APPLICATIONS OF MECHANISTIC PAVEMENT DESIGN IN NEW ZEALAND (II)

Case Histories Comparing Design Prediction with Post Construction Measurement and Analysis

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SUMMARY

The AUSTROADS Pavement Design Guide has been used for the mechanistic design of pavement rehabilitation in New Zealand for several years. A number of projects have now been completed where pavement testing has been carried out before and after construction, giving the opportunity to compare design prediction with the in situ performance achieved by the rehabilitation. Case histories involving different forms of construction in various parts of New Zealand are presented, quantifying the improvement in performance resulting from the use of AUSTROADS procedures. Data is also presented for typical in situ material properties of unbound granular overlays and cement based stabilised basecourses.

INTRODUCTION

Rehabilitation design for unbound granular pavements in New Zealand is now based on mechanistic procedures given in the Pavement Design Guide (AUSTROADS, 1992) and the Transit New Zealand Supplement to the AUSTROADS Guide (TNZ, 1997).

Mechanistic analysis allows pavement rehabilitation design to be carried out from first principles, calculating stresses and strains in the existing pavement. The advantage to the designer is that he will obtain an understanding of the mechanics of the behaviour of each specific section of the pavement, increasing the opportunity for innovative design. With insight into the relevant distress mechanism(s), selection of the most appropriate rehabilitation measure can then be made with assurance that the correct problem is being addressed and the solution will be cost effective and provide long service.

REHABILITATION DESIGN METHODS

Deflection testing and back analysis (using layered elastic theory) of the deflection bowl induced by a standard wheel load provide the basic parameters for mechanistic design.

For unbound granular pavements the principal design criterion is limitation of the vertical strain at the top of the subgrade. Where a bound layer is present and additional criterion (horizontal tensile strain at the base of the layer) is also applied. Trial pavements are modelled using alternative rehabilitation treatments to determine the most effective solution.

Five rehabilitation options used in New Zealand for unbound granular pavements with chip seal surfacing are: unbound granular overlay, friction course overlay, cement stabilisation of the existing basecourse, "upside-down" reconstruction and full depth granular reconstruction.

Examples of each type are included within the trial sections. Specific comparisons are given below.

CASE HISTORIES

General

Each case study is presented showing the following graphs:

a) Unbound granular overlay requirements
b) Cement stabilisation depth required
c) Resilient modulus of the upper layer (usually basecourse)
d) Resilient modulus of the subgrade
e) Subgrade strain ratio

The unbound granular overlay has been computed using the General Mechanistic Procedure and the AUSTROADS subgrade strain criterion (AUSTROADS, 1992; TNZ, 1997) for unbound pavements, i.e.:

$$\epsilon_{des} = 0.008511(N_F)^{-0.14}$$

where:

ϵ_{des} = limiting vertical compressive design strain at the top of the subgrade.

N_F = design future traffic (ESAs).

Where a cement stabilised layer is present, the tensile strain at the base of the stabilised layer has also been checked, using the criterion given in TNZ (1997).

The depth of cement stabilisation required has been computed assuming the pavement will be rehabilitated using the same tensile strain criterion and qualifications given by ARRB (1996). ARRB recommends assuming a design modulus of 5000 MPa in the cement bound layer, and that the effective traffic loading (ESA) for cement stabilised material be taken as 10 times the actual ESA.

The residual modulus of the upper layer and the subgrade are both shown on the graphs as isotropic values. AUSTROADS (1992) recommends that cement stabilised basecourse should be modelled as a material with an isotropic modulus, whereas unbound layers should be modelled as anisotropic materials with the vertical modulus equal to twice the horizontal modulus. The AUSTROADS anisotropic vertical modulus for granular basecourse is found by dividing the isotropic modulus by 0.75. The AUSTROADS anisotropic modulus for the subgrade is found by dividing the isotropic modulus by 0.67 (using equations presented by Ullidtz, 1987). Moduli values quoted in the text, are in terms of the AUSTROADS convention.

