PERFORMANCE BASED SPECIFICATIONS FOR UNBOUND GRANULAR PAVEMENTS

Procedures for Demonstrating Achievement of Design Life

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Introduction

Pavement maintenance specifications are increasingly calling for "Operational Performance Measures" for rehabilitation treatments. One of these requires that the treatment is constructed so that post-construction materials testing and FWD testing confirm achievement of the design life. Often only post-construction testing is available and the procedures which maintenance contractors should follow to demonstrate achievement, are less well defined. This article is intended as a discussion document, and gives some alternative methods, depending on test data available, with suitable rationale for application. Rehabilitation treatments are addressed primarily. In some cases, new pavement construction can be assessed similarly but with limitations.

Design Verification of Rehabilitation Treatments

Using the design bases given in the Austroads Guide (Ref. 1), the future performance (expected life) of a rehabilitated pavement is most practically verified by non-destructive methods (eg deflection tests). A typical requirement s is that 95 or 97.5% of the pavement should not reach a terminal condition until at least 25 years of traffic has been sustained. A readily appreciated way of demonstrating life is with cumulative distribution curves for pavement parameters and noting the 95 percentile values. At least 6 alternative approaches may be considered.

1. *Austroads Simplified Deflection.* The most simple alternative uses only Benkelman Beam or central deflection from FWD. The curve relating future traffic loading to deflection is given in Figure 6.5 of the Austroads 2004 Rehabilitation Guide (Ref. 1), which is unchanged from the 1992 Guide (Ref. 2a). The method has low reliability. It may well provide unconservative results if very stiff subgrades are present and results may be unduly conservative for very soft pavements or resilient soils which are resistant to permanent deformation (eg volcanic ashes). A scaling factor (Sd) may be applied to deflections in situations where precedent has proven the basic relationship requires modification (eg highly resilient unweathered volcanic ashes). A principal disadvantage is that no fundamental criteria, namely subgrade strains, are assessed to give a mechanistic appreciation, and there is no check that shallow shear deformation will not occur.

2. *Austroads GMP.*
   This uses post-rehabilitation deflection bowls, back-analysed using as-built pavement layering and elastic theory, to determine vertical strains at the top of the subgrade (and elsewhere if preferred) comparing these with Austroads allowable values. A strain factor may be applied (eg for resilient volcanic soils) only where precedent has proven the basic Austroads relationship can be modified. If no direct precedent information is available, back-analysis of distressed sections in close proximity can be considered, provided the distress mode is subgrade fatigue (rutting) and the past traffic is known.

3. *Austroads Strain Precedent.*
   This method uses the Austroads design chart and the Austroads subgrade strain criterion to calculate pavement life where deflection data after rehabilitation are available, but no pre-rehabilitation deflection results been obtained. Pre-rehabilitation deflections are not required by TNZ's specification, but without such data, the means of demonstrating pavement life has not been defined in the TNZ Supplement, which covers only those cases where both pre and post testing has been carried out. The parameters required using Austroads principles for assessing precedent are the percentage of the road in terminal condition, the past traffic ESA (N_p), future traffic (N_f), depth of granular layers before rehabilitation (D) and corresponding subgrade in situ CBR inferred from deflection measurements. A graphic illustration of the procedure is given in Figures A1 and A2 and the arrows show the sequence of the analysis. Using Figure 8.4 of the Austroads Guide, the "precedent" CBR is given by the intercept of D and N_p. Some resilient subgrades (eg volcanic ash) can tolerate higher strains than "typical" subgrades hence the precedent CBR can be higher than the in situ CBR inferred from deflection testing. By entering Austroads Figure 8.4 with D and the inferred in situ CBR the inferred past traffic for a typical Austroads pavement (N_{pA}) may be determined. The Austroads subgrade strain criterion (eg Figure 9, Ref 4) may then be used to determine the allowable Austroads subgrade strain at N_{pA}. (The reason is that this strain criterion was originally derived using Figure 8.4 specifically, as a basis.) From precedent, the site allowable strain has the same value at N_p. The allowable strain for the future traffic (N_f) is then given by the greater of Eqn 10.3 (Ref. 3), or the standard Austroads value.

