ANNEX G
Injection and sealing of cracks

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REHABCON
Strategy for maintenance and rehabilitation in concrete structures
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1 Introduction

It is normal with cracks in reinforced concrete structures. However, for some parts of particular structures, cracks can affect the strength, function, durability and appearance of the structure. In this cases measures have to be taken to reduce their effects. To be able to take the right measures it is important to know the cause of cracking. Depending on the time of cracking the type and cause can be determined.

<table>
<thead>
<tr>
<th>Type of cracking</th>
<th>Sub-division</th>
<th>Time of appearance</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic settlement</td>
<td>Over reinforcement</td>
<td>Ten minutes to three hours</td>
<td>Very early age</td>
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<td></td>
<td>Arching</td>
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<td>Change of depth</td>
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<td>Formwork settlement</td>
<td>Random</td>
<td>Half an hour to six hours</td>
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<td></td>
<td>Over reinforcement</td>
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<td>Parallel</td>
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<tr>
<td>Plastic shrinkage</td>
<td>Over reinforcement</td>
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<td></td>
<td>Parallel</td>
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<tr>
<td>Self desiccation</td>
<td>w/c &lt; 0.45</td>
<td>During hardening</td>
<td>Early age during the hardening of the concrete</td>
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<tr>
<td>Crazing</td>
<td>After surface treatment</td>
<td>One to seven days, sometimes much later</td>
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<td></td>
<td>Against formwork</td>
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<td>Thermal cracking</td>
<td>Surface cracking</td>
<td>One day to some weeks</td>
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<td>Through cracking</td>
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<tr>
<td>Drying shrinkage</td>
<td>One-side drying</td>
<td>One to several months</td>
<td>After part of the structure has been completed</td>
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<td>External restraint</td>
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<td></td>
<td>Differential final shrinkage</td>
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<tr>
<td>Thermal cracking</td>
<td>Surface cracking</td>
<td>During cooling to long-term ambient temperature</td>
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<td></td>
<td>Through cracking</td>
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<td>Pre-stressed concrete</td>
<td>Cracks at anchorage</td>
<td>After pre-stressing</td>
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<td>Loading cracks</td>
<td>Micro cracks</td>
<td>At loading</td>
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<td>Tensile cracks</td>
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<td>Flexural cracks</td>
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<td>Shear cracks</td>
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<td>Torsional cracks</td>
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<tr>
<td>Long-term loading cracks</td>
<td>Cracks at anchorage</td>
<td>After completion of creep</td>
<td>During service life</td>
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<td>Imposed deformation</td>
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<td>Ground settlement</td>
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<tr>
<td>Corrosion in reinforcement</td>
<td>Chloride initiated</td>
<td>More than one year</td>
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<td>Carbonation initiated</td>
<td>More than five years</td>
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<tr>
<td>Sulphate attack</td>
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<td>More than five years</td>
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<tr>
<td>Alkali-silica reaction</td>
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<td>More than five years</td>
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<tr>
<td>Alkali-carbonate reaction</td>
<td></td>
<td>More than five years</td>
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<tr>
<td>Freezing and thawing</td>
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<td>Fire</td>
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Table 1. Different forms of cracks in concrete.
Several factors can combine to form a crack. A crack, which appears later, can have been initiated earlier for a different reason.

Before initiating remedial measures, it should be considered whether they are necessary.

For fine cracks exposed to one-side water pressure autogenous healing will sometimes occur. To facilitate this the water gradient should be raised slowly. If autogenous healing will not occur within a few weeks it is unlikely that it will occur.

Some of the cracks can not be repaired with injection or sealing but the damaged concrete has to be removed e.g. at chloride initiated corrosion. There are still no good methods to treat the ASR problem.

At the selection of repair method and material it is important to know if the cracks are dormant or live, the width of the cracks and the moisture content (from dry to percolating water).

Injection and sealing of cracks is a specialist task both for advisers and contractors.

There exist two main methods to take care of sealing of cracks: Injection, which is an internal treatment, to fill most of the cracks and voids and by those means seal the cracks. Surface sealing which can be divided into two groups one with membranes applied either as liquids or preformed (bonded or unbonded) sheets and another one in which a suitable dimensioned groove is made and filled with an appropriate sealant.

Injection is the most important method and it is therefore in greater detail described. Surface sealing is also partly described in the annex “Surface treatment”


2 Injection

2.1 Introduction

Grouting is widely spread as a method of strengthening and sealing concrete. A.C Houlsby, 1990 has made a historical review of the grouting technology. Generally, holes are drilled into the structure of concrete mass in order to make the cracks or leached channels accessible to pump a fluid grout into the same. Knowledge about the grouting technique and grouting material is to a high extent founded on empirical relations and improvisation.

The purpose of the injection is to tighten (water or air tightness), protect (protect from ingress of materials aggressive to the concrete or the reinforcement) and/or strengthening (restore the integrity of the structure) the structure.

