:
X: 330.000
Y: 350.000
Z: 335.000
Size: 3.757e+001

Increments:
Move: 6.998e+000
Rot.: 10.000

Block Property bulk

🟦 2.099080e+006
🟥 3.148610e+006
🟩 4.324100e+006
🟦 1.636100e+007
🟪 2.900000e+008
🟫 3.333330e+008
🟧 2.166670e+009
⬛ 1.560000e+010
🟦 2.833300e+010
🟩 1.750000e+011

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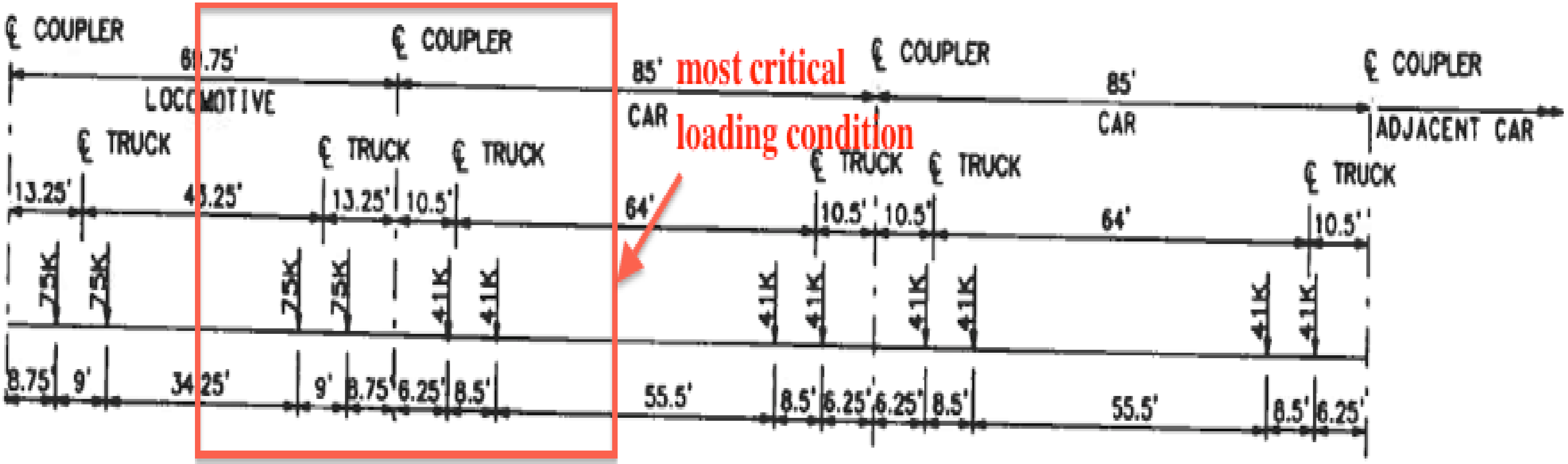
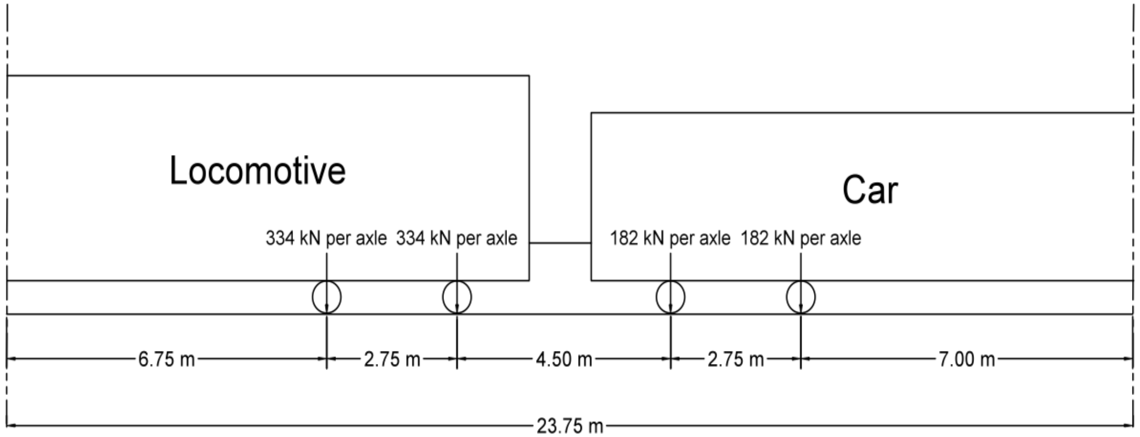
Modeling of Rail Systems on EPS Geofoam – Commuter Rail

Description	E MPa	ν	Geometry
Rail	210000	0.3	78 mm wide, 153 mm deep
Sleeper (3D/2D)	31000/11600	0.3	242 mm wide, 200 mm deep
Ballast	310	0.3	308.8 mm thick
Sub-ballast	130	0.49	203.2 mm thick
Structural Fill	400	0.3	914.4 mm thick
LDS	30000	0.18	203.2 mm thick
EPS 39	10.3	0.103	top layer
EPS 29	7.5	0.103	second to fifth layer
EPS 22	5	0.103	sixth to bottom layer
Foundation Soil	174	0.4	20 m thick

