HETEK

Repairs during the Construction Phase
Field Studies

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Authors: Ole Viggo Andersen, Anders K. Christoffersen, Bodil Børgesen

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Abstract:

The field studies conserns inspection of repairs made in the construction phase on 4 bridges and 1 tunnel. The studies include visual inspections and petrographical analysis of cores drilled out of repairs and adhesion tests. The studies also include informations from the quality control during the construction phase.

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1. Introduction and background

The subjects of the field studies were the following:

- To register the quality of the repairs which were made in the construction phase. The registration concerns new as well as old constructions. The quality has compared with the surrounding construction concrete.

- To collect and evaluate information from the construction phase concerning test of repairs and injection of cracks.

Information from the field studies together with the State of the Art report formed the basis of a report with recommendations for the contractors technology.

Background
The background for the field studies was the report: State of the Art, August 1996: Repairs during the construction phase, ref. [1].

With reference to the field studies of the repairs of the Øresund land works the following defects and repairs were the most frequent, ref. [3]:

- Defects during the construction phase are: too small concrete covers, holes and honeycombs and cracks.

- Repair methods most commonly used were based on filling out of holes with concrete cast in form, shotcrete or repair with mortar and injection of cracks.

Assumptions and limitations
The field studies were limited to the following:

- The studies include repairs performed in the construction phase on concrete of high quality.

- The field studies concern 5 structures - 4 bridges and 1 tunnel. Repairs were selected as representative for the jobs.

- The age of the structures was between 0 and 25 years.

- The investigated repairs included the following:
  - Repairs made with concrete.
  - Repairs made with shotcrete.
  - Repairs made with mortar.
  - Injection of cracks.

- The studies were based on:
  - Visual inspection of the repairs
  - Petrographical analyses - macroanalyses of cores taken from the repairs
  - Petrographical analyses - microanalyses of thin sections taken from the cores
  - Adhesion tests

- The studies include collection of relevant information from the construction phases - specification, tests results etc.

2. Summary

The inspection of the repairs was carried out from July through September 1996. The inspection includes repairs on 4 bridges and 1 tunnel.

The repairs were made on high quality concrete in the construction phase. The defects were holes, honeycombs and cracks.

2.1 Programme for inspection and testing

The inspections and analyses include 13 repairs. The inspections were done with reference to the Road Directorate's recommendations for inspections of structures ref. [5]

Visual inspection: Visual inspection includes detection of defects such as cracks etc. on the surfaces of the repairs.

Cores: Cores were drilled out in the middle of the repairs and in the casting joints. 26 cores were sampled.

The dimensions of the cores were Ø75/Ø80 mm which were drilled out through the repairs and into the construction concrete behind the repairs.

Macroanalyses: The macroanalyses give a survey of the appearance and structure of the drill core. Serious defects such as honeycombs, cracks etc. were registered. The macroanalyses clearly demonstrate how repairs can affect the quality of the final construction with regard to durability and function.

Microanalyses: 6 thin sections were prepared for microanalyses in the microscope. The thin sections were prepared from repairs made with concrete, repairs with shotcrete and repairs with mortar. The repairs were selected representing old and new repairs. The thin sections were selected from areas of good quality without defects. The microanalyses shall reveal detailed information about the repairs so that a comparison between repairs and the construction concrete.

Adhesion tests: Testing has been performed in accordance with NT BUILD 365 or the BOND-method. Data from the construction phase has also been collected. Tests have been performed on all types of repairs.

Overview of repairs, inspections, tests and analyses with respect to repair methods:

Repair method	Structure / year of completion	Testing and analyses
Repairs with concrete cast in forms	Tunnel 1996	Visual inspection of 2 repairs 4 cores Macroanalyses and microanalyses Adhesion tests
	Bridge 1 1991	Visual inspection of 1 repair 2 cores Macroanalyses and microanalyses Adhesion tests
Repair with shotcrete	Tunnel 1996	Visual inspection of 2 repairs 4 cores Macroanalyses and microanalyses Adhesion tests
	Bridge 3 1981	Visual inspection of 1 repair 2 cores Macroanalyses
	Bridge 4 approx. 1978	Visual inspection of 2 repairs 4 cores Macroanalyses and microanalyses Adhesion tests
Repair with mortar	Bridge 2 1996	Visual inspections of 2 repairs 4 cores Macroanalyses and microanalyses Adhesion tests
	Bridge 1 1991	Visual inspection of 1 repair 1 core Macroanalyses Adhesion tests
	Tunnel 1996	Visual inspection of 2 repairs 4 cores Macroanalyses and microanalyses Adhesion tests

Figure 1: Bridge 1 was built in 1991. The two defects which were inspected were located on the side of the girder. The defects were described as bad compaction or mechanical defects. One of the defects was repaired with concrete and the other was repaired with mortar.

Figure 2: Bridge 2 was built in 1996. The two defects which were inspected were located on the inner side of the side beam. One defect was caused by settlement of the concrete in the form while the deck in the vicinity was compacted and vibrated. The other defect consisted of holes which were approximately 0.5 m long 15 cm high and 10 cm deep. Both defects were repaired with mortar.

Figure 3: Repairs at the inner corner of the edge beam on bridge 2. The defect was caused by settlement of the concrete at very early age.

Figure 4: The tunnel was built in 1996. The six repairs which were inspected were located on the inner side of the tunnel walls from 0-2 m above bottom slab level. The defects were holes and porous areas due to bad compaction or due to of ice and snow in the bottom part of the form. The holes and porous areas were repaired with repair concrete (similar to the construction concrete), mortar or shotcrete respectively.

