Hydrated Cement Treated Crushed Rock Base (HCTCRB) and Repeated Load Triaxial Testing

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Abstract

As a result of poor performance of crushed rock base (CRB) on various roads in the Perth metropolitan area, a project involving laboratory testing using repeated load triaxial testing equipment was undertaken to investigate ways of improving the strength of CRB. It was found that small quantities of cement can be added to the CRB at the quarry and stockpiled for at least 7 days for hydration to take place and still improve resistance to deformation of the CRB when wet. The material with cement is then disturbed, loaded onto trucks and used as a normal crushed rock base. Road trials by Main Roads Western Australia were undertaken and supported the results from the RLT. As a result all Perth highways only use crushed rock bases with cement that have been stockpiled for 7 days and commonly refer to this product as Hydrated Cement Treated Crushed Rock Base (HCTCRB).

Similar concerns in New Zealand with early failures of granular pavements led to a field trip to Perth to learn about Hydrated Cement Treated Crushed Rock Base (HCTCRB). Main Roads WA emphasized the importance of undertaking Repeated Load Triaxial testing, production and road trials to check if the HCTCRB has the effect of increasing the strength of the source aggregate and grading.

Since the Perth field trip laboratory studies using the Repeated Load Triaxial apparatus on HCTCRB using New Zealand aggregates have been undertaken. This paper introduces the concept of HCTRB and reports on the results of studies with HCTCRB undertaken in Perth and more recently in New Zealand. Repeated Load Triaxial testing developments are also discussed along with its proposed introduction into TNZ M/4 Basecourse Specification.

Introduction

As a result of poor performance of crushed rock base (CRB) on various roads in the Perth metropolitan area, a project involving laboratory testing using repeated load triaxial testing equipment and resulting road trials was undertaken to investigate ways of improving the stiffness and reducing the moisture sensitivity of the CRB. It was found that small amounts of cement significantly improved the materials resistance to deformation when wet.
It was also found that the small quantity of cement can be added to the CRB at the quarry and stockpiled for at least 7 days for hydration to take place. The material with cement was then disturbed, loaded onto trucks and used as a normal crushed rock base. This method of adding cement and stockpiling still resulted in improved resistance to deformation when wet. Further, there is a significant advantage in manufacturing the Hydrated Cement Treated Crushed Rock Base (HCTCRB) as there is no time restraints in placement and there is a reduced risk of the material becoming too stiff and cracking.

Transit New Zealand is very interested in this method of adding cement to a basecourse aggregate, stockpiling and then using as a basecourse with improved resistance to deformation/rutting. The HCTCRB in Perth is classified as a modified aggregate in the Transit New Zealand Supplement to the Austroads Pavement Design Guide. Modified aggregates are recommended in the NZ Supplement for use for high trafficked state highways as an economical alternative to structural asphalt. Transit also see’s there is a market for lower quality aggregate’s previously not meeting Transit’s specifications to be modified with cement (or similar additive) to improve their performance to allow their use. Transit New Zealand has developed a Repeated Load Triaxial test (a device that simulates repeated wheel loadings) from recently completed research and will soon implement into TNZ M/4 Specification for Basecourse Aggregate.

Repeated Load Triaxial Tests on HCTCRB

In 1996 Main Roads Western Australia undertook a laboratory study using the Repeated Load Triaxial apparatus to better understand the performance of pavement basecourse materials, commonly used in the Perth Metropolitan area (Butkus & Goh, 1997). The investigation programme involved repeated load triaxial testing on pavement materials to characterise resilient modulus and permanent strain/deformation characteristics. In particular, the emphasis was on examining crushed rock base (CRB) which has shown poor performance in some recently constructed sections in Perth. CRB samples were sourced from six metropolitan quarries and also from existing pavements that have performed both satisfactorily and poorly. For comparison purposes, some tests were performed on 2% bitumen stabilised limestone (BSL) basecourse and crushed limestone subbase material.