The subgrade strain ratio is the maximum vertical compressive strain at the top of the subgrade when the pavement is loaded by 1 ESA, divided by the allowable strain (for the design future traffic) using the AUSTROADS subgrade strain criterion). This parameter is used to normalise the strains to give a more direct perception of the degree to which a subgrade is being overworked. A ratio of no more than 1 indicates that no strengthening overlay is required to provide the required design life. Ratios greater than 1 indicate that greater structural capacity is required, through overlay, stabilisation etc. If the subgrade strain ratio is much less than 1 in a newly overlaid pavement then some degree of overdesign may be indicated in an unbound pavement. The lives of pavements with bound layers are usually governed by horizontal tensile strains at the base of the bound layer.

Case 1: Unbound Granular M/4 Overlay

Fig. 1 shows an unbound granular pavement on a flat alluvial plain. The subgrade is soft clay with high watertable. The first half of the road has been in service for many years and shows substantial rutting and loss of shape. The second half of the road was recently rehabilitated using some pre-overlay repair (digouts) then unbound granular overlay from design by TNZ (1989), State Highway Pavement Design and Rehabilitation Manual. Because the original pavement profiles for both sections of the road were similar, this example provides a representation of before and after rehabilitation conditions.

Looking first at the lowermost graph (subgrade strain ratio), analysis shows that the subgrade strain in the old pavement is up to twice the AUSTROADS allowable value. The rehabilitated section shows strains of less than half the allowable, i.e. there appears to be some element of overdesign.

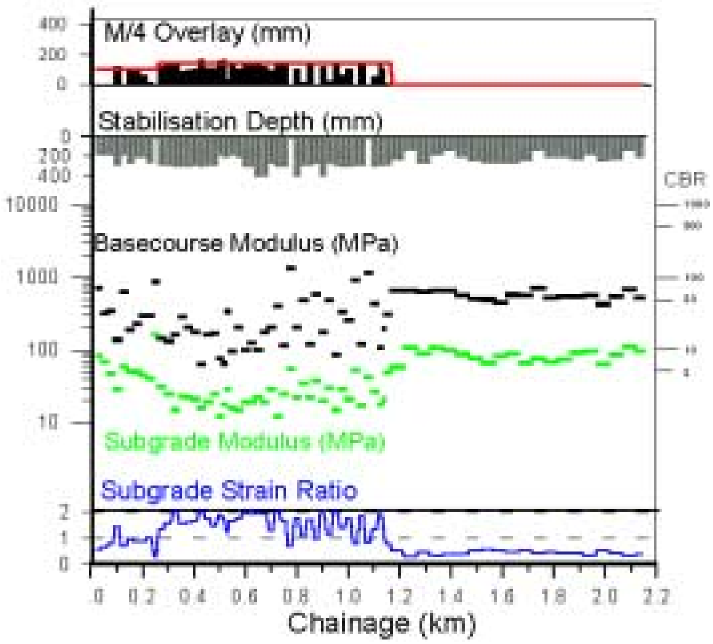

Figure 1 Unbound granular pavement on soft clay. Old basecourse to Ch 1.2, then overlaid with M/4 to Ch 2.2

The next graph shows that the design subgrade modulus for the soft clay is about 20 MPa. After rehabilitation, the subgrade modulus as increased considerably due both to surcharge consolidation effects of the overlay and non-linearity of the subgrade modulus. If non-linearity effects are not taken into account, substantial over-design can result. The old basecourse has very poor uniformity and low modulus. The good quality well compacted M/4 overlay has achieved a minimum (5 percentile) vertical modulus of 550 MPa (assuming vertical to horizontal anisotropy of 2:1), ie at the top end of the range suggested by AUSTROADS (1992). The two upper graphs show that cement stabilisation depths would be excessive, and that a substantial overlay is required on the old section.

Case 2: Unbound Granular Overlay on Volcanic Ash Subgrade

Rehabilitation of a pavement formed on a central Waikato ash subgrade is shown in Figures 2 and 3.