4. *GMP Precedent.*
   This may be applied where post rehabilitation deflections only are available. The post-construction deflection bowls are used with the as-built pavement layering to back-calculate the post construction strains at the top of the subgrade in the usual manner using layered elastic theory. The layering is then reduced by the known overlay thickness, to determine the subgrade strains prior to overlay, which in conjunction with the past traffic loading define the precedent strain criterion. The usual TNZ supplement method (Eqn 10.3 as given below) is then followed to determine allowable strains and hence residual life under the future traffic. A complication arises where the overlay thickness (h_o) is large compared to the pavement thickness after overlay (H_f), ie where h_o/H_f is large. In this case non-linearity of the layer moduli may become significant and a strain correction factor (F_c) should be applied. The

strain correction factor must be found from precedent from similar forms of construction on similar subgrades (same geological formation), but is typically about 0.5-0.7. Higher values give more conservative results. A calibrated fit to the back-calculated strains prior to overlay is obtained by multiplying the nominally calculated strains by $(1-F_c* h_o/H_f)$.

5. *TNZ Precedent.*
This is the standard TNZ method and applies where deflection data are available both before and after rehabilitation, and good pavement profile data are recorded. The TNZ Supplement to the Austroads Guide (Chapter 10, Ref. 3) documents the procedure. The allowable design strain (ε_{des}) is given by Eqn. 10.3 (Ref. 3) ie: $\varepsilon_{des} = \varepsilon_{cvs} (N_f/N_p)^{-0.23}$ and Eqn 10.4 (Ref. 3) depending on the percentage of the road that is in a terminal serviceability condition.(Where adequate numbers of deflection tests, say 30 or more, have been obtained the relevant percentiles could be adopted, as there is then no need to rely on the theoretical distribution assumption of the Supplement.) The required inputs are the cumulative distributions of strains at the top of the subgrade (ε_{cvs}) from deflection bowl analyses (before and after rehabilitation), the percentage of the road in terminal condition and the Future/Past traffic ratio (N_f/N_p). The calculations are straightforward and an example calculation with graphical output is shown in Figure B1 and B2.

At present, Austroads methods require that unbound granular pavements are checked only for vertical strain at the top of the subgrade. The TNZ Supplement provides a significant advance in that a check for shallow shear in the basecourse layer is included. While this may be practical for rehabilitation, it is less suitable for post-construction verification, hence non-destructive FWD testing provides a more convenient alternative measure. It is also desirable to have a parameter that will confirm that further densification of the basecourse and subbase layers is unlikely to be significant from the time of acceptance testing. This leads to 4 supplementary measures that may be applied in addition to the above 5 main approaches.

A. *Curvature Check on Near Surface Deformation*
This uses the Austroads 2004 Rehabilitation Guide (Ref. 1), to check that residual life is not governed by curvature using the curves from Appendix 6.2, or alternatively the Austroads 1992 Guide (Ref. 2a, 10.4). The curvature function was originally developed for bound asphaltic surfacing but more recent practice by some Australian authorities has been to use both curvature as well as central deflection for performance prediction of unbound granular layers. The curvature function is standardised to a 40 kN load. This method can be over conservative on very deep soft subgrades, or if the curvature function is applied in its original form. A scaling factor (Sc) may be applied to the curvature function for situations where precedent has proven that the basic Austroads relationship requires modification. One authority (MRWA) uses a prescribed <u>mean</u> curvature, but for applying an equivalent method on other contracts, it would be more consistent with other Operational Performance Measures to apply a <u>95 percentile</u> acceptance criterion, by using an appropriate scaling factor

for curvature. The MRWA system for unbound granular pavements is equivalent to applying the Austroads 1992 Guide with a scaling factor of 2.1 to the curvature function when using a 95 percentile acceptance criterion. Accordingly an interim factor of about 2 is recommended for trial in other unbound granular pavements.

