EARLY DAMAGES DUE TO ALKALI AGGREGATE REACTIONS IN A SWIMMING POOL – DIAGNOSIS AND RATE OF EXPANSION

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Abstract

Most alkali silica reactive rock types in Norway are slowly reactive. Damages may, however, develop very fast if the local environment is too severe. In 2006 SINTEF was engaged in a case, where a swimming pool already after 1.5 years in service had developed damages due to ASR. The temperature in the swimming pool is extraordinary high, i.e. 33-38 °C. The initial alkali content in the concrete was 3.7-4.5 kg/m^3 Na_2O-eqv (CEM I) and the content of reactive aggregates is high.

Thorough examinations have confirmed that expansions due to ASR have lead to extensive cracking, both in the concrete trough and in the supporting concrete structures.

The structural consequences of the progressing expansions have been evaluated, and two different repair actions have been considered: 1) Destruction and rebuilding of a new pool and 2) Building of a new inner concrete trough separated from the expanding old one.

Keywords: alkali silica reactions, diagnosis, swimming pool, increased temperature, early age damages

1 INTRODUCTION

Most alkali silica reactive rock types in Norway are so called slowly reactive [1]. The first signs of damage due to ASR (i.e. cracks or expansion) are normally not visible until 15-20 years of service life [2, 3]. The case presented in this paper, however, shows that the damages may develop very fast if the local environment is too severe. In 2006 SINTEF was engaged in a case, where a swimming pool already after less than two years in service had developed severe damages, e.g. in the form of tiles falling off the inside faces of the pool and cracking of the concrete. Field and laboratory examinations were performed, both to document the cause of damage, the extent of cracking and the moisture condition in the concrete. The outside surfaces of the concrete trough, both the bottom and a wall, were instrumented in order to measure the development of cracks with time.

2 THE POOL STRUCTURE AND CONCRETE COMPOSITION

The swimming pool has a complex geometry, partly with different bottom levels and curved side walls. The main part of the pool has, however, an approximately rectangular shape with dimensions about 8 m x 17 m. The thickness of the bottom plate and the walls is 250 mm. The pool trough is supported by walls, beams and columns. Along one long side of the trough, columns with height 1.6 m are standing with a centre distance of approximately 3 m. One beam is supporting the bottom plate in the longitudinal direction, approximately in the middle part of the bottom plate.

Two different concrete recipes have been used, one for the bottom plate and one for the walls. The nominal cement content is 340 kg/m^3 (Norcem Standard CEM I with 1.08 % Na_2O-eqv) and 360 kg/m^3 (Norcem Industri CEM I with 1.25 % Na_2O-eqv), respectively. 2.7 % silica fume of binder content is added to the bottom plate concrete, no silica fume in the walls. The initial alkali content in the concretes is calculated to 3.7 and 4.5 kg/m^3 Na_2O-eqv, respectively. As the pool water is desinfected by use of hydrogen peroxide (H_2O_2), no external alkali supply should be expected. The content of reactive rock types in the 0-22 mm aggregate used is high, estimated to above 50 %. According to the Norwegian national regulations [4], the alkali content has to be less than 3.0 kg/m^3 Na_2O-eqv if the aggregate is classified as alkali reactive.

The inside surfaces of the pool are tiled. There is a cement based membrane with high diffusivity under the tiles, which in fact can not be expected to keep the concrete dry. The swimming pool was built in 2004. The water temperature in the pool is extraordinary high, i.e. 33-38°C. It should be noticed that these exposure conditions are quite similar to the RILEM AAR-3 38 °C CPT [5].

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3 FIELD EXAMINATIONS

3.1 General

After less than two years in service, severe damages were observed inside the swimming pool. In order to document the cause and extent of damage, both field and laboratory examinations were performed.

Visual inspections and field measurements were performed at three stages: In May 2006 (preliminary), in November 2006 and in June 2007. The most comprehensive inspection was carried out in November 2006. The main results from the inspections are presented in the following sections.

3.2 Visual inspections

Outside/underside of the pool trough

Cracks are observed in almost all outside faces of the pool walls, both as single cracks and map cracking. The crack formation is observed to be dependent of the height of the wall, e.g. single cracks in lower walls (< 0.7 m) and map cracking in higher walls (about 1.5 m). An example of map cracking is shown in Figure 1.

Cracks are also observed in all visible areas of the underside of the pool bottom, mainly as map cracking. On the underside of the water gutters, cracks are observed as single cracks perpendicular to the pool walls. Extensive cracking with water leakage is observed in one gutter corner, accelerating from May 2006 to June 2007 (i.e. from 1.5 to 2.5 years in service), see Figure 2.

