BCR2A’09
Railroad Track Design
Including Asphalt Trackbeds
Pre-Conference Workshop

Introduction to
Railroad Track Structural Design

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Interaction, Vertical Load Distribution, and Deflections

Components do not function independently!
Each component layer must protect the one below.
Deflection Profile

Static vs. Dynamic Loads

• Dynamic loads higher
  – Acceleration from speed
  – Downward rotation of wheel
  – Smaller wheels, faster rotation, more acceleration

• Speed/wheel influence
  – \( P_v = P + \theta P \)  (AREMA)
    where \( P_v \) = Vertical Dynamic Load (lbs)
    \( \theta = \frac{D_{33} x V}{D_w x 100} \)
    \( D = \) Wheel diameter (in)
    \( V = \) Speed (MPH)
    \( P = \) Static Load (lbs)
  – Larger wheels impose less influence

• Additional dynamic loads from impacts such as caused by wheel flat spots, rail discontinuities (e.g. frog flangeways), track transitions (e.g. bridge approaches), track condition, etc.
Different Wheel Diameters

- 33 inches
- 36 inches
- 38 inches
- 28 inches
Track Stiffness

• Rail is assumed to be a beam on an elastic foundation

• Modulus of Track Elasticity, $u$ (or $k$) (a.k.a. Track Modulus)

  $$u = \frac{P}{\Delta}$$

  where
  
  $u =$ Modulus of Track Elasticity (lbs/in/in)
  $P =$ Wheel load per unit length of rail (lbs/in)
  $\Delta =$ Unit of Track Deflection (in), less “play” or track “looseness”

  or

  $$u = \frac{P}{S}$$

  where
  
  $u =$ Modulus of Track Elasticity (lb/in/in)
  $P =$ Wheel load (lbs) required to deflect the track 1 inch on one tie
  $S =$ Tie spacing (in)
Classic Approach to Track Analysis and Design

- Continuously supported beam

Notes:
- $a =$ tie spacing “s”
- $w(x) =$ deflection “y”

• Talbot equations

Rail Moment: \[ M_o = 0.318P x_1 \]
Deflection: \[ Y_o = 0.391P/u x_1 \]
Rail Seat Load: \[ Q_o = 0.391PS/x_1 \] (Note: \( Q_o \) a.k.a. \( F_{max} \))

where: \( P = \) Wheel Load (lbs)
\( u = \) Track Modulus (lbs/in/in)
\( S = \) Tie spacing (in)
\( x_1 = (\pi/4)(4EI/u)^{1/4} \) (in)
\( EI = \) Flexural rigidity of rail

with: \( E = \) Modulus of Elasticity of Rail (30x10^6 psi)
\( I = \) Rail Moment of Inertia (in^4)
Master Diagram

Source: Hay, W.W., Railroad Engineering, 1982
Load Deflections and Bending Moments

Source: Hay, W.W., Railroad Engineering, 1982
Determination of Rail Seat Forces (Q or F)

Pressure $p(x)$ [lb/in] Curve

Source: Kerr, A.D., Fundamentals of Railway Track Engineering, 2003
Pressure Distribution vs. Track Modulus

Pressure distribution for 115 RE rail and various $k$-values

Source: Kerr, A.D., Fundamentals of Railway Track Engineering, 2003
Pressure Distribution vs. Rail Weight

Pressure distribution for various rails and $k = 3,000 \text{ lb/in}^2$

Source: Kerr, A.D., Fundamentals of Railway Track Engineering, 2003
Relationship Between $F_{\text{max}}$ ($Q_o$) and $P$

Source: Kerr, A.D., Fundamentals of Railway Track Engineering, 2003
Maximum Rail Moment and Rail Seat Force Locations

Maximum Rail Seat Force Locations

Maximum Rail Bending Moment Locations
Design Steps (AREMA, U.S. DoD, and Others)  
(Generalized)

1. Select design wheel load based on most common, heaviest car and desired track speed. Consider all wheels in a truck and proximity of adjacent cars.