B *CBR Check for Near Surface Deformation*

The TNZ Supplement (Figure 10.2) sets out a check for shear deformation in the pavement layers using CBR. Using a CBR-modulus correlation for aggregates (Ref. 6), low strength basecourse may be inferred from back analysis of deflection tests. This procedure is a pass/fail criterion rather than progressive, ie failure downgrades life at a test point to zero.

C *Strain Check for Near Surface Deformation*

A comparable check to the above method may be provided by limiting vertical strains in each layer. A similar Danish procedure has been noted by Ullidtz (1978), which applies the same fatigue criterion for the subgrade to each overlying granular layer. Credible models for unbound pavements showing near surface distress have been obtained by factoring the Austroads subgrade strain criterion up by a factor between 1.0 and 1.3 and applying this at the mid height of each unbound granular layer. The mid-height rather than top of each layer is adopted for the normal case where moduli of successive overlying layers increase, but the top of the layer is taken if there is no increase. No in-depth study of a wide range of aggregate types has yet been documented, but the procedure does go some way to meet a call from practitioners requiring a constraint to safeguard against shallow shear.

D *Check on Modular Ratios*

Austroads sets out the increase in modulus that can be expected in successive overlying granular layers in relation to the subgrade modulus. The concept has been widely verified in NZ unbound granular pavements, and provides a simple and robust technique for establishing that a pavement has been compacted as well as practicable (given the subgrade condition and thickness of overlying layers) and hence that ongoing settlement within the pavement layers will be minimal. Details are given in Ref. 4.

A flow diagram (Chart 1), indicates the selection process for finding the best method, in which the leftmost path gives the maximum reliability and most soundly based alternative, for the extent of test data and input parameters available.

Design Verification of New Construction

All of the above options which rely on post-construction deflections only, may be applied to new full-depth pavements rather than overlays where there have been several months of trafficking and the pavement has had time to shake down. Prediction of pavement life is necessarily, much less certain for pavements which have not experienced several months of trafficking. Green pavement present the "soaked/unsoaked design" problem: ie either the pavement is over wetted and/or under compacted during construction and will settle down over time or, with construction done in summer and the water table having potential to rise during winter, greater strains may develop long term. In either case any in situ CBR (from Scala or FWD) needs to be considered by personnel, familiar with the site, who can apply informed judgement on which way to factor the results. If there is uncertainty, it is preferable to use laboratory soaked CBR and Figure 8.4 (Ref., 2) for New Zealand conditions. If the subgrade modulus is lower than expected from comparison with soaked CBR tests, reconsideration of the design may be appropriate. One issue with Figure 8.4 is that it is a precedent from Australian practice, which some New Zealand practitioners suspect may be less conservative for NZ pavements, as it is empirically based and has its origins in environments which may typically experience lesser degrees of subgrade saturation. Subgrade strain typically contributes about 50% of the maximum surface deflection. In view of the above considerations, use of central deflection results alone, without full bowl information (to separate the layer moduli and apply any necessary factors), may lead to unconservative design in new pavements.

Where testing is carried out during construction on subgrade, subbase or basecourse prior to sealing, the reduction in strains which can be expected with initial trafficking is being observed in a number of projects which will give an approximate measure of shakedown effects. Provided construction compaction is to B/2 specification, preliminary indications are that if subgrade strains are high (more than about 2000 microstrain) little or no increase in moduli of the granular layers will take place with trafficking. If shallow shear then initiates, moduli will reduce markedly with the lack of confining stress and rapid failure follows. However, where subgrade strains are limited to about 1000 microstrain, the granular layers are likely to experience an increase in modulus of about 30% with trafficking. Cement modified layers may provide greater improvement, but if modular ratios exceed the standard Austroads values (Ref. 4) by more than a factor of about 1.3, tensile fatigue may also need to be considered when estimating design life.

Conclusions

The standard Austroads Supplement procedure (Method 5 supplemented by Option B, ie 5/B) has been shown to meet acceptance criteria readily, provided standard design and construction practice has been followed, and it is unlikely to lead to over-design. It is hence in the contractor's interest to target this method. Where the pre-rehabilitation testing required for Method 5 has not been carried out, the alternative methods will require documentation of factors used if other than standard Austroads parameters are adopted. It is the view of the writers that any Method must be supplemented by at least Option A as a minimum, with the preference for robust design assurance being Method 5/B/C/D.

