RLT Testing

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Abstract

Aggregates are a necessary and important resource for the construction and maintenance of roads. In order to conserve this resource and to reduce the risk of early failure it is important to utilise a wider range of materials appropriate to their use, either in wet or dry environments and low, medium or high traffic loadings. Research by Dr Arnold at the University of Nottingham in England and recently with Transit New Zealand, ARRB TR Ltd and Austroads has shown that the Repeated Load Triaxial (RLT) apparatus can measure the deformation / rutting resistance of aggregates in wet and dry states at a range of loading conditions. The results from the RLT tests enable the performance / rutting in the road to be predicted to enable the aggregate to be categorised for use according to:

- wet or dry conditions;
- low, medium or high traffic loadings.

This paper reports on research to date, and the benefits of utilising such a performance test in the selection of aggregates.

Introduction

Pavement design and material selection has been relatively simple for the Pavement Engineer. The pavement thickness is determined by a chart and the pavement materials used are required to comply with the appropriate road controlling authority specifications. In comparison with our cousins in the geotechnical engineering field there is little engineering involved for the design of pavements and the selection of materials. However, behind the development of the thickness design charts and pavement material specifications a significant amount of engineering and research has been undertaken.

Much of the development of pavement material specifications was in a time of the former Ministry of Works and National Roads Board. During this time the Road Research Unit prioritised, managed and disseminated the research. The National Roads Board readily paid for and accepted the risk for pavement test sections established to evaluate new materials. Today's environment for research is significantly different. It is difficult to establish pavement test sections for the purpose of testing an alternative pavement material. Road controlling authorities are not willing to accept responsibility of failures and are restricted to using current approved specifications.

Performance Based Specifications

To provide an incentive for Contractors to be innovative and use local materials (stabilised or otherwise) in 1999 Transit introduced two new specifications: *Performance Based Specification for Structural Design and Construction of Flexible Unbound Pavements* TNZ B/3 and TNZ M/22 *Notes for the Evaluation of Unbound Road Base and Sub-base Aggregates*. These performance based specifications allowed Contractors to use alternative materials provided they met certain performance criteria being durability and rut resistance and accepted a 12 month warranty/maintenance period for the final constructed pavement.

Expectation in 1999 by Transit was Quarry operators would use TNZ M22 to develop their own aggregates that are more readily produced with less wastage. A Contractor would then utilise this aggregate to compete for a performance based contract as per TNZ B3. Seven years later the use of TNZ M22 and B3 has been minimal. Two examples of its use were near Nelson where a local aggregate that did not meet the crushing percentages in TNZ M4 could be used and Stevensons in Drury could use a lime modified aggregate.

Some reasons for the low uptake of performance based specifications TNZ M22 and B3 are:

- Contractors not willing to take the risk;
- Quarry operators not proactive in testing and marketing their local materials;
- For sites trialling the use of TNZ B3 the finished road pavement did not meet the expectations of Transit's project engineers and asset managers:
  - thus many debates over whether or not the pavement met the performance requirements of B3.

Waste and Energy Minimisation

Since 1999 Transit New Zealand have an environmental strategy that recognises government objectives to minimise waste and reduce energy usage. Efficient use of the aggregate resource by utilising locally available and waste materials was recognised as one way to reduce waste and energy use. However, the specification for basecourse aggregate TNZ M4 is restrictive allowing only premium quality crushed rock from quarries for construction of state highways. Transit are now open to adding as regional variants in M4 alternatives to premium quality crushed rock provided it can be proven to have similar performance. Recent additions to TNZ M4 include Recycled Crushed Concrete and Melter Slag Aggregate from the Glenbrook Steel Mill being waste materials that would otherwise be used as landfill.

Transit are confident in the performance of Recycled Crushed Concrete due to its extensive use for many years in Australia and results from testing at Transit's accelerated pavement testing facility CAPTIF. The Melter Slag has been used for many years already by Franklin District council and the roads have shown adequate performance. These waste product have already a history of use and thus more easily approved as an alternative to quarried crushed rock. For other waste materials such as mixtures of aggregate and glass approval is more difficult. Although, aggregate research utilising results from the Repeated Load Triaxial Test for predicting performance are promising (Arnold, 2004) as discussed in the following sections.

