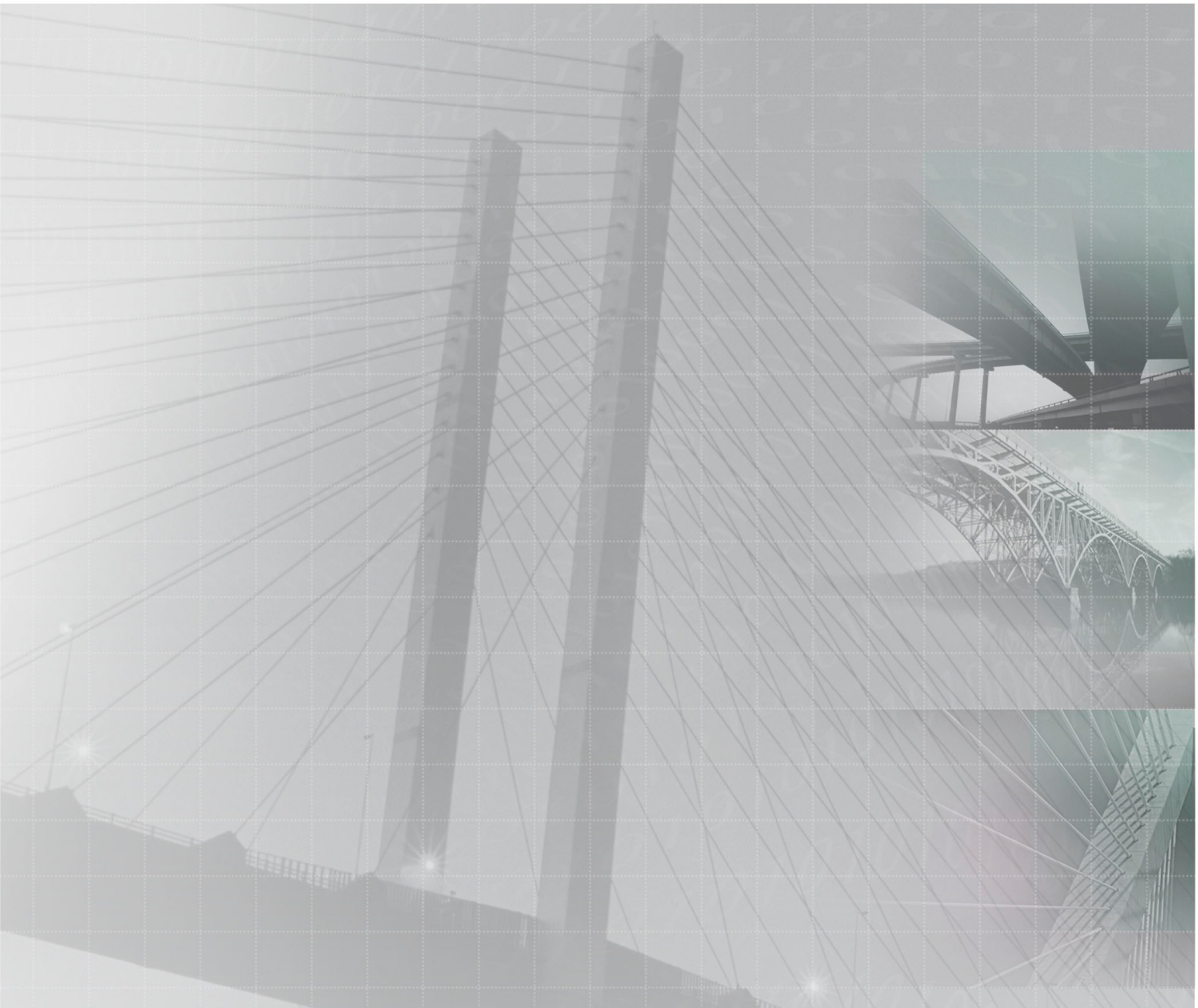

# Report number: ISI2012-17

## Plastic Shrinkage Cracking of Concrete

### Part 1: Guideline

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# 1. Introduction

The purpose of this guideline is to assist the concrete practitioner, technologist and/or specifier to estimate the risk of plastic shrinkage cracking, defined as Plastic Shrinkage Cracking Risk (PSC Risk), and evaluate methods of reducing the PSC Risk.