Limitations

All non-destructive methods need to be supplemented by test data that confirm the pavement aggregates are free-draining and durable (ie must comply with normal specifications/requirements for basecourse and subbase, especially fines content and crushing resistance).

For those methods requiring analysis of deflection bowls, it is important to ensure that both back and forward analyses use the same method (eg pseudo-static layered elastic theory, finite element, elastic-dynamic etc) and that the same assumptions (eg isotropy/anisotropy etc) are applied.

The Precedent Method is simply an analysis tool and should be regarded as no more reliable than the least reliable of its various input parameters. For this reason, it is important to ensure that the deduced subgrade strain ratios are reasonable. The subgrade strain ratio is a useful performance indicator for this assessment, ie the ratio of the calculated vertical strain at the top of the subgrade for the given pavement, to the allowable strain given by the Austroads Strain Criterion (Eqn 5.3, Ref. 1, or equivalent isotropic value from Ref. 4). Subgrade strain ratios of 1.5 are common with central North Island volcanic ashes while values of 2 are common in Taranaki ash.

The TNZ Precedent Method, can result in very large subgrade strain ratios (much greater than 2) being inferred if the number of years over which the past traffic was applied is over-estimated by the designer (eg if surface smoothing treatment has been carried out and not allowed for in the back-analysis). This "past lifetime" is a significant source of error. However, if the past traffic is overestimated because the ESA/HCV or percentage of HCV's have been overestimated and the same error is carried through to the future traffic estimation, then the predicted lifetime (years) will still be valid, because the ratio Nf/Np will still be correct. In these circumstances, the subgrade strain ratio will be anomalously high. This may be the reason for occasional examples of subgrade strain ratios as high as 4 which have been indicated on some contracts. At this stage, caution is recommended adopting values higher than 1.5 and thorough checking of precedent inputs used, for any values greater than 3.

