KENTRACK – A Railway Trackbed Structural Design Program

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Introduction

- Railroads
- Track Superstructure
- Track Substructure – support system
- Research in the last 20 years
HMA Trackbeds

- Overlayment
  - Ties placed directly over asphalt
  - Ballast is only used for cribbing
HMA Trackbeds

- Underlayment
  - HMA layer present between ballast and subgrade
  - Preferred over overlayment
  - Better service life than overlayment
HMA Trackbeds

- Underlayment
HMA Trackbeds

- Stronger support layer
- Reduced stresses onto subgrade
- Waterproofing layer
- No subgrade pumping
- Confining layer for ballast
Background

- Theoretical method
- Bousinessq’s Elastic Theory
  - Deficiencies:
  - Assumes the support system to be elastic, isotropic
Background

- Empirical equations
  - JNR Equation

\[ P_c = \frac{50P_m}{10 + h^{1.35}} \]

- Talbot’s Equation

\[ P_c = \frac{16.8P_m}{h^{1.25}} \]
Background

- **ILLITRACK**
  - Finite element method
  - Two dimensional

- **GEOTRACK**
  - Multilayered theory
  - Three dimensional model
  - It was developed to analyze all-granular trackbeds
Background

- **KENTRACK**
  - Developed specifically to analyze HMA trackbeds
  - Has the versatility to analyze all-granular trackbeds
  - Initially a DOS based program
  - Upgraded to a windows based platform with a Graphic User Interface
Theory behind KENTRACK

- Superposition of Loads

\[ S'_1 = S_2 \frac{P_1}{P} + S_4 \frac{P_2}{P} \]
- To calculate stresses and strains in rail and tie
Theory behind KENTRACK

- Multilayered System

- To calculate stresses and strains in the layers
Theory behind KENTRACK

- Material Properties
  - HMA trackbed is comprised of ballast, HMA and subgrade
  - All-granular trackbed is comprised of ballast, subballast and subgrade
  - Different equations are used to describe the material properties
Theory behind KENTRACK

- **Ballast**
  - In a new trackbed it behaves non-linearly
  - In an aged trackbed it behaves linearly

\[ E = K_1 \theta^{K_2} \]

\[ \theta = \sigma_1 + \sigma_2 + \sigma_3 + \gamma z (1 + 2K_0) \]

- **Subgrade**
  - Linearly elastic material
Theory behind KENTRACK

- Hot Mix Asphalt (HMA)
  Visco-elastic material
The dynamic modulus of HMA depends on
  - Temperature
  - Aggregate passing No. 200 sieve in %
  - Volume of bitumen %
  - Volume of air voids %
  - Asphalt viscosity
  - Load frequency
Theory behind KENTRACK

- Damage Analysis
  - Based on minor linear damage analysis criteria
  - Performed by periods (seasons, months)

\[ L = \frac{1}{\sum_{i=1}^{n} \frac{N_p}{N_a \text{ or } N_d}} \]
Predicted number of repetitions

Wheel Load = 36000 lb/wheel

For one car the total weight = 36000 lb/wheel x 8
= 286,000 lb/rep / 2000
= 143 ton/rep

The number of repetitions assumed per year = 200,000 rep/yr

The traffic per year = 200,000 rep/yr x 143 ton/rep
= 28,600,000 GT/yr / 1 x 10^6
= 28.6 MGT/yr
Theory behind KENTRACK

- HMA Damage Analysis
  - Fatigue cracking controls failure
  - Fatigue cracking is governed by the tensile strain at the bottom of HMA
  - Based on highway experience
  - Number of allowable repetitions ($N_a$) before failure

\[
N_a = 0.0795 \varepsilon_t^{-3.291} E_a^{-0.853}
\]
Theory behind KENTRACK

- **Subgrade Damage Analysis**
  - Excessive permanent deformation controls failure
  - Deformation is governed by the vertical compressive stress on top of subgrade
  - Based on highway experience
  - Number of allowable repetitions \( (N_d) \) before failure

\[
N_d = 4.837 \times 10^{-5} \sigma_c^{-3.734} E_s^{+3.583}
\]
Theory behind KENTRACK

Stresses and Strains

Asphalt Trackbed

All-Granular Trackbed
Methodology

- HMA trackbed cross-section

- Axle load = 36 ton
- Rail = RE132
- Wood tie

- Ballast layer: 8 in. thick
- HMA layer: 6 in. thick
- Subgrade: 200 in. thick

Subgrade modulus = 12,000 psi
Methodology

- Ballast trackbed cross-section
Methodology

- **Critical outputs for the two sections**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Standard HMA trackbed</th>
<th>Standard Ballast Trackbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgrade Vertical Compressive Stress (psi)</td>
<td>11.9</td>
<td>13.8</td>
</tr>
<tr>
<td>HMA Tensile Strain (in/in)</td>
<td>0.000183</td>
<td>N/A</td>
</tr>
<tr>
<td>Service life of Subgrade (yrs)</td>
<td>15.2</td>
<td>5.6</td>
</tr>
<tr>
<td>Service life of HMA (yrs)</td>
<td>19.8</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Effect of Subgrade Modulus on $\sigma_c$

Axle Load – 36 tons

![Graph showing the effect of subgrade modulus on vertical compressive stress. The graph compares HMA Trackbed and Ballast Trackbed. The y-axis represents Vertical Compressive Stress (psi), ranging from 0 to 18 psi in increments of 2 psi. The x-axis represents Subgrade Modulus (psi), with values ranging from 3000 to 21000 in increments of 3000 psi. Two bars for each subgrade modulus value are shown, one for HMA Trackbed and one for Ballast Trackbed. The bars for Ballast Trackbed are generally higher than those for HMA Trackbed.]
Effect of Subgrade Modulus on L 

