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 (para 4304(d)(ii)). (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-Green’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.”

“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 CO₂ 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 CO₂ 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 Britannica 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 present-day 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 sub-standard 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 ‘deteriorous’ carbonation is thus the responsibility of both the designer and the contractor.

Therefore, 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.

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.
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!