Trackbed Structural Design

including Geotrack and Other Related Items

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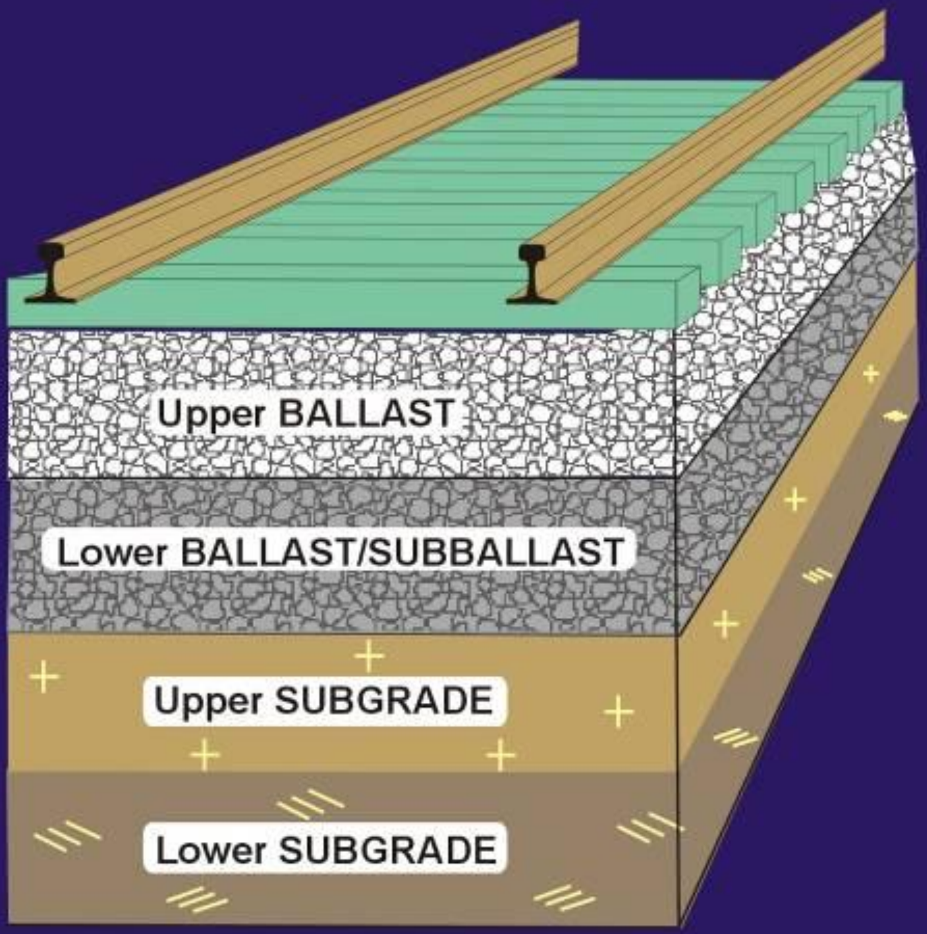
Presentation Outline

- Substructure
  - Role & Importance
- Granular Layer Thickness Design
  - Discussion
  - Example
- GEOTRACK
- Substructure Improvements
  - HMA
  - Reinforcement
  - Chemical grouting

Substructure: Role & Importance

Track Substructure



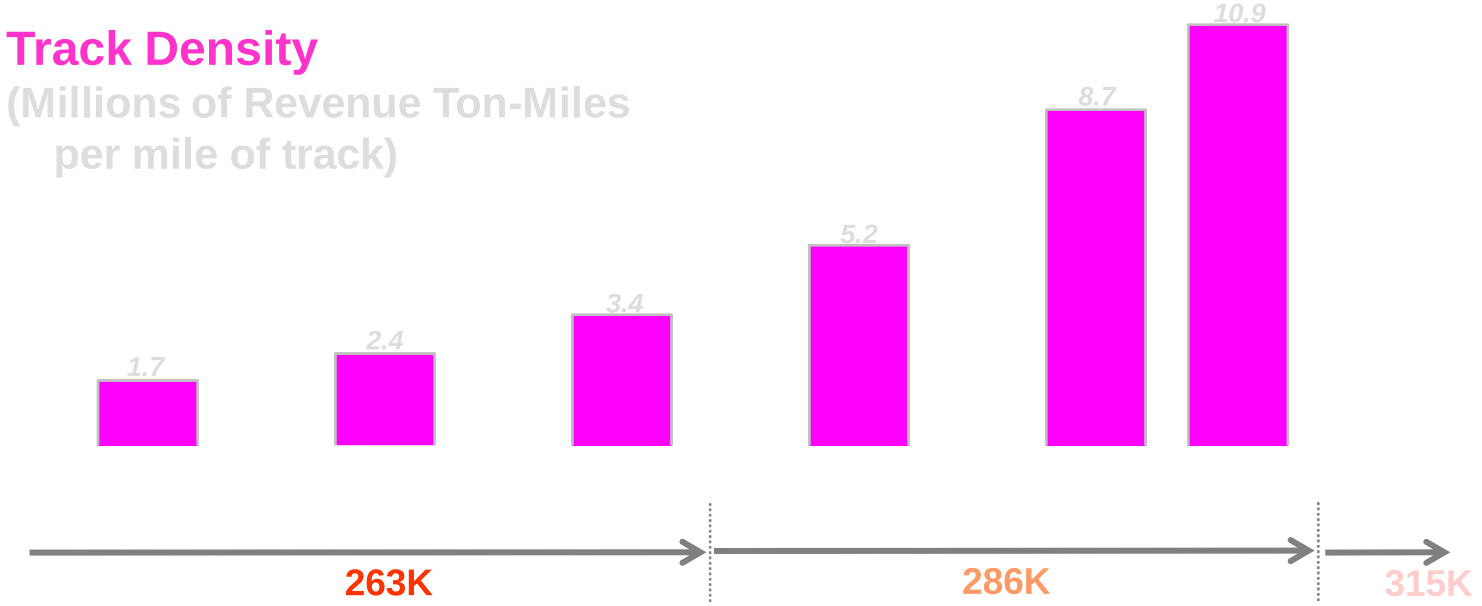
Functions of Ballast

- *Resist track forces*
- *Provide resiliency*
- *Provide void storage*
- *Facilitate maintenance*
- *Provide drainage*
- *Reduce stress to underlying layers*

