Project

Extended life of swimming pools through LCC
Master Thesis No. 420

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Extended life of swimming pools through LCC
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Extended Life of Swimming Pools through Life Cycle Costs
(Verlängerung der Nutzungszeit von Schwimmbädern durch Lebenszykluskosten)

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Aufgabenstellung

As a reason of a constant water impact, swimming pools have a high potential on damages. Hence, there are many flawed structures to investigate, analyze and maintain.

Goal of this report is to point out common defective parts and to analyze the impact of chlorine, chloride, air humidity on steel and concrete.

In the last years, CBI (Cement och Betong Institutet, Sweden) had to investigate swimming pool damages all over Sweden.

Next step will be to point out the differences of the German and the Swedish way of erecting swimming pools.

Furthermore a practical field study is part of this work

Last aspect is a variety study on LCC of two different swimming pool scenarios. The LifeCycleCosts of a new basin, with modern standards, is to compare with a traditional, but repaired, basin.
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Abgabe: 16.06.12, Bey 56
Ausgedrucktes, ringgebundenes Exemplar,
pdf-Datei,
Zusammenfassung 1000 bis 1500 Zeichen (inklusive Leerzeichen),
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Weiteres nach Absprache mit dem Betreuer

Öffentliche Verteidigung: in Absprache mit dem Lehrstuhl und dem Betreuer

Verantwortlicher Hochschullehrer

i.V.U. [Signature]

Prof. Dr.-Ing. Dr.-Ing. E.h. Manfred Curbach
Abstract

Swimming pools constructed with reinforced concrete require a high level of expertise within both, its planning and execution. To build waterproof concrete shells, extensive concrete technology knowledge, detailed planning of joint formation and high quality safety measures are needed. This thesis evaluates concrete technology features for swimming pool construction in Germany and Sweden. In particular, guidelines by DafStb, DIN and DgfdB provide the planner with detailed advice and specifics about swimming pools.

It also gives an overview about the actual condition of swimming pools in Sweden that reached an age of at least 30 years and shows structural consequences of mistakes in planning and construction of swimming pools.

The aspect of financial consequences is also analyzed. With the support of the software “Legep”, the methodology of LCC was used to estimate costs in the future. Additionally, a proposal of post tensioned concrete as a more sustainable technology for watertight concrete basins is shown and under equal aspects analyzed and compared.
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1 Introduction

1.1 Background

Swimming pools are considered to be special constructions in the field of structural engineering. Designing and constructing swimming pools requires a high level of expertise and thoroughness from engineers as well as from the craftsmen. Additionally, requirements for material and maintenance play an important role in the life of a swimming pool construction.

Mistakes in design or execution often lead to laborious and expensive repair works. Furthermore, the high competition in the building sector forces structural companies to provide cheap and fast execution, which is another reason of the need for remediation of defects. To create a durable, chemical resistant and waterproof sealing is without doubt the biggest challenge in constructing a swimming pool.

Even in the case of a non-seawater pools, the impact of chloride for the disinfection of the water affects the reinforced concrete. Water and chlorides belong to the substances reinforced concrete is most vulnerable to. Especially the environment requires a periodical investigation of statically important structures. Nevertheless, there are more facts to be considered, as there are the influences of the high relative humidity and the constant high temperature.

1.2 Aims and Scope

This report functions as a semester project in the fifth year of the authors study and was conducted during an study exchange at the KTH Stockholm.

The subject matter presented in this thesis was initiated by the Cement och Betong Institutet Stockholm (Cement and Concrete Research Institute, CBI). CBI as expert for technical issues and Fastighetskontoret and Idrottsförvaltningen (property and sports administration) as owners are aware of the importance of problems in public baths and initiated this work. The project aims to raise awareness of the subject of deterioration in public swimming halls and the high subsequent costs linked with this.

1.3 Outline

This paper starts with general components for swimming pools and how they ought to be conducted.

The deep insight in this subject within German literature, for example (1) and (2) was used to benefit this project. Chapter 3 comprises the state-of-the-art of swimming pool construction in Germany and Sweden, in particular the concrete tank.

In recent years, there has been a significant rise in the number of damaged bathing facilities in Sweden. CBI provided reports of investigated swimming pools to this study. The most frequently emerging damages are named and explained in chapter 4.
Additionally, chapter 5 gives guidelines about repair works for occurring damages.

Chapter 6 and 7 deal with a case study. Firstly, an existing swimming bath was investigated. Damages are named and mapped. Furthermore, proposals for repair works are given. Secondly, a life cycle cost analysis was conducted to show subsequent costs and an alternative of a new, sustainable solution.
2 Structural Background

When designing a swimming pool, there are many details and rules to consider. Since this work is for a Swedish audience about German technology, the focus lies on German standards and common rules. Furthermore, this work deals primarily with indoor swimming pools.

2.1 Bath construction

An increased water temperature since the 1970’s, high frequency in swimming pool buildings and increased turbulent movement of water are reasons for a rise of surface water evaporation with a high chloride rate. The high chloride content in the air leads to corrosion attack for the entire swimming bath construction. To avoid corrosion, stainless steel is a popular material for the roof construction. However, history shows that stainless steel cannot be seen as a guarantee for a safe structure (3). The example of Uster, Switzerland will be considered later on. Furthermore, contact between stainless steel and a metal with a different electrochemical potential is also to be avoided.

Condensation has to be avoided through an appropriate design in any construction. Therefore, swimming halls adjust the air temperature to about 2°C higher than the water temperature (4).

Wood, with its benefits in chemical resistance, seems a better solution. It is often used in new constructions. Glue-laminated timber beams are often seen for roof constructions. In particular, those timber beams are beneficial for curved structures and extraordinary shapes, as shown in figure. An examination of investigation protocols, provided by CBI, did not reveal significant damages in timber beams in swimming pool buildings. However, timber is vulnerable to the aggressive atmosphere too. In particular, high alkalinity and chlorine gases affect timber. Conifers have the highest chemical resistance. The effect of chemicals on wood is described in (5) in more detail and not in focus in this project.

Figure 1: Glue-laminated timber roof construction (34)
The surfaces and floors in swimming pools that are made of concrete are generally covered by ceramic tiles. For these materials it is important to have a high resistance towards chemical cleaning fluids and they should be both water- and splashproof. An anti-slip surface is a matter of course. Additionally, the movements of the substructure as there is shrinkage and drying have to be considered.

2.2 Basin

As a matter of fact, the basin itself is the most crucial part in a swimming bath and reflects the focus of this thesis.

Generally, a swimming pool consists of the structural material, sealing material, a covering layer e.g. tiles as well as an edge and a path around the basin. Figure 2 shows a general assembly of a swimming pool.

Because of its variety in design and the fact that customers prefer the appearance of tiles, reinforced concrete is the most common material for indoor swimming pools. This composite material mirrors the focus of this work.

To design a basin, detailed knowledge about water quality, disinfection system, chemical cleaner and the actual water temperature are required to choose an appropriate concrete composition. For example, there are high temperatures in thermal baths and a high chloride concentration in sea water pools that require deeper knowledge in planning and executing.

Figure 2: Assembly of a pool structure (39)
Structural Background

Figure 3: Bearing variants of foundation slabs of basins (6)

Slab of a basin

There are different systems for bearing the foundation slab of a basin. According to figure 3, there are 2 types of static systems:

- Continuously, by the columns supported slab
- Elastically supported slab

Aim is to minimize movement restraints between slab and the ground by facilitating low friction. One solution is to place a screed or thin concrete layer and cover it with a sliding layer of bitumen or another suitable material to avoid the bond between screed and slab. The basin is placed on top of the screed and is free to move.

Another common solution is a column supported basin. In this case, the slab has a fixed point in the center and the remaining bearings are executed as slide bearings. In the case of monolithic connection with bearing walls, bending moments in the jointing between walls and slabs have to be considered.

An inappropriate solution is a fixed construction, where the foundation slab is based on a rigid, rough ground. Movement due to shrinkage would be constrained and hence, cracks appear.

Static systems

The basin construction has to be monolithic to avoid too many joints and thus weak spots for leaks. However, it is important to decouple the basin from the surrounding structures to reach a minimum of strain stress and thus cracks in both the basin and surroundings. In the past, the path slab often rested directly on the basin.
wall, hence, there was a horizontal joint in the wall. Figure 4 shows 3 modern variants of connections between basin and surroundings. All 3 options avoid direct water contact. However, a path slab is always exposed to splash and runoff water. The variants a) single span beam and b) cantilever from surroundings are also critical. For both variants, a) and c) a watertight dilation joint is required. These joints require much maintenance and often lead to leakage. On the other hand, in variant b), there is a minimum risk of leakage. However, this variant is more complex in its construction and vulnerable to cracks due to strained shrinkage. To conclude, it is difficult to point out a generally best solution. Planners have to rank the above mentioned aspects for each objective.

Walls of a basin

In straight walls in a rectangular tank the hydraulic pressure causes vertical and horizontal bending moments. The direct horizontal tension caused by the direct pull due to water pressure at the end walls, should be added to that resulting from the horizontal bending moments. Walls act as a two way slab, whereby the walls are restrained in the horizontal direction, fixed on the bottom and hinged at the top. Consequently, the walls act as thin plates exposed to triangular loads with boundary conditions varying between fully restraint and partly restraint.

To minimize deformation due to shrinkage it is recommended to use concrete that produces a minimum of hydration heat (7). The German standard DIN EN 197 and DIN EN 14216 give low heat of hydration (LH) and very low heat of hydration (VLH) cement solutions.

Additionally, an appropriate choice of aggregates with a low thermal expansion value contributes to a reduction of hydration heat. The literature (1) recommends doubling the curing duration to constrain deformation through shrinkage.

More detailed information about concrete technology is given in the comparison between German and Swedish constructions.
Edge

A further crucial part of a swimming pool construction is the edge of the basin. There are many examples of catastrophic damages through a leakage between the edge and the path plate. Figure 5 shows one of the cases investigated by Arndt and published in (8).

Figure 5: Leakage at the edge of a basin (8)

Water transport from the basin to the path plate occurs through capillary suction. Capillary suction in concrete and mortar enables the water to soak into the cover layer of tiles and tiling adhesive. The water below the tiles demands to have the same water level as in the pool and tries to rise to the surface (8). The figures 6 and 7 below demonstrate the effect of the equal water level and show an appropriate solution for a seal movement joint between basin and path slab.

Figure 6: Scheme of a wrongly executed basin edge (8)
The path plate next to the edge has to be sealed and the whole construction needs a slope of 2%. As mentioned above, it rests on the head of the basin on one side and on the other side on a wall or pillar. In this case it works as a single span plate. Another execution variant could be a construction such as a cantilever (compare figure 4).

Sealing

Even if the concrete construction itself provides enough water resistance (maximum water and capillary zone: 10cm), it can be beneficial to complement the concrete with an additional sealing material. First of all, it can reduce the impact of underground movement (e.g. shrinkage). Secondly, it protects concrete against chemical attack through acids, chlorides and other chemicals, such as from cleaning agents.

Nowadays, synthetic fluids in combination with tiles present the state-of-the-art. In older buildings bitumen based materials for sealing connected with tiles without transition of forces, are common.

Intersections and applications

However, there is a bigger challenge in sealing a swimming pool other than only at the concrete surface. Intersections of ducts, discharge, drain or light installations are critical points...
Structural Background

and demand a very thorough execution. Figure 8 shows damages due to a leakage of a light installation.

![Image of leakage](image1)

**Figure 6: Leakage of a light installation (19)**

The problem of leaking intersections is the same as leaking joints. Water flows through the leak to adjoining surfaces and evaporates there, resulting in increasing the chloride concentration in the concrete surface. This infiltrates through the concrete, thus resulting in chloride induced corrosion of the reinforcement (see point 3.7)

![Image of pipe intersection](image2)

**Figure 7: Pipe intersection (36)**

![Image of pipe assembly sealing](image3)

**Figure 8: Pipe/ bushing assembly sealing (37)**

Figure 9 and 10 give appropriate solutions for pipe intersections and diverse applications in a waterproof concrete shell.
Impacts

During the design and planning stage, there are several impacts on a swimming pool to be considered. Some of these impacts occur during the whole life time, others only during the construction process. Generally, impacts on swimming pools can be divided into mechanical, physical and chemical impact.

- **Mechanical, load- induced impact**
  - Dead Load
  - Hydrostatic Pressure
  - Loads due to extra equipment, cleaning, amusement etc.
  - Live Loads
  - Earth Pressure (outdoor pools)
  - Groundwater Pressure (outdoor pools)

- **Mechanical, non- load- induced impact**
  - Shrinkage
  - Hydration heat development
  - Ground Setting (outdoor pools)

Partial or full restraint often leads to internal forces. Since these impacts play an important role for swimming pool structures, those are discussed in more detail in chapter 5.