2. Select a Track Modulus, \( u \) or \( k \), based on desired design deflection

3. Select rail size and section

4. Determine moment and loading coefficients

5. Check rail bending stress

6. Choose trial tie spacing and calculate maximum rail seat load
Design Steps (con’t)

7. Select tie size
8. Check tie bending stress
9. Determine and select plate size based on minimum area
10. Determine ballast surface stress
11. Determine ballast depth based on allowable subgrade stress
12. Calculate track deflection under load and check on acceptability
13. If deflection is unacceptable, re-do design

Always consider economics!
## Track Deflection vs. Track Performance

![Diagram showing track deflection ranges](image)

<table>
<thead>
<tr>
<th>Range</th>
<th>Track Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Deflection range for track that will last indefinitely</td>
</tr>
<tr>
<td>B</td>
<td>Normal maximum desirable deflection for heavy track to give requisite combination of flexibility and stiffness</td>
</tr>
<tr>
<td>C</td>
<td>Limit of desirable deflection for track of light construction (≤100 lb)</td>
</tr>
<tr>
<td>D</td>
<td>Weak or poorly maintained track that will deteriorate quickly</td>
</tr>
</tbody>
</table>

Track Modulus, $u$ or $k$, Typical Values

- Well maintained wood tie track, $\approx 3000$ lb/in/in
- Concrete tie track, $\approx 6000$ lb/in/in
- Wood tie track after tamping, $\approx 1000$ lb/in/in
- Wood tie track with frozen ballast/subgrade, $\approx 9000$ lb/in/in
- Track on Ballasted Concrete Bridge Deck, $\approx 8000$ to $12000$ lb/in/in

Modulus higher during excessively dry periods and lower when subgrade at or near saturation.
Rail Analysis and Design
(weight and section selection)

• Many rail weights and sections have evolved by the efforts of various designers
  – American Railway Association (ARA) forerunner to Association of American Railroads (AAR) {branded RA or RB on rail}
  – American Society of Civil Engineers (ASCE) {branded AS}
  – American Railway Engineering and Maintenance of Way Association (AREMA) (formerly American Railway Engineering Association (AREA)) {branded RE}
  – International Union of Railways {branded UIC}
  – Railroads (many designations)

  Note: Sometimes numbers, not letters, are used to denote sections. Depends on manufacturer.
• **Bending stress**

\[ S = \frac{M_o c}{I} \text{ or } S = \frac{M_o}{Z} \]

where

- \( S \) = Bending stress, psi
- \( M_o \) = Max bending moment, in-lbs
- \( c \) = Distance to base from neutral axis, in
- \( I \) = Moment of inertia of rail, \( \text{in}^4 \)
- \( Z \) = Section modulus, \( I/c \) (properties of rail section)

• **Allowable bending stress, typically is:**
  
  - 32,000 psi for jointed rail
  - 25,000 psi for continuously welded rail (CWR)
• Maximum bending moment, $M_o$

$$M_o = P(EI/64u)^{1/4} \quad (M_o = 0.318P_{x1})$$

where $M_o = \text{Max bending moment}$

$P = \text{Max wheel load, lbs (static or dynamic)}$

$E = \text{Modulus of elasticity} = 30 \times 10^6 \text{ psi}$

$I = \text{Moment of inertia, in}^4$

$u = \text{track modulus, lbs/in/in}$

Note: Must account for moments from adjacent wheels. Compute from Master Diagram, computer code, or EXCEL.

