Performance Based Testing for Design of Pavement Rehabilitation Treatments

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***Abstract*—In New Zealand the Austroads Pavement Design Guide is used to design pavement rehabilitation treatments. Often a range of designs are possible which theoretically give the same design life as the only design check is cover or strain at the subgrade soil level. Often the lowest cost treatment is chosen which is stabilisation with 1.5% cement as the check on the subgrade strain (i.e. pavement depth) shows it will meet the 25 year design life. However, in practice early failure results. One reason is that the standard treatment of in situ stabilisation with 1.5% cement returns to an unbound material and the unbound aggregate ruts. However, the Austroads design method only considers rutting in the subgrade layer by determining the required pavement depth while rutting in the granular layers is not considered. Further, there is often no acceptable laboratory tests with 1.5% cement to confirm sufficient strength is obtained. If laboratory tests are conducted they are typically traditional tests such as particle size distributions, maybe fines quality tests and possibly Unconfined Compressive Strength (UCS). Further, these tests may not test the actual stabilised mix which could encompass broken up chip seal layers and some top-up overlay material. All these traditional tests require judgement to interpret whether or not the chosen treatment will be suitable and not fail early. An alternative performance based approach to testing and design is being used on the New Zealand State Highway (NZTA) East Waikato Maintenance contract to determine the most appropriate pavement treatment that is economical and will not fail early. This performance based approach involves Repeated Load Triaxial tests on the in situ aggregate with a small proportion of broken down chip seal layers sampled from test pits to determine their performance in terms of rutting when unmodified. This Repeated Load Triaxial test calculates the rutting performance relationship (number of Equivalent Standard Axles needed to fail in rutting) [1, 2]. The rutting performance from the RLT test determines the most appropriate treatments and design assumptions. If the rutting performance of the in situ aggregate is poor then the proposed design relies on the cement bonds for strength. Hence, the flexural beam tests are undertaken to check if the proposed stabilised mix has enough tensile strength to ensure the material does not break and thus return to unbound within it's design life. If the stabilised mix does not have enough strength then an overlay is required with better quality aggregate. Conversely, if the rutting performance of the existing in situ aggregate is found to be good then only light quantities of cement are required for moisture sensitivity. Compared with the traditional design approach in New Zealand, the performance based design approach provides greater confidence that the subsequent chosen design will not fail early. Indeed the performance based design approach has resulted in more scientific argument to support a more robust treatment. In some cases the testing has supported an innovative lower cost solution. This paper details this advanced performance based design approach and gives results from the performance based tests for the East Waikato Maintenance contracts and the resulting designs implemented.**

Keywords—Pavement Design, rutting, Repeated Load Triaxial.

I. INTRODUCTION

In New Zealand a majority of the pavements are thin surfaced unbound granular pavements and rehabilitation treatments are either in situ stabilisation, granular overlay or granular overlay and then in situ stabilisation of the granular overlay. In situ stabilisation is most commonly around 1.5% ordinary Portland cement by dry mass of aggregate. The current pavement design method for rehabilitation treatments assumes an unbound granular pavement and is primarily based on the required aggregate cover needed to protect the subgrade for the future design traffic and measured subgrade CBR. A pavement design chart or the CIRCLY software following the Austroads Pavement Design procedures is used. This design method ignores the possibility of rutting in the granular layers. Test pits on existing pavements being rehabilitated often show that most of all of the rutting seen at the surface is from within the granular layers. Further, accelerated pavement tests on thinly sealed pavements report that 30% to 70% of the surface rutting is attributed to the granular layers [1, 12, 13, 14, 2].

The current mechanistic-empirical design method ignores rutting in the granular layers and considers only subgrade rutting based on early empirical granular pavement thickness design charts based on subgrade CBR and traffic [17, 18, 19]. For pavements that already have sufficient pavement depth theoretically a range of treatments will meet the required 25 year pavement design life including a rut smoothing treatment, in situ stabilisation with cement and/or bitumen or granular overlay. The existing design method cannot distinguish differences in life between the different treatments. Although, the traditional treatment is to modify the existing in situ aggregate through the addition of 1.5% cement (ordinary portland cement) as this is often the lowest cost. However, in some cases in situ stabilisation lasts less than 5 years despite the current design method based on the pavement depth and subgrade CBR (California Bearing Ratio) predicted a 25 year life.

