NZ Guide to Pavement Evaluation and Treatment Design

Rehabilitation guide
Traffic loading – design values

- Not addressed in either of the Guides
- Austroads Part 2 is due for imminent release
- New Zealand specific design methodology in Part 2 should be used
Learning outcomes

• AGPT Part:2 – New loading calculations for ME Design
• Why we are changing
• What are we changing to
• How is that different to old SAR/ESA
• What you will need to do
• Empirical designs keep old ESA approach.
Why - history

• 2012 approach considers relative damage between axle groups to be independent of Pavement Structure

• Current approach developed by Scala (1970a), simply compared axle group loads using surface deflections.

• Scala (1969, 1970b) – Noted that deflection axle group load equivalencies would change with pavement structure
Why - research

Moffet 2015: PhD Thesis

Austroads 2015: The influence of multiple-axle groups loads on flexible pavement design (AP-R481-15)

Table 1. Comparison of maximum surface deflection

<table>
<thead>
<tr>
<th>Pavement structure</th>
<th>Maximum surface deflection (mm)</th>
<th>53 kN SAST</th>
<th>80 kN SADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprayed seal</td>
<td></td>
<td>1.27</td>
<td>1.21</td>
</tr>
<tr>
<td>350 mm (normal standard) crushed rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgrade – CBR 5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>175 mm Asphalt (E=4000 MPa)</td>
<td></td>
<td>0.37</td>
<td>0.55</td>
</tr>
<tr>
<td>250 mm cemented material (E=5000 MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 mm select fill (E_max = 150 MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 mm select fill (E_max = 80 MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgrade – CBR 3%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Why - summary

Basically – to get better axle group equivalency

• Old approach: Same Group Deflection = Same Damage
  • i.e. 53 kN SAST = 80 kN SADT = ..... = 226 kN QADT

• New Approach: Same Strain = Same Damage
  • i.e. 53 kN SAST ≠ 80 kN SADT ≠ ..... ≠ 226 kN QADT
The details
The details - outline

• Common Elements to calculations
• The Empirical Approach (Deflection / ESA)
• The new ME Strain Approach
• New limits for AC loading calculations
• Loading Discussion
• Learning Outcomes - check
Common elements to traffic calculations

1. Select a Design Period (P) (Section 7.4.2)
2. Identify the Design Lane (Section 7.4.3)
3. Determine Initial Daily Heavy Vehicles in Design Lane (Section 7.4.4)
4. Determine the Cumulative Number of Heavy Vehicles (Section 7.4.5, 7.4.6)
5. Calculate Cumulative HVAG (Section 7.4.7)
6. Establish Traffic Load Distribution
Common elements – initial daily heavies

\[ N_i = AADT \times DF \times \%HV/100 \times LDF \]

where

- \( N_i \) = initial daily heavy vehicles in the design lane
- \( AADT \) = Annual Average Daily Traffic\(^2\) in vehicles per day in the first year (Section 7.4.4)
- \( DF \) = direction factor is the proportion of the two-way AADT travelling in the direction of the design lane
- \( \%HV \) = average percentage of heavy vehicles (Section 7.4.4)
- \( LDF \) = lane distribution factor, proportion of heavy vehicles in the design lane (Section 7.4.3)
Common elements – design heavies

\[ N_{HV} = 365 \times CGF \times N_i \]

where

\[ N_{HV} = \text{Design traffic in cumulative heavy vehicles} \]
\[ CGF = \text{cumulative growth factor (Section 7.4.5 and Section 7.4.6)} \]
\[ N_i = \text{average daily number of heavy vehicles in the first year of opening to traffic (Section 7.4.4)} \]

\[ N_{DT} = N_{HV} \times N_{HVAG} \]

where

\[ N_{DT} = \text{the cumulative heavy vehicle axle groups in the design lane over the design period} \]
\[ N_{HV} = \text{cumulative number of heavy vehicles (Section 7.4.5, Section 7.4.6)} \]
\[ N_{HVAG} = \text{average number of axle groups per heavy vehicle} \]
Specific elements to traffic calculations

Flexible Pavements (Section 7.6)
- Mechanistic-empirical Design
  - Calculate ESA per Axle Group and calculate Cumulative Number of Loads of each Axle Group Type and Axle Load (Sections 7.6.2, 7.5)
- Empirical Design
  - Calculate ESA per Axle Group (Section 7.6.2)

Rigid Pavements (Section 7.7)
- Calculate Cumulative Number of Loads of each Axle Group Type and Axle Load (Sections 7.5, 7.7)
Empirical ESA approach

\[ ESA_{ij} = \left( \frac{L_{ij}}{SL_i} \right)^4 \]

where

\[ ESA_{ij} \quad \text{Number of repetitions of a Standard Axle which causes the same amount of damage as a single passage of axle group type \( i \) with load \( L_{ij} \)} \]

\[ SL_i \quad \text{Standard Load for axle group type \( i \) (from Table 7.7 and Table 7.8)} \]

\[ L_{ij} \quad \text{\( j^{th} \) load magnitude on the axle group type \( i \)} \]
Empirical standard on axle groups