Figure 5: Bridge 3 was built in 1981. The defects which were inspected were holes from bad compaction in the bottom part of the slab due to lack of space between the prestressing ducts. The defects were repaired with shotcrete.

Figure 6: Bridge 3 during the construction phase. Reinforcement and prestressing ducts arranged before casting at the box girder.

Figure 7: Underside of bridge 3 box girders after form stripping before repair.

Figure 8: Bridge 4 was built in 1978. The two repairs which were inspected were holes from bad compaction on the outside of the edgebeam. The defects were repaired with shotcrete.

2.2 Visual assessments of repairs

Visual inspections included 13 repairs. The inspection includes registration of defects such as cracks, scaling etc.:

Repair method	Structure / year of completion	Visual assessment of repairs
Repairs with concrete cast in forms	Tunnel 1996	No indications of defects in the repairs.
	Bridge 1 1991	No indications of defects in the repair.
Repairs with shotcrete	Tunnel 1996	No indications of defect in the repairs.
	Bridge 3 1981	Cracks with max width of 0.2 mm and white extrusions on the surfaces.
	Bridge 4 approx. 1978	Vertical cracks and cracks in the joints with max width of 0.2 mm. The repairs have been surface treated.
Repairs with mortar	Bridge 2 1996	No indications of defects in the repairs.
	Bridge 1 1991	Cracks with max width of 0.2 mm in the joint between the repairs and construction concrete and vertical cracks in a local part of the repair.
	Tunnel 1996	No indications of defects in the repairs.

The visual assessments of the repairs in the field study gives very limited indication of defects. The surfaces were generally of a high quality though with another texture than the construction concrete. On the older structures this difference is hardly recognised.

On some of the repairs cracks with small width have been registered. The cracks were usually caused by shrinkage.

On one repair there was signs of white extrusions and cracks.

Figure 9: Repair under the edge of the bridge girder of bridge 3 - shotcrete repairs from 1978. Visual observations of the repairs are single cracks and white extrusions on the surfaces.

Figure 10: Repair under the middle of the bridge girder of bridge 3 - shotcrete repairs from 1978. Visual observations on the repairs are single cracks.

2.3 Petrographical analyses

26 cores have been drilled out of 13 different repairs in 5 different structures. Macroanalyses have been performed on the 26 cores on the basis of that 6 thin sections were prepared for detailed analyses in the microscope:

Repair method	Structure / year of completion	Summary of the results from macroanalyses
Repairs with concrete cast in forms	Tunnel 1996	No signs of defects in the repaired concrete
	Bridge 1 1991	No adhesion in joint between repair concrete and construction concrete.
Repairs with shotcrete	Tunnel 1996	Cracks (width approx. 0.5 mm) parallel to the surface. Holes behind the reinforcements. One core with no adhesion of the repair to the construction concrete.
	Bridge 3 1981	Large holes and bad compaction in the inner part of the repair.
	Bridge 4 approx. 1978	Holes behind reinforcement in the repair.
Repairs with mortar	Bridge 2 1996	Porous and inhomogen mortar and a porous structure.
	Bridge 1 1991	No signs of defects or low quality.
	Tunnel 1996	Hole in a section near the edge of the repair. Local area with porous mortar.

Repairs made with concrete

Repair made with concrete with aggregates of 0 - 32 mm or with aggregates of 0 - 16mm, when the repairs was less than 0,5 m^3. The concrete was similar to the construction concrete.

Bonding primer was not used. The defect concrete was removed by cutting with preumatic or electrical hammers at the surfaces the casting joints was cleaned with water jetting (low pressure). At the surface was the casting joint sawed with a diamond saw at a 90° angle.

Samples from repairs made with concrete indicated that most of the concrete is made with good quality with no signs of defects.

On one sample there has been a lack of adhesion to the construction concrete, which may be caused by the lack of cleaning from preparations of the casting procedure or due to a lack of compaction during the casting processes.

Repairs with shotcrete
Repair made with shotcrete was used for layers between 10 and more than 300 mm. The size of the aggregates is up to 8 mm. The materials was cement based without acrylic or latexbased additives.

Bonding primer was used in the tunnel but not on bridge 3 and 4. The defect concrete was removed by pneumatic hammer. In the tunnel was the surface cleaned with water jetting (low pressure). The casting joints was in the surfaces sawed with a diamond saw at an 90° angle.

Samples from repairs made with shotcrete show examples of the following defects:

- Large and small holes behind reinforcement bars in the repair, because the operator has not been able to fill the repair properly.
- Holes at the edge of the repairs, because the operator has not been able to fill the repair properly or due to settlement in the repair materials at very early ages.
- Air voids parallel to the surfaces. This is possible due to wrong working procedures during the spraying processes or from the smoothening of the surface layers after spraying.
- Lack of adhesion may be caused by lack of cleaning during the preparations of the repair.

Repairs with mortar
Repairs made with motar was used for layers up to approximately 40 mm and with aggregates 0 - 4 mm. The mortars was cementbased with acrylic additives. Bonding primers was used. Defect concrete was removed by pneumatic hammers and the surfaces was cleaned with water jetting (low pressure). Casting joints was in the surfaces sawed with a diamond saw at an 90° angle.

