In order to secure the new concrete against alkali-aggregate reactions when it was exposed to warm pool water with sodium chloride, the aggregates for the concrete mix had to be transported from distant locations:

Coarse aggregates were crushed granite from the island Bornholm in the Baltic, and the sand was transported from Jutland. The sand was pure quartz with maximum 0.15% flint. These aggregates had not shown any expansion during tests according to ASTM morter bar method (C227-81).

The cement was special danish cement with low alkali content.

In order to improve the strength and watertightness 35% flyash was added.

The water/cement ratio was 0.4.

Also the mortar for the new ceramic cladding was mixed with pure quartz sand as aggregate.

The arrangements in connection with the repair af the swimming pool should thus ensure

-that the new concrete is resistent to alkali-aggregate reactions, and

-that the old concrete is no longer exposed to imbibition and percolation of the water with sodium chloride, and thus secured against further alkali-aggregate reactions, as soon as the water content in the old concrete has dryed out below the critical level.

5. ACKNOWLEDGEMENTS

The thin sections and the petrographic examinations were made by Technological Institute, DK.

Some of the investigations were performed in cooperation with dr. G.M. Idorn, DK.

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DAMAGES TO SWIMMING POOLS DUE TO ALKALI SILICA REACTIONS

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1. INTRODUCTION

Serious damages have appeared in a number of Danish swimming pools during the last few years. Alkali silica reactions play an important role in the deterioration proces and lead to serious consequences as to repair.

Improved future practice and development of preventive and remedial measures should be based on thorough knowledge of what went wrong and why.

In the following is first given a record of yesterday's Danish design practice for swimming pools and secondly a report on a couple of pools with serious damages. Proposals for future practice, and for preventive as well as remedial measures, supported by test results, conclude the paper.

Key words: Alkali silica reactions, swimming pools, damages, repair.

2. DANISH SWIMMING POOLS CONSTRUCTED IN THE 1960'ties AND 1970'ties

Construction of outdoor swimming pools was booming in the late 50'ties and the 60'ties whilst the construction of public indoor pools gained momentum in the late 60'ties and continued through the 70'ties.

It is noticable that design and construction practice for the concrete pools was developed for the outdoor pools and later used for the indoor pools although significant differences between the conditions, to which the concrete is exposed, are present. A typical cross section of an outdoor and an indoor swimming pool are shown on fig. 1.

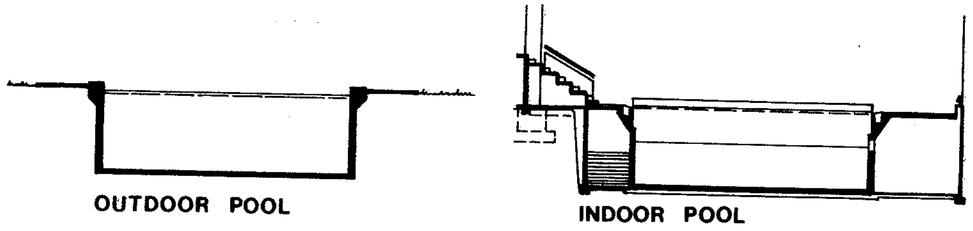


Fig. 1

Both are typically supported on the ground but whilst the outdoor pool has earthfill along its walls, the indoor pool is usually surrounded by a corridor used for piping and as inlet duct for the ventilation system of the swimming hall.

The common design and construction practice may be deducted from two lectures held by techn.dr. Anders Nielsen and myself, in the Danish Concrete Assosiation in 1978, published as a Danish Concrete Assosiation Publication No 5, 1978 /1/. In this paper you will find a recipe for construction of a water tight concrete swimming pool - formulated as ten commandments (fig. 2).

A: MATERIALS AND MIX

1 CEMENT MAX 350 kg m^3 (SHRINKAGE. TEMPERATUREGRADIENT)
MIN 300 kg m^3 (DENSITY)

2 AGGREGATES
DENSE. ALKALIRESISTANT
WELL GRADED. SUITABLE CONTENT OF FINES

3 V C MAX 0,45

4 ADMIXTURES
AIR-ENTRAINING AGENT, 4 - 6 % AIR
PLASTICIZERS . SUPERPLASTICIZERS

B: DESIGN

5 COVER MIN 30 mm

6 REDUCE RISK OF CRACKING

7 DESIGN WITH REGARD TO COMPACTION

C: CASTING AND CURING

8 CAREFULL COMPACTION
AVOID BLEEDING

9 CONSTRUCTION JOINTS
REDUCE NUMBER, SANDBLASTING, WATERING

10 CURING
KEEP MOIST CONTROLE TEMPERATURE

Fig. 2

It is of particular interest to note the comments Anders Nielsen had to the second "commandment":

"Alkali silica reactions should be prevented by use of alkali resistant aggregates and by producing a dense concrete. I should like to add that those pools I have inspected have not shown any sign of leakage or serious deterioration which could be refered to alkali silica reactions."

