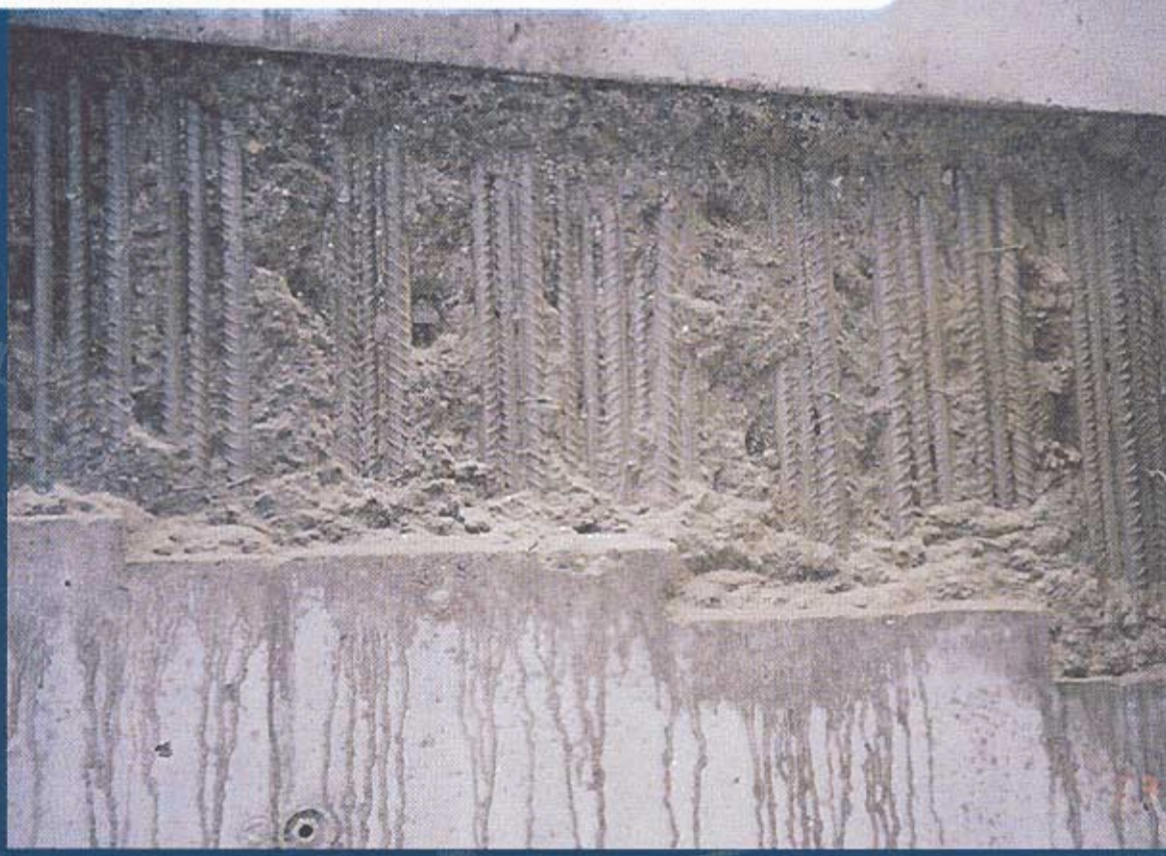
HETEK

Repair during the construction phase
State of the art



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STATE OF THE ART
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STATE OF THE ART
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Authors: Ole Viggo Andersen, Anders K. Christoffersen, Bodil Børgesen, Bent Foverskov

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Abstract: The State of the Art report contains a survey and an evaluation of current technology of repairs of concrete defects and non-conformities during the construction phase. The report conserns classification of defects and non-

List of contents

1. Introduction

The report is prepared by Consulting Engineers Nellemann, Nielsen and Rauschenberger A/S, represented by:

- Ole Viggo Andersen (Project manager)
- Anders Kirk Christoffersen
- Bodil Børgesen
- Bent Foverskov
- Bjørn Eriksen
- Lisbeth Hastrup

and by contractors, represented by:

- Jan Åke Anderson, SIAB/NPL
- Jørn Asmussen, LANDCON

1.1 Purpose

The purpose of the State of the Art Report is to present current technology used by contractors in recent jobs and discuss handling of repair methods, identification and evaluation af defects, work procedures, performance of repair materials, testing and acceptance criterias.

On the basis of the State of the Art, recommendations for further research and guidelines are suggested.

Definitions and terminology are described in the appendix 1.

1.2 Background

The report correlates information from reports of initial studies including the following reports, which is parts of the studys concerning HETEK the contractors technology. Program 8 repairs in the construction phase.

8.1 Non-conformities of concrete
8.2 Work procedures for repair
8.3 Repair materials
8.4 Testing methods and acceptance criterias
8.5 Illustrations

2. Summary

The report is based upon experiences from current large construction work sites for the bridge projects in Denmark, including the point of view of the supervisors and the contractors, and on generally accepted codes of practice and literature references.

Experience and information from other research projects, such as the BPS: Typical work procedures for repair of concrete, ref. [27], are also included.

Background also includes the specifications as prepared in the Road rules of Road Directorate ref. [11], ref. [38] and ref. [45].

The State of the Art Report is based upon the following initial studies:

- Inspection and evaluation of defects [15]
- A survey of current work procedures and specifications [41]
- A survey of current repair materials [42]
- A survey of current testing methods and acceptance criterias [43]

On the basis of project requirements, the contractor prepares work procedures and instructions for repair of defects. Typical defects are:

- Cracks
- Holes and honeycombs
- Air voids
- Minor surface defects
- Wrong dimensions
- Too little or too much cover
- Depressions
- Holes from drilled cores

Defects are evaluated with respect to durability, function, aesthetics and economical consequences, including dimensions and extension of the repair job in question. Defects are divided into the following classes:

- Defects of no significance
- Defects which can be repaired as finishing work
- Defects of little significance which can be repaired according to routine work procedures.

- Large defects which are considered of great significance demanding special investigations and evaluations and special specifications for the repair procedures.

From studies of the work procedures as used for large bridges the following has been observed:

- Operatives are tested regularly

- Repair materials are tested on "trial pours"

- All defects which require repair are noted on an inspection record sheet

- Specifications of repair materials are based on the supplier's information

- Filling materials are usually registered in a declaration system such as REPTON. REPTON is a Danish orgainzation for suppliers of repair materials, which control the documentation of repair materials.

- Testing of the finished repairs is usually based on visual inspection of cores and bond tests

- Routine work procedures are based on repair with filling materials or injection with epoxy

Existing guidelines include general specifications for repairs with filling materials such as concrete, shotcrete, mortar and injections.

Thus, there is a lack of practical guidelines for the work procedures and quality control.

There have been made no observations so far of the performance of repairs after a long period of exposure.

Evaluation and recommendations
It is recommended that further studies of the repair should include:

- Investigations of the performance and durability of repairs made several years ago.

- There should be prepared general accepted guidelines for work procedures which cover the following processes:

  - registration and evaluation of defects
  - specification of routine repair materials
  - testing of "trial pours"
  - testing of operatives
  - testing of the repair.

3. Inspection and evaluation of defects

Current practice of inspection and evaluation of defects in the construction phase comprises the following routines:

- Initial inspection after form stripping
- Evaluation of defects and selection of repair methods and materials
- Execution of the repairs including preparation and final treatment
- Inspection during the repair process, testing and final report

3.1 Initial inspection

Inspection of concrete constructions are performed in connection with form stripping or after the cooling process. The inspection procedure includes:

- Registration of defects, indentification, localization and extent

- Crack size measurement - as a result of the cooling process, alterations of crack sizes may occur, and significant variations have been recorded until 3 months after form stripping

- Cover control should be carried out with non-destructive measuring equipment in combination with measurements in drilled holes. The number of measurements should be adjusted to the actual conditions and the visible signs of defects.

3.2 Evaluation of defects

On basis of the above mentioned registrations, the consequences of the defects are evaluated on basis of the following parameters:

- **Bearing capacity** should be evaluated in connection with all kinds of defects. Large defects may require supplementary investigations and calculations to ensure that the safety and function of the construction are preserved.

- **Aesthetic demands** are included in the assessment of damages localized on visible construction parts, e.a. side beams and columns.

- **Durability and environmental impacts** are already defined as specially aggressive environment, but still there might be a need to evaluate the location of

the actual construction part in the construction, as the local conditions of exposure are important in the classification of the non-conformity.

- **Economical consequences** for the scheduled construction work are assessed on basis of an evaluation of the repair work.

