Deflection Response

- Benkelman Beam
- Deflectograph
- Falling Weight Deflectometer
Deflectograph (PAVDEF)
HWD/FWD Loading system
HWD/FWD Bowl
Deflection Measurement Devices

- **Benkelman Beam** - Standard Axle Load
  - 550 kPa Contact Stress
- **Deflectograph** - Standard Axle Load
  - 750 kPa Contact Stress
- **FWD/HWD** - Variable Load
  - Variable Contact Stresses
  - Fixed Contact Area
Overlay Design Methodology

• Deflection Reduction Method using Subgrade CBR ($D_{900}$) Estimate
• Deflection Reduction Method using equivalent CBR from Subgrade Modulus obtained by Back Analysis
• Mechanistic Design Method using calculated insitu Pavement and Subgrade Moduli from Back Analysis
Typical Deflection Bowl Shapes under a Standard Axle (40 kN) Load for the various Deflection Devices used by Main Roads – see next slide.
Typical Deflection Bowls
Granular base – 40kN Load

Typical Deflection Bowls - Unbound Granular Base - 40 kN Load

- Deflection (mm)
- Distance from Maximum Deflection (mm)

Lines:
- Red: Benkelman Beam
- Black: Deflectograph
- Blue: FWD
Typical Deflection Bowls - Unbound Granular Base - 40 kN Load

Deflectograph \( D_0 \) = 0.85 Benkelman Beam \( D_0 \)

Benkelman Beam \( D_0 \) \( \approx \) FWD 40 kN \( D_0 \) but Shape is different
Typical Deflection Bowls
CTB – 40kN Load
Typical Deflection Bowls - Full Depth Cat. 1 CTB - 40 kN Load

Deflectograph \( (D_0) = 0.7 \) Benkelman Beam \( (D_0) \)
Benkelman Beam \( (D_0) = 0.5 \) FWD 40kN \( (D_0) \)
Deflectograph \( (D_0) = 0.36 \) FWD 40kN \( (D_0) \)
Typical Deflection Bowls
CTB – 40, 60 + 80 kN Loads
• The absolute value of 40 kN deflection measurements on Bound Heavy Duty Pavements are too low for effective/confident back analysis.

• **Need higher loads** for testing Bound Heavy Duty Pavements
Deflection Surveys

The **spacing** of successive deflection tests is as follows:

**Urban Areas**

- Both inner and outer wheel paths for all lanes
- 25 m: heavy commercial vehicle lane (usually the outer lane)
- 50 m: fast lane
- 10 m: areas of high distress
Deflection Surveys

Rural Areas

• Both inner and outer wheel paths for all lanes
• 50 m: all lanes (this would be staggered between adjacent lanes)

The **recording** for deflection surveys consists of:

• Direction/lane description
• Wheelpath description
Typical results from deflection testing