Samples from repairs made with mortar show examples of the following defects:

- Holes at the edge of the repairs, because the craftman has not been able to fill the repairs properly or due to settlements in the repair materials at very early ages.
- Porous mortar due to lack of mixing and compaction.
- Air voids parallel to the surfaces. This is possible due to bad compaction during the filling and application of the mortar, or from the smoothening of the surface layers after application.

The cores show visible signs of inhomogenities, holes, cracks etc. which were created by the craftman who did the repair. The macroanalyses thus indicate that the repairs do not reestablish structural integrity, durability and functionality.

Figure 11: Bottom of the shotcrete repair of a bridge from 1987 (Bridge 3). The repair is very porous and the middle section has not been filled at all. The craftman has not been able to fill the repair while spraying from below which is the worst angle to use the shotcrete technic.

Figure 12: Shotcrete repair of the sidebeam of a bridge from 1978 (Bridge 4). There is a hole in the shotcrete behind the reinforcement. The craftman has not been able to fill the hole while spraying.

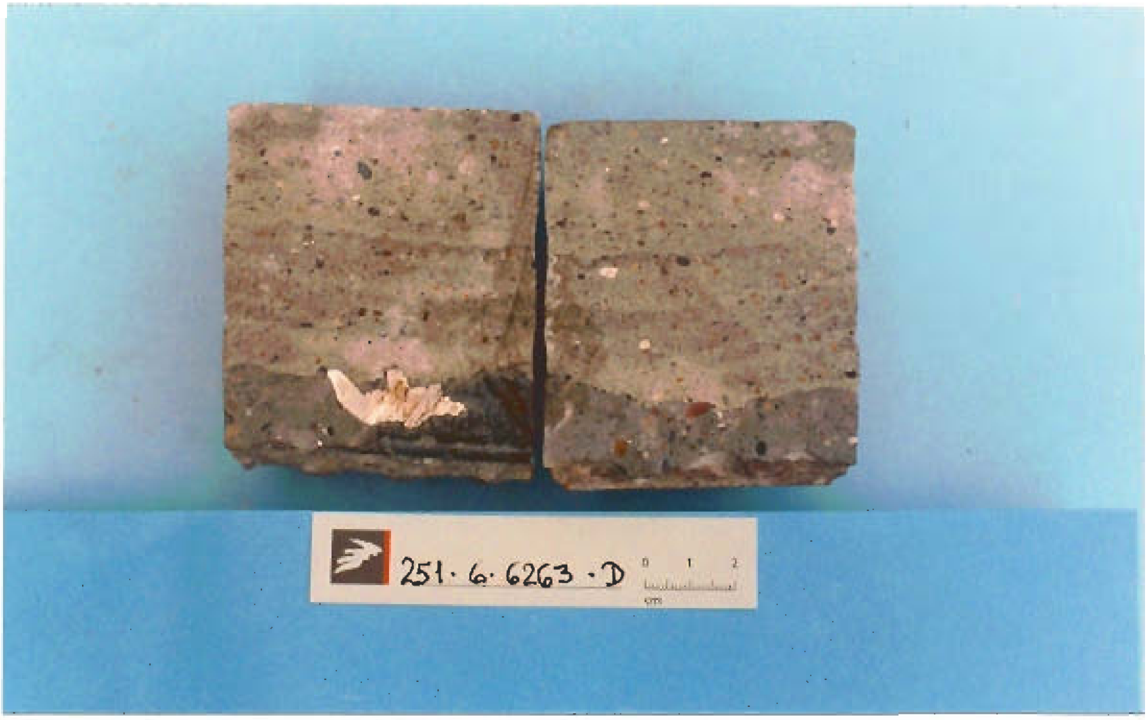

Figure 13: Shotcrete repair of a tunnel wall. The repair materials were well compacted with a homogeneous structure.

Figure 14: Repair with mortar on the inner side of the edge beam of bridge from 1996 (Bridge 2). The mortar is porous due to bad compaction and mixing and there is a weak section near the bottom part of the repair.