Supporting structures under the pool trough

The pool trough is supported by walls, beams and partly directly on columns. Along one long side of the trough, columns with height 1.6 m are standing with a centre distance of approximately 3 m. Each of the columns has 2-3 horizontal cracks (widths 0.15-0.20 mm) near the top, on the side turning out from the trough. On the opposite side, finer cracks are registered near the bottom of the columns.

One beam is supporting the bottom plate in the longitudinal direction, almost in the middle part. This beam has several vertical cracks, see Figure 3. The cracks diverge from cracks typically caused by bending moment, by running from the upper top of the beam side.

Inside faces of the swimming pool

The visual inspections inside the swimming pool are mainly performed with water present. At the preliminary inspection in May 2006, however, the pool was emptied. The following signs of damage are observed:

- Longitudinal cracks in the horizontal top surface of the walls, see Figure 4
- Vertical cracks in the walls, see Figure 5
- Loose tiles both in the pool walls and bottom floor, see Figures 6-7
- Severe cracking of the concrete behind the tiles, see Figure 7

3.3 Measurements of crack widths in reference areas

In order to measure the development of crack widths, i.e. the expansion, over time, two reference areas were established in November 2006. The reference areas were defined as square areas of 1 x 1 m^2, with two side lines (OA and OB) and both diagonals (OC and AB) representing the measuring lines, see Figure 8. Reference area 1 was established on the underside of the pool bottom, while reference area 2 was established on the outside face of the pool wall.

The width of each crack (cw) crossing the measuring lines is measured, and on the basis of the calculated total crack width pr line ($\sum$ cw/l) a Surface Crack Index, SCI, for each reference area is calculated as given in Equation 1.

$$SCI=\frac{\sum cw/l_{OA}+\sum cw/l_{OB}+\sum cw/l_{OC}+\sum cw/l_{AB}}{4} \qquad (1)$$

The method is developed in France [6] and is later modified for Norwegian conditions [7]. The results are presented in Table 1 and 2.

3.4 Measurements of Relative Humidity

In order to measure the relative humidity (RH) in the concrete, Humi-Guard sensors [8] were installed in different depths from the outside (dry) surfaces of the concrete trough. Holes were drilled in the concrete to aimed depths and plastic tubes with a sealing flange inserted into the holes. A sensor was then mounted on a sealing contact, which was inserted into each tube. The humidity inside a tube will be in equilibrium with a small concrete surface at the tube inner end. A reading is taken by connecting a meter to the sensor leads from the sealing contact. The system has a relative humidity range within 75-98 %, and the measurement uncertainty is given to be ca 2 % RH at 85 % RH.

Within reference area 1, three sensors were mounted in depths 115 mm, 155 mm and 165 mm from the outer (dry) surface, respectively. Within reference area 2, three sensors were mounted in depths 100 mm, 150 mm and 200 mm, respectively. The total thickness of the pool wall and bottom plate is 250 mm, which means that the RH is measured in distances of 50-150 mm from the water exposed surface.

Two of the sensors in area 2 were installed in November 2006, the rest of them in February 2007. Measurements have been performed until June 2007. Measurements performed regularly on two of the sensors from November 2006 to June 2007 show small variations over the period, see Figure 9, which indicates rather stable humidity conditions in the concrete. The RH values in the different measuring points in February 2007 are presented in Table 3, together with the corresponding measured temperatures.

3.5 Drilling of concrete cores for laboratory examinations

The preliminary examination in May 2006 included structural analyses of one core drilled from the upper vertical face of the pool wall, see Figure 10. During the main inspection in November 2006 two concrete cores were drilled from each of the two reference areas. The cores were wiped off immediately after drilling, tightly wrapped in plastic bags and transported to SINTEF´s laboratory. The laboratory examinations included material structural analyses, porosity measurements and determination of the degree of capillary saturation. The results from the material structural analyses are presented in section 4.

The diameter of the cores was 83 mm (near top of the wall), 92 mm (reference area 2) and 98 mm (reference area 1), while the length of the cores was approximately 140 mm. The localization of the drilled cores in the concrete sections is illustrated in Figure 10.