<table>
<thead>
<tr>
<th>Chainage (km)</th>
<th>Stress (kPa)</th>
<th>Surface Temp.</th>
<th>Air Temp.</th>
<th>Deflection (mm)</th>
<th>Deflection Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Offset 0</td>
<td>200</td>
</tr>
<tr>
<td>0.000</td>
<td>643</td>
<td>0.0</td>
<td>20.0</td>
<td>0.932</td>
<td>0.696</td>
</tr>
<tr>
<td>0.029</td>
<td>653</td>
<td>0.0</td>
<td>20.0</td>
<td>0.845</td>
<td>0.604</td>
</tr>
<tr>
<td>0.056</td>
<td>689</td>
<td>0.0</td>
<td>20.0</td>
<td>0.656</td>
<td>0.500</td>
</tr>
<tr>
<td>0.085</td>
<td>693</td>
<td>0.0</td>
<td>20.0</td>
<td>0.414</td>
<td>0.339</td>
</tr>
<tr>
<td>0.109</td>
<td>679</td>
<td>0.0</td>
<td>20.0</td>
<td>0.456</td>
<td>0.365</td>
</tr>
<tr>
<td>0.137</td>
<td>642</td>
<td>0.0</td>
<td>20.0</td>
<td>0.460</td>
<td>0.348</td>
</tr>
<tr>
<td>0.164</td>
<td>648</td>
<td>0.0</td>
<td>20.0</td>
<td>0.407</td>
<td>0.340</td>
</tr>
<tr>
<td>0.191</td>
<td>681</td>
<td>0.0</td>
<td>20.0</td>
<td>0.442</td>
<td>0.366</td>
</tr>
<tr>
<td>0.218</td>
<td>699</td>
<td>0.0</td>
<td>20.0</td>
<td>0.380</td>
<td>0.310</td>
</tr>
<tr>
<td>0.245</td>
<td>731</td>
<td>0.0</td>
<td>20.0</td>
<td>0.347</td>
<td>0.299</td>
</tr>
<tr>
<td>0.272</td>
<td>710</td>
<td>0.0</td>
<td>20.0</td>
<td>0.379</td>
<td>0.316</td>
</tr>
<tr>
<td>0.299</td>
<td>701</td>
<td>0.0</td>
<td>20.0</td>
<td>0.319</td>
<td>0.256</td>
</tr>
<tr>
<td>0.326</td>
<td>703</td>
<td>0.0</td>
<td>20.0</td>
<td>0.467</td>
<td>0.337</td>
</tr>
<tr>
<td>0.354</td>
<td>650</td>
<td>0.0</td>
<td>20.0</td>
<td>0.495</td>
<td>0.362</td>
</tr>
<tr>
<td>0.381</td>
<td>691</td>
<td>0.0</td>
<td>20.0</td>
<td>0.344</td>
<td>0.289</td>
</tr>
<tr>
<td>0.405</td>
<td>686</td>
<td>0.0</td>
<td>20.0</td>
<td>0.547</td>
<td>0.416</td>
</tr>
<tr>
<td>0.435</td>
<td>657</td>
<td>0.0</td>
<td>20.0</td>
<td>0.488</td>
<td>0.411</td>
</tr>
<tr>
<td>0.462</td>
<td>730</td>
<td>0.0</td>
<td>20.0</td>
<td>0.308</td>
<td>0.269</td>
</tr>
<tr>
<td>0.486</td>
<td>655</td>
<td>0.0</td>
<td>20.0</td>
<td>0.418</td>
<td>0.375</td>
</tr>
</tbody>
</table>
Deflection vs. Distance
## Deflection Criteria - Benkelman Beam Test

### Granular Pavements

<table>
<thead>
<tr>
<th>Rebound Deflection</th>
<th>Deflection Ratio</th>
<th>D900 Values</th>
<th>Residual Deflection</th>
<th>Condition of Pavement Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;0.9mm</td>
<td>&lt; 0.6</td>
<td>A</td>
<td>&lt; 0.15mm</td>
<td>Pavement and subgrade weak</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td></td>
<td>Pavement weak but subgrade weak</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>Pavement weak but subgrade strong</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.6</td>
<td>A</td>
<td>≥ 0.15mm</td>
<td>Pavement strong or marginal and subgrade weak</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td></td>
<td>Pavement strong or marginal and subgrade strong</td>
</tr>
<tr>
<td>≤0.9mm</td>
<td>&lt; 0.6</td>
<td>A</td>
<td>&lt; 0.15mm</td>
<td>Pavement and subgrade weak</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td></td>
<td>Pavement weak but subgrade strong</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>Pavement weak but subgrade strong</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.6</td>
<td>A</td>
<td>&lt; 0.15mm</td>
<td>Pavement strong but subgrade weak</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td></td>
<td>Pavement strong but subgrade marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>Pavement strong but subgrade strong</td>
</tr>
</tbody>
</table>

A = ≥ 0.3mm
B = ≥ 0.2mm AND < 0.3mm
C = < 0.2mm

Pavement and subgrade strong
Pavement marginal but subgrade weak
Pavement weak but subgrade strong
Pavement weak but subgrade marginal
Pavement strong but subgrade weak
Pavement strong but subgrade marginal
Pavement and subgrade weak
Pavement weak and subgrade marginal
Pavement weak but subgrade strong
Pavement weak but subgrade strong
Pavement marginal but subgrade weak
Pavement and subgrade marginal
Pavement strong but subgrade weak
Pavement strong but subgrade marginal
Pavement and subgrade strong
Pavement marginal but subgrade weak
Pavement marginal but subgrade weak
Pavement weak but subgrade strong
Pavement weak but subgrade strong
Deflection Bowl
Deflection Bowl
Typical Deflection Bowl

Rebound Deflection, $D_0 = \text{Max. Deflect} - \text{Residual Deflect}$

Deflection Ratio, $DR = \frac{D_{250}}{D}$

Curvature Function, $CF = D\_0 - D\_200$
Benkelman Beam Test
Residual Deflections

- Residual deflections represent the ‘permanent’ deformation of a pavement
- Residual deflections can be +ve or -ve
Deflection Ratio

