JUNE 2005

EARLY-AGE Shrinkage of Concrete

INTRODUCTION

Once it has stiffened, set and hardened, concrete is a relatively brittle material that shrinks over time. Cracking will occur if the concrete is restrained against the movement that results from this shrinkage. While long-term (drying) shrinkage has been the focus of specifiers, recent studies have shown that the early loss of moisture from fresh concrete can produce large tensile stresses in the concrete at a very early age, leading to early-age shrinkage cracking.

The focus on long-term shrinkage has led to increasingly tighter limits being placed on the 56-day drying shrinkage of concrete in order to control related cracking. Such specifications have very little impact on early-age shrinkage and the related cracking which may occur within a day or so of the concrete being placed. This cracking is often incorrectly diagnosed as resulting from drying shrinkage at a later age.

The shrinkage models currently used in Australian Codes and Standards do not take account of the movement resulting from the early-age shrinkage of concrete. Similarly, early-age effects are not measured in standard shrinkage tests on concrete specimens. Avoidance of the adverse effect of early-age shrinkage is thus best achieved by the adoption of good site practices – particularly good compaction and control of moisture loss.

Following background information on the evidence for, the mechanism of and the influences on early-age shrinkage and the associated cracking, this Data Sheet provides recommendations for minimising it and/or the resulting cracking of the concrete.

RECENT STUDIES have shown that the early loss of moisture from fresh concrete can produce large tensile stresses in the concrete at a very early age.

CEMENT CONCRETE & AGGREGATES AUSTRALIA

EARLY MOVEMENT IN CONCRETE

General

Almost as soon as water is added to the mix, a chemical reaction between water and cement (hydration) is initiated, although its effects may not be apparent for the first few hours. The impact of this time-dependent reaction on the setting, stiffening, hardening and strength development of concrete is well documented, but the fact that shrinkage occurs in the first few hours of its life has not been adequately recognised.

Recent research sponsored by Cement Concrete & Aggregates Australia (CCAA) at the University of Queensland[1,2,3] has shown that early-age shrinkage can develop strains in concrete of similar magnitude to those resulting from drying shrinkage. These develop at a time when the concrete has very little tensile strength and hence cracking is likely.

Similar cracking may also be what is known as 'plastic cracking'. This phenomenon is well documented[4] and is associated with drying conditions and loss of moisture through the concrete surface. The fact that cracking sometimes occurs at early ages in very benign environments (eg indoors where drying conditions and moisture loss are not evident and plastic cracking therefore unlikely) is evidence of the existence of early-age shrinkage.

Early-age Shrinkage

Concrete maintains almost semi fluid properties for a few hours. Hydration reactions are very slow during the first 3–4 hours of a concrete's life but accelerate over the following 8–12 hours when the concrete changes from a semi fluid state into a more rigid one capable of cracking. The time period depends on many variables including the constituents of the concrete, the mix proportions and weather conditions.

In freshly consolidated concrete, water in the spaces between the cement and the aggregate particles exert a positive pore pressure on the mix. As the surface layer of the concrete dries out, this situation changes and the concrete moves from a saturated to a partially saturated state. This causes capillary tension in the pore water which creates a capillary suction that draws the solid particles closer together. Where the concrete is restrained from contracting in this manner the shrinkage causes stresses to develop in the external layers. Where this stress exceeds the tensile capacity of the concrete it inevitably cracks. The difference in saturation levels throughout the depth of the concrete provides more than adequate internal restraint to cause these surface or near-surface tension stresses to develop. It is principally this internal restraint that leads to early-age shrinkage cracking.

This internal restraint mechanism supplemented by external restraint from formwork, subgrade friction, member geometry, etc can lead to early cracking.

Early-age shrinkage cracks may be obvious immediately or become apparent at a later time.

- **Immediate Cracking** – Immediate cracking can be evident within a few hours due to the internal and external restraints producing stresses in the upper layers of the concrete that exceed the tensile capacity of the concrete.
- **Later Cracking** – Early-age shrinkage effects can leave a 'weakness' in the concrete that will provide a strain release point or crack propagation location in the concrete when drying conditions occur.

INFLUENCES ON EARLY-AGE SHRINKAGE AND CRACKING

The following factors have a significant impact on the extent and magnitude of early-age shrinkage and associated cracking.

Restraint Against Movement

Restraint against movement is one of the prime reasons for cracking. Restraint does not change the early age shrinkage per se but increases the tensile stress on the concrete and the likelihood of the concrete cracking. The greater the restraint, the higher the risk of cracking.

All concrete is subject to some form of external restraint and some level of internal restraint as it dries out.

Compaction

Well compacted concrete limits the amount of contraction that is possible by eliminating voids and reducing the early-age shrinkage and potential for cracking. Good compaction increases the tensile strength of the concrete and hence its ability to resist tensile stress without cracking. Voids near the surface of the concrete are of particular concern as they significantly reduce the tensile capacity of the concrete in that location and can provide sufficient weakness for crack formation.