Results of the Perth Repeated Load Triaxial Study are summarised below (Butkus & Goh, 1997) with selected results in Figures 1 and 2:

- The repeated load triaxial test results indicate that CRB is extremely sensitive to moisture. Poor pavement performance can be expected when the moisture ratios exceed 60%. Poor pavement performance of CRB, which can be predicted by high deflection and curvature values invariably appears to be associated with field moisture contents above 60% Moisture Ratio (Butkus, 1994; Lee Goh, 1994).
- The CRB is not sensitive to density over the range 96 to 98% DDR. However testing has shown that modulus reduces at 100% DDR. Other recent work has supported this finding. It appears that at high densities the voids reduce to the extent that even at relatively low moisture conditions the CRB has the potential for poor performance.
- From the limited test results on BSL and crushed limestone, it is evident that crushed limestone is also moisture sensitive while BSL is much less susceptible to moisture. The modulus values for crushed limestone are comparable to CRB but the strain properties are inferior. The modulus and strain properties for BSL are superior to CRB.
The addition of cement to CRB dramatically improves the modulus and permanent strain properties. However, problems due to fatigue cracking can be expected because even small additions of cement, as low as 1%, can result in the CRB behaving as a bound material. In addition, there are time related construction restrictions because delays in compaction, after adding cement and water, will result in reduced achieved densities and subsequent reductions in strength. The use of blended cements, which were expected to extend the working time, did not clearly show significant advantages in their use.

The hydration test results show an improvement in the CRB modulus and strain characteristics, and reduced sensitivity to moisture. This method of stabilising the CRB is potentially a practical and effective solution to improving CRB performance without the problems associated with the material becoming bound. The stabilisation involved the addition of GP cement and water to the CRB and then allowing the hydration process to take place while at the same time disturbing the setting up process by breaking up the sample. After a sufficient length of hydration time the samples were compacted and subjected to repeated load triaxial testing.

The addition of superplasticiser only to the CRB appeared to increase the amount of total permanent strain, which is undesirable, while the addition of superplasticiser in combination with GP cement to the CRB showed improvements that were comparable to CRB stabilised with GP cement only ie. there was no advantage in adding the superplasticiser.

The effect of modifying the particle size distribution curves of the CRB within the specification grading envelope and adding small percentages of fines (material passing the 0.075 mm sieve) did not appear to significantly affect or improve the CRB performance, except that the addition of fines appeared to improve the permanent strain characteristics slightly.

In summary, the performance of the CRB can improved by ensuring either adequate dry back or stabilising with GP cement. Without stabilisation, it is imperative that CRB be dried back to a characteristic moisture content of 60% of OMC (Optimum Moisture Content) or less prior to application of the surfacing. The moisture content should be determined over the entire thickness of the base with two samples, one for the top half and one for the bottom half. Within the layer, no individual moisture content should be allowed to exceed 70% OMC. In addition to dry back, it is also imperative that the surface and subsurface road drainage be adequately designed to ensure that moisture is kept out of the pavement during service life. Any wetting up of the pavement is likely to reduce the service life.

The performance of CRB can be greatly improved by stabilisation with cement. The process where cement is added to the material at the quarry and allowed to hydrate in the stockpile before placement on the pavement shows great promise. The material improves considerably in stiffness and permanent strain characteristics and the problems of time constraints and the risks involved with bound materials usually associated with cement stabilisation are eliminated.
Figure 1 – Selected Repeated Load Triaxial Test Results from Perth Study Showing Effect of Cement and Moisture on Permanent Strain.
In New Zealand there has been some experimentation using the Repeated Load Triaxial apparatus and associated rut depth modelling with hydrated cement treated basecourses. The testing methodology used is the current draft Transit New Zealand method soon to be introduced. The 7 day hydration process was simulated in the lab by mixing water and cement in a mixing barrel and mixing again after 24 hours before putting in a sealed bag and leaving for 7 days before compaction. Initial results showed the hydrated cement sample showed little improvement from the source material. However, significant strength gains/resistance to rutting was found when the grading was changed to being finer than the TNZ M4 and an additional amount of water was for compaction to ensure some cementation occurs in the compacted sample. It should be noted that the amount of strength gain and
optimum cement contents required vary for different materials and hence specific laboratory studies are required to determine the most optimum mix in terms of cement, water and grading. Table 1 shows the results of rut depth modelling before and after cement modification together with a comparison with a good quality aggregate from Canterbury. Figures 3 and 4 shows the raw results from the Repeated Load Triaxial tests of the source aggregate and the source aggregate modified with cement using the 7 day stockpile hydration process.