- **Physical impact**
  - Penetration and transport due to fluids
  - Freeze- Thaw- Cycle (outdoor pools)

- **Chemical impact**
  - Fluids (Acids, Chloride, Ozone)
  - Salts (sea water)
  - Sulfates (brine, sea water)

The chemical impact has to be evaluated during the planning stage.
Reinforcement and wall thickness

A calculation of the investigated swimming pool in chapter 6 shows that requirements for the state of the serviceability is the deciding factor towards those of the ultimate limit state. The required reinforcement cross sectional area resulting from the maximum crack width analysis extends the reinforcement resulting from the ultimate limit state analysis. Additionally, figure 11 shows the result of a general comparison of an ultimate limit state and state of serviceability for a 25m basin, supported by columns every 5m. Up to a water level of 1.8m the required reinforcement depends on the serviceability requirements. With a water depth deeper than 1.8m, the longitudinal reinforcement according to the shear reinforcement is the deciding factor. It is also possible to install vertical shear reinforcement, which will lead to rising initial costs.

![Required Reinforcement](image)

Figure 9: Reinforcement according to ultimate limit state and state of serviceability

Depending on the size of aggregates (16 or 32mm), the minimum wall thickness is constructively limited to 260 alternatively 300mm. Next to the obligatory concrete coverage, there has to be a gap between the inner reinforcement of at least 140mm for 16mm aggregates and 180mm for 32mm. This gap has to be provided to ensure an appropriate placing and compacting of the concrete. Figure 12 shows a possible reinforcement configuration for a basin including the edge.
2.3 Criticism, costiveness, mistakes

Quality is generally a big challenge in the area of construction and so too in the field of swimming pools. High financial pressure through high competition and a shortage of time are reasons. Often they lead to defects and hence even higher costs. Additionally, it comes to lawsuits and a long period of a useless structure.

Personal mistakes and a lack of knowledge of construction workers are difficult to determine and to solve in a thesis like this. Nevertheless, the analysis of the provided investigation reports shows that human errors, such as wrongly stored jointing tapes, lead to serious damages.

Figure 10: Reinforcement assembly in slab and wall of a basin
3 Comparison of German and Swedish Standards

3.1 Regulation and standards in Germany

In context of this work, CBI Stockholm requested information about German practices for swimming pool construction. The high number of damaged swimming pools in Sweden triggered the idea to compare national standards and regulation of both countries, Germany and Sweden.

Due to the higher population of Germany and the larger number of swimming pools, associations that care for properly built swimming pools were established: DGfdB (“German association for the pool industry”) and Fachverband Deutsches Fliesengewerbe (“Federation of the German tiles industry”).

The literature shows that experts in Germany still do not agree on a unique solution. A usual execution comprises a waterproof concrete basin with a cement based sealing compound. However, there are possibilities of an epoxy or bitumen based sealing, which disadvantages are already mentioned above. Following this, the focus lays on the details of water proof concrete technology and relating regulations.

Determining the Concrete

For the design stage of a waterproof concrete basin some characteristics have to be determined

- Compression Strength
- Exposition Class
- Aggregate size
- Cement types
- Planning of joints
- Execution

Furthermore, other performances can be required, as there are:

- High water ingress resistance
- Cement with high sulfate resistance HS, low heat development LH or low alkali content
- For outdoor pools, air pores for a concrete with XF4 can be required
- Strength development: slow, medium, fast
- Limitation of fresh concrete temperature

The type of water, bathing water, brine- or sea water, gives the base for the concrete composition. In the case of brine water, a chemical water analysis to determine an exposition class is obligatory according to DIN 4030. When the sulfate content exceeds 1500mg/l, slag cement (HS) is mandatory. (6)

Additionally, a slag cement CEM III/B LH/HS/NA is recommended for basin structures. The low hydration temperature helps to avoid internal stresses during the curing process. In general,
Comparison of German and Swedish Standards

slow curing concretes, low cement content and replacing cement with fly ash are measures to decrease shrinkage.

Preliminary concrete strength is set by exposition class. For normal bathing water quality, this requires XC4 having a strength class of C25/30. However, in a brine and sea water pool XD2 or XS2 is required, with a strength class of C35/45 and a w/c- value of 0.50. In either case, a structural calculation considering the final water depth and the hydraulic pressure, possibly lead to higher than required compression strengths. In the case of ground based constructions, it is essential to assess the groundwater and its chemical attack on the concrete. (1)

Further requirements by guidelines of the DGfdB and the German standard DIN are summarized in the tables 1 and 2.

Table 1: Determination of concrete details for swimming pools

<table>
<thead>
<tr>
<th>Exposition class</th>
<th>Normal Water</th>
<th>Brine Water</th>
<th>Sea Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonation</td>
<td>XC4</td>
<td>XC4</td>
<td>XC4</td>
</tr>
<tr>
<td>Chloride</td>
<td>-</td>
<td>XD2</td>
<td>XS2</td>
</tr>
<tr>
<td>Freezing</td>
<td></td>
<td></td>
<td>XF1 for exposed outdoor pools</td>
</tr>
<tr>
<td>Chemical Attack</td>
<td>-</td>
<td>min. XA2</td>
<td>min. XA2</td>
</tr>
<tr>
<td>Minimum Compression strength</td>
<td>C25/30</td>
<td>C35/45 for ( r_1 &lt; 0.30 ) : C30/37</td>
<td>C35/45 for ( r_1 &lt; 0.30 ) : C30/37</td>
</tr>
<tr>
<td>Maximum Grain for Aggregates</td>
<td>32mm, limitation to 16mm depending on reinforcement distances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistency Class</td>
<td>min F3</td>
<td>F4 (better F5 or F6)</td>
<td></td>
</tr>
<tr>
<td>Concrete Coverage [mm]</td>
<td>40</td>
<td>55</td>
<td></td>
</tr>
</tbody>
</table>
| Further Requirements | - Cement with a low hydration development temperature  
|                      | - Sulfate resisting cement  
|                      | - Addition of fly ash to reduce cement content and minimize heat development  
|                      | - Constraint on the maximum fresh concrete temperature |

1) \( r = \frac{f_{cm2}}{f_{cm28}} \)
Table 2: Limit values and requirements of concrete composition

<table>
<thead>
<tr>
<th></th>
<th>Normal Water</th>
<th>Brine Water</th>
<th>Sea Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum Cement Content [kg/m³]</strong></td>
<td>280</td>
<td>320</td>
<td>320</td>
</tr>
<tr>
<td><strong>Minimum Cement Content with Additive of Fly Ash [kg/m³]</strong></td>
<td>270</td>
<td>270</td>
<td>270</td>
</tr>
<tr>
<td><strong>Maximum w/c-value</strong></td>
<td>0.55</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Maximum Fines Content</strong></td>
<td>c \leq 300 kg/m³: 400 kg/m³ fines content</td>
<td>c \geq 350 kg/m³: 450 kg/m³ fines content</td>
<td>Linear interpolation for the rest</td>
</tr>
</tbody>
</table>

A waterproof construction includes a limitation of cracks and crack width. The guidelines by the DGfdB determine the crack width linked with a hydraulic pressure, \( H_{\text{water}} \), to wall thickness, \( d_{\text{component}} \), ratio. Table 3 also shows guidelines by DAfStb (German Association for reinforced Concrete) (2) and recommendations by Lohmeyer/ Ebeling (7). The crack width threshold influences the rate of the reinforcement; the smaller the maximum crack width the higher the rate of reinforcement, see calculation in appendix E.

Table 3: Maximum calculated crack width

<table>
<thead>
<tr>
<th>( i = \left( \frac{H_{\text{water}}}{d_{\text{component}}} \right) )</th>
<th>Maximum Crack Width ( w_c ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements according to 25.04 by DGfdB [ ]</td>
<td>( i &gt; 5 ) \leq 0.10</td>
</tr>
<tr>
<td></td>
<td>( i \leq 5 ) \leq 0.15</td>
</tr>
<tr>
<td>Requirements according to &quot;waterproof guidelines&quot; by DAfStb</td>
<td>( i \leq 10 ) \leq 0.20</td>
</tr>
<tr>
<td>Recommendations by Lohmeyer/ Ebeling [ ]</td>
<td>( i \leq 25 ) \leq 0.20</td>
</tr>
<tr>
<td></td>
<td>( 2,5 &lt; i \leq 5 ) \leq 0.15</td>
</tr>
<tr>
<td></td>
<td>( 5 &lt; i \leq 25 ) \leq 0.10</td>
</tr>
</tbody>
</table>

Every basin structure with waterproof quality should be designed with easy shapes and as few as possible internal constraints. Possible designs for minimizing internal forces are already shown in chapter 2 in figure 3.

To compensate movements, caused by temperature variation and filling and emptying, expansion joints are used to secure the tightness of a pool. Those joints become necessary in basins longer than 25m. Thermoplastic joint tape and elastomeric joint tape are common solutions and are constituted in the German standards DIN 18541 and DIN 7865. Figure 13 shows a plan
view with the alignment of dilatation joints for a 50m long pool construction (in German) and figure 14 a detail of how a dilatation joint has to be executed.

50 m Becken

Figure 11: Scheme of installation of dilatation joints for a 50m indoor swimming pool (6)

Figure 12: Detail of a dilatation joint for waterproof concrete (9)
Execution and subsequent treatment

To avoid a segregation of the concrete, the maximum casting height is limited to 1m. The pouring of the concrete should be conducted in 30-50cm sections with thorough compaction, using a vibrating stick.

Directly after finishing the concrete surface and removal of the formwork, the concrete needs to be protected from drying. Appropriate measures are covering layers and curing films. Cooling with water leads to internal forces due to a high temperature difference and should be avoided. The guideline 24.04 by DGfdB (1) constitutes to double the time of subsequent treatment given in DIN 1045-3 and shown in table 4.

<table>
<thead>
<tr>
<th>Surface Temperature of the Concrete $T_c$ in °C</th>
<th>Strength Development of the Concrete $r = f_{cm2}/f_{cm28}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fast $r \geq 0.50$</td>
</tr>
<tr>
<td>≥ 25</td>
<td>1</td>
</tr>
<tr>
<td>25 &gt; $T_c$ ≥ 15</td>
<td>1</td>
</tr>
<tr>
<td>15 &gt; $T_c$ ≥ 10</td>
<td>2</td>
</tr>
<tr>
<td>10 &gt; $T_c$ ≥ 5</td>
<td>3</td>
</tr>
</tbody>
</table>

Monitoring

According to DIN 1045-3 (10), swimming pools belong to the monitoring category 2. Consequently, all above named measures, including curing measures and time have to be written in a document. The monitoring has to be conducted by a material testing institute belonging to the executing company and by an independent material expert.

<table>
<thead>
<tr>
<th>Monitoring Class</th>
<th>Normal Water</th>
<th>Brine Water</th>
<th>Sea Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring Class</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Execution of Monitoring
construction material testing institute (hired by company) + independent expert (hired by owner)

Assessment for the fresh Concrete

<table>
<thead>
<tr>
<th>Consistency Assessment</th>
<th>Normal Water</th>
<th>Brine Water</th>
<th>Sea Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency Assessment</td>
<td>during the first installation at the sample preparation for compression strength</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Equality of Concrete
visual assessment at each delivering vehicle
<table>
<thead>
<tr>
<th>Sample for Compression Strength according to DIN 1045-3</th>
<th>3 Samples per 300m³ or every 3 days of concreting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample for Water Ingress Test according to DIN 12390</td>
<td>Parties have to agree on the amount of samples</td>
</tr>
<tr>
<td><strong>Assessment for the hardened Concrete</strong></td>
<td></td>
</tr>
<tr>
<td>Depth of Water Ingress according to DIN 12390</td>
<td>$e_w \leq 50\text{mm}$</td>
</tr>
<tr>
<td></td>
<td>$e_w \leq 30\text{mm}$</td>
</tr>
<tr>
<td><strong>Compression Strength</strong></td>
<td>Parties decide: after 28d or 56d</td>
</tr>
<tr>
<td><strong>Assessment for the entire Structure</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Tightness of the Basin</strong></td>
<td>14 days water filling test after reaching the required strength (at least 28 days after installation)</td>
</tr>
</tbody>
</table>
Design Overview

In the following flow process chart, steps for designing a waterproof concrete shell are summarized.
3.2 Regulation and standards in Sweden

A literature study (11) and (12) and examination of CBI’s experiences about relevant Swedish swimming pool constructions are displayed in this chapter.