The Austroads Strain Precedent Method is relatively robust in that it will not, in practice, yield subgrade strain ratios much higher than 2, and may give slightly over-conservative results. It should provide a lower bound for expected life, and less conservative results should be obtained using the TNZ Method. With a forward analysis it is important to use lower bounds for D and CBR and an upper bound for Future ESA, but as the Austroads Strain Precedent Method is a back-analysis, any approximation of mean values should be upper bounds of D and in situ CBR and a lower bound of Past ESA. Because of the high dependence on input parameters, these and the observed performance of the newly constructed pavement should be critically reviewed before accepting residual life predictions based solely on precedent methods.
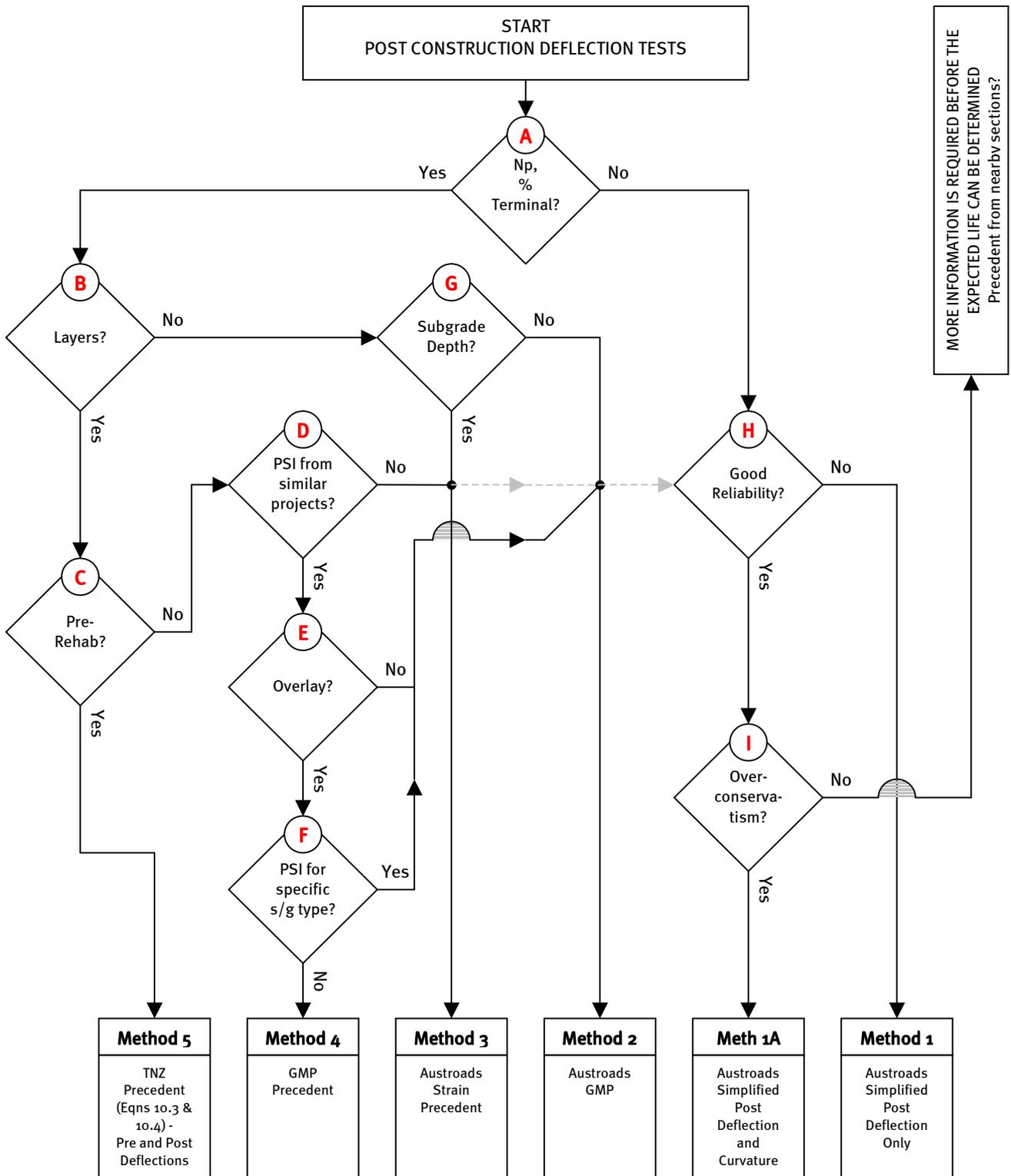
References:

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Flow Diagram for assessing most effective method for determining expected pavement life.

The following questions assist in resolving appropriate alternative procedures shown in Chart 1:

a) Are both the past traffic(ESA) and the percentage of road in a terminal condition known?
b) Are the as-built layer thicknesses known?
c) Are pre-rehabilitation FWD testing results available?
d) Is there precedent strain information from other similar overlay projects (where both pre and post –rehabilitation deflection results have been carried out)?
e) Has an overlay been applied (rather than just lime/cement treatment)?
f) Is there precedent strain information for performance of this specific subgrade type (ie pre-rehabilitation deflection surveys to calibrate strain performance relative to the standard Austroads subgrade strain criterion)?
g) Is the depth to the subgrade known?
h) Is good reliability required?
i) Is possible over-conservatism acceptable?
j) Is a check needed for shallow shear deformation
k) Is a check needed for ongoing traffic compaction

Chart 1. Flow Diagram for Alternative Procedures for Expected Pavement Life
(Leftmost path gives the maximum reliability and most soundly based alternative)

```
                    ┌─────────────────────────────────┐
                    │          START                  │
                    │ POST CONSTRUCTION DEFLECTION     │
                    │           TESTS                 │
                    └─────────────────────────────────┘
                                    │
                                   (A)
                                Np, % Terminal?
                    Yes ◄─────────┴─────────► No
```

A — Np, % Terminal?

B — Layers?   No

G — Subgrade Depth?   No

C — Pre-Rehab?   No

D — PSI from similar projects?   No

H — Good Reliability?   No

E — Overlay?   No

F — PSI for specific s/g type?

