Rehabilitating Crossing Surfaces
Effect of Sub-Structure Design on Long-Term Performances of Highway-Railway At-Grade Crossings
by
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Goals and Attributes
Rail/Highway Crossing Management

• Cost Effective Crossing
  – Safe
  – Smooth
  – Servicable
  – Long life

• Stable and Smooth
  – No costly disruption
  – Can be skipped over

• Accomplish
  – Minimum of time
  – 4-hour train curfew
  – 8 to 12-hour highway closure

• Utilize Cooperative Approach
  – Railroad company (contractor)
  – Local highway/governmental agency
Requirements and Objectives

• Fast-Track – RR = 4 hrs. Hwy = 8 to 12 hrs.
• Pre-Planned – Optimum Date, Share Responsibilities, Share Cost
• Cooperative – Railroad and Government Agency
• Premium Materials – Surface and Structure
• Quality Construction Techniques
• Adequately Engineered for Site
• Uses Latest Technology
Typical All-Granular Trackbed

Asphalt Underlayment Trackbed
Asphalt Underlayment

Compacted Ballast

Tie

Surface

Asphalt Trench

- Strengthens Trackbed Support
- Waterproofs Underlying Roadbed
- Confines Ballast and Track
- Utilizes “Fast-Track” System

8 to 12 in. thick

5 to 6 in. thick

12 ft.

Original Pavement & Base

- Reduces Subgrade Stresses
- Reduces Long-Term Settlement
- Extends Useful Life
- Improves Long-Term Performance
• Rome-Florence: First High Speed Line in Italy – 252 km – 1977-1986
• Debated between cement and asphalt
• Asphalt performed better – opted for use on all high-speed passenger lines

- 35 cm of ballast on top
- 12 cm of asphalt with 200 MPa modulus
- 30 cm of super compacted subgrade with 80 MPa modulus
New Railway Roadbed Design

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Assistant Senior Researcher, Track Structures and Geotechnology,
Track Technology Division

When laying track on earth structures, roadbed performance is extremely important for controlling track settlement and dynamic deflection. In order to meet roadbed performance demands in Japan, concrete roadbed is used for slab track (Fig. 1), and asphalt roadbed is used for ballasted track (Fig. 2); this structure is also standard for the Shinkansen bullet train. The roadbed design methods are described in the “Design Standard for Railway Structures (Earth Structures).” In the January 2007 revision to this design standard, a performance based design method was introduced. As the previous Design Standard for Railway Structures (Earth Structures) was based on specifications, the thickness of each layer of the roadbed design was specifically defined. With the performance based design method, however, it has become possible for the designers to design roadbed thickness to satisfy roadbed performance requirements. Specifically, by considering the fatigue life related to the number of trains, a method of designing thickness according to the importance of a particular section of track is described. Also, while the previous design concept was not consolidated with regard to a concrete roadbed for slab track or an asphalt roadbed for ballasted track, with this revision the roadbed design methods have been grouped together systematically.

With the new design standard, the earth structure performance rank for the relevant track is determined by the relative importance of the section of track and the track type. When designing the roadbed, a type of roadbed is selected to suit each of the various performance ranks. For performance rank I, concrete roadbed or asphalt roadbed for ballastless track is selected; for performance rank II, asphalt roadbed for ballasted track is used; and for performance rank III, crushed stone roadbed for ballasted track is selected. After the type of roadbed has been selected in this way, the roadbed structure design is carried out.

In the case of a concrete roadbed (Fig. 3), the following effects of train loads are checked for: displacement of the roadbed, breakage of the reinforced concrete base, fatigue damage, cracking, contraction, and thermal stresses. For asphalt roadbeds, the following effects of train loading are checked: displacement of the roadbed and fatigue damage of the asphalt mixture layer. In particular, in the case of an asphalt roadbed for ballasted track (Fig. 4), fatigue failure had not been considered in the previous design; however, this time a design method based on fatigue life has been introduced.