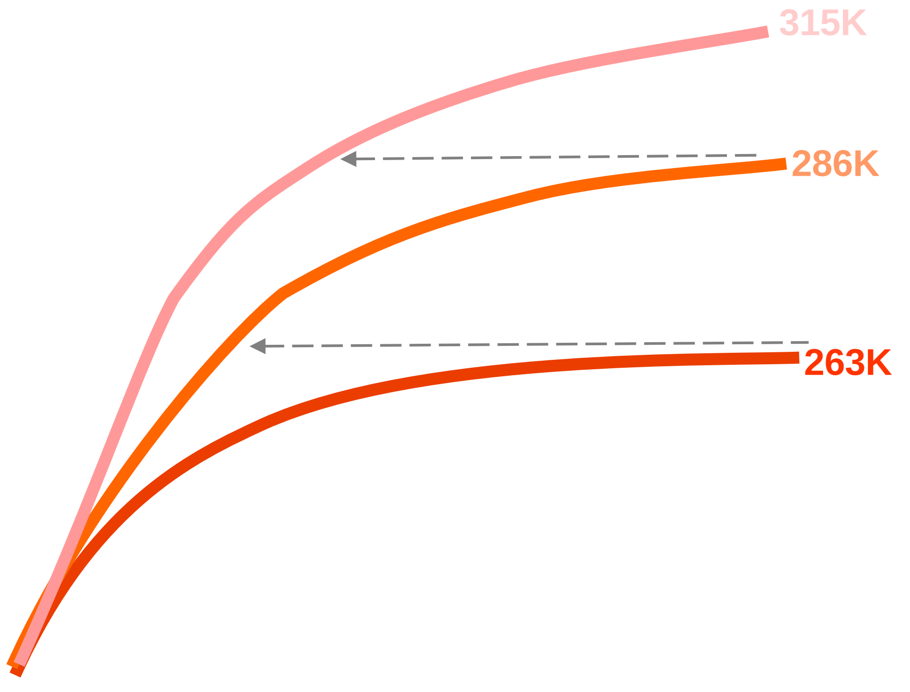
Functions of Subballast

- *Reduce stress to underlying subgrade*
- *Provide frost protection*
- *Provide separation between ballast and subgrade*
- *Prevent subgrade attrition*
- *Shed water away from subgrade*
- *Provide drainage of ground water from subgrade*

Importance of Substructure



Importance of Substructure



Annual Substructure Related Costs

- $14.1 Billion / yr Way & Structures
- ~ 50% Track Related
- ~ 40% Substructure Related
  - Direct – surfacing, cleaning, drainage, ballast
  - Indirect – component life, train delays
- ~ $2.8 Billion/yr Substructure Related Costs

Substructure Problems

- *Poor drainage*
- *Fouled ballast*
- *Subgrade failure or deformation*
- *Subgrade attrition*
- *Subgrade excessive swelling and shrinking*
- *Longitudinal variation*
- *Transitions*
- *Unstable embankments*
- *Sinkholes*

Granular Layer Thickness Design

Granular Layer Thickness (GLT)

- GLT = Ballast + Subballast
- Ballast → minimum 9 to 15 inches
  - Tamping, Void Storage
- Subballast → minimum 3 to 6 inches
  - Drainage, Separation
- GLT → minimum 12 to 21 inches
- <u>Subgrade protection ?</u>

→ Check minimum required GLT

Granular Layer Thickness Design

(Ref. Li, Sussmann & Selig, 1986)

- ***GLT = Ballast + Subballast***
- ***Limits Stress on Subgrade to Prevent :***
  - ***Progressive shear failure***
  - ***Excessive plastic deformation***
- ***Considers***
  - ***Operational conditions***
  - ***Soil conditions***

GLT Design – Operating Conditions

- Traffic Parameters
  - Static wheel loads
  - Train speed
  - Traffic (MGT)
- Converted Parameters
  - Design dynamic wheel load, P_d
  - Number of repeated load cycles, N

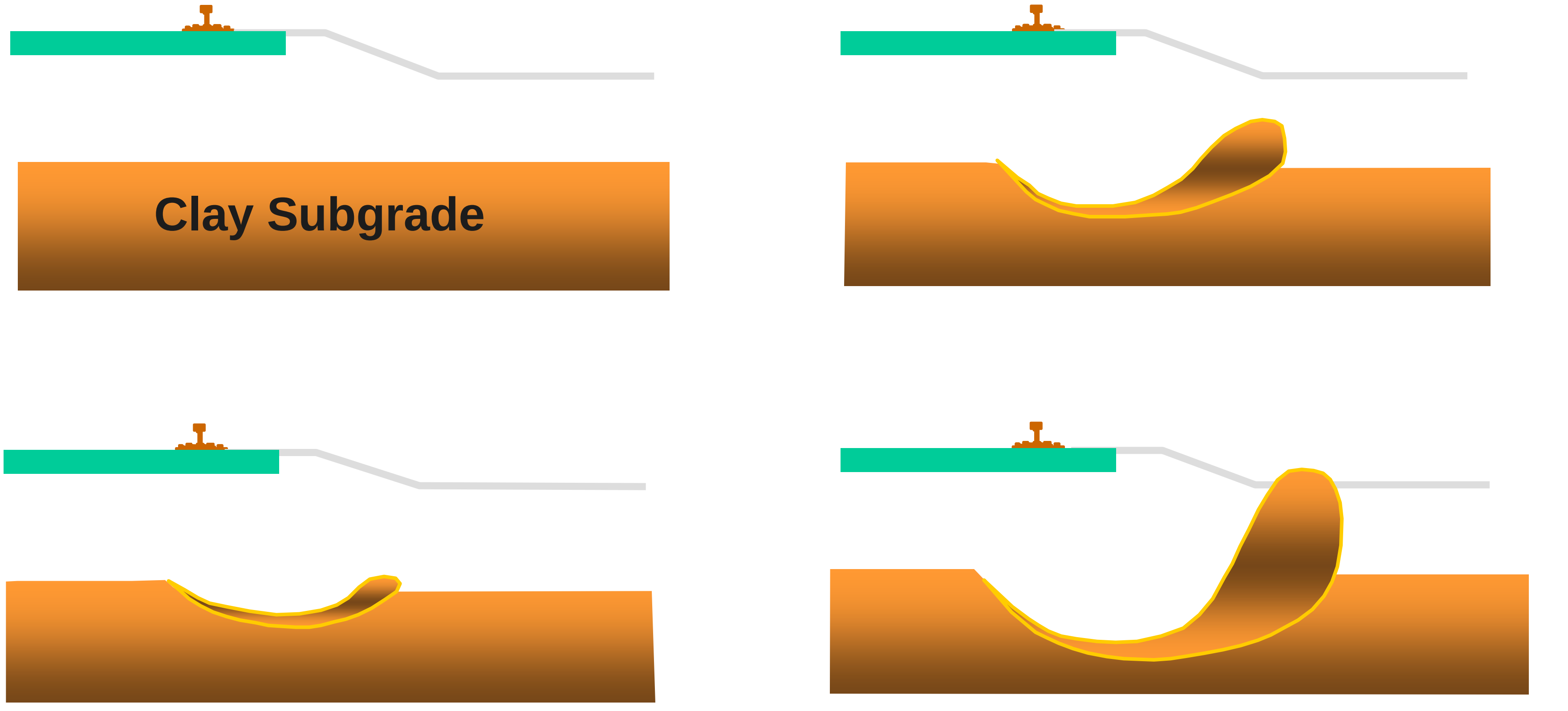
GLT Design – Material Properties

- **Ballast / Subballast**
  - Resilient Modulus, E_b
- **Subgrade**
  - Soil type
  - Resilient Modulus, E_s
  - Compressive strength, σ_s
  - Thickness of deformable layer

