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
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

Track Density
(Millions of Revenue Ton-Miles per mile of track)

- 1.7
- 2.4
- 3.4
- 5.2
- 8.7
- 10.9

263K 286K 315K
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
- **Subgrade protection?**
  → Check minimum required GLT
Granular Layer Thickness Design

(GLT = Ballast + Subballast)

Limits Stress on Subgrade to Prevent:
- Progressive shear failure
- Excessive plastic deformation

Considers
- Operational conditions
- Soil conditions

(Ref. Li, Sussmann & Selig, 1986)
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, $\sigma_s$
  - 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)

Clay Subgrade
Excessive Plastic Deformation (Criterion 2)

Original Subgrade Surface

Subgrade

Trapped Water
GLT Design Example – Soil Conditions

- **Ballast / Subballast**
  - new, clean
  - $E_b = 20,000$ psi

- **Subgrade**
  - Stiff sandy silt (ML)
  - $\sigma_s = 21$ psi, $E_s = 16,000$ psi

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>$a$</th>
<th>$b$</th>
<th>$m$</th>
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<tr>
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<td>1.2</td>
<td>0.18</td>
<td>2.4</td>
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<tr>
<td>CL</td>
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<td>0.16</td>
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<tr>
<td>MH</td>
<td>0.84</td>
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<tr>
<td>ML</td>
<td>0.64</td>
<td>0.10</td>
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Table 1: Soil Parameters for GLT Design
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**
  - $N = (100 \times 20) / (4 \times 18) = 2.8 \times 10^7$ cycles
GLT Example – Criterion 1

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

2) From ‘Beta’ Chart with $\varepsilon_p$ and $N$: $\beta = (\sigma_d / \sigma_s) = 0.62$
3) \[ \sigma_d = \beta \sigma_s = 0.62 \text{ (21 psi) } = 13.0 \text{ psi} \]

4) **Calculate Influence Factor,** \( I_e = \frac{\sigma_d \times A}{P_d} \)
   \[ = \frac{13.0 \times 1000}{58,000} = 0.22 \]
   \[ [A = 1000 \text{ for English units}] \]

5) **From Influence Chart:** \( H / L = 3.0 \)
   \[ [L = 6'' \text{ for English units}] \]

6) \( H = 3.0 \times 6'' = 18.0 \text{ inches} \)
GLT Example – Criterion 2

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

2) Calculate influence factor $I_\rho$:

$$I_\rho = \left( \frac{\rho_a}{L} \right) \left( \frac{P_d}{\sigma_s A} \right)^m \times 100 = 0.85$$
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) \( H = 2.6 \times 6'' = \boxed{15.6} \) inches

Therefore, Criterion 1 controls:

Required GLT = \boxed{18.0} inches
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 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
Substructure Improvements
Substructure Improvements

- HMA
- Reinforcement
- Chemical grouting
Hot Mixed Asphalt (HMA) Underlayement
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°)
Predicted Life of HMA

Based on Huang et al, 1987 and Rose, 1987

12" Ballast, 6" HMA, Ea = 500,000 psi, 36K Wheel Load

(Based on Huang et al, 1987 and Rose, 1987)
Example: Grade Crossing – GPR and HMA

- Trapped Water Extends underneath Crossing, but GPR Scans are Obscured by Grade-Crossing Surface
- Trapped Water
- HMA to Raise Drainage Surface
- High Moisture

Horz: 1” = ~20’
Vert: 1” = ~ 2’
Reinforced Ballast
Test Section

Not to Scale
Reinforced Ballast – TOR Settlement

Settlement (in.)
-2.0
-1.5
-1.0
-0.5
0.0

Clean, Grid
Fouled, Grid
Clean, No Grid
Chemical Grouting

Presumed Existing Conditions:

Undercutting Option:

Grouting Option:

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