As early failures of in situ and stabilized pavement and overlay treatments were occurring on a number the New Zealand State Highway (NZTA) [15]. For the East Waikato Maintenance contract where according to the current New Zealand design method a 25 year life was expected there was a need to reduce this risk. . Hence, an alternative performance based approach to testing and design that considers rutting in the granular layers was introduced as an additional design check. This paper details this new approach and demonstrates how this has and will prevent early failures.

II. Additional Performance Based Design Approach

The additional performance based design approach for pavement rehabilitations was developed from research involving NZTA's accelerated pavement testing facility CAPTIF [1], [2], [3], and [4].

It is emphasised that this is an additional design check over and above traditional pavement design methods and is used to check the life of the granular and stabilized pavement layers for determining the best treatment.

There are two methods of design for rehabilitation treatments for granular pavements, either the limiting tensile stress method for heavily cemented stabilised pavements or the unbound/modified granular method. The limiting tensile stress method requires the use of higher cement contents to when the existing/in situ aggregate is poor quality and forms a bound layer to prevent rutting. The unbound/modified method is based on the rut resistance of the source aggregate as shown in the flow chart in Figure 1.

For each site to be rehabilitated samples of the in situ aggregate are taken from the road and re-compacted for testing in the Repeated Load Triaxial apparatus (Figure 2). The Repeated Load Triaxial (RLT) permanent strain test in accordance with NZTA T15 Specification for RLT Testing [9] determines the rut resistance of the unbound aggregate. If the rut resistance is good or minimal permanent strain then the design can be unbound granular and only minimal binder is needed in stabilization to form a modified material as the rut resistance is achieved from the aggregate interlock. Conversely if the rut resistance is poor, as found from the RLT test (Figure 2), then the tensile strength design approach is used where the cement bonds are relied upon for rut resistance.

