TMC – Tinni Management Consulting

PAVEMENT INFORMATION NOTE

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The following Discussion Paper summarises the reasons for the virtual irrelevance of cracking that may occur in rigid pavement LMC subbases. It should become a **reference document** to all who are involved with concrete paving and its QA administration.

A lot of time and cost is wasted by conscientiously mapping cracks that may have become apparent in subbases. The question must be asked: "why are we doing this?" and "what will it achieve?"

THE REASONS and EFFECT of CRACKING in LMC SUBBASES

1 PURPOSE

The purpose of this Discussion Paper is to explain the mechanism of the development of shrinkage and setting cracks in the mass concrete rigid pavement subbases and to explain the relevance of these in the total pavement structure and the longevity of the end product.

The discussion then focuses on the requirements and ambiguities of the RTA Specification DCM R82 – Lean-Mix Concrete Subbase.

2 INTRODUCTION

More often than not, Client specifications nowadays are a mixture of some 90% of method and 10% end product requirements. When it comes to cracks in concrete pavements, however, they only spell out non-conformances, but of course, do not offer advice, reasons or solutions for the avoidance or repair of any unplanned cracking. There is no recognition that the non-conformances may also be due to the very strict methods that have been stipulated which may not equate to the end product requirements. Too often the supervisors infer that the slab(s) should be removed and replaced without taking cognisance whether this is actually required or whether such action actually improves or detracts from the overall durability of the pavement.

Specifications only refer to setting and plastic shrinkage cracks and the allowable (very accurate) quantum of these. This infers that when this arbitrary extent is exceeded, the cracks become nonconforming regardless of their cause or relevance in the final durability of the pavement structure. It is important to note, however, that there is no inference that the only acceptable disposition is slab removal and replacement. There is also silence on the non-acceptable crack width, whether it is hairline, 2mm or 10 mm wide.

3 DISCUSSION

As the concrete sets, it will initiate internal shrinkage stresses which will cause cracking during the time when there is not enough strength (gain) in the concrete to absorb these.

With the 5 MPa LMC mass concrete subbases it is normal to accept these as part of the structural design even though this is not the case. Ideally, the transverse cracks occur at approximately 5 m spacing. These are often followed by the central longitudinal crack. Because of the length vs width ratio in a road slab, longitudinal stresses will start to predominate first and hence the transverse cracking is expected first. With only the 10 m transverse width, the stress build-up in this direction is generally delayed, but true to the theory, the 5 m spacing longitudinal crack will also develop. Because this occurs later, the concrete has gained more strength and often the longitudinal crack is discontinuous. This is illustrated in Attachment A.

To quote from Austroads 2008 Pavement Design Guide*: "LMC subbases are constructed as mass concrete without transverse joints and will therefore develop cracks. It is intended to achieve a pattern of relatively closely spaced and narrow cracks that provide a degree of load transfer and which, in conjunction with the debonding layer , will not reflect into the base".* Here it might be noted that:

1. The spacing of the cracks has not been nominated, but it is accepted that they could be closely spaced.
2. The cumulative length of cracks per unit area has not been mentioned.
3. The maximum width of cracks has not been specified, i.e. the aggregate interlock is not an issue.

We know that the rate of shrinkage is not linear and the amount is also dependant on the strength of the concrete (see Clause 6 hereunder). With higher strength, the rate and amount of heat of hydration increases and thus also the shrinkage increases.

One of the problems with shrinkage occurs with higher strength concrete when setting starts earlier and stresses are created quicker. Cracking will occur at shorter intervals, eg at 3 m spacing and longitudinal cracking often starts at the same time, In this instance there are likely to be 2 longitudinal cracks at roughly the same spacing as the transverse ones. What happens then the longitudinal and transverse cracks approach each other simultaneously and diagonal cracking will occur. This mechanism is shown in Attachment B. The vector diagram illustrates the reasons for changes in direction of the cracks when the longitudinal and transverse cracks approach simultaneously. As soon as the diagonal stress relief occurs, the stress directions within the slab are re-oriented and the tendency for any systematic cracking or direction of cracking is lost. This occurs away from the free edges.

Attachment A depicts the conventional development of shrinkage cracks when the transverse ones precede the longitudinal.

It is worth reflecting on the actual mechanisms of non-structural cracking before analysing the RTA Specification and its requirements.