The Swedish standards require that every swimming pool in Sweden should use concrete of exposition class XD2 against chloride deterioration. Consequently, the maximum water – cement ratio is determined to be 0.45. The estimated life span of 50 years and the exposition class XD2 require, according to (11) a concrete coverage of 30mm. Table 5.5 in (11) gives an overview of possible concrete mixture formulas for the exposition class XD2. The minimum compressive strength is set to 42.5 N/mm². Only CEM I and CEM II cement with a maximum slag content of 50 m-% are allowed.

According to the Swedish standards (12) swimming pools belong to the execution class 2. This comprises a visual inspection and a regular and systematic measurement of major work. Moreover, an inspection report has to be prepared. Inspections are conducted as self inspection in accordance with the procedure of the constructor.

3.3 Valuation and Interpretation

The literature study shows, that there is a significantly larger number of regulations and technical reports about all topics regarding swimming pools and pool halls in Germany. However, there are no particular numbers about the effectiveness of the measures given in German regulations. In the following, differences are discussed and, regarding their consequences interpreted.

The lower w/c-ratio caused by the exposition class XD 2 has the purpose of decreasing the risk of chloride ingress into the concrete. The lower the w/c-value the lower the capillary suction. Consequently, there is less risk for chloride ingress. On the other hand, Schäffels experiments (13) revealed the influence of the w/c-ratio on the shrinkage behavior. The results show that with a lower w/c-ratio the autogenous shrinkage increases and so the risk of crack formation.

Furthermore, Schäffel analyzed the effect of different cement types on autogenous shrinkage. The German literature (6) recommends the usage of a blast furnace slag cement, CEM III, to reduce autogenous shrinkage. Schäffel justifies this effect with the lower C₃A content in slag cements.

Further benefits of slag cement compared with Portland cement are shown by Dewald in (14). For big concrete structures like basins, high hydration heat development can become a risk factor. High temperature in the core and lower temperatures at the surface cause strain forces and thus cracks in the young concrete. Table 6 shows that slag cement has a lower heat development than Portland cement.
Dewald also points out that slag cement has a lower chloride diffusion coefficient. This fact is based on the lower capillarity in the concrete. Osborne (15) has shown that a slag cement based concrete in a marine environment after 5 years comprises only 0,5 m-% of chlorides at 21mm depth while a portland cement based concrete already contained 2,0 m-% chlorides under the same conditions. The reinforcement of the portland cement based concrete is already highly endangered to corrode.

To conclude, German regulations focus more on minimizing cracks due to shrinkage and achieve a chloride ingress resistance through slag cement. Swedish standards on the other hand focus on very dense concrete with low porosity and accept the risk of crack formation.

Besides the cement, there are differences in construction, too. Apparently, the higher concrete coverage demanded by the DGfdB decreases the corrosion risk. A longer curing time in Germany prevents cracks due to early shrinkage. The differences for the maximum permissible crack width make German constructions more durable.

Probably the biggest difference between German and Swedish swimming pool construction lies in the monitoring requirements. In practice, the difference between internal and independent monitoring of building material and execution can be significant. The 14 days waterproof test ensures a satisfactory level of water tightness due to cracks and leaking joints.

However, implementing German guidelines cannot be seen as a general solution for swimming pool damages. Because of the great variety of damages and reasons for those, it is very difficult to qualify all the German measures. However, implementing guidelines for swimming pool constructions in Sweden could improve the quality. Not only has the standard comparison, also an analysis of investigation reported of CBI Stockholm, led to the proposal that stronger monitoring requirements during the execution could bring improvements in the quality of swimming pools.

### Table 6: Heat development of different cement types

<table>
<thead>
<tr>
<th>Cement Type</th>
<th>Hydration Heat Q [J/g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland</td>
<td>375- 525</td>
</tr>
<tr>
<td>Blast Furnace Slag</td>
<td>355- 440</td>
</tr>
<tr>
<td>Portland Puzzolane</td>
<td>315-420</td>
</tr>
<tr>
<td>Portland Oil Shale</td>
<td>360- 480</td>
</tr>
</tbody>
</table>
4 Damages

4.1 Microorganism

Warm water is not only perilous for the structure; furthermore, it is a good environment for microorganism and mould. Disinfection due to chlorine is not a 100% guarantee to avoid bacterial growth. Nutrition can be given by building materials, for example incompletely cured epoxy sealings that are based on organic substances. Furthermore, exudation (skin particles, hair and others) can also be assimilated by microorganisms.

Microorganisms and mould can be distinguished in a colour change of joints between tiles (often black). Not only are black joints considered to be unaesthetic and deteriorate the building material, it also affects the health of bathers.

In his field studies, Arndt (8) emphasizes rules to minimize the risk of microorganism and bacteria. As already mentioned, a high water temperature facilitates increased bacterial growth. Consequently, operators of swimming pools should choose a water temperature as low as possible acceptable to its patrons. Microorganism needs a rough surface to colonize. Arndt gives an example (8) of a swimming pool with a high porous material for tile joints. Those joints are hard to clean and create a good environment for bacteria.

Furthermore, a high water movement and a frequent exchange of water helps to minimize the risk of bacterial grow.

4.2 Cracks

Cracks are reasons for leakage. An examination of CBI’s project experience gave evidence that cracks are the main reason for catastrophic damages. It is important to differ between cracks in the upper, protective layer and cracks through the entire structure. The latter has to be filled with injections immediately.

The main types of cracks, appearing in swimming pool structures, are shrinkage cracks and structural cracks.

4.2.1 Shrinkage cracks

Shrinkage is often the cause of short and/or wrong curing. The process of plastic shrinkage takes place from the first until the eighth hour after mixing the concrete. During this process, water from the upper layer evaporates as well as water in the capillary pores. The resulting deformation (capillary shrinkage) is retarded by the lower level concrete, which has less shrinkage deformation. The low tensile strength of the concrete causes the cracking in the surface area. Crack widths up to 2mm and depth till 10cm can occur (16). The strength of the effect of plastic shrinkage depends on many facts, for example:

- Temperature and relative air humidity of the environment
- Exposure to wind, direct sunlight
Another type of shrinkage, important for swimming pools, is drying shrinkage. It happens mainly when a pool is emptied for a longer period of time.

We can differ between two types of bonding between the hydration products:

- Primary bonds (chemical)
- Secondary bonds (physical)

The strong primary bonds allow, hardened cement paste to keep its strength under water.

On the other hand, secondary bonds rely on the water content. Consequently, concrete swells in case of high water content and it shrinks with low water content. In this case, the surface layers tend to shrink, while the lower lying concrete does not. That leads to cracks and curling at the surface as shown in figure 16.

The curling effect often causes a spalling or lifting effect on the tiles. No matter which type of shrinkage is considered, it is the cement component in the concrete which is shrinking. Consequently, the less cement in concrete the less the autogenous shrinkage.

4.2.2 Structural cracks

Structural cracks appear through the occurrence of deformations through loads or temperature. As already mentioned, because of the large amount of concrete and its heat development during hydration, it is important to separate the pool construction from surrounding objects.
4.3 Flaking of Coating

Concrete is in a continuous state of curing, even after some time it still can release water. For coated basins, there is always the risk of water below the coating!

According to guidelines from the German community of pool industry (Deutsche Gemeinschaft für Badewesen e.V.) (1), a pool can be built both, as a watertight concrete tank or with an extra sealing on the concrete surface. There are advantages and disadvantages for both. While the watertight tank system is vulnerable to separating cracks, problems with sealing can be much more problematic:

- Emerging, water filled blister due to too early covering of the concrete
- Perforation during construction or other mechanical stresses
- Cracks due to exceeding the maximum crack bridging capability

Ingress of water between concrete and sealing can lead to a permanent attack on concrete and reinforcement due to aggressive water. Furthermore, water filled blisters lead to the lifting.

Damages to sealings are very complex and expensive to repair. Usually, it is necessary to remove all tiles, mortar and sealing to create a new seal cover layer.

4.4 Corrosion

As for most reinforced concrete structures, corrosion is a significant problem especially in older swimming pools. In a good quality concrete, steel bars have excellent protection. At the beginning, an alkaline atmosphere, due to a reaction between the

![Figure 15: Influence of passivation to the electrical current (41)](image)
mixing water and the cement particles, is created. In this emerging alkaline atmosphere, with a pH-value of at least 12.5, steel bars are protected from corrosion. Furthermore, the concrete mixture should strive for a minimum of permeability to inhibit the infiltration of aggressive gases and fluids. However, in the case of lost passivation, through carbonating or too high chloride content, steel bars are vulnerable to corrosion.

For corrosion to occur, a difference in the electrical potential within the steel-concrete system is required. At the heterogeneous surface of steel, areas acting as an anode and areas acting as a cathode are formed. For the electrochemical process to proceed, it also needs an electrical conductivity between the cathodic and anodic sites and a pathway (electrolyte) that provides ionic continuity between the anodic and cathodic sites.

In the electrochemical process, the water in the pores of the concrete contains dissolved ions and functions as an electrolyte. Positively charged ions from the anode go into solution and electrons are released.

\[ 2\text{Fe} \rightarrow 2\text{Fe}^{++} + 4e^- \]  (anodic half cell)

The steel bar itself works as a conductor and permits the transfer of electrons to the cathode. There are the electrons in the presence of water and oxygen are consumed and become hydroxyl ions.

\[ 4e^- + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{OH}^- \]  (cathodic half-cell)

Finally, the electrolyte carries the ions back to the anode and completes the electrical circuit.

The hydroxide ions from the cathode reaction and the positively charged ferrous ions from the anode form ferrous hydroxide, which, with the oxidation, converts into hydrous ferric oxide, also known as rust.

\[ 2\text{Fe}^{++} + 4\text{OH}^- \rightarrow 2\text{Fe(OH)}_2 \]

\[ 2\text{Fe(OH)}_2 + 2\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O} \ [\text{For09}] \]

The process of metal corrosion is accompanied by an increase of the volume of the steel sometimes up to twice the original. In reinforced concrete, this leads to cracking or spalling of the concrete layer occurs, when the pressure from the increased volume exceeds the tension strength of the concrete.
Damages

As mentioned above, stainless steel is a popular solution in modern constructions. In the field of swimming pools, it is used not only for hand rails, ladders and decorative items; it is also applied in suspended ceilings.

Historic examples [ceiling collapse in Uster, Switzerland and Steenwijk, Netherlands] (3) have shown that stainless steel in combination with a disregard of design rules leads to stress corrosion cracking (SCC).

Since the 1970’s, use of swimming pools changed dramatically. An increase of the water temperature led to longer stays in swimming pools and made them more attractive for leisure purposes. Due to the higher temperature and the higher frequency of bath guests a higher amount of disinfection material has been required. To create a comfortable climate and to avoid condensation on indoor objects, e.g. windows, the hall temperature is about 1°C above the water temperature. However, ceiling parts are cooler than the air temperature and the chloride containing water condensates onto structural parts. While the condensed water on the steel suspension dries out, the chloride remains and since this is a continuous process, it results in significant chloride accumulation.

This increase of chloride presents a disruption in micro cracks in the structure of stressed steel. The described corrosion process takes place at the peak of the crack. In these cases, a failure occurs suddenly. Consequently, it is difficult to predict SCC.

4.6 Carbonation

Carbonation is an effect caused by reactions between carbon dioxide from the atmosphere and hydrates in the cement paste matrix of concrete. This reaction causes a reduction of the...
alkalinity of the concrete; hence the protecting steel atmosphere is neutralized to a pH value of about 9. If the steel gets in contact with water and oxygen, it results in corrosion.

The chemical process can be described as a reaction of carbon dioxide, $\text{CO}_2$, with calcium hydroxide, $\text{Ca(OH)}_2$, resulting in the formation of calcium carbonate $\text{CaCO}_3$.

$$\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$$

Carbon dioxide also reacts with water in the concrete pores and forms a carbonic acid. This weak acid reacts with calcium carbonate to form calcium bicarbonate.

$$\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{Ca(HCO}_3\text{)}_2$$

At the final stage, some of the solution penetrates and combines with calcium hydroxide to form calcium carbonate.

$$\text{Ca(HCO}_3\text{)}_2 + \text{Ca(OH)}_2 \rightarrow 2\text{CaCO}_3 + 2\text{H}_2\text{O}$$

In conclusion, the reactions show that the alkalinity producing calcium hydroxides are consumed by carbon dioxide. The resulting calcium carbonate has a pH value of about 8-9. (17) Consequently, the protecting passivation layer is lost and the steel is endangered to corrode.