Axle load - 36 tons 

Predicted Service Life (yrs) vs. Subgrade Modulus (psi) 

- Subgrade Life in Ballast Trackbed 
- Subgrade Life in HMA Trackbed 
- HMA Life in HMA Trackbed
Effect of Subgrade Modulus on $\varepsilon_t$

Axle load – 36 tons

![Bar chart showing the effect of subgrade modulus on tensile strain for an axle load of 36 tons. The x-axis represents subgrade modulus in psi, ranging from 3000 to 21000, and the y-axis represents HMA tensile strain in in/in. The chart illustrates how tensile strain increases with decreasing subgrade modulus.]
Effect of Axle Load on $\sigma_c$

HMA Trackbed

Ballast Trackbed
Effect of Axle Load on $\varepsilon_t$

![Graph showing the effect of axle load on HMA tensile strain for different subgrade moduli.](image-url)
Effect of Axle Load on $L_a$

![Bar chart showing the predicted service life of HMA with different subgrade moduli and axle loads.](chart.png)
Effect of Axle Load on $L_d$

HMA Trackbed

Ballast Trackbed
## Effect of Ballast Thickness

Asphalt Track Bed  
Subgrade Modulus 12000 psi, Axle Load 36 ton

<table>
<thead>
<tr>
<th>conditions</th>
<th>Tensile Strain in the asphalt</th>
<th>Compressive Stress on Subgrade</th>
<th>Service life of Asphalt Layer</th>
<th>Service life of subgrade layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Thickness - 4 Ballast Thickness - 10</td>
<td>0.000167</td>
<td>12.6</td>
<td>23.77</td>
<td>10.36</td>
</tr>
<tr>
<td>Asphalt Thickness - 6 Ballast Thickness - 8</td>
<td>0.000183</td>
<td>11.9</td>
<td>20.42</td>
<td>15.51</td>
</tr>
<tr>
<td>Asphalt Thickness - 8 Ballast Thickness - 6</td>
<td>0.000180</td>
<td>11.0</td>
<td>22.37</td>
<td>23.3</td>
</tr>
</tbody>
</table>
### Effect of Ballast Thickness

<table>
<thead>
<tr>
<th>Subballast Thickness - 0</th>
<th>Compressive Stress on Subballast</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast Thickness – 14</td>
<td>Compressive Stress on Subgrade</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>Service life of Subballast Layer</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Service life of subgrade layer</td>
<td>5.56</td>
</tr>
<tr>
<td>Subballast Thickness - 6</td>
<td>Compressive Stress on Subballast</td>
<td>20.1</td>
</tr>
<tr>
<td>Ballast Thickness - 8</td>
<td>Compressive Stress on Subgrade</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>Service life of Subballast Layer</td>
<td>2.13</td>
</tr>
<tr>
<td></td>
<td>Service life of subgrade layer</td>
<td>5.72</td>
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<tr>
<td>Subballast Thickness - 8</td>
<td>Compressive Stress on Subballast</td>
<td>23.4</td>
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<tr>
<td>Ballast Thickness - 6</td>
<td>Compressive Stress on Subgrade</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>Service life of Subballast Layer</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>Service life of subgrade layer</td>
<td>6.03</td>
</tr>
</tbody>
</table>

Ballast Track Bed
Subgrade Modulus 12000 psi, Axle Load 36 ton
### Comparison of the KENTRACK Predictive values (KPV) Versus In-Track Data (ITD) for the CSX Mainline at Conway, Kentucky

<table>
<thead>
<tr>
<th>Thickness Ballast-HMA inches</th>
<th>Vertical Compressive Stress on <strong>Ballast</strong> KPV/TTD psi</th>
<th>Vertical Compressive Stress on <strong>HMA</strong> KPV/TTD psi</th>
<th>Vertical Compressive Stress on <strong>Subgrade</strong> KPV/TTD psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 / 5</td>
<td>47.9 / -</td>
<td>21.0 / 16.0</td>
<td>13.6 / -</td>
</tr>
<tr>
<td>10 / 8</td>
<td>48.7 / -</td>
<td>22.0 / 15.0</td>
<td>11.7 / -</td>
</tr>
</tbody>
</table>

### Comparison of the KENTRACK Predictive values (KPV) Versus In-Track Data (ITD) at TTCI in Pueblo, Colorado

<table>
<thead>
<tr>
<th>Thickness Ballast-HMA inches</th>
<th>Vertical Compressive Stress on <strong>Ballast</strong> KPV/TTD psi</th>
<th>Vertical Compressive Stress on <strong>HMA</strong> KPV/TTD psi</th>
<th>Vertical Compressive Stress on <strong>Subgrade</strong> KPV/TTD psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 / 4</td>
<td>43.5 / -</td>
<td>11.7 / 14.9</td>
<td>8.3 / 8.0</td>
</tr>
<tr>
<td>8 / 8</td>
<td>47.0 / -</td>
<td>21.9 / 114.9</td>
<td>8.2 / 7.7</td>
</tr>
</tbody>
</table>
Summary

- KENTRACK is a versatile program that can be used to analyze HMA and all-granular trackbeds
- HMA trackbeds improve the service life and perform better than all-granular trackbeds
- Damage analysis values are conservative
- Subgrade modulus is a very important factor in trackbed design
Future Research

- Study the aging of HMA in railroad trackbeds.
- Develop damage analysis equations for HMA and all-granular trackbeds.
- Attempt to incorporate dynamic factors in the analysis.
KENTRACK Version 2.0.1

- Modified from DOS to Windows with a Graphic User Interface
- Values can be modified easier than the previous version
- Data files can be opened using the new version
- Input and output files can be accessed easily
KENTRACK Version 2.0.1

Contains:
• Program
• Help File
• Example Data Files

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