Use of marginal and local aggregates modified or otherwise that do not currently comply with TNZ M4 specification are also recognised as reducing waste and energy. This will result in less wastage at the quarry less transportation of aggregates over long distances. An example currently being investigated by Transit is a local modified aggregate with 3% lime for use for roads in the Northland region. Although, the motivation for the Northland modified aggregate is to eliminate early pavement failures due to weakening of aggregates when wet.

Prevention of Premature Pavement Distress

A key component in a pavement relies on the pavement materials performing adequately. Pavement materials are required to:

1. spread the wheel loads to reduce the load on the soft underlying subgrade (soil) and/or other weaker pavement materials ;
2. not fail in shear (i.e. shoving or rutting) with the application of wheel loads;
3. have minimal deformation, where most of the deformation occurs in the subgrade;
4. not deteriorate structurally over the design life;
5. adequately hold and support the surfacing; and
6. not be detrimental to the performance of the surfacing (e.g. cracking).

The requirement to adequately spread the load over the subgrade is currently ensured by providing adequate pavement thickness as determined using the pavement thickness design procedures in the Austroads Pavement Design Guide. All the other requirements listed are satisfied by using an unbound granular aggregate that complies with the specification for basecourse aggregate TNZ M4. This specification is a recipe for quarries to make a basecourse that has been proven over time. However, recent early pavement failures being a result of the pavement basecourse aggregate having insufficient strength when wet has questioned the ability of TNZ M4 to produce an adequate material.

In New Zealand there is anecdotal evidence that compliant M4 aggregate from different quarries perform differently. This is of particular concern for very high trafficked roads when the aggregate with the greatest resistance to rutting are required. As discussed in the next section the Repeated Load Triaxial test is being researched as a means to identify aggregates more suitable for very high trafficked roads.

The current specification for basecourse aggregate TNZ M4 due to its empirical/recipe approach to selecting aggregates cannot distinguish differences in performance between aggregate types. Further, it is expected a modified aggregate with small quantities of cement or lime will provide superior performance in terms of rut resistance in wet conditions to that of traditional aggregates that comply with TNZ M4. Evidence of this is in Northland where a modified local GAP 65 aggregate which does not comply with TNZ M4 was found to solve the rutting problems that was occurring with traditional M4 aggregates. The Transfield PSMC01 contract on SH3 has also found the same conclusion. Current methods of design do not recognise the superior rut resistance of a local modified material which is not affected by moisture. Also current specifications do not allow the use of a local modified aggregate. Thus, a local modified aggregate that could solve any rutting problems of traditional M4 aggregates are not used.

Repeated Load Triaxial Apparatus

The RLT apparatus tests cylindrical samples of soils or granular materials. Figure 2.9 illustrates a typical Repeated Load Triaxial apparatus test set up. For RLT tests the axial load supply is cycled for as many cycles as programmed by the user. The axial load type is usually programmed as a sinusoidal vertical pulse with a short rest period. Although possible for some RLT apparatuses, in this study the cell pressure was not cycled simultaneously with vertical load, but held constant. Two types of repeated load tests are usually conducted, being either a resilient or permanent deformation test. Triaxial testing is a research tool with the aim to simulate as closely as possible the range of conditions that will be experienced in a pavement.

The RLT (Repeated Load Triaxial) apparatus applies repetitive loading on cylindrical materials for a range of specified stress conditions, the output is deformation (shortening of the cylindrical sample) versus number of load cycles (usually 50,000) for a particular set of stress conditions. Multi-stage RLT tests are used to obtain deformation curves for a range of stress conditions to develop models for predicting rutting.