• $I$ and $c$ are a function of design
  – Greater weight - greater $I$
  – Increase height - greater $I$ (limiting factor is web height - thickness ratio)

• Must keep maximum bending stress less than or equal to allowable bending stress
### TABLE 24.3 Properties of Typical Rail Sections

<table>
<thead>
<tr>
<th>Section</th>
<th>Weight per Yard (lb)</th>
<th>Moment of Inertia (in.)</th>
<th>Base to Neutral Axis (in.)</th>
<th>Section Modulus (Base)</th>
<th>Area (sq in.)</th>
<th>Height (in.)</th>
<th>Base Width (in.)</th>
<th>Head Width (in.)</th>
<th>Head Radius (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>133 RE</td>
<td>133.4</td>
<td>86.0</td>
<td>3.20</td>
<td>27.0</td>
<td>13.08</td>
<td>$\frac{7}{16}$</td>
<td>6</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>132 RE</td>
<td>132.1</td>
<td>88.2</td>
<td>3.20</td>
<td>27.6</td>
<td>12.95</td>
<td>$\frac{7}{8}$</td>
<td>6</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>131 RE</td>
<td>131.2</td>
<td>89.0</td>
<td>3.20</td>
<td>27.0</td>
<td>12.90</td>
<td>$\frac{7}{8}$</td>
<td>6</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>130 RE</td>
<td>130.0</td>
<td>77.4</td>
<td>3.03</td>
<td>25.5</td>
<td>12.71</td>
<td>$\frac{3}{4}$</td>
<td>6</td>
<td>2\frac{15}{16}</td>
<td>14</td>
</tr>
<tr>
<td>120 RE</td>
<td>120.9</td>
<td>67.6</td>
<td>2.92</td>
<td>23.1</td>
<td>11.85</td>
<td>$\frac{1}{2}$</td>
<td>5\frac{3}{4}</td>
<td>2\frac{7}{8}</td>
<td>14</td>
</tr>
<tr>
<td>115 RE</td>
<td>114.7</td>
<td>65.6</td>
<td>2.98</td>
<td>22.0</td>
<td>11.25</td>
<td>$\frac{5}{8}$</td>
<td>5\frac{1}{2}</td>
<td>2\frac{21}{32}</td>
<td>10</td>
</tr>
<tr>
<td>112 RE</td>
<td>112.3</td>
<td>65.5</td>
<td>3.00</td>
<td>21.8</td>
<td>11.01</td>
<td>$\frac{5}{8}$</td>
<td>5\frac{1}{2}</td>
<td>2\frac{23}{32}</td>
<td>14</td>
</tr>
<tr>
<td>110 RE</td>
<td>110.4</td>
<td>57.0</td>
<td>2.83</td>
<td>20.1</td>
<td>10.82</td>
<td>$\frac{1}{4}$</td>
<td>5\frac{1}{2}</td>
<td>2\frac{25}{32}</td>
<td>14</td>
</tr>
<tr>
<td>100 RE</td>
<td>101.5</td>
<td>49.0</td>
<td>2.75</td>
<td>17.8</td>
<td>9.95</td>
<td>6</td>
<td>5\frac{3}{8}</td>
<td>2\frac{11}{16}</td>
<td>14</td>
</tr>
<tr>
<td>90 RA A</td>
<td>90.0</td>
<td>38.7</td>
<td>2.54</td>
<td>15.23</td>
<td>8.82</td>
<td>$\frac{5}{8}$</td>
<td>5\frac{1}{8}</td>
<td>2\frac{3}{16}</td>
<td>14</td>
</tr>
<tr>
<td>75 AS</td>
<td>75.2</td>
<td>23.0</td>
<td>2.36</td>
<td>10.0</td>
<td>7.38</td>
<td>$\frac{13}{16}$</td>
<td>4\frac{3}{16}</td>
<td>2\frac{15}{32}</td>
<td>12</td>
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<tr>
<td>106 CF&amp;I</td>
<td>106.6</td>
<td>53.6</td>
<td>2.85</td>
<td>18.8</td>
<td>10.45</td>
<td>$\frac{3}{16}$</td>
<td>5\frac{1}{2}</td>
<td>2\frac{21}{32}</td>
<td>14</td>
</tr>
<tr>
<td>119 CF&amp;I</td>
<td>118.8</td>
<td>71.4</td>
<td>3.12</td>
<td>22.9</td>
<td>11.65</td>
<td>$\frac{13}{16}$</td>
<td>5\frac{1}{2}</td>
<td>2\frac{21}{32}</td>
<td>14</td>
</tr>
<tr>
<td>136 CF&amp;I</td>
<td>136.2</td>
<td>94.9</td>
<td>3.35</td>
<td>28.3</td>
<td>13.35</td>
<td>$\frac{5}{16}$</td>
<td>6</td>
<td>2\frac{15}{16}</td>
<td>14</td>
</tr>
<tr>
<td>155 PS</td>
<td>155.0</td>
<td>129.0</td>
<td>3.38</td>
<td>36.7</td>
<td>15.20</td>
<td>8</td>
<td>6\frac{3}{4}</td>
<td>3</td>
<td>–</td>
</tr>
<tr>
<td>152 PS</td>
<td>152.0</td>
<td>130.0</td>
<td>3.50</td>
<td>37.0</td>
<td>14.90</td>
<td>8</td>
<td>6\frac{3}{4}</td>
<td>3</td>
<td>–</td>
</tr>
<tr>
<td>140 PS</td>
<td>140.6</td>
<td>97.0</td>
<td>3.37</td>
<td>29.0</td>
<td>13.80</td>
<td>$\frac{5}{16}$</td>
<td>6</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