Carbonation induced corrosion requires a RH of between 40%–80% (18). If the ambient air humidity is too low, carbon dioxide can ingress easily, but most pores are dry and it cannot come to corrosion. On the other hand, if concrete is too wet, practically all the pores are filled with water and carbon dioxide can only diffuse very slowly through convection or diffusion after it dissolves into water.

Figure 17: Effect of relative humidity on the depth of carbonation (32)
Besides the decrease in pH value, carbonation has another effect on concrete. The resulting calcium carbonate has a larger volume than the calcium hydrates resulting in a reduction of porosity and an influence on strength and deformation properties. (17)

### 4.7 Chloride

Recently, new methods for disinfection of swimming pool water have appeared:

- Silver method
- Ultra filtration
- UV- radiation method
- Water treatment with ozone.

However, due to cost efficiency adding chlorine is the most common method. Either as chlorine gas [1], a dilution in sodium hypochlorite [2] or calcium hypochlorite, which reacts with the water and forms hypochlorous acid (HClO).

\[
\text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HCl} + \text{HClO} \quad \text{[1]}
\]

\[
\text{NaClO} + \text{H}_2\text{O} \rightarrow \text{NaOH} + \text{HClO} \quad \text{[2]}
\]

These substances can be divided into free chlorine, which is exploited by organic substances in the water, and to nitrogen combined chlorine. Table 7 shows threshold values for chlorine in accordance to the German standard DIN 19643.

<table>
<thead>
<tr>
<th></th>
<th>Free Chlorine [mg/l]</th>
<th>Combined Chlorine [mg/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>min</strong></td>
<td><strong>max</strong></td>
<td><strong>max</strong></td>
</tr>
<tr>
<td><strong>General Pool</strong></td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Warm Bubble Pools/Jacuzzi</strong></td>
<td>0.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

In normal water (no salt, no thermal basin), the maximum chlorine content of 0.8 mg/l is not considered to reach the maximum chloride concentration of 0.35 m-% of the cement content, through capillary suction. As a result, there is no exposition class XD given by any official standards in Germany for normal water. For sea water and brine basins XS2, XD2 and XA2 are to be considered. (6)

However, chloride induced corrosion becomes a problem in swimming pools if there are areas of high chloride concentration. The content of chloride used for disinfection is generally not high enough.
Critical spots are intersections and joints, where water evaporates and chlorides accumulate. Combined with the high temperature in the swimming pool environment, the peril of corrosion is considered higher than for example in a multi storey car park (19).

If it comes to ingress of chloride into concrete and it exceeds the chloride threshold (0.35m-% of the cement content), it depassivates the steel locally and leads to corrosion due to a change of the electrical potential. Consequently, the steel corrodes and it forms a ferric chloride, which reacts with the available hydroxyl ions to ferric hydroxide.

\[ 2Fe + 6Cl^- \rightarrow 2FeCl_3 + 4e^- \]
\[ FeCl_3 + 2OH^- \rightarrow Fe(OH)_2 + 3Cl^- \]

### 4.8 Influence of Temperature and RH on carbonation and chloride

During the 1970’s, the environment of indoor swimming pools changed dramatically in Sweden (4). With an increase of water temperature, the length of time each bather increased, too, and with it the frequency of their returns. During this time, many new swimming baths were built and old ones were renovated.

With the increase of the water temperature, owners had to rise the environmental temperature in order to increase comfort and to avoid condensation on surrounding objects, e.g. windows and structural objects. Additionally, the public’s demand for bigger pools has led to increased water surface and moisture evaporation.

Nowadays, the atmosphere in swimming baths has a temperature of about 28-30°C and relative air humidity of about 55-65%. However, warm air is able to absorb more moisture, which makes swimming pools not comparable with usual buildings. Figure 20 shows that a cubic meter of air with 30°C has the potential to absorb 75% more water than a cubic meter of air at

![Figure 18: Relation between moisture content, temperature and RH](image-url)
Nevertheless, experts (20) and (4) do not agree, whether the constant high temperature and high RH are indeed an aggressive medium itself. However, as a matter of fact, this atmosphere promotes the ingress of chlorides (18).

5 Repair methods and principles

This chapter deals with repair strategies and principles for the above named, occurring damages. Repair methods are chronologically explained in the order of when damages possibly occur.

Crack repair methods

Cracks in a swimming pool basin can be detected by a, in Germany obligatory, water filling test of the shell construction.

For fine cracks up to 0.1mm exposed to water, autogenous healing can occur. The self-healing process can be chemical, physical or mechanical. In the chemical process the development of calcium carbonate with a higher volume has the best impact. The physical process can be explained as an expand of the hardened cement paste. Loose material transported by the water to narrow spots in a crack display the mechanical process. Literature shows, that cracks of 0.1 mm can be sealed by self-healing. (21)

Separation cracks have to be injected. Injection materials can be classified depending on their composition:

- Hydraulic binders
- Polymer binders
- Gels

and depending on their function:

- Force transmitting
- Ductile filling
- Swelling filling.

For the purpose of swimming pools, polymer binders are the most common solution. These binders are able to transmit forces and accommodate subsequent movement. These properties help to keep a basin watertight, since there is a considerable movement in the structure.

Hydraulic binders are beneficial because of their low costs, compatibility to the surrounding structure, predictable durability, environmentally friendliness and low safety requirements for
Repair methods and principles

workers. On the other hand, hydraulic binders have disadvantages in their ability of absorbing movement and in their ability to penetrate all cracks. (22)

![Diagram of injection packer and crack sealing](image)

**Figure 19: Arrangement of injection packer (23)**

Injections are conducted through packers in drilling holes. Figure 21 (in German) shows a schematic arrangement for packers to seal a crack in a wall. After detailed planning of the grout material, injection depth and allowable pressure, packers can be mounted into the drill holes. The grout can be pumped into the structure and will create a lid. The lid enables the creation of a counter pressure which is essential to achieve a thorough injection. Usually, grouting starts at the lower end of a crack and up to the next packer. The distance between two packers is about 0.5m and 1m.
Microorganism

Microorganism attacks often result in larger structural interventions. Generally, the origin of the damages lies below the tiles or sealings or in the pores of cementitious materials. The solution of these damages often results in replacing the affected areas.

Flaking of coating and lifting of tiles

For lifted tiles, the solution is to replace them with new ones. The effect of drying shrinkage will end as soon as the basin is filled with water. In the case of flaking coatings, the repair work can be more laborious. Often, it is difficult to replace only a section of damaged coatings. If there is a leakage in the interconnection between new and existing coating, damages appear again. Consequently, flaking coatings have to be replaced in large areas.

Corrosion as a reason of Carbonation

In general, the repair principle for corrosion in carbonated concrete is to reestablish the alkaline milieu. Figure 22 (in German) shows drawings for appropriate repair systems. Only deteriorated and cracked concrete has to be removed. Repair mortar or concrete must have a sufficient resistance towards carbonation and a high alkalinity. Eventually, application of a surface protection system, to increase the carbonation resistance can be beneficial.

Another option is to use a repair concrete with very low water permeability. This system is based on the idea of avoidance of water ingress to the reinforcement level. Hence, the process of corrosion can be hindered.

If both of the above mentioned strategies do not lead to a sustainable solution, there is the possibility of coating the reinforcement with synthetic and alkaline resistant material. This measure requires complete removal of the concrete and a thorough execution of the covering.

![Figure 20: Repair work for carbonated concrete](image-url)
Corrosion as a result of chloride concentration

The case of chloride induced corrosion differs from carbonation in some points. If chloride is detected at the concrete surface, a profile of concentration and ingress depths has to be carried out.

The process of repassivation is not allowed. Concrete that exceeds chloride concentrations has to be analyzed more deeply and possibly has to be removed. (23) Additionally, to avoid uncertainties, there should be a safety margin to prevent the remaining chloride in the concrete from causing further damage. Repair materials should ensure that there is no further chloride ingress. Usually, a surface protection layer is installed. Figure 24 (in German) displays a scheme for an appropriate repair system in concrete with high chloride concentration.

Because of its uncertainty, the water restraint strategy is not recommended. (23)
In the context of upcoming renovation work in a swimming bath near Stockholm, Sweden, the building owner decided to have the basic structure of the pool investigated. CBI Stockholm received the assignment to conduct a wide ranging analysis on its condition.

**Description of the object**

The swimming bath was built in 1980. However, it was rebuilt in 1989 after a fire in 1987. The swimming bath comprises of a 25m basin, a 10m children’s basin and an amusement basin including slides and a wave machine as shown in figure 25 and 26.

Sodium hypochlorite and sulfuric acid are used for the disinfection system. All pools are covered with tiles on a concrete construction with water proof concrete quality. The overflow gutter was executed as a Finnish system (8).
Investigation

CBI conducted a visual investigation, a chloride analysis by concrete powder abstraction, measured the concrete coverage and measured the extent of carbonation depth with a Phenolphthalein solution. During the investigation, all the pools were water filled and open for guests. Consequently, there was no closer visual inspection of the inner surface of the pools. However, the operator did not report of any lifting tiles or similar damage.

The observation did not reveal significant damages at the inside of the pool area. Only, as shown in figure 27, steel pillars, covered with wood, have begun to corrode due to the aggressive environment and splash water. Furthermore, the concrete coverage was at least 35mm and is considered to be high, for a construction from 1989.

25m pool

In general, the basin construction was in a good condition. The movement joint between the ground and the wall construction, which is generally a critical object, was in a good condition and did not show any damages or leakage. However, damages and objects that need to be repaired are pointed out below.

The 25 m pool was built on walls and is supported by pillars in the center (which could not be investigated). The shrinkage of the long concrete walls led to wide dilatation joint with leakage, figure 28. Previous repair works of filling the joint were not sustainable.
Furthermore, the investigation showed numerous leaking intersections of pipes and ducts. The difficulties of sealing these critical spots are already mentioned above. In many cases it comes to unaesthetic scum as shown in figure 29.

**10m children’s pool**

The children’s teaching pool is located next to the 25m basin. A leak between the slab and the up going wall led to corrosion of the reinforcement in the slab, see figure 30.
The leaking water caused a high amount of chloride and led to corrosion of reinforcement at the bottom of the wall. The increasing volume, due to the corrosion products, has caused the concrete to spall. The carbonation depth was measured to be 12mm.

Figure 28: Flaw due to corrosion in floor slab

Cracks in the slab led to a penetration of water. Consequently, the water causes the development of stalactites and stalagmites, as shown in figure 31.

Figure 29: Stalactites due to a leaking crack

**Machine room**

The machine room is placed between the 25m basin and the amusement pool.
A leak between the slab and a beam led to strong corrosion and accompanied by that, wide cracks and spalled concrete at two spots, see figure 32 and 31. The water penetrated through the leak and has led to a high chloride content in the reinforced concrete and caused corrosion as described in point 3.1.

A leak at the warm water jacuzzi causes standing water in a small chamber next to the machine room, see figure 35. Furthermore, it causes the corrosion of the reinforcement at an adjacent concrete wall. Figure 34 shows how a corroding steel bar force a crack in the concrete.
Amusement basin

Cracks in the walking slab led to water ingress and consequently to an accumulation of chloride. The resulting corrosion and the concrete spalling are shown in figure 36 and 37.

Measurements and samples

Concrete cover and carbonation depths were measured at the sampling points showed in appendix C. The concrete coverage layers were measured with a pachometer, shown in figure 38 or with a sliding caliper. Furthermore, concrete borehole cores were taken out of the structure for chloride analysis in the laboratory. Chloride samples for analysis were taken at the reinforcement level.

To determine the carbonation depth, a pH indicator fluid (phenolphthalein) was sprayed at the sampling points. The area changing colour to pink/purple indicates high alkalinity above pH 9.
Results from laboratory and in situ examination

Table 8 shows the results of 3 concrete pieces and 6 samples of concrete drilling powder taken on 6th March 2012. There are maps in appendix C that display locations where the samples were taken. It is shown that there exists a significant risk of reinforcement corrosion. Carbonation depth partly reached the reinforcement level and the chloride content exceeds the threshold locally.

Abbreviations T, V and B are used: T stands for ceiling (Swedish: tak), V for wall (vägg) and B for beam (balk).

