AP-R434-13

AUSTROADS RESEARCH REPORT

Review of Definition of Modified Granular Materials and Bound Materials



Austroads

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Published May 2013

ISBN 978-1-921991-99-8

Austroads Project No. TT1358

Austroads Publication No. AP-R434-13

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Review of Definition of Modified Granular Materials and Bound Materials

Austroads
Sydney 2013

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- promote improved practice and capability by road agencies.
- promote consistency in road and road agency operations.

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SUMMARY

The Austroads *Guide to Pavement Technology Part 2: Pavement Structural Design* classifies pavement materials into essentially five categories according to their fundamental behaviour under the effects of applied loadings: unbound granular materials; modified granular materials; cemented materials; asphalt; and concrete.

In the Austroads Guide thickness design procedures, modified granular materials are assumed to have insufficient tensile strength to fatigue crack under repeated load applications; they are considered to behave as unbound granular materials.

In the Austroads *Guide to Pavement Technology Part 4D: Stabilised Materials*, guidance is provided on the 28-day Unconfined Compressive Strength (UCS) values to differentiate the tensile capacity of modified materials from that of bound materials:

- modified materials: 0.7 MPa < UCS < 1.5 MPa
- bound materials: UCS greater than 1.5 MPa.

Concern has been expressed as to whether a UCS of 1.5 MPa is an appropriate division between modified and bound materials given the significantly different pavement structures depending on the material classification. This report explains the origins of these strength criteria and recommends changes to the *Guide to Pavement Technology Part 4D: Stabilised Materials (2006)* and *Guide to Pavement Technology Part 2: Pavement Structural Design (2012).*

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1 INTRODUCTION

The *Guide to Pavement Technology Part 2: Pavement Structural Design* (Austroads 2012) classifies pavement materials into essentially five categories according to their fundamental behaviour under applied loadings:

- unbound granular materials
- modified granular materials
- cemented materials
- asphalt
- concrete.

The Austroads Pavement Task Force expressed a need for a review of the definition of modified granular materials. According to Austroads Guide Part 2 thickness design procedures, modified materials are assumed to have insufficient tensile strength to fatigue crack under repeated load applications: they are considered to behave as unbound granular materials.

In the *Guide to Pavement Technology Part 4D: Stabilised Materials* (Austroads 2006), guidance is provided on the 28-day Unconfined Compressive Strength (UCS) values to differentiate the tensile capacity modified materials compared with bound materials:

- modified materials: 0.7 MPa < UCS < 1.5 MPa
- bound materials: UCS greater than 1.5 MPa.

These material definitions differ from those in the previous *Guide to Stabilisation in Roadworks* (NAASRA 1970, NAASRA 1986, Austroads 1998).

Accordingly this report reviews the origin of the various definitions of modified granular materials and summarises research findings and recommends changes to the Austroads *Guide to Pavement Technology*. This research was undertaken as part of Austroads technical research project *TT1358 Strategic Review of Pavement Design Practice*.

2 REVIEW OF CEMENT AND CEMENTITIOUS STABILISED MATERIALS DEFINITIONS

2.1 1970 NAASRA Guide to Stabilisation

In 1970 the National Association of Australian State Road Authorities (NAASRA) published the *Guide to Stabilisation on Roadworks* (update to metric version in 1973). Cement treated materials were divided into two general types:

- Cement modification in which cement, up to about 3% by weight of soil, is added. This small amount of additive results in a pavement which was considered to behave as a 'normal flexible' pavement.
- Cement stabilisation in which a sufficient quantity of cement is added to produce a material having significant tensile strength when compacted and cured. A cement content of about 10% is generally regarded as the upper limit for economic use in roadworks.

In terms of strength criteria, values for California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) were provided but only for stabilised base materials. To be suitable as cement stabilised base a minimum 7-day UCS of about 1000 kPa (150 psi) was required, at modified maximum dry density and optimum moisture content. However to limit the incidence of undesirable crack patterns, an upper UCS limit of 1700 kPa (250 psi) was used.

Note that:

1. Strength criteria differentiating cement modified materials from cement stabilised materials was not provided.
2. In the 1970 Guide, the maximum 7-day UCS requirement of 1700 kPa (250 psi) was the same as the minimum UCS requirement in the United Kingdom for durability (Ingles & Metcalf 1972).