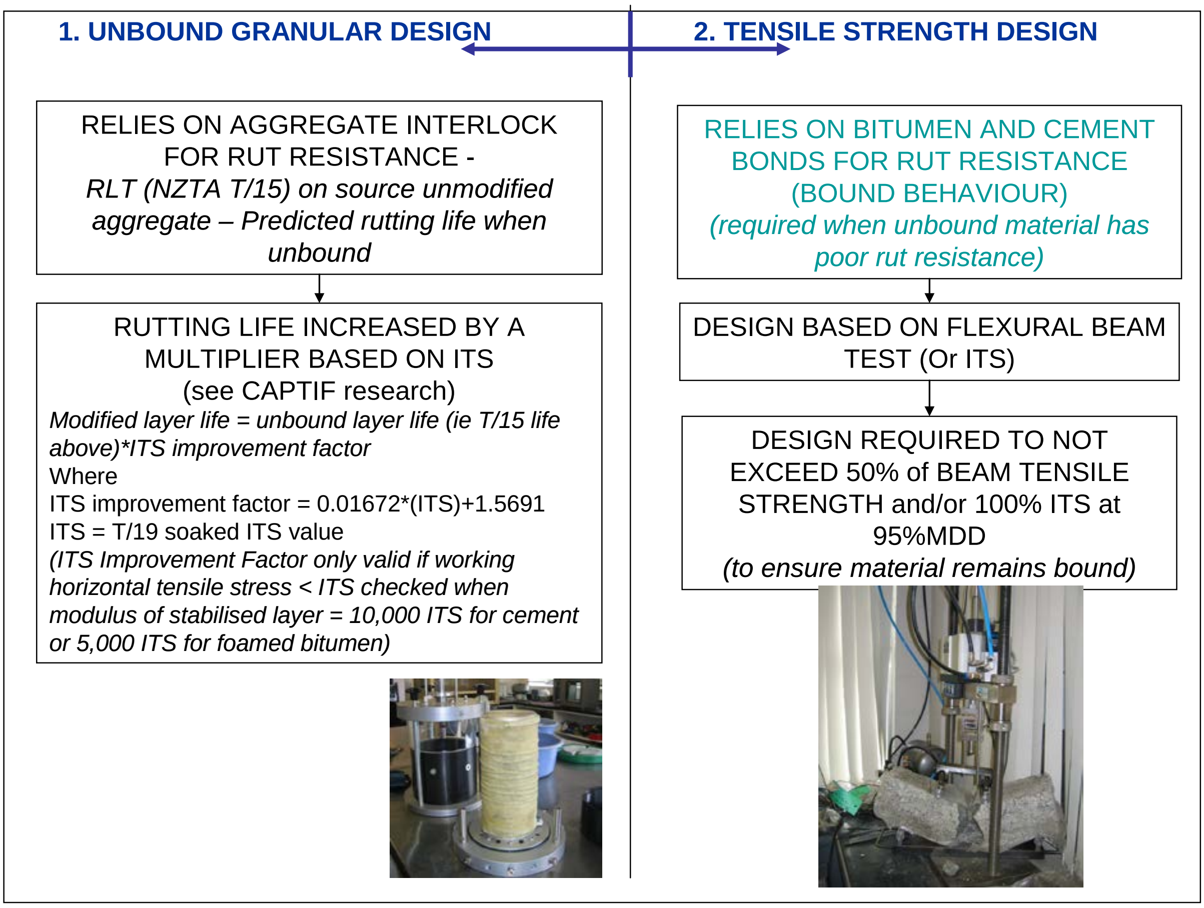

FIGURE 1. Design Method for Stabilisation Dependent on the Quality of the Source Aggregate.

