Moisture Ingress of Cemented Basecourse

Yang Sheng Yeo[1], Peerapong Jitsangiam[2] and Hamid Nikraz[3]
[1]PhD Researcher of Curtin Pavement Research Group, Curtin University
[2]Lecturer of Civil Engineering, Curtin University
[3]Professor of Civil Engineering, Curtin University

Synopsis: Moisture ingress is a primary catalyst for pavement damage and plays a key role in the performance of pavement materials in service. This is evident from the issues faced as a result of high moisture sensitivity of crushed rocks used in the construction of Kwinana Freeway in Western Australia. Cement treatment is deemed a potential solution to reduce moisture sensitivity. The moisture ingress into cement treated crushed rocks can be based on the unsaturated flow theory and quantified with the term Sorpitivity, S, i.e. the square root rate of inflow volume. The linearity of the Sorpitivity when plotting inflow volume against the square root of time, $t^{0.5}$ also provides an indication of the homogeneity of the material. This paper assessed the Sorpitivity of cement treated crushed rocks based on results from the Tube Suction Test procedures developed by Texas Department of Transportation (TxDOT). The tests shows that Sorpitivity decreases with the increase in cement content which means that higher cement content reduces the moisture sensitivity of pavements. The Sorpitivity also showed a high least-square regression of $R^2 > 0.9$, which indicates that the materials are homogeneous.

Keywords: Sorptivity, cemented basecourse, unsaturated flow, pavement, moisture ingress.

1. Introduction

Crushed rock basecourse is an economical option for road construction in Western Australia due to its availability and economy, which lead to its use in the construction of Kwinana Freeway, Western Australia in 1992. However, prior to its completion severe deficiencies manifested as large curvatures measured with the Benkelman beam were measured in a number of sections along the freeway.

This prompted Main Roads Western Australia (MRWA) to undertake an in depth investigation of the behaviour of crushed rock base to better understand the basis behind the failures of Kwinana Freeway [1]. The investigation involved an extensive laboratory program followed by the construction of trial pavements.

It was identified that the failures were associated to the sensitivity of the basecourse to moisture ingress. The laboratory program therefore consisted of repeated load triaxial tests of crushed rock basecourse under various moisture levels and treatment. It aimed to identify the material's response to changes in density and moisture and also to study improvement options to minimise the effects of moisture. These options included drying back, cement treatment and modification in particle size distribution [2]. Trial sections were then constructed as part of Reid Highway to evaluate the recommendations concluded from the laboratory investigations.

As a prologue to this paper, the discussions for crushed rock base sensitivity to moisture and effects of cement treatment from MRWA's investigation are presented.