The accompanying commentary document discusses the mechanisms of plastic shrinkage cracking and accompanying phenomena in detail and also presents the rationale for this guideline.

Plastic shrinkage cracking is defined as the (typically sudden) development and widening of cracks within the first few hours after concrete placing due to the loss of moisture. These cracks could be further widened over time due to conventional drying shrinkage and/or temperature changes.

Plastic settlement cracking can be distinguished from plastic shrinkage cracking as it does not occur due to the loss of moisture, but due to differential settlement within a concrete body. These two phenomena often coincide and plastic shrinkage typically widens settlement cracks.

This guideline estimates the risk of plastic shrinkage cracking based on the following values:

- Plastic Period [hours]
- Evaporation Rate [kg/m$^2$/h]
- Bleeding Volume [kg/m$^2$]
- Volume of micro fibres added [optional]

These values can be determined using tests or by an estimate based on experience.

# 2. Plastic Period

The Plastic Period of concrete is defined as the period after the compaction of the concrete to the initial setting time (point of stiffening) of the concrete. For the case of self-compacting concrete it is the period from the placing of the concrete to the initial setting time (point of stiffening). Typical values for the Plastic Period (measured in hours) are shown in Table 1.

Table 1. Typical values of the Plastic Period

| | Plastic Period [hours] |
|---|---|
| Fast Setting Concrete | 1 to 2 |
| Medium Setting Concrete | 2 to 3 |
| Slow Setting Concrete | 3 + |


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The Plastic Period should be measured taking the effect of the on-site conditions into account. This measurement can be done on-site or in a laboratory. Three testing methods are proposed:

1. Using a concrete mortar penetrometer according to ASTM C 403. If done in a laboratory the concrete temperature and ambient temperature should be representative of the expected temperatures on-site.
2. Using the test for the setting time of cement according to SANS 50196-3, but sieving the fresh concrete through a 4.75 mm sieve to obtain a mortar. If done in a laboratory the concrete temperature and ambient temperature should be representative of the expected temperatures on-site.
3. Pencil test. A simplified test which can be used with some degree of accuracy is indenting the concrete surface with the sharp end of a pencil. If the pencil does not penetrate the concrete to leave a pronounced indentation on the surface when pressed lightly, the concrete has reached initial set. Note that if the surface of the concrete dries it would give a misrepresentation of the initial setting time. Evaporation of the sample should be prevented during this test. A glass or Perspex cover over a ¾ filled cube would be sufficient.

# 3. Evaporation Rate

The Evaporation Rate is defined as the rate at which surface water would evaporate from the concrete during the Plastic Period. The Evaporation Rate is influenced by the ambient temperature, concrete surface temperature, wind speed and relative humidity. It is typically assumed that the concrete surface is 6 °C warmer than the ambient temperature, but is strongly influenced by the degree of sun radiation. Typical values for the Evaporation Rate are shown in Table 2.

Table 2. Typical values of the Evaporation Rate

| | Evaporation Rate [kg/m$^2$/h] |
|---|---|
| Low Evaporation | 0 to 0.5 |
| Medium Evaporation | 0.5 to 1.0 |
| High Evaporation | 1.0 + |

The Evaporation Rate can be calculated by either using the following equation or using the nomograph shown in Figure 1.

$$ER = 5\left[(T_C + 18)^{2.5} - \frac{RH}{100}(T_A + 18)^{2.5}\right](V + 4) \times 10^{-6}$$

with ER the evaporation rate, $T_c$ the concrete temperature, $T_a$ the ambient temperature, RH the relative humidity in % and V the wind speed in km/h.

