A new approach to laboratory testing of stabilised materials

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ABSTRACT

In 2003 there was a realisation by many industry practitioners that Australia lacked a unified approach to the testing of stabilised materials and that the current Australian Standards did not meet the stringent requirements required for road construction. Many excellent papers based on single task research projects have been published in the last ten years and these can now be used to develop a new suite of Austroads test methods for stabilised materials using various binders (ie cement, lime, bitumen and chemicals).

Using the research and performance data now available along with similar test methods, a new series of test methods based on research outcomes is currently being developed. These will be specific for road construction and represent a significant step forward in the harmonisation of Australian laboratory procedures. These test methods also give consideration to existing test moulds, mechanised elements of the test, all binder types and will be free to access from the Austroads web site.

This paper outlines how research is being used to deliver the best outcomes to designers and laboratory technicians and work towards a consistent approach to the testing of stabilised materials in Australia. The paper also includes a discussion on further research needs to further refine laboratory testing and resolves some of the uncertainty in results of the current test methods.

INTRODUCTION

The last 30 years has seen each road authority use local research outcomes to develop their own test methods and specifications for road making. The failings of new technology or pushing the design envelope on materials has led to the need for additional tests to predict field performance. With the increasing number of test methods, each new test methods relies on other test methods resulting in a complex network of test methods, each unique to the State.

There is little desire by road authorities to harmonise test methods as specifications are unique to the region. The introduction of the Australian Asphalt Paving Association (AAPA) national specification in 2001 also highlighted the problems of each region having dedicated test methods for the preparation of samples and testing regimes (Austroads, 2002a). The evolution of regional test methods is not confined to asphalt, but also applies to bound and unbound granular materials.

The Australian Stabilisation Industry Association produced its first national specification in 1999 (AustStab, 1999) and recognised one of its limitations was variable test methods from region to region. The goal of a widely accepted national specification can only be reached if the test methods are more universal. A frequent comment by industry practitioners is that the pavement material on the other side of the Murray River[1] isn't so different as to require a special test method!

The development of new and existing standards should consider the following issues:

- field sampling
- particle size distribution
- requirements for preconditioning
- sample size (mould)
- compaction and curing

[1] The Murray River forms the border between NSW and Victoria.

The debate on whether a material is bound, modified or granular was put to rest in 2004 with the introduction of the definitions in Table 1. Most practitioners now regard these limits as a sensible approach to the categorisation of stabilised materials which use these new binders.

Table 1: Stabilisation may result in unbound, modified or bound materials (Austroads, 2006).

Category of stabilisation	Indicative laboratory strength after stabilisation
Subgrade (subgrades and formations)	CBR[1] > 5%
Granular (subbase and basecourse)	40% < CBR[1] < +100%
Modified (basecourse)	0.7 MPa < UCS[2] < 1.5 MPa
Bound (basecourse)	UCS[2] > 1.5 MPa
NOTES: 1. Four day soaked Californian Bearing Ratio (CBR). 2. Unconfined Compressive Strength (UCS) values determined from test specimens stabilised and prepared using Standard compactive effort, normal curing for a minimum 28 days and 4 hour soak conditioning.	

All too often, chemical binder suppliers claim a wealth of laboratory testing from overseas countries but fail to provide adequate documentation on the preparation, mixing conditions and pavement materials tested, making it difficult to make any 'real sense' to the results. New test methods that require consistent preparation of samples will hopefully overcome the current difficulties in assessing the laboratory performance of various chemical binders.

It is recognised world-wide that laboratory testing cannot replicate field conditions. However with appropriate shift factors, laboratory testing should provide a reasonable approach to predicting field performance provided that the design equations used to determine the repetitions to terminal distress are appropriate for the stabilised material.

FIELD SAMPLING

It is well known that some sites required for insitu stabilisation have significant variability due to:

- material variations (particularly due to road widening or where natural gravels are sourced from a borrow pit)
- particle size distribution variations resulting from construction operations (such as when grid rolling has been used or overlays have been used without mixing)
- pavement thickness variations, both longitudinally and transversely
- natural subgrade variability due to topography and geomorphology
- intermittent maintenance applications, such as from patching (AustStab, 2006) and section reseals
- the use of existing subbase and subgrade materials with base materials

The selection of representative samples for testing therefore requires careful selection of the samples and an understanding of what may be achieved when using a combination of insitu materials, rather than a rigid approach of using only base materials for stabilisation. There are many examples where the subgrade material has been successfully used with the base material to form a stabilised material.