- Austroads Reference Load - Single axle with two sets of dual wheels that carries a load of 80 kN.
- The loads on other axle groups that cause the same damage as a Standard Axle are:

<table>
<thead>
<tr>
<th>Axle Configuration</th>
<th>Load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Axle Single Wheels</td>
<td>53</td>
</tr>
<tr>
<td>Single axle Dual Wheels</td>
<td>80</td>
</tr>
<tr>
<td>Tandem Axle Single Wheels</td>
<td>90</td>
</tr>
<tr>
<td>Tandem Axle Dual Wheels</td>
<td>135</td>
</tr>
<tr>
<td>Triaxle</td>
<td>181</td>
</tr>
<tr>
<td>Quad axle</td>
<td>221</td>
</tr>
</tbody>
</table>
Empirical ESA approach

The design number of Equivalent Standard Axles of traffic loading (DESA) is calculated as follows (Equation 37):

\[ DESA = \frac{ESA}{HVAG} \times N_{DT} \]

where

\[ \frac{ESA}{HVAG} = \text{average number of Equivalent Standard Axles per Heavy Vehicle Axle Group} \]

\[ N_{DT} = \text{cumulative number of Heavy Vehicle Axle Groups over design period (from Equation 35)} \]
Empirical Approach is easy

Axles Loads = \(26kN\) \(45kN\)

Equivalent Standard Axles = \(\frac{26}{53}\)^4 + \(\frac{45}{90}\)^4
Empirical design loading

Figure 8.4: Design chart for granular pavements with thin bituminous surfacing

\[
t = \left[ 219 - 211 \log(CBR) + 58 (\log(CBR))^2 \right] \log(\text{DESA}/120)
\]
Empirical design loading

Figure 8.4: Design chart for granular pavements with thin bituminous surfacing
ME approach – 2017 AC fatigue equation

\[ N = \frac{SF}{RF} \left[ \frac{6918(0.856V_b + 1.08)}{E^{0.36} \mu \varepsilon} \right]^5 \]

where

- \( N \) = allowable number of repetitions of the load-induced tensile strain
- \( \mu \varepsilon \) = load-induced tensile strain at the base of the asphalt (microstrain)
- \( V_b \) = percentage by volume of bitumen in the asphalt (%)
- \( E \) = asphalt modulus (MPa)
- \( SF \) = shift factor between laboratory and in-service fatigue lives (presumptive value = 6)
- \( RF \) = reliability factor for asphalt fatigue (Table 6.16)
2017 AC fatigue equation in practice

Asphalt

\[ N_{ij} = \frac{1}{n} \times \frac{SF}{RF} \times \left[ \frac{6918(0.856V_b + 1.08)}{E^{0.36} \mu \varepsilon_{ij}} \right]^5 \]

where

\[ N_{ij} \] = allowable number of repetitions of axle group type \( i \) with total load equal to the \( j^{th} \) load magnitude

\[ n \] = number of individual axles within axle group type \( i \) (e.g. \( n = 2 \) for a tandem axle group)

\[ \mu \varepsilon_{ij} \] = load-induced tensile strain at the base of the asphalt (microstrain) caused by a single axle, with the same number of tyres as those used by the individual axles within axle group \( i \), applying a load equal to the \( j^{th} \) load magnitude divided by \( n \) (microstrain)
ME approach – calculate strains for all cases

\[
\mu \varepsilon_{ij} = \frac{L_{ij}}{n} \times \frac{\mu \varepsilon_{SAST,53}}{53}
\]

for single axle with single tyres \hspace{1cm} (a)

\[
\mu \varepsilon_{ij} = \frac{L_{ij}}{n} \times \frac{\mu \varepsilon_{SADT,80}}{80}
\]

for single axle with dual tyres \hspace{1cm} (b)

where

\[
\mu \varepsilon_{ij} = \text{load-induced strain caused by a single axle, with the same number of}
\]

\[
\text{tyres as those used by the individual axles within axle group } i, \text{ applying a}
\]

\[
\text{load equal to the } j^{th} \text{ load magnitude divided by } n \text{ (microstrain)}
\]

\[
L_{ij} = \text{magnitude of the } j^{th} \text{ load applied to axle group } i \text{ (kN)}
\]

\[
n = \text{number of individual axles within axle group type } i \text{ (e.g. } n = 2 \text{ for a}
\]

\[
\text{tandem axle group)}
\]

\[
\mu \varepsilon_{SAST,53} = \text{strain induced by a single axle with single tyres applying a load of 53 kN}
\]

\[
\text{(microstrain)}
\]

\[
\mu \varepsilon_{SADT,80} = \text{strain induced by a single axle with dual tyres applying a load of 80 kN –}
\]

\[
i.e. \text{ the Standard Axle (microstrain)}
\]
ME approach – all case calculations