Modeling of Rail Systems on EPS Geofoam – Commuter Rail



most critical loading condition



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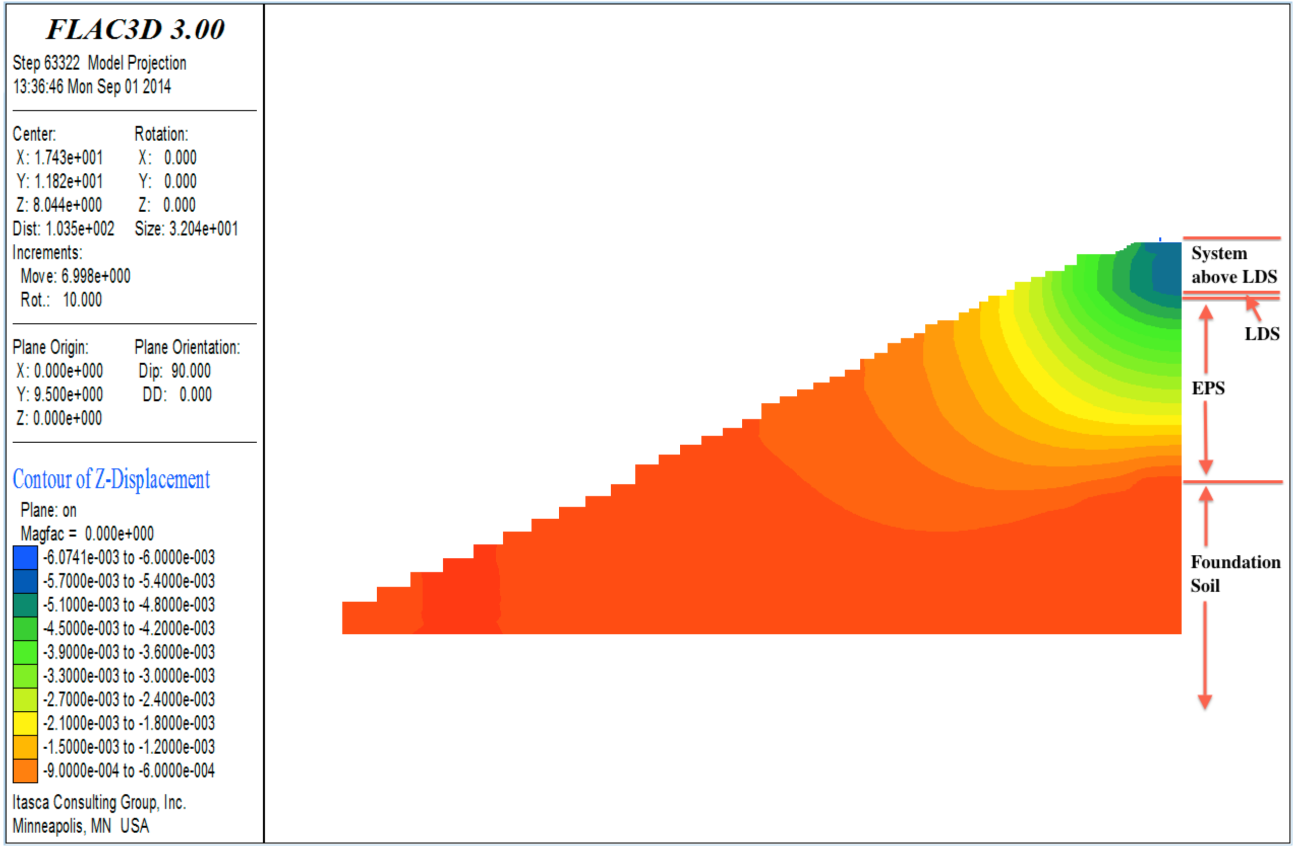
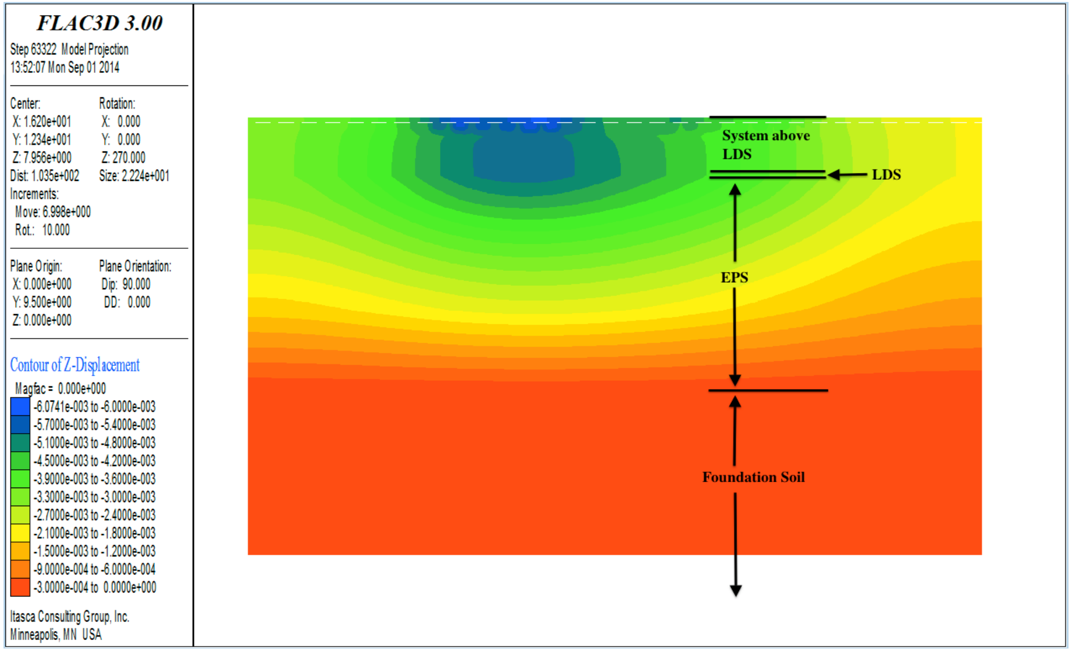
Modeling of Rail Systems on EPS Geofoam – Commuter Rail





6 mm of vertical displacement predicted by model
4 mm (max) measured by accelerometers

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Overview

- Case Histories of Rail on EPS
- Numerical Modeling of Case Histories
- Deflection Monitoring
  - Commuter Rail
  - Light Rail
- Subsequent Ballast Testing