For deeplift insitu stabilisation, some of the subgrade has been successfully used and provided the subgrade material has been classified as a non-reactive clay, the use of fine material with a lime based cementitious blend should provide satisfactory performance.

When sampling, some practitioners have used profiler attachments on skidsteer machines as a way of simulating the particle size distribution of the material after mixing (see Figure 1).

Figure 1: The use of the profiler attachment to a skidsteer can provide a breakdown of the material during site investigations.

PERFORMANCE MEASURES ON BINDERS

The analysis of performance data for different binders indicates that the various binder groups do perform in different ways (Austroads, 2006). The classification developed for chemical binders is appropriate for all binder types in terms of assessing their performance (see Table 2). For example, a test carried out on dry samples of a stabilised material with a binder which behaves as a surfactant, may lead to little change in performance when compared to a sample not treated with a binder. Therefore, performance measures should match the way the material behaves in the field and be conducted under suitable test conditions, i.e. the sample should be soaked.

Table 2: Different binders react in various methods.

Characteristic	Action
Cementing	Binder hydrates when in contact with water leading to strong bonds being formed in the material
Adhesion	Act as a glue in bonding particles
Surfactant	reduce surface tension (wetting agent)
Dispersant	separate fine particles from each other
Hydrophobic	repel or reduce moisture ingress
Ionic bonding	reverse the electrostatic charge on some soil platelets
Adsorption	attract atmospheric moisture to reduce dust emission
Dilatant	dispel water when compacted under vibration

PARTICLE SIZE DISTRIBUTION (PSD)

Various road building materials are sourced from quarries, borrow pits or even recycled material from a previously stabilised pavement. It cannot always be assumed that the grading of the material is suitable for a specific binder. The limits of particle size distribution for the pavement base material shown in Figure 2 are suggested grading limits for cementitious and bituminous binders[2]. Whilst cementitious binders have been used successfully when the PSD of the untreated material is outside the distribution limits, better performance can be sought by mixing either fine (Zone B) or coarse aggregates (Zone C) to get the material PSD within the common grading limits (Zone A) for granular base layer materials.

Many practitioners consider that although the grading limits for lime are not so critical compared to a material that is well graded, they will affect the quantity of lime required to meet the desired strength or stiffness.

SAMPLE SIZE

The UCS has been used for many years as a key mix design criterion. The sample is commonly compacted to standard compactive effort to a given moisture content and cured, and then either soaked in water or tested in its unsoaked state. The material tested must have some cohesive or tensile strength to permit testing and the ratio of height to diameter will impact on the failure strength. Work by Sherwood (1993), established the variation in failure strength due to the shape and size of the sample as shown in Table 3.

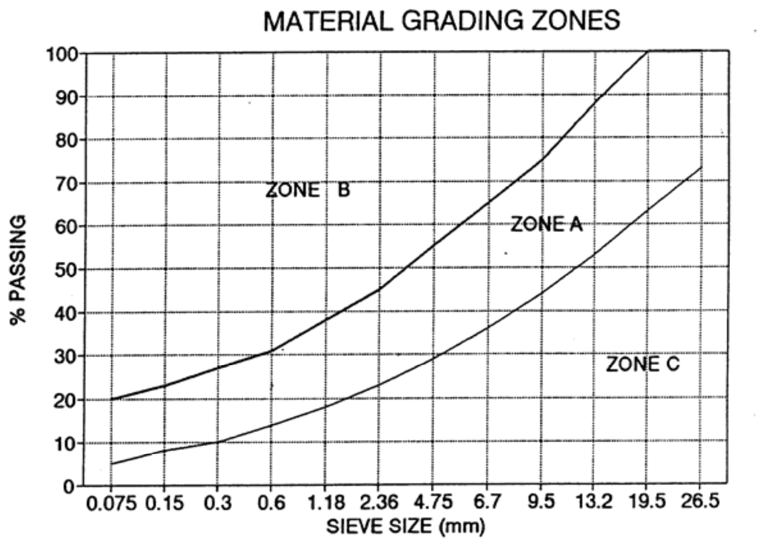

Figure 2**:** A suitable material for stabilisation starts with good particle size distribution (Austroads, 2002a).

Table 3: Correction factors for cube and cylinder sizes (Sherwood, 1993).