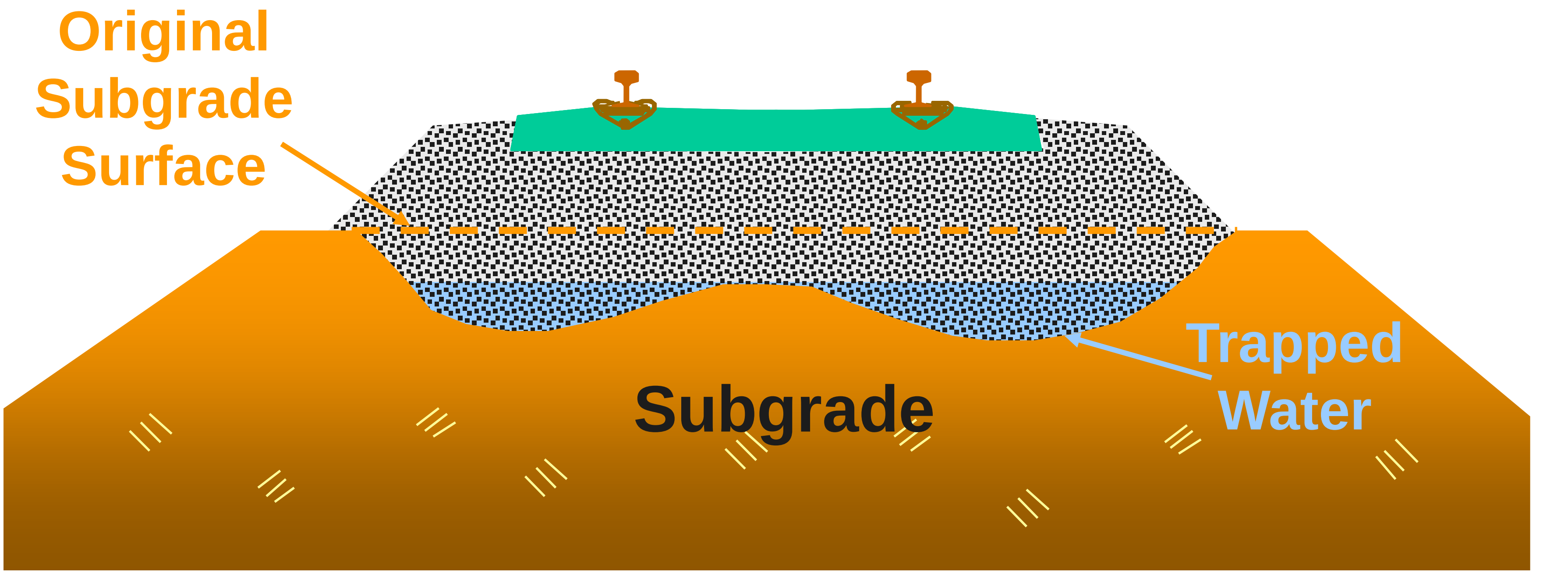
GLT Design – Criteria

- ***Prevent subgrade progressive shear failure (Criterion 1)***
  - ***limit total cumulative plastic strain at subgrade surface for design period***
- ***Prevent excessive subgrade plastic deformation (Criterion 2)***

Progressive Shear Failure (Criterion 1)



Excessive Plastic Deformation (Criterion 2)



GLT Design Example – Soil Conditions

- **Ballast / Subballast**
  - *new, clean*
  - E_b = 20,000 psi
- **Subgrade**
  - *Stiff sandy silt (ML)*
  - σ_s = 21 psi, E_s = 16,000 psi

Table 1: Soil Parameters for GLT Design

Soil Type	a	b	m
CH	1.2	0.18	2.4
CL	1.1	0.16	2.0
MH	0.84	0.13	2.0
ML	0.64	0.10	1.7

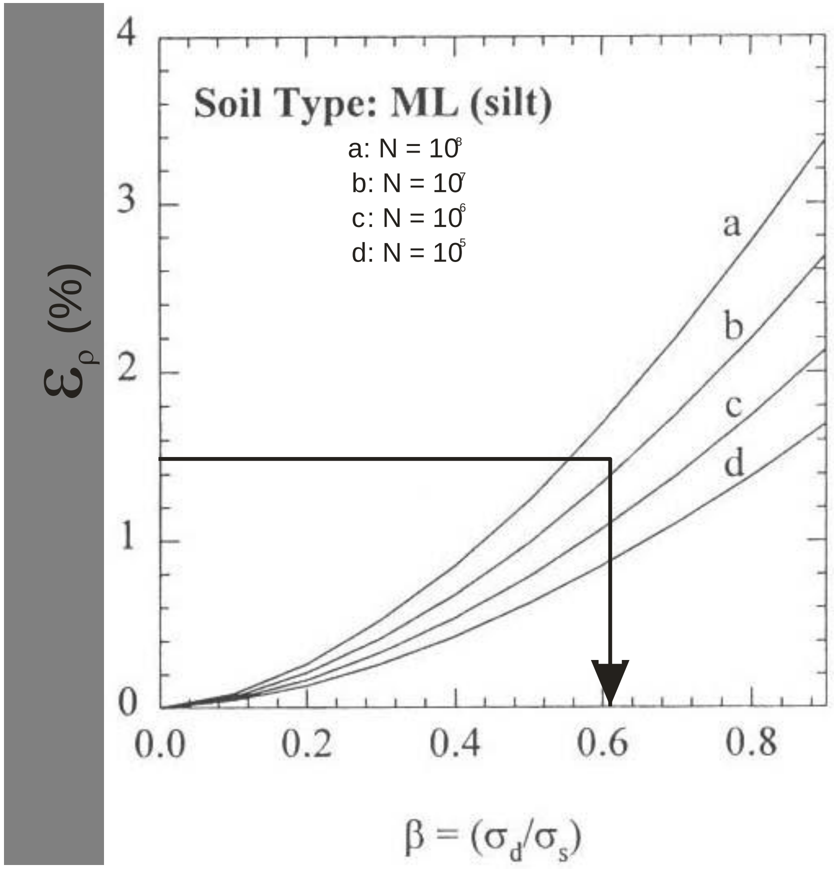
GLT Example – Operational Conditions

- *Static wheel load, P_s = 18 tons = 36,000 lb*
- *Dynamic wheel load, P_d = 58,000 lb*
  - *per AREMA with 65 mph speed, 36” wheels*
- *Traffic = 100 MGT/yr*
- *Design life = 20 years*
- *Load cycles*
  - *N = (100 x 20) / (4 x 18) = 2.8 x 10^7 cycles*