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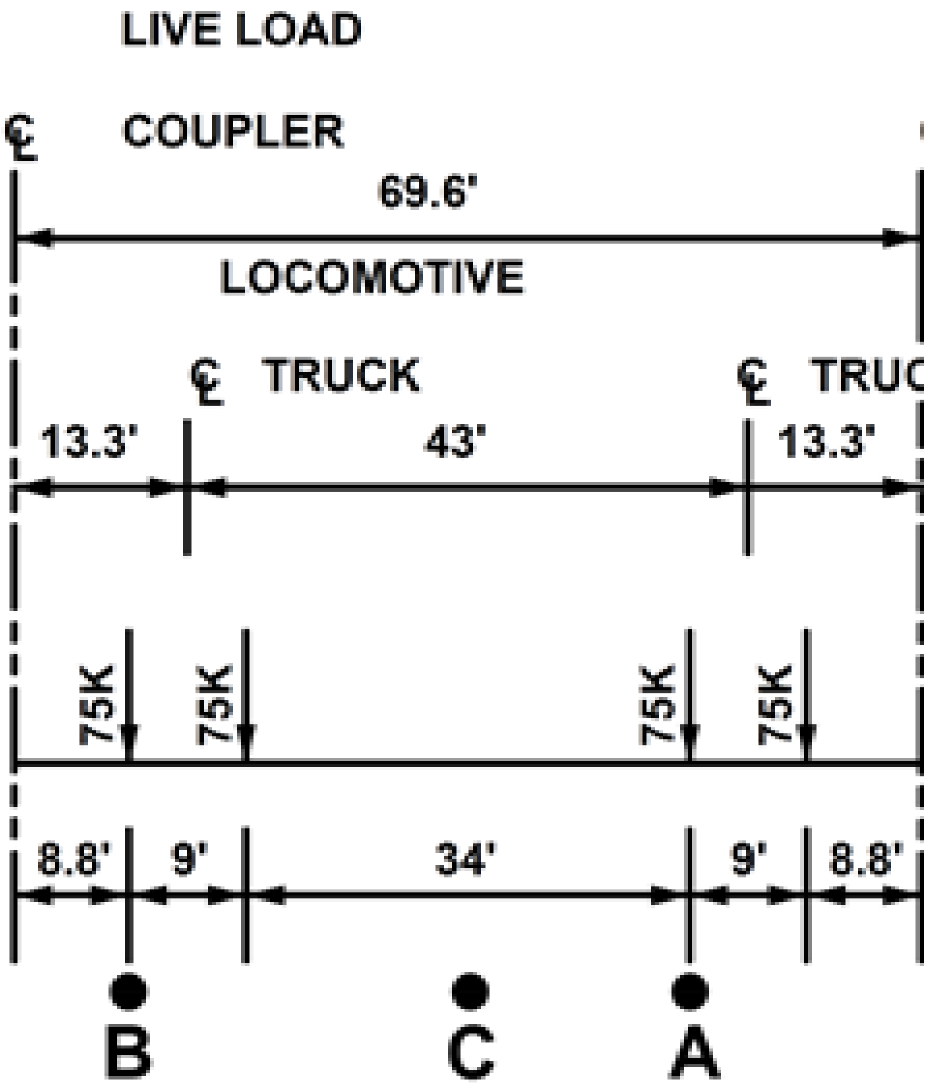
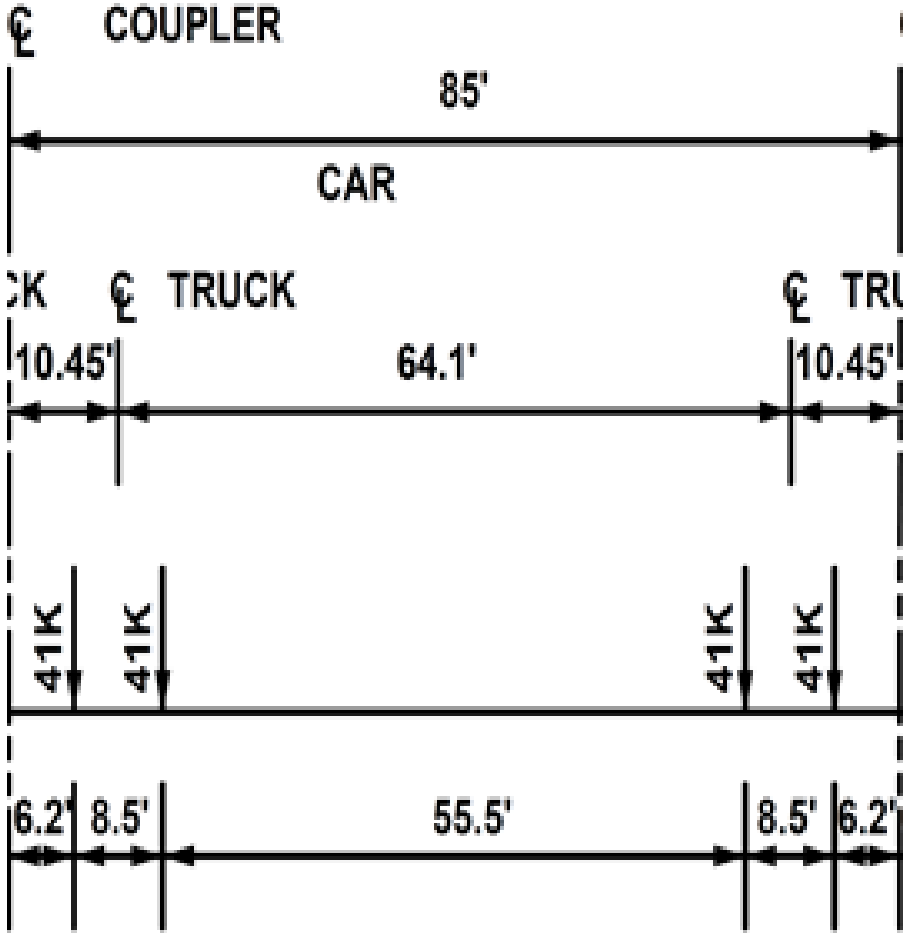
Deflection Monitoring Locations – Corner Canyon

