On Board Measurement of Vertical Track Modulus

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4. Maintenance Scheduling
5. Trending
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Problem Statement - Theory
Sensitivity of Track Deflection to Changes in Modulus

Deflection Relative to wheel contact point
Real Track Load/Deflection

LVDT Data at Level, NE on 04/18/05

Load [lbf]

Deflection [in]

33,850 lbf

13,540 lbf

6,890 lbf

X=1m

X=2m

X=3m

X=4m

11/17/2006
Rail Deflection vs. Load (Stiffness)

\[ k = k_A = \frac{P}{\delta} \]

\[ k = k_B = \left[ \frac{\Delta P}{\Delta \delta} \right]_{P_{\text{low}}, P_{\text{high}}} \]

\[ k = k_C = \left. \frac{\partial P}{\partial \delta} \right|_{P^*} \]

All Different Definitions

Fig. IV.34. Test results obtained by the Talbot Committee (1918, p. 935)
Engineering Model of Track

\[ EI \frac{d^4 w}{dx^4} + p(x) = q(x) \]
Linear (Winkler) Model

- Differential Equation

\[ EI \frac{d^4 w(x)}{dx^4} + uw(x) = q(x) \]

\[ p(x) = uw(x) \]

- Solution

\[ y(x) = \frac{P\beta}{2u} e^{-\beta x} [\cos(\beta x) + \sin(\beta x)] \]

\[ \beta = \left( \frac{u}{4EI} \right)^{1/4} \]
UNL (cubic) Model

- **Differential Equation**
  \[ p(x) = u_1 w + u_3 w^3 \]
  \[ EI \frac{d^4 w}{dx^4} + u_1 w + u_3 w^3 = q \]

- **Numeric Solution**
  \[
  \begin{bmatrix}
  w(x) \\
  w'(x) \\
  w''(x) \\
  w'''(x)
  \end{bmatrix} =
  \begin{bmatrix}
  w'(x) \\
  w''(x) \\
  w'''(x) \\
  -\frac{1}{EI} \left( u_1 w(x) + u_3 w^3(x) \right)
  \end{bmatrix}
  \]
  \[ \int_0^r (u_i w + u_3 w^3) dx = \frac{P}{2} \]

- State space notion
- Boundary conditions

11/17/2006
Definitions of Track Modulus/Stiffness
Measurement System
Proposed Approach

- Distance between lasers, $d$, changes as car encounters soft track
Field System
Hopper Car
Movie from BNSF Testing
Relative Deflection to Modulus

- Relative Deflection is Related to Modulus using the Winkler (or other) Models
- Relative Deflection is Measured Along Track
- Embedded Odometry, GPS, Time
Movie from UPRR Testing 4/05

- Movie
Revenue Service Testing
Previous Tests

A-OPPD Arbor Line – 10 miles (7/9/04)
B-BNSF Hastings – 80 miles (9/17/04), (4/5/06)
C-UPRR Marysville Sub – 35 miles (4/19/05)
D-UPRR South Morrill Sub – 240 miles (4/19/05)
E-BNSF Lincoln to Ashland – 80 miles (9/15/05), (1/31/06)
F-BNSF Lincoln to Tecumseh – 110 miles (10/18/05)
G-UPRR Boone, to Ralston, IA – 60 miles (4/19/06)
H- BNSF Lincoln, NE to Gillette, WY – 700 miles (6/22-23/06)
I- UPRR Bill, WY to North Platte, NE – 300 miles (8/9/06)
J- BNSF Kansas City, MO to Lincoln, NE – 200 miles (11/3/06)
A Typical Mile
A Smooth Mile
BNSF MP 265.84
No Geometry Defect - Pumping

Ravenna: MP 265.8 to 265.9 (6/22/06)

\[ \mu = 0.15637 \]

\[ \sigma = 0.083144 \]

POS [mil]

\[ y_{ref} [in] \]
BNSF MP 265.84
No Geometry Defect - Pumping
MP 268.55
Mud in Mullen

Ravenna: MP 268.5 to 268.6 (6/22/06)

\[ \mu = 0.12629 \]
\[ \sigma = 0.12114 \]
MP 268.55
Mud in Mullen
MP 268.55
Mud in Mullen
Bouncing
MP271.62 – IRJ
New Bolt

Ravenna: MP 271.6 to 271.7 (6/22/06)

\[ \mu = 0.13374 \]
\[ \sigma = 0.15733 \]
MP271.62 – IRJ
New Bolt
Maintenance Scheduling
Recent UPRR testing

- About 350 miles on Orin (BNSF/UP joint line), Power River (UP), and South Morrill (UP) subdivisions.
- >300 MGT/year; often 250 MGT/track/year
## Top Exceptions over 270 miles

<table>
<thead>
<tr>
<th>MP</th>
<th>Track Feature</th>
<th>Track</th>
<th>Data-Mean</th>
<th>$\sigma$</th>
<th>$\mu$</th>
<th>$\sigma$ Ratio</th>
<th>GPS</th>
<th>GPSσRatio</th>
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<td>0.080</td>
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<td>0.815</td>
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<td>9.42</td>
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<td>6.30</td>
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**DERAILMENT**
- 14 days after test
- Broken field weld

**DERAILMENT**
- 30 days after test
- Frog/non-insulted joint
On August 23 at 2:44am, CNAKI-22 derailed at MP 172.91 on Track 2. Operating at 43 mph. Derailed 8 cars. At the crossover. Cause is a broken field weld. Cost is $1.51 million. Track was out of service on Main 1 for 9 hours and 16 minutes; on Main 2 for 22 hours and 46 minutes.
MP172 – MP173

42.030667708 N
-104.041930407 W

0 lbs
15:44:40 D4

0D0: 22006.78

Vel: -44.6mph
On September 10 at 1:45pm, CATKI-09 derailed at MP 78.4 on Track 2. Operating at 47 mph. Derailed 4 cars. They felt a rough frog in the "OS", then went into emergency. Cause is a non-insulated joint bar. Cost is $1.2 million. Track was out of service on Main 1 for 10 hours; on Main 2 for 1 day, 8 hours, 45 minutes.
Trending
A Bridge

Lincoln to Ashland: MP 47.58 to 47.68

\[ \mu = 11.9053 \]
\[ \sigma = 0.081238 \]

40.9133 - 96.5349
A Bridge – Change
Soft approach is softer
A 5 Span Bridge – No Change
A 5 Span Bridge – No Change
A Turnout – IMPROVEMENT!

Lincoln to Ashland: MP 36.22 to 36.32

\[
\mu = 11.8816, \quad \sigma = 0.076137
\]

11/17/2006
A Turnout – IMPROVEMENT!
The Future
Autonomous Operation
Autonomous Operation
Future Testing

- 300 Miles on BNSF Coal line on 11/21
- Ashland – Trending in November
- Autonomy Stage 2 – Short Distances
  - at C&EB – 4 miles on 10/12 and again on 10/27
  - Purcel box
  - Short range data link (802.11)
  - Power supply on hopper (no recharge)
- Autonomy Stage 3 – Medium Distances (<50 mi)
  - BNSF west yard, Havelock, Council Bluffs
  - Alltell wireless
- Autonomy Stage 4 – in unit train to WY?
Thanks

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- Rich Kotan, OPPD
Questions