Pavement evaluation using the Traffic Speed Deflectometer

Jeffrey Lee | Principal Pavements Engineer | ARRB Group
Jothi Ramanujam | Director (Pavements Rehabilitation Section) | Department of Transport and Main Roads
Agenda

1. Overview of Traffic Speed Deflectometer (TSD)
2. National Asset Centre of Excellence (NACOE) P40 Research – Part 1
3. NACOE P40 Research – Part 2
4. Summary and conclusions.
Overview of TSD
TSD Schematics

- 10-tonne load applied to a dual-tyred single rear axle
- Doppler lasers measure the velocity of the deflected pavement under load
- Doppler lasers only located along outer wheel path. Similar measurement along inner wheel path will be helpful
- Strain gauges (4) measure the dynamic axle loading.
TSD measurements

- Over 12,000 km scanned across Queensland in 2014
- Over 20,000 km scanned across Queensland in 2015
- Currently conducting 2016 survey in Queensland (April – August).
TSD measurements (cont.)

- Deflection
- Texture
- Rutting
- Roughness
- Ground Penetrating Radar (GPR)
- High-resolution images
- Automatic crack detection
- Surveying at traffic speed (typically 70-90 kph)
Hawkeye software output

- ARRB Hawkeye software
Measurement principle

Deflection Slope = $\frac{V_V}{V_H}$
Measurement principle (cont.)

- Measures the velocity of deflection rather than displacement.
- Vertical velocity \((V_V)\) and horizontal velocity \((V_H)\) data for each 20 mm travelled.
- Surface velocity is integrated with respect to time to yield deflection.
- Deflection slope – the slope of the laser-measured deflections.
- Doppler lasers calibration is very important.
Integration of FWD velocity signal

Integrate with time

Velocity Profile
(from Geophones)

Deflection Profile
NACOE P40
Research – Part 1
## Correlation of FWD vs TSD

<table>
<thead>
<tr>
<th>Road Name</th>
<th>Pavement Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ipswich – Boonah Road (211)</td>
<td>Sprayed Seal</td>
</tr>
<tr>
<td></td>
<td>265mm Foamed Bitumen</td>
</tr>
<tr>
<td></td>
<td>Sprayed Seal</td>
</tr>
<tr>
<td></td>
<td>265mm Foamed Bitumen</td>
</tr>
<tr>
<td></td>
<td>Sprayed Seal</td>
</tr>
<tr>
<td></td>
<td>265mm Foamed Bitumen</td>
</tr>
<tr>
<td>Centenary Highway (910)</td>
<td>220mm Granular Base</td>
</tr>
<tr>
<td></td>
<td>150mm Granular Subbase</td>
</tr>
<tr>
<td></td>
<td>100 – 140mm Granular Lower Subbase</td>
</tr>
<tr>
<td>Deception Bay Road (121)</td>
<td>80 – 150mm AC</td>
</tr>
<tr>
<td></td>
<td>300mm Granular</td>
</tr>
<tr>
<td>D’Aguilar Highway (40A)</td>
<td>Sprayed seal</td>
</tr>
<tr>
<td></td>
<td>200mm Category 1 CTB</td>
</tr>
<tr>
<td>Bruce Highway (10A)</td>
<td>255mm AC</td>
</tr>
<tr>
<td></td>
<td>250mm Lean Mix Concrete</td>
</tr>
<tr>
<td></td>
<td>Cross-Section Vary. Typically</td>
</tr>
<tr>
<td></td>
<td>80 – 120mm AC</td>
</tr>
<tr>
<td></td>
<td>250mm – 375mm Granular</td>
</tr>
<tr>
<td>Caboolture Connection Road (9905)</td>
<td>130mm AC</td>
</tr>
<tr>
<td></td>
<td>130mm Granular</td>
</tr>
<tr>
<td></td>
<td>130mm AC</td>
</tr>
<tr>
<td></td>
<td>130mm Granular</td>
</tr>
</tbody>
</table>
2015 TSD vs FWD – Centenary Highway