2.2 1986 NAASRA Guide to Stabilisation

In 1978, a NAASRA/ARRB Workshop on Stabilisation (NAASRA 1978) was held with the view of discussing revision of the 1970 Guide. This eventually led to the NAASRA *Guide to Stabilisation in Roadworks* (NAASRA 1986).

The two categories of cement treated materials were revised as follows:

- Cement modified materials – they are used and evaluated in the same manner as conventional unbound flexible pavement materials. Cement modified materials were assumed to have a very closely spaced network of fine, benign cracks and not to develop the open systematic network of widely spaced open cracks of some bound materials.
- Cement 'bound' materials – these have a sufficiently enhanced elastic modulus and tensile strength to have a practical application in stiffening the pavement.

In terms of strength criteria of modified and bound materials, the 1986 Guide stated:

> There are no established criteria for demarcation between 'modified' and 'bound', although arbitrary limits of 80 kPa (Indirect Tension) or 800 kPa (Unconfined Compressive Strength) after 7 days moist curing have been suggested. These levels of strength may have some justification in respect of base (as an attempt to limit stiffness and shrinkage cracking), but they are not necessarily appropriate for other courses. The criteria apply to reasonably graded materials with maximum particle size of 20 mm or more.

> Bound materials have high moduli in the range 2000 to 20 000 MPa and consequently their use in some situations can lead to reduced pavement thickness. Cement bound products sometimes exhibit a regular pattern of widely spaced cracks, caused primarily by the combination of high tensile strength, hydration shrinkage, and subgrade constraint. Bound materials would usually have tensile strengths much greater than 80 kPa (determined at Optimum Moisture Content and Maximum Dry Density (Standard Compaction) moist cured 7 days).

At the Workshop, Dr Robin Dunlop of the Ministry of Works and Development New Zealand presented a keynote address reviewing the design and performance of roads incorporating lime and cement stabilised pavement layers. Dunlop recommended that cemented soil (cement bound material) should have a tensile strength of greater than 80 kPa after seven days curing at 20 °C. It seems this 80 kPa tensile strength limit influenced the 80 kPa indirect tension strength limit in the 1986 Guide. Note that the indirect tensile strength is about a factor of 1.5 greater than the direct tensile strength (CSIR 1986). Hence the 1986 Guide 80 kPa indirect tension limit is equivalent to about 50 kPa tensile strength – significantly lower than Dunlop's minimum for cement bound material. It is interesting to note that Dunlop's paper was also instrumental in South Africa's adoption of 750 kPa upper limit for 7-day UCS for modified soil in the same year (CSIR 1986).

2.3 1998 Austroads Guide to Stabilisation in Roadworks

When the Guide was revised in 1998, further changes were made to the categories of cementitious stabilised materials. Two broad categories (Table 2.1) of cementitiously stabilised materials were adopted:

- Modified materials – where only small amounts of cement are used and the resulting materials may be characterised as an unbound material for pavement design purposes.
- Bound materials – where the stiffness and tensile strength of the materials are sufficiently enhanced by the addition of cement to have a practical application in stiffening the pavement. These bound materials are often further categorised as lightly-bound and heavily-bound.

Table 2.1: Typical properties of modified, lightly-bound and heavily-bound materials

Material type	Layer thickness (mm)	Design UCS at 28 days (MPa)	Design modulus (MPa)
Modified	Applicable for any thickness	≤ 1.0	≤ 1 500
Lightly-bound	Generally < = 250 mm	1–4	1 500–2 000
Heavily-bound	Generally > 250 mm	≥ 4	2 000–20 000

Note: For slow setting binder the 28 day test results will be less than the values shown but will continue to increase in the field for at least 6 to 12 months.

Source: Austroads (1998).

The 1998 *Guide to Stabilisation in Roadworks* also included the following text, similar to the 1986 NAASRA Guide:

> There are no firmly established criteria to differentiate between modified and bound materials. However, for reasonably well-graded base materials values of 80 kPa for indirect tensile, 0.8 MPa for UCS (7 days moist curing) or a resilient modulus value of 700–1500 MPa may be useful as a guide.

