Unbound Granular Pavement Design

Tonkin & Taylor Ltd,
Pavements Group

Coverage:

Scope

- Concepts
- Rehabilitation
- New pavements
- AUSTROADS
  - Conventional/Mechanistic
  - Transit Research
- Otago Issues
- Case Histories

Notes and references available on www
Structural Design Methods

1. Experience based
2. Empirical
3. Mechanistic-Empirical

Subgrade Type

Traffic

Standard Thickneses for various Combinations

Design

Experienced Based

- Traffic
- Materials
- Long term in situ water content
- Chart Design
  - (Austroads Fig. 8.4)

Mechanistic-Empirical

- Traffic
- Materials
- Long term in situ water content
- Design criteria
- Structural analyses
- Determine stresses/strains
- Compare design criteria
  -(Layered Elastic Theory)

>>>New pavements

>>>Rehabilitation, widening,

Post-construction verification: B/2 compliance, Deflection
Empirical – Deflection based acceptance

Notes:
1. Deflections shown are for chip sealed unbound granular pavements.
2. Revised by P. D. to Min. A. S. surface.
3. ACCEPTANCE DEFLECTION assumes a 10% improvement over 1st year of service.
4. Sufficient deflection findings are assumed for statistical sample.
5. 0% value applies unless higher failure risk is specified.

Limitations - Deflection Bowl Shape

High strains

Silty Basecourse

SOUND BASECOURSE

SUBBASE

LOWER SUBBASE

PEAT

Stress/strain – not deflection
Deflection cost effective on small projects, in “normal” terrain
Layered Elastic Design

Falling Weight Deflectometer

- Sensors lowered onto existing pavement
- Loading plate with central sensor
- Impact load 30 ms
- Surface deflection bowl recorded
- Buffer design developed that provides stresses and strains within the pavement that correspond with those induced by a heavy vehicle (8 tonne axle)
- Test is repeated to confirm accuracy
FWD Record
Load and deflections Vs Time

Deflections from 9 geophones from centre of load plate to 1.5 m

Load pulse

< 30 milliseconds >

Structural Interpretation-back analysis

- Multi-layer elastic model, back-calculates moduli from deflection bowl:
  EFROMD2
  ELMOD
  EVERCALC (www)

Calculate stiffnesses of each layer from the impact load and shape of the deflection bowl using elastic theory

- Layer Stiffness = $E \times h^3$. 
Back analysis inputs

- FWD Impact Stress and Deflections
- Pavement type (AC, chipseal, stabilised)
- Layer thicknesses (up to 3, maybe 4 layers)
  - as built
  - maintenance records
  - test pits (esp. if sensitive)
- Environmental factors
  - temperature (AC only)
  - seasonal effect.

Back-analysis outputs

- Subgrade modulus (accurate)
- Subgrade modulus non-linearity (soil type/drainage)
- Layer moduli (E = 10 CBR approx.)

Typical values:

- M/4 basecourse 100 - 1000 MPa
- AC 2000 - 6000 MPa
- Cemented 2000 - 40,000 MPa
Structural Interpretation - Forward Analysis

CIRCLY, ODEMARK, ELMOD, EVERSTRESS etc
http://www.wsdot.wa.gov/TA/Software/

- Inputs
  - Pavement layer thicknesses
  - Layer moduli (from back analysis)

- Deterioration models
  - Established Strain Criteria
  - AUSTROADS 92, AASHO Road Test
  - ARRB TR Model
  - HDM

Mechanistic Analysis Strain Criteria

Load Repetitions = \([9300/\text{microstrain}]^7\)

ESA - Equivalent Single Axles

Permissible microstrain

SAR: Standard Axle Repetitions calculated using damage exponent of 4 (slope above) Chart Design

Number of load repetitions

eg AUSTROADS:
Subgrade Strain Ratio

Vertical strain at top of subgrade

Allowable Strain (Austroads)

SSR>1  Premature distress likely
SSR<1  Over design
SSR=1  Cost effective design

Structural Interpretation - Outputs

• Basecourse strain
• Subgrade strain
• Subgrade strain ratio *
• Critical layer (greatest strain) and distress mechanism
• Depths of digouts or reconstruction.
• Thickness of overlay required -5 options +
  - TNZ Supp. (SHPDRM & Precedent Strain
  - AASHTO, TRRL
• Depth of cement stabilisation required (TNZ Supplement)
• Residual Life
Subgrade Design CBR