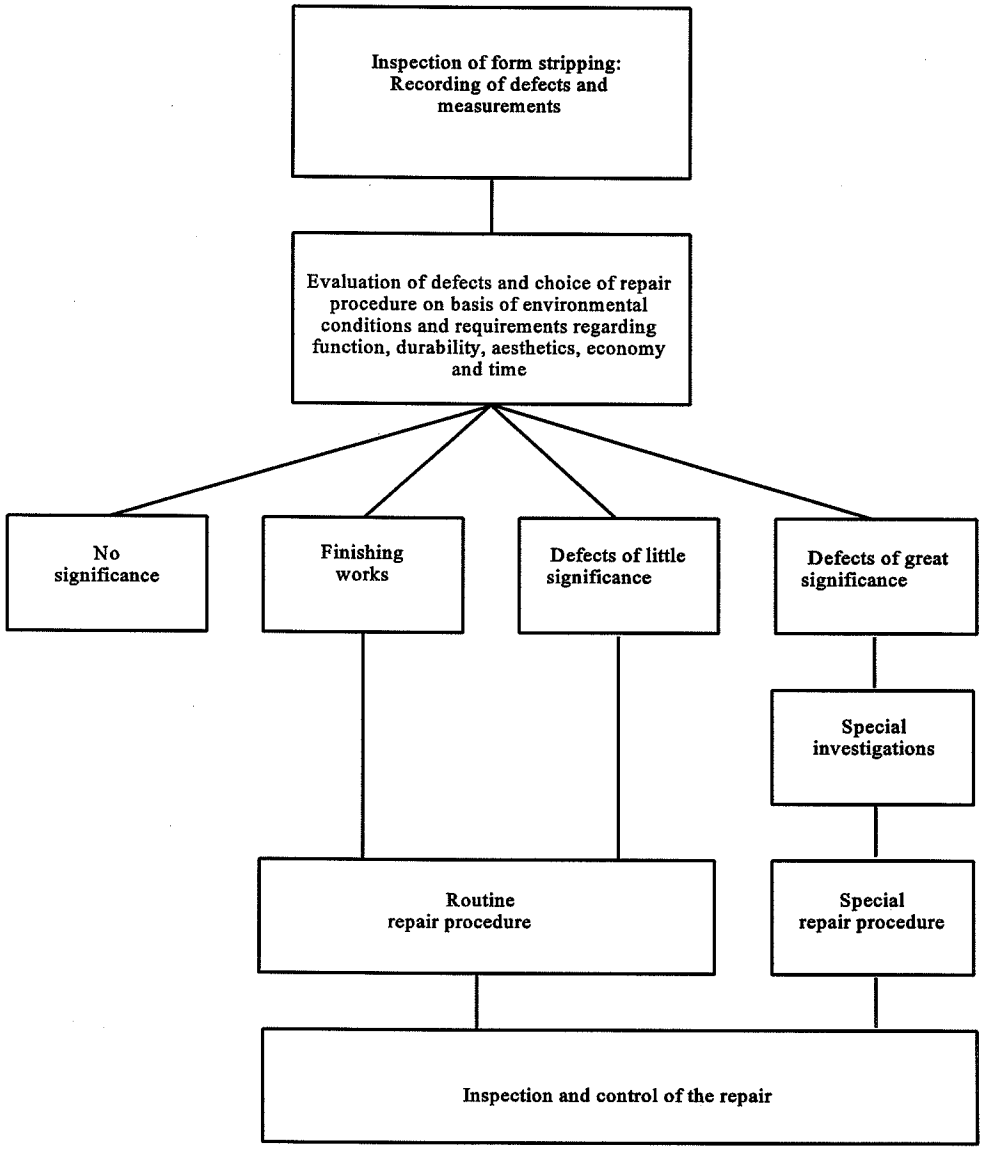
On basis of these considerations, it is evaluated whether the defects are of little or great significance - or of no importance at all.

In principle, insignificant defects can be left unrepaired.

Investigations of significant defects are dependent on the type and the extent. In this connection it is evaluated wheather the individual non-conformities are to be considered **small** or **large**.

Small defects open up the possibility that the contractor can choose a routine work procedure. Large non-conformities require thorough investigations and evaluation of possible remedial actions, which may involve other parties.

The following figure shows the handling procedure of concrete repairs in the construction phase:



Ill. 1. Procedure of inspections and repairs in the construction phase

3.3 Execution of the repair process

The first part of the repair process consists in preparations such as removal of damaged concrete and cleaning and preparation of base prior to execution of the repairs. Often it is not possible to lay down precise criteria for the amount of damaged concrete to be removed, for example in connection with repair of honeycombs. Furthermore, it will often be desirable to perform a current evaluation of the quality of the concrete base, as the removal of damaged concrete and cleaning might reveal damages which were invisible at the surface.

The second part consists in the application of the repair materials and finishing, incl. curing.

The work procedures can be divided into the following categories:

- **Finishing work** are repairs which can be planned, and therefore to be specified as routine repair work procedure before start of casting. Finishing work comprises repair of the following types of damages: Burrs and irregularities and cavities in the surface, pores, clamp holes, cooling pipes, holes from drilled cores.

- **Routine repair procedures** relate to defects arisen in the production and execution phase, which are of only little significance as regards economy, durability, function and aesthetics, and which occur because of errors in the production. Routine repairs concern the following types: Small honeycombs of a limited extent; too small and too thick covers influencing the durability; irregular geometry; smaller settlements, small cracks of only little significance for durability; small cavities around joints.

- **Special repair procedures** are large repairs with significance as regards economy, time schedules, durability, function and aesthetics. The special repair procedures comprise the following types: Large honeycombs; too small and too large covers influencing the durability, or localized in critical areas; irregular geometry exceeding the given standards; large cracks of significance to durability and larger cavities around joints.

3.4 Inspection during repairs and after completion

Often it is necessary to carry out inspections during the execution of work to adjust the demands to the execution of repairs, including preparations.

In connection with the Client's supervision of the quality of the work, current inspections, including recordings of non-conformities, etc., are carried out.

At the latest, by the end of the work, the repairs are inspected to ensure that they are of the required quality.

The final inspection includes testing of adhesion, visual inspections of the surface and of samples and cores.

4. Defects

Typical defects recorded in connection with production of high performance concrete:

- Cracks
- Cavities
- Holes and honeycombs
- Wrong dimensions
- Too little or too much cover
- Depressions/cavities
- Cavities around waterstops
- Holes from drilled cores
- Cooling pipes
- Clamp holes
- Air voids
- Minor surface defects

In the following, each defect is described and recommendations for evaluation whether to treat the defects as finishing work or as defects of a little or great significance based on general experiences of construction function, durability and economical consequences are given.

In each case, the evaluation should be adapted to the actual conditions, the environment and the demands to the construction, and the given guidelines/limit values should be considered as guiding experience.

Significant non-conformities in the pore structure of the concrete, strength, too high water/cement ratio, etc. are generally considered as defects of great significance demanding further inspection and evaluations.

Cracks
Cracks occur in connection with production of concrete constructions and are caused by:

- Early-age thermal cracks
- Settlements
- Plastic shrinkage og drying
- Structural impacts

Characteristic symptoms

- Early-age thermal cracks caused by changes in the temperature in the concrete profile. Changes in temperature can occur as a consequence of the hydration of the concrete, developed by the chemical reactions in the concrete, air temperature, and the temperature in adjacent casting joints.

- Cracks might occur as a result of inadequate compaction due to a too stiff concrete not sufficiently compacted. The cracks can be through-going and are often occuring at the bottom of a casting.

- Cracks might be caused by settlements in the new cast concrete as a consequence of the downward movements of aggregates and may result in cracks in the surface along the reinforcement and form edges.

- Settlements may also occur as a consequence of movements of the form.

- Plastic cracking due to evaporation from the surface of the new cast concrete.

- Shrinkage cracking due to drying of the hardened concrete can result in through-going cracks.

- Cracks can also occur as a consequence of static damages from bending, shear, crushing, anchoring defects, splitting and tension.

Cracks can be divided into single cracks and map cracks. Cracks can occur in the cover and be limited to the top layer, or as through-going cracks allowing transport of fx water through the construction or parallel to the surface.

Cracks can occur at an early stage in connection with form stripping or later in the curing process during the after treatment, or in connection with general use.

Assessment of cracks

The size and extend of the cracks can vary in the course of time. The cracks are divided into moving cracks and static cracks. The crack size is measured as the crack width, and length or number per m^2 at the surface of the concrete or at (drilling) cores - as a visual inspection and/or as a structural analysis in microscope. Cracks parallel to the surface can be localized by means of acoustic measurements.

Following general guidelines can be given for the classification of cracks:

Map cracks and single cracks are considered to be of little significance - or none at all, if the crack width is less than 0.2 mm.

Larger cracks of a width exceeding 0.2 mm are considered of little significance, provided the crack is not through-going and only occuring in a small area, i.e. smaller than 1 m and not under constant water pressure.

Map cracks and single cracks of a width exceeding 0.2 mm spread over an area larger than 1 m/1 m², and cracks under constant water pressure or caused by lack of bearing capacity are generally considered of great significance. Furthermore, constructive cracks of a width exceeding 0.2 mm.

Holes and honeycombs
Holes and honeycombs can occur during the production as a result of inadequate compaction of the concrete. Holes and honeycombs in the concrete surface can occur as a result of accidents in connection with handling of tools, insufficient coating oil at the form work, inadequate concreting/vibration of the concrete or

Characteristic symptoms
Holes and honeycombs appear as a porosity in the surface, and appear as superficial honeycombs in the concrete cover or as holes of a depth until or beyond the reinforcement.