GLT Example – Criterion 1

1) Assume allowable plastic strain, $\varepsilon_p = 1.5\%$

2) From 'Beta' Chart with ε_p and N: $\beta = (\sigma_d / \sigma_s) = 0.62$



GLT Example – Criterion 1

3) $\sigma_d = \beta\, \sigma_s$ = 0.62 (21 psi) = **13.0 psi**

4) **Calculate Influence Factor, $I_\varepsilon = (\sigma_d \times A) / P_d$**

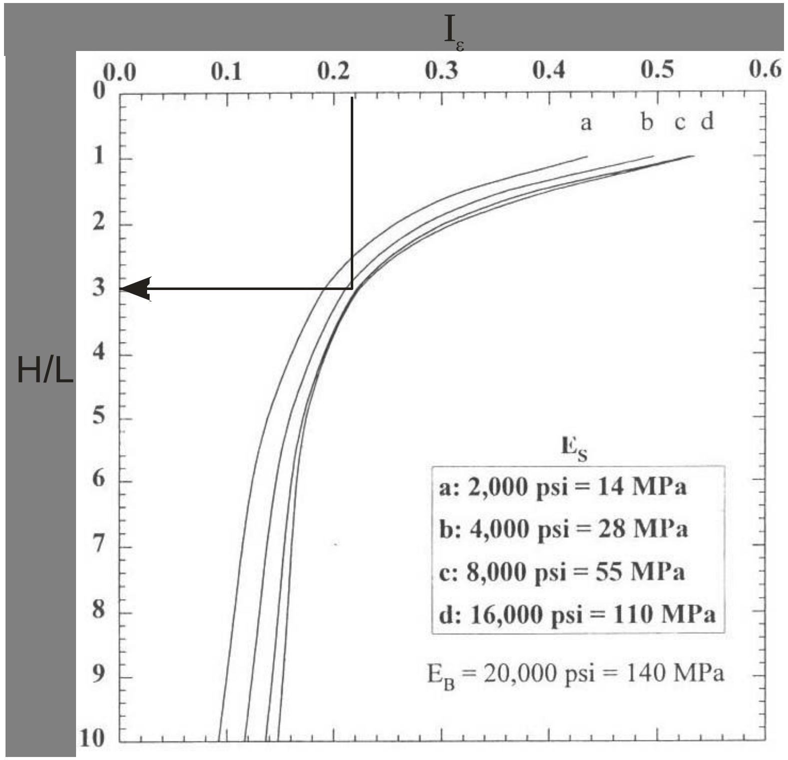
= (13.0 x 1000) / 58,000 = **0.22**

[A = 1000 for English units]

5) **From Influence Chart: H / L = 3.0**

[L = 6" for English units]

6) **H = 3.0 x 6" = <u>18.0</u> inches**



GLT Example – Criterion 2

1) Assume allowable plastic deformation, $\rho_a = 1$ inch

2) Calculate influence factor I_ρ :

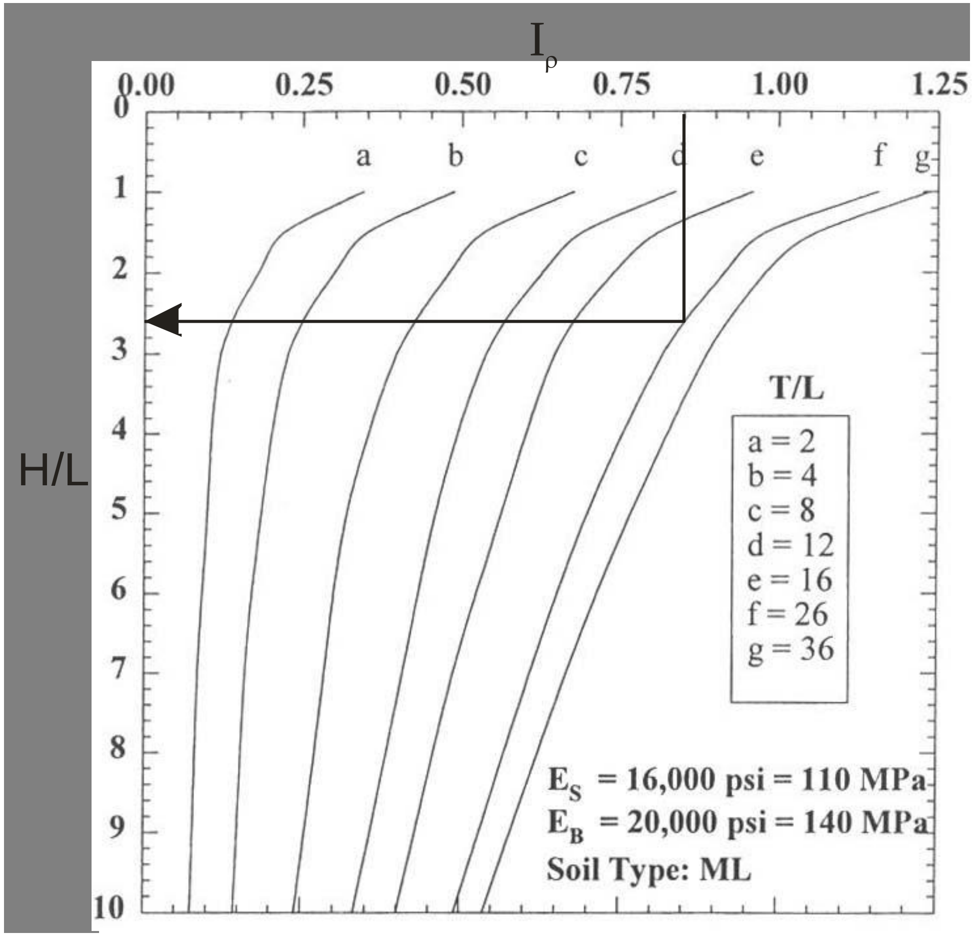
$$I_\rho = \left((\rho_a / L) \Big/ a\,(P_d / \sigma_s A)^m \; N^b \right) \times 100 = 0.85$$

GLT Example – Criterion 2

3) From Influence Chart: H / L = 2.6

(Thickness of deformable layer, T = 13 ft, and L = 6” for English units)

4) H = 2.6 x 6” = <u>15.6</u> inches



Therefore,
Criterion 1 controls:

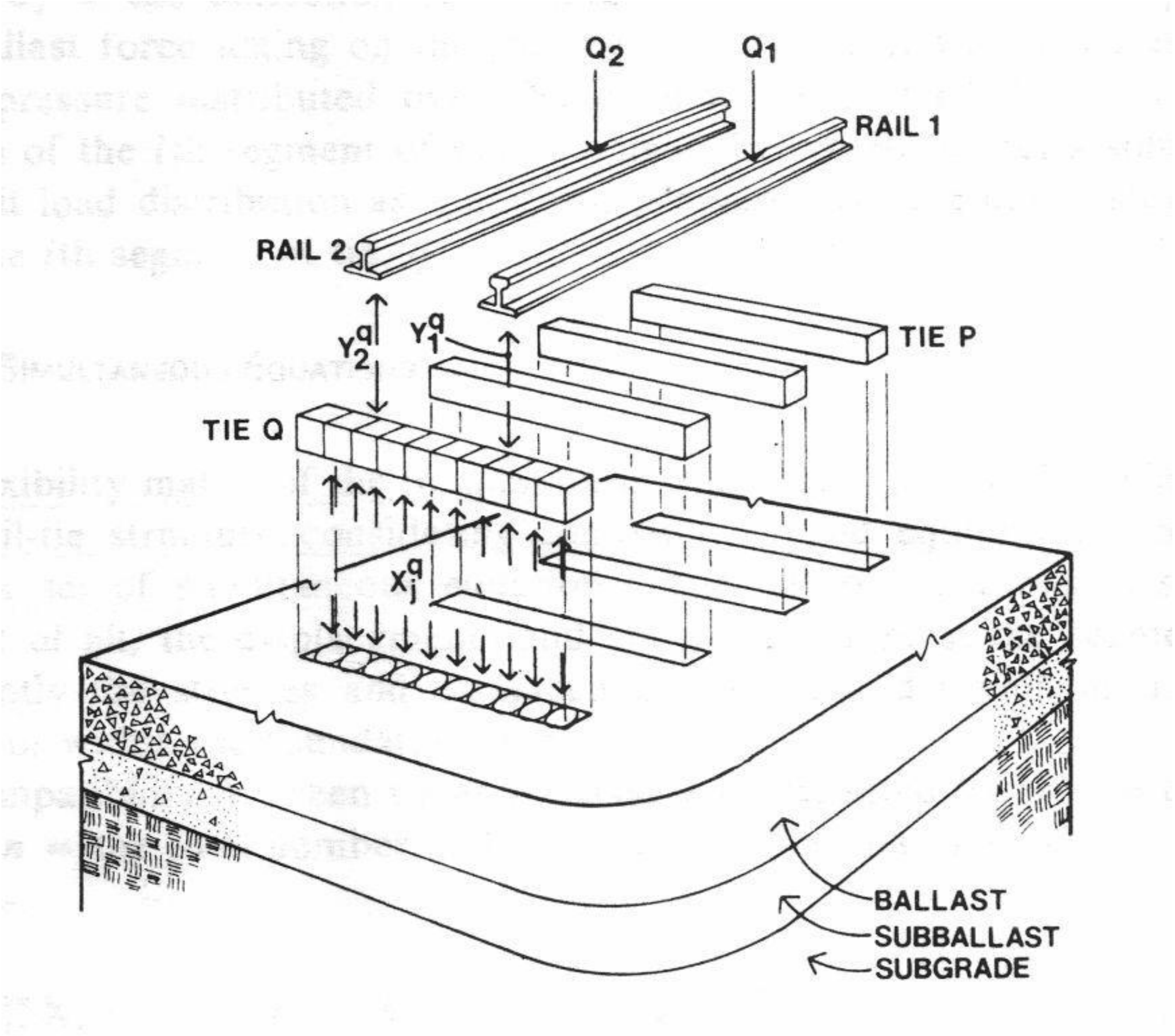
Required GLT = <u>18.0</u> inches

GEOTRACK

GEOTRACK *(Ref. Chang, Adegoke and Selig, 1980)*

- *Developed to emphasize the geotechnical aspects of track behavior*
- *Provides analysis of induced stresses and deformations in substructure*
- *3D, elastic, multilayer model*
- *Up to 4 superimposed vertical axle loads*
- *Stress-state dependent (nonlinear) modulus from iterative solution*
- *Separation of tie and ballast*

GEOTRACK Forces and Elements



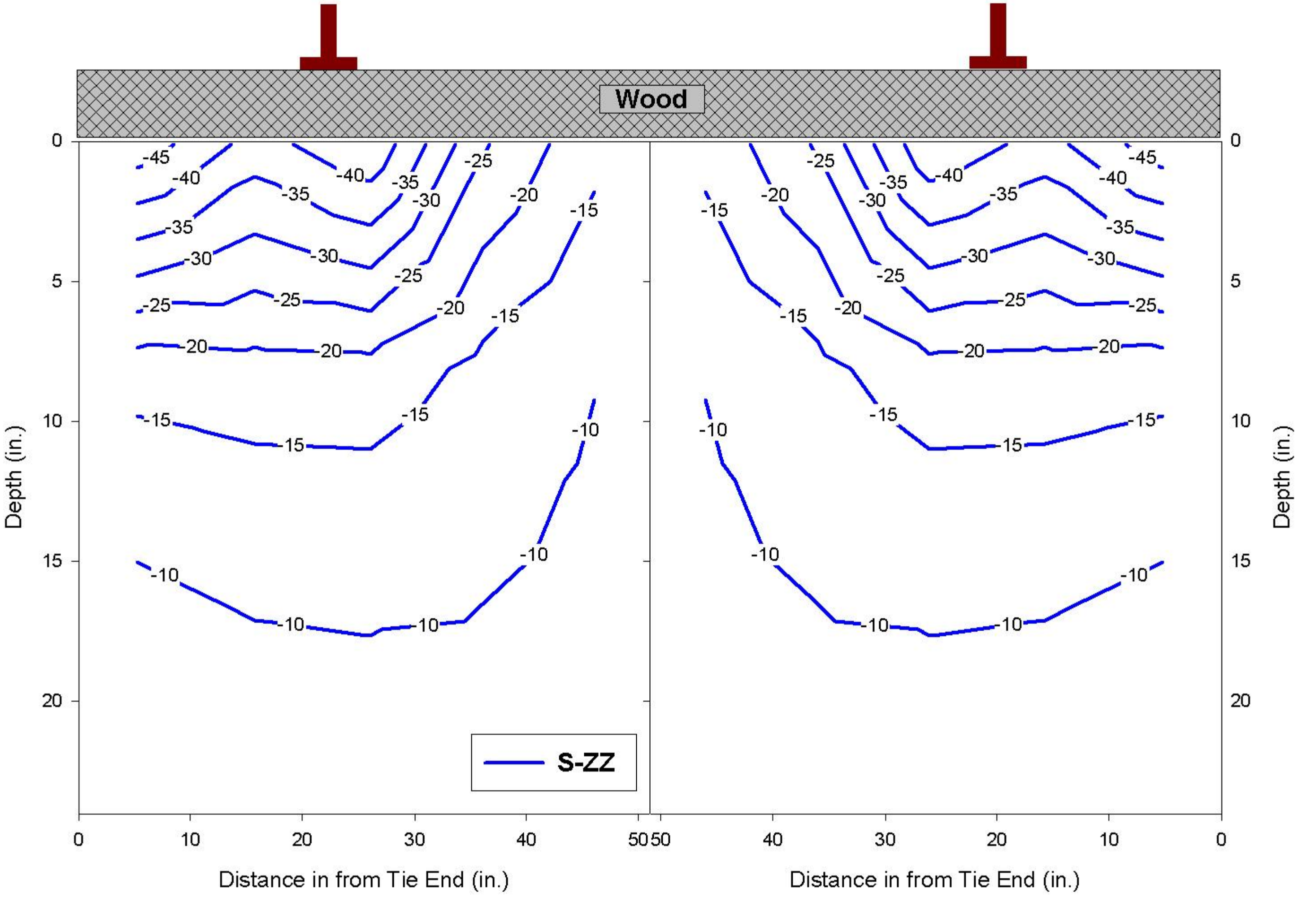
GEOTRACK Components

- Rails – linear elastic beams with concentrated reactions at each tie
- Rail/Tie connection is linear spring
- Ties – linear elastic beams
  - 10 equal segments
- Ballast, subballast, subgrade
  - Up to 5 linear elastic layers
  - infinite width - horizontal
  - semi-infinite half-space - vertical

