DISCUSSION

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Weak interlayers in flexible and semi-flexible road pavements: Part 1

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COMMENT

The paper states the following: "A strongly cemented layer might show signs of carbonation, but the strength of the carbonated material is still adequate for its use and purpose in the pavement. This could be described as 'non-deleterious' carbonation (or simply carbonation), whereas when carbonation causes the properties of the material to deteriorate to the extent that the layer cannot fulfil its intended function it is known as 'deleterious' carbonation, in the context of this set of papers." (pp 34–35)

Some of the causes for the formation of weak interlayers listed in the paper are the following:

- Detrimental carbonation of chemically stabilised layer from below or from sides after construction. (p 38)
- Some materials perform well in laboratory tests, but have a tendency to form a soft surface or soft base in the field (Bergh 1979). (p 38)
- Weakening due to detrimental carbonation, dry out and/or wet-dry cycles is probably the most common cause of surface weakening of chemically stabilised layers. (p 39)
- Note that in chemical soil stabilisation, carbonation almost invariably weakens the stabilised material. (p 39)
- If a chemically stabilised layer has been badly cured – even allowed to dry partially only once – the upper layer has probably been weakened. (p 39)
- Most weak layers, interlayers, laminations and/or interfaces can be prevented by good construction practices. (p 40)
- In order to prevent the formation of weak interlayers the specifications specify the following:
  - Curing of a chemically stabilised layer for at least seven days is carefully specified and it is stated that drying out or wet-dry cycles may be the cause for rejection if the layer is damaged thereby (para 3503(h)). (p 40)
  - No priming shall be carried out on a base which is visibly wet or which is at moisture content in excess of 50% of the OMC (para 4104). (p 40)
  - Before priming, the base shall be broomed and cleaned of all loose material (para 4105). (p 40)
  - Asphalt shall not be placed if free water is present on the working surface or if the moisture content of the underlying layer, in the opinion of the engineer, is too high, or if the moisture content of the upper 50 mm of the base exceeds 50% of the OMC (para 4205(b)). (p 40)
  - Before applying a tack coat or asphalt, the surface shall be broomed and cleaned of all loose or deleterious material (para 4205(c)(ii)). (p 40)
  - Before applying a seal, the moisture content of the upper 50 mm of base shall be less than 50% of the OMC (par 4304(d)(i)). (p 40)
  - Additional precautions may be required when utilising marginal or substandard materials (Netterberg *et al* 1989). (p 40) [These additional precautions are not mentioned in the paper.]

The paper concludes that weak layers, interlayers and laminations have more than one cause, but most can be prevented simply by application of known good construction practices. (p 41)

From these remarks it is clear that the paper sees the main cause of 'deleterious' carbonation as construction-related and therefore the contractor's responsibility.

I would like to refer to Dr P Paige-Green's TREMTI paper of 2010 to show that, even if the true cause of 'detrimental carbonation' was the carbonation of the surface layer by the carbon dioxide in the air, that it is still a water-driven reaction. Allow me two quotes from Paige-Greene's 2010 TREMTI paper:

> "During the early 1980s a number of problems related to the loss of stabilisation and disintegration of stabilised layers in roads (lime and cement) were reported in South Africa. This led to many comprehensive investigations and it was shown without any doubt that the problems were related to carbonation of the stabilised materials. A paper was presented at the TREMTI conference in Paris in 2005 indicating that many of the problems in South Africa that were attributed to carbonation, were actually caused by 'water driven reactions' and were thus material related and not construction related. This paper assesses the fundamental principles of each of the processes and draws conclusions as to their likelihood and the increasing occurrence of stabilisation problems. It is concluded that, although there is indubitable proven field and laboratory evidence for carbonation of stabilised layers, there is no solid scientific evidence for the occurrence of 'water driven reactions' in soil stabilisation in roads."
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> "The carbonation reaction depends on the solubility and diffusion of the components. The diffusion is controlled by the concentration differences and is an inward diffusion of CO_2 gas and carbonate ions (Lagerblad 2005). The gas diffusion is much faster than ion diffusion. Thus the rate of reaction is controlled by the humidity in the material, i.e. how much liquid fills the connected pore system. In dry material the CO_2 can penetrate well, but there is insufficient water for the reaction to take place. In the saturated condition, only the carbonate ions move and carbonation is slow. Typically, the reaction is most likely and rapid at humidities of 40 to 70% (Lo & Lee 2002; Ballim & Basson 2001; Gjerp & Oppsal 1998)."