Assessment of holes and honeycombs
Several honeycombs in the same casting (or at the same surface) might indicate generally inadequate compaction of the concrete resulting in reduced strength and durability.

Guidelines for honeycombs:
Honeycombs are in general considered of little significance if height and/or width are less than 2 mm, if they appear singly, i.e. only one in each casting, and only in construction parts which are not under constant water pressure.

Honeycombs or holes are considered of great significance if height and/or width exceed 2 mm per 2 m, if there are more than one in each casting, if it is honeycombs under constant water pressure, through-going honeycombs or holes in the concrete walls, etc.

Wrong geometrical dimensions
This type of defects might occur if the dimensions of the form are incorrect, or if the form has slipped during concreting.

Characteristic symptoms
Deviations from limits can occur in smaller or larger scales. The deviation itself can also be smaller or greater and with this more or less visible.

Assessment of deviations from limits
Deviations in geometry can have an influence on the function of the construction (eg. structure clearance) or aesthetics.

Deviations from limits which are normally estimated to be of little significance are deviations causing an increase of the cover thickness and which do not occur in a larger scale and which are of little importance to function and aesthetics.

Deviations causing a reduction of the cover thickness which occur in a larger extent or exceed limits for the function of the construction are estimated to be of great significance.

Too little or too much cover
Wrong cover thickness can occur as a consequence of wrong geometry of the form work, slip of the form in the concreting process or if the reinforcement moves during the concreting process.

Assessment of wrong cover thickness
Cover can be registered by non-destructive measurement, e.g. cover metre or x-ray supplemented by the drilling of holes. If the cover thickness is less than dictated the deviations can have an influence on the durability of the concrete/reinforcement. Deviations can be of importance to the load-bearing capacity of the construction.

Deviations of the cover are considered of little significance when the cover varies locally with less than 15-20 mm (depending on the total cover), or when the cover thickness locally is larger than specified.

Cover thicknesses which deviate more than 15 mm from the specifications and/or occur extensively are consideres of great significance.

Settlements etc.
Settlements can occur as a consequence of settlements in the fresh concrete.

Characteristic symptoms
Depressions or cavities in the upper side of concrete floors.

Assessment of depressions
Small depressions occurring to a small extent have no influence on the durability of the concrete. Large or numerous depressions, depressions uncovering the reinforcement or reducing the cover thickness substantially can cause a reduction of the durability of the concrete. Furthermore depressions can cause unsatisfactory drainage conditions.

Depressions are of little significance if the depth is less than 4 mm per 1 m and if they do not occur in a larger scale.

Depressions are of great significance if the depth is more than 4 mm per 1 m or if they occur in a larger scale.

Holes by waterstops
Holes by waterstops can occur as a consequence of the waterstops not being sufficiently secured or if insufficient compaction has been made.

Characteristic symptoms
Especially waterstops in the middle of joints are difficult to secure in the right position and to obtain complete encasing with a correct placement of casting joint.

Assessment of holes by waterstops
Holes by waterstops are estimated to be of great significance.

Holes after the removal of drilled cores, cooling pipes, clamp holes etc.
Holes occurring as a consequence of sample-taking or in connection with embedded cooling pipes and clamps etc.

Characteristic symptoms
These holes are considered as finish works, which are defects known in advance.

Assessment of holes occurring after sample-taking etc.
These holes are estimated to have no influence on the strength and durability of the concrete, if the sample-taking or removal of cores have incurred no unnecessary damage to the concrete..

Air voids
Air voids in the surface of the concrete can be a consequence of wrong compaction of the fresh concrete or too dense forms with a geometry where it is difficult for the air to get out.

Characteristic symptoms
Airholes in the concrete are seen as small and large holes on the surface.

Assessment of air voids
Differentiation is made between single air voids and air voids which occur in groups. Furthermore, several air voids at the bottom of a casting can indicate that the air has not been driven out by vibration.

Air voids are in general of little significance.

Minor surface defects
Minor surface defects can occur as a consequence of inaccurate form work.

Characteristic symptoms
The defects will be seen as 'bumps' on the surface in a smaller scale.

Assessment of minor surface defects

Minor surface defects will normally be seen as a cosmetic problem which does not influence the function and durability of the concrete. The discrepancies will be treated as finish works if they are in a scale that does not incur financial consequences.

5. Repair procedures

Routine repair procedures for finishing works and repair of minor defects are specified by the contractors before casting the concrete structures. Routine repair instructions can be classified as follows,

- preparations
- smoothing
- filling with mortar, concrete and shotcrete
- repair of cracks

Based on the experiences from the execution of recent concrete structures principles and general guidelines are described in the following work procedures.

Overleaf, illustration 2 gives a survey of routine repair procedures for finishing and overhaul of non-conformities of secondary importance.

Defects	Preparations	Routine repair procedures	Comments
Honeycombs and cavities, non-conformities regarding tolerances, concrete cover and settlements	- Cutting away/intersection - Pneumatic removal of concrete/dust - Water jet cleaning	1. Manual application of mortar or concrete 2. Casting with concrete or mortar 3. Shotcrete	- Particularly applied for downward surfaces - Not suited for downward surfaces - Specialized contractor requested; not to be applied on horizontal surfaces
Air voids	- Water jet cleaning	1. Smoothing	
Minor surface defects	- Grinding or cutting away	-	
Holes from core sampling, clamps etc.	- Water jet cleaning	1. Manual application of mortar or concrete 2. Casting with concrete or mortar	- Suitable for downward surfaces - Not suitable for downward surfaces
Cracks - not exposed to water pressure	- Cracks and surface cleaned with compressed air or by water jet - Injection nipples are installed	1. Injection 2. Filling with mortar 3. Sealing	- Demands specialized contractor - Easy accessible method. Particularly suitable for cracks below 0.2 mm and/or static cracks.

Ill. 2: *Conspectus of routine repair procedures for finishing and overhaul of non-conformities of secondary importance.*

5.1 Preparations

Preparations of concrete structure consist of removal of concrete with defects, if necessary, with succeeding surface cleanup.

Honeycombs and cavities

By means of a right-angle grinder a track, the depth of which must be min. 10 mm, is made with a clear spacing of at least 20 mm to the part of the concrete which is to be removed. As a better alternative the track may be cut in an angle of 45^{o} and the surface shall be sandblasted. Bad quality concrete is cut away by means of a chipping hammer or water jet at hight pressure more than 500-700 bar.. Loose concrete and dust are to be removed by means of compressed air. The surface is made ready by water jet cleaning at max. 200 bar.

Air voids
Application of water jet cleaning at max. 200 bar for removal of loose particles and dirt.

Minor surface defects
Minor surface defects are cut away or grinded until geometry conforms to the proposed features.

Non-conformities to tolerances
In principle, the methods described under **Settlements** and **Minor surface defects** can be applied on settlements and peaks which do not comply with tolerances of dimension, provided that the cover thickness makes it possible.

Incorrect cover thickness
If the cover is too thin, the following procedure may be applied: The limitation of the area in question is cut into a sharp, approx. 5 mm deep, edge. On visible surfaces straight lines, vertically and horizontally, are cut. The local area is chipped in small spots with a distance of app. 0.25 m. The surface is made ready by water jet cleaning.

As an alternative the reinforcement can be exposed by removing the concrete and then the reinforcement surface shall be cleaned by water jet before surface treatment

Settlements etc.
The limitation of the actual settlement is cut into a sharp edge, approx. 5 mm deep. The bottom of the settlement is cut in such a way that the concrete surface is grained. The surface of the settlement is made ready by water jet cleaning.

Holes from core sampling, clamps etc.
The cavity in question is made ready by water jet cleaning at max. 200 bar.

5.2 Smoothing

Application:	The method of smoothing air voids of little significance, and in occurence of small settlements below 10 mm's depth. Usually, plastering with small-grained repair mortar is applied.
Work procedure:	When water jet cleaning is accomplished, the concrete base is usually watered in such a way that the surface is saturated, but dry at the surface. The mortar is applied and processed with trowel, and, possibly, spattle and skimming board, until all air voids are filled in. When the mortar is almost set, surplus mortar is wiped off, e.g. by burlap, in such a way that only air voids are filled in. The hardening process ought to be accomplished without impact from bright sunshine, rain, or high wind. Treated

areas ought to be protected against drying up for approx. 4 days.

5.3 Filling in

Filling in is accomplished where large layer thicknesses are needed. Filling in can be performed by manual application of mortar, and by casting with concrete, mortar, or shotcrete.

Method 1 Manual application of mortar

Application	At vertical and horizontal surfaces. May be applied in connection with repair of settlements (5-20 mm), honeycombs, limited cavities, the layer thickness of which is less than 20 mm, cavities and holes from cores, sampling etc.
Working instructions	After accomplished preparation of the concrete layer, the concrete base is saturated, byg dry at the surface before the filling in. The mortar is applied, and correct compaction of the mortar is of great importance. When the filling in is accomplished, the mortar must be protected against drying up, sunshine, wind, and rain for 5 days. The surface must be smooth and without faults.
Materials:	Mortars based on cement, possibly added plastic emulsion and curing compound.