While the strength criteria for cement modified material was reasonably consistent with the 1986 Guide, the inclusion of advice on typical design modulus (700–1500 MPa) well in excess of those for unbound material, resulted in inconsistency with the text of the 1992 *Austroads Guide to the Structural Design of Road Pavements* which stated that:

> Modified granular materials are granular materials to which small amounts of stabilising agents have been added to improve their performance (e.g. by reducing plasticity) without causing a significant increase in structure stiffness.

As the typical modified material design moduli in the 1998 *Guide to Stabilisation in Roadworks* were two to three times the values for unbound granular materials in the 1992 *Guide to the Structural Design of Road Pavements*, the use of modified materials resulted in a significant increase in pavement stiffness.

The 1998 *Guide to Stabilisation in Roadworks* stated that bound materials have moduli typically in the range 2000 to 20 000 MPa, which is consistent with the 1986 NAASRA Guide and reasonably consistent with the 1992 *Guide to the Structural Design of Road Pavements*. However, the inclusion of the lightly-bound material category in the 1998 Guide was new and the design modulus values below 2000 MPa were not consistent with the 1992 *Guide to the Structural Design of Road Pavements* which has a minimum presumptive modulus of 2000 MPa for bound materials. It seems that the inclusion of the lightly-bound category may have been due to fact that RTA NSW classified materials with a design modulus of 2000 MPa as lightly-bound whereas materials with a design modulus of 5000 MPa were classed as heavily-bound (RTA NSW 1997).

2.4 Austroads Guide to Pavement Technology

Austroads (2002) developed mix design procedures as part of Austroads project *N.T & E 9910 Improved Characterisation and Specification of Stabilised Quarried and Recycled Materials* in conjunction with technologists from industry and road agencies. It was suggested that the UCS criteria for bound materials compacted to 100% Standard Maximum Dry Density should be revised as follows:

- Modified materials: a maximum 7-day UCS of 1.0 MPa (for GP and GB cementitious binders), but where 'slow-setting' binders are used this limiting value is applied at 28 days curing. Note that this UCS was higher than the value of 0.8 MPa adopted in the 1998 Guide and implied a maximum 28-day UCS of about 1.3 to 1.4 MPa.
- Lightly-bound materials: for materials stabilised with GB or GP cement, a minimum 7-day UCS of 1.5–2.0 MPa. The equivalent 28-day UCS values are about 2.5–3.0 MPa.
- Heavily-bound materials: for materials stabilised with GB or GP cement, a minimum 28-day UCS of 3–4 MPa for GP or GB cement.

More recently, the definitions of modified and bound materials have changed with the publication of the *Guide to Pavement Technology: Part 4D Stabilised Materials* (Austroads 2006) and the *Guide to Pavement Technology Part 2: Pavement Structural Design* (Austroads 2012). The following changes were made to the criteria for modified and bound materials (see Table 3.1 of Part 4D shown as Table 2.2 in this report):

- The division between lightly-bound and heavily-bound materials was removed from Part 4D.
- The maximum UCS value for modified base materials was increased from 1 MPa in the 1998 Guide to 1.5 MPa in the 2006 Guide. In addition, this value is higher than the 1.3–1.4 MPa value proposed by Austroads (2002).
- The minimum UCS of 1.5 MPa for bound base materials, whilst within the range of the 1998 Guide values, was considerably lower than the value of 2.5–3.0 MPa proposed by Austroads (2002).
- The design moduli were removed from Part 4D and Part 2 was amended to state that a maximum design modulus of 1000 MPa is normally adopted for modified materials.

Table 2.2: Types of stabilisation

Category of stabilisation	Indicative laboratory strength after stabilisation	Common binders adopted	Anticipated performance attributes
Subgrade	CBR(1) > 5% (subgrades and formations)	▪ Addition of lime. ▪ Addition of chemical binder.	▪ Improved subgrade stiffness. ▪ Improved shear strength. ▪ Reduced heave and shrinkage.
Granular	40% < CBR(1) < + 100% (subbase and basecourse)	▪ Blending other granular materials which are classified as binders in the context of this Guide.	▪ Improved pavement stiffness. ▪ Improved shear strength. ▪ Improved resistance to aggregate breakdown.
Modified	0.7 MPa < UCS(2) < 1.5 MPa (basecourse)	▪ Addition of small quantities of cementitious binder. ▪ Addition of lime. ▪ Addition of chemical binder.	▪ Improved pavement stiffness. ▪ Improved shear strength. ▪ Reduced moisture sensitivity i.e. loss of strength due to increasing moisture content. ▪ At low binder contents can be subject to erosion where cracking is present.
Bound	UCS(2) > 1.5 MPa (basecourse)	▪ Addition of greater quantities of cementitious binder. ▪ Addition of a combination of cementitious and bituminous binders.	▪ Increased pavement stiffness to provide tensile resistance. ▪ Some binders introduce transverse shrinkage cracking. ▪ At low binder contents can be subject to erosion where cracking is present.