In this way, by systemizing roadbed design thinking to suit the design standard revision, and with the introduction of the performance-based design method, flexible design to suit the importance of the track section has now been made possible.
• With the new design standard, the earth structure performance rank for the relevant track is determined by the relative importance of the section of track and the track type. When designing the roadbed, a type of roadbed is selected to suit each of the various performance ranks.
• Performance Rank 1 – concrete roadbed or asphalt roadbed for ballastless track is selected
• Performance Rank 2 – asphalt roadbed for ballasted track is used
• Performance Rank 3 – crushed stone roadbed for ballasted track is selected.
• After the type of roadbed has been selected in this way, the roadbed structure design is carried out.
Germany

- German Getrac - ballastless track
- Track Panels are directly supported by asphalt
- Two Types: Getrac A1 and Getrac A3
France

- 3 km Test Section on the TGV World Record High Speed Line
- 357.2 mph
- 30 cm ballast
- 14 cm of bitumen coated gravel
- 20 cm sub layer
- Reduce sub-layer thickness
- Testing underway

Paris to Strasbourg Line
Began Operations in 2007
Excavating trackbed and checking grade

Removing old crossing 08:30

KY 303 Condition prior to rebuild

Began excavating

Excavating trackbed and checking grade
Dumping asphalt 10:15

Spreading asphalt

Compacting asphalt and dumping ballast

Dumping and spreading ballast
Compacting ballast

Positioning new panel

Spreading cribbing rock 11:30

Tamping ballast
3 weeks later

Compacting hand-spread approaches

Regulating ballast 12:40

Finished compacting asphalt approaches 16:50

3 weeks later
US 129 Alcoa/Maryville, TN
Hillsborough County, FL
• Hillsborough County, Florida
Coal Dock

Figure 20. CMG 6.6 Kentucky Coal Terminal 8/7/06

Figure 21. CMG 6.6 Kentucky Coal Terminal 8/21/06
Pressure Cell

- Geokon Model 3500-2
- 9 in. Diameter
- Strain Gage
- Snap-Master
- Thermistor

Cell Placement on Asphalt
Pressure Cell Measurement Configuration
Cell Location at Richmond
Loaded Coal Train at Richmond

P-Cell 819 Beneath Rail in Crib

P-Cell 820 Beneath Rail and Tie

P-Cell 821 C/L Track in Crib

P-Cell 822 C/L Track and Tie

2 6-Axle Locomotives

Initial 2 Cars

Pressure (psi)

Time (s)
Loaded Auto Train at Richmond

P-Cell 819 Beneath Rail in Crib

- 1 6-Axle Loco
- 1 4-Axle Loco
- Initial 2 Cars

Pressure (psi)

Time (s)

P-Cell 820 Beneath Rail and Tie

- 1 6-Axle Loco
- 1 4-Axle Loco
- Initial 2 Cars

Pressure (psi)

Time (s)

P-Cell 821 C/L Track in Crib

- 1 6-Axle Loco
- 1 4-Axle Loco
- Initial 2 Cars

Pressure (psi)

Time (s)

P-Cell 822 C/L Track and Tie

- 1 6-Axle Loco
- 1 4-Axle Loco
- Initial 2 Cars

Pressure (psi)

Time (s)
Loaded Concrete Truck at Richmond
Cell Location at Lackey
Loaded Coal Train at Lackey

P-Cell 510 Beneath High Rail and Tie

2 6-Axle Locomotives

Initial 2 Cars

Pressure (psi)

Time (s)

P-Cell 511 Beneath High Rail and Tie

2 6-Axle Locomotives

Initial 2 Cars

Pressure (psi)

Time (s)

P-Cell 806 C/L Track and Tie

2 6-Axle Locomotives

Initial 2 Cars

Pressure (psi)

Time (s)

P-Cell 207 Beneath Low Rail and Tie

2 6-Axle Locomotives

Initial 2 Cars

Pressure (psi)