Method 2 Casting with concrete or mortar

Application	Large settlements, honeycombs, and cavities are repaired by casting with concrete or mortar. The particle size of the mixture must be adapted to the layer thickness in question.
Work instructions:	If the repair is to be accomplished at a vertical surface or at a lower surface, concrete formwork must be applied. The concrete base must be watered in advance, meaning that the surface is saturated, but dry at the surface. Ordinary concreting or repair mortar is accomplished, and the concrete/mortar is compacted by vibration. After the filling in, the concrete/mortar must be protected against drying out, sunshine, wind, and rain for 5 days. The surface must be smooth and without faults.
Materials:	Concrete and mortars based on cement and curing compound.

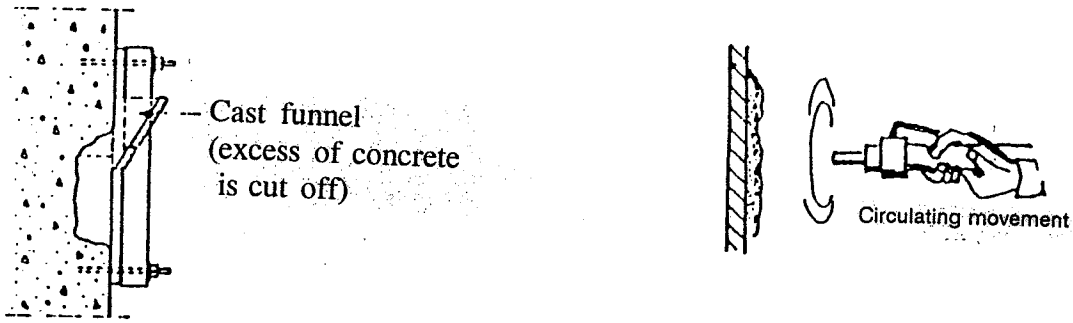
Method 3 Shotcrete

Application: For repair of large-scale honeycombs and cavities, repair of incorrect concrete cover thicknesses, the method of filling in with shotcrete can be applied.

Working instructions: The area to be filled in is framed, and adjoining areas are covered. Shotcrete is sprayed on by means of special equipment. The shotcrete is built up from the bottom and upwards. The work procedure is accomplished by plastering until the surface is as smooth as the surrounding concrete surface.
After the filling in, the shotcrete repair must be protected against drying out, sunshine, wind, and rain for 5 days.

Materials: Drymix of concrete or mortar and curing compound.

Illustration 3 illustrates Method 2 and Method 3.



Method 2 Method 3

Ill. 3. *Concrete formwork, Method 2, ref. [5], and Shotcrete, Method 3, ref. [16] BYG-ERFA 060375.*

5.4 Repair of cracks

Repair of cracks can be accomplished by injection, cutting and filling in, or sealing. Selection of method and materials is made a.o. on the basis of an assessment whether the actual cracks are static or elastic and whether the crack is exposed to water pressure.

Method 1. Injection

Application: Cracks, the width of which exceeds 0.2 mm on vertical and horizontal surfaces.

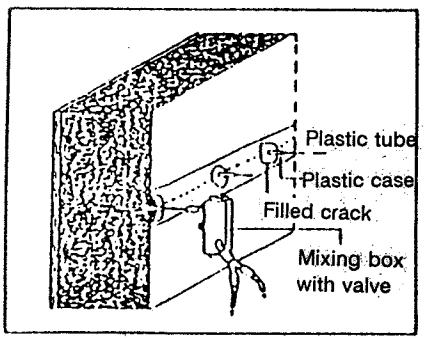
Work instructions: Injection can be accomplished in accordance with the 3 different methods described below,

- Injection through drilled-in nipples and with a sealed crack;
- Injection through drilling in spears to the middle of the cracked cross-section. Without sealing the crack.
- Injection through drilled-in nipples, the spacing of which is approx. 300 mm, and with a sealed crack.

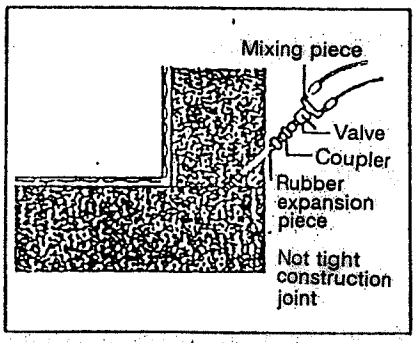
Pump aggregate is to be applied when using the above-mentioned methods.

Materials: Elastic materials such as polyerethanes and acrylats/acrylic ester are applied for injection of moving cracks. Less elastic materials such as cement sludge and epoxys are applied for static cracks which are dry.

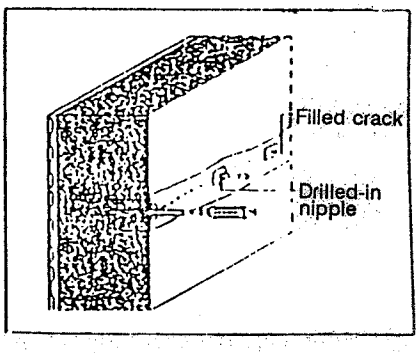
Below Method 1 is illustrated.



Injection through drilled-in nipples with disposable cartridges which are filled to pressure above the atmosphere



Injection through drilling in spears to the middle of the cracked cross-section without sealing the crack. By injection, a pump aggregate is used.



Injection through drilled-in nipples with a sealed crack. By the injection, a pump aggretage is used.

Ill. 4. *Injection of cracks, Ref. [16], BYG-ERFA 890516*

Method 2. Cutting and filling in

Application: Single cracks, the widths of which exceed 0.2 mm, can be repaired by cutting and subsequent filling in.

Work instructions: The carved crack is filled with mortar. If cement-based mortar is applied, the concrete surface must be saturated, but surface dry. After the filling in, the concrete/mortar must be

protected against drying out, sunshine, wind, and rain for 5 days. As an alternative epoxy may be used.

Materials: Elastic agents such as polyerethanes and acrylats/acrylic ester are applied for injection of moving cracks. Less elastic materials such as cement sludge are applied for static cracks.

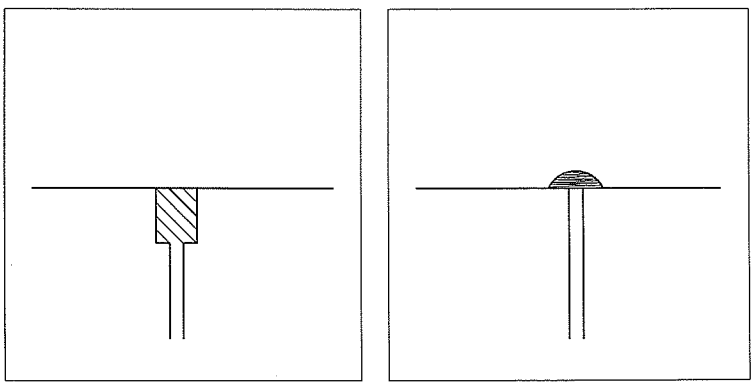
Method 3. **Sealing**

Application: Sealing of individual cracks and map-cracking, the width of which is less than 0.2 mm, is an adequate measure.

Work instructions: The sealing agent is applied upon the concrete surface by means of paint brush or spattle. If cement-based coatings are applied, the concrete base must be saturated, surface dry. After the filling in, the concrete/mortar must be protected against drying out, sunshine, wind, and rain for 5 days.. Epoxy coating is an alternative to cement-based coating.

Materials: Cement-based coatings with acrylic reinforcement are applied in connection with sealing against aggressive environment.

Illustration 3 illustrates Method 2 and Method 3.



Ill. 3. *Repair of cracks by application of Method 2, cutting and filling in, and Method 3, sealing.*

In general, it applies to the above-mentioned repair methods that the concrete must be saturated before application of the overhaul product.

To ordinary concrete the effect hereof is positive; however, regarding high performance concrete, the absorbtive capacity of which is comparatively inferior, the effect will presumably be less positive.

5.5 Special repair procedures

Special repairs have influence on the functioning and effective life of the structure in question. Overhaul methods are selected on the basis of established examinations of the defects. Accomplishment of repairs may be expensive and complicated. In each single case it will be necessary to assess in which way and to which extent the overhaul is to be performed.

This chapter gives a general survey of overhauls, subdivided as follows,

- Special preparations
- Large-scale removal of concrete
- Strengthening of structures
- Surface treatment

Special preparations

Application of special methods for pre-treatment of concrete surfaces may prove necessary. As examples of the most frequently applied methods can be stated,

- Blast cleaning with sand or possibly other blowing agents (dolomite or slag)
- Water jet cleaning with added sand
- High-pressure water jet cleaning (more than 200 bar)
- Flame cleaning

Large-scale removal of concrete

Removal of concrete with defects of great significance might be necessary, e.g. by incorrect geometry or incorrect siting, too high water/cement-ratio, incorrect compactness, or incorrect air void structure of the concrete. In each single case the established requirements on the concrete structure must be thoroughly assessed. Further, it must be checked whether other possible measures are applicable.