However, Ballim & Basson also state that no carbonation takes place when the pores are completely dry or when they are fully saturated and that the rate of carbonation also increases with increasing ambient temperature (Fulton 2002 p 150). Neither of these conditions is normally found in chemically stabilised layers. In actual fact, the moisture regime of the stabilised layer is usually closer to 50% of the OMC as can be seen from the above quotes.

Encyclopaedia Britanica states:

> "The atmosphere is made up of a number of gases of which water vapour is in many respects the most important. This importance arises from the fact that water vapour is the only constituent of air whose state changes at the temperatures encountered in the atmosphere. Water substance occurs as vapour (invisible), as liquid (fog, cloud and rain droplets) and as a solid (ice crystals, hail and snowflakes). The subject

of atmospheric humidity deals only with water in its vapour state."

Relative humidity gives the amount of water vapour present in a volume of air as a percentage of the maximum possible amount of water vapour in that volume at the same temperature. The relative humidity depends on the temperature, as well as the water vapour content.

Wikipedia states the following about the effect of carbonation on phenolphthalein:

"The acid-base indication abilities of phenolphthalein also make it useful for testing for signs of carbonation reactions in concrete. Concrete has naturally high pH due to the calcium hydroxide formed when Portland cement reacts with water. The pH of the ionic water solution present in the pores of fresh concrete may be over 14. Normal carbonation of concrete occurs as the cement hydration products in concrete react with carbon dioxide in the atmosphere, and can reduce the pH to 8½ – 9, although that reaction usually is restricted to a thin layer at the surface. When a 1% phenolphthalein solution is applied to normal concrete it will turn bright pink. If the concrete has undergone carbonation, no colour change will be observed."

Therefore, the carbonation of cement-stabilised layers cannot take place without a certain amount of water vapour being present. Therefore it is a water-driven or water-activated reaction. However, the pink colour of the phenolphthalein on the loose powdery interlayer shows that the cement-stabilised layer is not carbonated. Furthermore, the contractor has no permanent control over the moisture regime in the stabilised layer, which is specified to be close to 50% OMC and thus in the active carbonation humidity range. Therefore the problem is material related.

The fact that performance of the stabilised material on site sometimes differs from the performance in the laboratory is due to the fact that laboratory design tests presently do not simulate specified construction conditions on site. It is not possible for the contractor to simulate laboratory conditions on site during construction. The laboratory tests should simulate site constraints.

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RESPONSE FROM AUTHORS

The additional precautions which may be required when utilising marginal or substandard materials were discussed by Netterberg *et al* (1989) referred to in our paper.

Carbonation is inevitable in the long term as both Portland-type cements and lime are unstable, both under normal atmospheric conditions and those in the road and soil. However, it can be prevented or delayed in engineering time by means of suitable design, e.g. a sufficiently high stabiliser content and/or a high density (used as a proxy for low permeability to air) and construction precautions, e.g. good stabiliser control, compaction and curing. Obviously, only the latter aspects are under the contractor's control and therefore his responsibility. Most of these factors are specified and/or regarded as good engineering practice. The prevention of 'deleterious' carbonation is thus the responsibility of both the designer and the contractor.

It is correct that carbonation is most rapid under conditions of intermediate humidity of about 40 – 70% and very slow under very dry or saturated conditions, and in that sense it does require water, as do many other chemical reactions. However, it is driven more by the difference between the partial pressure of carbon dioxide in the atmosphere, pavement air or soil air, and that in the stabilised layer and only requires water vapour or minute amounts of water as a carrier. During curing the upper part of the layer is exposed to the humidity of the atmosphere when it is allowed to dry, as is often the case. As southern African conditions are usually warm and at such intermediate humidities, they are in fact often at an optimum for carbonation. Moreover, it has been shown that carbonation is accelerated by wet-dry cycles, which are worse than doing nothing (Netterberg *et al* 1987).