Tie Analysis and Design  
(size and spacing)

- Action under load
  - Early belief that tie reaction was uniform
  - Not so, Talbot found that stress concentrated under rail seat

Source: Hay, W.W., Railroad Engineering, 1982
Theoretical Design

- Force diagram (close to center-bound condition)

- Look at bending moments under center and rail seat
  - $M_c = (Q_o/4)(L_1 - 2L_2)$
  - $M_r = -Q_oL_2^2/L$

$L = L_1 + 2L_2$

$Q_o$ must account for adjacent wheels. Recall, pressure distribution and principle of superposition.
Maximum allowable bending moment

- Simple beam moment
  
  \[ S = \frac{Mc}{I} \]
  
  or
  
  \[ M = \frac{SI}{c} \]

  where

  - \( M \) = bending moment, inch-lbs
  - \( I \) = moment of inertia = \( \frac{bh^3}{12} \), in\(^4\)
  - \( c \) = dist from base to neutral axis = \( \frac{h}{2} \), inches
  - \( S \) = allowable wood fiber bending stress, lb/in\(^2\)
  - \( h \) = tie height, inches
  - \( b \) = tie width, inches

  then

  \[ M = \frac{(bh^3S/12)}{(h/2)} = bh^2S/6 \]

- \( S \) varies by wood specie (e.g., 1000 psi for shortleaf yellow pine, 1200 psi for longleaf yellow pine, 900 psi for douglas fir, and 1400 psi for oak)
• "Optimal" tie length

Source: Hay, W.W., Railroad Engineering, 1982
Practical Design

• Load distribution

  – Bearing area is \( \frac{2}{3} \) of tie length (tamping zone), so

  \[
  A'_{b} = \frac{2}{3}Lb
  \]

  and unit load on ballast will be

  \[
  p_{a} = \frac{2Q_{o}}{A'_{b}}
  \]

  thus

  \[
  p_{a} = \frac{3Q_{o}}{Lb}
  \]

  where

  \[
  p_{a} = \text{unit tie pressure on ballast} \leq 65 \text{ psi for wood, } \leq 85 \text{ psi for concrete}
  \]

  \[
  A'_{b} = \text{total tie bearing area, } \text{in}^{2}
  \]

  \[
  L = \text{tie length, inches}
  \]

  \[
  b = \text{tie width, inches}
  \]

  \[
  Q_{o} = \text{Rail seat load, lbs (static or dynamic), based on trial tie spacing}
  \]
Plate Analysis and Design
(size selection)