Below several concrete removal methods are described. Including primary fields of application and disadvantages of the individual methods. Ref. [16] Partial removal of concrete, BYG-ERFA (89 12 18). Tool/method are selected in accordance with character and extent of non-conformity.

Method	Primary fields of application	Disadvantages
Concrete shears	Primarily applied for grinding of thin walls, consoles and storey partitions. Grinding of concrete plates where space and accessibility are limited. Grinding of concrete plates for which particular environmental requirements are established	Disadvantages of the method are e.g. limited shear thickness and operational range, reduced suitability if reinforcement is considered maintained, the equipment is heavy and best suitable suspended in a tackle etc. Application of all-service mask is obligatory.
Water jet	By applying a water jet of a high pressure between 300-2000 bar, concrete may be removed and surfaces cleaned.	Special safety precautions are required, especially with hand-held equipment. There have been serious accidents with this method.
Chipping by means of electric or pneumatic tools	In connection with small-scale jobs manual tools are applied. Large-scale jobs make it possible to install the tools upon machines.	Disadvantages of the method are e.g. dust, noise, and vibration disturbances. A certain degree of space and accessibility is required. Application of remote-controlled machines is advisable in order to reduce the operator's exposure to dust, noise and vibrations. Application of hearing protection devices and dusk masks is obligatory.
Blasting by means of explosives	The method is applied in connection with piercing of concrete plates, the thickness of which exceeds 30. Demolition of large amounts of reinforced concrete. Mini-blastings in connection with overhaul works and exposure of reinforcement with a view to re-use of the reinforcement.	Accomplishment of blastings needs special training and licence. Post-chipping by means of hand-operated tools is often required.
Cutting and boring with cutting diamonds	Piercing. Fragmentations which require clean adjoining surfaces. Combined with other methods of fragmentation.	High noise level and water spillage

Strengthening of structures

Strengthening of structures may be complicated and expensive measures. Thorough evaluation of the defects and subsequent assessment of possible remedial measures are required.

According to ref. [4] and [5] strengthening may be specified due to incorrect geometry, incorrect original reinforcement, or too weak concrete.

- Strengthening might consist of subsequent concreting in order to increase the useful height;
- Mounting of external reinforcement;
- Tightening-up with external tension cables;
- Bonding of reinforcement;
- Injection of weak areas.

Surface treatment
According to ref. [17] surface treatments can be classified as follows,

- Impregnation improves compactness against chloride penetration and carbonation;
- Thin film is primarily applied for aesthetic reasons;
- Thick film improves compactness against chloride penetration and carbonation;
- Thick film is able to absorb deformations of the underlying concrete;
- Membranes yield efficient protection against chloride, carbonation, and water permeability. Only to be used after prior precise calculation of moisture conditions of the concrete.

Costs of surface treatment maintenance ought to form part of assessments concerning application of the method.

6. Repair materials

Specification of repair materials and application hereof in connection with actual repair procedures of high performance concrete constructions have been recorded. Current practice can be summarized by the following:

- Selection of repair materials is a result of assessment and classification of non-conformities / defects, the suitable repair method, and requirements on colour and structure of the finished surface.

- Routine repair procedures have been prepared for defects of little significance and finish works. These procedures include product name and supplier's relations to each individual repair procedure. The procedures are assessed by the client's consultant.

- Non-conformities / damages of great significance for the durability of the construction and the economic consequences in connection with the accomplishment are scrutinized. All parties of the project participate in this scrutiny before defining a suitable repair method and the suitable repair materials.

- Supplementary specifications of materials' properties, composition, testing, relations to inspection schemes etc. in relation to the supplier's product specifications are elaborated before executing the repair procedures. This includes testing of chloride permeability, adhesion and visual inspections of cores.

- Specific qualification requirements to the qualification of the operatives in connection with application of repair materials and accomplishment of repair are established.

- Receiving inspection is performed. Materials which are not comprehended by inspection schemes are applied. Testing of materials' properties for the accomplished work is effected as spot-tests.

- Current specifications of repair state the following product types,

    - Primer (adhesion-improving treatment of casting joints);
    - Repair mortar in the form of ready-mixed dry products which are to be mixed with water before manual application;
    - Repair mortar in the form of ready-mixed mortar for spray plastering;

- Usually, concrete for overhaul of large hollow spaces is specified in accordance with the rest of the construction concrete;
- Shotcrete is based on ready-mixed products;
- Curing agents;
- Levelling materials in the form of cement-based mortar added with plastic material;
- Filling material for filling of cracks can be used in the form of cement-based or epoxy-based products. Perhaps supplied with fibres;
- Epoxy products and acrylic- and cement-based materials for crack injection.

The basis of classification of repair materials into categories is the interim editions of the CEN-standards, (ref. 24). This is considered expedient as the classification of standards and material categories - although not necessarily throughout consistent - are considered structuralizing within the sphere for several years to come.

In proportion to the proposed CEN-classification with its seven material categories, ignoring the division into repair systems **with** improved strength grades and systems **without** is considered adequate. In relation to the high performance concrete these categories have the joint designation *fill in materials*. Otherwise the classification stated in the CEN-proposal is observed.

According to the CEN-proposal the repair materials' categories which are used on high performance concrete are as follows,

1. Surface finishing;
2. Filling in (structural capacity/non-structural capacity);
3. Repair systems with adhesive characteristics (bonding);
4. Injection;

On assessment of the suitability of materials regarding accomplishment of qualitatively satisfactory repair, below you will find a record of particular conditions to be observed in connection with application, properties of different material types, and experience gained during the application hereof. Only properties which ought to be the object of particular alertness during application of the materials are described. An overall gross list concerning conditions / material properties to be considered in connection with the accomplishment is stated below,

- Mechanical properties such as adhesion, wearability, E-module, pressure resistance, tearing strength, elasticity;
- Treatability, including viscosity, Pot-Life, and slump;
- Contraction, including chemical and physical losses;
- Creep;
- Weatherproofness;
- Water repellency;
- Water vapour diffusion density;

- Dirt-repellency;
- Fire-protective ability;
- Frost and thawing;
- Aesthetics;
- Chemical resistance, including chlorides and carbonation
- Possibilities of re-treatment;
- Environmental conditions in general.

6.1 Surface treatment

The different types of surface treatment are characterized e.g. by layer thickness, material type, coating method and function,

- Impregnation;
- Thin-film coating;
- Thick-film coating;
- Membranes.

There is a great variety of surface treatment agents with different modes of action and different contents of chemical agents. The agents can be divided into main groups based on e.g. cement, plastic-emulsions, asphalt, aluminium, rubber, epoxy and different mineral products and combinations hereof.

Definitions

Surface treatment materials are defined as materials which protect the concrete solely by preventing penetration/impact of harmful agents from the surroundings into the surface structure of the concrete.

Impregnation is surface treatment with a solution with good penetration strength (1-20 mm) into the concrete surface. Impregnation gives the entire concrete surface inclusive of cavities, voids and cracks a non-hydrophilic effect without generating a visible coating.

Thin-films coating is a surface treatment the layer thickness of which is approx. 0.1-0.5 mm.

Thick-films coating is a surface treatment containing products composed in order to obtain layer thicknesses of approx. 0.8-2.5 mm.

Membranes may consist of fluent or pasty materials which are applyed in layer thicknesses of approx. 0.5-5 mm. The materials are based on acrylic, epoxy, polyester or polyurethane. Further, membranes may consist of materials based on asphalt, bentonite, plastic foil, steel, etc.

Application
In particular, the surface treatment systems are used for repair/protection of constructions in connection with defects in the form of,

- small top layers on exposed/crucial construction parts;
- inferior density of the top layer;
- crazes (self drying-out/chemical contraction; plastic contraction; impacts;
- aesthetics/appearance (tarnish)
- chemical decomposition

It must be emphasized that surface treatment in connection with repair of high performance concrete in particular aggressive environments are used in cases considering defects of great significance only where the effect counterbalances the rather limited advantages concerning economy and durability.

Membranes are applied in very particular cases where it is necessary to apply a decidedly new safeguarding material upon the concrete surface.

Impregnation with e.g. silicone is not a suitable method regarding concrete with water/cement-numbers below 0.4. Silicone impregnation agents are of limited durability and frequent retreatments are necessary to obtain a lasting effect.

Opinions vary whether impregnation can be a means of reducing chloride penetration. Membranes are applied where a sealed surface is requested.

6.2 Filling materials

The filling materials are classified in the three main types mentioned below,

- repair mortar/concrete;
- premixed concrete;
- shotcrete.

As is the case with surface treatment agents, a great variety of filling materials with different modes of action and with different contents of chemical agents exists.

As main groups the materials are based on cement; plastic emulsions may be added. The repair mortar often contains fibres and contraction-inhibitory additives and improved adhesive qualities are obtained by polymerization.

Definitions
Repair mortar/concrete consists of a mixture of cement, aggretates with the maximum particle size of which is approx. 4 mm and, possibly, different additives such as acrylics and polymers. Mortars bases on epoxy as binding agent are also used. **Repair concrete** has a maximum particle size of approx. 16 mm. The mortar/concrete is mixed on the construction site. No further additives but water is used.