**Table 8**: Chloride content and carbonation depth

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth [mm]</th>
<th>Chloride/ cement [mass-%]</th>
<th>Cement content [mass-%]</th>
<th>Carbonation depth [mm]</th>
<th>Concrete coverage [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>15-25</td>
<td>0.29</td>
<td>8.5</td>
<td>31</td>
<td>19</td>
</tr>
<tr>
<td>T2</td>
<td>30-40</td>
<td>0.89</td>
<td>5.8</td>
<td>12</td>
<td>36</td>
</tr>
<tr>
<td>T3</td>
<td>30-35/ at reinforcement</td>
<td>1.91</td>
<td>14.5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>T4</td>
<td>25-35</td>
<td>not calibrated chloride content</td>
<td>2.7</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>V1</td>
<td>45-55</td>
<td>0.39</td>
<td>4.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>V2</td>
<td>at reinforce- ment</td>
<td>12.31</td>
<td>15.6</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>P1</td>
<td>20-30</td>
<td>0.43</td>
<td>10.1</td>
<td>24</td>
<td>38</td>
</tr>
<tr>
<td>B1</td>
<td>at reinforce- ment</td>
<td>0.22</td>
<td>16.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B2</td>
<td>25-30</td>
<td>2.29</td>
<td>9.8</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Results from Static analysis

An analysis of existing reinforcement revealed that, according to both German and Swedish requirements regarding crack width limitation, the existing reinforcement is not sufficient.

Meaning and Recommendation

The entire swimming bath is generally in a good condition; however, there are several spots with significant damage that should be repaired. A structural calculation according to the German standards and regulations, which are considered to be the deciding factor in this case, revealed an insufficient percentage of reinforcement. The existing reinforcement according to the present drawings, appendix D, suffices requirements for the ultimate limit state but not these for the state of serviceability. However, the visual investigation did not show any open cracks or water permeation through the basin. Neither were there any revealing lifting tiles inside the pool or any corrosion or similar damages. Additionally, the crack width analysis,
according to DIN 1045-1, is considered to be on the safe side and the analysis was based on the strictest possible assumptions. Consequently, since the formulas are based on probabilistic values, there is a minimum risk that there are cracks wider than 0.1mm due to a lack of reinforcement percentage. (2)

The handwritten calculations according to the German standard DIN 1045, and the above mentioned guidelines for designing swimming pools, are attached in appendix E.

Consequently, damages are caused either by insufficient execution of the initial construction and repair work or ongoing deterioration due to carbonation and chloride ingress.

Considering the laboratory results, there is evidence that carbonation and chloride ingress have taken place at the investigated basin. The data leads to the prediction that in the long term there will be severe structural damages to the structure. The condition of two beams (B1 and B2) shows significant damages. However, laboratory results of B1 do not reflect the existing damage. Both beams are strongly affected by chloride ingress, which led, in combination with reinforcement corrosion, to the deterioration of the concrete. Both beams, B1 and B2, should be completely replaced. The ongoing process of decreasing reinforcement cross section and spalling concrete causes a decrease of its load bearing capacity and thus risking failure of the beam. Regarding the rehabilitation of the beams, it is essential to fix the leakage to prevent a repetition of the process. In both cases, a dilatation joint has been the reason for water ingress. In context of replacing the beams, a new dilatation joint with a new jointing band should be installed.

In connection with the repair of the above, measures should be taken to prevent continued damage progress. The tested material samples give evidence that there are locally high chloride concentrations, e.g. V2. For a sustainable repair work, concrete should be removed up to 200mm beyond and 25mm behind the corroded reinforcement. New concrete coverage should be at least 30mm. Since the chloride concentration is caused by leakage, it is essential to stop any further water ingress through joints and intersections. The issue of water leaking at intersections occurred several times. To reach a life span of at least 50 years after rehabilitation, it is recommended to seal all leaking intersection as shown in figure 9. An appropriate solution for the refurbishment of leaking dilatation joints is given in figure 14.
There is a well-known fact that acquisition of capital in the construction industry, in both public and private sector, is based on initial purchase costs. So far, minimizing the production cost has been the mayor aim of both, owner and executor. However, buildings induce costs over their entire life time; starting with erection, operation, maintenance and finally demolition and disposal. Figure 39 shows a scheme of occurring costs during a building’s life time in context of a future oriented way of construction, it is the aim to avoid subsequent costs because of savings for erection costs. Consequently, the following chapter not only considers initial construction costs, but also estimates subsequent costs due to maintenance and repair work. (24)

Only a few exceptions consider whole life costs in the investment stage, e.g. military approaches (25). However, the concept of whole life cycle cost is not new; the department of industry HMSO, London, England dealt with the topic and published its article “Life Cycle Costing in the Management of Assets” in 1977. White defined LCC in 1976: “The life cycle cost of an item is the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life”. (26)
Elements of a LCC analysis

The first step is to define all occurring costs before occupying the considered facilities. All points are added to the calculation with their full value. Depending on the detail of the calculation, costs for land acquisition, site investigation, design services etc. can be added to construction costs. (27)

Secondly, operation costs are added to the LCC analysis. Operation costs are all annual costs excluding maintenance and repair. Costs have to be discounted to their present value with the formula:

$$PV = \frac{(A_0 \times (1 + d)^t - 1)}{(d \times (1 + d)^t)}$$  \hspace{1cm} (27)

Where:
- $PV$ = Present Value
- $A_0$ = Amount of recurring cost
- $d$ = Real Discount Rate
- $t$ = Time (expressed as number of years)

Operation costs can be costs for insurance, water, electricity, cleaning. All structural measures to maintain or reestablish the value of a structure are added under the point maintenance and repair. Costs in future have to be estimated, by historical data or literature, and can be calculated as annual costs. Additionally, all costs have to be discounted to their present value. (27)

The forth step are replacement costs that include all future costs for replacing larger building components. These costs also have to be estimated and discounted to their present value. Since these costs are one-time, they can be discounted with:

$$PV = \frac{A_t}{(1 + d)^t}$$  \hspace{1cm} (27)

Where:
- $PV$ = Present Value
- $A_t$ = Amount of one-time cost at a time $t$
- $d$ = Real Discount Rate
- $t$ = Time (expressed as number of years)

The fifth step reflects the definition of the residual value of an alternative to a certain time. The residual value is the net worth of an object at the end of the considered life time. Finally, that all costs are calculated and discounted to their present value all costs can be summed up for each alternative and compared to each other. (27)

Standards and name definitions

ISO 15686-5 “Buildings and constructed assets – Service life planning – Part 5: Whole life costing” (ISO/TC59/SC14) defines the difference between whole life costs (WLC), life cycle costs(LCC) and through life costs(TLC). WLC comprises, in addition to LCC, revenues and external costs like interest rates for loans etc. TLC, in general, only considers costs during the operation time excluding initial costs. (27)
Furthermore, the report “Enterprise Directorate-General” (2003), published by the Task Group 4 (TG4) based on the DG Enterprise and Industry provides guidelines for LCC analyses. In general, assumptions for future occurring costs and in determining interest rates reflect the difficulties in conducting a LCC analysis. With consideration of discount rates, a change from static to dynamic calculation takes place. The calculation of a discount rate enables a determination of present values in the future. The resulting cash value reflects the amount of money that has to be invested with the determined interest rate to achieve the required money in the future. (27) This comparison is important in the case of investments at different times: High investments with low subsequent costs can be compared with low investments and higher subsequent costs.

**LCC as basis for decision-making**

Life cycle cost analysis can be used for following purposes:
- Comparison of two or more projects
- Control of ongoing projects
- Long term planning and budget calculation

For this work, the purpose of comparison is in focus. For reinforced concrete structures, as swimming pools basins, the subject of deterioration due to the aggressive environment is very important. Consequently, as civil infrastructure is aging, owners have to spend a significant percentage of their budget on renovation or replacement. Obviously, there is a high financial incentive to extend the service life of existing structures and design new high quality reinforced concrete structures with less maintenance and repair demands. In the following, the methodology of LCC is used to determine decisions for investments to minimize subsequent costs due to maintenance and repair works.

A lack of data caused the usage of a German construction cost planning software called “Legep” provided by WEKA. The cost assumptions are based on the Sirados database. Moreover, the software is based on the report by TG4 that is mentioned above. Additionally to construction costs, for example of a basin, this software provides costs for repair work for deteriorated structures as well as costs for maintenance. *Legep* can also be used for a life cycle analysis (LCA) that considers energy consumption but was not the focus of this project.

**Comparison**

In this project, LCC is used to compare a repair scenario of the investigated, 32 year old structure with a new construction over a time span of 80 years. The strong requirements for crack width and high demand of reinforcement resulting from the structural analysis of the investigated basin led to the idea to build the new pool with post tensioned concrete. This technology is already common for waste water tanks and septic tanks that also have strict requirements regarding crack width.

Due to post tensioned concrete, it is possible to lower the degree of reinforcement dramatically. Hence, it is possible to decrease cost for steel and balance the more expensive technology for the prestressed technology.
Especially for 50m long swimming pools, post tensioned technology is considered to be worthwhile. Firstly, it is possible to build pools without dilatation joints. Furthermore costs for injections are reduced, since the risk for separating cracks is minimized. The structural analysis in appendix G also shows that the demand for steel is far less than for regular reinforced concrete. On average, a swimming pool requires 32cm²/m of reinforcement. A prestressed pool instead only requires 3cm²/m prestressed steel plus 18cm²/m to prevent early cracks due to hydration heat. Figure 40 and 41 show a post tensioning system and a regular reinforcement of swimming pools (minimum reinforcement for the post tensioned system is missing).

An installation of central post tension strands helps to set the complete cross section under pressure. Strain tension forces cannot exceed the tension strength of the concrete; hence, cracks do not appear. To avoid cracks due to shrinkage, only 30% of the post tension stress can be imposed after 7 days. A fully post tensioning can be assembled after 28 days, respectively when nearly 100% of the compression strength is reached. (28) Appendix F shows schematically how a cross section of a prestressed concrete basin looks like.

**Assumptions for repair scenario**

Following discussions with the property administration of Stockholm as well as with swimming pool experienced engineers at CBI Stockholm, the costs for repairing the existing swimming pool were deduced.

It is assumed that the recommendation of replacing the two hardly damaged beams, renewing leaking movement joints and repairing corroded steel bars are appreciated and conducted. Furthermore, it is planned to renovate all tiles in the swimming hall. However, the investigations showed that there are several spots where chloride thresholds at the reinforcement are already exceeded, but no corrosion took place so far. For the calculation it is assumed that for the next 70 years, the frequency of corrosion and concrete spalling increases. This assumption is confirmed by Breit (29) and figure 42.
Consequently, the whole life cost calculation comprises high repair costs with increasing age of the existing basin.

**Assumptions for post tensioned scenario**

The comparison scenario is based on a completely new basin structure. Therefore the old one has to be demolished and the waste appropriately disposed. For comparison reasons, the new pool has the same length; however it is possible to use the change for a longer pool for competition issues. The new pool is based on a concrete basement with a sliding foil. The former pillars are removed; hence the new pool will have a water level between 1.5m and 1.8m. Next to the actual basin, the path around the pool will be renewed.

The post tensioned system requires low- maintenance. It is assumed that over the considered life span of 50 years, there will only be visual investigation and little repair work.
Results

Both calculations, post tensioned and repair work, were conducted with different discount and building price inflation rates. The results in appendix H show that the initial prices for the new prestressed swimming pool are about three times higher than those of the repair work. However, the assumptions used by the software Legep and the fact that there is already chloride in many parts of the basin, lead to higher maintenance and repair costs in the future. In the static calculation, the costs for repair work meet the costs for the new pool in 78 years. Consequently, the option of replacing the existing pool with a new construction is not worthwhile.

On the other hand, considering the cash values (in appendix H “Barwert”) of both scenarios, the effect of dynamic calculation becomes apparent. In a first calculation with the assumption of 3% discount rate for capital in the repair scenario, the cash value for the post tensioned pool is much higher, because the investment costs for repair work decrease with the assumption that owners gain more interest than they have to spend in inflation. However, in reality, it is common that public owner spend capital in other facilities instead of interest rates. Consequently, a second calculation with 0% interest was conducted. With a rising construction prices in both cases of 1%, both post tensioned and repair scenario happened to have nearly equal cash values. If the case of 0% interest rate was considered to be realistic, owners would spend the same amount of money for both variants, even though the post tensioned variant has higher initial costs in the beginning.

After the LCC analysis a second calculation was conducted. A calculation of costs for the post tensioned reinforcement and comparison with the regular reinforcement has confirmed the estimation in (30) that starting with a volume of about 1000m³ prestressed tanks are economically cheaper. Figure 43 shows the result of the calculation. The fact that dilatation joints, that are necessary for 33m and 50m basins, lead to even higher costs, is not considered here. The calculation is based on the price catalogue Sirados which is included in the used software Legep and price information from the company DSI GmbH office Langenfeld.