2. Moisture Sensitivity, the Hydration Test and Cement Modification

As part of the laboratory work commissioned by MRWA to investigate crushed rock basecourse, the effects of density and moisture to resilient modulus were assessed. Samples with varying densities and moisture were prepared to 100/80, 98/60, 98/50, 96/80 and 96/60 (dry density ratio/moisture ratio) to represent the in service conditions of basecourses. The results of these analyses are shown in Figure 1 and 2 below [2].
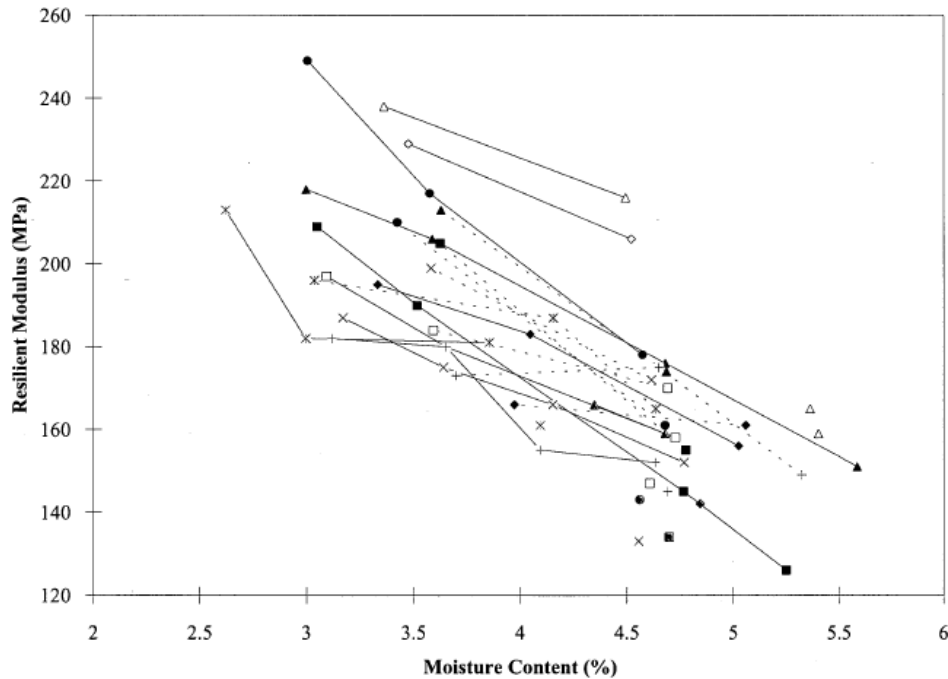
Figure 2 Relationship of moisture content and resilient modulus

As clearly seen from Figures 1 and 2, crushed rock basecourse are highly sensitive to moisture fluctuations where moisture ratios in excess of 60% result in reduced resilient modulus of the material [2]. This was also supported from test results from in-situ crushed rock base undertaken as part of the investigation. Following this, tests were undertaken to assess the use of cement to modify the behaviour of crushed rock base.

The cement treated crushed rock were tested for its performance against various cement content (0.5%, 1%, 2% and 3%), cement set time prior to compaction, curing time and a Hydration Test. The Hydration Test was designed by MRWA to assess whether part of the improvement of crushed rock base was due to factors other than the cementation process. The test involves an interference of the cementation process by regularly remixing the material prior to compaction. These properties and the conclusions are shown in Table 1 below

Table 1 MRWA Investigated Improvement Options

Properties	Cement content tested	Observation
Resilient modulus	0.5, 1, 2 and 3	• Increased performance generally (increased resilient modulus, strain rate and permanent strain) • Increased performance with increased moisture ratio
Cement set time	2	• Decrease performance with increasing set time
Curing Time	2	• Increased performance with curing time • Increased performance with increased moisture ratio
Hydration Test	2	• Reduced sensitivity to moisture

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From the test results, it is concluded that the treatment of cement provided better performance against repeated load. However, tests undertaken by Lee Goh [3] suggested that crushed rocks basecourse will behave as stabilised (bound) materials when more than 1% cement is applied because the measured Unconfined Compressive Strength (UCS) is more than 1 MPa.

Instead, the modification through treatment of cement less than 1% and the product of the Hydration Test was deemed as options to reduce the moisture sensitivity of the crushed rock base. These options were tested through trial pavements constructed on Reid Highway.

Detailed information regarding the trial pavements are reported in [4]. In summary, the Reid Highway trial pavements concluded in the following observations pertinent to the two cement treatment options, i.e.

- Low cement options showed issues of homogenous distribution and permanency
- The hydrated cement treated crushed rock base (HCTCRB) initially showed good improvement against moisture sensitivity but were later exhibited issues with stabiliser permanency

With the measure of moisture a critical component to assess the integrity of pavements in Western Australia, this paper presents the mechanisms involved in the ingress of water and an alternative measurement method for moisture in pavements using the Tube Suction Test.

3. Unsaturated Flow and Sorptivity

In conventional soil mechanics, the permeability of materials are determined based on Darcy's law which assumes soils are in a fully saturated condition. However, pavements are dried back prior to seal and mostly unsaturated throughout their service life. The permeability under such conditions are known as unsaturated flow.