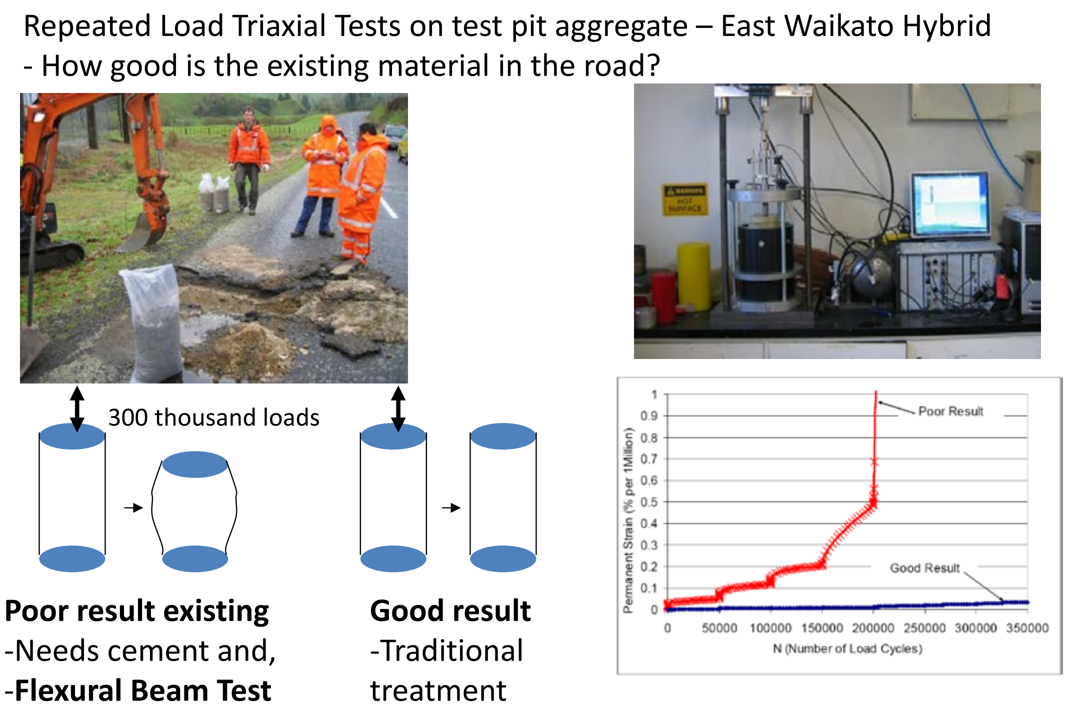

FIGURE 2. REPEATED LOAD TRIAXIAL TESTING OF IN SITU AGGREGATE

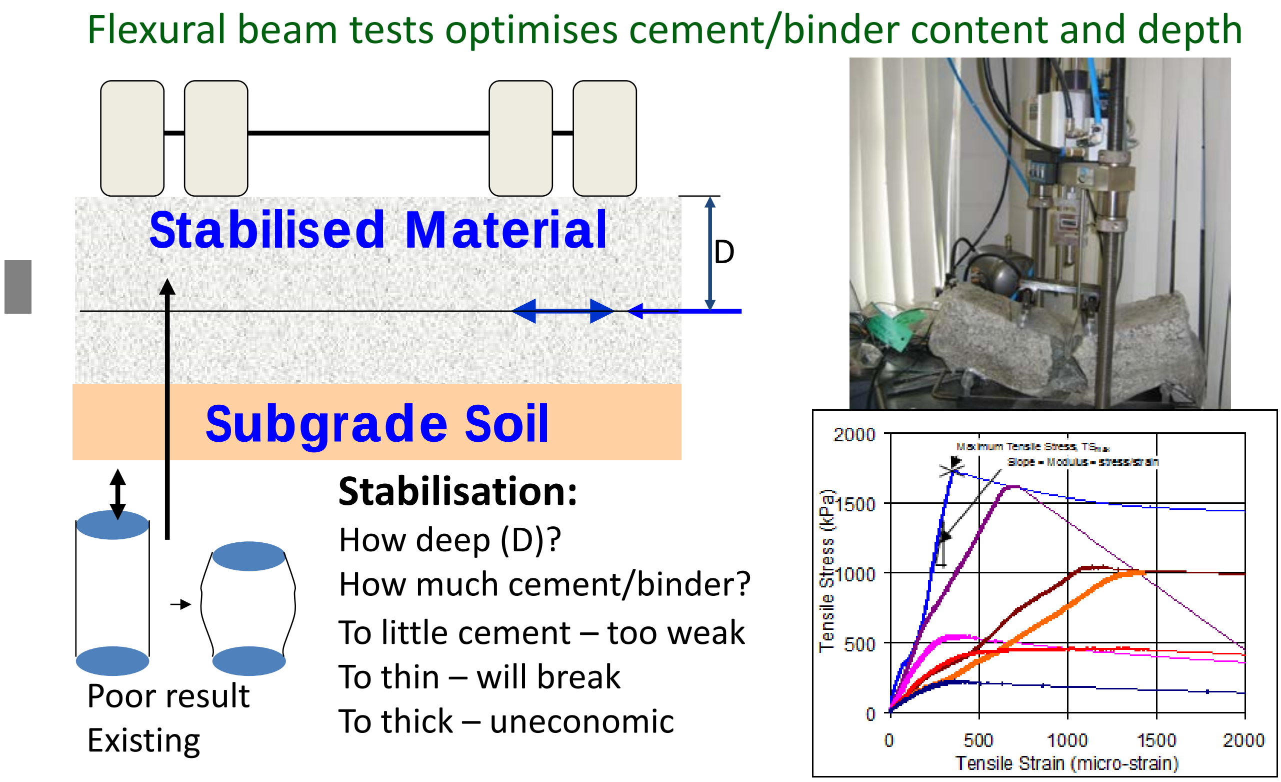

FIGURE 3. FLEXURAL BEAM TEST FOR STABILISED MATERIALS

III. Repeated Load Triaxial Test

The RLT apparatus following the NZTA T/15 [9] specification applies repetitive haversine loading of 4 Hz for a total of 300,000 loading pulses delivered in 6 stages of 50,000 cycles each where each loading stage increases the severity of loading (Table 1). The output is deformation (shortening of the cylindrical sample) versus number of load cycles for a particular set of stress conditions. Multi-stage RLT tests are conducted in accordance with NZ Transport Agency T/15 [9] to obtain deformation curves for a range of stress and strain conditions (Figure 2). This is to develop models for predicting rutting and life in pavement design. For fill and subgrade materials the stress conditions in the RLT test are adjusted to represent stress conditions in service. The RLT allows the prediction of pavement rutting and the test method and analysis have been validated with testing at NZ Transport Agency test track CAPTIF [1].