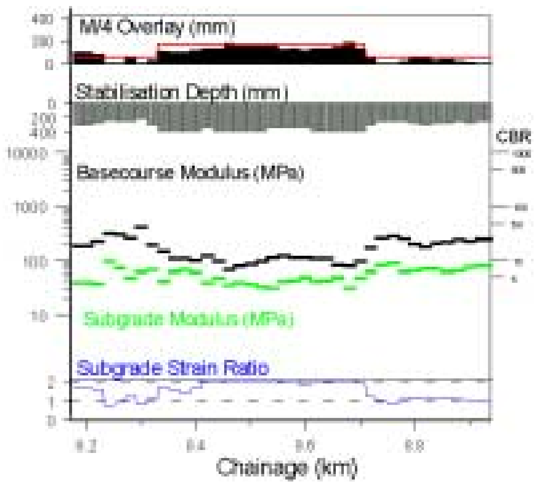

Figure 2 Unbound granular pavement on ash subgrade (before overlay)

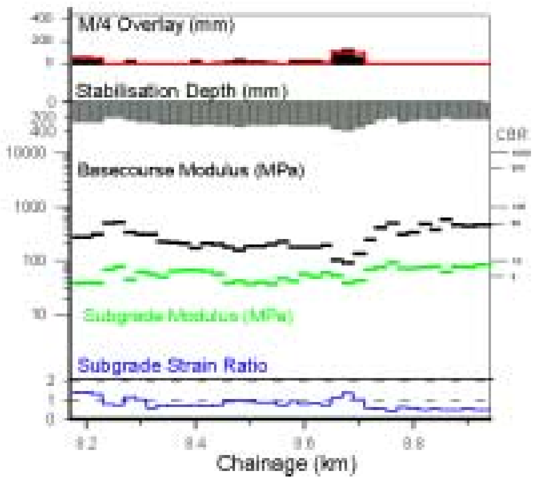

Figure 3 Ash subgrade after M/4 overlay

Testing of the original pavement showed very high strains in the subgrade. The subgrade strain ratio (under the future traffic loading) was 2 or more for much of the section, but local experience has shown that the local volcanic ash can usually tolerate much greater strain than typical soils derived from sediments or weathering products. Analysis of past performance was carried out, using both comparison of precedent strain ratios and also the procedure given in the Transit NZ Supplement to the AUSTROADS Pavement Design Guide. The precedent subgrade strain ratio (i.e. based on past rather than future traffic) was found to be in the range of 1.5 to 2.

A similar result has been obtained for a number of pumice and ash sites in the North Island, i.e. based on past performance, these soils perform substantially better than would be expected using the AUSTROADS subgrade strain criterion.

The rehabilitation design was based on a value engineering decision including:

1. Past performance of the pavement
2. Providing a new primary basecourse layer (due to marginal strength within the existing pavement)
3. Providing sufficient total granular pavement depth for the future traffic loading

A "reseal and do nothing" trial was undertaken over the first 200m of the project length. The trial involved laying a section of polymer seal and a section of polymer seal underlain with a geotextile.

Over the next section from Ch 8.32 to 8.72 a 150 mm M/4 overlay was adopted, reducing to 100 mm overlay for the remainder. The reseal was undertaken in April 1998 and the overlay in November and December 1997. To date the works are performing well, although it is too early to evaluate the appropriateness of the design considering that it has only carried 1% of its design load.

Repeat testing was carried out several months after completion of overlays. The pavement layers were difficult to model individually without constraining the subbase layer moduli, therefore the full depth of new basecourse and subbase layers were modelled as a single thick layer. Accordingly the "basecourse modulus" plotted is an average of all the pavement layer moduli. It is interesting to note the way that the basecourse moduli follow the subgrade moduli, reinforcing the characteristic of unbound layers that their moduli are generally limited by the support provided by the underlying soil layer. After overlay (Fig. 3), there appears to be a localised section, near Chainage 8.7 where the basecourse modulus is unusually low. It has been influenced in part by a low subgrade modulus but this is likely to be only part of the problem. The constructed overlay appears to be relatively thin or perhaps under compacted. Post - constuction testing in this manner provides a useful check on workmanship. Nevertheless, the subgrade strain ratios can be realistically compared before and after rehabilitation. In the parts that were overlain, the subgrade strains have successfully been reduced to close to the AUSTROADS allowable values, and on the basis of past performance, the life of the section (in terms of rutting induced by subgrade strains) should exceed the design requirement.

