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Case Study

Renovation of an alkali–aggregate reaction damaged swimming pool

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ABSTRACT

The alkali–aggregate reaction (AAR) is an expansion reaction of the aggregate in concrete caused by the alkalinity of hydrated cement, which may disintegrate concrete. The alkali–silica reaction (ASR) is the most general form of AAR which only rarely causes degradation in Finland. The pool at Tampere Swimming Centre was only the third such case in the country. Condition assessment by several parallel methods was used to determine the existence and extent of ASR. A total of 34 samples were drilled from the concrete structures of the swimming pool. The samples were examined by scanning electron microscopy (SEM) and an X-ray diffractometer as well as by thin section analyses and tensile and compressive strength tests of concrete.

Based on the assessment, it was decided to repair the damaged concrete and stop the ASR by proper waterproofing. Tensile and compressive strength tests on the concrete indicated that a relatively light renovation method was sufficient because the deterioration of the concrete was still incipient and the target service life of the repairs was only 20–25 years. Self-compacting concrete was determined to be a good solution for concreting the narrow spaces between dense reinforcement. Self-compacting concrete was used also for concreting the splash canals and supporting consoles. The renovation was based on installing proper waterproofing between the concrete surface and the ceramic tiling.

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1. Introduction

Tampere Swimming Centre, completed in 1979, has three separate swimming pools: the main pool, a children's pool and a so-called paddling pool, see Fig. 1. The main pool is 50 m long and has eight lanes. It can also be divided into two shorter pools with a hydraulic lift bridge. The extension completed in 2007 contains a 25 m swimming pool and a diving pool.

The major renovation of the Tampere Swimming Centre started in May 2013. It involved improving the HVAC systems and water treatment as well as some new space arrangements. All changing rooms and showers as well as surfaces of the pool area were also renovated. After the renewal of the hydraulic lift bridge it is also possible to stage official 25 m swimming competitions. The extension remains as it is.

Disintegration of concrete due to alkali–aggregate reaction (AAR) was detected in the concrete structures of the swimming pools during the renovation. None of the pools had ever been waterproofed. The propagation of AAR requires a

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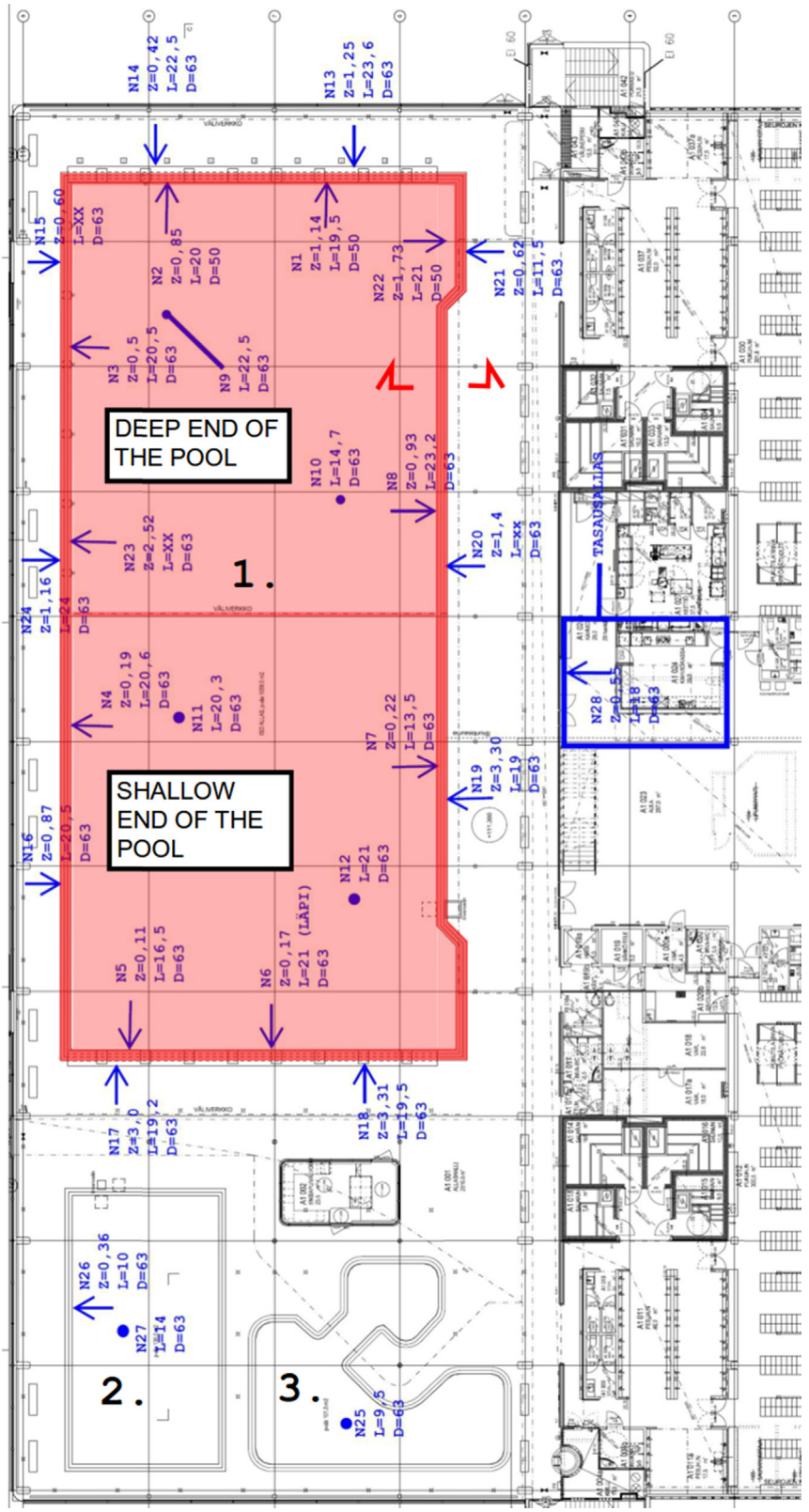

