

# A REASSESSMENT OF SOME ROAD MATERIAL STABILIZATION PROBLEMS

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## **ABSTRACT**

In the interest of environmental sustainability and cost efficiencies, the need to make use of marginal road construction materials and to recycle existing pavement materials is increasing. This is frequently accompanied by the use of chemical stabilization to ensure that the appropriate material quality and structural capacity is achieved. Although South Africa has more than half a century of experience in the stabilization field, the number of problems arising on road construction and/or rehabilitation contracts involving chemical stabilization appears to be increasing. Various reasons seem to be contributing to this, including the increasing lack of suitable skills and experience, inadequate specifications (and the interpretation thereof), the need for more rapid construction and changes in equipment and product specifications and construction techniques.

A number of problems affecting chemically stabilized layers have been identified recently, but this paper discusses only the design and construction requirements for the provision of durable and effective stabilized layers. These include defining the correct type and quantities of stabilizer, effective laboratory and field test techniques to ensure the best stabilization design and appropriate construction techniques. The latter are related primarily to the construction time and curing of the stabilized layers. Suggestions to overcome ambiguities in current specifications are made and innovative solutions to avoid many of the problems are proposed.

## **1. INTRODUCTION**

In order to enhance environmental sustainability and the cost effectiveness of road construction and rehabilitation, the need to make use of marginal road construction materials and to recycle existing pavement materials is increasing. This is frequently accompanied by the use of chemical stabilization to ensure that the appropriate material quality and structural capacity is achieved. Although South Africa has more than half a century of experience in the stabilization field, the number of problems arising on road construction and/or rehabilitation contracts involving chemical stabilization appears to be increasing. Various possible reasons for this are discussed below.

In this paper, the discussion is restricted to conventional chemical stabilization using lime and the available range of cements and extended cements. The discussion is also applicable to combinations of these with other materials such as flyash and ground granulated blast-furnace slag. Problems related to the use of proprietary chemical stabilizers such as sulphonated oils, polymers and bitumen (emulsion or foamed) are not covered in this paper.

## **2. COMMON PROBLEMS WITH STABILIZED ROADS**

Methods for the design and construction of stabilized materials in South Africa were developed mostly in the 1960s and 1970s culminating in the publication of TRH 13 (NITRR, 1986a) as well as various guideline documents (Gautrans, 1994: 2004) and books (Ballantine and Rossouw, 1972; 1989). The technologies developed at this time made South African practitioners and researchers international leaders in the field of stabilization of road materials. Little additional research or development was carried out in South Africa after the early 1990s, with practitioners essentially using the published techniques. However, over the past 10 years or so, many of the experienced practitioners have been replaced by younger engineers lacking the experience and knowledge gained during the developmental stages of chemical stabilization and the number of problems encountered seems to be increasing.

During this period, the specifications for lime and cement have also changed, changes in the production techniques and raw materials have occurred and significant changes in some of the construction techniques (eg, the relatively recent introduction of in-place recycling machines) have taken place.

Based on a number of recent investigations, various possible reasons for the apparent increase in stabilization problems have been identified. These include the increasing lack of suitable skills and experience in both the design and construction of stabilized layers, inadequate specifications (and the interpretation thereof) the need for more rapid construction, poorer materials being stabilized, changes in equipment and product specifications and evolving construction techniques.

## **3. SPECIFICATION OF STABILIZED MATERIALS**

### **3.1 Materials**

Materials used in stabilized layers are required to conform to the requirements specified in the Standard Specification (COLTO, 1998), or the project specification where applicable. The current Standard Specifications for stabilized materials are minimal, with a range of limits for selected test requirements, depending on the stabilized material class, ie, C1 to C4. These include criteria for the material classification before treatment, the Plasticity Index after treatment, the laboratory determined unconfined compressive strength, the indirect tensile strength (for C3 and C4 materials only) and a reference to the need for durability requirements in the Project Specification. These specifications are summarized in Table 1.

Although considered to be incomplete in a number of respects as discussed later in this paper, one of the significant problems is that related to the grading specification of G6 material for C3 and C4 stabilized layers. This allows material with a nominal maximum size of either 63 mm (crushed material) or two thirds of the layer thickness (ie, 100 mm for a typical 150 mm layer) for uncrushed material (unless otherwise specified in the project specifications). As the use of stabilized bases increases, it has become evident that aggregate of this size is too large and can produce unacceptably stony finished surfaces on stabilized base materials prior to priming, with concomitant problems. It has also been noted that material with a nominal maximum size of 63 or 100 mm, unless passed through a square screen instead of the more usual grizzly, often has one of its dimensions considerably larger than 100 mm, seriously affecting the surface finish. The presence of such material can be either acceptable or unacceptable depending on the user's interpretation of the existing specification.