Bleeding

Inadequate bleed water on the surface of concrete will increase the early-age shrinkage and the propensity of the concrete to crack. The rate at which concrete bleeds is more important than the total amount of bleed water in predicting whether or not the concrete will dry, shrink and crack at an early age. While bleed water remains on the surface of the concrete there can be no suction created in the capillaries of the concrete and no danger of early-age shrinkage and cracking.

Surface Drying

Surfaces that dry in the first few hours will exhibit higher early-age shrinkage and are more prone to cracking. Early-age shrinkage will lead to cracking only if the surface of the concrete is allowed to dry in the early hours of its life. This is of concern in all environmental conditions and not merely in hot or drying weather.

Very Early Protection

Protection of concrete surfaces during the first few hours will reduce the early-age shrinkage and the chance of cracking. Protection may be provided by using wind breaks, fog spraying with water or applying an evaporative retarder (eg aliphatic alcohols). The latter is frequently the most practical method; they are sprayed onto the concrete surface immediately it is screeded and re-applied after each subsequent finishing operation such as trowelling and brooming.

Recent studies have shown that this alone can stop a great deal of the cracking caused by early-age shrinkage. The aliphatic alcohols slow down the rate of evaporation from the concrete surface and hence delay the increase in the suction forces that promotes the cracking until the concrete has a higher tensile capacity and is more able to resist the developed tensile stresses.

Curing

Concrete that is not cured will exhibit greater early-age shrinkage and be more prone to cracking. It is vital to keep moisture in the concrete surface for longer than the few hours the surface protection method covers; hence it is important to initiate an adequate curing regime within a few hours of placing.

Joints

Joints in concrete paving do not affect the early-age shrinkage but are a means of relieving the strains developed as a result of that shrinkage and hence control cracking. Where joints are in place at a very early age (ie within a few hours of placing), they can limit the strain that builds up in the concrete and assist in preventing early cracking. Later forming of joints will not provide any control over early-age shrinkage cracking.

AVOIDING EARLY-AGE SHRINKAGE CRACKING

From the early-age shrinkage mechanism and the factors affecting it, it is clear that the following will reduce early-age shrinkage and resultant cracking.

- Reduce external restraint, eg reduce subgrade friction
- Provide adequate compaction
- Provide early surface protection against drying
- Adequately cure the concrete
- Provide joints early.

A successful outcome is much more dependent on these site practices than on the specification of tighter shrinkage limits – which have been shown to have little impact on early-age shrinkage and associated cracking.

REFERENCES/FURTHER INFORMATION

1 Rebibou S J, Dux P F and Nooru-Mohamed M B *Shrinkage in Concrete Pavements* Paper presented at 21st Biennial Conference of the Concrete Institute of Australia, 2003

2 Dux P F *Mechanisms and Significance of Cracking in Concrete* Paper presented at Concrete Institute of Australia Symposium, Brisbane, September 2000

3 Dux P F, Morris P H and Ribibou S J *Early and Later Age Shrinkage of Concrete* Paper presented at New Zealand Ready Mixed Concrete Association Conference, Napier, 12–13 September 2003

4 Cement Concrete & Aggregates Australia – Data Sheets
Plastic Settlement Cracking
Plastic Shrinkage Cracking
Drying Shrinkage of Cement and Concrete
Hot Weather Concreting
Download from **www.concrete.net.au**.

JUNE
2005

CCAA OFFICES

SYDNEY OFFICE:
Level 6, 504 Pacific Highway
St Leonards NSW Australia 2065
POSTAL ADDRESS:
Locked Bag 2010
St Leonards NSW 1590
TELEPHONE: (61 2) 9437 9711
FACSIMILE: (61 2) 9437 9470

BRISBANE OFFICE:
Level 14, IBM Building
348 Edward Street
Brisbane QLD 4000
TELEPHONE: (61 7) 3831 3288
FACSIMILE: (61 7) 3839 6005

MELBOURNE OFFICE:
2nd Floor, 1 Hobson Street
South Yarra VIC 3141
TELEPHONE: (61 3) 9825 0200
FACSIMILE: (61 3) 9825 0222

PERTH OFFICE:
45 Ventnor Avenue
West Perth WA 6005
TELEPHONE: (61 8) 9389 4452
FACSIMILE: (61 8) 9389 4451

ADELAIDE OFFICE:
Greenhill Executive Suites
213 Greenhill Road
Eastwood SA 5063
POSTAL ADDRESS:
PO Box 229
Fullarton SA 5063
TELEPHONE: (61 8) 8274 3758
FACSIMILE: (61 8) 8373 7210

EXTRACTIVE INDUSTRIES OFFICE
PO Box 243
Henley Beach SA 5022
TELEPHONE: (61 8) 8353 8151
FACSIMILE: (61 8) 8353 8151

TASMANIAN OFFICE:
EXTRACTIVE INDUSTRIES OFFICE
PO Box 246
Sheffield TAS 7306
TELEPHONE: (61 3) 6491 2529
FACSIMILE: (61 3) 6491 2529

WEBSITE: www.concrete.net.au

EMAIL: info@ccaa.com.au

LAYOUT: Helen Rix Design