Fig. 1. Plan view of the pool complex and locations of taken concrete samples. The main pool is highlighted.

high moisture content of concrete. The warm water (+24 °C) in the pools had kept the moisture content of the structural concrete high since 1979.

1.1. Structures of the swimming pool

The thickness of the lower section of the pool wall is 400 mm and that of the upper section 300 mm. The ground slab as well as the entire pool are founded on concrete piles. The thickness of the ground slab is 400 mm. The joint area in the length of 2000 mm the ground floor and wall are 50 mm thicker. The walls are in sight in the basement of the swimming pool. There was diving apparatus at the other end of the pool until 2007 which is why that half of the pool is 4 m deep throughout. The depth of the pool is only 1.2 m at the shallow end and 1.8 metres in the middle. The lowest parts of the pool walls are heavily reinforced (TW10, c80) which has a serious impact on the repairability of the pool.

According to old drawings, the concrete used in the pool structures was C25/30. And because the concrete was considered watertight, no waterproofing was used as was typical at the time. A separate screed layer (20–60 mm) was applied on the surface of the structural concrete and topped with ceramic tiles.

2. Alkali–aggregate reactions

The alkali–aggregate reaction is an expansion reaction of the aggregate in concrete caused by the alkalinity of hydrated cement, which may disintegrate concrete. The existence of AAR was first discovered in the USA in the 1940s, and it is generally divided into three types according to the reacting aggregate: alkali–silicate reaction, alkali–carbonate reaction and alkali–silica reaction (Gjørv, 2009). All AARs require a reactive aggregate, a sufficient amount of alkali ions in the hydrated cement, and a minimum relative humidity of concrete of 80% (Punkki and Suominen, 1994).

The alkali–silica reaction (ASR) is the most general form of AAR. For the alkali–silicate reaction to take place, the pore water must contain dissolved sodium (Na_2O) and potassium (K_2O) alkalis, and the aggregate must contain minerals that have low resistance to alkalinity. The gel produced by the reaction absorbs much water from its surroundings, which causes its volume to grow leading to internal pressure within the pore system. As the internal pressure exceeds the tensile strength of concrete, cracks form in the concrete structure allowing the relatively soft gel to extrude through them (Neville, 1995).

The alkali–silicate reaction is similar to ASR as to the reaction mechanism, but there are some differences in the physical and chemical form of the gel and other reaction products. The disintegration process of the concrete is remarkably slower than in ASR, which is why the reaction is usually referred to as a slow or delayed alkali–silica reaction (Pyy et al., 2012).