To achieve a successful repair it is important to know the properties and function of the structure, to select an injection material with the “right” properties and work out a plane for execution, which can fulfil the intended goal.
Concrete injection is treated in the European Standards EN 1504-5, ENV 1504-9 and EN 1504-10. These standards also refer to a lot of test standards.

2.2 Structure

Damage

Concrete structures are often subjected to internal damage that can impair both structural integrity and water tightness. The most common types of damage are cracks due to thermal movement shortly after pouring and porous areas due to leaching, the latter often initiated by the former. Injection grouting is often an economically advantageous method to repair this kind of damage. Grouting is in this case a method for rejuvenation of the concrete structure. The cause and extension of the damage and its influence on the structure must be made. The crack system and crack apertures are often relatively unknown. Above all these uncertainties is the fact that it is difficult to evaluate the grouting result and attempts are seldom performed.

Examination

Crack patterns, crack widths, depth and orientation must be surveyed as well as the location and size of the voids. The moisture state, cleanliness and possible movement of the cracks are also of significance. The moisture state can vary from dry to flowing water. The movements can be frequent (traffic load), daily or yearly.

The examination can be visual, include core drilling and use of non-destructive methods

Requirements

The requirements of the structure and the repaired structure as load bearing capacity, function and others like durability and aesthetics must be made clear.

2.3 Injection material

The injection material can be divided into three classes depending on their material composition

- hydraulic binders
- polymer binders
- gels

The products can also be classified in three categories according to their intended use

- force transmitting filling
- ductile filling
- and swelling fitted filling

Products for force transmitting filling of cracks are products, which are able to bond to the concrete surfaces and transmit forces across them.
Products for ductile fillings of cracks are products, which are able to accommodate subsequent movements.

Products for swelling fitted fillings are products which are able in the reacted state to swell and reswell by subsequent water adsorption, where the water molecules are bonded to the molecules of the injection products.

Hydraulic binders can be used for force transmitting fillings. Polymer binders can be used for all three categories and gels for swelling fitted fillings. Gels have no adhesion to the concrete.

The injection product must remain workable in the batch quantities used during the time required to execute the work. It must have the ability to penetrate the crack with its width and length.

The product must fulfil the requirements for water tightness, strength and bonding for the present moisture state and possible movements during hardening. The product must also be compatible with the concrete, the reinforcement and possible water stopper.

Each category of grouts has its advantages and disadvantages. The main advantages of cementitious injection grouts are their low cost, compatibility with the environment, the binder is the same as for concrete, predictable durability and possibility to repeat the injection in the future. Other benefits are the environmental friendliness and that they can be handled without special safety equipment for the workers. The disadvantages, compared to the solution grouts, are the limited penetration ability.

Penetrability is a summarised term for the grout ability to penetrate crack apertures, cracks and channels. The limiting factor can be rheology (Bingham behaviour) if the grout is characterised as a homogeneous fluid (Paoli et al, 1992), or plug formation when the grains stick together. The ability of a grout to penetrate cavities, channels and porous material, the penetrability, depends on two things, the rheology and the filtration stability. The Bingham behaviour can be limited by the use of super plasticizers. Extensive laboratory tests on stable, low w/c-ratio, injection grouts show that the most significant limitation to their penetrability is the tendency of cement grains to agglomerate into an impermeable filter cake. The ability of a grout to pass constrictions of the flow path without clogging can be designated filtration stability (Alemo, Hansson (1997), Eklund (2003)).

Figure 1 Arches and agglomerates are formed at the entrances of cracks (Alt. 1) and at changes of crack width (Alt. 2), which obstruct further penetration of the grout. Hansson P. (1994)
The filtration stability of a grout is not solely governed by the maximum particle size of the cement as important is the concentration of grains (w/c-ratio), the chemistry of the pore water and the grain size distribution. Exactly which the properties are that influence the penetrability, and the magnitude of the influence, are still not entirely understood. Filtration stability becomes the property that dominates the penetration ability of the grout when the aperture width is in the range of 0.3 mm or less, according to performed tests at Vattenfall Utveckling (Alemo, Hansson, 1997).

A method of assessing the penetrability of a grout by measuring the filtration stability has been developed at Vattenfall Utveckling AB (figure 2). The testing is performed on fresh mixed grout and properties as cement quality, admixtures and mixing efficiency that affect the penetrability are considered. Filtration tests give a more reliable prediction of the penetrability than traditional rheological measurements.

![Figure 2 Filtration stability measurement device](image)

The measuring device can be used both in laboratory experiment and for field-testing of cementitious-based grouts.

A cementitious-based grout should have very low bleeding so all the cracks will be filled with high quality grout.

The injection product and procedure must be harmless for the environment and the workers using prescribed safety equipment.

### 2.4 Execution

The execution can be divided in four parts, preparation, equipment, execution and control.

**Preparation**

This part includes a detailed plane for drilling, drilling, cleaning of the drilling holes and cracks, placing of packers and possible sealing of cracks to get a counter pressure.