4 MATERIAL STRUCTURAL ANALYSES

The first step in a material structural analysis performed at SINTEF is a visual inspection of the concrete core with emphasis on presence and character of any cracks and possible precipitations in the air voids. In the next step the concrete core is divided into two parts in the length direction. One of the halves is used to prepare a plane polished section for macroscopic investigations (i.e. presence and extent of cracks, aggregate origin (crushed or natural), air distribution and possible reacted aggregates/reaction products). The plane polished section is impregnated with fluorescent epoxy, thus the cracks and air voids are easily detected by use of an UV-lamp. The area of the plane polished section is approximately the diameter of the core multiplied with its length, i.e. 83/92/98 x 140 mm^2 in this case. From the second half of the concrete core one or more thin sections are normally prepared, each of them covering an area of 28 x 48 mm^2. The thin sections are examined by use of a polarizing microscope with UV filters. By use of this microscope it is possible to detect among others the air content, the rock types, any reacted particles, and the presence of any cracks and/or precipitations. In order to give a precise diagnosis of any presence of ASR, it is required to detect alkali gel during the thin section analysis. In this case one thin section was prepared from each core, localised in the very inner part of the core (as close as possible to the water exposed concrete, see Figure 10).

The results from the material structural analyses are given in Table 4. When evaluating if and to what extent ASR appears in the samples, special attention is paid on investigating whether the ASR forms cracks within the aggregates and/or in the cement paste. Examples of observations are given in the Figures 11-14.

The thin section analyses documented that the reacted rock types are sandstone, mylonite, greywacke and phyllite.

5 DISCUSSION

The material structural analyses performed document that the cracking and expansion of the concrete in the swimming pool are caused by ASR, even though the age of the structure is only a few years. These early damages are exceptional in Norway, where most reactive aggregates are classified as slowly reactive and the first signs of cracking are not expected until 15-20 years of service life. The high amount of reactive aggregates (estimated to > 50 %) in combination with high average temperature in the concrete (approximately 30 °C) is assumed to be the reason why the degradation process runs so fast in this case.

The reaction products are found both in the pool walls and the bottom plate. In the wall and the bottom plate the alkali gel is found in the inner parts of the drilled cores, in a distance from the water exposed surface of approximately 110-120 mm. The relative humidity of the concrete in these depths is measured to be above 90 %, i.e. high enough to initiate reactions. No signs of ASR are found in the outer, drier parts of the concrete cores, although extensive cracking is observed in these parts (with crack depths up to 120 mm).

The observed crack patterns on the outside/underside of the pool trough are compatible with an expansion of the concrete near the water. The following structure parts are specially mentioned:

- The beam supporting the bottom plate has vertical cracks running from the top of the beam to the bottom, indicating that the beam is loaded by tension due to expansion of the bottom plate.
- Columns supporting the concrete trough have horizontal cracks both in the upper part (outside) and lower parts (inside), indicating that the columns are stressed by the expanding trough which forces the top of the columns outwards.
- Larger, free concrete areas in both the pool bottom and the walls have characteristic map cracking. The crack formation is compatible with multiple direction tensile stresses in the outer parts of the concrete due to expansion of the concrete near the pool water.
- The upper parts of the concrete walls are heavily cracked. This is probably due to high water content in the concrete (exposed from three sides) and easy access for expanding (not restraint)
- Tiles on the concrete near the water gutters are falling off. This is probably due to shear- and tensile stresses caused by expansion of the concrete.

The initial measurements of crack widths on the outside/underside of the trough in 2006, after about 2 years in service, indicate that the total expansion of the concrete is approximately 1.3 ‰ (roughly considered equal to the initial Surface Crack Index in Table 1 and 2). Measurements in June 2007 indicate a slight tendency of increasing crack widths/further expansions (+0.2 ‰). The measurements are, however, performed on the opposite side of where the expansions take place, and this may disturb the measurements as long as internal stresses are being built up over the cross section. According to the Norwegian regulations [4] a maximum expansion of 0.5 ‰ is allowed for laboratory casted concrete prisms after 1 year of exposure according to the Norwegian 38°C CPT. The crack width measurements in field indicate a concrete expansion exceeding this limit, which indeed founds that the pool suffers from an aggressive damage development.

Visual registrations on the underside of the water gutter (Figure 2) document an increase in the extent of damage over the period May 2006 - June 2007. Visual inspections from inside the pool also show an increase in damage by increasing crack widths (Figure 5) and an increasing number of broken/loose tiles.

It is likely that the expansion and cracking of the concrete near the pool water will continue and lead to increasing water ingress into the concrete sections. As the water ingress proceeds, alkali aggregate reactions will be initiated in continuously new parts of the pool walls and the bottom plate, causing an increasing extent of cracks/tile damages and finally major leakages through the concrete trough.