• Two basic types
  – Single shoulder
  – Double shoulder

• Size
  – Width sized to fit tie
  – Length to keep stress on wood tie $\leq 200$ psi
  – Stress = $Q_o$/Plate Area
  – Limited set of fixed sizes
    (generally choose smallest size possible for economics)

• Distance between shoulders
  (double shouldered plates)
  spaced to match rail base width
Ballast Analysis and Design
(depth determination)

Source: AREMA, Manual for Railway Engineering, Chapter 16, 2000
Gaussian Distribution Curves and Subgrade Pressure

• Ballast depth (ballast and subballast combined) = \( f(\text{applied stress, tie reaction, and allowable subgrade stress}) \)
  
  – Talbot Equation
    \[ h = (16.8p_a/p_c)^{4/5} \]
    where  
    \( h \) = Support ballast depth  
    \( p_a \) = Stress at bottom of tie (top of ballast)  
    \( p_c \) = Allowable subgrade stress  
    Note: Stress distribution independent of material  
  
  – Japanese National Railways Equation
    \( p_c = \frac{50p_a}{(10+h^{1.25})} \)
  
  – Boussinesq Equation
    \( p_c = \frac{6P}{2\pi h^2} \)  
    where \( P = \) wheel load (lbs)
  
  – Love’s Formula
    \( p_c = p_a\{1-[1/(1+r^2/h^2)]^{3/2}\} \)
    where  
    \( r \) = Radius of a loaded circle whose area equals the effective tie bearing area under one rail
• **Ballast vs. subballast**
  - New construction or reconstruction
    • Generally, half of overall ballast depth should be highest quality available
    • 6” minimum depth for subballast (AREMA)
    • Railroads may have own minimums (e.g. CN requires 12”)
  - Existing track
    • All or some of the “old” ballast layer becomes “new” subballast layer when new ballast is added, but old material likely to be of marginal quality and layer function may be compromised
    • Bottom ballast and subballast differentiation becomes blurred
  • “Ballast” layer often described as having a “top” ballast section and “bottom” ballast section. The “top” ballast section encompasses the tamping zone.
Subgrade Allowable Stress (Pressure)

- "Traditional" design value of 20 psi
- AREMA recommends limiting stress to 25 psi
- Using soil strength with a factor of safety
  - AREMA recommends a factor of safety of at least 2 and as much as 5 or more depending on the traffic (wheel loads and load repetitions) and soil conditions.
  - Company design standards will dictate (e.g. Army allows a design unconfined compressive strength \(q_u\) of 1.0 \(q_u\) for "normal" traffic levels - less than 5 MGT/yr - and design of 0.8 \(q_u\) when traffic levels exceed 5 MGT.)
  - Hay recommends factor of safety of 1.5 as applied to an ultimate bearing capacity of \(\leq 2.5\ q_u\), thus allowable stress \(\leq 1.67\ q_u\).
# Allowable Subgrade Bearing Pressures