Figure 41: Cost comparison between post tensioned and regular reinforcement
8 Conclusion

8.1 Conclusion
Generally, swimming pool structures are highly affected by their environment due to direct water and chloride impact. If not thoroughly executed, swimming pools deteriorate faster than assumed in the design stage and cause high subsequent costs. This project shows consequences of insufficient execution, planning and operation of swimming pools. Furthermore, technologies to prevent the most frequently occurring damages are mentioned and standards for constructing swimming pools are discussed. The comparison of German construction rules shows points for improvements in the field of Swedish pool construction. A case study mirrors theoretically explained problems and is the basis for a LCC analysis. The final LCC analysis shows the economical consequences of strongly deteriorating swimming pools. Additionally, this project shows the decision making function of a LCC analysis. For the analysis, the technology of post tensioned concrete, which is a common solution in waste water tanks, was implemented and compared to existing constructions.

8.2 Discussion
This project shows that it is not possible to give a solution for the issue of damages in swimming pools. Every case has to be investigated individually. However, stronger regulations in monitoring during the construction phase and quality assurance measures will bring significant improvements.

The results, given in the LCC analysis, are representative but not transferable to other swimming pools. The investigated swimming pool is, after 32 years, relatively young and generally in a good condition. Even though the life cycle cost analysis did not reveal an unexpected solution, in this case a new basin, it has shown that it is an approach worth considering. For older and more damaged basins, an analysis of life cycle cost for a further 50 or more years can end in another solution, so that a replacement with a new basin is worthwhile.

Furthermore, this analysis shows that the technology of post tensioned concrete reflects a more sustainable and, in many cases, a more economical solution. The above mentioned benefits, no cracks, no dilatation joints and savings in reinforcement, become more significant the larger the planned basins are.

8.3 Further Research
The literature study shows that there is a lot of knowledge about constructing swimming pools correctly. However, the focus of this thesis lay on objects older than 30 years and does not include data about new constructions. A study about new swimming pools helps to qualify the sustainability of the state of the art.
Conclusion

Since there are many reasons for damages in older swimming pools, there are many points to consider. In his report (31), Arnke started to analyze the relation between higher investment costs, higher quality and sustainability of materials in swimming halls. Even though he could not find a solution, an expansion of the research can lead to more representative data to assume costs in the future.

For the application of post tensioning in swimming pools, more extensive research of existing examples should highlight more about the technology. For an accurate LCC, historical data about maintenance and repair costs for both, regular reinforced and prestressed concrete, can support or replace assumptions that were used in this project.
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21. **Jooss, Martin.** *Selbstheilung von Beton unter Temperatureinfluss.* Stuttgart : Cracks in a swimming pool basin can be detected through, in Germany obligatory, water filling of the shell construction. Water leading separation cracks have to be injected., Institut für Werkstoffe im Bauwesen, Universität Stuttgart.


### Appendix

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T1: Leaking dilatation joint

T2: Leakage and cracks at previous repair works

T3: Concrete spalling caused by corroded reinforcement

P1: Repaired pillar

Overview of taken samples for chloride analysis (1)
B1: Heavy corroded and damaged beam

B1: Spalled concrete at a corroded beam

V1: Leakage between beam and wall

V2: Flaking coat

Overview of taken samples for chloride analysis (2)
Static system

Concrete:

Steel:

Assumption

Coverage: investigation \( \sim 30-35 \text{mm} \)

\[
\begin{align*}
\bar{d}_c &= 0.25 \text{m} - 0.04 - 0.015 - 0.06 = 0.189 \text{ m} \\
\bar{d}_{sy} &= 0.25 \text{m} - 0.04 - 0.015 - 0.042 = 0.177 \text{ m}
\end{align*}
\]
Appendix E

- impacts

Slab: \( q_{k} = 0.25 \text{m} \cdot 0.0 \text{m} \cdot 25 \frac{\text{kN}}{\text{m}^3} = 6.25 \frac{\text{kN}}{\text{m}} \)

Installation: \( q_{k} = 0.06 \text{m} \cdot 1 \text{m} \cdot 25 \frac{\text{kN}}{\text{m}^3} = 1.5 \frac{\text{kN}}{\text{m}} \)

---

Hydrostatic pressure

\[ q_1 = 335.64 \frac{\text{kg}}{\text{m}^3} \cdot 3.81 \frac{\text{m}}{\text{s}^2} \cdot 1.1 \text{m} = 10744 \frac{\text{kN}}{\text{m}} \]

\[ q_2 = 335.64 \frac{\text{kg}}{\text{m}^3} \cdot 3.81 \frac{\text{m}}{\text{s}^2} \cdot 1.5 \text{m} = 14651 \frac{\text{kN}}{\text{m}} \]

---

Cutting forces according to RSTAB 5.15 simulation

Ultimate limit state

with \( \sigma_0 = 1.35 \)

\( \sigma_a = 1.5 \)

Field: \( M_{\text{Ed max}} = 58.35 \frac{\text{kNm}}{\text{m}} \)

Pillar: \( V_{\text{Ed max}} = 74.41 \frac{\text{kN}}{\text{m}} \)

\( M_{\text{Ed max}} = -76.87 \frac{\text{kNm}}{\text{m}} \)

Limit state of serviceability

\( \Psi_1 = 0.5 \)

\( \Psi_2 = 0.3 \)

Field: \( M_{\text{Perm}} = M_{\text{Ed max}} + \Psi_1 \cdot M_{\text{Ed max}} \)

\( = 111.27 \frac{\text{kNm}}{\text{m}} \)

\( M_{\text{Freq}} = 13.88 \frac{\text{kNm}}{\text{m}} \)

\( M_{\text{Dare}} = 20.41 \frac{\text{kNm}}{\text{m}} \)

Pillar: \( M_{\text{Perm}} = 26.82 \frac{\text{kNm}}{\text{m}} \)

\( M_{\text{Freq}} = -35.575 \frac{\text{kNm}}{\text{m}} \)

\( M_{\text{Dare}} = -37.44 \frac{\text{kNm}}{\text{m}} \)

\( V_{\text{Ed Perm}} = 27.579 \frac{\text{kN}}{\text{m}} \)

\( V_{\text{Ed Freq}} = 33.845 \frac{\text{kN}}{\text{m}} \)

\( V_{\text{Ed Dare}} = 49.61 \frac{\text{kN}}{\text{m}} \)
hand calculation to check cutting forces from RSTAB

simplified system

\[ q = 1.35 \cdot 7.75 \frac{kN}{m} + 1.8 \cdot 14.65 \frac{kN}{m} = 32,4375 \frac{kN}{m} \]

\[ M_{\text{field}} = 0.079 \cdot 32,4375 \cdot 4.5^2 = 511,29 \frac{kNm}{m} \]

\[ M_{\text{pillar}} = -0.103 \cdot 32,4375 \cdot 4.5^2 = -676,565 \frac{kNm}{m} \]

\[ Q_{\text{max}} = -0.605 \cdot 32,4375 \cdot 4.5 = -228,341 \frac{kN}{m} \]
Analysis for the decisive field (5)

\[ M_{Ed} = 58.95 \, \frac{kNm}{m} \]

\[ \mu_{Ed} = \frac{0.05295 \, \frac{kNm}{m}}{A_0 \cdot (0.18) \cdot A_4 \cdot 1.67 \, \frac{m^3}{c^2}} = 0.1165 \]

\[ \omega = 0.1170 \]

\[ A_s = \frac{M_{Ed}}{f_{Ed} \cdot b \cdot d} = \frac{M_{Ed}}{347.826} \cdot (0.1170 \cdot 1.0 \cdot 0.18 \cdot 1.4 \cdot 1.67) \]

\[ A_{syneq} = 9.01 \, \frac{cm^2}{m} \]

\[ A_{wach} = 13 \, \frac{cm}{m} \implies A_h = 14.69 \, \frac{cm^2}{m} \]

Shearing force at bearing \( F \)

for the evidence it is allowed to use the force at a distance \( d \) from the bearing:

\[ P_{Ed} = P_F + \frac{(P_F - P_E) \cdot (b + d)}{L} = 13.380 + \frac{(13.38 - 13.38) \cdot (0.2 + 0.125)}{4.5} \]

\[ P_{Ed} = 13.32 \, \frac{kNm}{m} \]

\[ V_{Ed} = V_F + \left(d + \frac{b}{2}\right) \left(P_F + \frac{P_{Ed} + P_F}{2}\right) \]

\[ = -74.41 + (0.429 + 0.21) \left(13.380 + 13.32 - 13.38 \right) \]

\[ = -69.22 \, \frac{kN}{m} \]
Appendix E

no shearing reinforcement

\[ V_{Rd,ct} = \left[ \frac{0.45}{\gamma_c} \cdot \eta_n \cdot \beta \cdot (\alpha \cdot f_{ck} \cdot f_{ck})^{0.3} \right] \cdot b \cdot d \]

\[ \gamma_c = 1.5 \]
\[ \eta_n = 1.0 \]
\[ \beta = 1 + \left( \frac{200}{c_d} \right)^{0.5} \leq 2 \]
\[ K = 2 \]

\[ f_{ck} = 25 \frac{MN}{m^2} \]
\[ b = 1m \]
\[ d = 0.189m \]

\[ f = \frac{A_{sc}}{b \cdot d} = \frac{14.69 \cdot 10^{-4}}{1 \cdot 0.189} = 0.077 \leq 0.02 \]

\[ V_{Rd,ct} = 0.101 MN \leq 101 kN > 69.22 = V_{Ed} \]

\[ V_{Rd,ct, min} = \left[ \eta_n \cdot \left( \frac{K_n}{\gamma_c} \right) (K^3 \cdot f_{ck})^{0.5} \right] \cdot b \cdot d \]

\[ K_n = 0.0525 \text{, because of } \]
\[ d = 0.60m \]

\[ = 0.0335 MN < V_{Rd,ct} \]
\[ > V_{Ed} \]

(41)

no shear reinforcement needed
punching shear at pillar F

\[ V_{Ed} \leq V_{rd} \]

\[ V_{Ed} = V_{Ed} \cdot \frac{\beta}{u} \]

\[ u = 4 \cdot 1.5 \cdot 0.189 + 4 \cdot \frac{0.4}{2} = 4.934 \text{ m} \]

\[ V_{Ed} = 74.4 \cdot \frac{4.934}{4.934} = 74.4 \text{ kN} \]

minimum reinforcement

percentage of reinforcement in \( x \) and \( y \) direction

\[ x : \quad f_x = \frac{14.69}{18.5} = 0.78 \% \]

\[ y : \quad f_y = \frac{14.69}{17.7} = 0.83 \% \]

analysis for decisive \( x \)-direction

\[ m_{Edx} = \eta \cdot V_{Ed} = -0.125 \cdot 74.4 \cdot \frac{4.934}{4.934} = 9.30 \text{ kN} \]

\[ \eta = 0.125 \text{ for pillars inside the slab} \]

\[ f_{Eds} = \frac{m_{Edx}}{b \cdot d^2 \cdot f_{cd}} = 0.018 \]

\[ \omega = 0.02 \]

\[ \min a_x = \omega \cdot b \cdot d \cdot \left( \frac{f_{cd}}{f_{cd}} \right) = 0.02 \cdot 1.00 \cdot 0.189 \cdot \frac{14.47^2}{342.826} = 1.54 \text{ cm}^2 \]

existing reinforcement on \( b_x = 0.3 \cdot 4y = 1.014 \text{ m} \)

\[ a_{sc} = \frac{14.69 \text{ cm}^2}{14.69} = 1 \]

punching shear

\[ V_{rdx} = \left[ \frac{0.14}{8.5} \cdot \eta \cdot \kappa \cdot (100 \cdot f_{cd}^2) \right] \cdot d \]

\[ \eta = 1 \]

\[ f_{cd} = \sqrt{0.0078 \cdot 0.0083} = 0.008046 < 0.02 \]

\[ \kappa = 2 \]

\[ V_{rdx} = 0.1433 \text{ MN} \geq 143.9 \text{ kN} > 40.39 \text{ kN} = V_{Ed} \]

\( \Rightarrow \) no punching shear reinforcement needed
Limit state of serviceability

decisive is the reinforcement percentage between axis 23 and 24
with $M/12 = A_\text{s} = 112.43 \text{ cm}^2$.

