LOAD DAMAGE EXPONENTS

Rationalising LDE's for New Zealand Unbound Granular Pavements

Mechanistic Analysis - Distress Modes from Data Mining

Traditional mechanistic design considers only 1 mode for unbound, 2 for bound pavements
RAMM data now enables up to a dozen or more to be considered, as warranted, and calibrated to region or sub-region

GeoSolve

Structural distress modes

1 aggregate rutting (basecourse or subbase)

2 aggregate shear (shoving) of basecourse or subbase

3 aggregate instability -pumping/(unbound) /potholing

4* aggregate weathering –mineralogical changes in fines

5 aggregate attrition – physical generation of fines

6 cracking (conventional, bottom up) of bound layers

7 flexure (top down cracking) of bound layers

8 bond loss (cement bound reverting to unbound)

9 bitumen hardening (aging)

10 subgrade rutting

11 subgrade shear

12 accumulated deformation

13 roughness progression

14 shrinkage cracking (viz FBS with curing/ thermal)

Overlays are calculated for structural distress modes only

Surfacing distress modes

15 seal deformation (more likely as multiple seal layers accumulate)

16 flexure (top down cracking in seal or thin AC)

17 reflection cracking

18* seal flushing

19 ravelling

Economic triggers

20 excessive maintenance costs for the surfacing (seal, thin AC)

21 excessive maintenance costs for structural layer(s)

Other characteristics that affect timing of triggers include:

22* loading frequency effects on inter-particle bonds

23* Cement curing

24* bitumen embrittlement (environmental ageing)
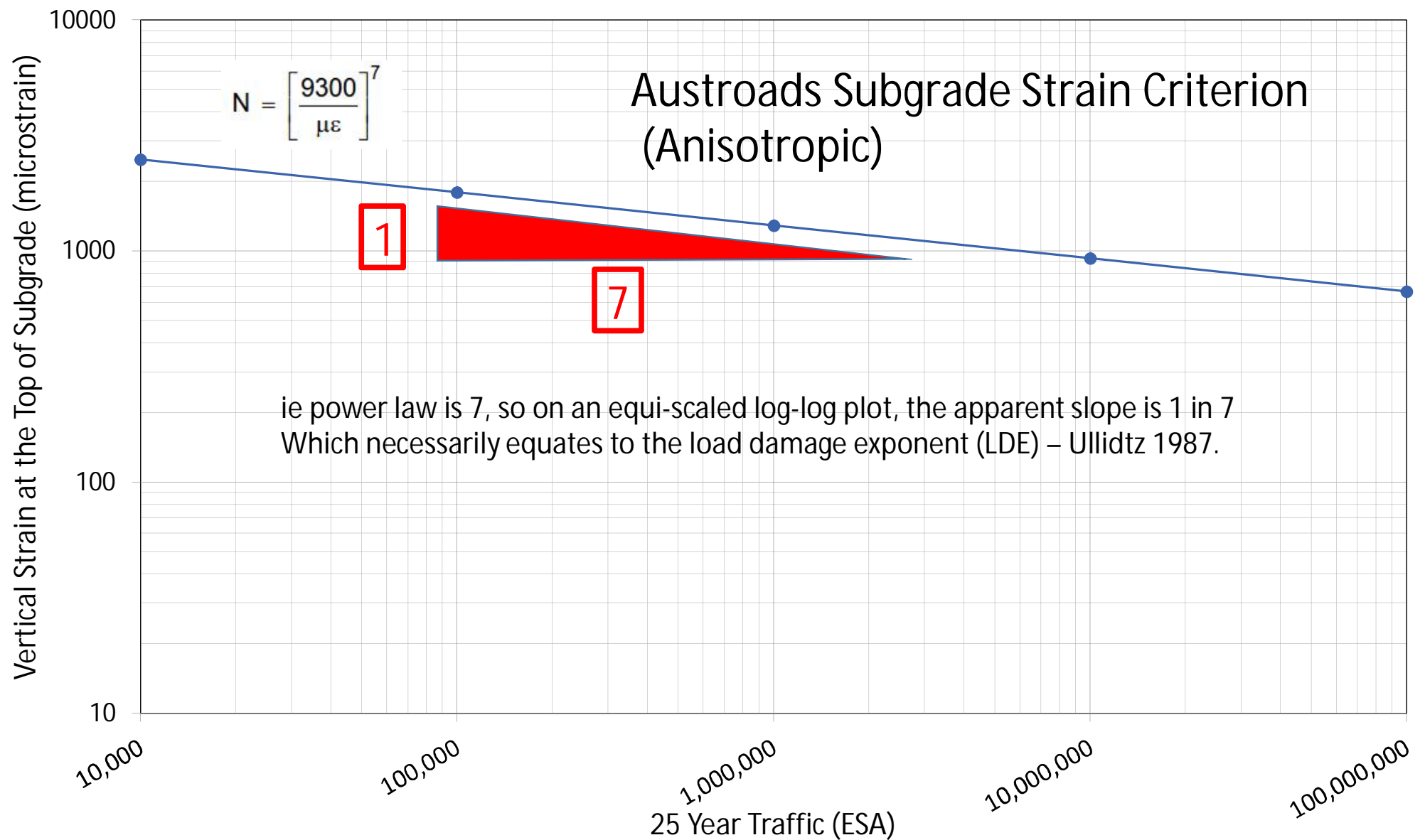
25* subgrade –subbase intrusion

26* frost heave

27* particle breakdown in freeze-thaw cycles

- 4, 18 & 22-27 Not explicitly included in current modelling

- Vehicle speed and temperature included for individual modes

(Refer pp 14)

Each one of these modes which is load dependent, has its own load damage exponent

Austroads Subgrade Strain Criterion
(Anisotropic)

$$N = \left[\frac{9300}{\mu\varepsilon}\right]^{7}$$

ie power law is 7, so on an equi-scaled log-log plot, the apparent slope is 1 in 7
Which necessarily equates to the load damage exponent (LDE) – Ullidtz 1987.

Vertical Strain at the Top of Subgrade (microstrain)

25 Year Traffic (ESA)

Rationalising LDE's

- Load Damage Exponents vary widely.