GEOTRACK Output

- Superstructure
  - Rail and tie deflections
  - Rail seat load
  - Rail and tie bending moments
  - Tie / Ballast reaction
- Substructure
  - Vertical deflection
  - Complete stress state
    - Deviator stress
    - Bulk stress
    - Principal stresses and directions
- Track modulus for the combined system

Sample Output



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Substructure Improvements

Substructure Improvements

- HMA
- Reinforcement
- Chemical grouting

Hot Mixed Asphalt (HMA) Underlayment

HMA Underlayment

- ***Potential Benefits***
  - ***Internal drainage***
  - ***Stress reduction to subgrade***
  - ***Increase track stiffness***
  - ***Improved constructability of new track***
- ***Key Design criteria***
  - ***Excessive Deformation***
    - ***Accumulation of plastic strain***
  - ***Fatigue***
    - ***Repeated load build-up of tensile strain and stress***

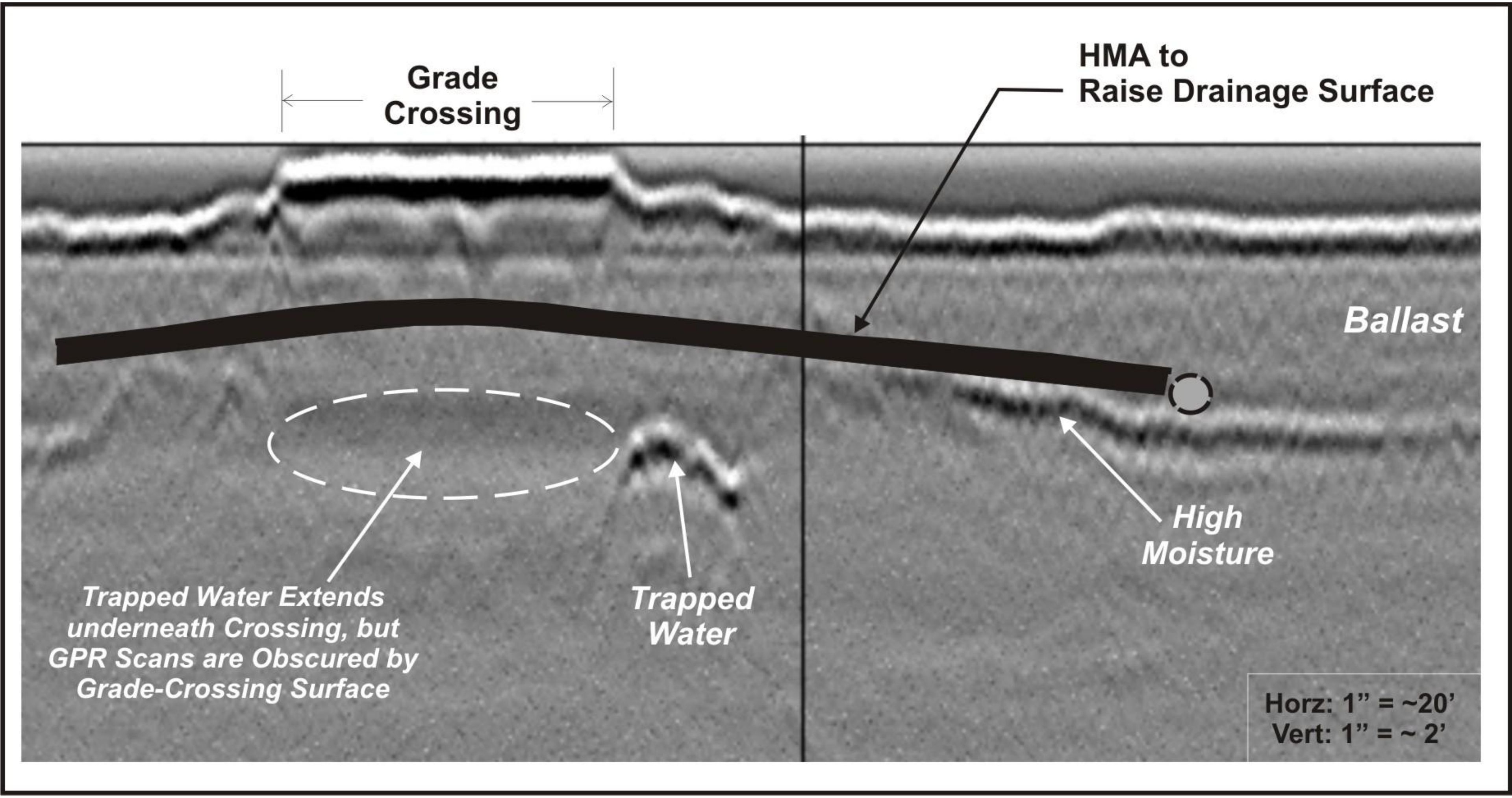
HMA Underlayment

- *Potential Benefits*
  - *Internal drainage*
  - *Stress reduction to subgrade*
  - *Increase track stiffness… (too high?)*
  - *Improved constructability of new track*
- *Key Design criteria*
  - *Excessive deformation – (Accumulation of plastic strain)*
  - *Fatigue – (Repeated load build-up of tensile strain and stress)*
- *Key Construction criteria*
  - *Good subgrade*
  - *Good internal and external drainage*
  - *Compaction (low voids, not* $<175^{o}$*)*