4 NON-STRUCTURAL CRACKING

Volumetric change in concrete cannot be prevented as concrete expands and contracts due to movement of moisture and temperature changes. This occurs from the onset of casting. If such movements are excessive or if the internal stresses created by the desire to expand or contract are greater than the strength available in the early age concrete at the time, the concrete will crack. There are preventative measures that can be taken to slow down the development of these stresses and thus allowing the concrete to gain sufficient strength to resist cracking to some degree

There are two distinct mechanisms that drive early volumetric change. The first results from **pore water suction** and the second from **thermally induced strain**.

Early age cracking is termed as **plastic cracking.** The factors influencing the amount and time of plastic shrinkage are the rate of evaporation, quantity of pores in the mix, i.e. the amount of air and water at the time of placing, the theoretical pore diameters and the resultant pore water suction created stresses. Plastic shrinkage cracking is still quite unpredictable as besides the main causes, every concrete mix will still behave differently through built-in factors such as the fine aggregate grading, admixtures used and the binder content, composition and fineness. A number of researchers (including RTA) have confirmed (?) that under compaction can also be a major contributor to plastic cracking. It has been suggested that anything less than 99% Relative Compaction should be of concern. In the case of mass concrete subbases, we do not measure compaction, may be we should.

Later age cracking, after the initial hardening, is identified as being caused by **drying shrinkage.** The amount of drying shrinkage which occurs in all concretes, depends on the characteristics of the materials used, mix proportions, concrete strength, placing methods, quality of compaction and the efficiency of curing

5 STRAIN DEVELOPMENT MECHANISM

Concrete mixes are designed to contain a certain amount of air. Hence, it can be assumed that air and water co-exist in the pores of the concrete. This results in surface tension at the air/water interface. With a simple “capillary model” it can be demonstrated that the surface tension causes negative pressure (compared to atmospheric) in the pore water. This is normal for the moisture suction or capillary potential and is expressed as a stress (or pressure). As the water evaporates and is used in hydration, the negative stress within the water in the pores increases and tends to draw the solid particles in the concrete more and more together.

For cracks to occur, certain stresses and strains need to be in place.

Immediately after casting, concrete enters a dormant period. This is at least until the initial set commences. The concrete strains are small and stresses tensile. These result from consolidation and reduction of the original pore pressure. The presence of bleed water is a good indication of this phase.

As the bleed water dries and hydration commences, internal suction is established. In the first instance this is primarily in the upper concrete. Pores become only partially saturated and significant internal suction pressures are created. As a consequence, also significant compressive stresses are introduced into the top layer of concrete. Further tensile strains develop due to the thermal expansion from the heat of hydration.

In the case of concrete slabs, there are now two types of strain: **free strain** and **stress related strain.** The latter results from conditions that restrain the free movement of the slab. This latter illustrates the significance of even debonding and need for uniform (low) coefficient of friction on the underside of the slab as a factor for subsequent crack control.

6 THERMAL EXPANSION

This is an issue what the methods specifications overlook completely. Here it should be noted that the Coefficient of Thermal Expansion in concrete varies from ~23 x 10^{-6}/ºC for fresh concrete and to an average of 10 x 10^{-6}/ºC in hardened concrete. This 2½ fold increase for fresh concrete also demonstrates the proneness to plastic shrinkage cracking soon after casting.

The specifications also overlook the fact that the types of coarse and fine aggregates affect the magnitude of the thermal expansion movements in concrete. From AS3600, the Coefficients of Thermal Expansion for different aggregate concrete are given as:

6.8 microstrain/ºC with limestone aggregate
8.6 microstrain/ºC with basalt aggregate
9.5 microstrain/ºC with granite aggregate
10.8 microstrain/ºC with sand and gravel
12.2 microstrain/ºC with quartzite aggregate.

This possible 100% difference in behaviour, i.e. potential shrinkage, is not recognised by the RTA Specifications.

7 RTA LEAN MIX CONCRETE SUBBASE SPECIFICATION - DCM R82

Clause 5.1.1 – Typical Subbase Cracking

LMC Subbase will typically form full depth transverse cracks continuous for the full width of the paving run at approximately 3 -15 m centres. In subbase placed in a single pass more than 6 m wide, longitudinal full depth cracks may also typically occur at spacings of approximately 4 m and in continuous lengths exceeding "4 m."

Clause 5.1.2 – Plastic Shrinkage Cracks

"Plastic shrinkage cracks are discrete cracks of less than 300 mm and a depth of less than 50% of the slab thickness which do not intersect a formed edge. No remedial action is required if a bond breaker is applied, but the Contractor must immediately implement Corrective Action."