6 STRUCTURAL CONSEQUENCES AND RECOMMENDATIONS FOR REPAIR

The alkali-silica reactions cause internal stresses in the concrete, both compressive and tensile stresses. The tensile stresses initiate cracks when the tensile strength is exceeded. The long term structural consequences of the cracking are primarily related to the reduced tensile strength of the concrete, which again primarily influences the shear capacity of the structure and the bond properties of the reinforcement. In shear a larger portion of the force has to be taken by the reinforcement. The reinforcement will, however, obtain additional tensile strain due to the concrete expansions and thereby reach the yielding point at an earlier stage than assumed in design. This will lead to (or result in) earlier yielding for moment actions and less contribution to the shear strength of the shear reinforcement.

In this case, the early stage damages will strongly affect the serviceability of the structure, long before the structural properties are affected. Loose and broken tiles are not acceptable as the pool guests may cut themselves on sharp edges, the visual expression of the pool area becomes shabby and the hygienic conditions may be unacceptable. Later damages will develop as water leakages through the concrete trough and into the technical rooms in the basement, causing huge maintenance problems and need for frequent shutdowns of the swimming pool.

The consequences of the ASR in the concrete structure are severe, even after a few years in service. Running maintenance work will not be sufficient to keep the pool in a satisfactory condition, and a comprehensive repair will be necessary within a short period.

The nature of the ASR mechanism (need for reactive aggregates, alkalis and water) requires that the repair action either focuses on 1) removing the reactive components or 2) hindering water access to the reactive concrete. As a consequence of this, two repair actions have been evaluated: 1) Destruction and rebuilding of a new pool and 2) Building of a new inner concrete trough totally separated from the expanding old one by a water tight membrane and a flexible draining layer, e.g. of light weight aggregate. It must be taken into account that the expansion of the old concrete will continue until it has dried sufficiently. Both alternatives have been found technical feasible, but the final decision is to be made by the owner based on economical and practical considerations.

7 CONCLUSIONS

Extensive field and laboratory examinations have been performed in 2006-2007 of a Norwegian swimming pool built in 2004, suffering from cracking and flaking tiles. Based on the present results, the following may be concluded:

- The structural analyses document that the cracking and expansion of the concrete in the swimming pool are caused by ASR, even though the age of the structure is only a few years. The reaction product, alkali gel, is found in both the pool walls and the bottom plate, so far only in short distance, i.e. 110-120 mm, from the pool water.
- The observed crack patterns on the outside/underside of the pool trough, and in the supporting structures, are compatible with an expansion of the concrete near the pool water.
- The initial measurements of crack widths on the outside/underside of the trough indicate that the total expansion of the concrete after 2 years in service is approximately 1.3 ‰.
- It is likely that the expansion and cracking of the concrete near the pool water will continue and lead to increasing water ingress into the concrete sections. As the water ingress proceeds, alkali aggregate reactions will be initiated in continuously new parts of the pool walls and bottom plate, causing an increasing extent of cracks/tile damages and finally major leakages through the concrete trough.
- The consequences of the damages are at this early stage related to the serviceability of the structure. Loose and broken tiles may cause injury to the pool guests, a shabby visual expression of the pool area and unacceptable hygienic conditions in the pool. Later damages will develop as water leakages, causing huge maintenance problems and need for repeated shutdowns of the swimming pool.
- The consequences of the ASR in the concrete structure are severe and a comprehensive repair will be necessary within a short period. Two different repair actions have been evaluated: 1) Destruction and rebuilding of a new pool and 2) Building of a new inner concrete trough separated from the expanding old one. Both alternatives have been found technical feasible, but the final decision is to be made by the owner based on economical and practical considerations.

8 REFERENCES

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TABLE 1: Measured crack widths and calculated Surface Crack Index on the underside of the pool bottom (reference area 1).

Date	OA		OB		OC		AB		Surface Crack Index (mm/m)
	$\Sigma cw/l$ (mm/m)	No. of cracks	$\Sigma cw/l$ (mm/m)	No. of cracks	$\Sigma cw/l$ (mm/m)	No. of cracks	$\Sigma cw/l$ (mm/m)	No. of cracks	
2006-11-07	0.65	6	1.40	7	1.79	12	1.34	10	1.30
2007-06-20	0.70	6	1.45	7	2.20	12	1.61	11	1.49
Change	+0.05	0	+0.05	0	+0.41	0	+0.27	1	+0.19

TABLE 2: Measured crack widths and calculated Surface Crack Index on the outside face of the pool wall (reference area 2).