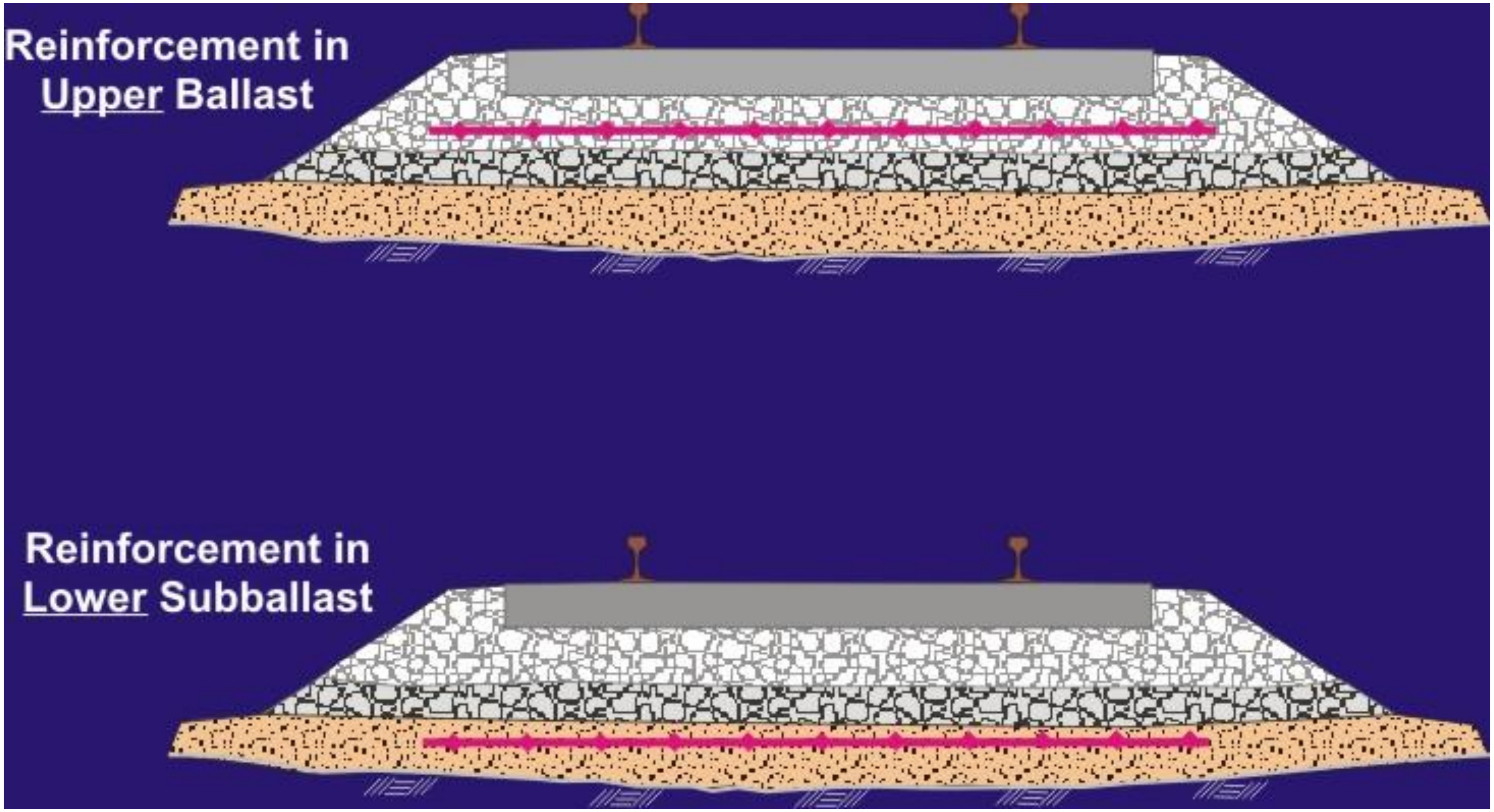
Predicted Life of HMA

(Based on Huang et al, 1987 and Rose, 1987)