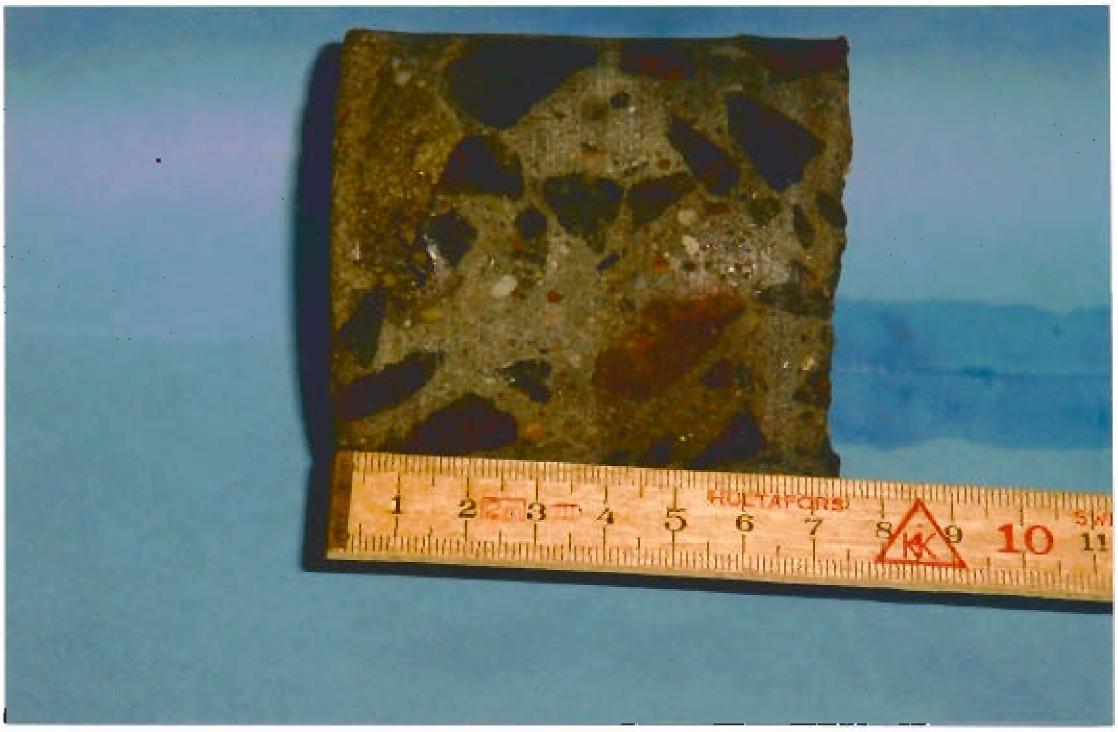

Figure 15: Repair with mortar in a tunnel wall. There is a hole in the section near the edge of the repair due to bad compaction.

Microanalyses on thin sections
Six thin sections were prepared from cores representing repairs with no defects. The thin sections represent repairs with concrete, shotcrete and mortar made on new and old structures.

Repair method	Structure / year of completion	Summary of the defects observed at the microanalyses
Repairs made with concrete	Tunnel 1996	Small cracks in the construction concrete near the joint. Air bubbles near the aggregates indicating insufficient compaction of the repair concrete. Early age shrinkage cracks in the repair concrete.
	Bridge 1 1991	There is no adhesion in the joint between the repair concrete and the construction concrete. The loss of adhesion originates from early age of the repair.
Repairs made with shotcrete	Tunnel 1996	Early age cracking in the casting joint due to shrinkage and insufficient cleaning of surface of the surface of the construction concrete
	Bridge 4 approx. 1978	Minor loss of adhesion due to insufficient cleaning in the preparation of the construction concrete.
Repairs made with mortar	Bridge 1 1991	No defects observed.
	Tunnel 1996	Inhomogeneous air entrapped in the mortar. Cracks parallel to the surface in the construction concrete and adhesion loss.

Repairs made of concrete
The repairs made of concrete were generally of the same quality with respect to aggregates, mix, cement etc. as the construction concrete.

Thus the following defects were observed:

- Cracks in the construction concrete near the casting joint, due to mechanical preparations of the construction concrete before casting of the repair concrete.
- Loss of adhesion were observed on the samples. The loss was probably due to shrinkage of the repair concrete.
- Air bubbles were located along the edges of aggregates indicating insufficient compaction of the repair concrete compared with the construction concrete.

Evaluations: Most of the defects observed on the samples origin from the early ages of the repairs, which means that they were implemented by the working procedures.

Repairs made of shotcrete
The repairs mad of shotcrete were of good quality with the following characteristic properties and observations:

- The W/C ratio of the shotcrete were generally lower than W/C ratio of the construction concrete.
- The carbonatisation of the shotcrete was approximately half the depth of the construction concrete.
- The shotcrete was made in layers where the properties variated with the depth of the layers.
- Air bubbles up to approximately 8 mm wide x 0.5 mm were trapped in the shotcrete.
- There are no cracks in the shotcrete.
- The adhesion is fully intact except in small areas (approximately up to 10 mm) where the surface has not been cleaned sufficiently.

Evaluations: The analysed shotcrete repairs were of good quality except for minor lacks of cleaning of the construction concrete resulting in loss of adhesion of the shotcrete.

Repairs made of mortar
The repairs made of mortar were generally of good quality, with the following observations:

- Lower W/C ratio than the construction concrete.
- Good adhesion between the mortar and the construction concrete.
- There were fine cracks in the construction concrete near the joints of the repair. This indicates that the preparation and removing of damaged concrete can implement further mechanical damages, thus creating a weak zone in the construction concrete. The result may be reduced adhesion.

Evaluations: The analysed repairs were of good quality except for the casting joints and some entrapped air voids.

General remarks

General remarks to the analyses were as follows:

- The quality of the repairs are generally good thus there were some defects caused by the working procedures: These were, among others, reasons, insufficient preparation of the concrete surfaces before repairing and insufficient compaction of the repairing materials.
- There is no indication of differences of the conditions or quality of the samples due to different ages of the samples.