Table 1: RLT Test Loading Conditions [9]..

Stage	A	B	C	D	E	F
Cyclic vertical stress (kPa)	90	100	180	330	420	550
Cell Pressure (kPa)	120	41.7	90	140	110	50
Cyclic Vertical Loading Speed	Sinusoidal/Haversine at 4Hz					
Number of Loads (*N*)	50,000 *for each test stage.*					

IV. Flexural Beam Test

The flexural beam test is the same as the flexural tensile strength (Modulus of Rupture) test used for concrete beams [12]. This test determines the maximum tensile strength of the stabilized aggregate and the Young's modulus which are used in the tensile strength design approach in pavement design using the computer software program CIRCLY [6], [7]. Figure 3 illustrates the flexural beam test.

V. Unbound Granular Design Approach

The unbound granular design approach follows the same method as in the Austroads Pavement Design Guide for new pavements but as an additional check on the life of the granular materials using vertical strain criterion derived from the Repeated Load Triaxial test. This process of deriving a strain criterion from the Repeated Load Triaxial test and how the test predicts wheel track rutting is detailed in [1, 2, 3, 4]. The vertical strain criterion for the granular layers is used in the pavement design software CIRCLY [6, 7] as detailed in Figure 4. If the granular material is stabilized then a traffic life multiplier is applied to the life predicted when unbound. The traffic life multiplier is a function of the stabilized materials tensile strength as found in the Indirect Tensile Strength (ITS) test and derived from testing at NZTAs accelerated pavement testing facility CAPTIF [10]. The ITS test method can be found in the NZTA Draft T19 specification [16]

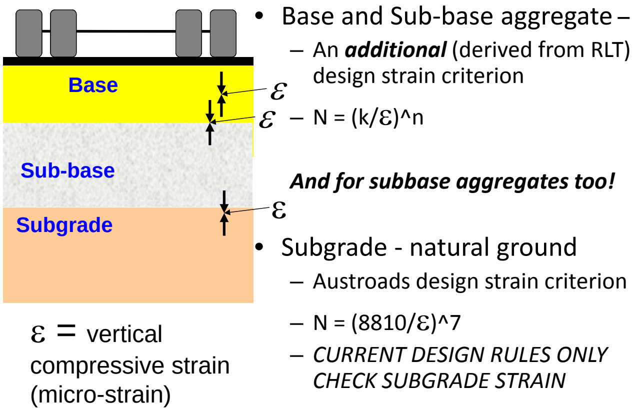

Figure 4. Vertical Strain Criteria To Check Life of Granular Layers

VI. Tensile Strength Design Approach

If a poor RLT result is found on the existing basecourse, then the tensile strength design approach is used. This method of design aims to ensures there is sufficient binder and stabilized depth (D, Figure 3) to ensure the cement (or other binder) bonds remain intact to form a bound layer over the design life. This is because the rut resistance is reliant on the cement bonds as the in situ aggregate has poor rut resistance as indicated by the RLT test even in dry conditions.

The Austroads Pavement Design Guide together with the pavement design software CIRCLY allows the designer to check the life of cement bound layer (Figure 3). This is to ensure the stabilised material maintains strength over the design life. It is important that the stabilised material has sufficient thickness and is well supported as this prevents a return to unbound behavior and the stabilized material remains bound. A tensile strain criteria found from flexural beam tests is used in design to ensure this occurs [Figure 5 and Equation 1]. This criteria was derived from NZ Transport Agency research [8] that found if the tensile strain and tensile stress at the base of the stabilized layer caused by a truck axle is less than 40% of the tensile beam flexural strength then the fatigue life is at least 2 Million passes of that truck axle.