- Andrew Dawson:
  - UGM behaviour is of different types and cannot be modelled with a single power law relationship because changes in conditions cause behaviour to move from one type to another.

- This is consistent with a major study of NZ unbound granular in-service pavements using in-situ testing.
- However, as long as LDE's remain the basis of NZ Road User Charges, a simple approximation is required.
- Very large LDE's necessarily occur as terminal deformation in a single pass is approached, simply because the percentage of plastic, relative to elastic deformation becomes very large: the ability to sustain only one pass is essentially the same load as the static bearing capacity limit, ie general failure
- Consideration of extremes (1 ESA and max ESA), soon leads to the conclusions that characteristic limiting strain envelopes (ESA vs Strain) should not be straight lines on log log scale, but are highly curved as they grade from a theoretical (infinite)/very large LDE at very low ESA, to very steep (LDE approaching 1.0) as they approach the upper bound traffic limit for premium quality unbound aggregates (70 MESA has been suggested from Australian practice).
- As a result, any straight line design envelope must be an oversimplification and cannot be both efficient and reliable, except under given restrictions including a narrow range of design ESA. However these traditional approximations, including the Austroads subgrade strain criterion can be a convenient surrogate design tool for new pavement design in a region with no better precedent performance data, provided use is confined to preliminary design or additional conservatism is applied. Such simplistic criteria should not be used for rehabilitation design or predicting pavement life.

Exposure

- Pore pressures develop, either regularly or occasionally, affecting in-service roads subject to rainfall infiltration.
- This mechanism is consistent with research into seal permeability (Patrick, 2009 and later) and well documented permanent deformation characteristics of partially saturated versus dry RLT tests (Theyse, 2002).
- Under increasing load, a greater load magnitude will have little or no effect on the confinement (and hence modulus) of a dry soil, but as saturation increases an increasing proportion of the applied load will apply to the pore pressure, hence reducing the effective confining stress, necessarily resulting in reduced modulus and consequent increased permanent strain under each load cycle.
- It follows that the characteristic ESA vs Strain envelope for a dry granular aggregate or soil must be steeper (lower LDE) than for the same material under the same conditions but subject to what may be relatively short periods of increased water content.

From the study to date:

LDE in-service = 2 to 3 x LDE sheltered environment

More specifically:

For a typical New Zealand unbound granular pavement with thin chip seal surfacing exposed to rainfall, the multi-layer /multi-distress mode "effective" in-service load damage exponent is likely to be much larger than that of a similar pavement in a sheltered environment with damage quantified only by VSD.

- If the rainfall tends to be higher and temperatures lower than average, the LDE will tend to be higher.
- For thicker surfacings, (multiple uncracked seal layers, or thin AC) the LDE should tend to be lower.
- For thick structural AC, with low permeability, (1) the LDE for subgrade deformation may well the same as for a sheltered environment, but (2) the LDE for AC may be the more relevant consideration.
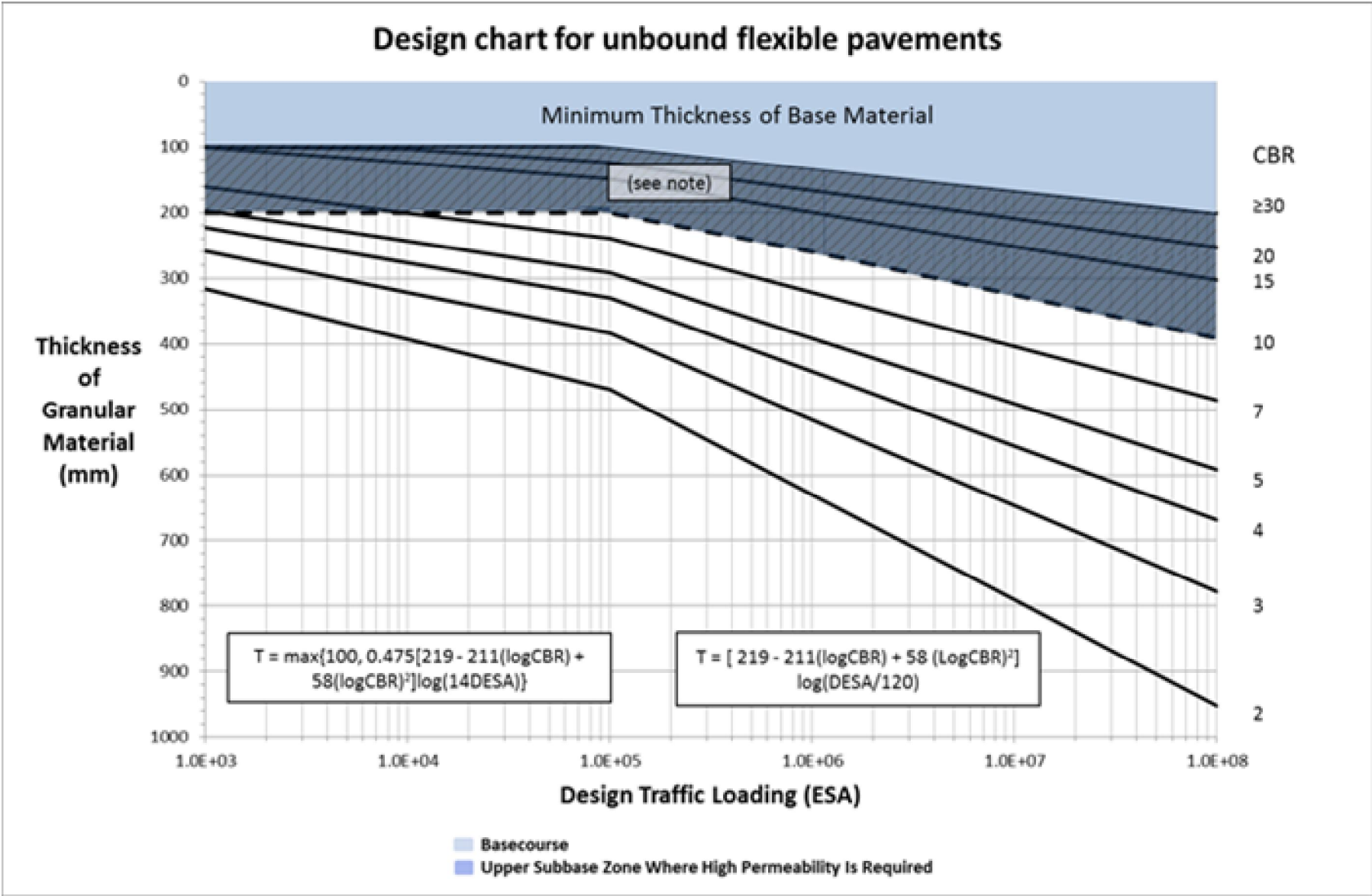
Comparison of all published LDE's. This worksheet from a detailed literature search is available for update with any additional relevant data for due consideration.