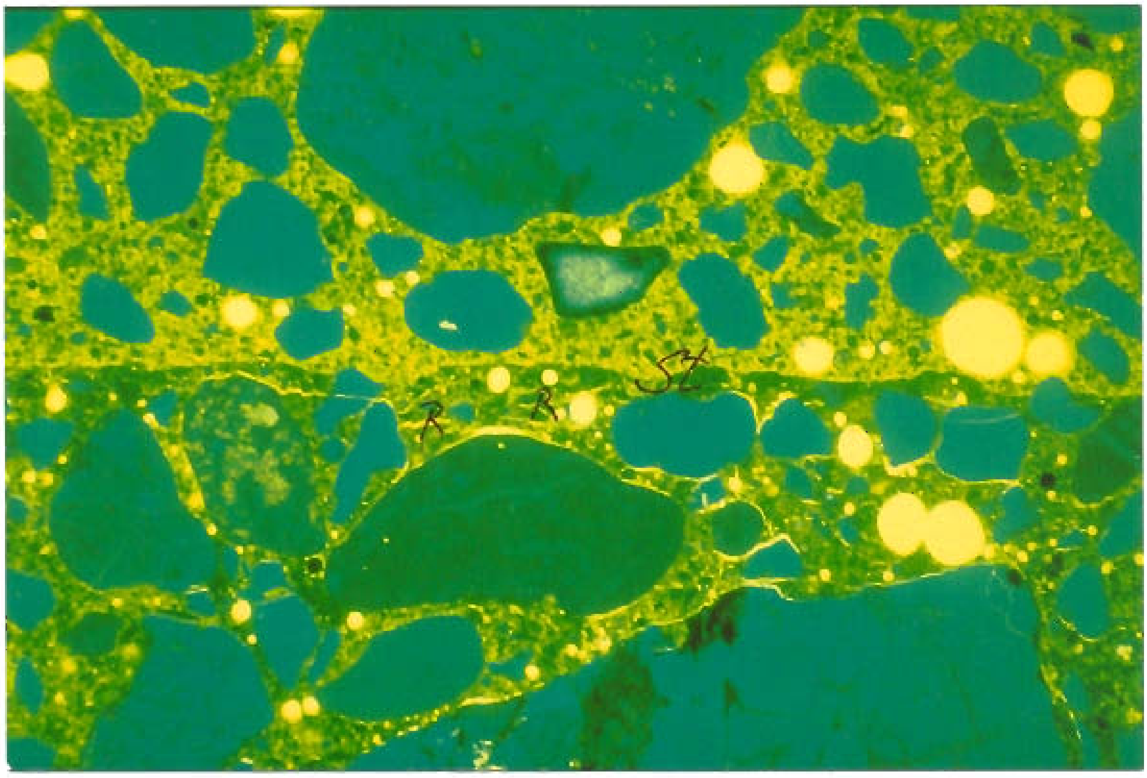

Figure 16: (Photo 5 from the enclosure 7) Illustration covers a section of app. 3 x 4 mm: Thin section prepared from the horizontal casting joint between repair concrete (made in the tunnel in 1996) and construction concrete. There was continuos adhesion and homogeneous structure of the repair concrete. There were parallel cracks (R) in the construction concrete indicating damages due to the demolition and removal of concrete before the repair. The cracks cause loss of adhesion strength and reduced durability of the repair.

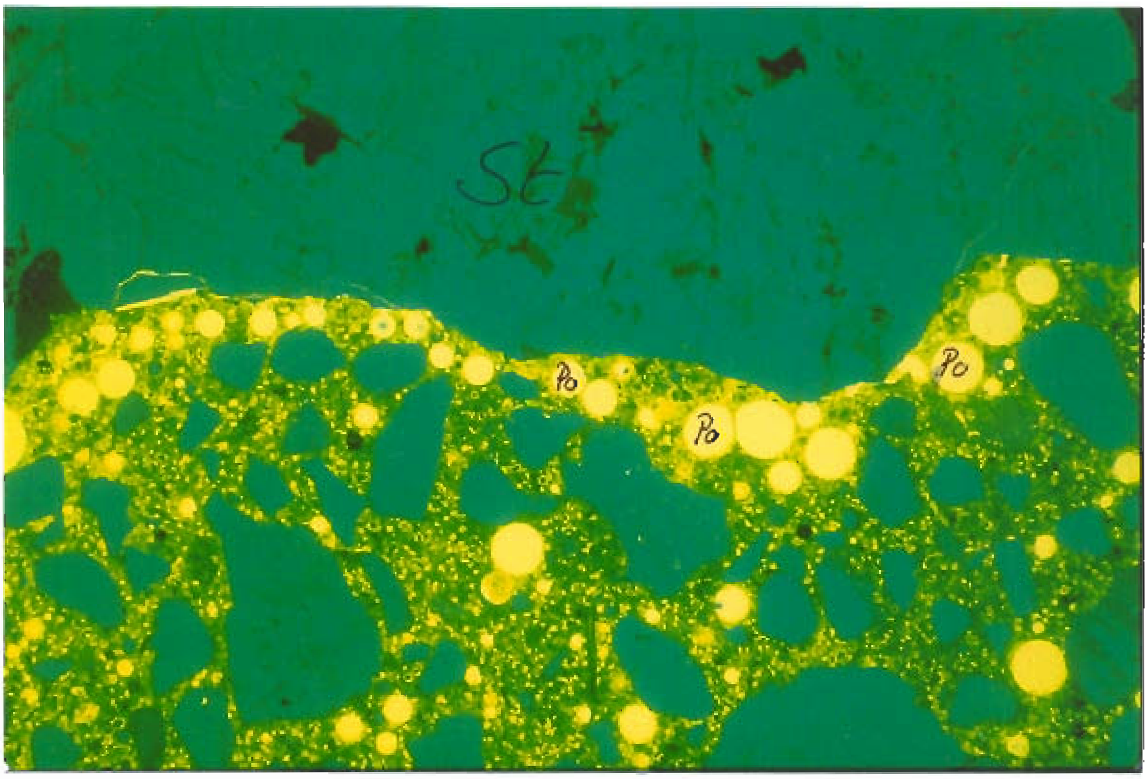

Figure 17: (Photo 6 from the enclosure 7) Illustration covers a section of app. 3 x 4 mm: Thin section prepared from the internal part of repair concrete made in the tunnel in 1996. Air bubbles were located along the stones, thus indicating insufficient compaction of the repair concrete.