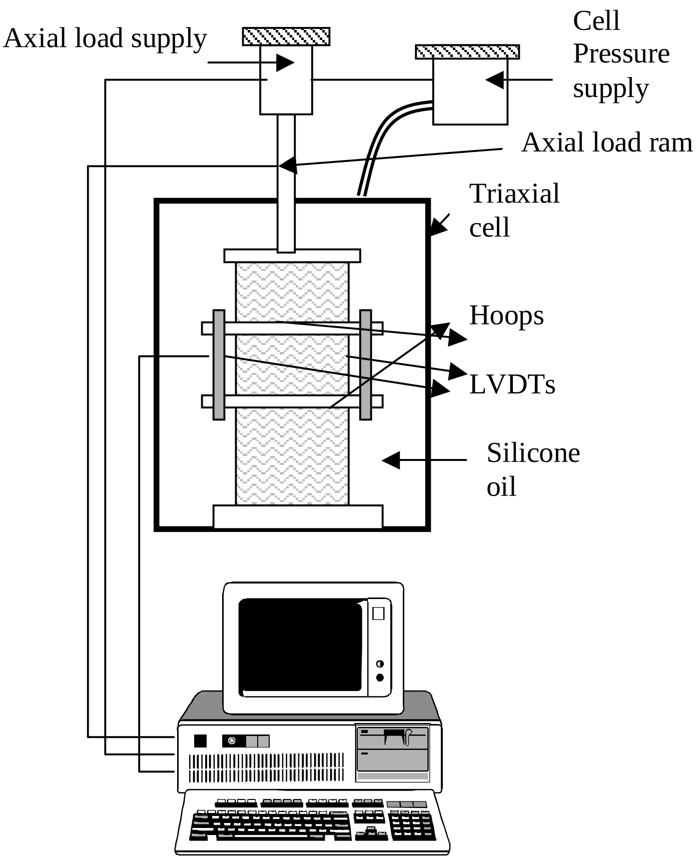

Figure 1 – Repeated Load Triaxial Apparatus

Development of a Performance Test for Aggregates

Research at Transit New Zealand's accelerated pavement testing facility CAPTIF (Arnold et al, 2004a; Arnold 2004) found that pavement aggregates all complying with Transit New Zealand (Transit) specification for basecourse aggregate (TNZ M4) resulted in different pavement lives (defined by reaching a certain terminal rut depth). Pavement depths and the subgrade were the same and thus the only differences in performance were attributed to the differences between aggregates. The differences in performance could not be detected with the TNZ M4 specification as all the aggregates passed this specification. However, Arnold (2004) found that permanent strain tests using the Repeated Load Triaxial (RLT) apparatus with appropriate modelling could predict the differences in performance found in the CAPTIF tests.

Research by Austroads (Vuong 2003a and 2003b) also found the RLT could predict performance of aggregates used in pavement tests at ARRB's ALF (Accelerated Loading Facility). Results from Arnold's (2004) and Vuong's (2003a and 2003b) have been expanded to develop a practical RLT test for use in specifications for the selection of suitable aggregates/materials (as could include recycled, industrial by-products and waste materials such as glass) for pavement base layers in the current Transfund project, Predicting In-Service Performance of Alternative Pavement Materials. This research will trial, validate and refine the practical RLT test developed in the Transfund project, Predicting In-Service Performance of Alternative Pavement Materials.

Results From Repeated Load Triaxial Tests

To investigate the rutting performance of different basecourse aggregates RLT tests were undertaken on nine New Zealand aggregates. The aggregates conformed to TNZ M/4 specification. The aggregates investigated came from different sources:

- Stevensons Drury Quarry
- Ponds Road Quarry (Greywacke - 3 materials)
- Poplar Lane Quarry

- Hunua Quarry
- Oreti River Quarry
- Waitakere Quarry
- Tauhara Quarry (Dacite).

Results have been reported anomalously as materials 1,2,3…. rather than actual quarry source. There are nine materials and are in no particular order. This is due to the possible sensitivity of the results and further analysts and tests are yet to be conducted before any conclusions and certainty of the results is obtained.

The RLT apparatus in the Civil Engineering Department Transportation Laboratory at the University of Canterbury, Christchurch was used for the tests. To simulate dry and wet conditions in the pavement basecourse the samples were tested at 70% and 85% of Optimum Moisture Content (OMC). The samples were compacted to the dry density required (95% DOC - Degree of Compaction).

The results of the RLT tests were analyzed to produce the plastic strain rate values over the later stages of each stress state (load cycles 20,000 to 50,000) for different stress conditions defined by the mean principal stress, *p* and deviatoric stress, *q*, (Table 1). Stress state 1 and 2 are most representative to the stress conditions in a thin surfaced flexible pavement under 80 and 100 kN axle loads.

Table 1 - Multi-stage RLT loading regime according to Arnold (2004)

RLT Testing Stress Stage	1	2	3	4
Deviator stress - q (kPa) (cyclic vertical stress)	180	270	330	420
Mean stress - p (kPa)	150	150	250	250
Cell Pressure, σ_3 (kPa)	90	60	140	110
Cyclic Vertical Loading Speed	Sinusoidal at 4 Hz			
Number of Loads (*N*)	4 x 50,000 cycle stages = 200,000 cycles per test			
Data Recorded	Plastic strain versus load cycles Resilient modulus versus load cycles			

Figure 2 shows the development of axial plastic strain versus number of number of load cycles for a basecourse aggregate applying the multi-stage RLT loading regime according to Arnold (2004).