Date	OA		OB		OC		AB		Surface Crack Index (mm/m)
	$\Sigma cw/l$ (mm/m)	No. of cracks	$\Sigma cw/l$ (mm/m)	No. of cracks	$\Sigma cw/l$ (mm/m)	No. of cracks	$\Sigma cw/l$ (mm/m)	No. of cracks	
2006-11-07	1.08	7	1.42	7	0.95	8	1.77	11	1.31
2007-06-20	1.43	8	1.62	7	1.00	8	1.88	11	1.48
Change	+0.35	1	+0.20	0	+0.05	0	+0.11	0	+0.17

TABLE 3: *Measured Relative Humidity (%) and Temperature (°C) in the concrete trough*

Date	*Reference area 1(distance from the underside of the pool bottom)*			*Reference area 2 (distance from the outside surface of the pool wall)*		
	1-1 (115 mm)	1-2 (155 mm)	1-3 (165 mm)	2-1 (100 mm)	2-2 (150 mm)	2-3 (200 mm)
2007-02-02	92,4 % 30,9 °C	94,3 % 31,1°C	96,1 % 31,3°C	87,4 % 29,8°C	94,8 % 29,6°C	96,8 % 30,7°C

TABLE 4: *Results from the structural analyses of the drilled concrete cores*

Pool wall near the top (preliminary examination)			*Reference area 1(underside of the pool bottom)*			*Reference area 2 (outside of the pool wall)*		
Visual inspection of cores	*Plane polished section*	*Thin section*	*Visual inspection of cores*	*Plane polished section*	*Thin section*	*Visual inspection of cores*	*Plane polished section*	*Thin section*
White precipitations in air voids. Clear signs of ASR	Clear signs of ASR	Alkali gel in cracks and air voids. Clear signs of ASR at an advanced stage	Minor signs of ASR	No signs of ASR	Alkali gel in air voids. Signs of ASR at an early stage	Minor signs of ASR	No signs of ASR	Alkali gel in cracks and air voids. Clear signs of ASR at an advanced stage

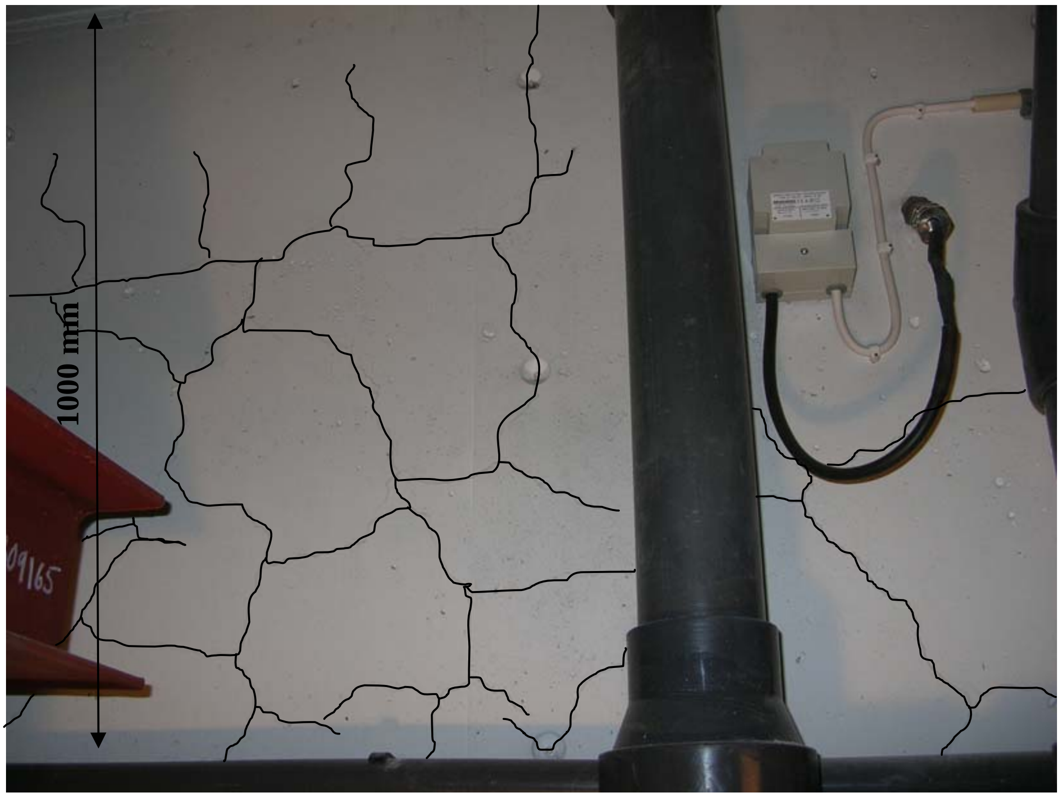

Figure 1: Map cracking on the outside face of the pool wall. Note that the cracks are intensified by drawings on the photo.

Figure 2: Visually evaluated increase in water leakage through cracks in the water gutter. Photos taken in May 2006 (upper), November 2006 (left) and June 2007 (right).