Locomotive Loading – Commuter Rail

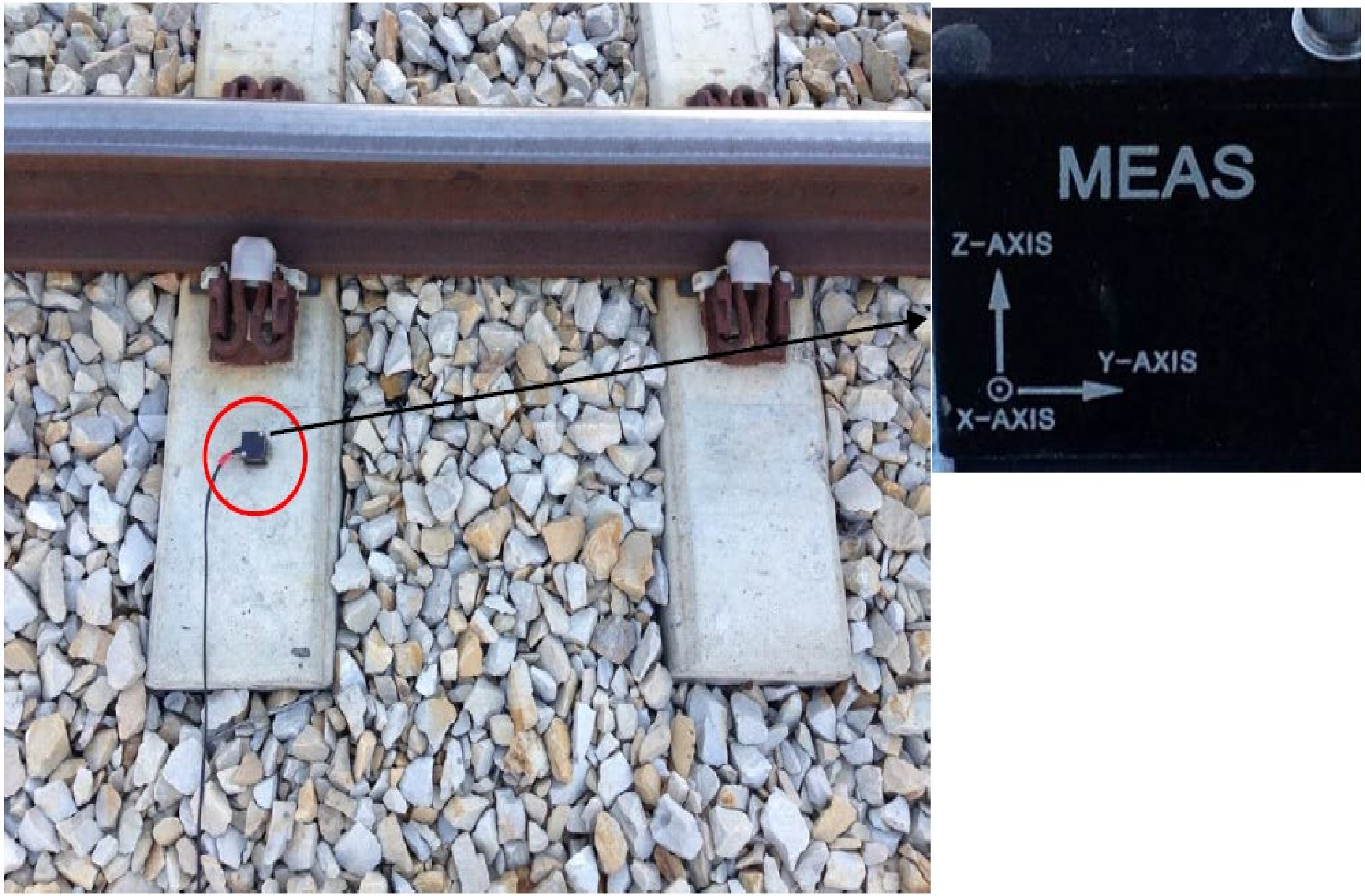


Car Loading – Commuter Rail



COMMUTER RAIL TRAIN

Deployment of Accelerometers – 3 Component



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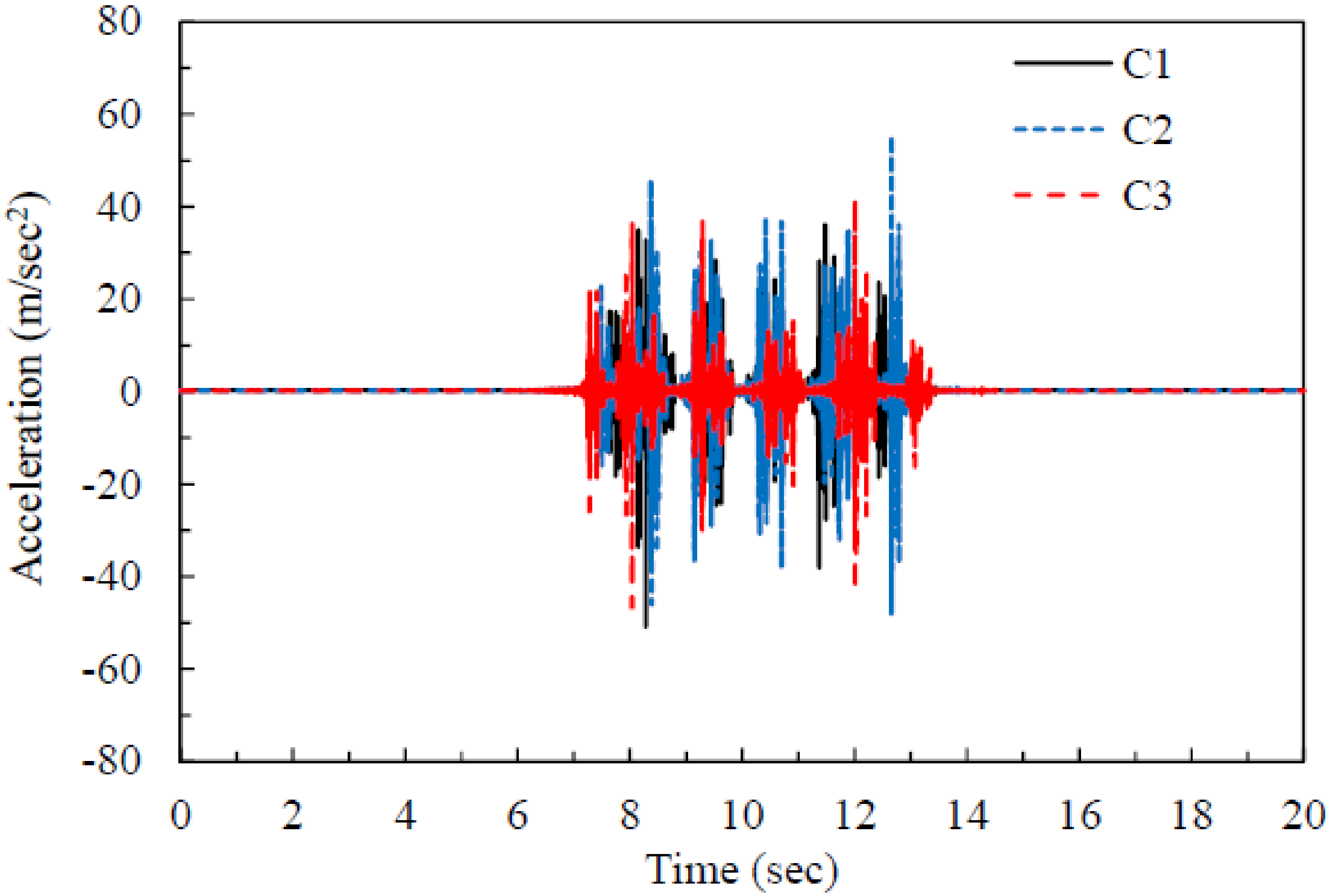
EPS Embankment Accelerations – Commuter Rail