Case 3: Friction Course Overlay

Figs 4 and 5 show a heavily trafficked granular basecourse in a 50 kph zone, before and after friction course overlay. Testing of the original pavement shows that the subgrade strains are only marginally larger than allowable and about 100 mm of unbound granular overlay would be required. As there was only minor loss of shape, 30 mm friction course surfacing was adopted. (A bituminous overlay is structurally equivalent to an unbound granular layer which is approximately 3 times thicker.) The post construction testing shows only minor reduction in subgrade strains (as expected) but most of the road should provide the intended design life.

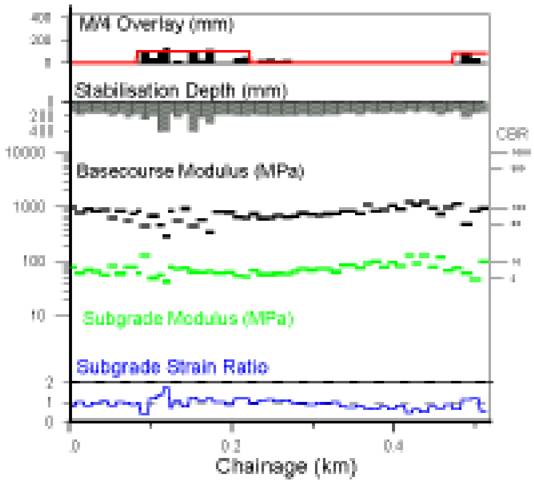

Figure 4 Unbound pavement before rehab

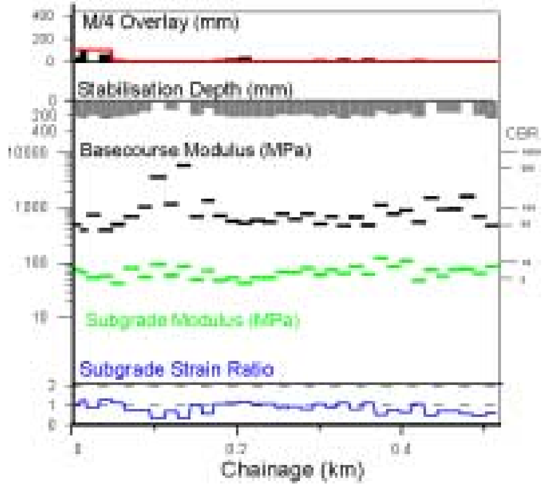

Figure 5 After friction course surfacing

Case 4: Cement Modified Pavement Recycling

Figures 6 and 7 show the pre and post construction testing of a site in northern Hawkes Bay. Here the existing pavement was recycled by milling cement into the existing top surface layers. In addition, top up M/4 material was included beyond Chainage 4 where the original subgrade strains were high (often twice the AUSTROADS allowable values. Both the subgrade and basecourse in the original pavement had highly variable moduli.