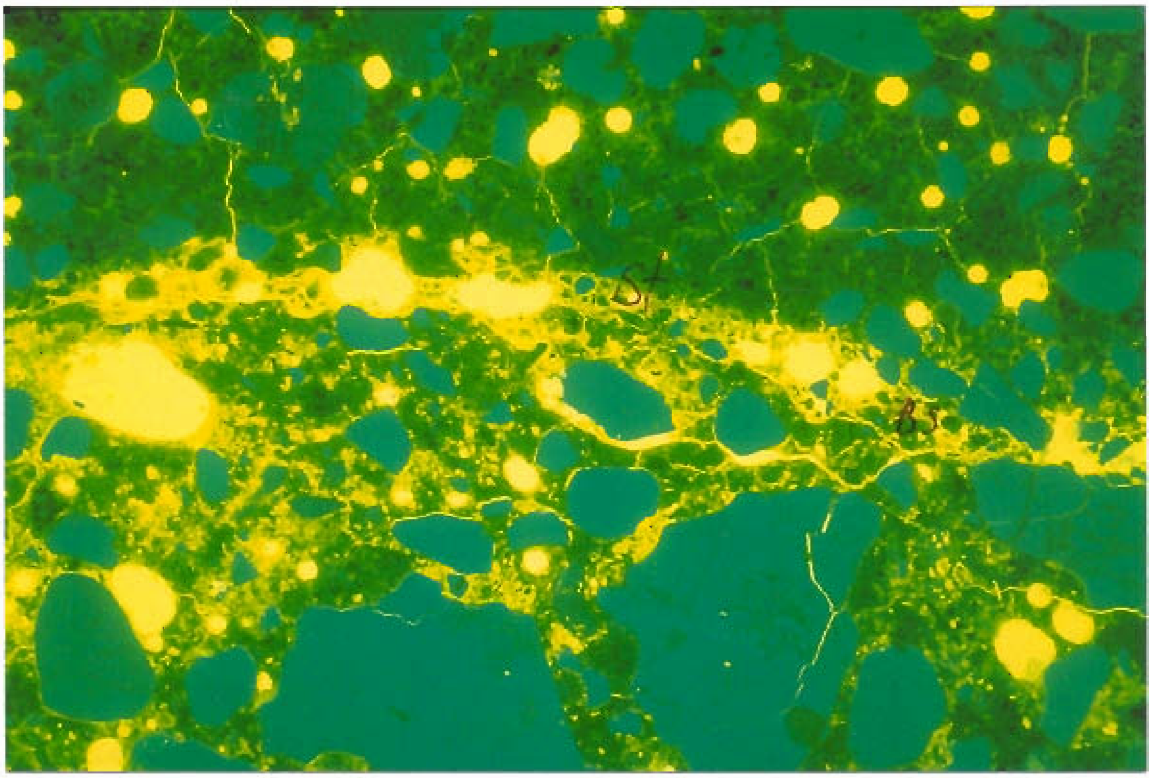

Figure 18: (Photo 17 from the enclosure 7) Illustration covers a section of app. 3 x 4 mm: Thin section prepared from the internal casting joint between shotcrete at the top part and construction concrete. The repair were made on the side beam of a bridge in approximately 1978. There is dust and dirt on the surface of the casting joint which cause lack of adhesion.