The alkali–carbonate reaction effected by the alkalinity of some limestones and cement produces a swelling clay-like substance. The gel that forms at high humidity swells about 4% by volume creating pressure within the pore system of the concrete. The cracking of concrete weakens the bond between the aggregate and the cement paste (Neville, 1995).

AAR generally means slow deterioration of concrete. The degradation rate is influenced by prevailing conditions as well as the quality of the aggregate and cement. In the case of silicon-containing rocks, AAR develops sooner, in 2–5 years, whereas with slower reacting rocks, like sandstone and limestone, the reaction may take 10–20 years to develop. AAR has been reported to occur also with highly stable rocks such as granite, quartzite and sandstone (Gjørv, 2009). With blended cements like BFS and PFA, AAR is less common since fewer reacting alkalis are generally involved than with OPC (Punkki and Suominen, 1994).

A concrete structure suffering from AAR typically exhibits discolouration due to surface moisture, irregular pattern cracking, swelling and oozing of a gel-like reaction product from the cracks (Neville, 1995). The damage from AAR resembles the cracking caused by frost attack and often coincides with it (Punkki and Suominen, 1994). The most significant difference between AAR and frost damage is the pattern of cracking, which in the case of frost damage is most intensive close to the outer surface and loses intensiveness with depth. AAR cracking begins deeper inside the concrete and produces a more regular cracking pattern across the entire concrete structure (Rønning, 2001).

In Central Europe and Scandinavia, AAR typically occurs in massive concrete structures like bridges and dams (Punkki and Suominen, 1994). Despite its similar bedrock with Sweden, Finland has been considered an AAR free country (Richardson, 2002). In the last ten years, 56 cases of AAR in concrete have been reported, two of them in swimming pools – this being the third. Most cases of AAR have affected bridges and buildings (Pyy et al., 2012).

3. Condition assessment of the swimming pool's concrete structures

A total of 34 samples were drilled from the concrete walls and bottom of the swimming pool. Twenty-eight were inspected visually and six were sent for thin section analysis. Two samples were studied by scanning electron microscopy (SEM) and two with an X-ray diffractometer.

3.1. Visual inspections

White void fillings were found in the sheared surfaces of concrete samples, see Fig. 2. SEM examination revealed that the white void filling material was alkali–silica gel. The white filling was typically discovered at a depth of 80–120 mm from the

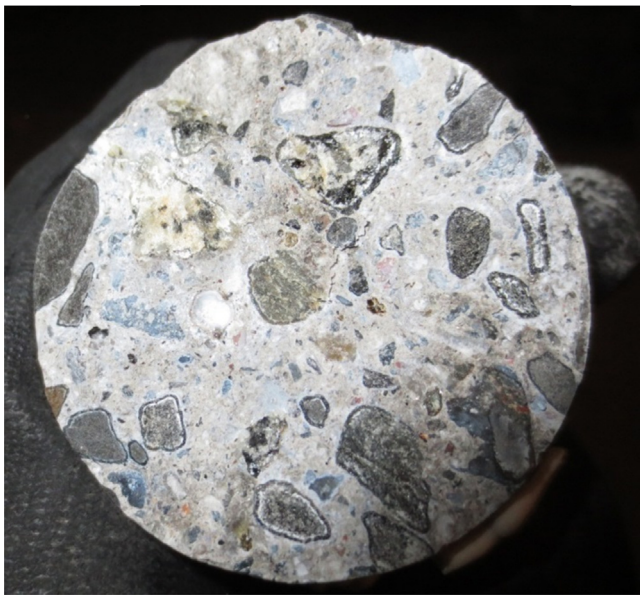

Fig. 2. Alkali–silica gel in voids.

surface of a concrete sample. The cracking detected in 11 samples was considered to have been caused by drying shrinkage after casting. No cracks or disintegration were detected in any of the 17 samples.

3.2. Thin section analyses

According to the thin section analyses of six samples, the quality of the used aggregate was adequate, its bonding to cement paste was mainly satisfactory although weakened by ettringite due to the high moisture content of the concrete and AAR. The share of metamorphic rock (gneiss) and fine-grained quartz of the total aggregate of the concrete was approx. 10–20%. The degree of alkali–silica reaction between the samples varied. Far advanced deterioration was typically found at a depth of 50–150 mm from the surface of samples, but it was also detected at 200 mm. Plenty of crystallised ettringite as well as alkali–silica gel was found in the voids and cracks of the concrete. Existence of both alkali–silica gel and ettringite was confirmed with an X-ray diffractometer.