## Table 10.4 Allowable subgrade bearing pressures

<table>
<thead>
<tr>
<th>Subgrade Description</th>
<th>In-Place Consistency</th>
<th>Allowable Pressure below Track psi</th>
<th>kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well graded mixture of fine and coarse grained soils: glacial till, hardpan, boulder clay (GW-GC, GC, SC)</td>
<td>Very compact</td>
<td>65 - 100</td>
<td>450 - 690</td>
</tr>
<tr>
<td>Gravel, gravel-sand mixtures, boulder-gravel mixtures (GW, GP, SW, SP)</td>
<td>Very compact</td>
<td>55 - 85</td>
<td>380 - 590</td>
</tr>
<tr>
<td></td>
<td>Medium to Compact</td>
<td>40 - 60</td>
<td>280 - 410</td>
</tr>
<tr>
<td></td>
<td>Loose</td>
<td>25 - 50</td>
<td>170 - 350</td>
</tr>
<tr>
<td>Coarse to medium sand, sand with little gravel (SW, SP)</td>
<td>Very compact</td>
<td>30 - 50</td>
<td>210 - 350</td>
</tr>
<tr>
<td></td>
<td>Medium to Compact</td>
<td>25 - 30</td>
<td>170 - 210</td>
</tr>
<tr>
<td></td>
<td>Loose</td>
<td>15 - 25</td>
<td>100 - 170</td>
</tr>
<tr>
<td>Fine to medium sand, silty or clayey medium to coarse sand (SW, SM, SC)</td>
<td>Very compact</td>
<td>25 - 40</td>
<td>170 - 280</td>
</tr>
<tr>
<td></td>
<td>Medium to Compact</td>
<td>15 - 30</td>
<td>100 - 210</td>
</tr>
<tr>
<td></td>
<td>Loose</td>
<td>8 - 15</td>
<td>60 - 100</td>
</tr>
<tr>
<td>Fine sand, silty or clayey medium to fine sand (SP, SM, SC)</td>
<td>Very compact</td>
<td>25 - 30</td>
<td>170 - 210</td>
</tr>
<tr>
<td></td>
<td>Medium to Compact</td>
<td>15 - 25</td>
<td>100 - 170</td>
</tr>
<tr>
<td></td>
<td>Loose</td>
<td>8 - 15</td>
<td>60 - 100</td>
</tr>
<tr>
<td>Homogeneous inorganic clay, sandy or silty clay (CL, CH)</td>
<td>Very stiff to hard</td>
<td>25 - 50</td>
<td>170 - 350</td>
</tr>
<tr>
<td></td>
<td>Medium to stiff</td>
<td>8 - 25</td>
<td>60 - 170</td>
</tr>
<tr>
<td></td>
<td>Soft</td>
<td>4 - 8</td>
<td>30 - 60</td>
</tr>
<tr>
<td>Inorganic silt, sandy or clayey silt, varved silt-clay-fine sand (ML, MH)</td>
<td>Very stiff to hard</td>
<td>15 - 30</td>
<td>100 - 210</td>
</tr>
<tr>
<td></td>
<td>Medium to stiff</td>
<td>8 - 25</td>
<td>60 - 170</td>
</tr>
<tr>
<td></td>
<td>Soft</td>
<td>4 - 8</td>
<td>30 - 60</td>
</tr>
</tbody>
</table>

Source: Selig and Waters, Track Geotechnology and Substructure Management, 1994
Design Standards, Criteria, and Approaches

- Many railroads (including non-U.S. railroads) have established design standards and/or criteria.
- Differences do exist between railroads. Examples include:
  - Some use \( \frac{2}{3} \) of wood tie length in analyses; some use entire length.
  - Some use entire concrete tie length in analyses; some use \( \frac{2}{3} \) length.
  - Some use a rail seat force of \( Q_o \times 1.5 \).
  - Allowable bending stress in rail may vary.
  - Allowable rail seat load for determining plate size may vary. Depends on wood specie. Range about 250 – 400 psi. (AREMA recommends 200 psi).
• Differences (con’t)
  – AREMA recommends a tie reaction of 65 lbs/in$^2$ under wood ties and 85 lbs/in$^2$ under concrete ties, but some railroads use the same for both (e.g. 75 lbs/in$^2$) – Stiffer track $\rightarrow$ Higher loads!
    • Why these values?
    • Ballast quality and ability to resist crushing forces (ballast degradation is the number 1 cause of ballast fouling)
  – Some railroads use different track modulus (u) values in design. For example, Spring u may be used for rail bending and ballast depth, but Winter u used for rail seat forces. Other railroads may use a single u value.
# Canadian National Example