Specimen size and shape	**Correction factor for 150 mm cube**
150 mm cube	1.00
100 mm cube	0.96
200 x 100 mm diameter cylinder	1.25
115.5 x 105 mm diameter cylinder	1.04

In Australia, samples for stabilised materials are prepared for strength testing using moulds at 105 mm diameter by 115 mm high (or 1 to 1 ratio). Similar size cores extracted from the field, permit ready comparison of laboratory to field values. One could present a sound case that all cylindrical samples should be prepared to a height to diameter ratio of 2 to ensure the appropriate fracture lines are developed during testing of the sample. However with current Austroads design models based on work at 100 by 100 mm, the required calibration and extra cost to the laboratories to change to a new mould size, is hard to justify given

[2] These limits are intended when the pavement material is to be a bound base layer.

no major signs of distress from this test procedure and therefore not feasible in a climate of shrinking research dollars.

AS 1289.5.1.1 and AS 1289.5.2.1 are only applicable to the material passing the 37.5 mm AS sieve. Both tests use the 105 mm diameter mould, and when more than 20% material is retained on the 19.0 mm sieve, a 152 mm diameter mould is used.

AS 1289.5.4.1 may be used to make corrections for soils containing up to 20% oversized material (material retained on the 37.5 mm sieve on a wet basis). The AS 1289 series are not applicable to cohesive materials containing more than 20% retained on the 37.5 mm sieve.

AS 1289.5.5.1 is only applicable to cohesionless soils but does handle materials with maximum particle size up to 75 mm. The method is also applicable to material that contains up to 5% by mass of material passing a 0.075 mm sieve, except that silty sands with neoplastic fines may contain up to 12% passing the 0.075 mm sieve.

APPLICATION RATE

The application rate is typically based on sufficient binder being added to the pavement material such that the quantity of binder is greater than the lower bound or less than the upper bound limits specified by the test method, specification or designer. Mix design procedures detailed in the Austroads reports form a good guide for practitioners (Austroads, 2003).

In a laboratory, the percentage of binder determined for a project is calculated from the mass of the binder (kg) mixed with the pavement material in kg. The mass of pavement material on the laboratory table is of sufficient quantity to make up the samples to be tested. Even if the laboratory produces more stabilised material than what is required for the moulds, this excess material should be discarded. This forms the basis of an application rate on mass rather than volume of material. It is difficult to establish the volume of binder to be used in the laboratory as it is a function of the density of the binder when it settles into the storage container. For this reason alone, it is not used in the industry.

Once the percentage of binder (binder mass over pavement sample mass as a percentage) is established, the application rate can be determined by the following equation:

Rate (kg/m^2) = T x MDD x R/100

Where:

T = Thickness of stabilised layer (mm)
MDD = Maximum dry density of stabilised pavement material (t/m^3)
R = Application rate from the lab testing (%)

When specifying the application rate of the binder for stabilisation, use the rate by mass.

COMPACTION

Laboratory compaction methods on stabilised materials are used to:

- determine the MDD and optimum moisture content (OMC) of the untreated and treated material
- prepare laboratory test specimens for various mechanical and moisture tests
- evaluate compaction aid binders[3]

The determination of the OMC of the subgrade or pavement material is used by the contractor as a guide for additional water content required in the mixing process. In Australia, most if not all contractors will compact

[3] Chemical binders that are solely used for granular stabilisation and do not result in a bound pavement material.

stabilised materials to less than (or dry of) the OMC. Therefore, any sample preparations in the laboratory should be 'dry' of OMC rather than greater than OMC.

The compaction level for sample preparation and compliance varies across Australia. In 2001, an Austroads working group on road stabilisation agreed that the default compaction method was 100% standard compaction because:

- most of the documented research work in Australia has been based on standard compaction of samples at 100%,
- no performance data for bound stabilised materials had been presented showing that either standard or modified compaction had achieved a better performance in the field, and
- concern was raised over the long term health implications of laboratory staff when using a heavier compaction device with more repetitions.

Whilst both standard and modified compaction should achieve similar outcomes, the level of compaction in the laboratory test program should be similar to the specified compliance level in the works[4].

Some pavement materials consist of 'soft' coarse aggregates, such as sandstone and tuff, which may break under the mixing process[5], resulting in a change to the overall particle size distribution. During site investigations these 'soft' gravels should be identified and the rotor speed reduced to minimise this breakdown. Alternatively, it is common to blend the soft aggregates with harder aggregates by overlaying the new material prior to mixing the binder. The latter solution is known to provide a better outcome in western Victoria where tuff has been used in road construction since the 1960s (Yeo, 1997).