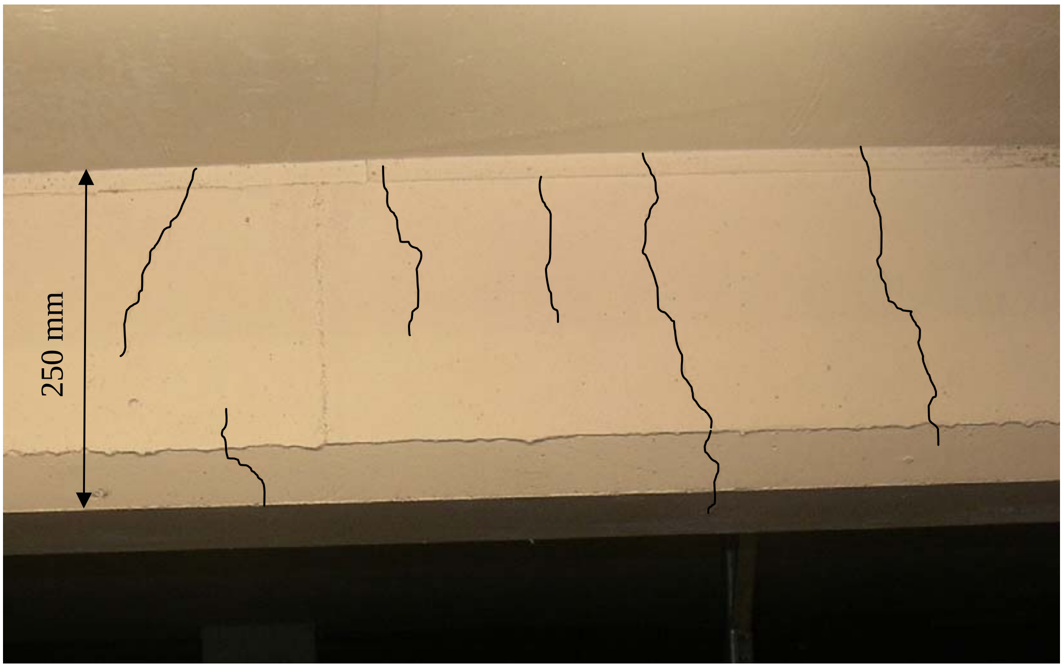

Figure 3: Vertical cracks on the supporting beam. Note that the cracks are intensified by drawings on the photo.

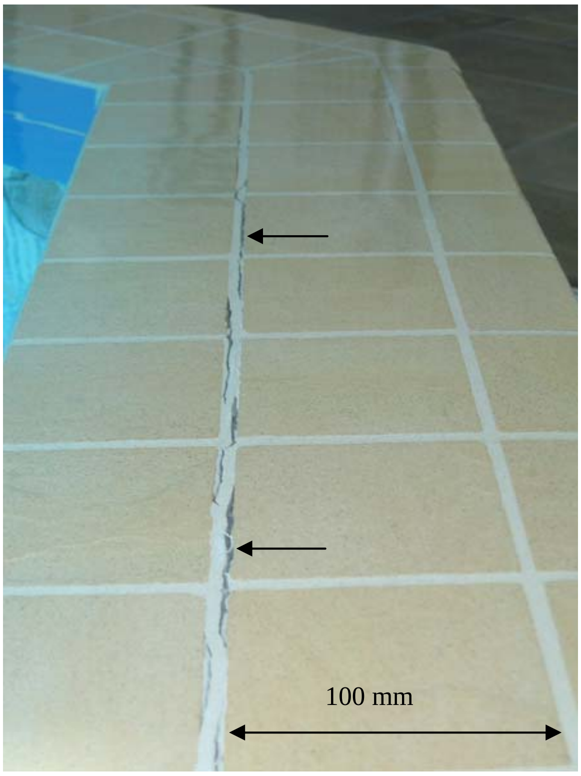

Figure 4: Longitudinal crack in the horizontal top surface of the wall.