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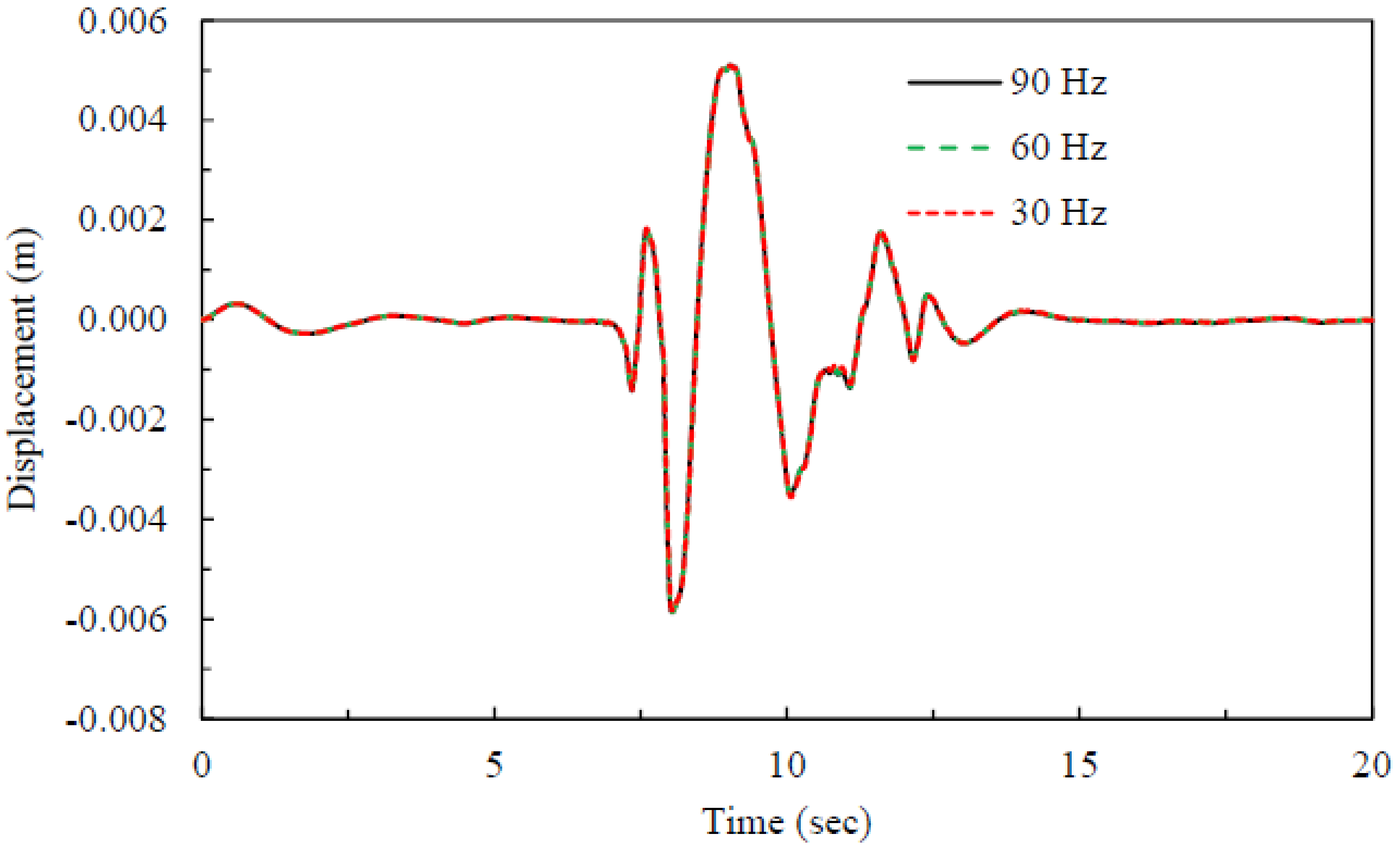
EPS Embankment Deflections – Effects of Upper Frequency Bandpass Filtering on Integration



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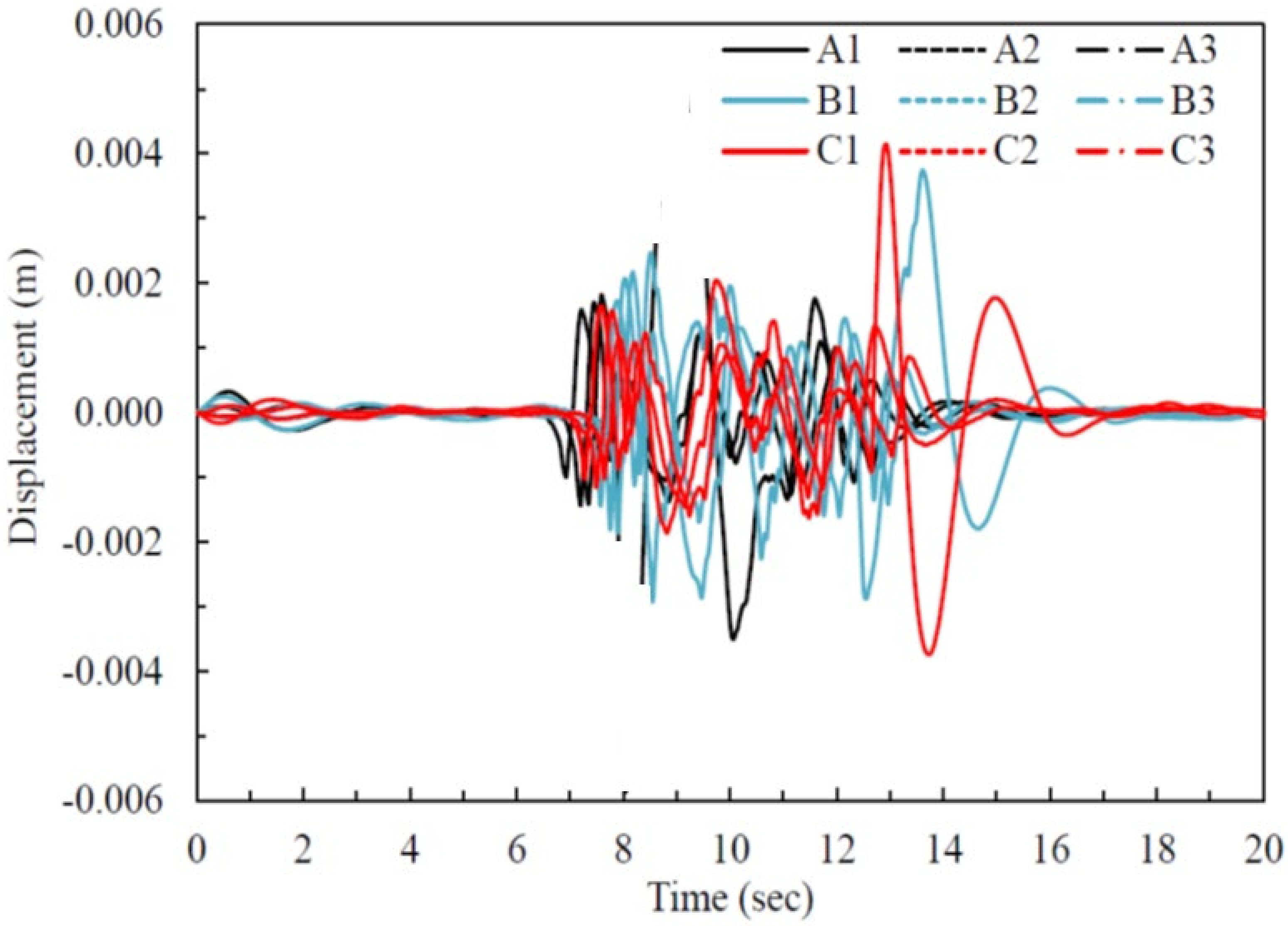
EPS Embankment Deflections – Commuter Rail