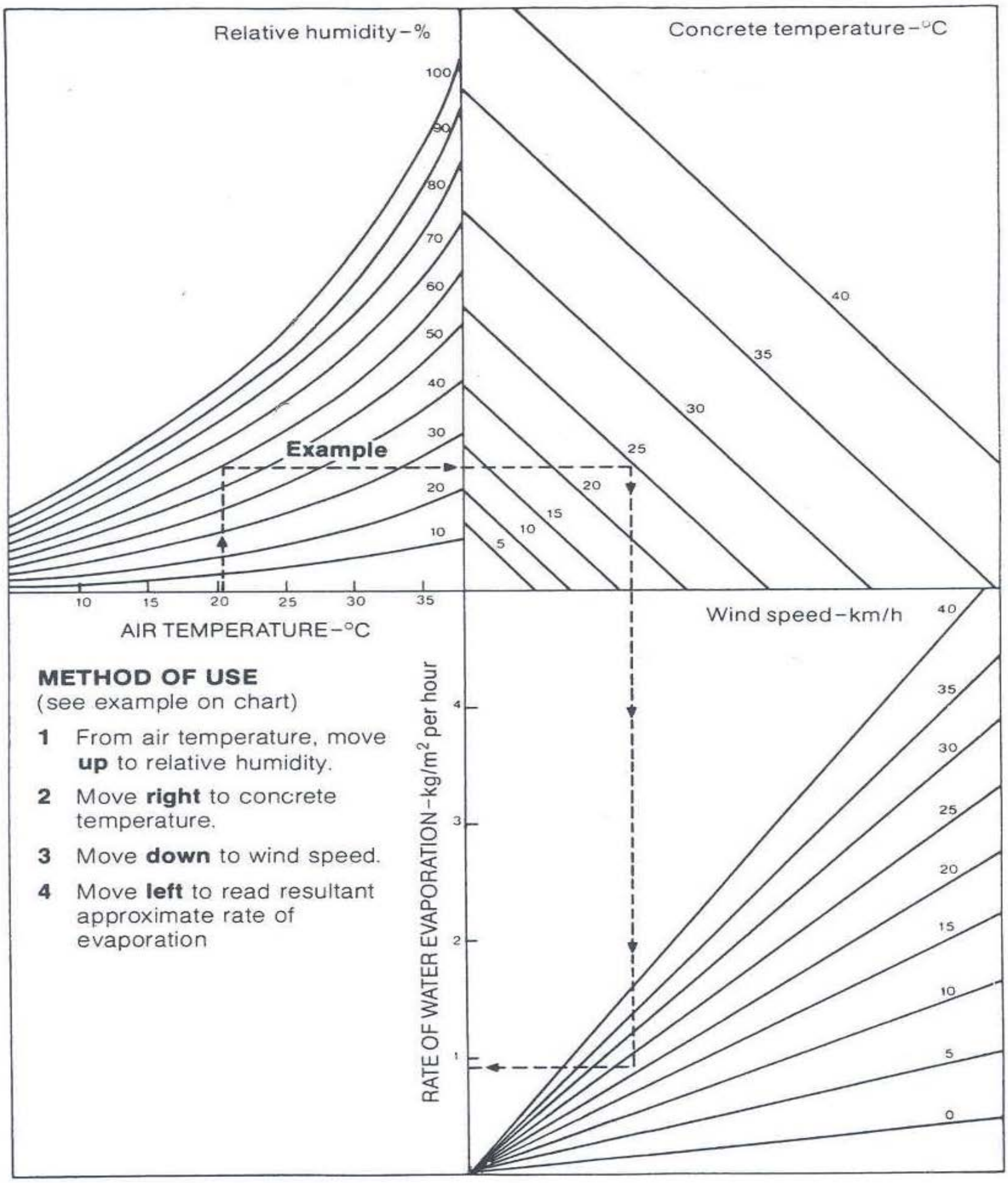


Figure 1. Nomograph to determine the evaporation rate of concrete surface water.

## 4. Bleeding Volume

Bleeding is the upward movement of water due to the settlement of the concrete particles. The Bleeding Volume is the total amount of water that migrates to the surface and is measured in $kg/m^2$. Typical Bleeding Volumes are shown in Table 3.