1 Four day soaked CBR.
2 Values determined from test specimens stabilised with GP cement and prepared using standard compactive effort, normal curing for a minimum 28 days and four hour soak conditioning.

Source: Austroads (2006).

2.5 Discussion

2.5.1 Review of Current Road Agency Specification for Strength of Cement Bound Materials Definitions

To assist in the review of the definition of cement bound materials, it was considered instructive to review the minimum UCS strength of materials that is currently accepted by state road agencies.

Table 2.3 summarises the minimum UCS requirements for cementitious bound materials. It is noted that the Category 2 Queensland TMR material has the lowest minimum UCS of 2 MPa at seven days, which equates to about 2.6 MPa at 28 days. Given the TMR specification requires the use of 25% fly ash blend the long-term increase in strength will be greater than for GP cement. By comparison with these specifications, the minimum value of 1.5 MPa given in Part 4D of the *Guide to Pavement Technology* (Table 2.2) is substantially lower.

It was also noted that using Equation 6.3 of the *Guide to Pavement Technology* Part 2, materials with a UCS of 1.5 MPa have a calculated design modulus less than 2000 MPa. As Part 2 does not provide a fatigue relationship for cemented materials with a design modulus less than 2000 MPa, the fatigue life of a pavement which include bound cemented materials with UCS less than 2 MPa cannot be determined unless its modulus is measured and found to be at least 2000 MPa.

In summary, the requirement in Part 4D that the UCS ≥ 1.5 MPa is well below the minimum UCS requirements in state road agency standard specifications. To reduce the risk that materials will be manufactured without the assumed properties of bound materials, it is recommended that the minimum 28-day UCS at 100% Standard Maximum Dry Density be increased to 2 MPa.

Table 2.3: Summary of minimum strength requirements of cementitious bound materials

Road agency	7-day UCS	28-day UCS	Test density
Roads and Maritime Services New South Wales (RMS)	GP cement: 4 MPa Slow setting(1): 3 MPa	–	100% standard MDD
Roads Corporation, Victoria (VicRoads)	GP cement: 5 MPa GB cement: 3.5 MPa Supplementary cementitious blends: 3 MPa	–	100% modified MDD
Department of Transport and Main Roads Queensland (Queensland TMR)(2)	Category 1: 3 MPa Category 2: 2 MPa	–	100% standard MDD unsoaked
Department of Planning, Transport, and Infrastructure, South Australia (DPTI)	–	GB cement: 4 MPa	96% modified MDD

1 3 MPa limit applies provided at least 1 MPa strength gain between 7 and 28 days.
2 The minimum 7-day UCS shown is based on a cementitious blend of 75% cement and 25% fly ash. Where another combination of stabilising agent is to be used, the minimum 7-day UCS is to be determined through laboratory testing to ensure a one year UCS equivalent to the 75/25 cement/fly ash blend.

2.5.2 Definition of Maximum Strength of Cementitiously Modified Materials

Part 2 of the *Guide to Pavement Technology* provides mechanistic thickness design procedures for sealed flexible pavements. Three underlying assumptions of the procedures are that:

- subgrade, unbound granular and modified granular materials have no tensile strength and hence do not develop tensile strain under load
- materials without tensile strength will not fatigue crack
- modified granular materials behave in a similar manner to unbound granular materials.

Based on these assumptions, maximum allowable tensile strength of modified materials would be zero and hence the maximum UCS would also be zero.

However, even though subgrade and unbound granular materials do not fatigue crack, a number of researchers have measured non-zero tensile strengths of these materials.

Wallace (1998) measured the tensile strength of dry-back unbound granular materials to be about 60 kPa. This corresponds to about 90 kPa indirect tensile strength, similar to the 80 kPa arbitrary upper limit for cement modified material in the 1986 NAASRA *Guide to Stabilisation in Roadworks*.