Analysis of maximum stress

- Concrete compressive stress $\sigma_c \leq 0.45 \ f_{ck}$

$$\sigma_c = \frac{2 \cdot M}{b \cdot x \cdot z}$$

max $H = - 37.44 \frac{kN}{m}$

$$x = \frac{d_\text{e} \cdot A_{sl}}{b} \left( - 1 + \sqrt{1 + \frac{2 \cdot b \cdot d}{d_\text{e} \cdot A_{sl}}} \right)$$

$$x = 9.89 \text{ cm}$$

$$z = d - x = 17.27 \text{ cm}$$

$$\sigma_c = 8.87 \frac{kN}{cm^2} \leq 0.887 \frac{kN}{cm^2} \leq 0.45 \ f_{ck} = 1.125 \frac{kN}{cm^2} \quad \checkmark$$

- Steel tension stress $\sigma_s \leq 0.8 \ f_yk$

$$\sigma_s = \frac{M}{z \cdot A_{sl}}$$

$$\sigma_s = 17.48 \frac{kN}{cm^2} \leq 0.8 \cdot f_yk = 32 \frac{kN}{cm^2} \quad \checkmark$$

Minimum reinforcement to prevent cracks $> W_k$

- hydraulic gradient: $i = \frac{h}{d}$

$$i = \frac{b}{d} = \frac{15}{0.25} = 6$$

Maximum crack width according to:

- GfOdB $i > 5 \rightarrow W_k \leq 0.1 \text{ mm}$
- GAFStB $i < 10 \rightarrow W_k \leq 0.2 \text{ mm}$
- Lohmeyer $S < i < 10 \rightarrow W_k \leq 0.1 \text{ mm}$

15
minimum reinforcement for strain after 28 days due to shrinkage, temperature and so on

\[
\min A_s = k_e \cdot k \cdot f_{\text{c eff}} \cdot \frac{A_{\text{eff}}}{\sigma_s}
\]

\[
\sigma_s = \left( \frac{\sigma_{\text{bs}} - 3.6 \cdot 10^6}{d_s^*} \right)^{0.5}
\]

chosen \( d_s^* = 12 \text{ mm} \)

\[
\sigma_s = 193.705 \frac{N}{mm^2}
\]

\( f_{\text{c eff}} = 3.0 \frac{N}{mm^2} \), assumption if not known when first crack appears

\( k = 0.8 \) inner strain with \( h < 0.3 \text{ m} \)

\( k_e = 1.0 \) safe side

\[
\min A_s = 1.0.8 \cdot 3.0 \cdot \frac{0.25 \text{ m}^2}{193.705} = 34.64 \text{ cm}^2
\]

existing reinforcement \( A_{\text{exist}} = 2 \cdot \frac{12.43 \text{ cm}^2}{m} = 24.86 \text{ cm}^2/m \)

not sufficient

maximum reinforcement diameter

\[
d_{s_{\text{max}}} = d_s^* \cdot \frac{k_e \cdot k \cdot h_t}{4(h - d)} \cdot \frac{f_{\text{c eff}}}{f_{\text{c10}}} \geq d_s^* \cdot \frac{f_{\text{c eff}}}{f_{\text{c10}}}
\]

\[
h_t = 0.5h
\]

\[
d_{s_{\text{max}}} = 5.7 \text{ mm} > 14 \text{ mm} \quad \text{decisive, } d_s^* \text{ with table 5.37a in ISAT-18}
\]

\[
d_{s_{\text{max}}} = 14 \text{ mm} > d_{s_{\text{exist}}} = 12 \text{ mm}
\]

. sufficient
crack width limitation due to loads

bending moments at pillar \( E \) is decisive

minimum reinforcement due to ultimate limit state

\[
\begin{align*}
\text{meds} &= -76.87 \text{ kN/m}^2 \\
\mu_{\text{eds}} &= 0.4519 \\
\omega &= 0.1438 \\
\frac{x}{d} &= 0.021 \\
\frac{z}{d} &= 0.916 \\
& \Rightarrow \ z = 17.342 \text{ cm}
\end{align*}
\]

\[
\min A_s = \frac{1}{\psi_{\text{cd}}} \left( \omega \cdot b \cdot d \cdot f_{\text{cd}} \right) = \frac{12.64 \text{ cm}^2}{\text{m}} < A_{s\text{ex}} = 14.68 \text{ cm}^2
\]

minimum reinforcement due to crack width limitation

\[
\begin{align*}
\text{med}_{\text{cr}} &= -37.44 \text{ kN/m} \\
\psi_s &= \frac{med_{\text{cr}}}{2 \cdot a_{\text{exist}}} = 145.24 \frac{N}{mm^2}
\end{align*}
\]

\[
\min A_s = k_e \cdot k \cdot f_{\text{c}\text{eff}} \cdot \frac{Act}{\psi_s}
\]

\[
\begin{align*}
k_e &= 0.4 \text{ for bending} \\
k &= 0.8 \\
f_{\text{c}\text{eff}} &= 3.0 \text{ MPa} \\
Act &= 1 \text{ m} \left( 0.25 \text{ m} - 0.033 \text{ m} \right) \\
&= 0.218 \text{ m}^2
\end{align*}
\]

\[
\min A_s = 13.9394 \text{ cm}^2 = 0.218 \text{ m}^2
\]

existing \( A_s = 2 \cdot 14.68 \text{ cm}^2 = 29.36 \text{ cm}^2 \)

no additional reinforcement
Appendix E

Minimum reinforcement analysis according to Thomas Schrepler (43)

"Bauwerke aus wasserundurchlässigen Beton" in Bauphysik-Kalender 2008

Analysis of central strain

$$a_{s_n} = a_{s_2} = \frac{-B \cdot C + \sqrt{(B \cdot C)^2 + 8 (A - 2 \cdot d_{s2}/(h \cdot k))}}{2 \cdot d_{s2}}$$

$$B = \frac{2.5 \cdot d_s \cdot d_{s2} \cdot b^2 \cdot k \cdot f_{c,eff} \cdot h}{3.6 \cdot E_s \cdot W_k \cdot 2}$$

$$C = \frac{E_s}{E_{cm}} \cdot \frac{A}{2.5 \cdot b \cdot h \cdot k}$$

$$h = 0.25 \text{ m}$$

$$d_s = d_k = d_{s2} = 5 \text{ cm}$$

$$d_s = 12 \text{ mm}$$

$$f_{c,eff} = 3.0 \text{ MPa}$$

$$k = 0.8$$

$$E_s = 200,000 \text{ N/mm}^2$$

$$E_{cm} = 26,700 \text{ N/mm}^2$$

$$W_k = 0.4 \text{ mm}$$

$$a_{s_n} = a_{s_2} = 16.76 \text{ cm}^2 / \text{m}$$

Minimum existing $$a_{s_n} = a_{s_2} = 12.43 \text{ cm}^2 / \text{m}$$

Not sufficient
Walls as two way slab

Static system

Span width ratio: \( \frac{L_x}{L_y} = \frac{25\,m}{1.8\,m} = 16.67 \rightarrow 2 \rightarrow \theta = \frac{90}{2} \)

SBT 48, 5.49 \( \Rightarrow f_x = f_y \)

\( s_x = s_y \)

\( q_{id} = 14.885 \times 1.5 = 22.3275 \, kN/m \)

Bending moments:

\( m_x = \frac{22.3275 \times (2.5\,m)^2}{2} = 141.3 \, kN \cdot m \)

Minimum moment = crack moment

\( m_{cr} = \frac{6 \cdot 0.5^2}{8} \cdot 27 \times 0.833 = 23.63 \, kN \cdot m \)

Minimum crack moment

<table>
<thead>
<tr>
<th>Table 3a, in SBT 48</th>
<th>5.138</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_d = \frac{18.9,cm}{\sqrt{22.0833/g \cdot m}} )</td>
<td></td>
</tr>
<tr>
<td>( k_d = 3.63 )</td>
<td></td>
</tr>
</tbody>
</table>

\( \Rightarrow k_s = 2.38 \)

\( A_{d_{cr}} = 2.38 \times \frac{27.0833}{18.9} = 3.44 \, cm^2/m \) (without normal tension force)

\( A_d = 2.38 \times \frac{27.0833}{18.9} + \frac{2 \times 14.685 \times 0.85}{63.5} = 4.423 \, cm^2/m \) (with consideration of normal tension force)

\( A_{crit} = \frac{10 \times 12\,mm^2}{14.3 \, cm^2/m} \) sufficient

but, not sufficient for serviceability analysis
wells as one-span-beam

\[ q = 1.5 \times 14.65 \text{ kN/m} = 21.975 \text{ kN/m} \]

\[ M = \frac{21.975}{1.5} (1.5 \text{ m})^2 = 3296 \text{ kNm/m} \]
BBV Litzenspannverfahren $300m^2 - 1m$

Stressing Anchor

$\phi12mm - 12.5cm$
Draft design of post-tensioned swimming pool

Assumptions:
- Slab on sliding foundation with a thin concrete layer $\mu = 0.6$ [ ] (42)
- C25/30 with $E_{cm} = 30,500 \, \text{kN/m}^2$ and $f_{cm} = 2.5 \, \text{Nm}^2$
- Maximum crack width $w_{cr} = 0.4 \, \text{mm}$
- Thickness $h = 30 \, \text{cm}$
- RH = 70%

Steel underground bending moment of slab negligible

Main loads are strain forces → strain over the entire cross section

Central post-tensioning at $h/2$

Strain calculation according to Gunkler and Bechle in:
"Bemessungswerkzeug für zwangsbeanspruchte dünne Schalplatten im Betriebszustand"

(1) Deformation according to load independent impacts

Shrinkage according to figure 20 and 21 in DIN 1045-1

$E_{cas} = -0.07 \%$

$E_{cds}$ with $k_0 = 2 \cdot \frac{A}{d} = 2 \times \frac{0.3 \, \text{m}^2}{1 \, \text{m}}$

$= 600 \, \text{mm}$

$E_{cds} = -0.4 \%$

Total shrinkage $E_{cs} = -0.47 \%$
Appendix G

Temperature expansion

\[ \varepsilon_T = V_T - \alpha T \]

\[ V_T = 30 \text{kN} \quad \text{assumption for maximum temp. difference, e.g. during construction in winter} \]

\[ \alpha T = 1.1 \times 10^{-5} \quad \text{[]} \]

\[ \varepsilon_T = \pm 0.33 \% \]

\[ \varepsilon_{\text{total}} = -0.7 \% \]

2) Vertical loads: dead load, water loads

\[ V = 0.35m \cdot 25 \frac{\text{kN}}{\text{m}^2} + 1.8m \cdot 935 \frac{\text{kN}}{\text{m}^2} \cdot 9.81 \frac{\text{m}^2}{\text{s}^2} \cdot 1000 \frac{\text{N}}{\text{kN}} \]

\[ = 26,334 \frac{\text{kN}}{\text{m}^2} \]

3) Support conditions

Elastic bond between slab and soil

\[ k_{\text{elas}} = \frac{1}{1 + (EA)_{sl} \cdot \frac{A}{(EA)_{soil} + 0.15 \cdot l_{sl} \cdot E_{sl,\text{shear}}} \]

\[ A_{\text{min}} = 0 \quad \text{for slab on sliding soil} \]

\[ E_{\text{shear}} = 450 \frac{\text{MN}}{\text{m}^2} \quad \text{[]} \]

\[ k_{\text{elas}} = 0.03284 \]

decoupling of soil and slab

\[ k_{\mu} = \mu \cdot l_{\mu} \cdot \frac{V}{d_{sl} \cdot E_{sl}} \quad \frac{1}{\varepsilon_{\text{min}}} \leq 1 \]

\[ d_{sl} \cdot h = 0.3 \text{m} \]

\[ l_{\mu} = 0.5 \cdot l_{sl} \quad \text{[]} \]

\[ k_{\mu} = 0.037 \]
distance to deformation origin from which sliding of slab is expected

\[ x_{res} = \frac{\mu \cdot \xi_v \cdot l_{sl}^2}{k_{elast} \cdot 8 \cdot E_{con} \cdot (E1)^2 \cdot \gamma} \]

\[ \gamma = 0.7 \]

\[ (BAF SB: Betonbaukun Umgang mit wasser eingebrachte stah ) \]

\[ l_{sl} = 2.96 \text{ m} < 0.5 \cdot l_{sl} = 1.48 \text{ m} \]

partly decoupled

resulting deformation strain coefficient

\[ k_{res} = \frac{x_{res}}{0.5 \cdot l_{sl}} \cdot k_{elast} + \frac{0.5 \cdot l_{sl} - x_{res}}{0.5 \cdot l_{sl}} \cdot k_{\mu} \]

\[ k_{res} = 0.050247 \]

2. Determine central strain

\[ \varepsilon_{strain} = k_{res} \cdot E_{con} \cdot \varepsilon_{sl} = 1.073 \frac{\text{MN}}{\text{m}^2} \]