Premixed concrete is applied for concretings which demand large-scale layer thicknesses or for replacement of concreting sections where concrete formwork is necessary, and where premixed high performance concrete is applicable.

Shotcrete is delivered as a dry mixture of aggregates and cement, the design of which makes it suitable for pressurized spraying upon existing concrete constructions.

Application
The filling materials are typically applied for repair of defects such as:

- filling with mortar or concrete of cavities, settlements etc;
- establishment of sufficient cover above reinforcement;
- filling with mortar or concrete of honeycombs.
- filling with mortar holes from samples, cores, clamps etc.

Repair concrete is particularly suited for repair of approx. 20-150 mm thick layers. Repair mortar is applied for layers, the thicknesses of which are approx. 4-20 mm. There is a differentiation between manual application in thin and thick layers respectively.

Regarding high performance concrete, application of products with adhesive- and contraction-improving qualities is of great importance. The finished surface of high performance concrete tends towards being smoother than the surface of traditional concrete surfaces. By means of e.g. test overhauls it can be substantiated whether the adherence is satisfactory or not.

When applying filling materials it is considered relevant that the properties of repair concrete correspond to the high performance concrete of the remaining part of the structure as regards composition, density, strength, E-module, frost resistance and chloride permeability..

As to high performance concrete, to which requirements on e.g. strength are heavy, repair mortars/concretes containing alumina cement must not be applied.

Overhauls of structures, which are to receive cathodic protection, make demands on the conductivity of the repair product.

In general, the content of chlorides, alkali, etc. of the applied repair mortar must not exeed the requirements on the high performance concrete.

In particular, experience of the following matters ought to be acquired,

- adherence;
- treatability and consistency;
- contraction.

6.3 Primer (Repair systems with adhesive properties)

Such systems contain products is used to the adhesion between the repair product and the structural concrete.

Typically, the products will contain a selection of synthetic materials in the form of polymers etc. However, they may also be found in the form of cement-based mortars. Application of the products shall be considered in coherence with application of the filling materials as described in chapter 6.2.

Definitions

Repair systems with adhesive properties are defined as materials which improve the adhesion between the overhauled concrete and the repair system, e.g. a repair mortar/concrete product.

Materials for incorporation into various repair products in order to improve the properties of the products belong to this group too.

Application

Primarily the production is applied as preparatory basis for filling systems or as addition to repair products without adhesion improving properties.

The synthetic bonding is coated upon the repair-prepared surfaces or compounded into the repair mortar etc. It functions by adhesion between the solids of the two different materials.

Cement grouts function - made wet-in-wet - by hydration of the cement grains.

Regarding application on high performance concrete, synthetic bonding is considered suitable as the "smooth" surface of the concrete may cause problems for unmixed concrete washing cements.

By possible later application of electrochemical methods electrical properties of the materials shall be considered.

The setting time of an adhesion-improving concrete washing ought to be minimum 1 hour at 20^0 C. Regarding contents of harmful agents the requirements on concrete washing agents are identical with the demands on repair mortars.

In particular, experience of the following matters regarding concrete washing ought to be acquired,

- adhesion;
- pot life.

6.4 Injection systems

The injection systems can be based on cement, epoxy, polyurethane, and acrylic respectively. Futhermore, the injection materials are classified in elastic and non-elastic systems.

Definitions

Injection systems are defined as products which pressurized can fill in concrete crack formations.

Application

The injection systems are suitable for filling in of fine crack formations larger than 0.2 mm by virtue of their liquefying and adhesive properties.

Application of special-purpose tools is necessary when applying the systems: Nipples, pumps, clearance barrier materials etc.

Cement-based injection systems are used for repair static and rather course cracks with crack width more than 3 mm.

Epoxy-based injection systems are used for repair of static and dry cracks with a crack width between 0,1 and 3 mm.

Acrylic and polyerethan injection systems are used for moving cracks and cracks exposed to water, and are not normally used for structural purposes.

In connection with the application the following conditions are considered often:

- size of cracks;
- depth of cracks;
- moisture resistance;
- strength;
- elasticity.

Cracks originated because of structural defects and/or water-actuated cracks require special precautions.

Application demands specially trained staff and particular working environment measures.

Particular focusing on registration of the causes of failure ought to take place in connection with observation of facts. Do the failures e.g. occur due to insufficient preparation of the crack basis or due to conditions owing to the applied materials?

The cement-based concrete washing mortars function primarily by formation of a protective film on the surface of the embedded steel.

Both protection systems will cause increased adhesion between steel and concrete.

Application
The systems are applied for obtaining extra security regarding corrosion protection of reinforcement, either as a preventive measure or in connection with overhauls, during which the reinforcement gets exposed.

By application of the products, electrochemical conditions are to be closely assessed, as the application may cause formation of local cathode/anode areas with possible formation of a corrosive environment around the reinforcement. It is of utmost importance that the treatment covers the entire extent of the exposed steel.

7. Testing methods and acceptance criteria

This chapter summarizes the methods and criteria which form the basis of current practice, testing and acceptance of the concrete repairs.

Requirements concerning accomplishment of repair and selection of materials appear from the following,

- quality requirements and requirements concerning compatibility with high performance concrete as specified on the basis of eg. VD's AAB for concrete construction etc;
- requirements as to safety and health hazards at construction sites;
- requirements to the external environment in the form of minimizing impacts on neighbours and the surrounding nature.

7.1 Testing methods and acceptance criterias for the repair materials

The basis of the description of testing methods and acceptance criteria for repair materials is among others the below-mentioned experience gathered in connection with accomplishment of repairs of high performance concrete,

- The contractors carry out trial repairs that will be tested. Tests will include determination of materials' properties, such as e.g. chloride permeability which is measured in accordance with the ASSHTO T277-831, according to which the results are to be compared with results from measurements from the applied construction concrete. Other properties such as adhesion and resistivity are frequently determined.
- Regarding the compatibility of the repair materials there is normally referred to requirements stated in e.g. VD's ABB for concrete structures [38] or A/S Øresund's Guidelines for selection of concrete [40] and the actual *Særlige Arbejdsbeskrivelse SAB.*
- Most of the applied repair materials are attached to REPTON [23]. On this basis several declarated materials' properties are stated, established in accordance with the technical provisions of the declaration scheme.

On the basis of acknowledged and commercially available schemes, standards and/or directions, a survey of relevant properties and testing methods applied in connection

with ordinary construction concrete has been elaborated. These schemes, standards and directions are mentioned below,

- REPTON, declaration scheme for cement-based materials for repair of concrete [23];
- ZTV-SIB/ZTV-RISS, the German technical regulations and guidelines for protection and repair of concrete constructions [33] and [35];
- CEN, pr EN 1504-1, EU-standard for products and systems for protection and repair of concrete constructions [24];
- *Vejdirektoratets ABB* [38] (publication from the Danish Road Directorate)
- *Vejledning i valg af beton. A/S Øresund* [40]
- DTI R60-93/ TI-O [26]
- *BPS - Typiske beskrivelsesafsnit betonrenovering, reparation, høringsudgave* [27] (Typical description sections, concrete rehabilitation, repair, hearing edition).

Typically, the Danish schemes/directions deal with different purviews of the repair material field, whereas the CEN-standards and the ZTV-regulations are more profound and attempt to cover the entire material field, cement-based as well as non cement-based repair materials, materials for surface protection etc.

The schemes/directions mentioned consist of a variety of tests, controls, requirements and directions for repair materials, which is why a proper classification and comparison of test and acceptance criteria are difficult to accomplish without comprehensive collation of data. According to the authors' opinion there is a definite need for collation and classification of data in connection with elaboration of the directions.

The recording has been made at a material classification level. This level may be amplified into product levels if it proves expedient later on.

Based on the evaluation of work procedures for repair of large-scale construction projects materials are normally specified by assigning a product declared in accordance with the REPTON-scheme. Non-cement-based repair materials which are not comprised by this particular control scheme have to conform to possible requirements stated in the work descriptions or supplementary requirements/testings demanded from the manufacturers only.

REPTON
The REPTON-scheme comprises cement-based repair materials only, not solely synthetic materials. The scheme establishes testing methods regarding declared materials' properties, but apart from that no acceptance criteria for the declared values are established.

The declared properties are:

Components/fresh repair mortar:
- grading curves;
- additions;
- chloride content;
- density;
- consistence;
- air content;
- expansion.

Hardened repair mortar:
- compressive strength, 28 days;
- flexural strength, 28 days;
- shrinkage;
- E-module;
- adhesive strength;
- max. layer without cracking.

Crucial conditions regarding high performance concrete, such as:
- frost resistance;
- chloride permeability;
- carbonation;
- thermal expansion coefficient

are not to be declared. The manufacturers have to test these properties on their own.

The scheme makes it possible to compare the properties of the repair products and to advance joint requirements to properties. However, the testing methods are still not harmonized, as different methods are tolerated to a certain extent.