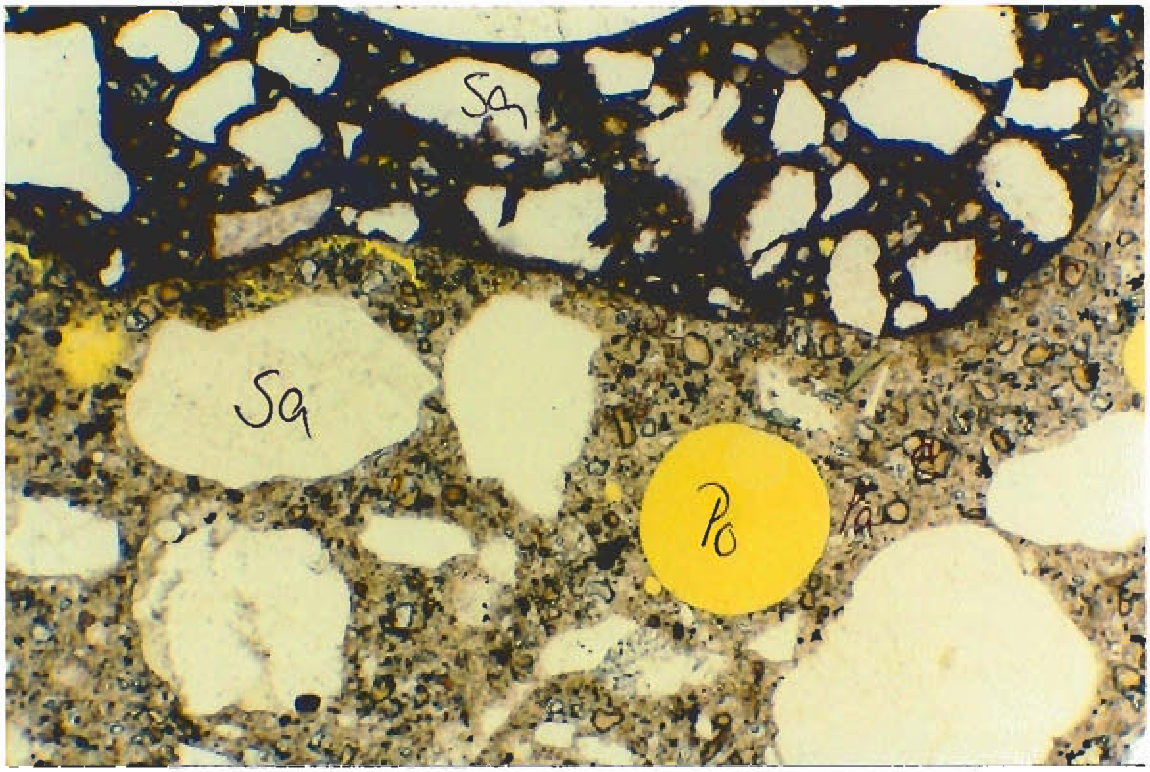

Figure 19: (Photo 19 from the enclosure 7) Illustration covers a section of app. 3 x 4 mm: Thin section prepared from the internal casting joint between mortar at the top part and construction concrete. The mortar is of good quality without inhomogenities.

2.4 Adhesion tests

Adhesion tests have been executed with respect to NT BUILD 365 or the BOND method. Adhesion tests generally indicated that the weak zone is located near the casting joint or in the structural concrete behind.

Repairs made with concrete

Tests carried out on bridge 1 (1991) was measured to 0,95 MPa

Repairs made with shotcrete

Tests carried out on the tunnel:
Average = 1.50 MPa
Min. = 1.20 MPa

Tests carried out on Bridge 4 (1978):
Average= 2.06 MPa
Min. = 1.40 MPa

Adhesion of the shotcrete generally demonstrates sufficient strength with a high minimum and average strength.

2.5 Results from the construction phase

From an inspection and an evaluation of a number of projects the following general conclusions were made:

- The number of repairs is considered to be small (one repair per approx. 2-700 m3 concrete). Defects of great significance are observed per 5,000 m3 of concrete.

- The quality test and inspections of the repair processes vary from job to job. The specifications were not detailed in this matter.

From the construction of a tunnel which included more than 36,000 m3 of concrete the following observations were made ref. [4]:

Shotcrete was tested before starting the job. The tests included: Adhesion tests, resistivity tests, petrographical analyses and chloride diffusion:

Property/test	Specifications/ requirements	Test results
Adhesion strength NT BUILD 365	Average strength > 1.1 MPa Min. strength > 0.9 MPa	Average strength = 1.60 MPa Min. strength = 1.50 MPa
Resistivity	Test of the construction concrete = 38.4 KOhm	Test of the shotcrete = 33.0 KOhm
Petrographical analyses	Comparison with analyses of other shotcrete - no precise specification	No great deviation recognized.
Chloride diffusion ASSHTO T277-831	Comparison with the construction concrete. The construction concrete measured 1903 Columbs.	The shotcrete measured 2259 Columbs (10-60 mm) and 1281 Columbs (60-110). The results are considered low to moderate.

Further adhesion tests were carried out during the construction phases with the following observations:

The shotcrete was tested after every 10 repairs. The average was more than 1.5 MPa and the mininum more than 1.4 MPa.

Repairs with mortars were tested previous to the building of the tunnel . The average strength was more than 1.3 MPa and the minimum was more than 1.2 MPa. Tests during the construction were carried out after every 10 repairs: Average strength was more than 1.7 MPa and the minimum strength more than 1.4 MPa.

From evaluation of repairs of a large bridge project ref [2] the following observations were made:

- Adhesion tests indicate an average adhesion strength of 3.1 MPa.

- Chloride permeability tests (ASSHTO T 277 231) indicate that the permeability of the repair mortar, the repair concrete and the construction concrete are similar.

- The petrographical analyses indicate no defects in the repairs except for fine cracks vertical to the surfaces, some air inclusions and micro cracks in the constructions concrete near the joint surfaces. This indicates damages due to the mechanical processes of removing the damaged concrete.

2.6 Injection of cracks

Three different technics of injection of cracks have been described:

- Injection with modified acrylic products
- Injection with polyurethane
- Injection with epoxy resin

The methods have been used to seal cracks and leaking joints in tunnel and bridge foundations.

The epoxy resin was used to reestablish structural integrity and strength.

Figure 20: (Photo: RENESCO) Injection of cracks on the top deck of a tunnel. The injection included more than 900 injection valves in drilled holes and more than 900 litres of acrylic injections materials were used.