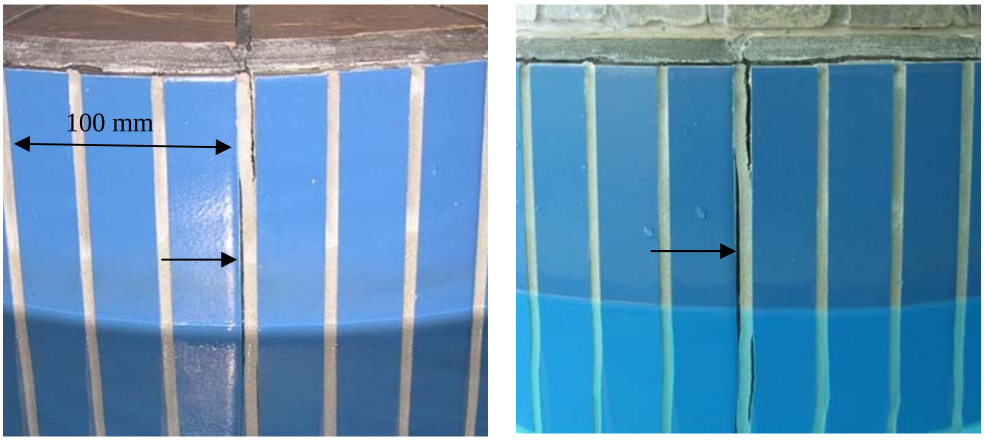

Figure 5: Increasing vertical crack in the tiled pool wall. Photos shot in November 2006 (left) and June 2007 (right), respectively.

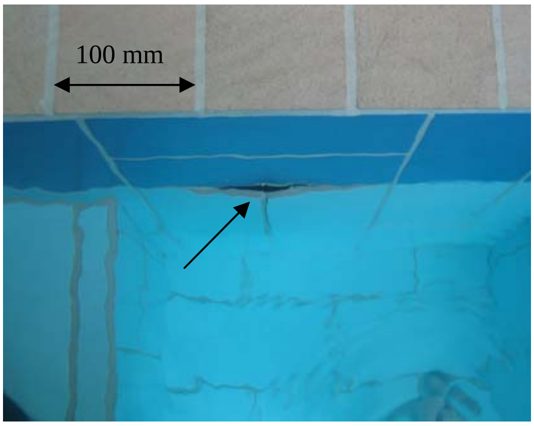

Figure 6: Loose tiles on the pool wall.

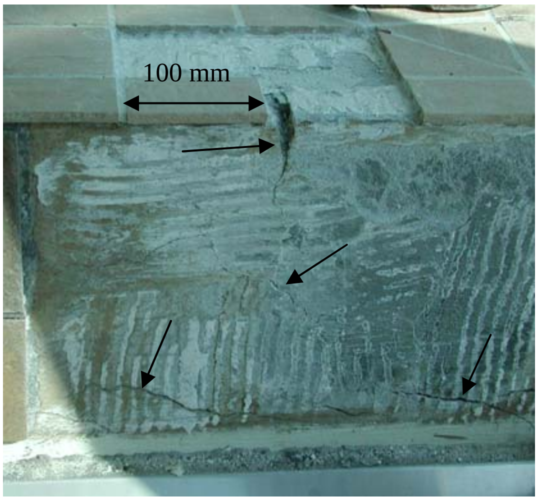

Figure 7: Cracking of the concrete behind the tiles on the vertical surface near the top of the wall, above the water gutter (see Figure 11).

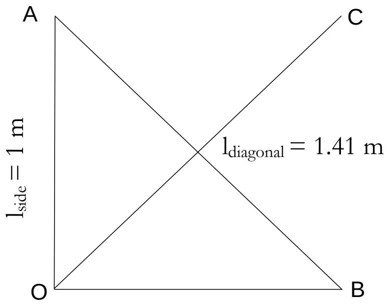

Figure 8: Reference area with four measuring lines.

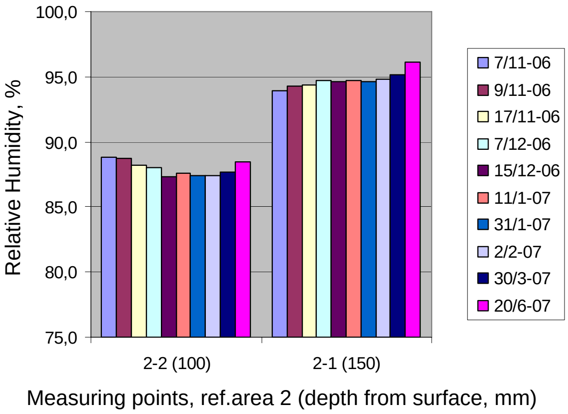

Figure 9: Variation in Relative Humidity in two measuring points over the period November 2006 - June 2007. The measuring points are located 100 mm and 150 mm, respectively, from the outer surface of the 250 mm thick pool wall.