Soft aggregates can be pretreated by repeated compaction in the laboratory using Test Method T102 (RTA, 2001b), which is a way of simulating this effect in the laboratory.

For foamed bitumen stabilised materials, gyratory compaction (80 cycles) is generally adopted, however this test only determines maximum density as there is no concept of OMC. Experience to date indicates that foamed bitumen stabilised materials[6] are easier to compact at the same depth as materials stabilised with a cementitious binder. Nevertheless, it is recommended that the sample is prepared at 2 to 4% dry of the OMC to achieve good compaction of foamed bitumen stabilised materials.

ORGANIC MATERIAL

Whilst many of the existing pavement materials have little to no organics content, there has been some early distress of stabilised materials due to an unforseen organic content. The level of organic content can impact on pavement properties measured in the laboratory, such as absorption and retention of water, compressibility, UCS and shear strength. Organic matter levels are commonly highest in surface materials, such as ridge gravels, but wide variations are possible in existing pavement materials. Where there may be suspicion of organic content in the material or the test results do not appear to follow rational trends, the untreated material should be tested for organic content to AS 1141.34 or AS 1289.4.1.

CURING TECHNIQUES

The most common curing technique is to place the sample in a room operating at 23 ±2°C at a humidity of at least 90% for a period of 28 days. Table 4 notes the typical compaction and curing protocols used for various binders. Chemical binders have their own group of specially developed curing regimes, most originating from overseas laboratories (Vorobieff, 2004a).

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[4] For subgrade stabilisation standard compaction is generally adopted throughout Australia.
[5] The rotor in most modern reclaimers has the rotor operating at between 150 to 200 rpm. In addition, the bullet shaped teeth versus traditional paddles at the end of the apertures can cause soft coarse aggregates to breakdown.
[6] With or without a supplementary binder, such as lime.

Table 4: Compaction and curing regimes for preparing stabilised materials for strength testing (Vorobieff, 2004b).

Material	Binder	Compaction	Curing
Subgrade	Lime	Standard	28 days @ 23°C ± 2°C
Pavement	Lime	Standard	28 days @ 23°C ± 2°C
	Cement & cementitious	Standard[1]	28 days @ 23°C ± 2°C or 7 days @ 65°C ± 5°C[3]
	Foamed bitumen	Gyropac[2]	3 days @ 60°C[4]

Notes.
1. Austroads recommends the use of standard compaction although some jurisdictions still use modified compaction (Austroads, 2002b).
2. Qld Dept. of Main Roads (QDMR) prefers to use Marshall compaction at 50 blows (Ramanujam, 2000).
3. VicRoads and some local government engineers in NSW and QLD specify 7 days @ 23°C ± 2°C for UCS
4. QDMR prefers 3 days @ 40°C (Ramanujam, 2004)

Many practitioners consider the 28-day test too long a duration for either the mix design or the evaluation of alterative binders within a tender period. There has therefore been a trend to shorten the curing period to 7 or 3 days at 65°C or 60°C for cementitious and bituminous binders respectively. This allows the designer to assess the results after 7 days and still have time for further testing to explore other binder alternatives if required. Roads & Traffic Authority (RTA) has conducted research in the early 2000s on water bath and oven curing techniques but could not draw a conclusion without more detailed follow up research (Walter, 2005).

Better accelerated testing is required for all binder types without compromising the laboratory performance outcomes. Consideration should be given where the stabilised material develops a much higher strength that that can be achieved from ambient curing temperatures.

Some chemical binder suppliers have come up with their own unique curing regimes which can create unusual circumstances/conditions for the chemical reaction of the binder with the pavement material and which is highly unlikely to simulate field conditions. The curing regime should also match the end condition of the stabilised material, whether the material behaves as a granular, modified or bound material. There is an erroneous but common belief by many practitioners that the curing period is only critical when the material is bound.

At this stage, the author is unaware of any binder being cured to cyclic temperature conditions and designers should therefore be wary of binder suppliers requesting cyclic curing conditions for their specific binder.

PRECONDITIONING SAMPLES

Preconditioning CBR samples prior to the test for subgrade testing has been common place for many years. The preconditioning usually takes place with either a 4 or 10-day soaking of the sample. The duration of the soaking is a factor of the moisture conditions of the subgrade during the pavement life. The longer the soaking duration, the greater the potential to record a lower CBR value in the test.