3.3. Tensile strength tests

Tensile strength tests were carried out on 34 samples. Eight samples were cut in several parts to determine the variation in tensile strength of concrete between different depths and possible disintegration of concrete. Tensile strength varied between 0.5 and 4.4 MPa. The lowest tensile strength was detected in samples where alkali–silica reaction was observed on the failure surface. Poor, under 1.0 MPa, tensile strength was detected in a total of 5 samples while the average tensile strength of the rest of the samples was 2.5 MPa. Based on tensile strength tests, the alkali–silica reaction had typically occurred at a depth of 60–120 mm from the surface of samples.

3.4. Compressive strength tests

A total of 25 compressive strength tests were carried out. Seven samples were cut in several parts to determine the variation in compressive strength of concrete at different depths. The compressive strength of concrete was, on average, 61.5 MPa and standard deviation 11.4 MPa. Thus, unlike the tensile strength tests, the compressive strength tests of concrete did not indicate disintegration of concrete. Disintegration of concrete weakens the bond between the aggregate and the cement paste which affects the tensile strength of concrete before its compressive strength.

This might be because compressive strength of concrete is not as good an indicator of disintegration as tensile strength.

3.5. Relative humidity of concrete

The relative humidity of a concrete ground slab was measured from a total of 16 points so that parallel measurements were carried out at depths of 300 mm and 350 mm. The average relative humidity of concrete at the deep end of the pool was

87.8%. The results for the deep end of the pool were uniformly slightly higher compared to the shallow end (RH 83.0%), probably due to the higher water pressure on the ground slab at the deep end. The relative humidity of concrete was systematically higher at a depth of 300 mm (av. RH 85.1%) than at 350 mm (av. RH 80.3%). Water pressure made water penetrate into the pore structure of the concrete of the ground slab at the shallow end. All measurement results on the ground slab at the deep end of the pool were so close to each other that moisture diffusion from ground cannot be excluded.

4. Renovation of the pool

All wall structures as well as the ground slab had been affected by alkali–silica reaction. In places, ASR had proceeded so that incipient disintegration was usually found at a depth of 60–120 mm. Ettringite was also detected in the pore structure of the concrete, but the content was so low that it could not have caused internal cracking of the concrete.

Sodium hypochlorite has been used to treat the water in the swimming pool. The dissolved sodium derived from the used sodium hypochlorite has contributed to ASR. Concrete naturally contains cement-based alkalis like sodium and potassium, which means that sodium hypochlorite can only accelerate the reaction, not cause it.

4.1. Repair possibilities

Several possibilities were considered based on the damage to the pool:

a) to demolish and rebuild the pool,
b) to do nothing and just allow the ASR to proceed, or
c) to repair concrete damage and install waterproofing.

The first two options were naturally out of the question due to the required time and cost (Case a) and safety concerns (Case b). The interior of the swimming centre also played a major role in the selection of the repair method: the idea was to keep it as close to original as possible. Here, the target service life of the repairs was 20–25 years, which meant that demolishing and rebuilding the pool would mean excessive repairs.

4.2. Repair of damaged concrete and installation of waterproofing

ASR needs, above all, a high moisture content to proceed. Thus, the easiest way to stop ASR in a swimming pool is to install proper waterproofing between the ceramic tiling and the concrete. ASR will stop after the concrete is dry enough. Despite ASR, the concrete of the pool was still in relatively good condition: most results of tensile strength tests on the concrete were good and those of compressive strength tests excellent. Therefore, it was decided to remove 70–150 mm of deteriorated concrete from the surface of the pool, to reinforce and recast the surface layer, and finally waterproof the dried concrete before tiling, see Fig. 3. The success in achieving the target service life of the repairs depends on the performance of the waterproofing.