Core drilling, which is more expensive than hammer drilling, usually produces sharper edges between the hole and the crack, which improve the penetrability.
Cleaning of the holes, cracks and voids from the waste of the drilling are very important for the result of the injection. Cleaning the drill hole with a water jet or similar device has in certain grouting project been a determining factor for penetrability.

It is important to find out which drilling holes which are in contact with each other when the execution is planed. If several holes are in connection to each other it is important to measure the grouting pressure in at least two of the holes. The registration makes it easier to analyse the spread of the grout between the holes.

**Equipment**

Among equipment can be mentioned, mixer, storage vessel, pump, pressure measure, packers and registration equipment. It is of great importance that the grouting equipment is in good shape and cleaned properly. Dirty wearied equipment contributes to a lower penetrability of the grout. Cementitious-based grouts are generally more difficult to mix than polymer- or gel based ones, in order to get a good penetrability. The higher demands of mixing efficiency in the cementitious based grouts, means that the equipment often has to more advanced.

**Execution**

A detailed plane for the execution must be made. This includes the sequence of the holes to be injected, allowable pressure and at what conditions the injection of a hole should be interrupted. The cracks in the concrete structure are often sealed with grouting when using grouting as a repair method. Shallow holes are drilled in the structure with a fixed distance between them. Packers are mounted and the grout is pumped into the structure, the grout will then create a lid. The lid makes it possible to create a counter pressure, which is of importance for the grouting operation. The distance between the holes are determined by the crack aperture, crack depth and the penetrability of the grout. Usually the packers are mounted at a distance of 0,5-1 m.

The grouting of the crack starts at the lower end of the crack and continues to the next packer when the grout reaches the next packer. The allowable grouting pressure is determined due to the spread of the grout and the strength of the structure. If the grout is spread across a large area it can give rise to large forces inside a structure.

**Control**

A plane for the control should be worked out, which include which measures should be taken if the requirements are not fulfilled. Important parameters to log are:

- Grouting pressure \([P]\)
- Flow of grout \([Q]\)
- Used receipt.

Except the three parameters above, it is useful to analyse the quotient of the flow/ pressure \((Q/P)\). The quotient can give useful information about the progress of the grouting work. The quotient should be lower (a) when the grouting time passes, to achieve a successful grouting operation. A rising quotient (b) indicates that the grouting is not working properly, see figure 3.
3 Surface Sealing

At surface sealing of cracks it is important to make the sealing on the most humid side of the structure. A sealing on the wet side will better withstand possible water pressure and there is less risk for increase of the humidity behind the sealing, which can lead to frost damage. There are examples where sealing on the wrong side have decreased the durability. As mentioned earlier there are two different methods of surface sealing of cracks. One to make a groove and fill it with an appropriate sealant and the other to use membranes, which can either be applied as liquid or sheet.

3.1 Grooves

This method is usually used for live cracks. The width of the groove is dimensioned in such a way that the total movement will not exceed about 25% of the width. Special care should be taken if the movements are cyclic. The depth of the groove is dependant on the type of sealant.

Three different types of sealants are used namely mastics, thermoplastics and elastomers. These groups consist on their part of different related materials.

Mastics are cheap, they remain plastic and may not recover their original profile and should not be used at cyclic movements. The total movement should not exceed 15% of the width of the groove. The groove should be cut so that its depth is twice the width.

Thermoplastics are poured at a temperature usually above 100°C. The total design movement is about 25% of the groove width. The depth/width ratio of the groove should be about 1. Some of the materials become hardened and lose elasticity after a few years exposed to sunlight.

Elastomers can be one-part or two-part materials. They have usually excellent adhesion to concrete and have an elongation capacity of more than 100%, but in practice this should be limited to about 25%. The groove depth/width should be about 0,5. It is important to prevent the material to adhere to the bottom of the groove.
### 3.2 Membranes

Membranes as preformed sheets can be used to cover just the crack or the whole surface.

For strait live cracks flexible strips can be used. These are usually only bonded at the edges of the strip by the use of a strip of masking tape or other debonding agent. A disadvantage is that if water comes in, the debonded area can work as a channel.

Joints from sheets covering larger areas are usually bonded or welded to achieve a continuous water barrier.

Membranes applied as liquids are treated in the annex “Surface treatment” and are therefore not treated here. Some of these membranes have also crack bridging capacity.
REFERENCES

EN 1504-5, “Products and systems for the protection and repair of concrete structures – Definitions - Requirements – Quality control and evaluation of conformity – Part 5: Concrete injection”

EN 1504-9, “Products and systems for the protection and repair of concrete structures – Definitions - Requirements – Quality control and evaluation of conformity – Part 9: General principles for the use of products and systems”

EN 1504-10, “Products and systems for the protection and repair of concrete structures – Definitions - Requirements – Quality control and evaluation of conformity – Part 10: Site application of products and systems and quality control of the works”