If the upper base dries to 50% of MAASHO OMC before priming, and to less than this before sealing, the whole base will not necessarily remain exactly at this, but will in time equilibrate to something of this order – on average about 0.6 OMC in the base as a whole and 0.75 OMC in the sub-base (Emery 1992). Whilst published (Netterberg &Haupt 2003) and unpublished measurements of suction and humidity show that the relative humidity in the base as a whole is mostly over 99%, this varies during the daily temperature cycle and can be much lower in the upper base. The combination of suitable and varying humidities and high temperatures in the base, but probably especially the high partial pressures of CO_2 in the underlying layers and roadbed air – which latter can easily exceed 10 or 20 times that of the atmosphere – constitute an environment suitable for carbonation in the medium to long term (e.g. Netterberg 1987, 1991; Sampson *et al* 1987). In spite of the apparently unfavourably high average humidity in the pavement layers, it has been known since at least 1984 that complete carbonation of a lime or cement-stabilised pavement layer from the bottom upwards can occur (Netterberg 1987, 1991; Sampson *et al* 1987; Paige-Green *et al* 1990).

Contrary to Dr Semmelink's opinion then, the conditions in a pavement are actually conducive to carbonation and, as the above-mentioned authors have shown, it does indeed occur and it does also weaken the layer. However, it does not always lead to distress or failure of the pavement, and in this sense only is not always deleterious.

Regarding the phenolphthalein test, it is important to note that a deep red (or purple) only indicates a pH of more than about 10 and that phenolphthalein starts to turn pink at a pH of about 8.3, is pale pink by 8.5 and a dark pink or light red by 9. A pink colour therefore only indicates the presence of very little (probably less than about 0.2%) lime or cement, and a deep red more than about 1%, whereas only a pH of more than about 12.4 can be taken as indicating the more or less complete absence of carbonation. This is a very old test, and Netterberg's (1984) main contribution was to use diluted hydrochloric to confirm that the stabiliser had indeed been added and that it was therefore carbonation.

A pink – and in some cases even a red – colour therefore usually indicates either partial carbonation or that very little stabiliser was present in the first place, the acid test usually providing the answer.These tests are of course only indicative and qualitative, and a chemical or mineralogical analysis is required for confirmation and quantitative determination of the degree of carbonation.

Whilst it is correct to say that the contractor has no permanent control over the moisture regime, it is only specified to be less than 50% of OMC in the upper 50 mm of the layer before sealing. Fifty percent of OMC does not equate to a relative humidity of 50% – in fact it is likely to be much higher than this, but is dependent on the material, as well as other factors. Premature drying out is of course deleterious in the sense that it both promotes carbonation and prevents hydration of the cement. In this case there may be a conflict between the specification requirement to dry out and the need to keep it moist to promote proper curing.

However, it is only correct to state that the problem is material related insofar as the material properties affect the equilibrium moisture content, compactability and permeability. It is also only correct to state that **some** laboratory design tests (such as UCS) do not simulate site conditions, as these are simulated by the wet-dry test (wet-dry cycles and, effectively, surface carbonation) and the UCS and PI tests before and after accelerated, complete carbonation of the whole briquette.

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The effects of placement conditions on the quality of concrete in large-diameter bored piles

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COMMENT

I was very interested to read this useful contribution to the practical aspects of concreting on site, specifically for bored piles. The information given is very helpful in assessing the influence of ingressing water into such pile holes during concreting operations, and I would like to commend the authors on their contribution.

It reminds me of a case I dealt with about 30 years ago, on exactly the same problem. Unfortunately we did not have this paper to refer to then, because it could have saved quite some difficulties. The case involved a series of deep (20 m) bored piles for a very large cement silo. I was privileged to work with the late Dr Ross Parry-Davies on the problem–I as a young and somewhat green engineer and academic, he as an already well-experienced and knowledgeable geotechnical engineer of substantial reputation.

There had been a lot of water ingress into some of the pile holes before and during concreting. While the piling contractor had taken all the necessary precautions, there was concern that the water may have compromised the integrity of the piles. Consequently, cores were taken through the full depth of some piles. The appearance of the cores was remarkably similar to the photographs given in the cited paper. It was obvious that water had created lenses in the concrete at certain points.

The client and his engineer were of the opinion that the contractor had been negligent in the piling operation. It was our contention that all reasonable precautions had been taken, but that in spite of these, the ingressing water had caused problems in the piles – problems that would have been very difficult to avoid. I recall having to defend my theory of how the ingressing water had affected the piles before a very critical and somewhat caustic senior engineer, which was certainly intimidating! After considerable argument, the client and the engineer eventually accepted our explanation, and it was decided to remedy the piles by grouting of the voids. I am happy to report that the cement silo has operated quite successfully for the last 30 years, and continues to do so!

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