- Precedent from as-builts of nearby roads
  - in situ long term condition of subgrade considered
- Laboratory CBR (soaked vs unsoaked)
- Scala
- FWD – nearby surfaces, or can be directly on subgrade, grass, loose gravel or cohesive soil with crust (elastic)

Subgrade Modulus, \( E \) (MPa) = 10 \* CBR

- Austroads – 10%ile CBR
- NB - Transit require 95% reliability
Presumptive Traffic Load Distribution

- Austroads 2004 Chapter 7
- State Highways - Too conservative for local roads

Austroads CBR

TNZ Supplement to Austroads Guide

www.transitnz.govt.nz

Traffic - ESA

Large range (almost an order)

Long term in situ w/c

Design CBR usually 2-6

5%ile CBR = 0.4 x Median

10%ile CBR = 0.5 x Median

100

100

10

10
Design

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- Traffic
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>>> New pavements

>>> Rehabilitation, widening,

Post-construction verification: B/2 compliance, Deflection
Transition to Mechanistic Design

http://www.pavementanalysis.com/pages/Applications/PaveDesign/PaveDesign.php
Austroads Sub-layering

### Results - Conventional (non-volcanic) Isotropic Subgrade

#### Basic Model

<table>
<thead>
<tr>
<th>Layer</th>
<th>Design Thickness (mm)</th>
<th>Isotropic Modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basecourse</td>
<td>100</td>
<td>234</td>
</tr>
<tr>
<td>Upper Subbase</td>
<td>226</td>
<td>126</td>
</tr>
<tr>
<td>Lower Subbase</td>
<td>226</td>
<td>37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Layer</th>
<th>Design Thickness (mm)</th>
<th>Isotropic Modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>111</td>
<td>234</td>
</tr>
<tr>
<td>Layer 2</td>
<td>111</td>
<td>172</td>
</tr>
<tr>
<td>Layer 3</td>
<td>111</td>
<td>93</td>
</tr>
<tr>
<td>Layer 4</td>
<td>111</td>
<td>50</td>
</tr>
<tr>
<td>Layer 5</td>
<td>111</td>
<td>27</td>
</tr>
</tbody>
</table>

### Equi-thick Sub-layer Model

<table>
<thead>
<tr>
<th>Layer</th>
<th>Design Thickness (mm)</th>
<th>Isotropic Modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgrade</td>
<td>Infinite</td>
<td>20</td>
</tr>
</tbody>
</table>

#### Notes:

1. Upper pavement (above orange line) must be free draining (to at least 180 mm).
2. Above is for "conventional" (non-volcanic) subgrades. For volcanic subgrades, go to [Volcanic Subgrade](#).

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**Sub-layer Modular Ratios - Unbound**

- $E_{\text{subgrade}}$ independent of subgrade
- $E_{\text{base}}$ doubles for each 125 mm
Austroads Sub-layer Modular Ratios

Austroads (2004) Chapter 8

- Divide the granular materials into 5 layers of equal thickness
- Adopt the vertical modulus for the top sub-layer from:
  \[ E_{\text{top of base}} = E_{\text{subgrade}} \times 2^{\left(\frac{\text{total granular thickness}}{125}\right)} \]
  (But not exceeding tabulated upper bounds for the materials.)
- Determine the modular ratio of successive sub-layers from:
  \[ R = \left[ \frac{E_{\text{top of base}}}{E_{\text{subgrade}}} \right]^{1/5} \]
- Calculate the modulus of each layer beginning with that immediately overlying the subgrade of known modulus.

In summary:

\[ E_{\text{top of base}} = E_{\text{subgrade}} \times (\text{function of total granular thickness}) \]

With little dependence on the quality of the unbound granular material if proper compactive effort is applied.

Modular Ratios

Transit – Research into Performance Based Specifications using FWD.

Normalised Modular Ratio: NMR

\[ \text{NMR} = \frac{\text{As-built modular ratio}}{\text{Standard modular ratio}} \]

Measure of compaction compliance with Austroads expectations
Moduli and normalised ratios for firm subgrade

Moduli and normalised ratios for variable subgrade
Case Histories: Post-construction

Cumulative Normalised Modular Ratio Distributions for New Trafficked Pavements

Transit LTPP Benchmark Sites
Case Histories: Transit Network

Cumulative distribution of normalised modular ratio for all Benchmark Sites

Case History: Construction

Increase in Normalised Modular Ratio with Additional Compaction
Construction QA

- Construction testing allows as-constructed modular ratios to be compared with expected results from known good practice, thereby giving an immediate performance indicator.
- It provides a check for overall B/2 compliance as the full depth of construction is evaluated, not just the surface layer.
- Allows decisions on severity of problem if B/2 fails.