Table 1 – Example showing rut depth predictions for the source aggregate with hydrated cement and without.

<table>
<thead>
<tr>
<th>RLT Sample</th>
<th>N (10^6), ESAs to get 25mm rut</th>
<th>N (10^6), ESAs to get 10mm rut in aggregate.</th>
<th>Aggregate rut depth rate mm per 1 Million ESAs</th>
<th>Modulus (MPa) (Top of Pavement)</th>
<th>Average Permanent Strain Rate 25k to 50k in RLT test %/1 Million</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCTCRB</td>
<td>3.4</td>
<td>22.9</td>
<td>0.4</td>
<td>440</td>
<td>0.12</td>
</tr>
<tr>
<td>TNZ M4 Canterbury Greywacke used at CAPTIF (Transits Accelerated Pavement Test Facility)</td>
<td>3.2</td>
<td>10.4</td>
<td>0.7</td>
<td>880</td>
<td>0.71</td>
</tr>
<tr>
<td>CAPTIF Result</td>
<td>3.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Source Aggregate used for HCTCRB above</td>
<td>1.8</td>
<td>1.9</td>
<td>4.1</td>
<td>260</td>
<td>1.71</td>
</tr>
</tbody>
</table>

Figure 3 – Repeated Load Triaxial Test of Hydrated Cement Treated Crushed Rock.
To further investigate this material and assess its performance in the field, a series of test sections were constructed on Reid Highway in Caversham, Perth in 1996 (Butkus, 2004). In addition to HCTCRB, test sections were also constructed of untreated CRB, insitu cement stabilised CRB, bitumen stabilised limestone, insitu cement stabilised limestone and a new product proposed for basecourse by industry called LIMUD.

**HCTCRB Test Sections**

All three sections of HCTCRB have performed well. The 200mm layer of 2% HCTCRB on Section 6 has given the best performance of all the test sections. However this section is also the only one that has significant pavement cracking in the form of transverse cracks at the centreline and on both shoulders. The cracks are not in the wheelpaths and are not believed to be due to traffic loading, but are associated with moisture changes in the highly active clay which underlies the embankment of this section.

The 100mm layer of 2% HCTCRB of Section 1 has also performed well. The trials also suggest that 1% HCTCRB is a suitable basecourse material, however it needs to be dried back to a lower moisture content than the 2% HCTCRB, and the addition and incorporation of such a small amount of cement requires very accurate process control.

The performance of 1% HCTCRB is considerably better than the performance of the sections of untreated CRB and suggests that this material is also an option on future works. Section 5, the 200mm layer of 1% HCTCRB performed very well at a characteristic density of 2.25 t/m³ and moisture content of 4.31%. If these values are related to the MDD/OMC of the untreated CRB, the corresponding characteristic density ratio and dryback moisture is 97% and 81%. The material would be more economical than the 2% HCTCRB, but the savings in...
cement may not be worth the increase of basecourse dryback required for good performance. Another issue with this material is that the incorporation of only 1% cement at the quarry would require very good control processes to ensure accurate cement quantity and adequate mixing. Based on the results from these trials, it could be specified that 1% HCTCRB must be compacted to a characteristic density of 97% and dried back to a characteristic moisture ratio of 75% with these values related to the MDD/OMC of the untreated CRB.

**0.75% insitu cement stabilised CRB**

In terms of D0 - D200 the 0.75% insitu cement stabilised CRB of Section 7 was the strongest of all the test sections at construction completion in July 1996. Since then there has been a definite weakening trend in the D0 - D200 test results, and in November 2003, the material was ranked in fourth position behind the 2% HCTCRB of Section 6, the CRB of Section 4 and the 1% HCTCRB of Section 5. Based on the average of all D0 - D200 tests undertaken since construction (Table 15), the 0.75% insitu cement stabilised CRB ranks second.

Although the performance of 0.75% insitu cement stabilised CRB of Section 7 has been good to date, the weakening trend in D0 - D200 is of some concern. Further monitoring of this material is required to determine at which point the strength stabilises and what the final strength is at that time. Until the long term performance of insitu cement stabilised CRB is properly understood, the material should be used with caution.