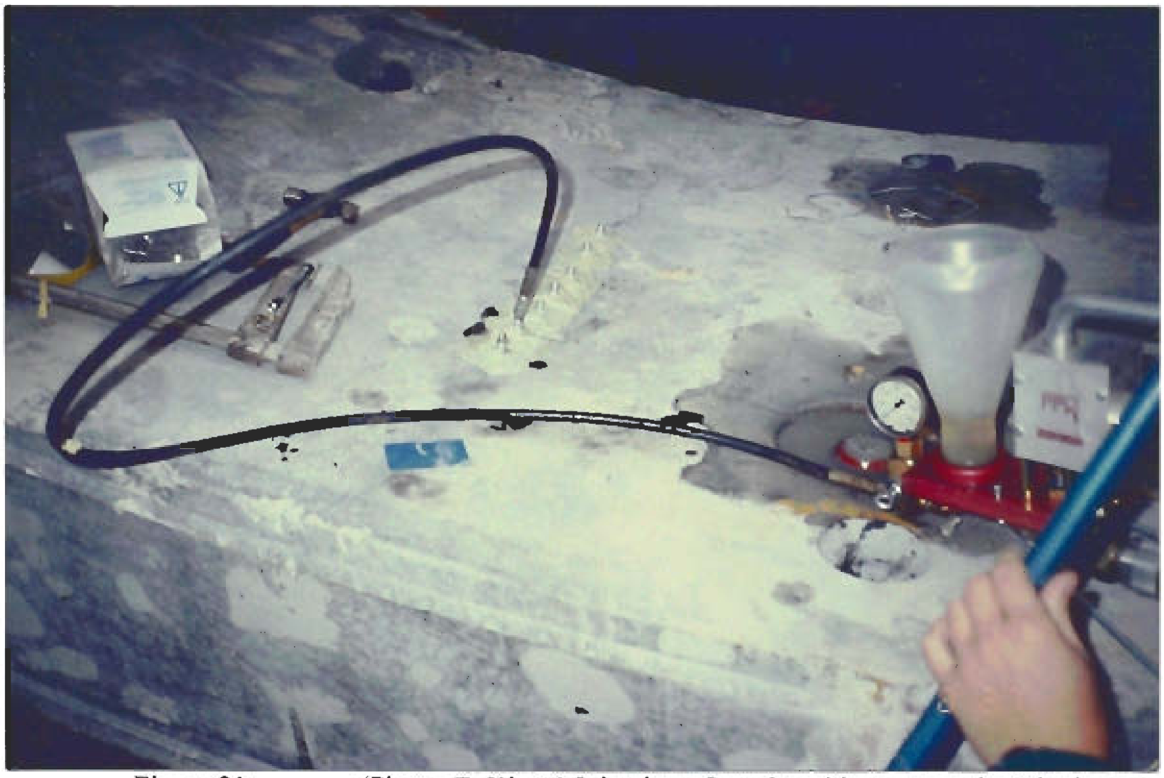

Figure 21: (Photo: E. Kluge) Injection of cracks with epoxy resin. Nipples are glued to the concrete surface on the top of the crack.

3. Discussions

The discussion is divided into two sections: Part 1 includes discussions and evaluations of the observations made by NNR on 4 bridges and 1 tunnel and part 2 includes observations and evaluations made by others or together with other parties during the construction phases.

3.1 Discussion of observations made by NNR on 4 bridges and 1 tunnel

Field observations were made on repair of new and old structures made of high quality concrete. The survey included visual inspections and assessments of the structures, petrographical inspections of cores drilled out of representative repairs including both macroanalyses and microanalyses on thin sections. Adhesion tests were also performed in order to measure the adhesion strength of the repairs.

The visual inspection of the repairs indicated that most of the repairs were without any major defects. Minor defects such as cracks in the casting joints, single cracks vertical to the casting joints and map crackings were observed. The cracks were generally less than 0.2 mm and of minor influences to the durability of the constructions.

More than 25 cores were drilled in more than 13 different repairs. The cores represented 3 types of repairs - casting with repair concrete, shotcrete and repair mortar. The samples included examples of defects and problems arising when concrete is repaired during the construction phase.

The petrographical analyses showed that defects in repairs (all types) made in the construction phase were:

- Cracks in the construction concrete near the casting joints due to mechanical preparations of the surfaces before repairing.
- Insufficient cleaning of the construction concrete before repairing.
- Holes and air entrapped in the repair materials because of insufficient compaction of the repair materials (mortar and concrete).
- Settlement in the repair material.

These defects in the repairs are mainly caused by the working procedures performed by the craftsmen.

Other defects such as cracks in the casting joints resulting in loss of adhesion may be caused by shrinkage of the repair materials (concrete and shotcrete) at earlier stages due to insufficient surface protection or lack of material properties.

The defects observed indicate that these repairs do not reestablish the structural integrity and durability. The defects which were observed were generated in the early stages of the repairs.

The petrographical analyses included both low and high quality of repairs for all types of repairs. The repairs made of high quality were recognised as being at the same level as the high quality construction concrete or even better with a lower W/C ratio. This means that repairs without defects may reestablish the high quality concrete sufficiently.

The adhesion results indicated that the adhesion strength of shotcrete were sufficient.

3.2 Discussion of other observations from the construction phase

Normally a defect was expected every 2-700 m3 of concrete. Serious defects were observed within every 5,000 m3 of concrete.

An example of preliminary testing of repair methods includes determination of adhesion strength, resistivity, chloride permeability and petrographical analyses. The results of the preliminary tests were comparable with the results from the testing of the construction concrete. Further tests of adhesion strength were performed after every 10 repairs. The tests were at the same level as of the preliminary tests. The petrographical analyses did not indicate severe defects.

Inspection and evaluation of repairs of a large bridge project included investigation of shrinkage and adhesion strength, petrographical analyses, chloride permeability and frost resistance. The results were generally comparable with the construction concrete. The repairs had a high adhesion strength, low chloride permeability and a high frost resistance. The investigation thus indicated fine cracks in the construction concrete caused by damages from the mechanical processes of removing the concrete.

The observations also indicated the demolision of concrete by high pressure water jetting were prefered.

3.3 General comments

It was generally recognized that the designers should be involved in the prevention of defects by securing appropriate arrangements and layout of reinforcement bars, joints, prestressing. See report: " HETEK: Vejledning i udformning og udførelse af armerede betonkonstruktioner re. [6]".

Some of the defects observed might influence the durability of the structures even through this is not observed on the structures investigated.

A full discussion of the impact of the defects observed awaits the results of the adhesion tests etc.

4. References

[1] State of the Art, Vejdirektoratet, 1996.

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