Approx. 70 mm of deteriorated concrete was removed from the upper parts of the walls using a high-pressure water-jet or a hydro-demolition robot, see Fig. 4. The aim was to penetrate 20–25 mm behind the existing vertical reinforcement and thereby ensure the durability of the old pool and the new concrete. Approx. 150 mm of deteriorated concrete was removed from the lower parts of the walls up to a height of 1500 mm from the ground slab. New and old concrete were joined with ribbed bars (Ø 12 mm, 4 pc/m^2). At the deep end of the pool, a 2000 mm layer of the ground slab concrete was removed along the walls. At the shallow end of the pool, an approx. 70 mm layer of concrete was removed off the top of the entire ground slab to the level of the existing reinforcement.

A temporary shield was built for using the high-pressure water jetting equipment and a hydro-demolition robot on the pool to keep splash water, moisture and removed pieces of concrete within a limited area. The working width of the hydro-demolition robot was 2000 mm both on the wall and the slab. In the corners which were inaccessible to the robot or spots demanding higher accuracy, concrete was removed with high-pressure water jetting equipment operated by a worker. When the concrete had been removed and washed out of all solutes, the condition and location of existing reinforcement was checked, and necessary auxiliary reinforcement was installed on top of new water treatment pipes, see Fig. 5.

4.3. Concreting

The dense and heavy reinforcement of the walls made compaction of concrete difficult with a conventional needle vibrator in a very narrow mould. Therefore, concreting was done with self-compacting concrete (C32/40) poured into moulds in approx. 500 mm layers. The aim was to ensure that all holes made by the hydro-demolition robot would be properly filled. Therefore, flow tests were made on fresh concrete at the concrete mixing-plant and in situ after transportation. The flow of concrete varied between 720 mm and 800 mm at the mixing plant and from 620 mm to 720 mm after transportation. To avoid cracking after drying of concrete, the water–cement ratio was 0.45 and maximum aggregate size 16 mm. The used cement type was CEM II/B-M, 42.5 N.