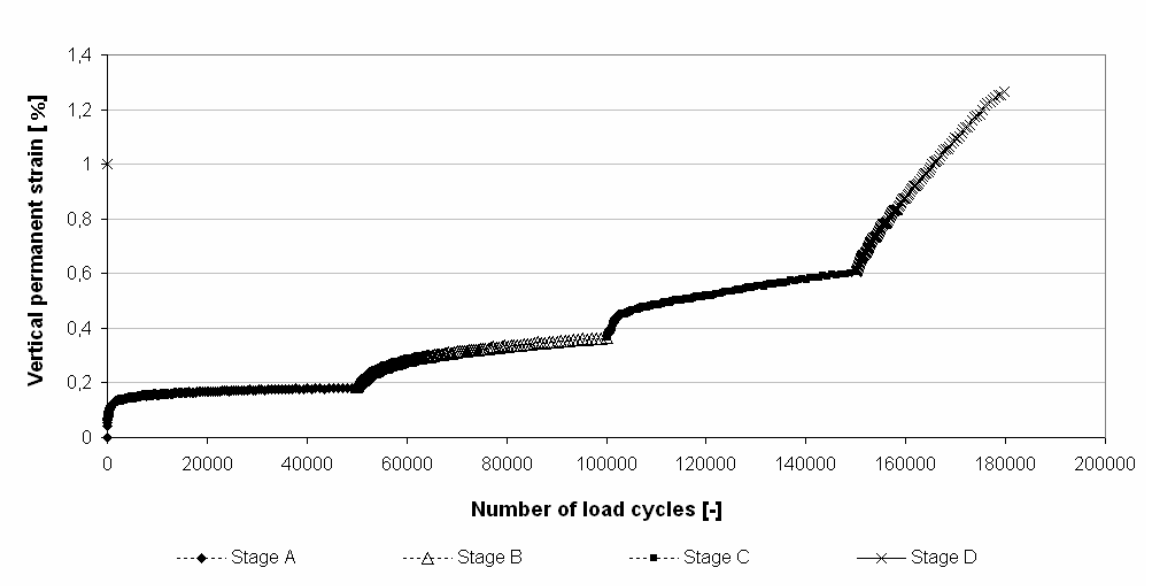

Figure 2 – Development of axial plastic strain versus number of number of load cycles using the multi-stage RLT loading regime according to Arnold (2004)

Based on the plastic strain rate values, the plastic deformation of a 100mm thick granular layer after the application of 1,000,000 load cycles was calculated for each stress state (excluding the first 20,000 load cycles – post compaction). For some tests, the plastic deformation after 1,000,000 load cycles would exceed 25 mm per 100 mm layer thickness.