ZTV-SIB/ZTV-RISS
The German ZTV-SIB directions apply to concrete and shotcrete, shot mortar/shotcrete with synthetic additives, cement-based repair mortars with synthetic additives (PCC-mortars) and synthetic repair mortars (PC-mortars), and surface protection agents classified into impregnation agents and surface agents.

ZTV-RISS applies to injection systems etc.

The directions contain general chapters on properties and application of repair materials and preparation of the concrete basis before the repair. Furthermore, each material category contains description and demands to,

- basis;
- definition of concepts;
- application;
- project basis/registration;
- prerequisites of repair;
- repair system and products;
- accomplishment;
- testing;
- handing over of the works;
- payment.

The directions refer to several German DIN-standards regarding testing and accomplishment and records of tested and approved additives. Furthermore, they state acceptance criteria/requirements to,

- quality and moisture content of the concrete basis;
- curing and mix proportion of products;
- min. execution temperature and temperature of the basis, typically 5-8^0 C;
- curing. Typically, protection against drying-out for at least 5 days is required;
- adhesion between concrete basis and repair system, typically with average values of 1.5 N/mm^2 with minimal value around 1 N/mm^2;
- compaction degree (typically 0.97-0.98).

ZTV can be used as a reference and a basis in connection with assessment of requirements for accomplishment of repairs and selection of repair materials.

CEN

The elaboration of the CEN-standards for protection and overhaul of concrete is still at a stage at which specific requirements for testing methods and acceptance criteria are only sporadicly stated in "unofficial" hearing-issues. CEN operates with general materials' properties/requirements and performance properties / requirements.

The CEN-standards comprise general material properties as follows,

- chemical and mineralogic design of cement;
- grading curve of the addition;
- contents of additives;
- infrared analysis;
- shrinkage;
- compressive strength;
- air content;
- Pot-Life;

- treatability;

and the below-mentioned performance properties which are classified into requirements for all applications, requirements for selected applications, and, finally, requirements for special applications.

Requirements for all applications,

- compressive strength;
- shrinkage;
- adhesion;
- carbonation resistance.

Requirements for selected applications,

- chloride content;
- capillary absorption;
- adhesion;
- carbonation resistance;
- thermic compatibility;
- E-module;
- creep.

Requirements for special applications,

- air content;
- shrinkage;
- Pot-Life;
- capillary absorbtion;
- resistance towards chlorid-ion penetration;
- sea-waterpermeability;
- treatability.

DTI - Surface treatment
DTI's publication *"Malinger og membraner til betons overfladebeskyttelse"* [26] ("Coatings and membranes for surface protection of concrete") gives a survey of testing methods regarding the materials' properties. The main types of products for surface protection are classified in [26] as follows,

- silicone impregnation agents;
- polymethyl methacrylate coatings;
- cement-based coatings;
- synthetic rubber coatings;
- silicate coatings;
- membranes and coatings (epoxy, acrylic, tar, polyurethane, bitumen, bentonite).

Application demands that tested properties such as chloride resistance, adhesion, carbonation resistance, durability etc. must be placed at the upper part of "the marking scale"; otherwise application of these agents on high performance concrete won't make sense. E.g.: The adhesion must be described as "very good".

BPS

The BPS-publication *"Typiske beskrivelsesafsnit betonrenovering og reparation"* [27] (Typical description sections, concrete rehabilitation, repair) covers the material categories: Corrosion preventing materials, adhesion-improving materials, repair mortars/- concretes, shotcrete, and reinforcement. The publication drafts a description of conditions concerning performance and conditions as to supervision and documentation. Moreover, it contains general chapters on repair, terminology, and instructions.

No supplementary testing is required provided that the products' properties have been tested in accordance with the REPTON-scheme or have been manufactured under an IDA- or a DANAK-approved product certification scheme.

Typically the BPS-publication recommends requirements to the materials as follows,

- Pot-Life (at least 1 hour at 20^0 C);
- adhesion (characteristic pull-off strength 1.2 MPa, 1.5 MPa and 2.0 MPa in passive, moderate and aggressive environmental classes respectively);
- compressive strength and modulus of elasticity (identical with the concrete);
- consistence;
- shrinkage (less than 0.03%);
- durability (frost, chloride permeability).

Testing of properties is typically referred to NT Build and DS-standards.

The basis for acceptance criteria for repair materials is that the properties of the repair materials must not be inferior to those of the concrete basis. This implies that properties as a minimum must comply with the requirements for concrete in aggressive environments. Furthermore, the properties must conform to possible special requirements to high performance concrete: compressive strength, adhesive strength, flexural strength, etc.

ROAD DIRECTORATE - AAB

General specifications from the Road Directorate ref. [11] abd [38] include major descriptions of repair works such as:

- shotcrete repairs
- repair with ready mix concrete
- repair with mortar

and

- injection of cracks.

Acceptance criterias concerning shotcrete repairs include that:

- the aggregate shall be prepared to secure good adhesion, impact strength, impermeability, frost resistance and min. shrinkage;
- size of aggregate between 6 mm and 16 mm;
- content of aggregates in the repaired section shall be min. 20%;
- no casting joints;
- a mixed batch shall be used within 45 min.

Testing methods and acceptance criteas concerning repairs with ready mix concrete correspond to the specification for construction works.

Testing methods and acceptance criterias concerning repairs with mortars and primers include:

- the repair mortars and primers shall be durable to alkali, water and bitumen;
- the repair mortars and primers shall be frost resistant and with low water permeability;
- the repair mortars and primers shall not be corrosive to the reinforcement;
- strength shall be compatible with the concrete basis;
- no cracks;
- cement based mortar shall be tested according to REPTON;
- the surface of finished repaired section shall be without contamination;
- adhesion test shall be executed on the concrete basis - min. 1.5 MPa;
- average of the adhesion of the repair mortar shall be 1.0 Mpa.

Testing and acceptance criterias for injection with cement mortar include:

- water/cement ratio $\leq$0,45. Weighing tests!
- compressive strength of cubes is min. 30 Mpa;
- fluidity = max. 15 s - measured as time to emptying a special container;

- expansion between 0% and 12% measured in a glass container;
- water absorpsion max. 4%;
- frost resistance.

7.2 Testing methods and acceptance criteria for work procedures

Current practice of testing and acceptance criterias for repair works are summarized as follows:

- trained operatives shall carry out a trial routine repairs with regular time intervals that will be tested. The test includes visual inspections at cores. Other tests such as determination of adhesion strength and chloride permeability also used.
- Testing of the cleaned surface before application of the repair materials may include:
  - visual inspection of the cleaned surfaces to register any contaminations.
- Testing of the finished repair works normally includes:
  - visual inspection of the repaired section and registration of defects such as cracks etc;
  - visual inspection of cores taken from the repaired section;
  - adhesion tests.

  Requirements are normally based on the AAB from the Road Directorate.
- During the execution of the repair processes protocols are prepared with notes regarding temperature, weather conditions etc.

Key properties

Directions with relevant guidelines for process control are stated as mentioned below,

- AAB, Road Directorate [11], [38]
- BPS - typical description sections [27];
- ZTV-SIB/ZTV-RISS [34], [35].

Requirements on accomplishment of repair work procedures may be classified as follows,

- preparations at the concrete basis;
- application/casting;
- curing;
- aesthetic requirements;
- control (internal or external);
- safety and health hazards.

For each of the partial processes the following factors must be assessed: Which properties will be relevant to measure? Which measuring methods are applicable? Which requirements can be advanced?

Testing and acceptance criteria
The established directions, testing and acceptance criteria of each of the key properties are discussed.

Preparations
In connection with preparation of the concrete basis, control of the below-mentioned properties is considered appropriate:

- The quality of the concrete basis is checked visually. Any remains of loose concrete?
  Does the structure of the concrete comply with the requirements? Any impurities to be removed?

  No method is established which can give a measurable result. Assessment of the quality of the layer is a very subjective precaution and very contingent on the individual supervisor. In special cases structural analyses of samples from drill cores are applied.

  There is no precise and conspectuous method of assessing of the concrete basis quality. Guidelines are established in VDPRØV.00/93. *Anvendelse af visuelle metoder*, cf. ref. [36] (*Application of visual methods*). Acceptance criteria are established during test treatment.

- Degree of contamination of the concrete basis can be measured, cf. VJ prøv 03/93. Contamination test, cf. ref. [36] in order to check whether the surface is sufficiently cleaned up and stripped of hazes. Results of the measurements are classified according to a graduated scale ranging from Substantial contamination to Immaterial contamination. Usually, an actual classification of the concrete surface corresponding to immaterial contamination is required.

  The usability of the method is the best regarding control of clean up on smooth surfaces in connection with surface treatment, and normally the method is not used in connection with filling and injection.

- Adhesion is measured in accordance with the VDPRØV.04/93. Pull-off testing, cf. ref. [36] or similar methods. The method is applicable for testing and control of concrete layers and for control of overhauls and surface treatments. The idea of the method is to glue round plates upon a smooth surface and afterwards to measure the tensile stress to be used in order to release the round plates from the concrete surface.