Centenary Highway (high strength granular pavement)
Maximum deflection D0 Correlation

\[ y = 0.900x + 0.138 \]
\[ R^2 = 0.699 \]
## Deflection measuring equipment

<table>
<thead>
<tr>
<th></th>
<th>Benkelman Beam</th>
<th>Deflectograph</th>
<th>Falling Weight Deflectometer (FWD)</th>
<th>Traffic Speed Deflectometer (TSD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analogy</td>
<td>![Benkelman Beam Image]</td>
<td>![Deflectograph Image]</td>
<td>![Falling Weight Deflectometer Image]</td>
<td>![Traffic Speed Deflectometer Image]</td>
</tr>
<tr>
<td>Speed of waveform while measuring</td>
<td>Stationary</td>
<td>1 m/s (3.5 km/h vehicle speed)</td>
<td>180 to 600 m/s (speed of Rayleigh waves*)</td>
<td>180 to 600 m/s ± 22 m/s (80 km/h vehicle speed)</td>
</tr>
<tr>
<td>Appropriate partial differential equations (PDE) for backcalculation</td>
<td>Static (x,y,z)</td>
<td>Static?</td>
<td>Dynamic (x,y,z,t)</td>
<td>Dynamic</td>
</tr>
<tr>
<td>PDEs currently used</td>
<td>Static</td>
<td>Static</td>
<td>Static</td>
<td>Static</td>
</tr>
</tbody>
</table>

*Rayleigh waves are long, low-amplitude waves that propagate on the surface of a fluid and are used to describe the speed of waveforms in soil.”
Construction of FWD bowl

FWD bowl constructed from peak motion of sensors at different offsets (STATIC APPROXIMATION OF A DYNAMIC PROBLEM)

* Mass (density) of pavement material
Propagation of Rayleigh Waves

Rayleigh wave

- Speed depends on frequency


High frequency only penetrates to **shallow** depth

Low frequency penetrates to **greater** depth
NACOE P40
Research – Part 2
Site instrumentation
Site instrumentation (cont.)

Coring  Saw cut  Sensor
Site instrumentation (cont.)

Data acquisition

FWD

Vehicle pass-by
Accelerometer measurements (FWD)

- Acceleration
- Velocity
- Displacement
## Accelerometer measurements (FWD)

### Comparison of Accelerometer and FWD Deflection Results

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Distance from Load (mm)</th>
<th>FWD Deflection (mm)</th>
<th>Accelerometer Based Deflection (mm)</th>
<th>Similarity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>182</td>
<td>0.256</td>
<td>0.282</td>
<td>9%</td>
</tr>
<tr>
<td>2</td>
<td>182</td>
<td>0.256</td>
<td>0.280</td>
<td>9%</td>
</tr>
<tr>
<td>3</td>
<td>182</td>
<td>0.420</td>
<td>0.477</td>
<td>12%</td>
</tr>
<tr>
<td>4</td>
<td>182</td>
<td>0.132</td>
<td>0.160</td>
<td>17%</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>0.247</td>
<td>0.255</td>
<td>3%</td>
</tr>
<tr>
<td>6</td>
<td>200</td>
<td>0.402</td>
<td>0.446</td>
<td>10%</td>
</tr>
</tbody>
</table>
Accelerometer measurements (Semi-trailer)
Summary and conclusions

- TSD collects a range of condition data at traffic speed. Engineers should not evaluate a pavement purely on the measured deflection values.
- Similar to a FWD, TSD measures velocity and obtain deflection through a numerical integration process.
- NACOE research provided additional data to correlate TSD with FWD.
- Deflection from trafficking vehicle is a complex dynamic problem. Comparing with other established deflection equipment is only the first step to understand the TSD measurement.
- In-ground instrumentation testing scheme proposed.
Maximising the use of deflection data in characterising the existing pavement
Deflection measurement devices

- Benkelman Beam – Standard Axle Load
  - 550 kPa contact stress.
- Deflectograph – Standard Axle Load
  - 750 kPa contact stress.
- Falling Weight Deflectometer (FWD)/Heavy Weight Deflectometer (HWD)
  - Variable load
  - Variable contact stresses
  - Fixed contact area.
- Traffic Speed Deflectometer.
Deflectograph
HWD/FWD loading system
HWD/FWD bowl
Pavement Rehabilitation Manual

1. Historical Data
   - Assess Functional Condition
     - Visual Rating
     - Functional Testing
   - Assess Structural Response to Load
2. Evaluate Materials
3. Chapter 1
   - Identify Pavement Type
   - Rehabilitation Purpose
   - Compile Evaluation Data
4. Chapter 3
   - Select Rehabilitation Options