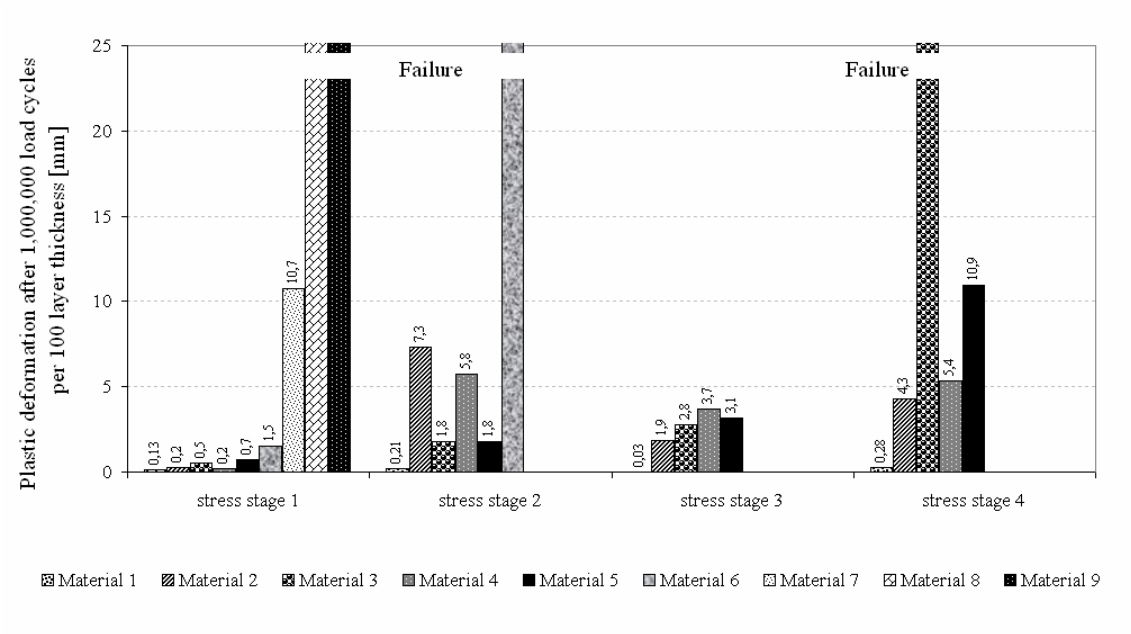

Figure 3 – Plastic deformation at different stress states (see Table 1) for the aggregates at dry condition (70% of OMC)

Figure 3 shows that the plastic deformation performance of the material is varying although aggregates conformed to TNZ M/4 specification. In particular three materials (Materials 7, 8 and 9) showed very poor plastic deformation performance in stress state 1 (failure) already. Other materials (Materials 1, 2, 3 and 4) showed good to very good permanent deformation resistance.

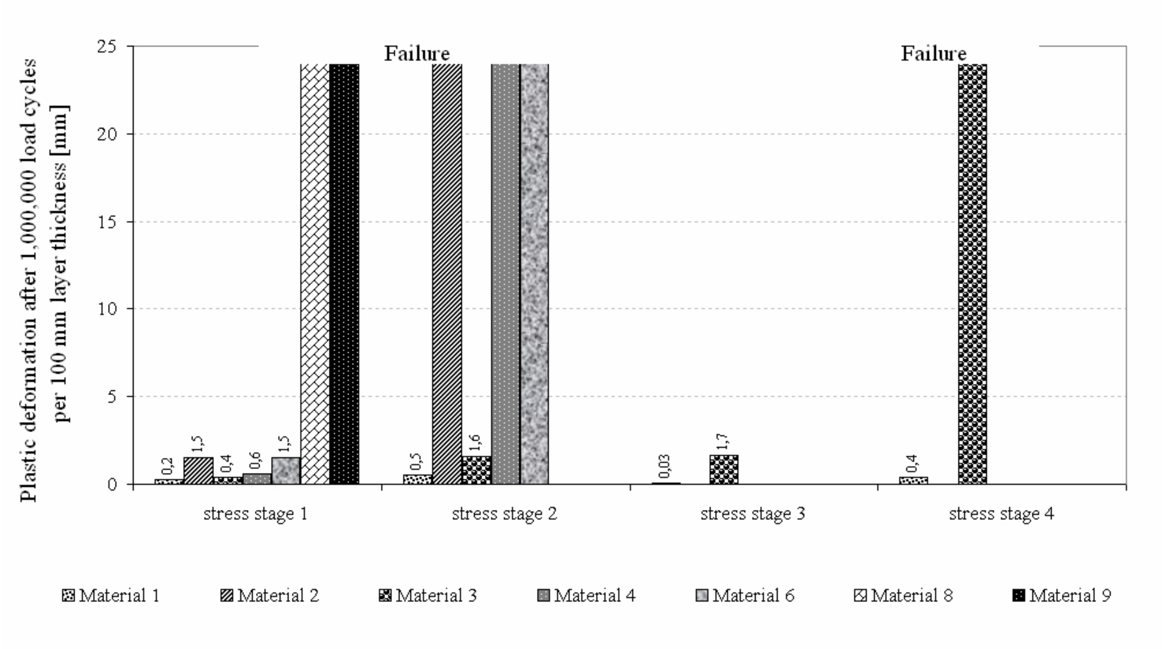

Figure 4 – Plastic deformation at different stress states (see Table 1) for the aggregates at wet condition (85% of OMC)

Figure 4 shows plastic deformation at different stress states for the aggregates at wet condition (85% of OMC). Increasing the moisture contents will lead to lower plastic deformation resistance because due to the increased lubrication and reduced friction between the particles. Only Material 1 shows very good deformation performance at wet conditions.