RTA has always preconditioned its UCS samples by soaking them in a bath for 4 hours prior to the test taking place (RTA, 2000). However this practice is not always adopted in other regions of Australia. For foamed bitumen samples, the resilient modulus is tested with the sample dry and 'wet' (Austroads, 2002b). The 'wet' phase of the test is a preconditioning of the sample to identify the modulus of the sample under very moist conditions.

No other forms of preconditioning are known other than soaking the sample prior to testing.

It is also important to precondition the samples when evaluating their strength or modulus, and industry supports this approach for future test methods.

TEST METHOD APPROACH

There was much debate a few years ago about whether a test method should contain the sample preparation and the mechanical test or whether for convenience, the test method should be separated. Another dilemma was where to detail any preconditioning of the cured sample (if required) within the test method. Many of the current test methods combine the sample preparation and the test, as this has been the accepted traditional approach. For example, RTA test method T131 (RTA, 2000) includes details on:

- binder source
- mixing
- compaction methods
- curing
- test preconditioning
- UCS test
- reporting

If every test method required the sample preparation and test details, it would be an increasingly large and unwieldy document if it also allowed for several binder types. It therefore seems more rational to separate the preparation and testing from the test method. Figure 3 outlines a proposed testing method protocol for all binder types. If this approach was taken, it would allow a range of binders to be cured to a set regimen independent of the test method[7].

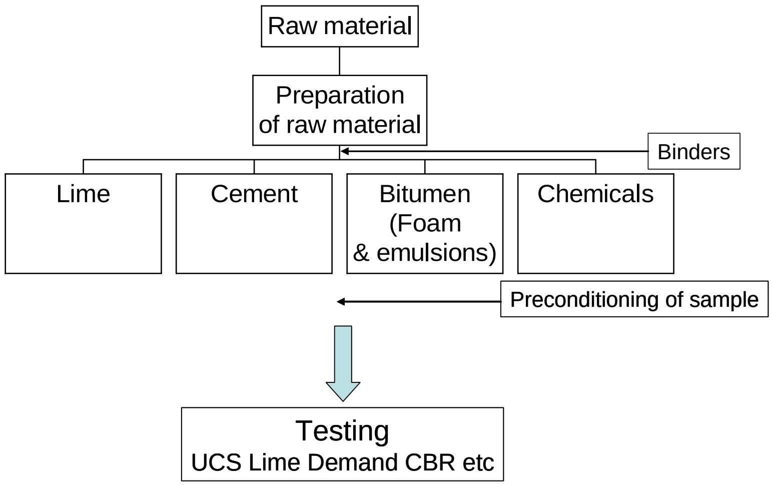

Figure 3: A new approach to test methods for stabilised materials.

It is anticipated that a series of proposed Austroads Test Methods will expand on the existing Australian Standards and State-based test methods. At this stage, the way forward with national test methods for roadworks, is to select appropriate categories of tests. The following list of test methods is currently being developed:

- Stabilised materials - Preparation of samples with cementitious binders
- Stabilised materials - Preparation of samples with lime for pavement layers
- Stabilised materials - Preparation of samples with lime for subgrade materials
- Stabilised materials - Preparation of samples with foamed bituminous binders for pavement layers
- Stabilised materials - Preparation of samples with bitumen emulsion binders for pavement layers

[7] The size of the sample for some tests would have to be taken into consideration.

- Stabilised materials - Preparation of samples with chemical binders for pavement layers
- Stabilised materials - Preparation of slab samples
- Determination of unconfined compressive strength
- Determination of the strength of stabilised materials - Indirect tensile method
- Determination of the resilient modulus and fatigue properties of stabilised materials – Indirect tensile method
- Determination of working time of stabilised bound materials
- Determination of the lime demand for subgrade materials
- Determination of capillary rise
- Determination of the vertical saturation of pavement materials
- Determination of the drying shrinkage
- Dry coring of stabilised materials
- Wet coring of stabilised materials

These test methods are not aimed at setting guidelines for target strengths, but delivering a consistent test method to allow the interpretation of performance data to be compared to laboratory design values. Individual specifications, such as 307 (VicRoads, 2005), provide guidance for determining the appropriate binder and application rate.