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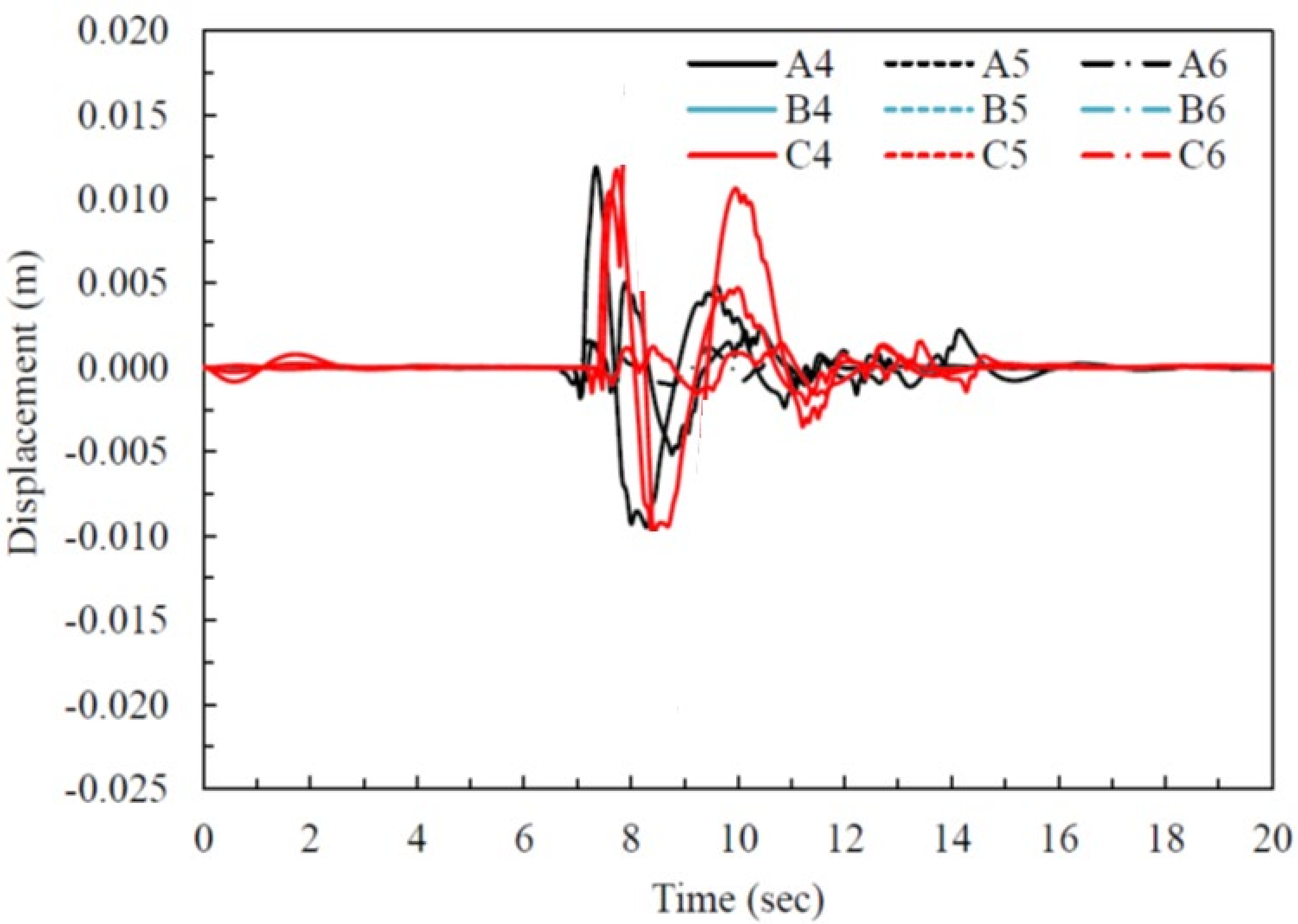
Earthen Embankment Deflections – Commuter Rail



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Overview

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- Numerical Modeling of Case Histories
- Deflection Monitoring
  - Commuter Rail
  - Light Rail
- Subsequent Ballast Testing

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Light Rail Embankments

Deflection Monitoring Location

UTA –Light Rail – Salt Lake City, Utah

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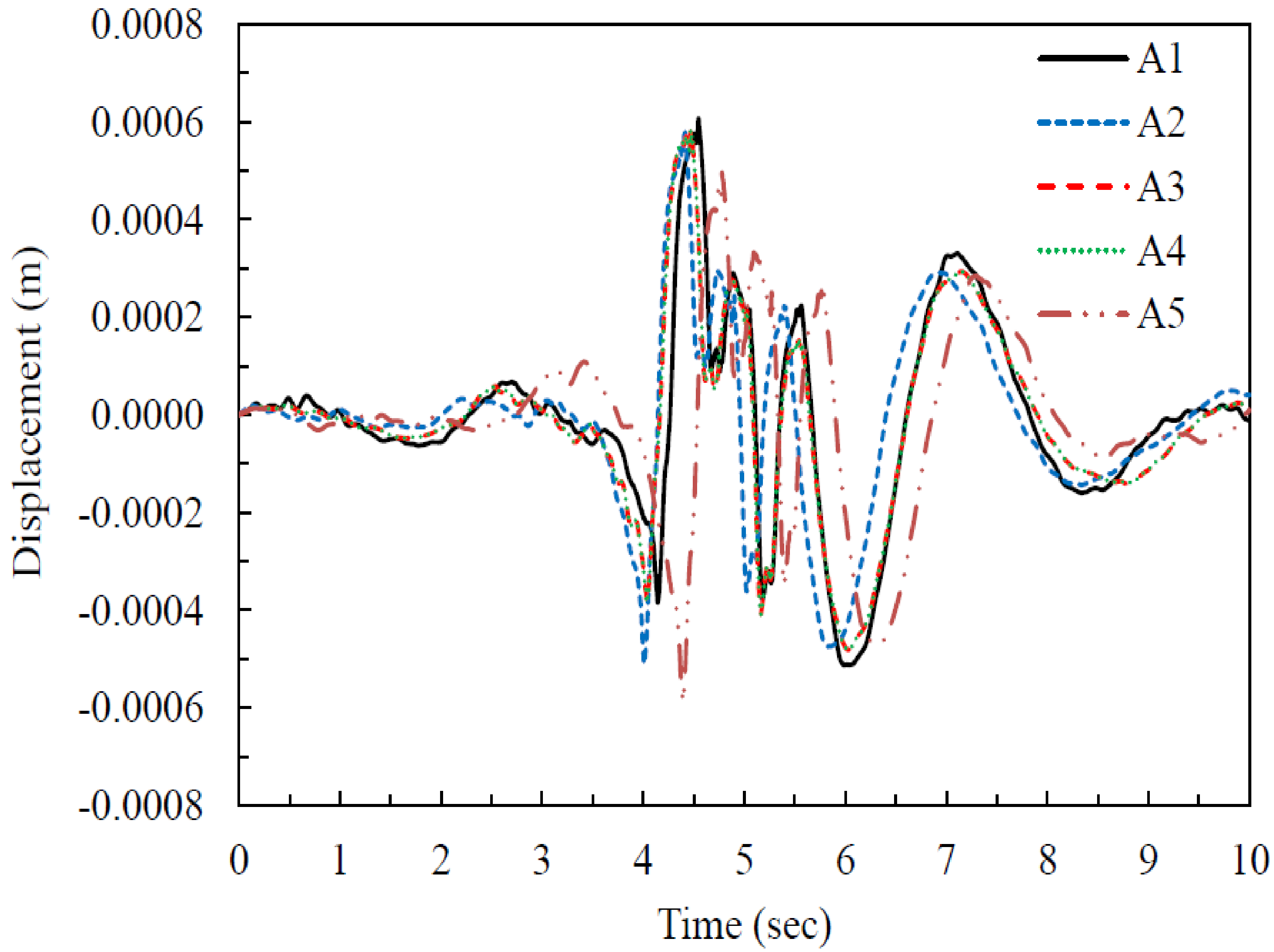
Light-Rail Deflections