**Table 1 Requirements for chemically stabilized pavement materials (COLTO, 1998)**

Criteria	C1	C2	C3	C4
Material before treatment	At least G2 quality	At least G4 quality	At least G6 quality	At least G6 quality
Atterberg limits after treatment	Slightly plastic	Slightly plastic	PI shall not exceed 6	PI shall not exceed 6
Design strength (MPa) At 100% Mod AASHTO density At 97% Mod AASHTO density	Minimum : 6 Maximum : 12 Minimum : 4 Maximum : 6	Minimum : 3 Maximum : 6 Minimum : 2 Maximum : 4	Minimum : 1.5 Maximum : 3 Minimum : 1 Maximum : 2	Minimum : 0.75 Maximum : 1.5 Minimum : 0.5 Maximum : 1
Indirect tensile strength at 100% Mod AASHTO density (kPa)			Minimum : 250	Minimum : 200
Durability: Fines lost Wet-dry Freeze-thaw	All characteristics, including amongst others the carbonated values with regard to durability, shall comply with the project specifications.			

It is often found that C3 and some C4 materials, particularly those derived from the stabilization of better quality G4 or G5 gravels have strengths in excess of 3 MPa with stabilizer contents as low as 2%. In these cases, the tensile strength should be assessed and limited to a maximum of about 300 kPa, in order to avoid excessive cracking of the layer, particularly when additional stabilizer is added to allow for material and construction variability.

### 3.2 Cements

In 2000, SABS published the SABS EN 197-1 specification for cement (SABS, 2000), replacing SABS ENV 197-1 which was released in 1992. The current specification is SANS 50197-1: 2000, which is not referred to in the existing COLTO specification. This specification identifies various “products in the family of common cements” based on their constituents, extenders and the relative proportions of these. A typical cement would now be identified as, for example, CEM II/B-V 32.5 R. This describes a Portland-fly ash cement containing 65 – 79% of clinker and 21 - 35% of fly-ash with a strength class of 32.5 MPa and the R indicates an early strength requirement. Despite this nomenclature being widely publicised and all cement sold using this classification, it is not uncommon to still see the specification of Ordinary Portland Cement (OPC) for road stabilization projects in tender documents and Bills of Quantities. OPC is currently a brand name of a cement, which is a CEM I 42.5N, and is not necessarily the best choice for stabilization of road materials.

Site experience and a number of laboratory investigations have indicated that for road stabilization purposes, it is preferable to use an extended cement, preferably a CEM II, CEM III, CEM IV or CEM V with a strength class of 32.5. CEM I cements, those with strength classes of 42.5 or higher and cements classified as R (high early strength) are expected to set more rapidly and thus reduce the available processing time on site (see section 6) and are thus not recommended as a first choice for road stabilization. It is imperative that designers are fully aware of the various types of cement and the implications of their use in road stabilization, although it is clear that all of the answers have not been provided yet.

## 4. STABILIZATION DESIGN

The purpose of the stabilization design is to select the optimum combination of geological material and stabilizer that will provide the required strength and durability to ensure that the structural capacity of the layer is adequate (but not excessive as this could lead to other problems) over the design life of the road. This requires that the correct type of stabilizer is used for the specific material and that a sufficient quantity of stabilizer is added. Although the Standard Specifications for the constructed materials (COLTO, 1998) are applied to ensure that the contractor constructs a layer to the quality that the engineer has based his design on, he still needs to optimize the material performance and the cost of the layer.

Techniques for the mix design of stabilized layers are described in various documents (NITRR, 1986a; Gautrans, 2004). These typically involve the testing of the material to be stabilized with various types and quantities of stabilizers to ensure that a suitable strength is obtained.

### 4.1 Materials

Materials to be stabilized are usually obtained from borrow pits or cuttings on new road construction projects. However, the need for rehabilitation of existing roads is currently probably greater than new construction. Optimum rehabilitation often involves the in situ recycling of the materials in the upper portion of the existing road with improvement by stabilization. The use of borrow material and the re-use of in situ materials have their own needs and problems. One aspect, however, common to both of these is the natural variability of the properties of the materials.