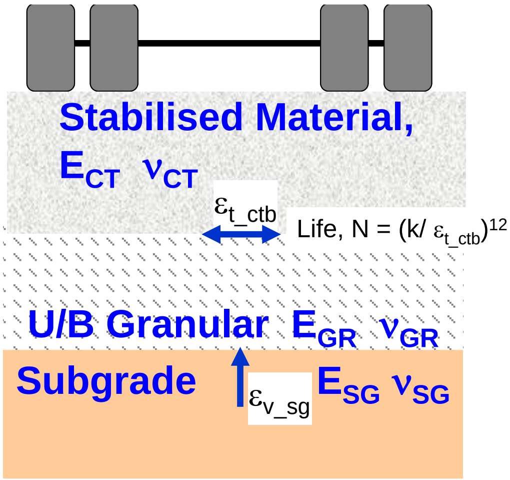

FIGURE 5. TENSILE STRAIN CRITERIA

$$k = \frac{1.265 \times TS_{max}}{modulus} \quad \text{[Equation 1]}$$

Where TS_{max} = maximum tensile strength measured in the flexural beam test.

Another more simplified design approach is to simply check that the tensile stress computed at the base of the stabilized layer is less than 40% of the maximum tensile strength measured in the flexural beam test. This is because the research [8] could not establish a fatigue curve but concluded that the fatigue life could be infinite if the tensile stress is kept below 40% of the beams tensile strength.

There are some risks in designing a bound pavement in terms of shrinkage cracks or premature fatigue cracking due to the constructed pavement not meeting design expectations. Thus, if this method of design is used a granular overlay is often applied to eliminate the risk of cracking at the surface or a bound base course is used on low volume roads in situations where there is a significant cost savings. This is often standard practice elsewhere internationally.

If the RLT test of the in situ aggregate when unbound and dry is poor an alternative to creating a bound layer is to import new good quality aggregate as an overlay and design using unbound granular design approach.

VII. CASE STUDY

Advanced testing assisted in determining the cause of the early failure and determined the most appropriate solution for the climbing lane on the Waikato side of the Kaimais in New Zealand. This pavement was identified as Helcor, State Highway 29, RS 42, RP 4760 - 4930. The existing road had significant wheel track rutting as shown in the site photo in Figure 6.

FIGURE 6. PHOTO OF PAVEMENT DISTRESS AT HELCOR SITE

This road site already had 600mm of aggregate over a subgrade CBR of 6% and current Austroads pavement design rules [5] could not determine why the road had failed early. The pavement depth was deemed to be sufficient for both past and future traffic. Thus for a neighbouring road section the design was to simply in situ stabilise with 1.5% cement to a depth of 200mm which using the current NZ Transport Agency and Austroads design rules [5] was deemed to have a 25 year design life. However, this newly stabilised road section has 50mm ruts after 3 years and is also in need of repair.

The Road Science team undertook RLT tests on both the basecourse and subbase aggregate which identified a weakness in the subbase aggregate (Figure 7). Using the RLT data in design it was found the subbase aggregate gave the shortest life. These results were presented at NZ Transport Agency along with several other design options which were discussed. Based on these discussions a suitable treatment was designed and constructed to remove the subbase aggregate and replace with better quality aggregate. The RLT test of the top 150mm of basecourse was found to be of good quality and was stockpiled and then reused in the pavement.