In the examples of damages in a number of outdoor and indoor swimming pools presented were numerous cases of cracks, corrosion of reinforcement, inefficient compaction, but none of alkali silica reactions. Neither were these phenomena a main theme in the following discussion.

On this background it may be established as a fact that the major part of Danish swimming pools up to the late 70´ties have been constructed without specific requirements to the alkali reactivity of the aggregates in spite of a recommendation issued by the so called Alkali Silica Task Group as early as 1961. Past experience together with the lack of recognized and operational testing methods and insufficient distribution of knowledge of suitable aggregate sources may be the reason for the optimistic view on the risk of alkali silica reactions, shared by consulting engineers and contractors.

3. INVESTIGATION OF SWIMMING POOLS WITH DAMAGES DUE TO ALKALI SILICA REACTIONS

In 1978 came the first report on serious damages refered to alkali silica reactions. This case has been reported by Mr Mørup.

The present paper deals with two public indoor swimming pools completed in 1978 which already in 1981 showed sign of leakages.

To follow these two swimming pools is particularly interesting as they are practically identical in size and design, cast with concrete supplied from the same ready-mix concrete plant using the same mix containing sand from the same quarry in Farum, north of Copenhagen. Sand which, as it has appeared later, contains a great amount of alkali reactive flint.

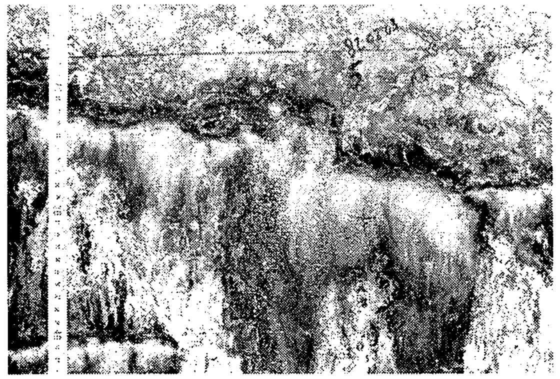
The investigation of the two pools comprised:
- o visual inspections, recorded on drawings and photographs, and
- o laboratory investigations on core samples, drilled from sound and damaged parts, including thin section microscopy and measurement of humidity and salt content profile through the wall.

The results of the investigation may be summarized as follows:

On the one pool alkali silica reactions were found within a limited area of approx. 15 sq.m. out of the total wall surface of 440 sq.m., i.e 3-4% of the surface area. The laboratory investigations showed heavy alkali silica reactions in the fine aggregate with internal cracking, but also revealed a commonplace fault as there appeared to be no coarse aggregate in the concrete. The error was acknowledged and that part of the wall was repaired by the contractor.

The other pool showed a somewhat more complicated picture. A larger area, approx. 15% of the total wall area, showed cracks due to alkali silica reactions (fig. 3 and 4).

Fig. 3



Note leakage around form tie

Fig. 4

Certain areas showed rather wide cracks with up to 0,3 mm width and although some indications of deficient casting and compaction ("cold construction joints" and insufficiently vibrated concrete below underwater lights and around ties), the laboratory investigations could not prove beyond doubt that the development of alkali silica reactions originated from initial cracks or other deficiencies.

The visual inspections indicated that the cracking starts on the exterior face of the wall. This observation gave rise to the theory that the heavy drying out of the exterior surface results in a concentration of salt (sodium chloride) near the exterior surface which initiates the alkali silica reactions. We tried to test this theory by measuring the chloride content through the wall and found on one sample the expected profile but could not establish a connection between cracking and salt concentration.

It was observed that after the first crack appeared, a crack pattern developed rapidly (2-3 months) over a certain area but then slowed down and eventually seemed to stop.

4. CONCLUSION AS TO CONSTRUCTION OF FUTURE SWIMMING POOLS

These last year's experience has not proved that our construction practice is entirely wrong. It may still be true that alkali silica reactions will not take place, even with a high content of alkali reactive aggregates, if the concrete is sound, dense and tight. However, we have to admit that concrete structures made under normal conditions will always have parts with small defects which may give access of the water to the aggregates and thus initiate the reactions. And if cracking is first started, the cracks will provide access to new parts and deterioration may develop. Briefly expressed: the safety margin is to small.