Construction QA

- The normalised modular ratio is a quantitative measure of construction uniformity and stiffness of the pavement layers, relative to the subgrade.
- The performance indicator is independent of subgrade weaknesses or subgrade non-uniformity.
- Readings should preferably be taken during construction or prior to sealing or application of a bound surface layer.
Otago Issues: Very soft subgrades (CBR<3)

• Austroads Light Traffic – 100-150 mm stabilised then CBR =3
• Transit – 150+ mm stabilisation
  - geogrid & geotextile *
  - 150 mm sacrificial granular layer and same CBR
• Geotextile – ideal if cost effective
• Geogrid – applicable in highly yielding subgrades (deflection 100 mm in trials). * Transit Supplement: Caution: “It is up to the geosynthetic supplier to provide relevant and credible evidence that such savings are applicable for the particular product in question”
• Geogrid trials on SH1 Fairfield Bypass – evidence lacking
• Geogrid undetectable in hit & miss layout –construction only
• Drainage plus validation of design CBR for any SIL on CBR<3

Otago Issues: Schist-derived silt

• Transit Supplement:
  Care should be taken assessing silty and sensitive subgrades. They can be significantly weakened by the inappropriate use of construction equipment and this should be noted in the contract documents.
• Otago schist-derived micaceous silts:
  +1 m of granular subbase needed on SH 1 pavements with silt fills compacted wet of optimum.
Otago Issues: Solid Density

- B/2 Compliance
- AP65- Correction for oversize in %MDD
- Saturation and %MDD are very dependent on solid density
- Solid density often “assumed”
- Percentage Solid Density Concept – an independent check on B/2 results
  Grading exponent “n”
  Fine M/4, n=0.41, coarse M/4 n=.63
  Dmax % = 86 + 20(0.5-n)

Otago Issues: Frost

- Transit Supplement: Indefinite guidance.
- Frost Resistant Design and Construction of Pavements in Central Otago [www.pavementanalysis.com](http://www.pavementanalysis.com)

- Sand Equivalent > 50 or;
- Percent passing 2.36 and 0.15 mm sieves give
  \[ P_{2.36}/P_{0.15} > 3 \]
- Freeze-thaw Heave < 14 mm

Laboratory after compaction or better, field after compaction
Case Histories

Demonstrating achievement of intended design life at end of construction

Rehabilitation projects

Long term study: Waihola passing lane
Deflection Surveys
Before and After Construction

Before  After M/4 overlay
Construction verification on yielding subgrade

Before

After part M/4 overlay

- Determine achievement of objective (full design life)
- Distinguish cause of any deficiency:
  - Design issue (over design / under design)
  - Construction QA
  - Subgrade non-uniformity
- Subgrade strain ratio
  (Actual / Austroads allowable strain)
References & Figures

- References, 2004 anh LVR, both TNZ supplements to Austroads 2005 and 2002? **
- Light Pavements – corresponding figure with same reliability No
- Transit requirements 95% 25 year design (but note 10 percentile CBR normally
- dcc criterion is for acceptance of new pavements
- Austroads 2004 – Fig 8.4 with hatched zone from S4 – reliability=?
- Traffic p 32 of TNZ supp to 04, ESA=1.4*HV, 3% growth, 25 years **
- Selection of design CBR, (copy ex Aust2004), Scala (silts not sands), deflection testing, design moisture content. Back calculated CBR (Precedent method).
- Mechanistic design concepts
- Subgrade strain criterion – all graphs from Odemark 2006*
- Determination of pavement parameters – using FWD – BMS subsection Es cumulative
- Manapouri es plots
- Mechanistic design spreadsheet – not if Fig 8.4
- Field verification of subgrade – during construction – Scala, FWD
- Weaving excess moisture.
- Compliance monitoring- spreadsheet ‘refer to nmr if fails
- frost criterion paper in references **
- Verification of design life – post construction testing
- Rehabilitation Design – Transit supplement

Subgrade improvement

- SIL properties
- Schist derived subgrade issues
- Geogrid/geofabric
Acceptance testing of pavement layers

- Austroads moduli for unbound layers
- Checks on compaction
- Case Histories from Otago

Demonstrating achievement of intended design life at end of construction

- Transit requirements
- Local Authority requirements
- Case History from Otago