Deflection ratio is used to indicate the stiffness of the pavement structure and is ‘fairly’ independent of surfacing type (AC/spray seal) or sub-grade CBR

\[
\text{Deflection Ratio} = \frac{D_{250}}{D_0}
\]

Deflection ratio of:

- > 0.8 indicates CTB or CTSB bound pavement
- 0.6 – 0.8 indicates good quality unbound pavement
- < 0.6 indicates a possible weakness in the pavement materials
Modulus vs. Deflection Ratio

Transport and Main Roads

SCALA, 1979
Curvature Function

- Curvature function is used to predict the fatigue life of an applied asphalt surfacing overlay or an existing asphalt surfacing

\[ \text{Curvature Function} = D_0 - D_{200} \]

- Representative curvature is determined as the mean of the curvature functions

- Representative of C.F. should have a C.V. of < 30%
$D_{900}$ Value vs. CBR Value
Bowl Survey Data

- Deflection $\rightarrow$ Strength
- Defln. Ratio $\rightarrow$ Stiffness
- Residual Defln. Ratio $\rightarrow$ Upper Pvt. or Surface
- Curvature $\rightarrow$ Asphalt Fatigue
- Deflection 900 $\rightarrow$ Subgrade
Historic Tolerable Deflection Criterion – Unbound Pavements
Historic Tolerable Deflection Criterion – Unbound Pavements
Historic Tolerable Deflection Criterion – Unbound Pavements
Deflection Reduction Overlay Design Philosophy

![Diagram showing deflection reduction overlay design philosophy. The graph plots deflection (in mm) against design traffic (in ESA's). The graph shows the deflection before and after the overlay for different traffic levels.](image-url)
Tolerable Deflection
Normal Design Standard
Tolerable Deflection
Normal Design Standard
Granular Overlay Process

1. For subgrade life, $N_s$, & $D_{900}$ value, determine $D_{tol}$

\[ \text{DEFL} \]
\[ D_{tol} \]
\[ N_s \quad N \quad N_\text{(EVA's)} \]

(DEFL vs TRAFFIC)

2. Determine thickness, $T_s$ for deflection reduction to $D_r$

\[ D_{tol} \]
\[ T_s \]
\[ D_r \quad \text{field} \]

(DEFL REDUCTION)
Design Exercise 1

The results of a Benkelmen beam deflection survey for a section of Toowoomba – Karara Road is attached.

1. Determine homogenous lots for both inner and outer wheelpaths.

2. Compare the representative values of the following for the homogenous sections for both inner and outer wheel paths:
   - rebound deflections
   - residual deflections
   - deflection ratio
   - curvature function
Design Exercise 1 (cont.)

3. For these sections, based on the deflection results, comment on the following:
- stiffness of the pavement material
- condition of the subgrade
Selection of Homogenous Lots

- Study bowl plots and delete bad bowls
- If AC surfacing – temperature correction
- Plot rebound deflections and residual deflections (check high/low)
- Visually subdivide rebound deflection plots into uniform subsections
Selection of Homogenous Lots (cont.)

• Determine statistical values
  o Mean ( \( \bar{x} \) )
  o Standard Deviation (s.d.)
  o Coefficient of variation (s.d./ \( \bar{x} \) )

For both IWP and OWP for rebound deflection

• If CV < 30% lot is homogenous
• If CV > 30% lot requires further subdivision until CV is < 30%
Example 1

REBOUND DEFLECTION (mm)

- OWP
- IWP

RESIDUAL DEFLECTION (mm)

DEFLECTION RATIO (D250/D6)

Rut Depth

Test Changes

LHS - RHS
### Transport and Main Roads

**CAMEOYA STUDY - TOMBURIA - KARVIYA MINI - KAMAYI LIPINTEL - CAMEOYA**

**SOUTH WEST DIVISION**

<table>
<thead>
<tr>
<th>Run</th>
<th>Chainage</th>
<th>No.</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>1</td>
<td>0.747</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>2</td>
<td>0.593</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>3</td>
<td>0.776</td>
</tr>
<tr>
<td>4</td>
<td>250</td>
<td>4</td>
<td>1.118</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>5</td>
<td>0.682</td>
</tr>
<tr>
<td>6</td>
<td>350</td>
<td>6</td>
<td>1.015</td>
</tr>
<tr>
<td>7</td>
<td>400</td>
<td>7</td>
<td>0.708</td>
</tr>
<tr>
<td>8</td>
<td>450</td>
<td>8</td>
<td>0.478</td>
</tr>
<tr>
<td>9</td>
<td>500</td>
<td>9</td>
<td>0.594</td>
</tr>
<tr>
<td>10</td>
<td>550</td>
<td>10</td>
<td>0.847</td>
</tr>
<tr>
<td>11</td>
<td>600</td>
<td>11</td>
<td>0.526</td>
</tr>
<tr>
<td>12</td>
<td>650</td>
<td>12</td>
<td>0.731</td>
</tr>
<tr>
<td>13</td>
<td>700</td>
<td>13</td>
<td>0.471</td>
</tr>
<tr>
<td>14</td>
<td>750</td>
<td>14</td>
<td>0.672</td>
</tr>
<tr>
<td>15</td>
<td>800</td>
<td>15</td>
<td>0.356</td>
</tr>
</tbody>
</table>