Nahlawi et al. (2004) measured the tensile strength of clayey soil and cement stabilised crushed rock. The tensile strength of the clay decreased with increasing moisture content: at optimum moisture content of 27.5% the tensile strength was about 80 kPa, whereas at 40% moisture content the tensile strength had decreased to about 30 kPa. The tensile strengths of the 3% cement stabilised crushed rock were considerably higher, 530–750 kPa.

Accordingly, as an interim measure pending further research, it is considered modified material should have a maximum tensile strength of 100 kPa. In terms of more commonly used characterisation tests, this equates to:

- a maximum indirect tensile strength of 150 kPa, assuming indirect tensile strength is 1.5 times tensile strength (CSIR 1986)
- a maximum UCS of 1000–1200 kPa, assuming UCS is 8 to 10 times the ITS.

As these are long-term strength values, they need to be reduced to equivalent 28-day strength maximum values. Considering this and the uncertainties in the origin of this definition, it is recommended that cementitiously modified materials be defined as having a indicative maximum 28-day UCS of 1 MPa at 100% Standard Maximum Dry Density. This is consistent with NAASRA and Austroads publications prior to Part 4D.

Nevertheless it needs to be recognised that this indicative strength is a guide only and does not necessarily ensure all modified materials will not be susceptible to fatigue cracking. For instance, Main Roads Western Australia experience with hydrated cement treated crushed rock base (HCTCRB), indicates the 28-day UCS of 1 MPa at 100% Standard Maximum Dry Density does not ensure that this material is not susceptible to fatigue. Conversely, some road agencies (i.e. VicRoads, TMR) currently have UCS requirements for modified materials that convert to 28-day UCS values at 100% Standard Maximum Dry Density of about 1.5 MPa. Generally these specifications are used for in situ stabilisation works which are commonly constructed under traffic. Such early-life trafficking is likely to produce micro-cracking of the modified material and hence reducing the risk of the material becoming bound.

Further research is required to improve the characterisation of modified materials to reduce the risk of these materials being susceptible to fatigue.

3 REVIEW OF LIME STABILISED MATERIAL DEFINITIONS

3.1 1970 NAASRA Guide to Stabilisation

In 1970 (update to metric version in 1973) the National Association of Australian State Road Authorities (NAASRA) published the *Guide to Stabilisation on Roadworks*. Lime treated materials were divided into two general types:

- Lime modification which included the upgrading of either fine grained soils or granular base materials with small amounts of lime (i.e. 0.5–3% by weight). In the case of granular base materials, 0.5–3% may be used for plasticity index reduction. With heavy clay soils, 2–3% lime is a common modification treatment.
- Lime stabilisation included the treatment of fine grained subgrade or select fill for use as subbase, with 3–6% lime. In addition, clay-gravels may be treated with 2–4% lime to provide a base quality material.

For mix design purposes, the 1970 Guide mix design UCS criteria required a minimum 7-day UCS of 700 kPa (100 psi) for lime stabilised base materials. However, UCS criteria were not provided for lime modified materials or lime stabilised subgrade, select fill or subbases.

3.2 1986 NAASRA Guide to Stabilisation

When the Guide was revised in 1986, the text emphasised the use of lime to modify clays, plastic sands and plastic gravels rather than the use of high lime contents to produce bound materials.

The 1986 Guide stated that the test methods used to differentiate lime modified from lime bound materials were similar to those for cement stabilised materials:

> There are no established criteria for demarcation between ‘modified’ and ‘bound’, although arbitrary limits of 80 kPa (Indirect Tension) or 800 kPa (Unconfined Compressive Strength) after 7 days moist curing have been suggested. These levels of strength may have some justification in respect of base (as an attempt to limit stiffness and shrinkage cracking), but they are not necessarily appropriate for other courses. The criteria apply to reasonably graded materials with maximum particle size of 20 mm or more.

3.3 1998 Austroads Guide to Stabilisation

There was a significant change in the philosophy of establishing the lime content with the publication of the 1998 Guide. There was less discussion about producing a lime modified or lime bound material: instead it recommended selecting a lime content such that properties were achieved in the long-term, for instance:

> The initial lime demand of the soil should be assessed for soil to be stabilised with lime to ensure that adequate lime is added to achieve an excess after initial reactions with the soil are completed so that the stabilised design properties are achieved in the long term.