Broadly speaking the recipe for making good water tight concrete given by Anders Nielsen in 1978 is still valid, but it should be stressed that the fine and coarse aggregates, must have a very limited content of reactive particles. But it is naturally not enough to say this. To achieve it, suitable and operational testing methods, that can be used in connection with a particular project, must be developed or aggregates must be delivered with certificate for resistance to alkali attack. Important development is on its way and it is believed that this conference may contribute hereto.

The general design of the swimming pool and its surroundings should also be looked upon and the influence of the drying out of the exterior wall surface on cracking and concentration of salt in the walls should be checked.

5. PREVENTIVE AND REMEDIAL MEASURES ON EXISTING SWIMMING POOLS

Basically there are four different repair methods:

a. Partial exterior repair of those areas which are damaged,
b. Partial repair of damaged areas and application of interior paste membrane,
c. Establishment of a membrane preventing contact between the salty water and the reactive aggregates, and
d. Total replacement of the damaged wall with a new one made in accordance with the principles mentioned above.

The four possibilities are illustrated on fig. 5a and 5b.

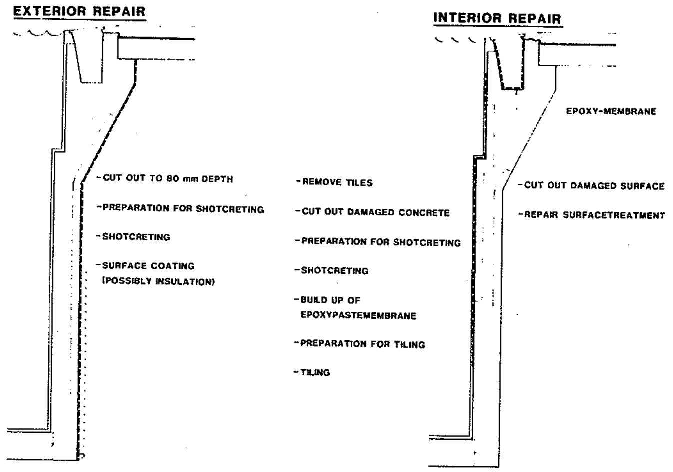


Fig. 5a

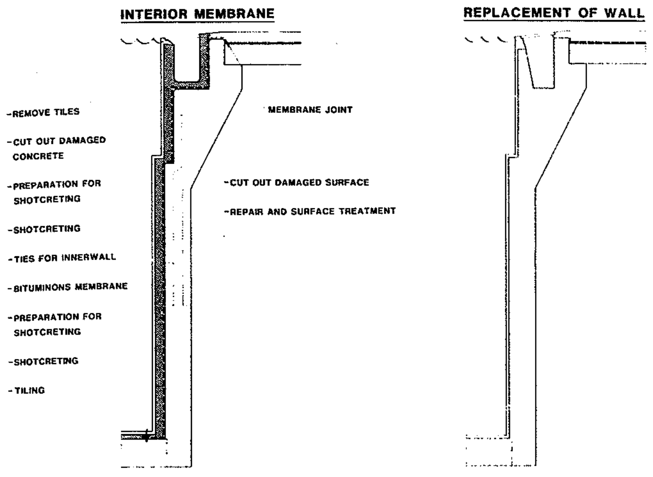


Fig. 5b

Now, if it really is the concentration of salt on the exterior face of the wall, that starts the reactions it may be sufficient to replace the damaged part of the exterior face with a dense concrete with non-reactive aggregates and reduce the drying out by a tight exterior cover. However, further investigations and tests should be conducted before this method can be considered a serious and long-lasting alternative.

The second and third repair method is based on the establishment of a membrane. In principle there are two posibilities, either a membrane of sheets or foils, e.g. bituminons sheets, or a membrane built up on the spot e.g. of epoxy. A foil membrane whatever material it is made of, will require an inner wall to carry the lining, normally tiles. This disadvantage makes the use of a membrane that can support the lining very attractive.

To investigate this posibility a number of such membranes have been tested in the laboratory of the Danish Engineering Academy. The properties we wanted to test were the permeability, the elasticity i.e. the ability to bridge concrete cracks, the adhesion and the durability.