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Overview

- Case Histories of Rail on EPS
- Numerical Modeling of Case Histories
- Deflection Monitoring
  - Commuter Rail
  - Light Rail
- Subsequent Ballast Testing

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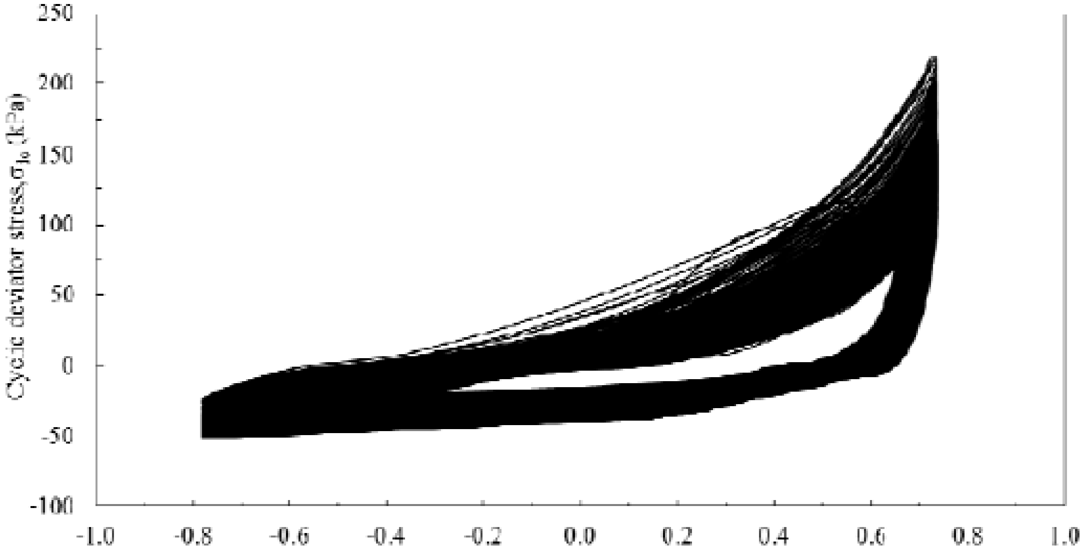
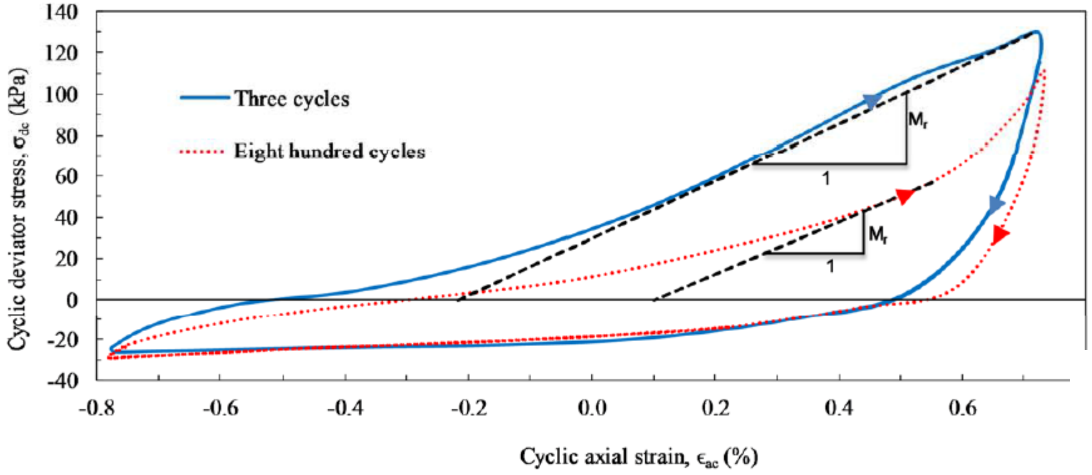
Ballast Testing