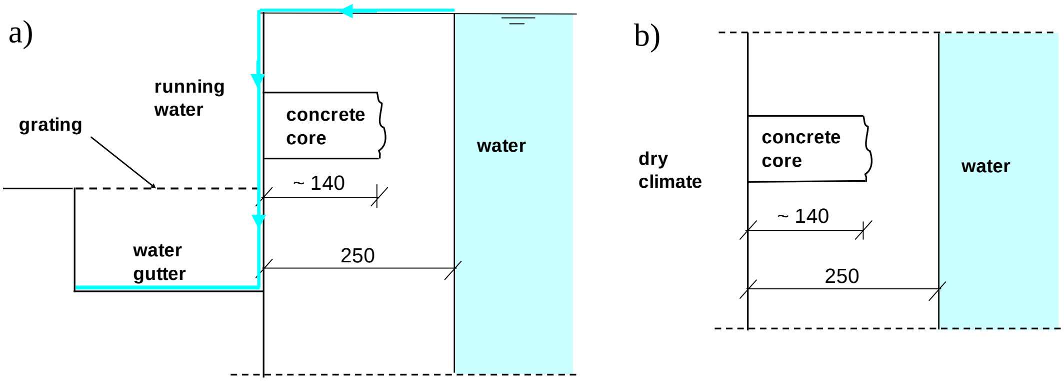

Figure 10: Localization of the drilled cores in the concrete sections. a) Near the top of the pool wall, exposed to water on three sides and b) the lower part of the pool wall and the bottom plate, exposed to water on one side.

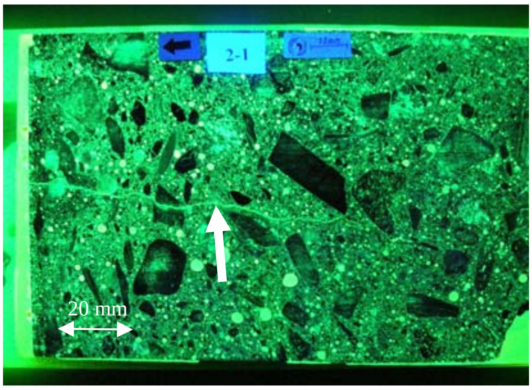

Figure 11: Plane polished section in UV-light, prepared from the core drilled from the outside (dry) surface of the 250 mm thick pool wall. Crack with depth 117 mm from this surface.

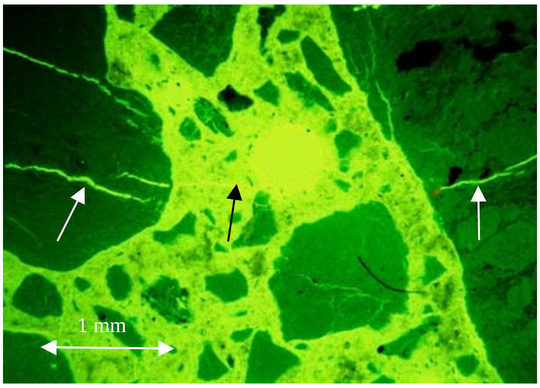

Figure 12: Thin section in UV-light, prepared from the inner part of the concrete core from the pool wall. Cracks in aggregate particles and in the cement paste.

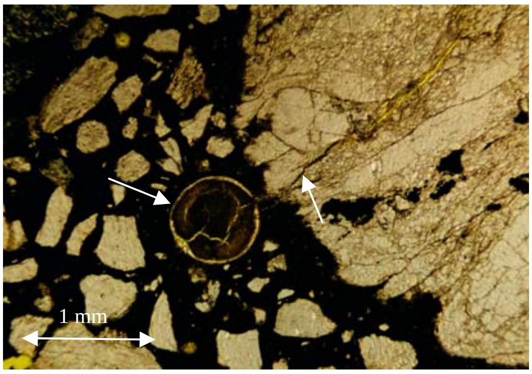

Figure 13: Thin section in normal light, prepared from the inner part of the concrete core from the pool wall. Alkali gel in crack and air void. The reacted aggregate particle is mylonite.

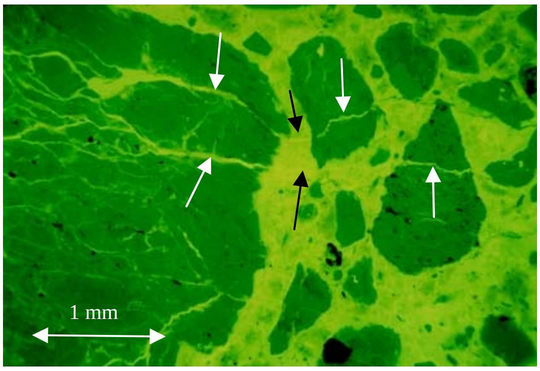

Figure 14: Thin section in UV-light, prepared from the concrete core from the top of the pool wall. Cracks in aggregate particle continue into the cement paste and further into other aggregate particles.