< ---------------------------Heavy Duty Pavements --------------------- >
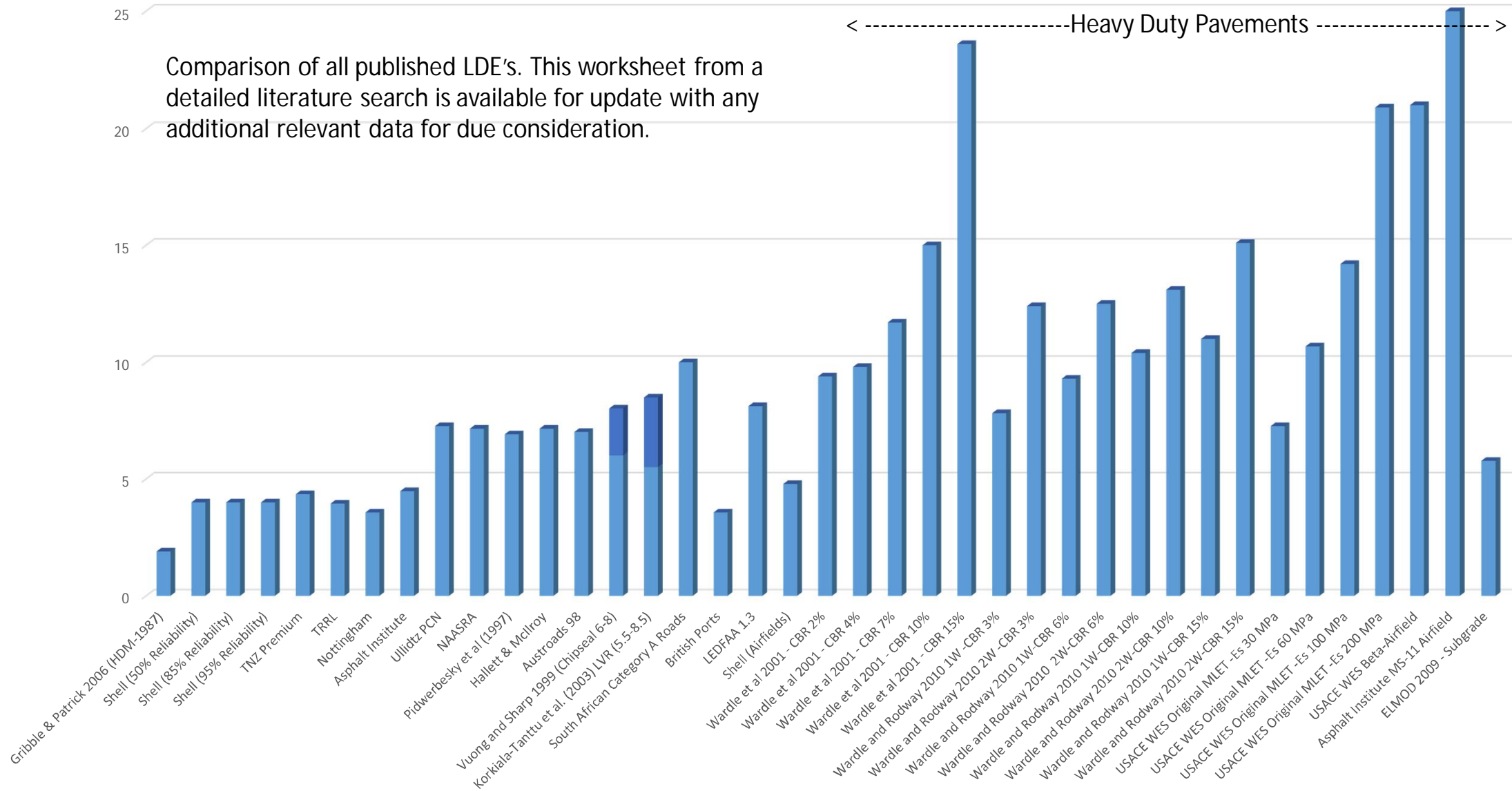
Deriving LDE's from other sources.

The origin of the Austroads subgrade strain criterion is the pavement thickness design chart for normal to heavy traffic (on the right), above 100,000 ESA. However there is also the Austroads chart for light traffic. If these two charts are combined, the result is as shown:

On average, LDE 7 applies to the normal-heavy traffic (on the right side), so intuitively, LDE is clearly different from 7 for the low volume roads on the left.

Design chart for unbound flexible pavements

Minimum Thickness of Base Material

(see note)

Thickness of Granular Material (mm)

CBR
≥30
20
15
10
7
5
4
3
2

$T = \max\{100, 0.475[219 - 211(\log CBR) + 58(\log CBR)^2]\log(14DESA)\}$

$T = [219 - 211(\log CBR) + 58(\log CBR)^2]\log(DESA/120)$

Design Traffic Loading (ESA)

Basecourse
Upper Subbase Zone Where High Permeability Is Required

Back-analysis of the combined design chart, (in the same manner as originally done by Youdale, using Austroads modular ratios), has been carried out comprehensively, to see what was implied in the way of LDE's for the entire ESA range, the short answer was as shown:


Subgrade Strain Criteria based on Austroads Figure 8.4
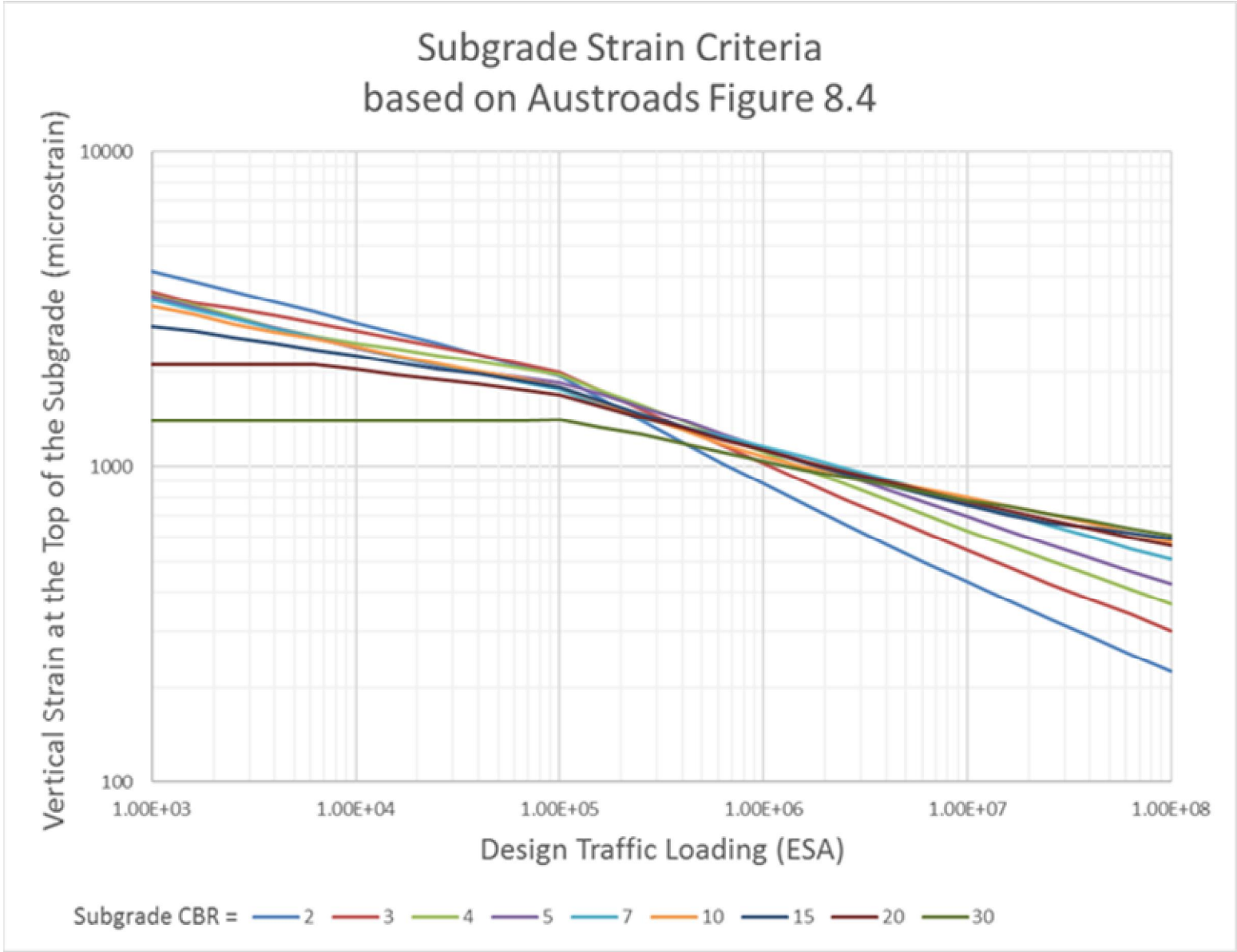
The slopes of these lines are summarised as a bar chart:

It is not intended that this set of back-calculated exponents should be regarded as necessarily valid, but it is a ball park indicator and a check on the implications of the Austroads design charts, from a different perspective. (The analysis has not show the extreme cases, where the slopes flatten to even higher LDE's).

The eye opener (or sheer coincidence depending on which side you wish to take) is that here we have mostly LDE 3-10 generated by the charts as established by Austroads. Also, for their low traffic roads note the LDE's go up, about +3 or +4 points higher than for roads with normal or heavy traffic: again almost an exact tie in with the spread of in situ measurement of millions of points on in-service New Zealand networks.