**2% BSL**

The performance of the 100mm layer of 2% bitumen stabilised limestone on Section 2 has been reasonable, but although considerably drier, is not as strong as the 100mm layer of 2% HCTCRB of Section 1. The 2% BSL is slightly stronger than the 100mm layer of CRB of Section 3. Based on past performance, BSL has been proven to be a good basecourse material, but due to the cost of bitumen is an expensive product which is being used less frequently.

**CRB**

CRB has been successfully used on the metropolitan road network for many years, but must be dried back considerably to ensure adequate performance. The performance of the 100mm layer of CRB of Section 3 has been reasonable but is in a very dry condition (44% of OMC). The strength of the 200mm layer of CRB of Section 4 was poor during its first six months of service. Since then, its performance has been good. If the performance of this section is typical of CRB, it suggests that in order to achieve conforming results for the curvature function on new pavement, CRB needs to be dried back to perhaps 50% of OMC prior to sealing.

**2% insitu cement stabilised limestone**

Limestone stabilised with 2% cement has been found to be difficult to bring to a suitable surface finish for sealing, and there are potential problems with binder adhesion. The material on Section 8 has also reduced steadily in strength, and in November 2003 had a curvature of 0.15mm the highest of all the test sections.
Based on the performance of this material on the test sections, 2% insitu cement stabilised limestone is unsuitable for use as basecourse on heavy duty pavements.

**LIMUD**

The performance of LIMUD used on Section 9 was the poorest of all the materials used on the test sections. One of the reasons for this is the poor control of the manufacture of the material on site. Based on the performance of the LIMUD on this test section the material is not suitable for basecourse on heavy duty pavements.

A point of interest is that despite the very high curvatures measured on the pavement of Section 9 during the first two years of service, the asphalt surfacing shows no sign of distress. This is in sharp contrast to early asphalt failure on other recent works where curvatures as low as 0.12mm – 0.13mm have been implicated as a cause of cracking of asphalt surfacing only 1 to 2 years old.

**Hydrated Cement Treated Crush Rock Base in Perth**

Based on the results of triaxial testing and road trials the road authority in Western Australia (Main Roads WA) developed a specification for Hydrated Cement Treated Crushed Rock Base (HCTCRB) (Main Roads, WA, 2003). Main Roads WA require all roads in the greater Perth Metropolitan are to use HCTCRB. Since this mandatory introduction in 2003 they have eliminated any rutting and found less potholes forming. Also, when potholes do appear it is simply the surfacing that has peeled off and the HCTCRB remains in-tack. This allows longer time periods for repairing the pothole/surfacing.

Despite the success in Perth, Main Roads, WA staff recommend to conduct your own laboratory study and field trials as every aggregate is different and reacts differently with cement.

**Future of Hydrated Cement Treated Crush Rock Base in New Zealand**

Transit New Zealand is very interested in the hydrated method of adding cement to a basecourse aggregate, stockpiling and then using as a basecourse with improved resistance to deformation/rutting. The HCTCRB in Perth is classified as a modified aggregate in the Transit New Zealand Supplement to the Austroads Pavement Design Guide. Modified aggregates are recommended in the NZ Supplement for use for high trafficked state highways as an economical alternative to structural asphalt. Transit also see’s there is a market for lower quality aggregate’s previously not meeting Transit’s specifications to be modified with cement to improve their performance to allow their use. Transit New Zealand has developed a Repeated Load Triaxial (a device that simulates repeated wheel loadings) test from recently completed research for aggregates modified or otherwise to determine their suitability for use as an alternative TNZ M4 basecourse in high, medium or low trafficked roads in wet or dry conditions.

**Summary**

The process of adding cement and water at the quarry and stockpiling for at least 7 days does still increase the strength/rutting resistance of basecourse aggregates and decreases the moisture sensitivity of basecourses. Repeated Load Triaxial tests primarily by Main Roads
Western Australia and more recently in New Zealand show a significant improvement in stiffness and reduction in permanent deformation for Hydrated Cement Treated Crush Rock Base. Road trials in Perth confirmed this finding and as such HCTCR is specified for all roads in the Perth Metropolitan area. Use to date in Perth has eliminated rutting and reduced the occurrence of potholes.

HCTCR will likely be used in New Zealand for high trafficked roads and a method to use local materials as alternative basecourses with the soon to be introduced Repeated Load Triaxial test in Transit New Zealand TNZ M4 Specification for Basecourse Aggregate.

References