Table 3. Typical Bleeding Volumes

| | Bleeding Volume [kg/m$^2$] |
|---|---|
| Low Bleeding | 0 to 0.75 |
| Medium Bleeding | 0.75 to 1.5 |
| High Bleeding | 1.5 to 3.0 |

The Bleeding Volume can be measured on-site or in a laboratory. A small container with a dimension/diameter of between 100 mm and 150 mm and a depth around 20 mm more than the specific concrete member to be cast. The sample should be filled and compacted to the same depth as the specific concrete member.

The specimen should be weighed directly after compaction using a scale accurate to the nearest gram. A lid should be placed firmly on the container to prevent evaporation and left undisturbed until the concrete reaches the initial setting time. The water should then be removed from the surface by tilting the specimen slightly and extracting the water with a syringe. The specimen without bleed water should then be weighed once again. The Bleeding Volume can be calculated using the following equation:

$$Bleeding\ Volume = \frac{m_{start} - m_{final}}{A}$$

with $m_{start}$ the mass in kg just after compaction, $m_{final}$ the mass in kg after the bleed water was removed and A the surface area of the specimen in m$^2$.

## 5. Reducing plastic shrinkage cracking using micro fibres

Synthetic micro fibres can be added to the concrete mix to reduce the PSC Risk. Different volumes of fibres can be added. Note the workability will be reduced when fibres are added, and the reduction will be more the larger the volume of fibres added. The addition of fibres also typically reduces the volume of bleeding. Therefore the PSC Risk should be calculated taking the adjusted bleeding properties into account when micro fibres are added.

Figure 2 shows the effect of the addition of different volumes of micro fibres on the PSC Risk. This reduction is defined as *Fibre Risk Reduction*. Note that different types of fibre will relate to different mass of fibres for a given volume of fibres. This is due to different densities. Polypropylene (RD = 0.91) and polyester (RD = 1.3) are the most commonly used fibres for this purpose and the *Fibre Risk Reduction* with increasing fibre mass is shown in Figure 3.

The *Fibre Risk Reduction* in Figures 2 and 3 are based on typical fibre geometry. These are:

- Polypropylene: diameter of 35 µm and length of 12 mm
- Polyester: diameter of 20 µm and length of 12 mm

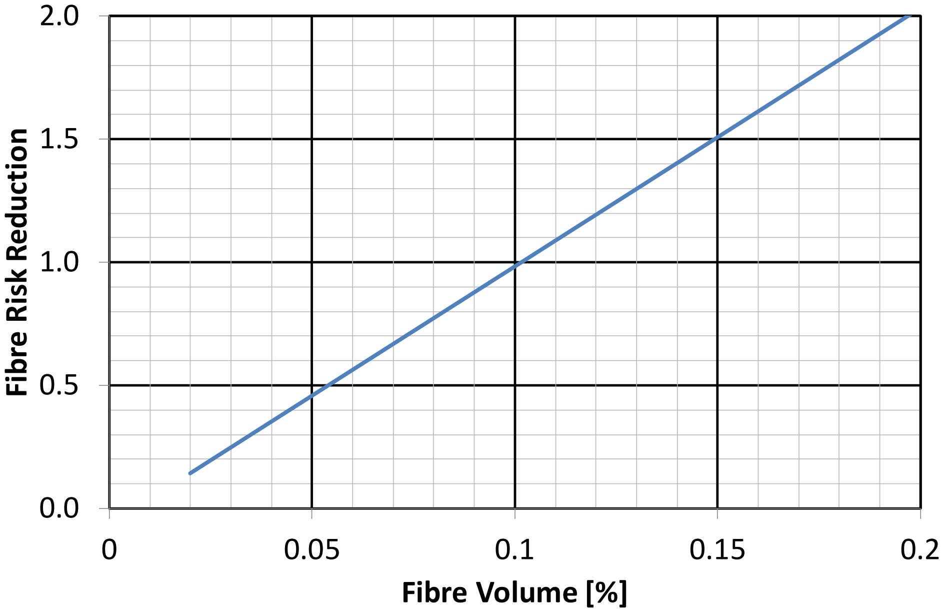


Figure 2. *Fibre Risk Reduction* with the addition of micro synthetic fibres indicated as a volume percentage.