Load Damage Exponent Implied by Austroads Figur 8.4 for normal to heavy traffic, and for light traffic combined.
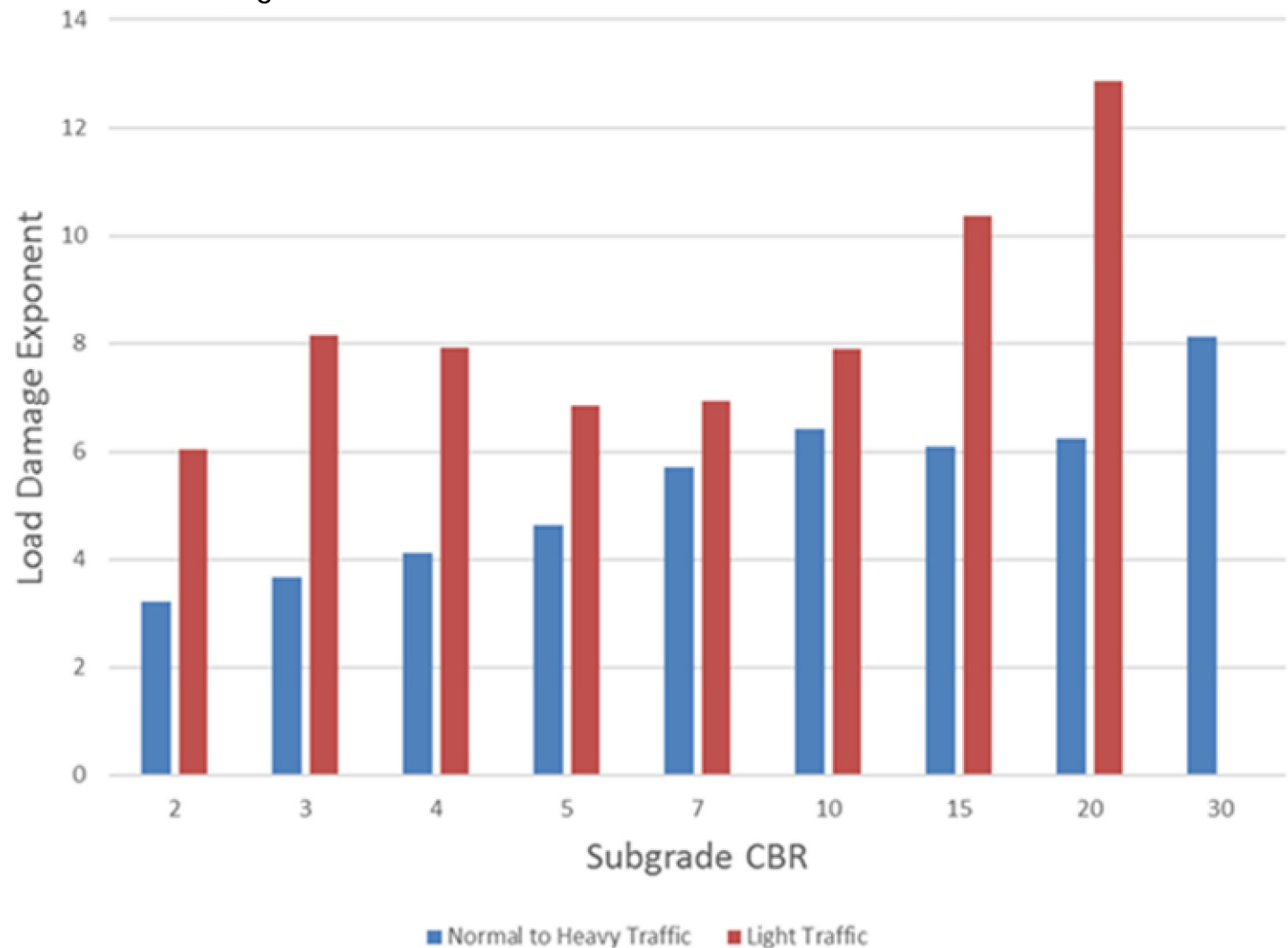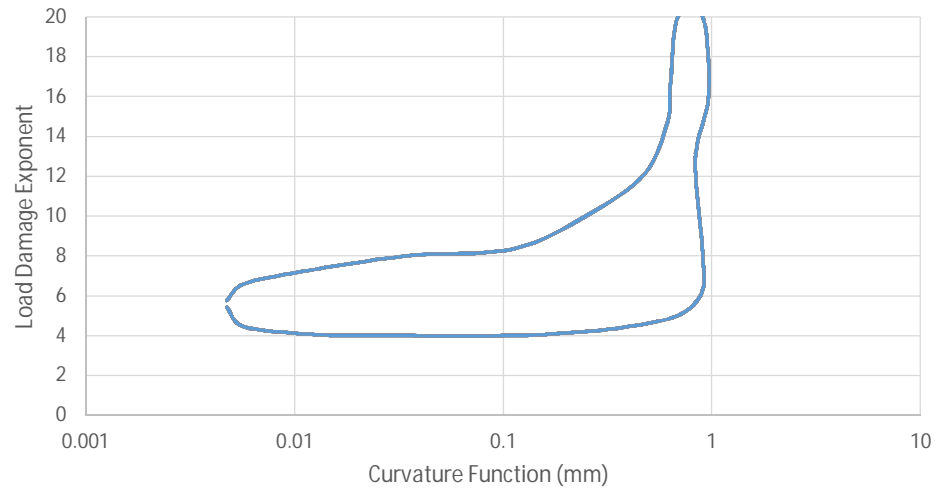
LOAD DAMAGE EXPONENTS: 1 and 99 Percentile Bounds