For lime stabilisation, the use of pH testing together with 28-day UCS testing was recommended to establish the optimum line content of a material. The optimum lime content was obtaining by plotting the UCS versus lime content.

No mention was made on the strength (e.g. UCS) to produce a lime modified material.

3.4 Austroads Guide to Pavement Technology

More recently the definitions of modified and bound materials have changed with the publication of the *Guide to Pavement Technology Part 4D: Stabilised Materials* (Austroads 2006) and the *Guide to Pavement Technology Part 2: Pavement Structural Design* (Austroads 2012).

In addition to the 1998 Guide guidance on establishing the lime content for long-term strength using pH testing, a mix design process was provided in which the required lime content can be determined in two ways:

- In Method A the lime content is determined based on the desired 28-day UCS. A suggested UCS for subgrade stabilisation is between 0.5 MPa < UCS < 1.0 MPa, whilst for modification of pavement layers, the suggested UCS is 0.5 < UCS < 1.5 MPa.
- In Method B the lime content is determined based on CBR. This is used primarily for subgrade materials where it is suggested that a minimum CBR of 5% is used.

The UCS requirements for pavement layers are the same as those recommended in Part 4D for cement stabilised materials. It is noteworthy that Austroads (2002), in agreement with the 1986 NAASRA Guide, suggested that the same UCS strength requirements can be used for lime modified and lime bound materials as well as cement stabilised materials (Section 2.4).

3.5 Recommended Changes to Austroads Guide to Pavement Technology

If the UCS requirements for cement modified materials are changed as recommended in this report, it is recommended that the maximum UCS value for lime modified pavement materials be amended.

Note that to ensure long-term strength gains of lime stabilised subgrades, some road agencies target a UCS of 1.5 MPa. Hence the above-mentioned maximum UCS for modified pavement materials is not necessarily applicable to treated subgrades.

4 REVIEW OF BITUMINOUS STABILISED MATERIAL DEFINITIONS

In the 1970 NAASRA Guide, the tentative UCS criterion for mix design purposes was a minimum 7-day UCS of 1000 kPa (150 psi) for bituminous stabilised base materials. Typically residual bitumen contents in use were 2–5%, nevertheless the material was considered not to be bitumen-bound and required 'protection for traffic abrasion by some form of bituminous surfacing'.

The above UCS design criterion was deleted in the 1986 NAASRA Guide and the mix design process simply mentioned that a strength test is usually included:

> The design of bituminous stabilised mixtures does not follow any well established procedures. Many different criteria for strength (both dry and soaked) and water absorption have been suggested.

Nevertheless, the 1986 Guide stated that the amount of binder in common use was considerably less than necessary for bitumen-bound pavement material.

When the 1998 Austroads Guide was published, a significant change in philosophy occurred as, for the purpose of pavement design, bituminous stabilised materials were classified to be either unbound, modified or bound materials depending on the type and quantity of binder. However, the Guide did not provide any criteria for classification. Typical residual binder contents were still 2–5%. No mention was made of UCS requirements for bituminous stabilised materials, although for bitumen emulsion stabilisation a minimum indirect tensile strength of 100 kPa was recommended, which implied a minimum UCS of about 1 MPa.

Austroads (2002) developed mix design procedures as part of Austroads project *N.T&E 9910 Improved Characterisation and Specification of Stabilised Quarried and Recycled Materials* in conjunction with technologists from industry and road agencies. In providing guidance on bituminous modified and bound materials, the same UCS strength requirements were adopted as for cement stabilised materials (Section 2.4). The report provided no information in support of this assumption.

With the publication of the *Guide to Pavement Technology Part 4D*: *Stabilised Materials* in 2006 yet another shift in philosophy of bituminous stabilised materials occurred. No mention was made of a mix design process for bituminous modified materials, but for bituminously bound materials a minimum indirect tensile modulus of 700 MPa was required. Although not clear from Section 3.3 of Part 4D, it seems that the UCS requirements (Table 2.2) are not applicable to bituminous stabilised materials. Amendment of Part 4D is therefore required to clarify this issue.