Clause 5.1.3 – Additional Longitudinal and Transverse Cracks

"Subbase cracking other than typical cracking as described in Clauses 5.1.1 and 5.1.2 is nonconforming if the cumulative length of cracking in any 25 m^2 of Subbase exceeds two metres. The Contractor must immediately implement Corrective Action."

Comments:

1. Plastic cracks should be <300 mm long. It is silent on width and extent.
2. For plastic cracks no remedial action required, but must implement CA.

3. The Specification is silent if the cracks are, say, 350 mm long.
4. Shrinkage cracks are expected to extend over the full width of pavement. Hence, cannot conform to the requirement of the total length being <2 m per 25 m^2.
5. Again CA expected as theoretically nonconforming if cumulative total more than 10 m, but no remedial action.
6. It is also noted that Clause 5.1 requires the Quality Plan to have an inspection schedule only.

8 METHODS SPECIFIED CRITERIA

- Binder: Cement - min 90 kg/m^3
  Flyash - min 100 kg/m^3
  Total binder - min 250kg/m^3
- Compressive strength: Trial Mix – min 6 MPa in 28 days
  max 15 MPa in 28 days
  Pavement – min 5 MPa in 42 days
- Slump: 20 – 40 mm
- Drying shrinkage: max 550 microstrain in 21 days.
- Air content: 5.0 ± 2%

Comments:

1 A binder content of minimum cement and flyash 90/160 proportion with the total of 250 kg/m3 will result in the concrete having a 7 day compressive strength of >5 MPa. This is regarded as far too strong a mix and is a major influence on the spacing and extent of setting cracks.
2 Once the maximum drying shrinkage is nominated, the means of control of setting crack behaviour also become quite limited.
3 Hence, if there is a claim of non-conformance by the Client, it can be argued that this is due to the specified requirements and that we need direction for the CA to be taken.
4 The concrete strength issue should be resolved at the Trial Mix stage.

9 SURFACE DISCONTINUITIES

Clause 4.5.1 allows **construction joints** to have a 3 mm differential (in height) on a 0.3 m straight edge. It notes that they do not need to be scabbled as no aggregate interlock is required. Longitudinal joints have the same criteria as well and a statement that they do not have to be corrugated.

Comments:

1 A joint is a "crack". Hence the same criteria would be accepted for cracks.
2 The corollary is that provided the setting cracks still maintain a smooth horizontal surface, they are not of concern
3 Since aggregate interlock is not essential, it means that the actual crack width is irrelevant.

10 CRACK REPAIR

Clause 4.10.3 states: "Full depth cracks which have spalled more than 10mm deep and 15 mm wide must be filled with suitable flexible sealant or a mixture of sand and bitumen to provide a surface flush with the subbase surface".

Comments:

1 This does not apply to the plastic shrinkage cracks as these are only 20 – 70 mm deep.
2 The Clause infers that having a smooth surface is the primary objective.
3 There is no mention that other cracks, of any size, have to be repaired.
4 There is no other clause which deals with "crack repair".

11 CONCLUSIONS

From the above, the following obvious conclusions can be drawn:

1 Some cracking of the LMC subbases will always occur. There are many factors that govern the actual extent.
2 One of the main causes is the high concrete strength often produced by the RTA minimum binder content of 250 $kg/m^{3.}$
3 Neither plastic or shrinkage cracking of the LMC subbase has no structural significance[(1)]. This is also why the width of cracks has not been nominated.
4 Provided there is <3 mm vertical difference in the crack sides, no action needs to be taken.
5 Cracks that have spalled deeper than 10 mm and wider than 15 mm need to be filled to create a smooth surface. Otherwise no actual crack sealing is required.
6 There is no suggestion in any documentation that at some condition the subbases should be removed and replaced.
7 The RTA nominated acceptance of only 2 m of crack in any 25 m^2 of slab is both illogical and incorrect. Furthermore, the reasoning cannot be substantiated.
8 Good construction practice would suggest that the amount of cracking should always be minimised. This is achieved through Corrective Action (often by trial and error) to the methods used for the various facets of procurement, production, placement and finish.