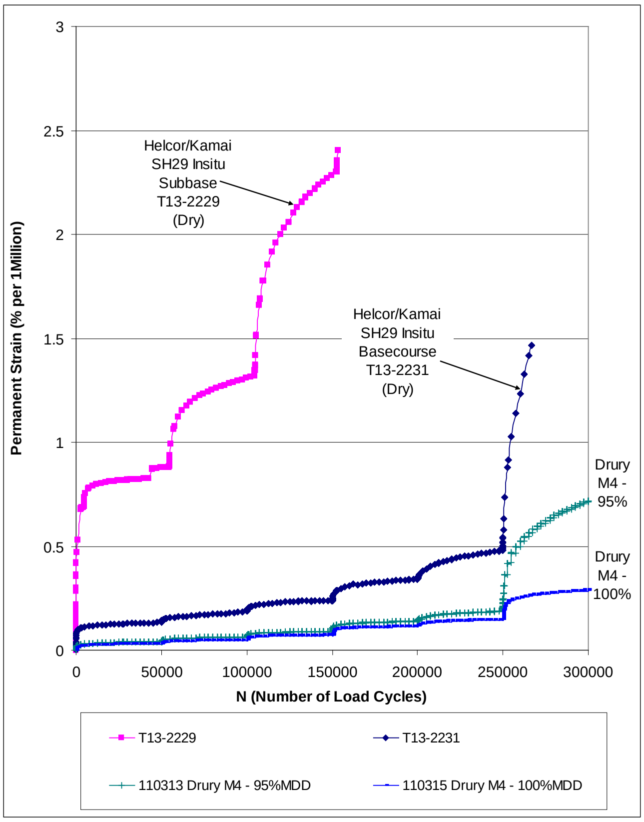

FIGURE 7. REPEATED LOAD TRI-AXIAL TEST RESULTS FROM BASECOURSE AND SUBBASE AGGREGATE SAMPLED FROM HELCOR

The design approach used was unbound granular using vertical strain criterion in the basecourse and subbase granular layers (Figure 4) that were derived from the NZTA T15 [9] Repeated Load Triaxial test (Figure 7) using the method detailed in the NZTA research project [3].

TABLE 2: DESIGN STRAIN CRITERION DERIVED FROM RLT TEST (FIGURE 7)

Strain Criterion: N=(k/strain)^n (Figure 4)	**k**	**n**	**Top Layer Modulus (MPa)**
Basecourse	**0.603**	**2.35**	**374**
Subbase	**0.098**	**3.02**	**150**

For this site a bound basecourse option was also explored but the resultant strengths from the flexural beam tests (Figure 8) were analyzed as being insufficient over the weak subbase aggregate. Further, for this high traffic site the risk of cracking was too high for a bound basecourse option.

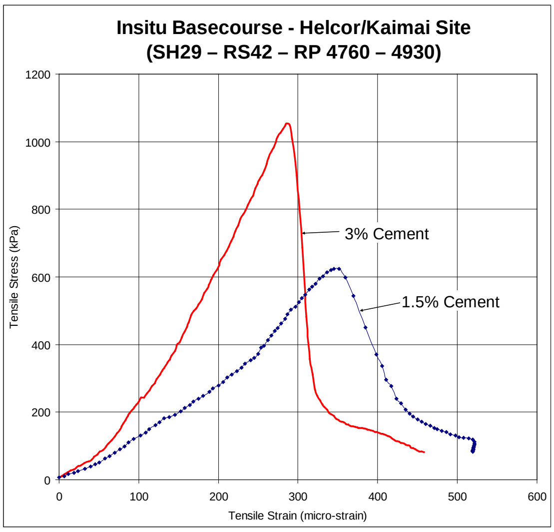

FIGURE 8. FLEXURAL BEAM TEST RESULTS

Current Austroads design methods were unable to determine poor performance of the subbase as the reason why the pavement failed early. Therefore the proposed treatment focused on removing the weak subbase and replacing with high quality crushed rock.

VIII. SUMMARY

This paper gives details on the advanced pavement design, testing and investigation methodologies used for the annual pavement renewals program in the NZ Transport Agency East Waikato Area Highway Maintenance Contract.

Research studies [1, 2, 3, 4, 8, 9, 10] were used for development of this design method which utilises the Repeated Load Triaxial and Flexural Beam tests to determine performance criteria for pavement design. .

The benefits of this new approach to design and testing has in some cases resulted in a lower cost pavement treatment solution, in other cases the scientific approach used was able to demonstrate to NZ Transport Agency that a more robust treatment was required.

ACKNOWLEDGEMENT

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