The result is specified as tensile stress (MPa), and varying acceptance criteria between 1.2 and below 2.0 MPa in specified strength are applied, cf. [34], [27].

The method is applicable for flush layers only, e.g. in connection with surface treatment.

Common rules regarding requirements on pull-off strength do not exist. A starting point can be that there must be no significant variation in relation to the applied construction concrete.

- Preparation grade is often assessed in connection with the repairs where an exposed corroded reinforcement is to be purified by means of e.g. sand blasting. Results of the purification are assessed according to a graduated scale as established in ISO 850-1 1988 *Visual assessment of surface cleanlines*, cf. ref. [37].

  Assessment criteria may be difficult to apply when the matter is about reinforcement which does not consist of regular surfaces as specified at the standard scale.

Application/casting of filling materials
The purified surface is pre-watered into dry-surface, water-saturated condition.

Air temperature is recorded, cf. VDPRØV.06/93 or VDPRØV.07/93 or VDPRØV.-17/93, ref. [36].

Concreting/coating are accomplished only under climatic conditions as prescribed in the manufacturers' directions, e.g. temperatures max./min. which fact normally corresponds to min. 5^0 C. Special requirements conditional on the actual product may occur. In connection with surface treatment it might be relevant to record the dewfall.

Curing
Repairs must be protected against impacts, frost, drying up, direct sunshine, and fall of rain, snow etc.

Usually it is recommended that the protection is at least 120 maturity hours in aggressive environmental class.

Traditionally the protection is accomplished by:

- spraying of fresh water
- covering with plastic foils
- spraying of sealing membrane (curing agent).

Certain requirements on max. evaporation from treated surfaces during the curing period are established, cf. the number of maturity hours.

Aesthetics
Usually it is required that the appearance of the repaired section must conform to the appearance of the surrounding concrete.

Safety and health hazards
Conditions such as,

- dust;
- noise;
- vibrations;
- chemical impacts;
- ergonomics;
- shielding and protective devices;

are to be generally assessed in connection with the overhauls.

Directions from the Danish Working Environment Service within these spheres and further the manufacturers' product information are to be observed and must form the basis of selecting the repair method.

7.3 Qualifications and skills of the operators

Today the Danish Working Environment Service makes certain requirements on staff members who conduct sand blasting and work with epoxy-containing products, organic solvents etc., cf. MAL-codes, directions etc.

In connection with major construction works specialized repair crews are usually employed. They are qualified as follows:

- experience from similar tasks;
- participation in necessary safety training courses etc.;
- participation in training and education, e.g. at the manufacturer;
- accomplishment of test treatments and trial repairs.

The further basis of elaborating directions may consist of the following elements,

- elaboration of a survey of necessary training with special reference to compliance with requirements on safety and health conditions;

- putting forward guidelines of test treatments which may be applied currently in connection with destructive measuring methods with the purpose of recording quality of repair. Recent practice includes testing of the skill with inspections.

8. Recommendations for further research and drafting of guidelines

The state of the Art report briefly describes the different stages of the repair process. As far as possible it is based on experience gained through on-going construction projects. However, parts of repairs indicate that it will be necessary to go more closely into certain subjects.

On the basis of the gained experience, the summary, and the conclusions, and in order to create the necessary basis for elaborating directions for repair, we recommend that investigations are accomplished as follows,

- assessment whether the extent of variants is sufficient;
- thorough assessment of work procedures, including assessment of curing procedures;
- elaboration of a general survey of materials, declared properties, relevant testings compared with defined criteria/requirements on test results, and key properties of the materials;
- directions and requirements from REPTON, BPS, ZTV, CEN etc. are to be compared and assessed with special reference to high performance concrete and further to be compiled systematicly in the various directions.
- Elaboration of a record of key properties for which it is relevant to make requirements concerning different types of materials, possibly in relation to repair methods;
- Going through and standardization regarding selection of test methods and acceptance criteria;
- Accomplishment of examinations of impact of repairs on function and durability of constructions. On the basis of studies of recently accomplished representative repaired structures and studies of repaired structures accomplished 5-20 years ago, the qualities and the consequences of repair upon durability and maintenance of the construction are assessed;
- Special studies of injections of crack formations.

Draft for directions
The directions can be described in accordance with the below-mentioned structure,

- inspection of defects;
- finishing works;
- standard work procedures;
- special work procedures.

9. References

Each individual section must point out materials and repair procedures including appurtenant testing and acceptance criteria. Description of prerequisites regarding quality and the environment is to be elaborated.

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Definitions

Defects
The term covers defects as well as damages recorded during the construction phase.

Defects of little significance
Defects of little significance influence the functioning of the concrete structure locally and limited only, constitute inferior risk for the life span, repairs are inexpensive (in relation to the construction budget) and are of little consequence for the time schedule.

Defects of great significance
Defects of great significance influence the functioning and the life span of the concrete construction.

Preparations
Preparations concerning concrete repair imply a procedure as regards removal of inferior quality concrete and a cleanup procedure for the concrete surface.

Reinforcement of structures
When required structural qualities are not obtained due to errors, the structure may be improved a.o. by means of external reinforcement, increased useful height by concreting and tightening-up with external tension cables.

High performance concrete
Normally, concrete conforming to the AAB-requirements of the Danish Road Directorate and the Danish State Railways is designated *high performance concrete*. In particular aggressive environments the requirements on water/cement-ratio and covers are more stringent.

Injection systems
Injection systems are defined as products which pressurized are able to fill concrete crack formations.

Impregnation
Impregnation is surface treatment with a solution with good penetration strength (1-20 mm) into the concrete surface. Impregnation gives the entire concrete surface inclusive of cavities, voids and cracks a non-hydrophilic effect without generating a visible coating.

Classification of defects
Defects are classified in main groups as follows,

- Finishing works;
- Defects of little significance;
- Defects of great significance.

Defects are classified on the basis of type and an assessment of extent of the defects in question.

Finishing works may be repair of holes from testing samples, injection and cooling ducts and couplers.

Other defects may be

- Cracks;
- Honeycombs and cavities;
- Air voids;
- Minor surface defects;
- Non-conformity to tolerances;
- Wrong cover thickness;
- Settlements and depressions etc.

Membranes
Membranes may consist of fluent or pasty materials which are applyed in layer thicknesses of approx. 0.5-5 mm. The materials are based on acrylic, epoxy, polyester or polyurethane. Further, membranes may consist of materials based on asphalt, bentonite, plastic foil or steel.

Surface treatment
Surface treatment materials can be defined as materials which protect the concrete solely by preventing penetration/impact of harmful agents from the surroundings into the surface structure of the concrete.

There is a differentation of the following types of surface treatment, characterized by e.g. layer thickness, type of material, application method, and functioning,

- Impregnation;
- Thin-films coating;
- Thick-films coating;
- Membrane.

Repair systems with adhesive properties
Repair systems with adhesive properties are defined as materials which improve adhesion between the concrete basis and the repair mortar product.

Repair of cracks
When applying the injection method, the cracks are filled by pumping in the injection material. Alternatively, cracks may be cut up and filled with mortar or sealed at the surface.

Shotcrete
Shotcrete is usually delivered as a dry premix and water is added during the spraying processes. The design of drymix makes it suitable for pressurized spraying upon existing concrete constructions.

Routine repair
Routine repair procedures are used as finishing works or to repair defects which are classified as of little significance. Repair which is accomplished according to routine repair work procedures, is inexpensive (in relation to the construction budget) and is of little consequence for the time schedule. Routine work procedures include preparations, smoothening, filling with mortar or concrete, and repair of cracks.

Particularly aggressive environments
Particularly aggressive environments can be defined as marine evironments, environments in the immediate vicinity roads, and/or environments exposed to thawing salt, fx bottom part of columns exposed to deicing salts from roads.

Special work procedures
Repair of defects of great significance to the functioning and life expectancy of the structure. Usually redressing and corrective actions bring along major economic consequences. E.g., special repairs may be large-scale removal of concrete, underwater repairs, surface treatment, and strengthening of structures.

Thin-films coating
Surface treatment, the layer thickness of which is approx. 0.1-0.5 mm.

Thick-films coating
Surface treatment containing products composed in order to obtain layer thicknesses of approx. 0.8-2.5 mm.

Repair mortar
Repair mortar consists of a mixture of cement, aggregates with the maximum particle size of which is approx. 4 mm and, possibly, acrylic and other additives. **Repair concrete** has a maximum particle size of approx. 16 mm. The mortar/concrete is mixed on the construction site. No further additives but water is used.

Ready-mixed concrete for repair
Ready-mixed concrete is applied for concretings which demand large-scale layer thicknesses, or for replacement of concreting sections where concrete formwork is necessary/possible, and where ready-mixed high performance concrete is applicable.

Smoothening
Working procedures as to smoothening of concrete surfaces consist of filling of minor air voids and surface defects below 10 mm. Usually, either concrete washing or thin-plastering is applied.

Construction phase
The report deals with defects originating during the **construction phase**.
A.o the performance phase encompasses the following phases,

- Finished casting;
- Reinforcement;
- Concrete mix;
- Casting;
- Finishing