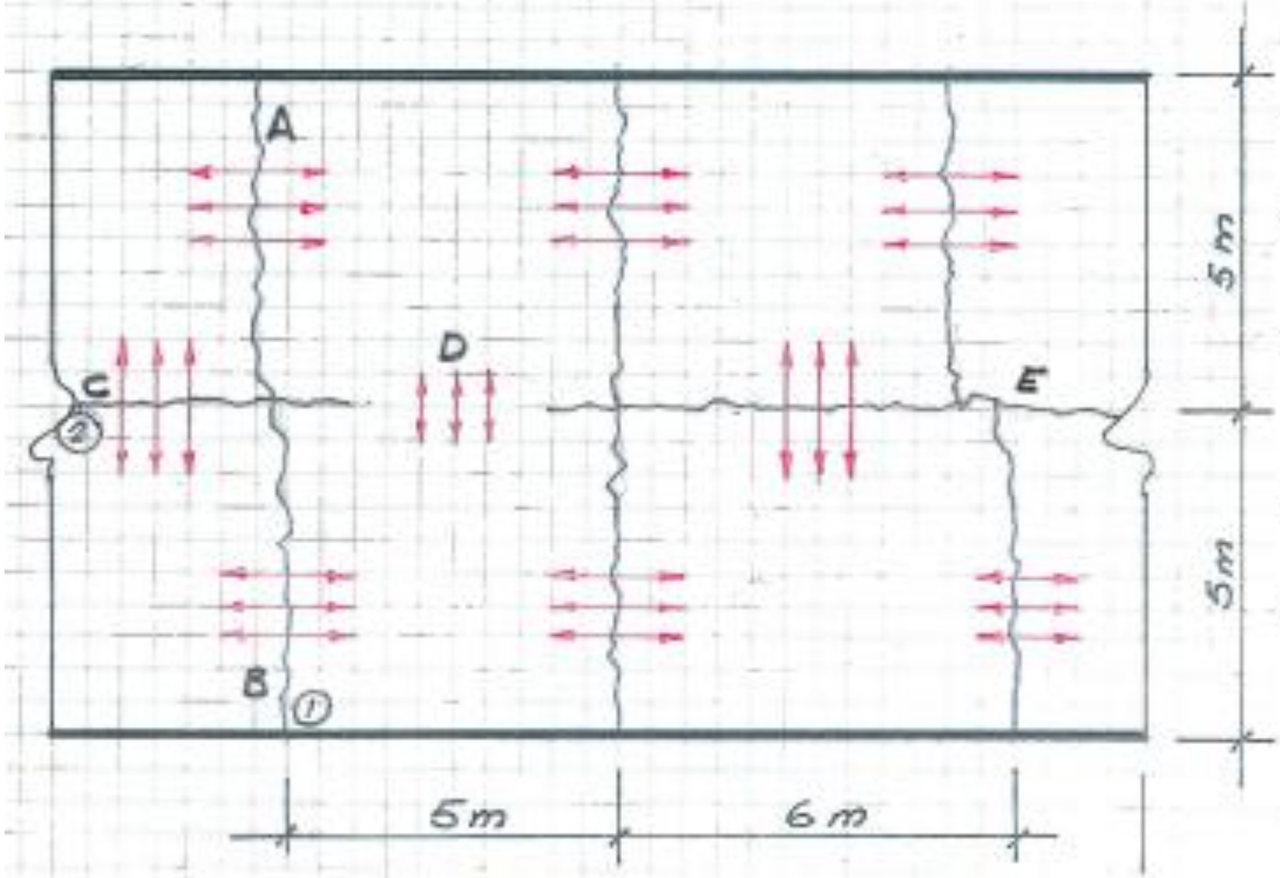
(1) **Note** – The Austroads Guide to Pavement Technology, Part 2: Pavement Structural Design (2008) defines the **Role of LMC** subbase as:
- Resist erosion of the subbase and limit "pumping" at joints and slab edges;
- Provide uniform support at joints and slab edges;
- Reduce deflection at joints and enhance load transfer across joints(especially if no other load transfer devices are provided, such as dowels);
- Assist in the control of shrinkage and swelling of high-volume-change subgrade soils.

12 POSTSCRIPT

It should be noted that the RTA internal document: "CR82 – Guide to QA Specification R82", is not a Contract Document and hence has no contractual standing.