Unweathered (crushed aggregate) and more so, partly weathered geological materials (gravels) have properties that can vary considerably. This is primarily the result of the effect of chemical reactions (hydration, hydrolysis, etc), physical processes (leaching, saturation, etc) and the effect of the environment (depth, water flows, temperatures, etc) in the vicinity of the materials on them over time. Thus materials from a single borrow pit or cutting can have a range of properties. Stockpiling and mixing of such materials can reduce the variability. The expected variability, however, needs to be clearly understood such that both the poorest and best quality materials are tested in the stabilization mix design and the stabilizer type and content can be adjusted as construction progresses.

#### *4.1.1 New construction*

For stabilized layers on new roads, the materials need to be identified prior to award of the tender. Current tender practices (based on bidding) often result in only a general identification of possible borrow materials with minimal testing. Only once on site, does the Contractor determine the actual materials to be used and then the stabilization design commences. By this stage, the amount and type of stabilizer to be added has already been priced for by the Contractor and the potential for problems such as under-stabilization and contractual claims increases.

It is essential that a proper materials investigation be carried out prior to the Contractor arriving on site. This involves the identification of suitable borrow areas, determination of the properties and variability of these materials and confirmation that sufficient materials are available. Only once this has been completed should the stabilization requirements (Section 4.2) be assessed.

#### 4.1.2 *In situ recycling*

Where in situ recycling of the existing road is being considered, the potential material for stabilization depends on the existing material in the road, the quality/control of the original materials, construction and the proposed milling operation, the degree and type of maintenance applied to the road and whether additional material will be added to the layer.

Typically, samples will be extracted at a fixed interval along the road (anything from 100 m to one or two kilometres) and the material tested (Atterberg limits, grading compaction characteristics and strength) in the laboratory. Other information such as the thickness of the layers, DCP profiles, material descriptions, etc is also obtained to assist with the structural design.

It should be borne in mind that during the milling/recycling operation, the grading of the material produced will be different from that obtained during conventional test pitting and sampling as a result of comminution by the recycling machine. This is not critical (in fact it is probably beneficial as large particles will be reduced in size) for stabilized materials and the change in plasticity as a result of milling is normally minimal. However, if either or both of the depth of milling or variability in layer thickness is such that various thicknesses of subbase are incorporated in the milled product, the properties of the material to be stabilized could be highly variable and differ significantly from that used in the stabilization design. Similarly, if material from borrow or a quarry is added to the layer to adjust levels or increase the thickness of the layer, this too would cause the quality of the recycled material to differ from that used in the stabilization design. These aspects need to be considered when carrying out the stabilization design to ensure that the material tested represents that likely to be used for construction as closely as possible.

#### 4.2 Stabilizer

The primary objectives of the stabilization design are to identify the type and quantity of stabilizer that will most cost-effectively produce a durable layer with the properties required for the structural design.

Most stabilization guideline documents provide a broad indication of the stabilizer type that is likely to perform best based on the Plasticity Index (Gautrans, 2004). This should be used only as a first approximation and a range of possible stabilizers should be investigated in the laboratory. A conventional stabilization process should firstly identify the Initial Consumption of Stabilizer (ICS) using the standard gravel ICL method (Appendix A in Ballantine and Rossouw 1989) with the proposed stabilizers. The method is not perfect and is currently being reviewed, but as an addition, it is recommended that a saturated solution of the stabilizer in water should be tested along with the individual samples as a reference point for the actual pH of the stabilizer. In order to ensure long-term stability, it has been recommended that the quantity of stabilizer added should exceed the ICS by at least 1% (Sampson and Paige-Green, 1990).

If a range of possible stabilizers is available in the area of the project, these should all be tested for cost effectiveness as the ICS could be different for the different materials. In addition, the availability of a particular product may change before commencement or during a project.

A representative sample of the material to be stabilized should then be tested with those stabilizers that appear to be the most promising from the ICS test with the addition of 1, 2, 3 and 4% stabilizer to determine the quantity that will provide the specified strengths (unconfined compressive and tensile). It is considered more important that the tensile strength requirement (within limits so as not to disrupt the pavement balance excessively

and consequently the pavement performance) is met as this property affects both the structural behaviour of the layer as well as the potential to degrade should the durability not be sufficient (Paige-Green, 1991).

The selected stabilizer content should then be that content shown to provide the required design parameters, provided that it exceeds the ICS by at least 1%. It has also been recommended (Gautrans, 2004) that an additional 1% stabilizer is added to the material to allow for variations in material properties and stabilizer distribution through the layer during mixing. This can often lead to excessively high stabilizer contents and it is suggested that the Engineer assesses the various test results to make an informed opinion on whether the additional 1% stabilizer should be used.