The two test methods on strength, and resilient modulus and fatigue properties of stabilised materials were developed during an Austroads project to improve strength data from modified and lightly bound materials, and seek a replacement to the traditional UCS and elastic modulus relationships found in the 1992 Austroads pavement design guide (Foley, 2001). The goal of the project leading to the test method was to test samples using a similar approach to asphalt and develop a protocol such that the modulus and fatigue characteristics could be established in the laboratory and a transfer function be used with a layered elastic analysis to lead to a predicted design life of the stabilised layer. Further trials of this project have been completed in Australia and it is hoped that the Austroads test methods will be completed in the near future.

As a consequence of the above project there was no recommended approach to the preparation of samples and this led practitioners to assist with the development of a new suite of sample preparation methods for stabilised layers.

STRENGTH VERSUS MOISTURE TESTS

Laboratory tests for pavement materials may be categorised into mechanical, durability and moisture tests, as summarised in Table 5. Since strength and moisture performance are closely related to field performance, all stabilised materials should be subject to a combination of these tests to establish the appropriate binder and application rate.

DEGREE OF UNCERTAINTY

A recent study by ARRB Research Group had established that the reproducibility of resilient modulus testing using AS 2891.13.1 was about 40% (Alderson, 2005). Such a high value can be accepted by assuming lower bound criteria otherwise care should be taken in specifying tolerances in a contract QA specification.

The accuracy or degree of uncertainty of a test method has been a difficult issue for sometime. The ISO Guide to the Expression of Uncertainty in Measurement notes the following sources of uncertainty:

- incomplete definition of the measurand
- imperfect realisation of the definition of the measurand
- nonrepresentative sampling - the sample measured may not represent the defined measurand
- inadequate knowledge of the effects of environmental conditions on the measurement or imperfect measurement of environmental conditions
- user bias in reading analogue instruments
- finite instrument resolution or discrimination threshold
- inexact values of measurement standards and reference materials

- inexact values of constants and other parameters obtained from external sources and used in the data-reduction algorithm;
- approximations and assumptions incorporated in the measurement method and procedure
- variations in repeated observations of the measurand under apparently identical conditions.

Table 5: Tests that may be used on stabilised materials.
NOTE: Does not include SRA test methods.

Test	Test Method
Mechanical	
CBR	AS 1289.6.1.1
Unconfined compressive strength	AS 1141.51
Resilient modulus & deformation	AS 2891.13.1
Moisture	
Capillary rise and swell	AS 1141.53
Permeability	AS 1289.6.7.1
Vertical saturation	TSA[B]
Durability	
Erosion[A]	T133[C]

Notes:
A Not common test
B. Test method in draft format and not published.
C. RTA Test method – erosion by brushing (RTA, 2001a)

Some moisture tests are carried out as a relative comparison to treatment options rather than using an absolute limit. In this instance, the degree of uncertainty in test methods relying on relative measures is unlikely to be critical compared to test methods that results in an absolute number. It is hoped that many of the developed Austroads test methods can provide a real measure of the degree of uncertainty in the test methods.

FURTHER WORK

The paper has highlighted the following key areas for future work on these proposed test methods:

- Accelerated curing – reduce the curing time to 3 to 7 days without compromising the reaction of the binder and pavement material
- Performance data – continue to correlate the performance data with laboratory mix design test results
- Degree of uncertainty – establish the accuracy of all test methods and include appropriate compliance measures that are outside the degree of uncertainty.

Whilst the points in Table 4 are applicable for most binders, for chemical binders, further work is needed to develop a suitable design model to complement the proposed test procedure. Although many trials have been conducted on chemical binders, the laboratory testing has not always been consistent enough to make national recommendations on the performance of the stabilised material.

CONCLUSION

A benefit to having consistent test procedures will be that road authorities and industry will get closer to a series of nationwide specifications, rather than the current situation of a myriad of special requirements across different regions which may not ultimately result in better outcomes.

If research funding is going to become further limited in the future, it is essential that laboratory protocols are consistent across regions to ensure that all learnings are built from a common base.

The belief by some practitioners that modified compaction of samples will provide a better performing bound stabilised pavement should be replaced with a requirement for all research testing to be conducted at standard compaction.

New or imported chemical binders should also be tested following a consistent approach, and AustStab recommends this initiative.

Finally, laboratory testing is a simple method for predicting the future performance of a stabilised material. The quality of the input materials and binders will provide a much better prediction of performance. Practitioners cutting corners to save money on the site investigation do so at the expense of the best outcomes for the rehabilitation process. Insitu stabilisation as a process, should not be wrongly implicated when things go wrong if no or incorrect laboratory testing has been carried out.

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