ATTACHMENT A

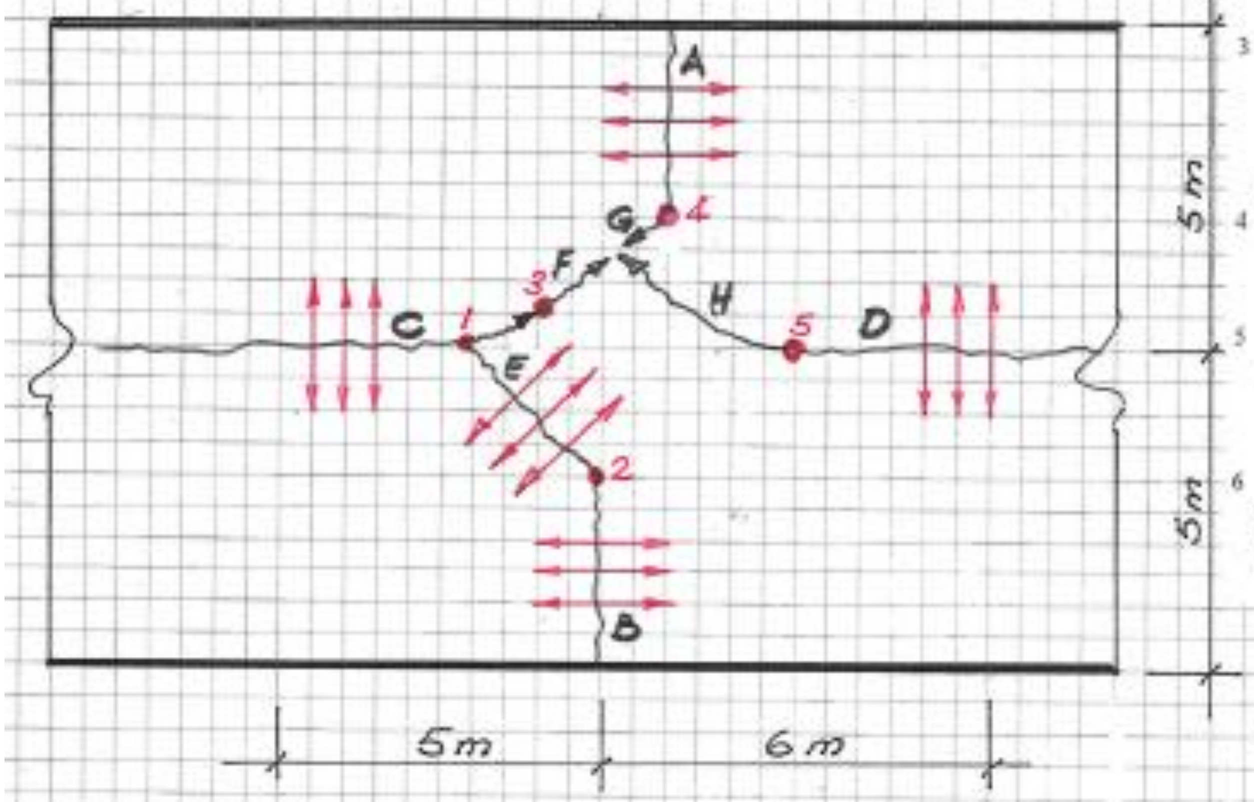
CONVENTIONAL DEVELOPMENT OF CRACK PATTERN WHEN TRANSVERSE CRACKING PRECEEDS LONGITUDINAL



1. Cracks A & B start developing from the free edges.
2. They reach the centre or even join up before the longitudinal crack C develops.
3. The wandering of the cracks is caused by the internal stress variations in the Coefficient of Friction on the underside.
4. Stresses D are too low to crack even the early strength of the concrete.
5. At E the longitudinal crack occurred before the transverse cracks met, hence the step.

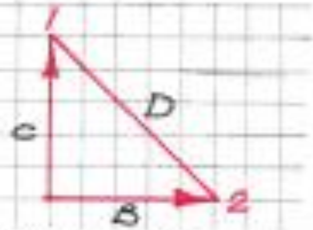
ATTACHMENT B

DEVELOPMENT OF CRACK PATTERNS WHEN LONGITUDINAL CRACKING CLOSELY FOLLOWS TRANSVERSE



"Diagonal" cracking causes chaos with internal stress directions and completely irrational crack patterns result.

1. Cracks A & B start developing from the free edges;
2. Because of high stresses, cracks C & D start developing shortly afterwards;
3. When crack B reaches Point 2 and crack C Point 1, crack directions alter as stresses along future crack E predominate (see Vector Diagram) and diagonal cracking occurs;
4. Similarly, the direction from Points 3 & 4 now also changes and diagonal cracks F & G result;
5. As crack D approaches, the distance to cracks F & G becomes shorter than to Points 3 & 4 and another diagonal crack H appears;
6. This diagonal cracking causes chaos with internal stress directions and completely irrational crack patterns result.



Vector Diagram representing stresses causing cracks B, C & D