I — Over-conservatism?   No

MORE INFORMATION IS REQUIRED BEFORE THE EXPECTED LIFE CAN BE DETERMINED Precedent from nearby sections?

Method 5	Method 4	Method 3	Method 2	Meth 1A	Method 1
TNZ Precedent (Eqns 10.3 & 10.4) - Pre and Post Deflections	GMP Precedent	Austroads Strain Precedent	Austroads GMP	Austroads Simplified Post Deflection and Curvature	Austroads Simplified Post Deflection Only

Figure A1

Figure A2

Interactive Graphs

Cumulative Distribution	Parameter Diagnosis	Network Data	**Residual Life**

Pre-Rehab File: `K:\Trial Section\Test FWD 2001\Test FWD 2001`   [Use Current] [Select]

Post-Rehab File: `K:\Trial Section\Test FWD 2003\Test FWD 2003`   [Use Current] [Select]

Calculate based on: `TNZ Precedent (Eqns 10.3 & 10.4) - Pre and Post FWD` ▼ [?] [Generate] [Reset]

Pre-Rehab | Post-Rehab

% road in terminal condition

- ○ 0 %   ○ 60 %
- ○ 10 %   ○ 70 %
- ○ 20 %   ○ 80 %
- ○ 30 %   ○ 90 %
- ○ 40 %   ○ 100 %
- ● 50 %   ○ Custom

Design Life Parameters

Past ESA: `3000`

Future ESA: `10000`

Subgrade Strain Ratios

Past Traffic Ratio: `1.42`

Future Traffic Ratio: `1.202`

Implied critical subgrade strain at 50% is 2828 microstrain
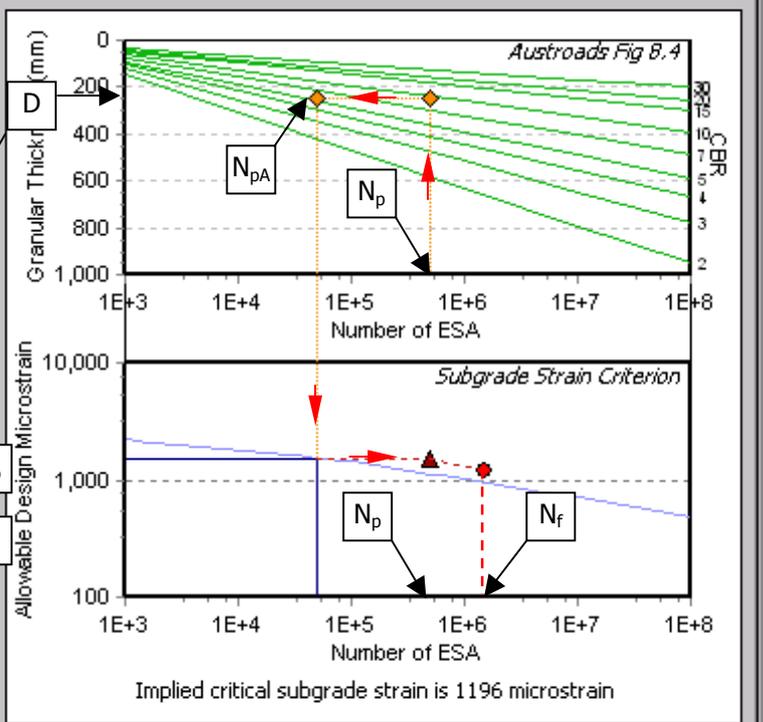
Figure B1   [... Data] [Export Picture] [Back]

Pre-Rehab | Post-Rehab

Design Life Parameters

Life (years): `25`

Past ESA: `3000`

Future ESA: `10000`

F/P ESA Ratio: `3.333`

TNZ Precedent

Pre-Rehab μStrain: `2828`

Allowable μStrain: `2144`

Subgrade Strain Ratios

Past Traffic Ratio: `1.420`

Future Traffic Ratio: `1.202`

Acceptance Criteria

Required Reliability: `95` %

Achieved Reliability: `97` %

95 % of the Road has a Residual Life > `73` years

Figure B2   [... Data] [Export Picture] [Back]