Unsaturated flow refers to the movement of moisture through porous materials where the water content is typically less than saturation and inhomogeneous [5] and involves external and internal forces, i.e. gravity and capillary. Theoretically, the unsaturated flow theory builds upon the Darcy equation by introducing a dimensionless variable which represents the volumetric water content of the material which attenuates the permeability factor [5]. A methodology for measurement of unsaturated flow is the term known as Sorptivity.

The term Sorptivity (S) introduced to unsaturated flow theory was first used by Philip in 1957 to explain the absorption of water into a porous solid due to capillary suction [5,6].

Sorpitivity is the rate of increase in water absorption against the square root of elapsed time. The cumulative volume water per unit inflow surface area as i can be represented as:

$$i = \frac{\Delta w}{\rho A} \tag{1}$$

where, i = inflow volume (mm)
Δw = change in weight (g)
A = cross sectional area of test face (mm^2)
ρ = density of water (assumed at 0.988 g ml^{-1})

Sorptivity, S is then defined as the gradient of the slope $i/t^{0.5}$ and its linearity represents the homogeneity of the specimen.

4. Dielectric Measurement and the Tube Suction Test

The Tube Suction Test is a moisture susceptibility test developed in the United States. Earlier versions of the Tube Suction Test was developed by the TxDOT to analyse the behaviour of ground-penetrating radar (GPR) signals of pavement materials [7] to formulate non-destructive methods for assessing in service roads. From these tests, it was noted that the dielectric permittivity, E_R, of materials was capable of characterising pavement materials. Through further funded research and a joint investigation between the Finnish National Road Administration and the Texas Transportation Institute (TTI), a standard Tube Suction Test was developed to assess the moisture susceptibility of granular materials. Further researches were then undertaken by Scullion et al. [8], and Guthrie et al. [9] on the moisture susceptibility of cement stabilised materials using the Tube Suction Test with promising results to ascertain the durability of the material.

Figure 3 Measurement of Dielectric Permittivity

Results of the Tube Suction Test is presented by the author in other publications [10], however, the measurements as part of the Tube Suction Test are used to calculate the Sorptivity of the crushed rock basecourse.
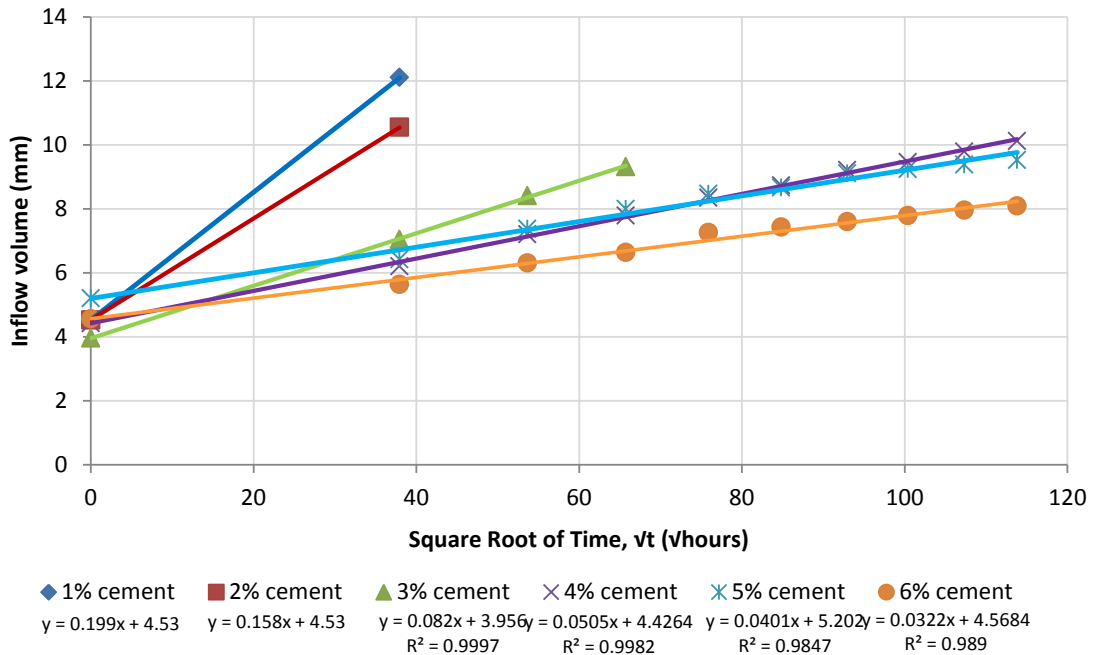
5.   Specimen Preparation and Testing Regime