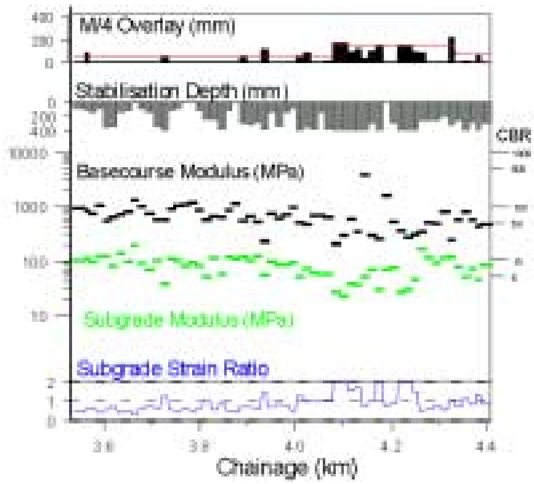

Figure 6 Unbound pavement before rehab

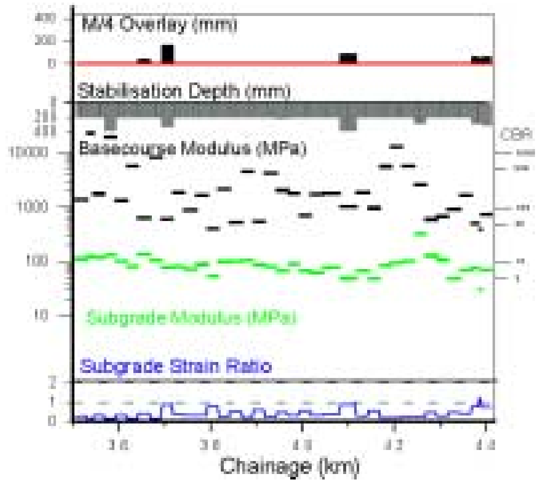

Figure 0 After cement stabilisation

The design concept for the pavement recycling projects, of which this site is one example, is to provide an alternative to full depth rehabilitation. Recycling aims to provide up to ten years of service, after which an unbound granular overlay or other rehabilitation treatment would be expected. The recycling process was targeted at sites where shallow shear was the principal cause of distress.

The process involves milling and relaying the cement-modified material to a depth of 200 mm. Because the subgrade was less protected at the far end of the site, this section was first overlaid with 100 mm of M/4 aggregate. In this case the milling/relaying process then incorporated this overlay, and the existing seal and top surface basecourse into a modified top surface layer. At the other end of the site the existing top surface layers only were milled and relaid. The full section was then chip-sealed.

The post construction testing has shown that subgrade strains have become much more uniform over the site and are for the most part much lower than those allowed by the AUSTROADS strain criterion. Isolated test points show that tensile strains at the base of the bound layer are above allowable values. We expect this modified layer to crack. However, cement contents and the construction process are intended to produce micro-cracks, rather than block cracking. The modified pavement surface has a more stable bitumen/binder ratio (as compared to the original very unstable top surface layer) with the addition of cement binder. This layer appears to provide a better distribution of the wheel loads over the subgrade and lower pavement materials.

Although the recycling projects have only been undertaken in the last three years, the results so far are encouraging. The development of any block cracking is a key issue that will be monitored.

Case 5: Upside Down Pavement Reconstruction

Figures 8 and 9 show analyses of deflection bowls from before and after construction of an "upside down" pavement (unbound M/4 basecourse over cement stabilised subbase consisting of reused aggregate and subgrade) overlaying a soft silt subgrade. The original pavement had high subgrade strains, and was exhibiting shallow shear (from poor basecourse materials) and deep-seated rutting. The upside down pavement concept aimed to reuse as much of the existing basecourse as possible. Stabilisation was adopted to construct a compacted layer from the existing thin basecourse (poorly graded alluvial gravel) and the silt subgrade, providing a sound subbase. The stabilised subbase was then overlaid with M/4 aggregate. The unbound granular overlay provides a stable surface that can be shaped and sealed. It also helps prevent any cracking in the subbase from extending through to the surface.

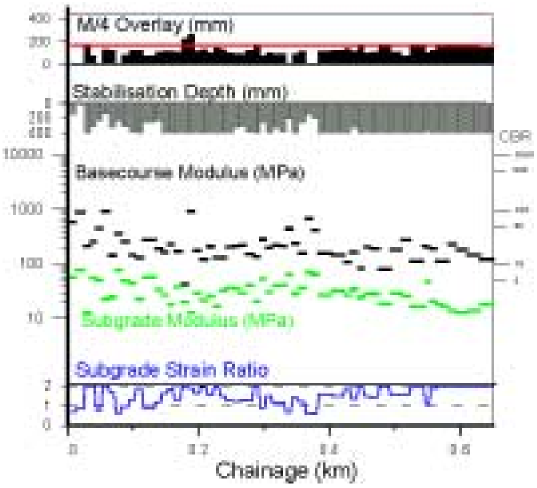

Figure 8 Unbound pavement before rehab.