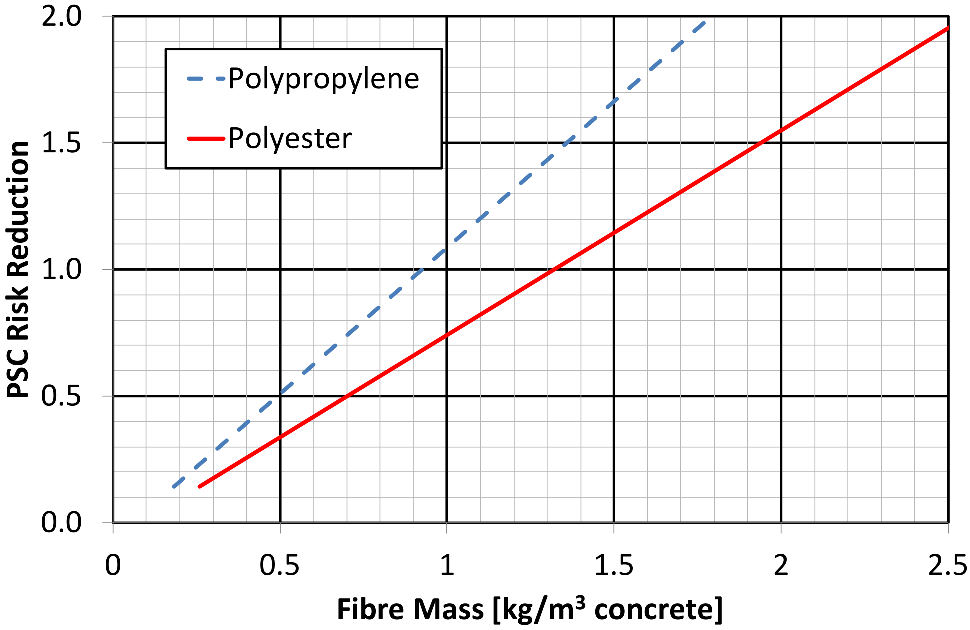


Figure 3. *Fibre Risk Reduction* with the addition of polypropylene and polyester fibres.

# 6. Plastic Shrinkage Cracking Risk

The Plastic Shrinkage Cracking Risk (PSC Risk) can be estimated with the following equation using the values calculated in the previous sections. The equation is as follows:

$$PSC\ Risk = (Plastic\ Period\ \times Evaporation\ Rate) - Bleeding\ Volume - Fibre\ Risk\ Reduction$$

Table 4 can be used to evaluate the estimated PSC Risk

Table 4. Categories for PSC Risk values

| | PSC Risk [kg/m$^2$] |
|---|---|
| No Risk | < 0.0 |
| Low Risk | 0.0 to 1.0 |
| Medium Risk | 1.0 to 2.0 |
| High Risk | 2.0 to 3.0 |

The calculated PSC Risk can be reduced by altering the conditions, mix design, construction practice and/or the (additional) addition of synthetic micro fibres.

# 7. Mitigating Plastic Shrinkage Cracking

The calculated Plastic Shrinkage Cracking Risk (PSC Risk) can be reduced to mitigate the probability of plastic shrinkage cracking. These include:

- Using a high pressure water spray above the concrete to increase the relative humidity (This will reduce the Evaporation Rate)
- Use wind breaks to reduce the wind speed over the concrete (This will reduce the Evaporation Rate)
- Protect the concrete from sun radiation to reduce the concrete temperature (This will reduce the Evaporation Rate)
- Reduce the delay in setting time (This will reduce the Plastic Period)
- Add a small volume of micro fibres (This will increase the Fibre Risk Reduction)
- Increase the bleeding of the concrete without jeopardising the quality of the concrete (This will increase the Bleeding Volume)