Crushed rocks sourced from Holcim quarry in Western Australia which meets Main Roads Western Australia Specifications 501 for aggregates are used for this experiment. General Purpose (GP) cement is used for stabilisation. Specimens are compacted to a target modified dry density 2.35 t/m^3 at OMC. The crushed rock sourced is widely used in Western Australia as basecourse material.

In undertaking this research, specimens measuring 105mm in diameter x 115mm in height are prepared for cement content by weight ranging from 2% to 6% cement. The specimens are then cured for 7 days in 100% relative humidity and at a constant temperature before complete dryback for 1 day in an oven at 60°C. Specimens are then wrapped with clear foil before being soaked in an enclosed water bath for 9 days with dielectric measurements undertaken every 24 hours using the Adek Percometer^{TM} as shown in Figure 3 below. Specimens are also weighed in every reading to determine the volume of water absorbed into the specimens.

5. Results and Discussion

The results for the inflow volumes calculated based on equation (1) are presented in Figures 3 below.

1% cement ◆ — y = 0.199x + 4.53
2% cement ■ — y = 0.158x + 4.53
3% cement ▲ — y = 0.082x + 3.956, R² = 0.9997
4% cement ✕ — y = 0.0505x + 4.4264, R² = 0.9982
5% cement ✳ — y = 0.0401x + 5.202, R² = 0.9847
6% cement ● — y = 0.0322x + 4.5684, R² = 0.989

Figure 3 Sorpitivity of Crushed Rocks with 1% to 6% Cement Content

The results shows that the cement treated crushed rocks obey the Sorpitivity principle, i.e. a linear relationship is evident between i and $t^{0.5}$. As expected, the Sorpitivity reduces with increasing cement content allowing better resistance against moisture ingress. The results for 3% cement beyond 100 $min^{0.5}$ reaches saturation and is omitted in identifying the sorpitivity of the specimen. A marked decrease in the gradient, i.e. Sorpitivity is observed between 2% to 3%, which suggests that the susceptibility of cement treated crushed rock to moisture fluctuations reduces when 3% or more cement are treated to the material. Furthermore, based on the least square regression, R^2, the materials tested possess a high degree of homogeneity. The Sorptivity of the specimens are summarised in Table 2 below:

Table 2 Summary of test results

Cement Content (%)	Sorptivity (mm/$t^{0.5}$)	Homogeneity, R^2
1	0.199	-
2	0.158	-
3	0.082	0.999
4	0.050	0.998
5	0.040	0.984
6	0.032	0.989

7. Conclusion

Cement treated basecourse conforms to the unsaturated flow theory and therefore its susceptibility to moisture can be quantified by a measurement known as Sorptivity, i.e. the square root rate of inflow volume. The Sorptivity can be assessed by undertaking the Tube Suction Test which also provides database to test in-situ moisture content. The results suggest that with cement treatment of more than 3%, the material has a marked reduction in its susceptibility to moisture damage and fluctuation. Moreover, it also suggests that the primary defense of cemented basecourse is gained from its degree of impermeability. This notion would imply that the Hydrated Cement Treated Crushed Rock fabrication methodology used specifically in Western Australia may be highly susceptible to moisture damage.

The testing regime applied this investigation also provides an indication of the homogeneity of samples. The samples undertaken in this investigation showed high homogeneity manifested a high linear regression of $R^2 > 0.9$. It is recommended that further tests using cross sections should be undertaken and be tested with other materials.

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