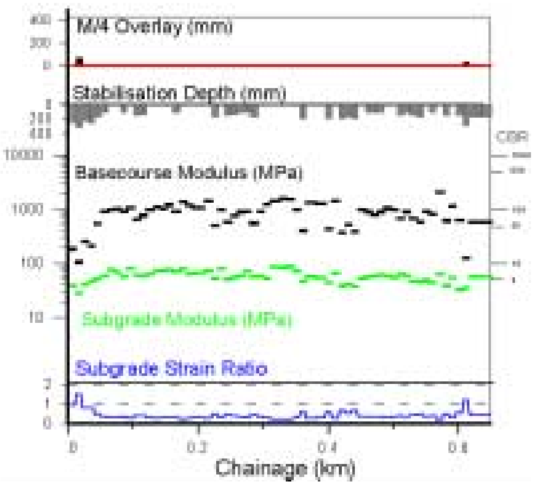

Figure 9 After "upside-down" reconstruction

The subgrade strains are very low, mostly less than half of the AUSTROADS allowable values. Limiting the horizontal tensile strains in the bound layer is a key factor in the design. Over the last 10 years two similar pavements have shown some signs of distress. The failure mechanism is localised block cracking and shear failure. In both cases the as constructed pavement depth was found to be less than the specified depth. However these cases suggest that more conservative design may be required for construction tolerances.
The majority of pavements built this way (many kilometres) are performing well. They can be adapted to both rural and urban situations.

Case 6: Full Depth Granular Reconstruction with M/5 Basecourse

Fig. 10 shows an example where only the post-reconstruction case is available. Testing was carried out immediately after completion, so minimal "shakedown" or compaction of the surface layers through trafficking would have occurred. The subgrade was lime stabilised, and an M/5 basecourse (alluvial gravel with less than 70% broken faces) was used.

The firm foundation resulted in a relatively stiff pavement structure and a design (5 percentile) vertical modulus of 490 MPa was achieved in the basecourse. (Greater values would be expected after compaction trafficking). This value is consistent with AUSTROADS (1992) recommendations. Subgrade strains are very uniform and close to allowable AUSTROADS requirements, indicating efficient design.

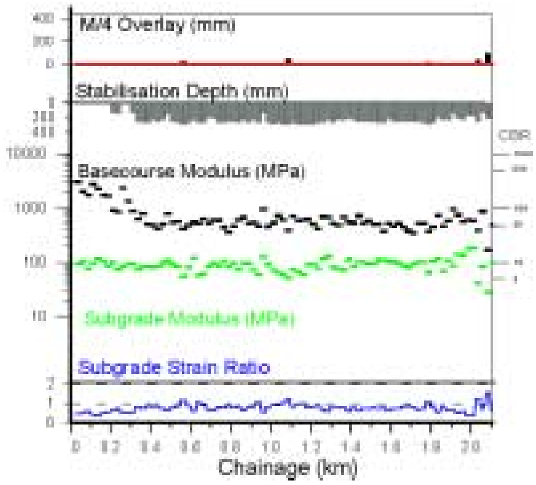

Figure 10 New M/5 Reconstruction

CONCLUSIONS

Rehabilitation treatments using AUSTROADS mechanistic design procedures are generally achieving the intended reductions in subgrade strains. Provided that the accepted strain criteria are appropriate, long-term performance should be assured. Ongoing monitoring of these cases is intended.

Post construction testing provides a guide to the effectiveness of conventional or non-conventional rehabilitation treatments, quantifying the degree of over or under-design.

North Island volcanic ash subgrades appear to provide an exception to the standard AUSTROADS strain criterion. Rehabilitation treatments are being proposed which will allow subgrade strains up to twice the recommended values in these soils. The Transit NZ Supplement to the AUSTROADS Design Guide provides a precedent based method that should provide assurance of long term performance, but further case histories need to be followed up with post-construction verification and long term monitoring.

Limited in situ testing of unbound basecourses (M/4 or M/5) suggests that the typical moduli recommended by AUSTROADS (1992) are quite appropriate design values for New Zealand conditions.

For cement stabilised pavements, case histories demonstrate that in practice, moduli of the stabilised materials are often highly variable, ranging from under 1000MPa to over 20,000MPa within one construction length. However, subgrade vertical strains can be reduced to very low values (ie associated rutting distress should be minimal). This is due to the good loadspreading ability of the cemented layer provided there is an adequate overall pavement depth. Appropriate strategies for addressing the effects of tensile fatigue, i.e. cracking, are hence most significant and the staged rehabilitation approach - such as planning for a later stage of unbound granular overlay can be most cost effective.

With ongoing projects for which the Cement Treated Basecourse concept is being considered, it is intended to target lower cement contents, and lower unconfined strengths to help achieve controlled micro-cracking rather than block cracking. Even with micro cracking a stable layer with good load spreading ability can be achieved.

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