**MEAN**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dev</td>
<td>0.706</td>
</tr>
<tr>
<td>CVAR CD</td>
<td>27.9</td>
</tr>
<tr>
<td>99TH</td>
<td>0.959</td>
</tr>
</tbody>
</table>

**Number Bowls = 14**  **Number Results = 14**  **Number of Sites =38**  **LHS Cal. factor = 1125**  **File = C:\NEW\0317-1.DAT**
Moisture Correction Factors

Depend on:

• Subgrade type
• Rainfall
• Location of water table
• Pavement type
Moisture Correction (cont.)

- Moisture correction factors are applied to the IWP Deflections in order to simulate the worst expected conditions in the outer wheel path
## Seasonal Correction Factors

<table>
<thead>
<tr>
<th>Pavement Condition</th>
<th>All Districts</th>
<th>1,2,6,12,13,14</th>
<th>3,4,5,7,10,15</th>
<th>8,9,11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak Pavements 90%H &gt; 1.5 mm</td>
<td>1 (1)</td>
<td>1.2 (1.3)</td>
<td>1.1 (1.2)</td>
<td>1.2 (1.4)</td>
</tr>
<tr>
<td>Intermediate Pavements 1.5 mm &gt; .90%H &gt; 0.9 mm</td>
<td>1 (1)</td>
<td>1.2 (1.3)</td>
<td>1.1 (1.2)</td>
<td>1.3 (1.5)</td>
</tr>
<tr>
<td>Strong Pavements 90%H &lt; 0.9 mm</td>
<td>1 (1)</td>
<td>1.2 (1.3)</td>
<td>1.1 (1.2)</td>
<td>1.4 (1.6)</td>
</tr>
</tbody>
</table>

* Value in brackets apply for silty and clayey silt subgrades where greater variation in deflection level may be expected.

**Note:** In situations where the water table is within one metre of subgrade level throughout most of the year, no correction should be applied.