5 CONCLUSIONS AND RECOMMENDATIONS

The origins of the current UCS strength criteria that differentiate modified granular materials from bound materials were investigated. Based on the above review, the following changes to the UCS design criteria are recommended for the Austroads *Guide to Pavement Technology Part 4D: Stabilised Materials* and *Part 2 Pavement Structural Design*:

- It is considered that the indicative maximum value of 1 MPa listed in the 1998 Austroads *Guide to Stabilisation in Roadworks* is more appropriate than 1.5 MPa in Part 4D. This proposed reduction in the maximum UCS value will reduce the risk that modified materials will have tensile capacity and hence may fatigue crack. For pavements which are opened to traffic soon after construction, load-induced micro-cracking may reduce the risk of fatigue cracking.
- In relation to the indicative value of 1 MPa for modified materials, a note will be added to the table in Part 4D mentioning that Main Roads Western Australia's experience is that to use this 1 MPa limit, Main Roads practice is to test at UCS specimens at their in-service density using Modified Compaction with 4 hours soaking before testing.
- In terms of the minimum UCS requirements for cementitiously bound materials, there is considerable doubt about whether cementitious materials with UCS greater than 1.5 and less than 2 MPa should be characterised as modified or bound. Using Equation 6.3 of the *Guide to Pavement Technology Part 2: Pavement Structural Design* (Austroads 2012), these materials have design moduli of 1500–2500 MPa. However, Part 2 does not provide procedures to predict the fatigue life of materials with a modulus less than 2000 MPa. In addition, none of the state road agencies standard specifications consider a material with a UCS less than 2 MPa to be a bound material. For these reasons it is recommended that Part 4D be changed to provide a minimum UCS 2 MPa for bound materials rather than the current value of 1.5 MPa.
- While soaking in water is often used prior to compression testing to determine durability and loss of strength under saturated conditions, in determining the UCS value of cement modified materials it is non-conservative to do so. It is recommended that cement modified materials be compacted at optimum moisture content to 100% Standard Maximum Dry Density, moist cured for 28 days and tested for UCS without soaking. Conversely, cement bound materials should be soaked prior to testing.
- In some cases the most appropriate modification may be to produce a cement modified material with negligible tensile strength. Therefore, the requirement for a minimum UCS value (0.7 MPa) for cement modified materials should be deleted, except where a pavement design accounts for an increase in stiffness of the modified materials.
- As modified and bound materials are used for both base and subbase, it is recommended that Table 3.1 of Part 4D be changed to remove the statement that the UCS limits only apply to basecourse.
- If the UCS values for cement stabilised materials are changed, it is recommended that the values for lime stabilised pavement materials should also be amended to provide consistency. Note that to ensure long-term strength gains of lime treated subgrades, some road agencies target a UCS of 1.5 MPa. Hence the above-mentioned maximum UCS for modified pavement materials is not necessarily applicable to treated subgrades.
- Table 3.1 of Part 4D implies that the UCS values are applicable to bitumen stabilised materials; however, the foamed bitumen mix design procedure in Part 4D does not include UCS requirements. It is therefore recommended that UCS requirements for bitumen stabilised materials be reviewed.

- Section 6.3 of Part 2 needs to be changed to reflect the above recommended changes to Part 4D.
- The minimum presumptive modulus of subbase quality natural gravel in the *Guide to Pavement Technology: Part 2 Pavement Structural Design* Table 6.7 should be increased from 1500 to 2000 MPa.
- In Section 12.6 of Part 2, additional text is required to describe the use of cemented materials with UCS of 1–2 MPa for lightly trafficked roads.

The above recommendations are interim measures pending further research. This is particularly important in relation to characterising the fatigue susceptibility of modified materials, as while the proposed reduction in the indicative maximum UCS value is step in the right direction, it does not eliminate the risk of fatigue in all modified materials.

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Keywords:

Modified granular materials, cemented materials, foamed bitumen, unconfined compressive strength, bound materials

Abstract:

This report investigates the origins of the current Unconfined Compressive Strength (UCS) criteria that differentiates modified granular materials from bound materials. Based on the review, a number of changes to the UCS design criteria are recommended to the Austroads *Guide to Pavement Technology Part 4D: Stabilised Materials* and *Guide to Pavement Technology Part 2: Pavement Structural Design*.