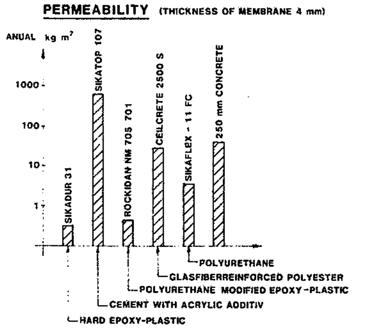
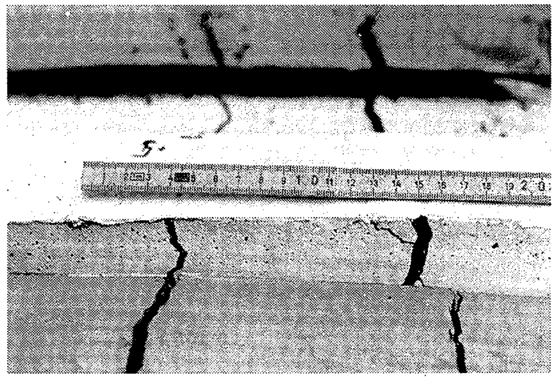


Fig. 6

a. The permeability should be of another order of magnitude than that of the concrete wall. We suppose some 10 - 100 times less. It was tested with the so called cup-method, a method in which it is the capillary suction in the porous material to which the membrane is fixed that drives the water through the membrane. On fig. 6 can be seen that the permeability of the most impermeable membrane in a thicknes of 4 mm is 1/100 of the permeability of 250 mm first class concrete.

b. Flexibility:

Cracks normally occuring in the concrete wall should not go through the membrane, i.e. it should safely be able to bridge a gap of 0.1 to 0.2 mm. We added a safety margin and required 0.4 mm. The various membranes were build up on concrete beams which were then bent in an ordinary testing machine (fig. 7 and 8). The best membranes could bridge a gap of more than 1 mm.



Sikaflex membrane bridge a crack of 7.5 mm.

Fig. 7

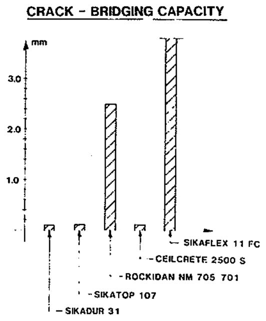


Fig. 8

c. Adhesion:

The adhesion of tiles and mortar to the membrane and of the membrane to the surface of the concrete should be on the same level as adhesion of tiles to concrete which we assume is approx. 0.6 N/mm^2. This is considerably more than the maximum water pressure that can be build up behind the tiles when the pool is emptied and which corresponds to 0.04 N/mm^2. Results of the test are given on fig. 9.

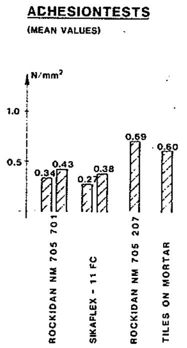


Fig. 9

d. Durability:

The material must be resistant to the pool water and have a reasonable lifetime. Documentation for durability is the most dificult to achieve. Accelerated tests are doubtfull and the suppliers guaranties are of little value. We believe that the epoxy materials are reasonable stable and hope to be able to test the durability on at least one of the pools to be repaired.

TECHNICAL AND ECONOMICAL COMPARISON OF REPAIR METHODS

(~400 m^2 POOLWALL)

EXTERIOR REPAIR (SURFACECOATING)		ELASTIC PASTEMEMBRANE (EPOXY + PLASTIC)	
+	–	+	–
EASY TO CARRY OUT	UNCERTAIN BASIS	LOW PERMEABILITY	DURABILITY NOT PROVED
EMPTYING OF POOL NOT REQUIRED	EXPECTED REPAIR WORK AT SHORT INTERVALS	NO CHANGE OF POOL DIMENSIONS	**SOME ENVIRONMENTAL** PROBLEMS DURING EXECUTION
	LIMITED SERVICETIME	GOOD TIGHTNESS CAST-IN PARTS (UNDERWATER LIGHT ETC)	
		FEW PENETRATIONS	
		PARTIAL REPAIR POSIBLE	
PRICE D.Kr. INCL.VAT 22 %	0.6 MILL.		2.4 MILL.

FOIL (BITUMEN) MEMBRANE		REPLACEMENT	
+	–	+	–
LOW PERMEABILITY	CHANGED POOL DIMENSIONS	GOOD DURABILITY	DIFFICULT EXECUTION
EXPECTED GOOD DURABILITY	COMPLICATED EXECUTION	WELL KNOWN AND TESTED MATERIALS	
	COMPLICATED ANCHORS AND PENETRATIONS		
PRICE D.Kr. INCL.VAT 22 %	5.5 MILL.		4.3 MILL.

Fig. 10

As conclusion, fig. 10 shows a technical and economical comparison of the four repair methods mentioned above. The figures should be taken with some reservation. It is estimates and only the repair with a bituminons membrane is based on the cost of a completed repair work.

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