Time (s)
Empty Coal Train at Lackey
Loaded Coal Truck at Lackey

P-Cell 510 Beneath High Rail and Tie

Pressure (psi) vs. Time (s)
Reduction of Dynamic Stresses

The graph shows the stress levels over time for both the 8 in. HMA surface and the subgrade surface. The stress levels are measured in psi and are plotted against time in seconds. The graph indicates a reduction in stress levels for both surfaces over time.
- Matrix-based array of force sensitive cells
- Silver conductive electrodes
- Pressure sensitive ink – Conductivity varies
- Crossing of ink – strain gauge
Rear Tires of Tractor of a 151,000 lb Loaded Coal Truck on Concrete Crossing of Kentucky Coal Terminal, Mile Post 6.6. May 25, 2004

9842 lb

135 psi

72.93 in\(^2\)

Force vs. Frames

Pressure vs. Frames
Front Tire of a CSXT Suburban on Asphalt Parking Lot in Ashland Oil Company. May 25, 2004

1652 lb

75 PSI

22.15 in^2

Force vs. Frames

Pressure vs. Frames
286,000 lb
62,000 lb
180 lb

13 - 20 psi
2 - 4 psi
6 psi
100 - 150 psi

Within Track
Surface
Trackbed Materials Classifications
Soil Tests
Moisture Content Test
between 1998 and 2007
Tests After Coring

**OK City Yard, New Subgrade**

<table>
<thead>
<tr>
<th>Year</th>
<th>In-Situ Moisture Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>17.4</td>
</tr>
<tr>
<td>1983</td>
<td>17.7</td>
</tr>
<tr>
<td>1984</td>
<td>16.7</td>
</tr>
<tr>
<td>1985</td>
<td>15.0</td>
</tr>
<tr>
<td>Avg.</td>
<td>17.0%</td>
</tr>
<tr>
<td>1986</td>
<td>18.1</td>
</tr>
<tr>
<td>1987</td>
<td>17.6</td>
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</tbody>
</table>

**Conway, KY Old Roadbed**

<table>
<thead>
<tr>
<th>Year</th>
<th>In-Situ Moisture Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>20</td>
</tr>
<tr>
<td>1984</td>
<td>18.4</td>
</tr>
<tr>
<td>1985</td>
<td>18.8</td>
</tr>
<tr>
<td>1986</td>
<td>17.5</td>
</tr>
<tr>
<td>1987</td>
<td>17.2</td>
</tr>
<tr>
<td>Avg.</td>
<td>18.4%</td>
</tr>
</tbody>
</table>
Proctor Test
Changes in Optimum Subgrade Moisture Contents Between 1998 and 2007

<table>
<thead>
<tr>
<th>Location</th>
<th>Change, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select Subgrade Guthrie, OK</td>
<td>1.0</td>
</tr>
<tr>
<td>Clay Subgrade OK City, OK</td>
<td>0.4</td>
</tr>
<tr>
<td>Clay Subgrade Quinlan, OK</td>
<td>0.0</td>
</tr>
<tr>
<td>Silt Subgrade Quinlan, OK</td>
<td>0.2</td>
</tr>
<tr>
<td>Subballast Hoover, TX</td>
<td>-0.1</td>
</tr>
<tr>
<td>Subgrade Hoover, TX</td>
<td>-1.4</td>
</tr>
</tbody>
</table>
Relationships for Roadbed/Subgrade In-Situ and Optimum Moisture Contents

\[ y = 1.248x - 3.513 \quad R^2 = 0.914 \]

\[ y = 1.062x - 1.203 \quad R^2 = 0.938 \]

\[ y = 1.148x - 2.267 \quad R^2 = 0.918 \]
Classification Tests
## Unified Soil Classification