Once the stabilization design has been finalised, the durability of the materials should be tested with the proposed stabilizer content. This requires a wet/dry brushing test (Sampson and Paige-Green 1990) and the residual UCS of a sample after accelerated carbonation under vacuum (eg, De Wet and Taute, 1985). Should the material/stabilizer combination not comply with the requirements of Sampson and Paige-Green (1990), the potential for problems in the field is high and the stabilization design should be revised. It is essential that appropriate durability testing techniques and limiting criteria are included in the Project Specification.

## **5. LABORATORY TESTING**

Laboratory testing of stabilized materials in South Africa typically follows the requirements of TMH 1 (NITRR, 1986b) or other recognized test methods. Typical TMH 1 tests include the particle size distribution, Atterberg limits, compaction characteristics, unconfined compressive strength, indirect tensile strength, etc. Other more specialized tests should, but are not always carried out: these include, for example, the Initial Consumption of Stabilizer determination (considered essential), wet/dry brushing test, Erosion Index test, etc.

A fact that many practitioners neglect to take account of is that laboratory testing is carried out under ideal controlled conditions. Small samples are tested allowing uniform distribution of the stabilizer through a well mixed and relatively homogeneous material. Laboratory temperatures are relatively well controlled and curing conditions are generally ideal. None of these is repeated in the field under normal construction conditions.

The same type of stabilizer that will ultimately be used on the project must be used in the laboratory mix design tests and fresh samples of the stabilizer must always be used. The supply of the various types of stabilizer, cement in particular, is very regional and the use of central laboratories could determine that a cement type that is not available on site without excessive haulage is suggested for the stabilization design. This should be avoided.

## **6. CONSTRUCTION AND CONTROL**

The best stabilization design can all be undone in the field by poor construction. A number of aspects need to be carefully supervised during stabilization work on site.

It is imperative that the control testing of all materials confirms that the properties remain within an acceptable range. Should the Atterberg limits or ICS change during construction, the stabilization design should be confirmed. Too often instances are seen where a single

stabilization design is carried out at the start of the project and borrow pits, stabilizer source or both change repeatedly along the road. Failure to confirm the stabilization design is courting disaster.

All laboratory testing is done at a controlled temperature (20 to 25°C). In the field, air temperatures of in excess of 40°C are not uncommon and actual material temperatures can be significantly in excess of this. It is a rule of thumb that the rate of chemical reactions (stabilization is a chemical reaction) doubles for every 10°C rise in temperature. Working at high field temperatures can thus reduce the time available for mixing and compaction of stabilized layers significantly. In order to assess potential working time a test protocol has been employed in Australia in which laboratory compaction of stabilized samples at the expected field temperature and after various delays between mixing and compaction is carried out (Vorobieff, 2006). An assessment of the effect of these delays on the density and strength is made to indicate the maximum permissible working time for the material under those conditions and its use is strongly recommended. The protocol has been modified for South African conditions and copies are available from the Author or from [bryan@cnci.org.za](mailto:bryan@cnci.org.za).

It is clear that as cementation of the material proceeds, the effort required to achieve the required compaction increases. This can be accommodated using heavier or different rollers but has the effect of degrading the upper portion of the layer, where bonds already formed (especially when stabilized with cement) will be broken down. A similar effect is also obtained during the common practice of “lightly rolling” the surface at the end of the day for “aesthetic” reasons. This practice should be discouraged.

An ongoing problem with stabilization is ensuring that the correct quantity of stabilizer is added and evenly distributed through the layer. Conventional testing using the methods (A15) provided in TMH 1 (NITRR, 1986b) results in problems when the calcium content of the material is significant in relation to the calcium content added to the material in the stabilizer. The variability in the natural calcium content is often larger than the amount of calcium added, making the test meaningless. In these cases it is essential that the number of bags added (or mass when distributed from bulk tankers) is tightly controlled as a record of stabilizer added. Sufficient holes should be assessed while taking samples for laboratory quality control/assurance testing to ensure that the depth of mixing was correct and by spraying phenolphthalein on the sides of the holes that a uniform distribution of lime through the layer was obtained. Although this is a rather non-quantitative technique, “seeing is believing”.

Samples taken from the field for laboratory testing should be moved to the laboratory and compacted within the same time frame as the material on the road, in order to provide comparable results. If this is not possible, the temperature of the samples should be reduced as far as possible to retard the reactions.