• Requires response to load calculation for each load and axle type

• Using layered linear-elastic modelling

• Can linearly scale response from model

• Demonstrated not to significantly affect outcome
2017 AC fatigue equation – in use

Asphalt

\[ N_{ij} = \frac{1}{n} \times \frac{SF}{RF} \times \left[ \frac{6918(0.856V_b + 1.08)}{E^{0.36} \mu \varepsilon_{ij}} \right]^5 \]

where

- \( N_{ij} \) = allowable number of repetitions of axle group type \( i \) with total load equal to the \( j^{th} \) load magnitude
- \( n \) = number of individual axles within axle group type \( i \) (e.g. \( n = 2 \) for a tandem axle group)
- \( \mu \varepsilon_{ij} \) = load-induced tensile strain at the base of the asphalt (microstrain) caused by a single axle, with the same number of tyres as those used by the individual axles within axle group \( i \), applying a load equal to the \( j^{th} \) load magnitude divided by \( n \) (microstrain)
ME damage caused by an axle group

\[ d_{ij} = \frac{e_{ij}}{N_{ij}} \]

where

\( d_{ij} \) = damage caused by axle group \( i \) with total load equal to the \( j^{th} \) magnitude

\( e_{ij} \) = expected number of repetitions of axle group \( i \) with total load equal to the \( j^{th} \) magnitude

\( N_{ij} \) = allowable number of repetitions of axle group type \( i \) with total load equal to the \( j^{th} \) load magnitude
ME Summing up the TLD damage

\[ D = \sum_{all \, i,j} d_{ij} \]

where

\[ D = \text{total damage of the asphalt, cemented material or lean-mix concrete layer resulting from the design traffic} \]

\[ d_{ij} = \text{damage caused by axle group } i \text{ with total load equal to the } j^{th} \text{ magnitude} \]
ME allowable HV axle groups

\[ A_{HVAG} = \frac{N_{DT}}{D} \]

where

\( A_{HVAG} \) = allowable HVAG repetitions for the asphalt, cemented material or lean-mix concrete layer

\( N_{DT} \) = cumulative heavy vehicle axle groups traversing the design lane during the design period

\( D \) = total damage of the asphalt, cemented material or lean-mix concrete layer resulting from the design traffic (Equation 49)
Converted back to allowable ESA

\[ A_{ESA} = \frac{N_{DT} \times ESA/HVAG}{D} \]

where

\( A_{ESA} \) = allowable ESA repetitions for the asphalt, cemented material or lean-mix concrete layer

\( N_{DT} \) = cumulative heavy vehicle axle groups traversing the design lane during the design period

\( D \) = total damage of the asphalt, cemented material or lean-mix concrete layer resulting from the design traffic (Equation 49)

\( ESA/HVAG \) = average ESA/HVAG for the design traffic load distribution (Section 7.6.2)
Mechanistic Empirical approach not that hard

Critical Strains

\[ \left( \frac{26}{1} \right) \mu \varepsilon_{SAST,53} \left( \frac{45}{2} \right) \mu \varepsilon_{SAST,53} \]

Allowable groups is Sum of

\[ N_{ij} = \frac{1}{n} \times \frac{SF}{RF} \times \left[ \frac{6918(0.856V_d + 1.08)}{E^{0.36} \mu \varepsilon_{ij}} \right]^5 \]
Thickness limits for AC – using DESA

<table>
<thead>
<tr>
<th>WMAPT</th>
<th>≤ 25 °C</th>
<th>26–34 °C</th>
<th>≥ 35 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design traffic loading limit (DESA)</td>
<td>$4 \times 10^8$</td>
<td>$2 \times 10^8$</td>
<td>$10^8$</td>
</tr>
</tbody>
</table>

$$N_{DT \ limit} = \frac{DESA_{limit}}{(ESA/HVAG)}$$

where

- $N_{DT \ limit}$ = Upper limit of cumulative number of Heavy Vehicle Axle Groups over design period for use in the asphalt fatigue damage calculations
- $DESA_{limit}$ = upper limit of the design traffic expressed as Equivalent Standard Axles (ESA) for use in the asphalt fatigue damage calculations (Table 7.9)
- $ESA/HVAG$ = average number of ESA per HVAG from the project traffic load distribution
Traffic loading - discussion

NZ Transport Agency has
- 1600 Traffic Counting site – 1 site per 7 km
- 390 Continuously – 1 site per 28 km
- 6 Weigh in Motion Site – 1 site per 1800 km
- Data averaged across sites
- Can estimate loading from AADT and %HCV
- Best estimates in RAMM

Australia has 200 Weigh in Motion Sites
- ESA/HCV ranges from 1 - 7

Questions also around “power laws”, reference loads/width and axle group equivalency.
Learning outcomes - check

- Austroads Guide to Pavement Technology Part:2 – New loading calculations for ME Design
- Why we are changing?
- What are we changing to?
- How is that different to old SAR/ESA?
- What you will need to do?
- Empirical designs keep old ESA approach.