<table>
<thead>
<tr>
<th>Project</th>
<th>Date</th>
<th>Unified</th>
<th>OMC</th>
<th>CBR</th>
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</thead>
<tbody>
<tr>
<td>Guthrie</td>
<td>1989</td>
<td>Silty sand</td>
<td>12%</td>
<td>14/5</td>
</tr>
<tr>
<td>OK City</td>
<td>1982</td>
<td>Lean clay</td>
<td>18%</td>
<td>8/3</td>
</tr>
<tr>
<td>Quinlan</td>
<td>1995</td>
<td>Lean clay</td>
<td>17%</td>
<td>9/4</td>
</tr>
<tr>
<td>Quinlan</td>
<td>1995</td>
<td>Sandy silt</td>
<td>13%</td>
<td>33/26</td>
</tr>
<tr>
<td>Hoover</td>
<td>1994</td>
<td>Subballast</td>
<td>9%</td>
<td>56/46</td>
</tr>
<tr>
<td>Hoover</td>
<td>1994</td>
<td>Clayey sand</td>
<td>11%</td>
<td>7/4</td>
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</tbody>
</table>
CBR Test
Comparison of 1998 and 2007 unsoaked and soaked CBR test values for the roadbed/subgrade
ASPHALT TESTS

CORES

RECOVERED ASPHALT
Resilient Modulus

$25^\circ C \ (77^\circ F)$
Resilient Modulus versus Age of Asphalt
Dynamic Shear Rheometer
25ºC (77ºF)
Longitudinal view of highway/rail crossing containing asphalt underlayment

----Approach----  ----Extent of asphalt underlayment----  ----Approach----

---------Crossing---------

<table>
<thead>
<tr>
<th>Station 1</th>
<th>Station 9</th>
<th>Station 12</th>
<th>Station 20</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Crossing Surface</td>
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</tr>
<tr>
<td></td>
<td>Asphalt Underlayment</td>
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<td></td>
<td>Station 8</td>
<td>RoadBed</td>
<td>Station 13</td>
</tr>
<tr>
<td>Station</td>
<td>Elevation (ft)</td>
<td>Date</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>---------------</td>
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<tr>
<td>1</td>
<td></td>
<td>5/13/02</td>
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</tr>
<tr>
<td>2</td>
<td></td>
<td>7/25/02</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>6/09/03</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2/10/04</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>2/2/05</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>3/14/06</td>
<td></td>
</tr>
</tbody>
</table>

- **WB**: Installed 5/13/2002
- **EB**:
Average Asphalt/Approach Settlement for Flag Spring (no underlayment)

Installed 5/13/2002
Average Asphalt/Approach Settlement for KY Coal Terminal #2

Installed 11/14/2002

- Approaches
- Crossing

Settlement (in.)

<table>
<thead>
<tr>
<th>Time (Months)</th>
<th>Settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>0.98</td>
</tr>
<tr>
<td>18</td>
<td>1.10</td>
</tr>
<tr>
<td>30</td>
<td>1.42</td>
</tr>
<tr>
<td>38</td>
<td>1.71</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (Months)</th>
<th>Settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>0.24</td>
</tr>
<tr>
<td>18</td>
<td>0.40</td>
</tr>
<tr>
<td>30</td>
<td>0.55</td>
</tr>
<tr>
<td>38</td>
<td>0.90</td>
</tr>
</tbody>
</table>

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Stanley
Average Top of Rail Elevations for US 60 Stanley

5/16/2002
6/13/2002
8/28/2003
1/20/2004
7/12/2004
6/10/2005
2/13/2006
11/16/2006

Installed 5/16/2002
Average Asphalt/Approach Settlement for US 60 Stanley

Installed 5/16/2002
Advantages of Enhanced Support

• Clearly Demonstrated

• Minimize Long-Term Settlement
• Settlement Asphalt Crossings was 41% of non-Asphalt Crossings
• Settlement Asphalt Crossings was 44% of Abutting Approaches
• Settlement of Non-Asphalt Crossings & Approaches – Similar


Thank You

Questions ???

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