## **7. CURING OF LAYERS**

Considerable research and investigation into the most appropriate means of curing stabilized layers was carried out in the 1980s (Netterberg et al, 1987; Sampson et al, 1987; Paige-Green et al, 1990). The results of this research were incorporated as far as possible in the CSRA (1987) and following COLTO (1998) specifications, but its implementation is not always carried out adequately. The status quo at the time, of using MC-30 cutback bitumen as a curing membrane was retained with some qualification. Subsequent experience has, however, shown that the conventional use of MC-30 does not provide an

effective curing membrane.

The other conventional curing technique in use at the time of preparation of the original CSRA (1987) and then the revised COLTO (1998) standard specifications was the use of water sprays. This was modified to allow water spraying for a maximum of 24 hours before an alternative treatment was applied. Observations and investigations have shown that water spraying is frequently carried out for up to 7 days, but that under South African conditions it is almost impossible to keep the stabilized layer **continuously moist** during hot sunny days. This results in the surface of the layer effectively being wet and dried at least twice a day and a detrimental effect on the layer occurs, as illustrated by Netterberg et al (1987).

In their comprehensive study of various curing techniques, Netterberg et al (1987) tested a wide range of curing techniques and only by keeping the layer continuously moist using a plastic sheet or a moist sand layer, did effective curing occur. Recent investigations have shown that thicker primes can be reasonably effective as they tend to form a skin on the stabilized layer. It is essential, that the effect of the curing procedure at a site is monitored and the necessary corrective action taken, but in all cases the layer should be covered by the next layer or sealed (in the case of base courses) as soon after compaction as possible.

It has been proposed that if the stabilized layer cannot be properly cured, it be left open to become sufficiently dry to allow sealing. In fact, this seems to have taken place on a number of projects in the 1960s and 1970s (E Kleyn, personal communication), without any apparent detrimental effect. The work of Netterberg et al (1987) showed, however, that allowing the layer to dry continuously resulted in significant detrimental carbonation.

It is suggested that perhaps, more use should be made of the Australian technique of applying a primer seal (essentially a viscous cut-back bitumen (MC 2500 or equivalent) or preferably a cationic rapid setting bitumen emulsion for South African conditions with 7 to 10 mm aggregate) shortly after compaction and then placing the final seal on the entire road once it is complete. A primer seal would provide an effective curing membrane as well as protecting the base course from the traffic that inevitably makes use of the unfinished road.

## **8. GENERAL DISCUSSION**

The question is often asked why carbonation is detrimental to the integrity of the stabilized layer in some cases and not in others. Many examples have been observed where entire stabilized layers have carbonated and yet the layer remains dense, intact and apparently strong.

It is propounded by the author that the untreated materials used on many existing older roads that show substantial carbonation but still perform adequately were of such a quality that the stabilization was really a bonus. It is only since using more marginal materials with poor gradings and inherently poor strength that the problems with carbonation have really surfaced. This reinforces the conclusion that carbonation is only detrimental to the material if the expansion forces induced by the volume changes as the lime (calcium hydroxide – either added or formed as a result of cement hydration) changes to calcium carbonate exceed the tensile strength of the cemented matrix surrounding the lime particles. If the material is sufficiently stabilized to resist these forces, no detrimental effect will influence the material. This obviously relates to the time that the bonds have to develop before being



carbonated. It is for this reason that the Indirect Tensile Strength values are considered to be much more important than is generally accepted (apparently mainly in basic crystalline materials and calcretes).

It should also be noted that when in situ recycling of distressed pavements (including any asphalt layers and particularly when the asphalt comprises more than 40% of the material) is being carried out, laboratory testing often indicates that excessive quantities of stabilizer are required. This is exacerbated when rapid curing techniques are used.

## **9. CONCLUSIONS AND RECOMMENDATIONS**

The recurring problems with the construction of stabilized layers cannot continue. It is imperative that, during the current upgrading of the relevant Standard Specification, all project specifications pay specific attention to the potential problem areas highlighted in this paper. This will involve a better understanding of the entire stabilization process and of the areas where things can go wrong.

The negligible cost savings involved in minimizing material and stabilization testing (a few thousand rand) prior to the project specification being developed have resulted in many cases of premature failure and/or claims worth millions of rand. There is definite evidence that this process needs to be reviewed and an improved procedure implemented.

It is also of utmost importance that those involved with chemical stabilization understand clearly the fundamental properties of stabilized materials and the processes and requirements of the stabilization design and the construction techniques.

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