## SPC 1301

### TABLE 1

**MINIMUM TRACK CONSTRUCTION STANDARDS**

<table>
<thead>
<tr>
<th>Description</th>
<th>Class 4 and Above</th>
<th>Class 2 &amp; 3</th>
<th>Class 1 and Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rail Weight</strong></td>
<td>Per SPC 3200 - Appendix &quot;C&quot; or as specified by the Division Engineer</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rail</strong></td>
<td>CWR</td>
<td>Class 3 - CWR</td>
<td>Class 2 - Jointed</td>
</tr>
<tr>
<td>(CWR or Jointed)</td>
<td></td>
<td></td>
<td>Jointed</td>
</tr>
<tr>
<td><strong>Tie Plates</strong></td>
<td>Per SPC 3600</td>
<td>Per SPC 3600</td>
<td>Per SPC 3600</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Rail Anchors</strong></td>
<td>Per SPC 3601</td>
<td>Per SPC 3601</td>
<td>Per SPC 3601</td>
</tr>
<tr>
<td><strong>Fasteners</strong></td>
<td>Elastic Fasteners</td>
<td>Cut Spikes</td>
<td>Cut Spikes</td>
</tr>
<tr>
<td></td>
<td>Cut Spikes (per SPC 3604)</td>
<td>(per SPC 3604)</td>
<td>(per SPC 3604)</td>
</tr>
<tr>
<td><strong>Ties Per Mile</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>2640</td>
<td>2640</td>
<td></td>
</tr>
<tr>
<td>Wood No. 1</td>
<td>3110</td>
<td>3110</td>
<td></td>
</tr>
<tr>
<td>Wood No. 2</td>
<td></td>
<td></td>
<td>Class 1 - 2980</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Industrial - 2840</td>
</tr>
<tr>
<td><strong>Track Ties</strong></td>
<td>Concrete (per SPC 3303)</td>
<td>Concrete (per SPC 3303)</td>
<td>Softwood or Hardwood</td>
</tr>
<tr>
<td></td>
<td>Hardwood</td>
<td>Hardwood</td>
<td>Hardwood</td>
</tr>
<tr>
<td><strong>Switch Ties</strong></td>
<td>Hardwood</td>
<td>Hardwood</td>
<td>Hardwood</td>
</tr>
<tr>
<td>Ballast</td>
<td>2-½” minus</td>
<td>2-½” minus or 2” minus</td>
<td>2” minus or AREMA Size No. 5</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------</td>
<td>------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Crushed Rock</td>
<td>12 inches</td>
<td>12 inches</td>
<td>6 inches</td>
</tr>
<tr>
<td>Minimum Depth Below Bottom of Tie</td>
<td>CWR–12”</td>
<td>Jointed-6”, CWR–12”</td>
<td>Jointed-6”</td>
</tr>
<tr>
<td>Shoulder width</td>
<td></td>
<td>AREMA Size No. 5</td>
<td>AREMA Size No. 5</td>
</tr>
<tr>
<td>Walking Ballast*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Sub-ballast                  |            |                        |                             |
| Minimum Depth                | 12 inches  | 12 inches              | 12 inches                   |
| Maintained Top Width         | 22 ft.     | 22 ft.                 | 22 ft.                      |

* Where walking ballast is required, it shall be applied in a minimum 4” thick surficial layer
BNSF Standard Cross Section
Shortcomings and Things to Think About

• Design approach is part science, part “art”
• Track modulus is neither constant nor precise
• Relationship between track deflection and performance not exact
• Assumed Gaussian pressure distribution not entirely correct
• The challenge is in determining allowable ballast and subgrade stresses
• Design approach is not robust
  – Ballast and subgrade properties not adequately considered
  – Tonnage (MGT) and load repetitions considered only indirectly
  – Variability in ballast/subgrade properties abound
  – Design approach does not consider maintenance issues and track degradation affects
  – Cannot consider usage of HMA and/or other reinforcing layers in design
  – Others
• Standard designs sometimes misapplied or interpreted
• Others
References