These RLT test results will undergo more complex analysis to determine mathematical relationships between stress and deformation/permanent strain. From the model and pavement stresses computed in a pavement finite element model rut depth will be estimated for each aggregate. Results of the rut depth calculations will be compared to anecdotal evidence of performance in the field and at CAPTIF to validate the RLT test and analysis method for use in specifications.

Presented in this paper is a simple analysis of the RLT results by simply using the slope of the permanent strain curve for each stress stage. Nevertheless most of the results to conform to field experience as the poor behaving aggregates (e.g. Material 9) have been used on state highways where early pavement failures (extensive rutting) occurred.

The RLT test results prelude that aggregates all complying with Transit New Zealand specification for basecourse aggregates (TNZ M4) resulted in significant different pavement rutting performance (defined by reaching a certain rut depth). Hence, the current specification (TNZ M4) due to its empirical/recipe approach to selecting aggregates cannot distinguish differences in plastic deformation performance between aggregate types.

Implementation of RLT Test

Transit New Zealand plan to revise the specification TNZ M22 to include the practical RLT test developed from the Transfund project to enable materials to be categorised as being suitable as base materials for high, medium or low traffic situations in either dry or saturated conditions. This will ensure the design life can be met; a range of materials including marginal materials (previously discarded) can be used in appropriate locations (ie. low traffic and dry environments); allow other alternative materials, e.g. industrial by-products (e.g. Melter Slag) and waste materials (e.g. glass, recycled crushed concrete) to be assessed and used appropriately according to their level of rut resistance in wet and dry conditions.

This research has undertaken RLT tests on aggregates in New Zealand where based on experience they are known to provide poor, average and good performance. As a result of these RLT tests the aggregates will be boxed into various categories of low, medium, and high traffic for both wet and dry conditions. Results of this categorisation will be compared with actual performance on the road (based on local knowledge) and at CAPTIF to validate and refine the method of performance assessment.

The next stage of the research will involve RLT testing of a modified/stabilised aggregate to determine through modelling the additional life (ie. Number of axle passes until a terminal rut depth is reached) that can be obtained compared with the non-modified aggregate. This will enable the benefits of modifying aggregate to be quantified to enable this as acceptable practice to obtain a high strength material capable to resist rutting for very high traffic roads (> 1 x 10^7 ESAs). The objectives of this research are to:·

- trial, validate and refine the practical RLT test developed in the Transfund project, Predicting In-Service Performance of Alternative Pavement Materials on materials currently used on New Zealand roads with known performance;·
- trial and validate the practical RLT test method into Transit's policy (TNZ M22) as a means of categorising materials in terms of low, medium, and high traffic and either wet or dry conditions;·
- evaluate the RLT test method to quantify the benefits of modifying/stabilising an aggregate in terms of increase in number of wheel loads to reach a certain rut depth;·
- to implement a test procedure that allows alternative materials (which includes aggregates, marginal materials, stabilised materials, those from recycled sources etc) to be used in the pavement with appropriate limits to the level of traffic and moisture condition.

Discussion

The Repeat Load Triaxial test conditions and interpretation is currently under development. Test conditions and interpretation methods are being developed based on an approach that best predicts rutting in granular pavements. Results from Transit New Zealand's pavement testing facility, CAPTIF, has been used to validate the RLT test method develop. This is important to keep the main reason in mind when developing a test rather than the detail of loading speed, shape of the loading pulse etc in the RLT test. Further, the RLT test developed will be based on the method of testing and interpretation used in research to date. This will ensure that the extensive tests already conducted on New Zealand aggregates can be used in the future for comparison with other RLT test results.

Conclusions

Results from this research will be a RLT test procedure and associated analysis to predict the magnitude of rutting and allowable design loading (ie. number of wheel passes until a 20mm rut depth). This fundamental approach to pavement design and material selection allows the benefits of modifying materials to be accurately quantified. Further, alternative materials such as those previously wasted (e.g. industrial by-products and recycled materials) can be assessed and used appropriately based on their predicted performance in replace of virgin aggregates. Increase use of waste materials and use of previously discarded aggregates has an environmental benefit through conserving the highest quality aggregates and using waster materials reduces the amount sent to landfill.

In summary the outputs of the research being a RLT test procedure and associated analysis to predict the magnitude of rutting and allowable design loading will have the following benefits:

- Reduced number of early rutting failures of new pavements;
- Quantification of the use of modified materials in terms of their superior resistance to rutting;
- Environmental benefits through increased use of waste materials and previously discarded aggregates.

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