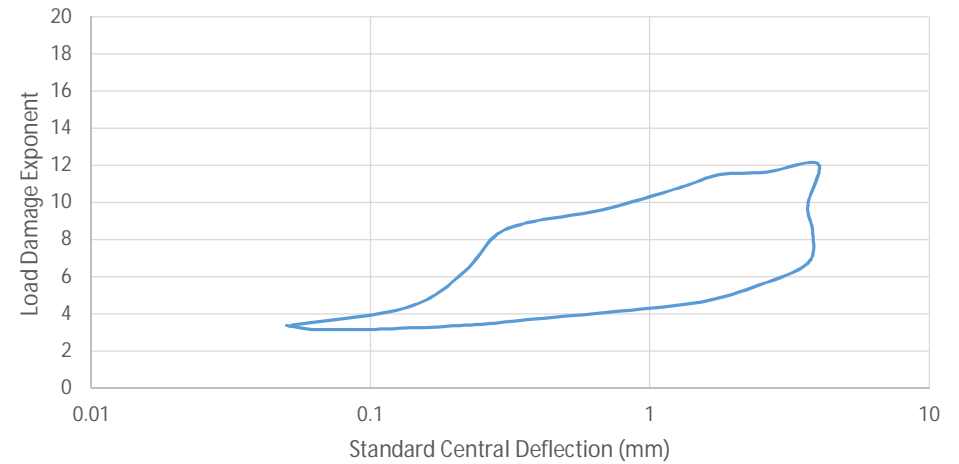LDE Range for State Highways where Subgrade is the Critical Layer (Governing)
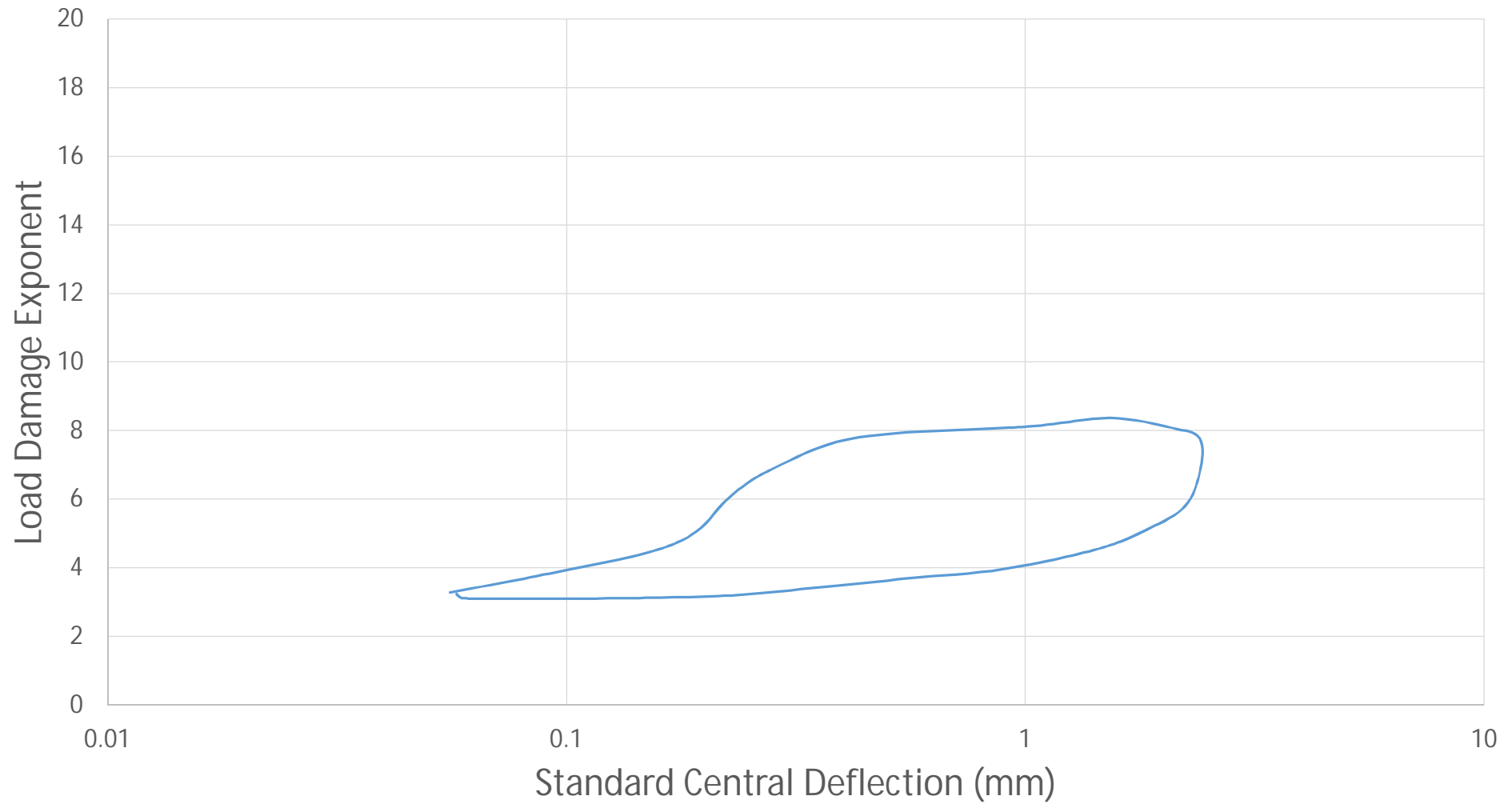
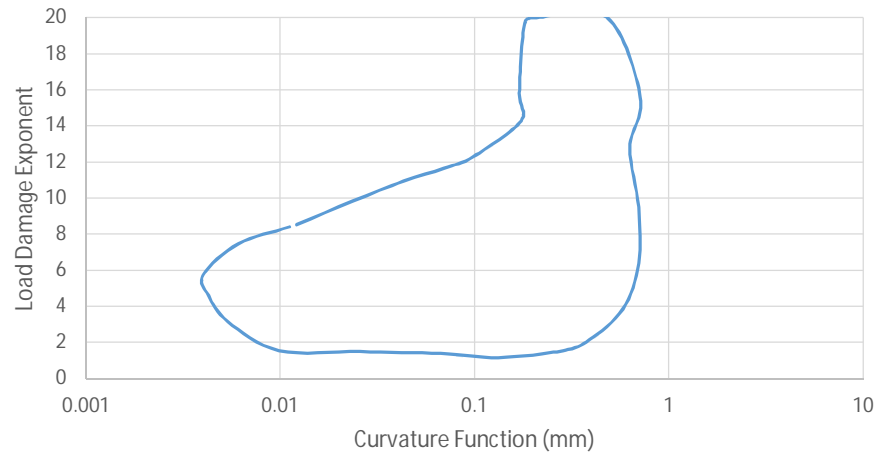# LOAD DAMAGE EXPONENTS: 1 and 99 Percentile Bounds
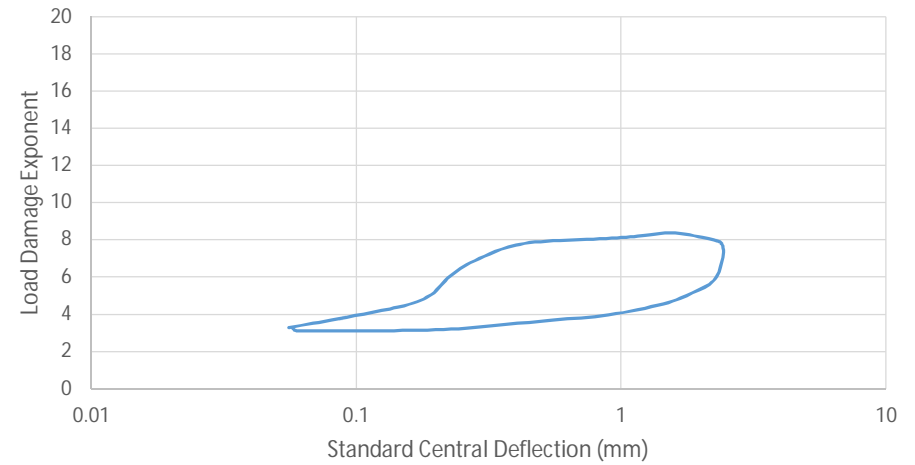
LDE Local Roads where Basecourse Layer is Critical