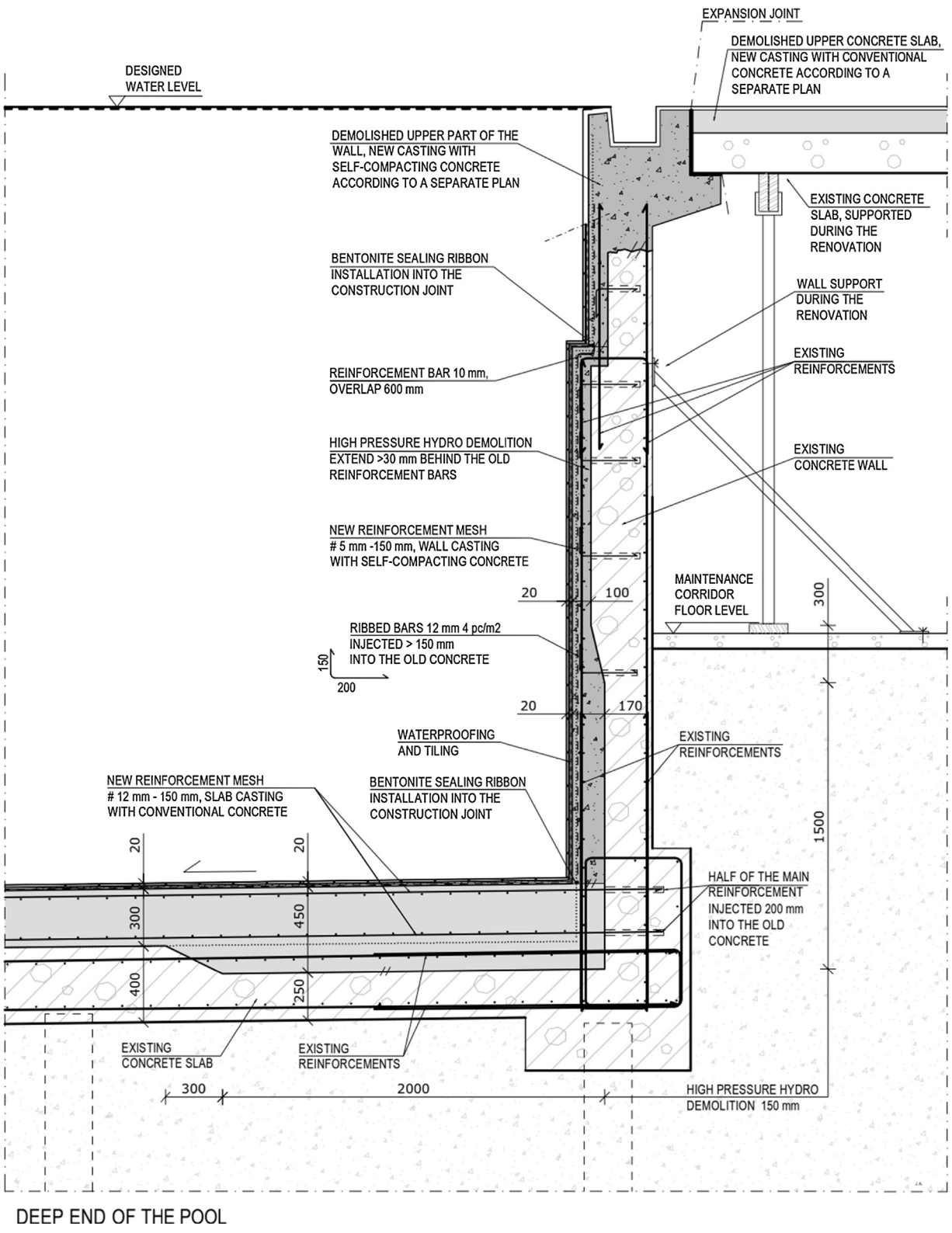

Fig. 3. Cross section of the pool. The grey parts are new concrete.

Fig. 4. The working width of the high-pressure water-jet cutter was 2 m. Concrete was removed under a temporary shield.

The walls are topped by splash canals. The intermediate floor is supported on consoles situated in the upper parts of the walls. Thus, the tops of the walls are relatively heavily reinforced. During the renovation, all the splash canals and consoles were chipped off because they were badly deteriorated by ASR and corrosion of reinforcement. The new water treatment system also needed major changes in the canals. The intermediate floor was supported temporarily on the basement, see Fig. 2. Splash canals and consoles were also cast of self-compacting concrete.

At the deep end of the pool, new water treatment pipes were installed on the old ground slab and a new reinforced slab 300 mm thick was cast on top of it, see Fig. 2. At the shallow end of the pool a new layer approx. 70 mm thick was cast of C32/40 concrete.

The work instructions advised removing loose and cracked concrete from the old structure before concreting. The surface demolished by high-pressure equipment must be and rough, washed and vacuumed. It was also advised to keep the old structure moist for two days before concreting and to let the surface dry until it appeared matt to reduce moisture absorption.

During concreting and curing it was advised to keep relative humidity and temperature constant (RH% $\geq$ 30, t = 20 °C, approx. normal indoor humidity in Finland in winter). Air flow and ventilation should also be avoided.

Fig. 5. Upper reinforcement of ground slab. New water treatment pipes were installed before reinforcement.

Fig. 6. Epoxy-based materials were used to seal all penetrations.

4.4. Curing and drying of concrete

To avoid the harmful cracking of concrete, curing must start within 2 h of concreting. The instructions were to cover the cast concrete with a filter cloth that was to be kept wet for at least 14 days after curing. After 14 days 80% of the shrinkage of the concrete has taken place and drying can be made 2–4 times faster by warm air blowers.

4.5. Installing waterproofing

Waterproofing was installed on the concrete surface after the concrete had dried to RH 92% at a depth of 50 mm. The waterproofing was strengthened with buckram at the corners. Pipe penetrations, etc. were sealed with epoxy-based materials, see Fig. 6.

5. Conclusions

The structure was found to have been affected by alkali–silica reaction during the condition assessment. ASR is very rare in Finland; this was only the third case detected in a swimming pool. That is why renovation designers and contractors have little experience and knowledge of effective repair alternatives. In the case described here it was decided to repair the damaged concrete and stop ASR by installing proper waterproofing. The target service life of the repairs was 20–25 years. Relatively light repairs were possible because the deterioration of the concrete was still incipient.

Self-compacting concrete was found a good solution for concreting narrow spaces with dense reinforcement. Self-compacting concrete was used also to concrete splash canals and supporting consoles.

Waterproofing could only be installed on relatively dry concrete. According to the manufacturer of the waterproofing material, the relatively humidity of concrete must be less than 92% at a depth of 50 mm before installation. To avoid cracking of concrete due to drying shrinkage, the concrete was allowed to dry for a relatively long time.

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