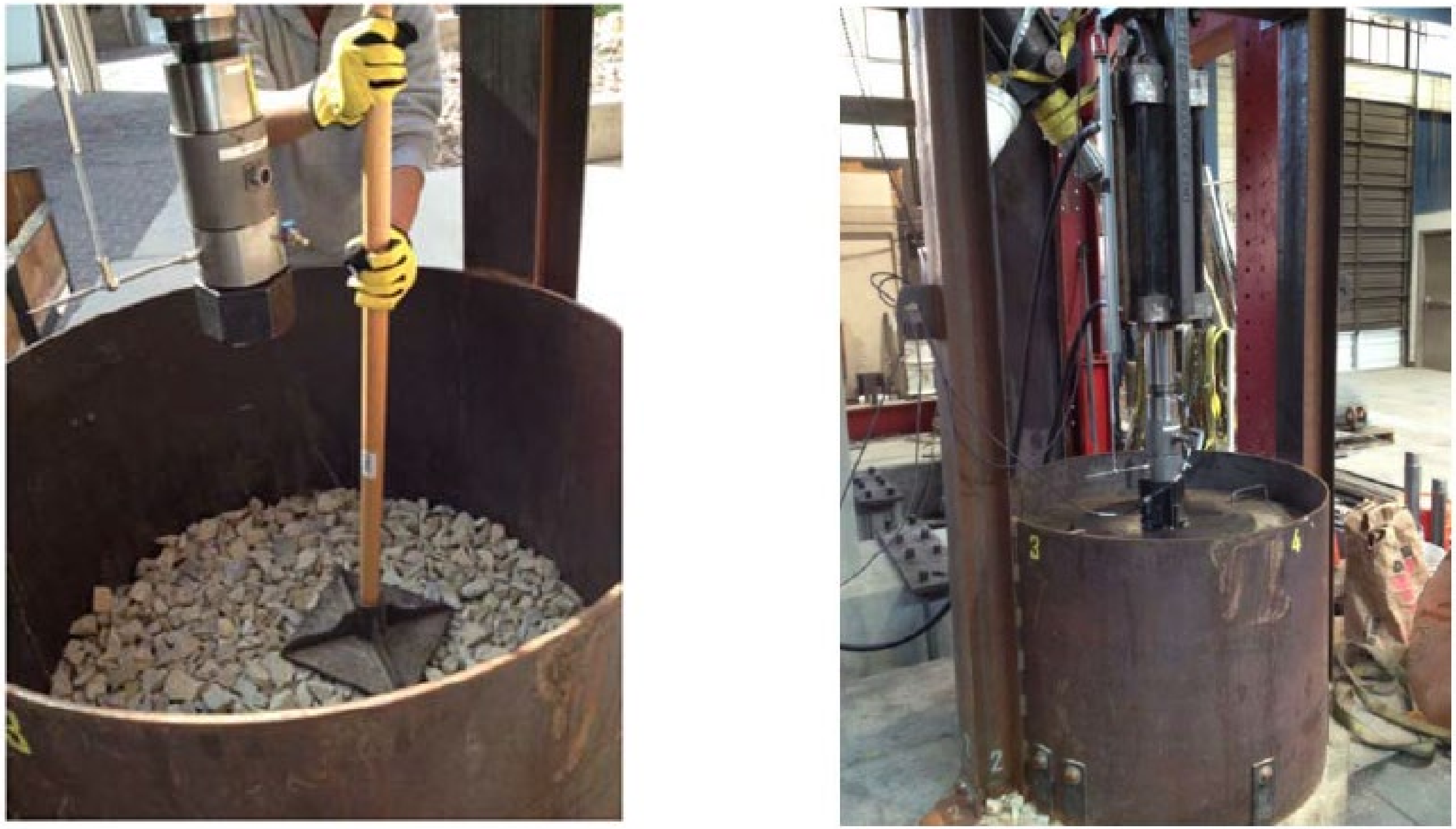




Mr = 14 MPa

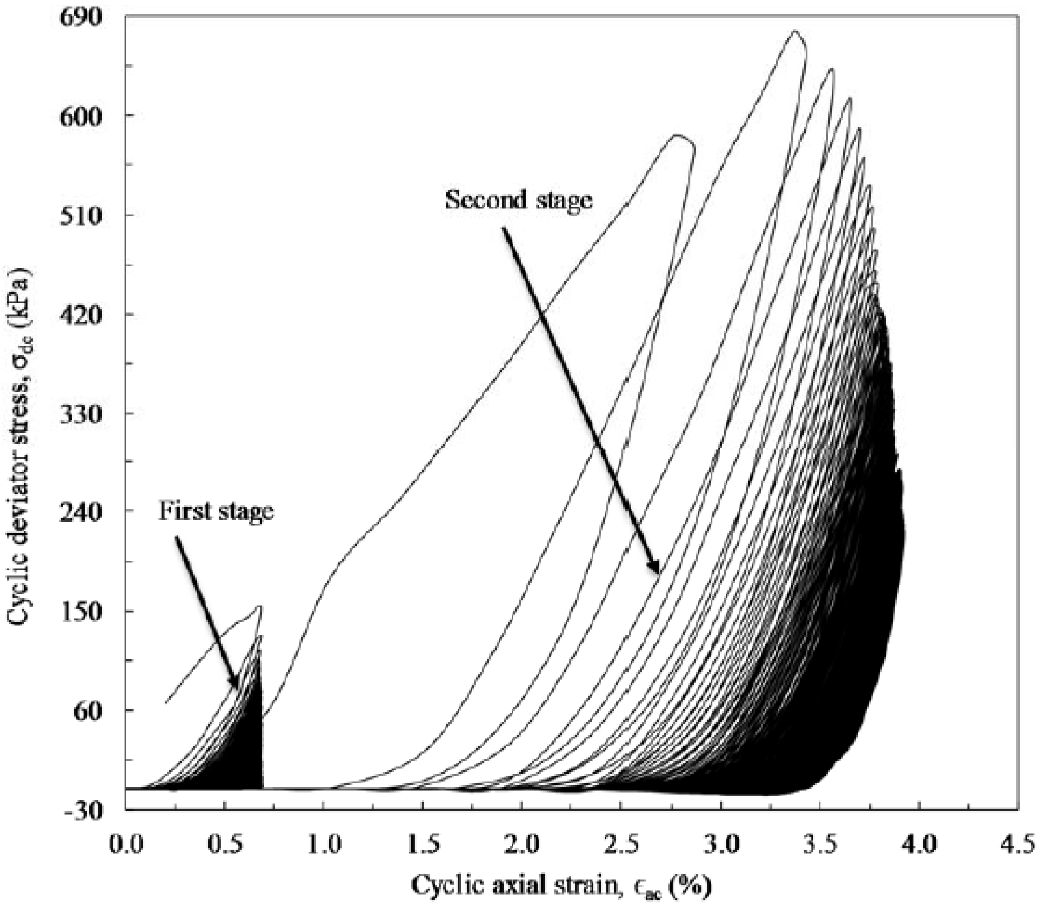
Low confinement cyclic triaxial testing of Ballast

Ballast Testing



Cyclic Chamber Testing of Ballast

Ballast Testing



Mr = 44 Mpa (2nd stage)

E = 52 Mpa (low confinement)

EPS Rail Embankment Conclusions

- Dynamic Deflection of EPS Embankment for Commuter Rail System is about 4 mm (0.16")
- Dynamic Deflection of Earthen Embankment for Commuter Rail System is about 10 mm (0.39")
- Dynamic Deflections on Light-rail system was one order of magnitude less than those measured on Commuter Rail
- Numerical modeling can be used to estimate these deflections
- Stiffness properties of Ballast can be highly variable depending on confinement, number of cycles and amplitude of applied cycle
- EPS appears to provide embankment and rail support for commuter and light-rail rail applications

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