**TABLE 1**
SEASONAL CORRECTION FACTORS
Moisture Correction

- Moisture movement occurs in pavements generally in the outer wheel paths only (assuming reasonable pavement drainage)
- CBR of the subgrade also varies with moisture
- Example:

```
<table>
<thead>
<tr>
<th>Season</th>
<th>OWP</th>
<th>IWP</th>
<th>IWP</th>
<th>OWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRY SEASON</td>
<td>MC/CBR</td>
<td>3% / 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WET SEASON</td>
<td></td>
<td>7% / 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```
Asphalt Fatigue

- Tensile Strain in asphalt depends on:
  - Traffic (E.S.A. ’s)
  - Temperature
  - Thickness
Curvature Function

- **Curvature function** is used to predict the fatigue life of an applied asphalt surfacing overlay or an existing asphalt surfacing.

\[
\text{Curvature Function} = D_0 - D_{200}
\]
Curvature Function

Curvature Function = \( D_0 - D_{200} \)

Representative curvature is determined as the mean of the curvature functions
Asphalt Overlay Process

1. FOR SUBGRADE LIFE, $N_s$, DET. THICKNESS VIA
   $\text{DEF} = \text{Df} + 1$
   $N_s$ $N(ESA's)$

2. CHECK REDUCTION IN CURVATURE DUE TO $T_d$.
   $CF$
   $CF(a)$ $T_d$
   $CF(b)$ (FIELD)
   (CURVATURE REDN)

3. DERIVE FATIGUE LIFE OF ASPHALT, $N_a$.
   $CF$
   $CF(a)$
   (CURVATURE v TRAFFIC)

4. COMPARE $N_s$ & $N_a$.
   DECISION OPTIONS.
   (I) MIN LIFE $N_s$, THICK, COSTLY
   (II) STAGE, REPEATED OVERLAYS
   (III) OVERLAY, MILL OFF AFTER $N_a$, OVERLAY $\rightarrow$ $N_a$
   (IV) OTHERS (INTERLAYER, POLYMER MODIFIED ASPHALT, ETC.).
Asphalt correction factor for deflection

Asphalt Temperature Correction for Deflection

\[ y = 0.0028e^{5.8857x} \]
\[ y = 0.0147e^{4.2176x} \]
\[ y = 0.0341e^{3.3809x} \]
\[ y = 0.0624e^{2.7687x} \]
\[ y = 0.0975e^{2.3295x} \]
\[ y = 0.1344e^{2.0138x} \]
\[ y = 0.1709e^{1.7818x} \]
\[ y = 0.2209e^{1.5235x} \]
Asphalt Stiffness Relationships
Worked example of QDMR procedures for asphalt overlay design
Asphalt Overlay Process

1. For Subgrade Life $N_S$ & $D_{900}$ value, determine $D_{tol}$
Asphalt Overlay Process (cont)

2. Check $D_{tol} > \text{ or } < D_{REP}$ deflection

3. Determine thickness ($T_{AC}$) for curvature before overlay and design traffic (ESA’s)
Asphalt Overlay exercise

*Fill in the top white cells of spreadsheet*

- temp.zone number – see Queensland map sheet 34
- temperature of existing asphalt – see FWD printout - sheet 12
- Depth of existing asphalt – see trench profile – sheet 3
- Asphalt correction factor for deflection – see sheet 36
Overlay Design (cont)

• Temperature Corrections
  o Deflections affected by temperature
  o Zones for Queensland
  o Corrections to both deflection and curvature functions
WMAPT - Weighted Mean Annual Pavement Temperatures

Sheet 34
Asphalt Fatigue Criteria

![Graph showing asphalt fatigue criteria](image)
Influence of Temperature Variations

1. Rebound Deflection ($D_0$)
2. Curvature Function ($D_0 - D_{200}$)

$$D_0' = 1.1 \times D_0$$
$$D_0' - D_{200}' = (D_0 - D_{200}) \times z'$$
Asphalt correction factor for deflection

Asphalt Temperature Correction for Deflection

\[ y = 0.0028e^{5.8857x} \]
\[ y = 0.0147e^{4.2176x} \]
\[ y = 0.0341e^{3.3809x} \]
\[ y = 0.0624e^{2.7687x} \]
\[ y = 0.0975e^{2.3295x} \]
\[ y = 0.1344e^{2.0138x} \]
\[ y = 0.1709e^{1.7818x} \]
\[ y = 0.2209e^{1.5235x} \]

Existing Asphalt Thickness (mm)

Deflection Adjustment Factor

0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1

0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0

50 75 100 125 150 200 250 300

Existing Asphalt Thickness (mm)
Asphalt correction factor for curvature function – see sheet 37
• Speed Corrections
  o Modulus increases with rate of loading
  o Speed of beam testing must lower than operating traffic speed
  o Corrections
  o Applicable for asphalt overlay on asphalt
Chart 14 – Zone 3 – 80kph

Asphalt Overlay Design (2600MPa): Zone 4 - 50kph, Zone 3 - 80kph

Deflection Before Overlay vs. Deflection After Overlay for various overlay thicknesses (50mm, 75mm, 100mm, 125mm, 150mm).
Before and After Deflections Asphalt overlay chart

CHART 14-Asphalt Overlay Design (2600MPa): Zone 3 - 80kph

Deflection Before Overlay
Deflection After Overlay

- 50mm
- 75mm
- 100mm
- 125mm
- 150mm

less than 50 mm thick

110 mm

Before
Chart 30 - Asphalt Overlay Design: Zone 3 - 80kph

Design Traffic (ESA) vs. Curvature Before Overlay

- Design Traffic (ESA) values:
  - 1E5
  - 1E6
  - 3E6
  - 1E7

- Curvature Before Overlay values:
  - 75mm
  - 100mm
  - 125mm
  - 150mm

- Key points:
  - Design Traffic (ESA) = 3E6
  - Curvature Before Overlay = 0.242
  - Curvature Before Overlay = 0.198
Asphalt Overlay Design: Zone 3 - 80kph

Chart 30 Zone 3 - 80Kph

Curvature Before Overlay vs. Design Traffic (ESA) for asphalt overlay design in Zone 3 at 80 km/h. The chart shows the relationship between curvature before the overlay and design traffic for different overlay thicknesses: 75mm, 100mm, 125mm, and 150mm. The data points are represented by various markers, and the trend lines indicate the expected curvature based on design traffic.