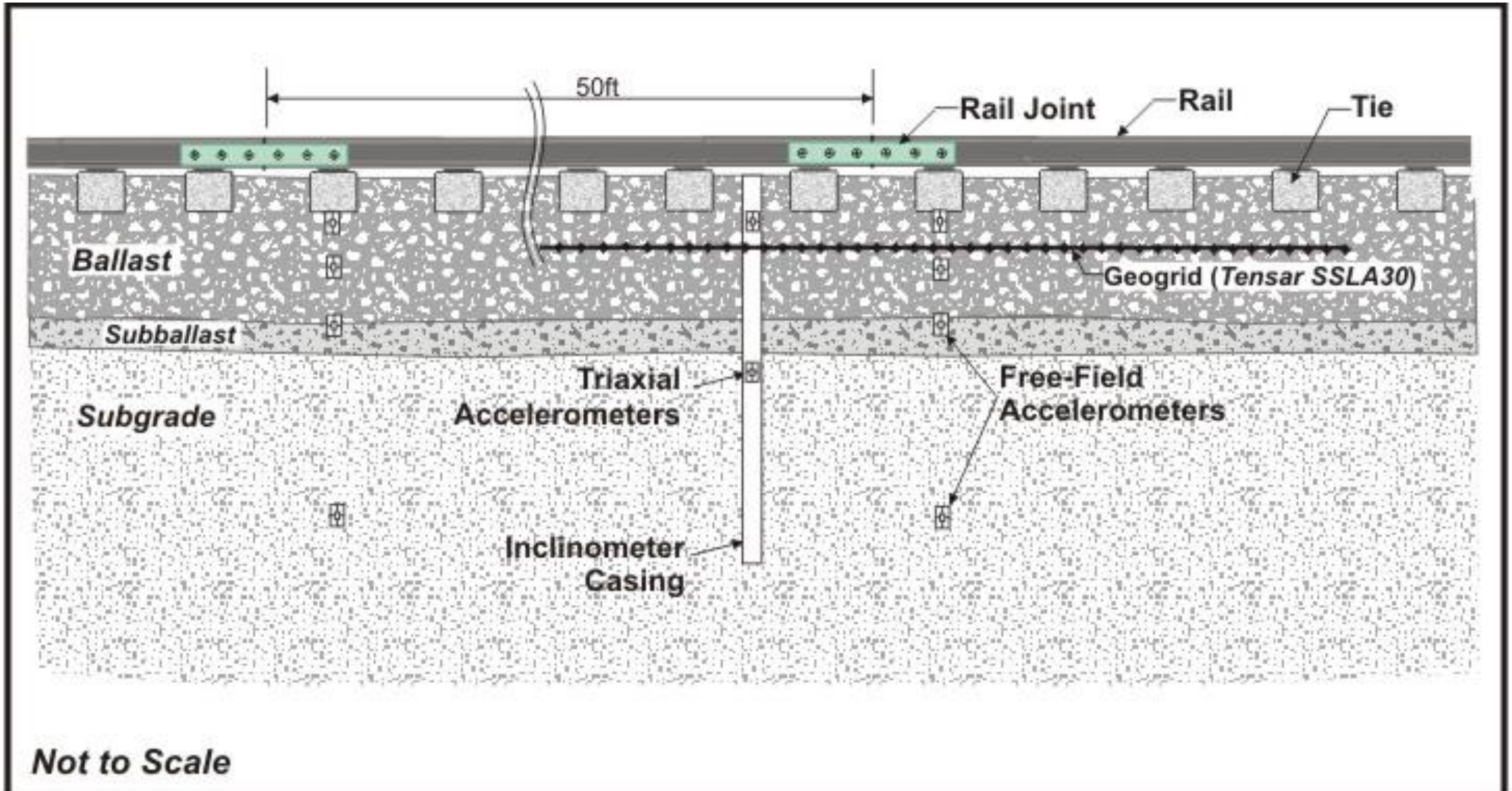
Example: Grade Crossing – GPR and HMA



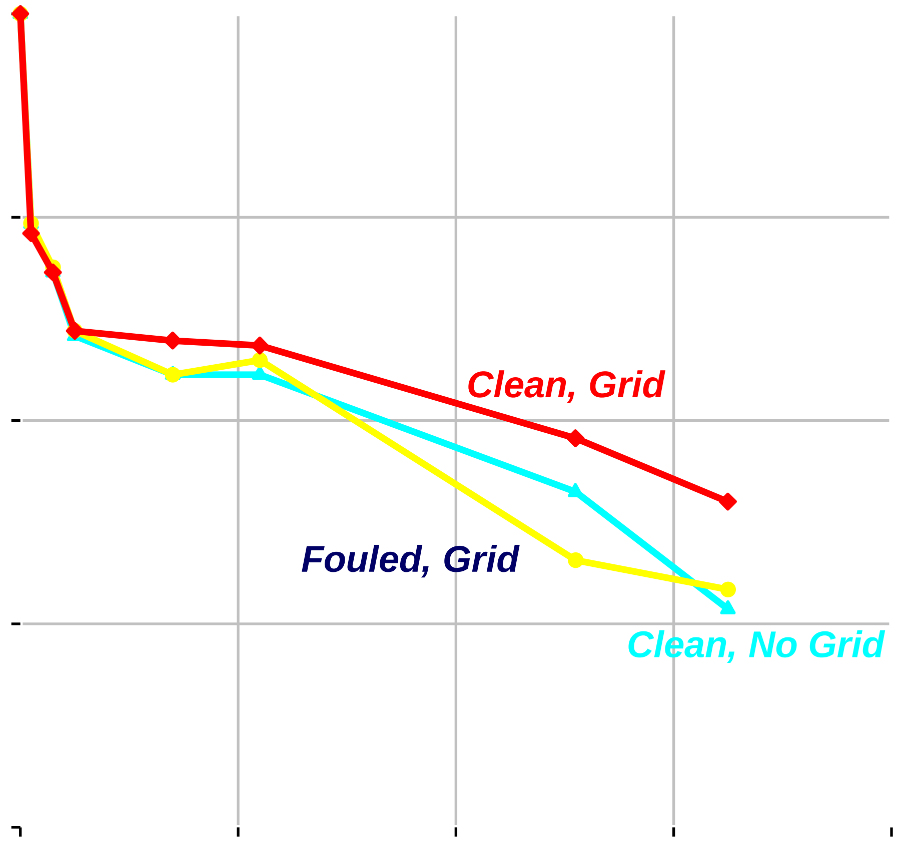
Reinforced Ballast



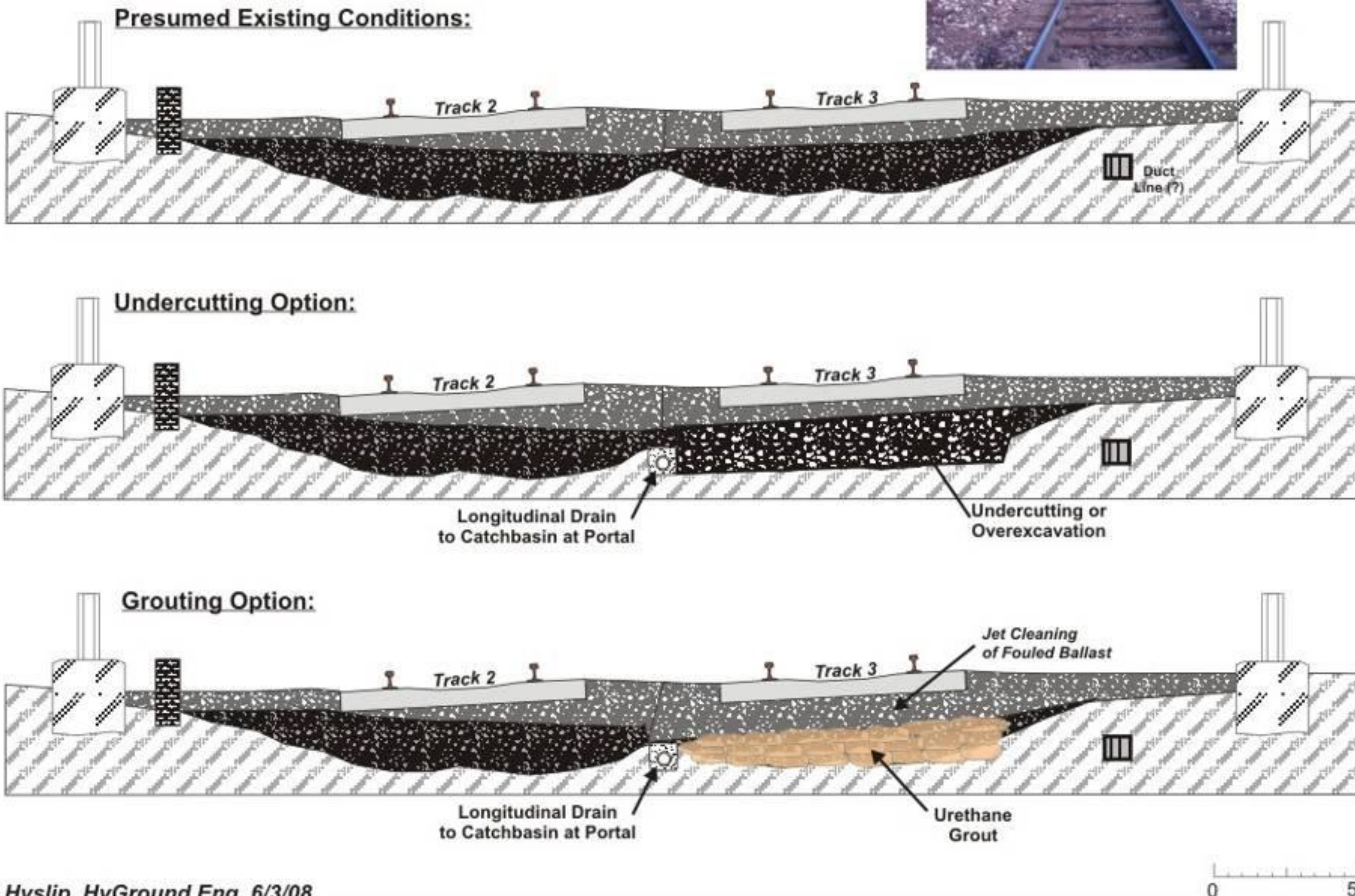

Test Section



Reinforced Ballast – TOR Settlement



Chemical Grouting



J.Hyslip, HyGround Eng. 6/3/08

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