LDE Local Roads Subgrade

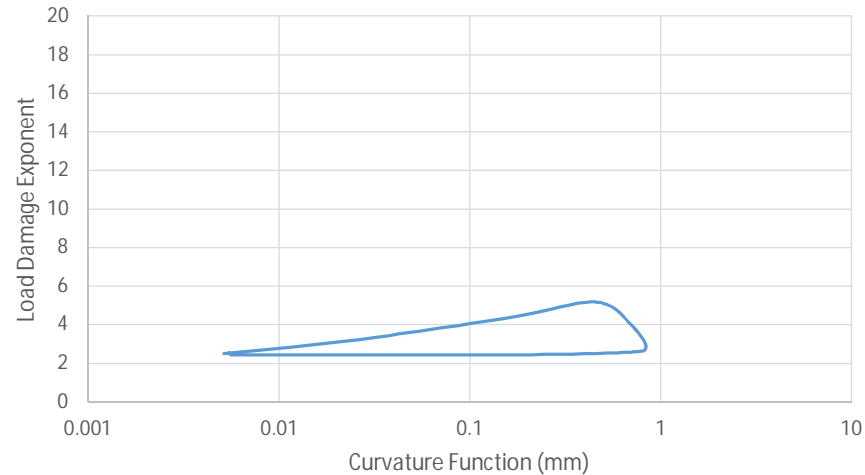### LDE State Highways where Basecourse Layer is Critical
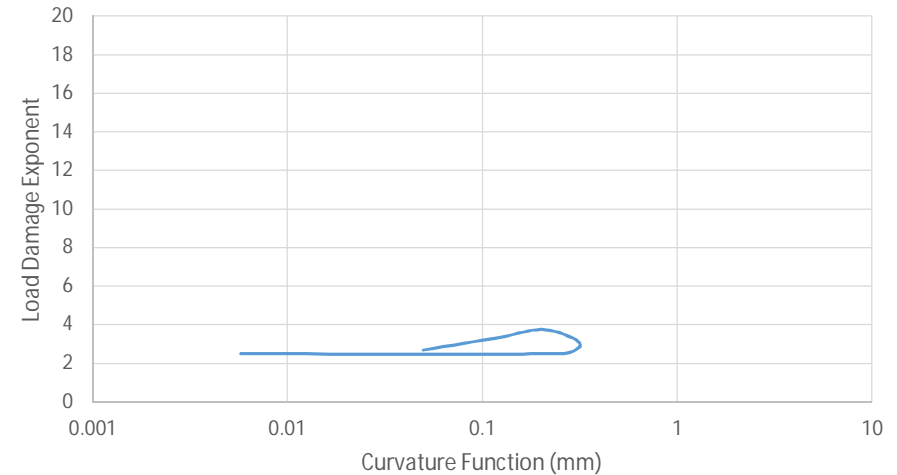

LDE State Highways Subgrade
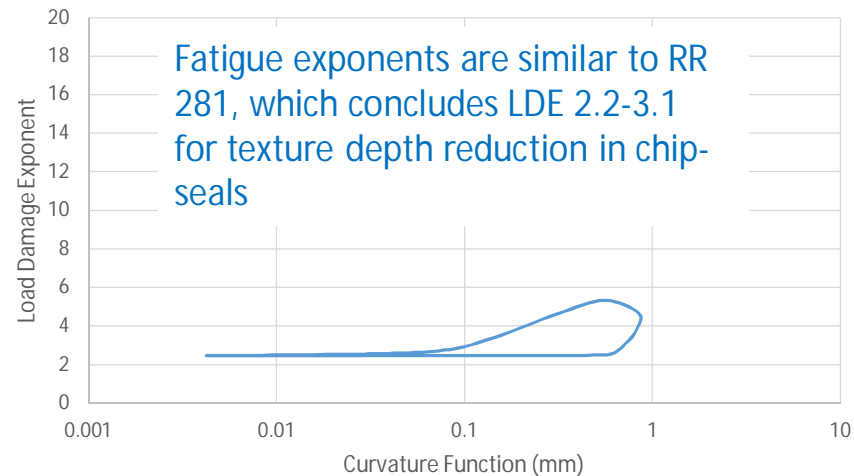
LOAD DAMAGE EXPONENTS: 1 and 99 Percentile Bounds

LDE Local Roads Surfacing (Chipseal)

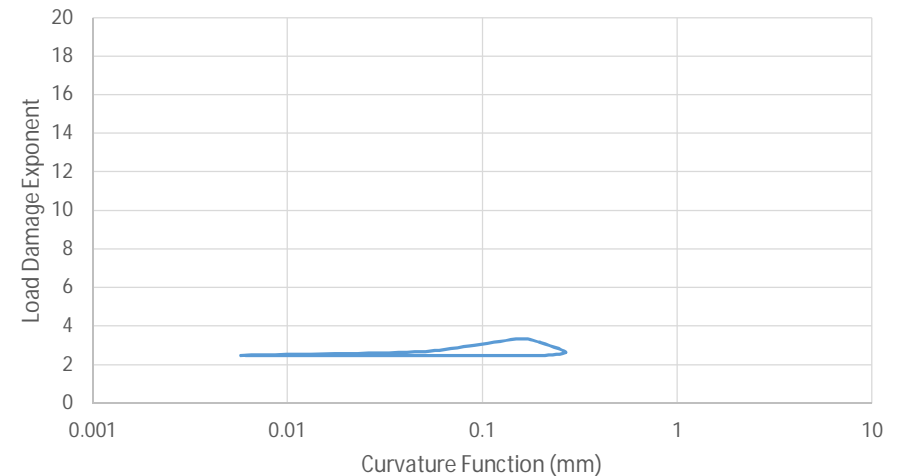## LDE State Highways Surfacing (Thin AC/OGPA)

LDE State Highways Surfacing (Chipseal)

Fatigue exponents are similar to RR 281, which concludes LDE 2.2-3.1 for texture depth reduction in chip-seals

LDE State Highways Surfacing (Thin AC/OGPA)

Load Damage Exponent is not related only to pavement "strength". LDE varies with:

- Pavement type, ie weak or strong, rigid, stabilised or flexible (increasing with stiffness)
- Layer that first reaches a terminal condition
- Nature of distress that governs the end of the pavement life (terminal conditions)
  - ie rutting, roughness, surfacing instability, excessive maintenance cost. Considering only one form of distress in one layer (subgrade rutting) can no longer be sustained as logical or approximate.
- The limit (acceptable severity) of the parameter defining the terminal condition
- The degree of saturation of the pavement layers (increasing with degree of saturation)
- Method of analysis of the data
- Material characteristics of the pavement layers and their treatment (unbound, modified or bound)
- Stiffness of the subgrade
- Extent of tyre wander (governed by lane width)
- Timing of any load increase (stage of the life cycle)
- Environmental factors that influence pavement stiffness or durability (climate, aging, water content)

The majority of the above are widely recognised.
www.transport.govt.nz/assets/Import/Documents/SKM20Engineering20Advice.pdf

LDE also varies with loading configuration:

- It is not just the magnitude of the load that affects damage, its configuration is also a major factor.
- It is now evident that the critical (governing) distress mode and affected layer will change as the geometry of the applied wheel(s) changes,
    - ie widely spaced dual wheels at low tyre pressures will tend to affect the deeper layers (eg subgrade likely to be critical) while single wheels at high tyre pressures tend to affect the upper layers (eg basecourse shoving becomes critical).
- Hence the exponent calculation also requires as inputs:
    - Axle configuration (wheel spacing)
    - Tyre width
    - Contact area (and hence load as a governing parameter)
    - Tyre pressure
- (As well as the pavement parameters on the preceding slide)

Determination of Pavement Wear using ESA Concept and Characteristic Design LDE

Simplified methodology to find the LDE that <u>appropriately characterises</u> each treatment length

      1. Determine loading and structural characteristics along the route

      2. Sub-section into homogeneous structural treatment lengths

      3. Identify the characteristic design profile on each treatment length (eg the point with 10 percentile life)

      4. Determine (from either accepted strain criteria or a network precedent performance study), the terminal distress mode and critical layer that applies for the characteristic profile, and adopt the governing LDE as characteristic.

Note, a point not always appreciated is that the characteristic (10 %ile) profile corresponds to <u>the 90 %ile LDE.</u> Hence the relevant LDE is usually considerably higher than the average.

Because the wear relationship is exponential, if using an LDE of 4 when the correct value is 7, an increase in axle load will provide very different remaining life. For a road with 20 years expected life under existing traffic, a 20 percent increase in axle load with an LDE of 4 reduces the expected life to 12 years, but if the actual LDE is 7, the change is more dramatic, reducing to only 7 years.   Adopting LDE of 1-3 when the correct value is 7, can easily give more than an order of magnitude reduction in pavement life.

These examples highlight the importance of giving due consideration to LDE determination and reliability if the precedent approach to the LDE method is used.

Summary - Load Damage Exponents

All distress modes: the limitation clause of RR 279 was very pertinent – *"The result of this accelerated pavement test principally provides an indication of the performance of a relatively strong pavement, on a strong dry subgrade, in ideal dry environmental conditions. The behaviour of weaker or saturated subgrades has not been investigated, nor have the effects on older and/or poorly maintained surfaces where moisture may be entering the base."*

Rutting damage: for most pavements, rutting alone is seldom the primary trigger for rehabilitation, hence reliance on LDE's from vertical surface deformation on test tracks should be viewed in the light of experience from engineers familiar with the historic performance of a particular network. Patrick (pers comm 29/9/16) reinforces this, saying his view remains that rutting is <u>not</u> a major issue: some degree of rutting is often present but is not the principal trigger for rehabilitation. If only rutting is present then rut filling at far lesser cost is the treatment, rather than rehabilitation.

Basecourse damage: for thin pavements where <u>damage is largely confined to the basecourse</u>, there is not a sufficient evidence base from test track pavements with the same failure mode , hence LDE's from detailed studies of in-service pavements may be the more reliable source.

Summary continued

Excessive maintenance costs: for thin pavements where <u>rehabilitation is triggered by excessive maintenance costs</u>, there are no comparable test track data with that criterion, hence LDE's from detailed studies of in-service pavements may be the only reliable source for that distress mode which in many networks is the principal trigger for rehabilitation of LVR unbound granular pavements.

All distress modes: LDE's will be <u>artificially low,</u> if averaged over different pavement forms. Precedent performance of in-service pavements (detailed engineering inspections of all treatment lengths proposed for rehabilitation in the network, each year, combined with structural analysis comparisons with every other treatment length in the network) provides reliable determination of LDE's for <u>every</u> distress mode.

Seasonal effects: - (water) if ignored will necessarily provide an unrealistic model of in-service pavement performance
- AASHO Road Test: Spring thaw, subgrade 18% decrease in modulus *decreases life by factor of 2.*
- Theyse: Unbound base layers – a 10% increase in saturation *decreases life by factor of almost 10 !*

The precedent approach necessarily ensures that the seasonal effect including the *behaviour of weaker or saturated subgrades has been incorporated, and so have the effects on older and/or poorly maintained surfaces where moisture may be entering the base.*

SOLUTION

For assessing pavement life - LDEs are not required. (NCHRP/SAPDM etc ESA revision. Use WIM basic axle groups. (ESA concept still convenient for overview, just better if ESAs are no longer used for detailed design, a change that has been widely promoted for decades overseas).

However for Road User Charges – LDE's may be the only option at present. A more rational approach is important for equitable charges that provide the right incentive to operators to minimise pavement damage

"For specific routes with high strength pavements, the damage law exponent used in calculating RUCs could be reduced from the current value of 4. Conversely, low strength low volume pavements should use higher values than 4 for damage law exponents." (Concluding sentences of section 9. Recommendations from NZTA RR 281). – Supported fully by all precedent performance LDE studies of New Zealand chip-seal networks, but now with the added benefits of detailed quantification of LDE's for all roads tested.

Whether it is practical to apply RUC's in this manner is not in the study brief and has not been addressed, but if a way can be found, then as far as technical issues are concerned, there appears to be general agreement, ie there is no uncertainty on either (a) the loading (the potential for optimising axle configuration ie numbers/loads/tyres/pressures) or (b) informed selection from any alternative routes. The optimum combination dramatically reduces damage for given total payload and the cost savings to RCA's are very substantial.