Diagram showing the process flow for pavement rehabilitation, starting with historical data, followed by assessing functional and structural conditions, evaluating materials, and then selecting rehabilitation options.
Case study 1

- Metro South District – Church Street
- Granular, thin asphalt, built 1974
- Past traffic = 1.8 x 10E6 Equivalent Standard Axles (ESAs)
- Details of results for the homogenous section: Outer Wheel paths (OWP), Westbound.
  - Summary of Condition Assessment:
    - Pavement Shape: fair – good
    - Some minor patching
    - Onset of cracking, mainly OWP
    - Rutting length → 20 mm in OWP over = 20%.
Case study 1 (cont.)

• Details of results for the homogenous section: OWP, Westbound:
  ▪ Structural assessment:
    ▪ Representative deflection = 0.99 mm, D900 = 0.27
    ▪ Deflection ratio = 0.55
    ▪ Residuals \(\rightarrow 0.16\), < 25% Maximum deflection.

• Verified \(\rightarrow\) proceed with design.
Case study 2

- Tarong Power Station access road
- Granular pavement with chip seal
- Four years old
- Past traffic: 3 X 10E5 ESA
- Details of Results for typical section: OWP, Eastbound
  - Structural assessment:
    - Representative deflection = 0.95 mm, D900 = 0.20
    - Deflection ratio = 0.55 mm
    - Residuals = <0.15 mm, < 25% maximum.
Case study 2 (cont.)

• Details of Results for typical section: OWP, Eastbound
  • Visual assessment:
    ▪ Extensively cracked, rutted and patched.

• Not verified
  • Investigation material quality/depth and related issues:
    ▪ Investigate the failure mechanism before proceeding with design.
Possible causes for Dr < expected in Case Study 2

• Distress results from pavement material inadequacy under load.
  ▪ Additional testing (pavement and subgrade material properties) needed to verify this and hence determine type of remedial treatment.

• Non-load associated factors are active and have significantly increased distress.
  ▪ For example, degradation of pavement materials under environmental influences.
Solution – Case 2

• Do not proceed with an overlay design based on deflection levels
• Look for alternative treatments/design methods
• The following alternative treatments could be considered:
  ▪ Surface subsurface drainage improvements
  ▪ Provision of a competent seal
  ▪ Sealing or improvements to shoulders
  ▪ Modification or stabilisation of pavement materials.
Step 1 – Visual assessment
Step 1 – Visual assessment (cont.)

- Predominant distress in left hand lane
- Fatigue cracking
- Numerous closely spaced transverse cracks
- Potholing.
Step 2 – Deflection testing

- HWD used at 60, 80 and 120kN.
- HWD used due to the presence of cemented layers.
- Deflection testing undertaken in the OWP at 25 m intervals.
Step 3 – 120kN deflection (mm) and curvature results
Step 4 – Field investigations

• FWD data plus visual survey used to determine areas for coring and sampling.
• 10 full depth cores undertaken through pavement layers (layer depths recorded).
• Dynamic Cone Penetrometer (DCP) testing undertaken through the core hole (for determination of subgrade CBR).
• Samples of the granular base layer were taken by cutting 300 mm x 300 mm squares from pavement.
• Back analysis of modulus values (moderated as per Table 5.7 and Table 5.8 in the Pavement Rehabilitation Manual.)
Step 4 – Field investigations (cont.)
Verification of compatibility

• Case study has proven that the condition assessment has been verified with structural assessment.
Equal deflection but not equal strain

<table>
<thead>
<tr>
<th>Pavement 1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>Material</td>
<td>Modulus (MPa)</td>
</tr>
<tr>
<td>(mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>Asphalt</td>
<td>2000</td>
</tr>
<tr>
<td>300</td>
<td>Unbound Granular</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Subgrade (CBR 3)</td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pavement 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>Material</td>
<td>Modulus (MPa)</td>
</tr>
<tr>
<td>(mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>Asphalt</td>
<td>1000</td>
</tr>
<tr>
<td>600</td>
<td>Unbound Granular</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Subgrade (CBR ~3)</td>
<td>38</td>
</tr>
</tbody>
</table>
Thank you