5. Crack stress according DIN 2045-1

\[ f_{crack} = k_c \cdot k_i \cdot f_{ctm} = 2.4 \frac{\text{MN}}{\text{m}^2} \]

Post tensioning

straight, central tendons

\[ \lambda_p = 1.0 \]

\[ A_{h2} = 0.30 \text{ m}^2 \]

\[ r_{inf} = 0.9 \]

\[ I_X = 0.00225 \text{ m}^4 \]

\[ r_{sup} = 1.1 \]

\[ z = \frac{h}{2} = 0.15 \text{ m} \]

Maximum concrete pressure \((\text{max } p)\)

\[ f_{con} < f_{ck} \cdot 0.6 = 20 \frac{\text{MN}}{\text{m}^2} \]

\[ P_{\text{max}} = \frac{\sigma_{f0}}{r_{\text{sup}} + r_{\text{inf}} \cdot z \cdot w} = 3.223 \frac{\text{MN}}{\text{m}^2} \]

\[ f_{con} < f_{ck} \cdot 0.4 = 10 \frac{\text{MN}}{\text{m}^2} \]

\[ P_{\text{max}} = \frac{\sigma_{f0}}{r_{\text{inf}} + r_{\text{sup}} \cdot z \cdot w} = 2.62 \frac{\text{MN}}{\text{m}^2} \]
decompression (min P)

\[ \sigma_{\text{min}} = 0 \]
\[ \sigma_{\text{min}} = 2.4 \, \text{MPa} \, \text{m}^{-1} \]

\[ P_{0,\text{min}} = \frac{-\sigma_{\text{crack}}}{A \cdot \frac{\mu + e^{-\frac{x}{k}}}{w}} = 0.2165 \, \text{MPa} \]

\[ P_{\text{min}} = \frac{P_{0,\text{min}}}{A - \alpha} = 270.665 \, \text{kN} \]

\( \alpha \)... losses due to shrinkage, creep, relaxation

assumption \( \alpha = 20\% \)

Chosen post-tensioning system: BBV Systems Litenspanverbinder ohne Verbund

2 tendons with 15.7 mm diameter \( (A_p = 150 \, \text{mm}^2) \) per m

\[ f_{\text{tend}} = 1500 \, \text{N/mm}^2 \]

\[ P_{\text{max}} = 2 \cdot 1483 \, \text{kN} = 3966 \, \text{kN} \]

\[ P_{\text{max}} = 2 \cdot 130 \, \text{kN} = 372 \, \text{kN} \]

\[ A_p = 300 \, \text{mm}^2 \]

\[ \Delta P_{\mu} = P_{\text{edge}} \left( A - e^{-\mu(k \cdot x)} \right) \]

\[ P_{\text{field}} = P_{\text{edge}} - \Delta P_{\mu} \]

\[ P_{\text{edge}} = P_{\text{field}} \cdot e^{\mu(k \cdot \frac{1}{2})} = 304.105 \, \text{kN} \]

losses from friction

\[ \mu \]

\[ k \]

\[ 0.05 \, \text{m} \leq 0.00872 \]

slack = 3 mm
post tension way

\[ \Delta L = \Delta L_p + \Delta L_c \]

\[ \Delta L_p = \frac{A}{E_p \cdot A_p} \int_0^x P(x) \, dx \quad \text{with} \quad P(x) = P_{\text{edge}} \cdot e^{-\mu(k \cdot x)} \]

\[ \Delta L_p = 1.32 \, \text{cm} \]

\[ \Delta L_c = \frac{A}{E_{\text{cm}} \cdot A_{\text{cm}}} \int_0^x P(x) \, dx \]

\[ \Delta L_c = 0.08 \, \text{cm} \]

\[ \Delta L = 1.43 \, \text{cm} \]

slack

steel stress before anchoring

\[ G_p = \frac{P_{\text{edge}}}{300,000 \, \text{mm}^2} = 10 \times 3.483 \, \frac{\text{N}}{\text{mm}^2} \]

developing of steel stress before anchoring

\[ G_p(x) = G_p \cdot e^{-\mu \cdot k \cdot x} = 10 \times 3.483 \cdot e^{-0.0000722 \cdot x} \]

\[ G_p(x = 25 \, \text{cm}) = 9.93 \, \frac{\text{N}}{\text{mm}^2} \]

through slack caused loosening length

\[ L_{SL} = \sqrt{\frac{\Delta L_{SL} \cdot E_p}{G_p \cdot \mu \cdot k}} = 1050,35 \, \text{mm} = 1.05 \, \text{m} \]

\[ G_p(x = L_{SL}) = 10 \times 2.33 \, \frac{\text{N}}{\text{mm}^2} \]

stress at stress in anchor after anchoring

\[ G_p' = G_p(x = L_{SL}) \cdot e^{-0.0000722 \cdot 1.05 \, \text{m}} = 10 \times 2.37 \, \frac{\text{N}}{\text{mm}^2} \quad \Rightarrow \quad P_{ke} = 303.71 \, \text{kN} \]

losses \[ \Delta P = 0.334 \, \text{kN} \]
Appendix G

Shrinkage

\[ E_{cs} = 0.7 \% \]

creep

\[ \phi_{0.6} = 3.0 \]

Figure A9 in DIN 1045-1

with \( t_0 = 7 \) days begin of stress

Concrete stress

\[ \sigma_{c,po} = \frac{P_{	ext{Computed}}}{A_b} = -\frac{N}{\text{mm}^2} \]

relaxation according EC 2 with assumption

\[ G_{po} = 0.85 \cdot \phi_{0.6} \]

\[ G_{po} = \frac{P_{	ext{Computed}}}{A_p} = 1000 \text{ N/mm}^2 \]

\[ \sigma_{po} = 980 \text{ N/mm}^2 \]

relaxation class 2, \( f_{res} = 275 \) and Figure 3.35 in Zilch

"Bemessung in Konstruktionen" 2. Auflage (2009)

\[ \frac{G_{po}}{f_{pk}} = 0.53 \]

\[ \Delta R_{27} = -2.5\% \]

\[ \Delta G_{pr} = -23.75 \text{ N/mm}^2 \]

\[ \Delta \sigma_{c,gr} = \frac{E_{cs} \cdot E_p + \Delta G_{pr} + \alpha_p \cdot \phi_{0.6} \cdot G_{po}}{1 + \alpha_p \cdot \frac{E_p}{A_{hk}} \left( 1 + \frac{A_{hk} \cdot \alpha_p}{E_p} \right)^2} \approx -1088.827 \text{ N/mm}^2 \]

actual losses \( \Rightarrow \alpha_{real} = \left| \frac{\Delta \sigma_{c,gr}}{\sigma_{po}} \right| = 12\% \) assumption with 20% on the safe side

\[ P_{\text{Computed}} = (1 - 0.12) \times 300 \text{ kN} = 264 \text{ kN} \]
decompression

$$G_c = \frac{\sigma_{nf} \cdot (-\sigma_{pf})}{A_{brulko}} + G_{crack} = 1.608 \frac{N}{mm^2} < f_{ctm}$$

concrete remains without cracks

max concrete stress under rare load probability

$$\sigma_c < 0.6 f_{ck} = 15 \frac{N}{mm^2}$$

$$\sigma_c = \frac{\sigma_{up} \cdot (-\sigma_{pf})}{A_{brulko}} = \frac{\sigma_{up} \cdot (-\sigma_{pf})}{A_{brulko}} < -15 \frac{N}{mm^2}$$

max concrete stress to avoid too much creep

$$\sigma_c < 0.45 f_{ck} = 11.25 \frac{N}{mm^2}$$

$$\sigma_c = \frac{\sigma_{up} \cdot (-\sigma_{pf})}{A_{brulko}} = \frac{\sigma_{up} \cdot (-\sigma_{pf})}{A_{brulko}} < -11.25 \frac{N}{mm^2}$$

maximum steel stress

$$\sigma_p_{max} < 0.65 f_{pk} = 1150,5 \frac{N}{mm^2}$$

$$\sigma_p = \frac{\sigma_{pf}}{A_p} = 880 \frac{N}{mm^2} < 1150,5 \frac{N}{mm^2}$$

$$t = 0 \quad after\ presetting$$

$$\sigma_{p_{max}} = min \left\{ 0.9 f_{po,tk}, 0.8 f_{pk} \right\} = 1350 \frac{N}{mm^2}$$

$$\sigma_p = \frac{\sigma_{pf}}{A_p} = 1000 \frac{N}{mm^2} < 1350 \frac{N}{mm^2}$$
Appendix G

Analysis for extra reinforcements in walls

central pre-stress reinforcement

\[ d = 300\text{cm} - 150\text{cm} = 150\text{cm} \]

loads

first calculation showed that minimum moment (crack moment) is much bigger than bending moment from hydrostatic pressure.

\[ m_{\text{crack}} = \frac{b h^2}{6} \cdot f_{\text{cm}} = 27,083.3 \text{ kNm/m} \]

Table 3% in SBT 18 5.118

\[ k_d = 2.38 \quad \Rightarrow k_s = 2.45 \]

\[ A_{\text{demand}} = 2.45 \cdot \frac{27,083.3}{k_s} = 4,423 \text{ cm}^2/\text{m} \]

considering stress from connecting walls

\[ A_{\text{demand}} = 4,423 + \frac{2 \cdot 12.584 \text{ kN/m} \cdot 1.5}{43.5 \text{ kN/cm}^2} = 5.64 \text{ cm}^2/\text{m} \]

\[ A_{\text{exist}} = 2 \cdot 150 \text{ mm}^2 - \frac{2}{4} = 600 \text{ mm}^2/\text{m} = 60 \text{ cm}^2/\text{m} \]

2 tendons every 50cm in the walls

no additional reinforcement.
minimum reinforcement, to avoid cracks in the first 7 days, before post-tensioning

\[ A_{min} = k_c \cdot k \cdot \frac{f_{c,60}}{G} \]

- \( k_c = 1 \)
- \( k = 0.8 \)
- \( G = 170 \text{ MPa} \) (Table 5.97 in 587-18)

\[ \frac{f_{c,60}}{G} \quad \text{and} \quad \frac{f_{c,60}}{G} = 0.5 \quad \Rightarrow \quad f_{c,60} = 0.5 \cdot 0.6 \text{ MPa} = 0.3 \text{ MPa} \]

\[ A_{min} = 17.8 \text{ cm}^2 / \text{m} \]

chosen: top and bottom \( \phi 12 - 12.5 \text{ cm} = 12.1 \text{ cm}^2 / \text{m} \)
Übersicht Kosten

Gesamtkosten

Bauwerkskosten (Kgr. 300 und 400) netto 80.729,84 €
Gesamtkosten (netto) MwSt-frei 0,00 €
Gesamtkosten (netto) 115.171,30 €
Mehrwertsteuer (19,0 %) 21.882,55 €
Gesamtkosten (brutto) 137.053,85 €

Davon Bauwerkskosten (Kgr. 300 und 400) (netto) 80.729,84 €

Kostenkennwert nach BRI 2.800,00 €/m³

Herstellungskosten

<table>
<thead>
<tr>
<th>BRI</th>
<th>BGF</th>
<th>NGF</th>
<th>NF</th>
<th>WF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neubaukosten KGR 100 bis 700 (netto) 41,13 €</td>
<td>57,59 €</td>
<td>82,27 €</td>
<td>82,27 €</td>
<td>115.171,30 €</td>
</tr>
<tr>
<td>Neubaukosten KGR 100 bis 700 (brutto) 48,95 €</td>
<td>68,53 €</td>
<td>97,90 €</td>
<td>97,90 €</td>
<td>137.053,85 €</td>
</tr>
<tr>
<td>Neubaukosten KGR 100 bis 700 mit sonstigen Kosten (netto) 41,13 €</td>
<td>57,59 €</td>
<td>82,27 €</td>
<td>82,27 €</td>
<td>115.171,30 €</td>
</tr>
<tr>
<td>Neubaukosten KGR 100 bis 700 mit sonstigen Kosten (brutto) 48,95 €</td>
<td>68,53 €</td>
<td>97,90 €</td>
<td>97,90 €</td>
<td>137.053,85 €</td>
</tr>
</tbody>
</table>

| Neubaukosten KGR 300 und 400 (netto) 28,83 € | 40,36 € | 57,66 € | 57,66 € | 80.729,84 € |
| Neubaukosten (brutto) 34,31 € | 48,03 € | 68,62 € | 68,62 € | 96.068,51 € |
| Neubaukosten mit sonstigen Kosten (netto) 28,83 € | 40,36 € | 57,66 € | 57,66 € | 80.729,84 € |
| Neubaukosten mit sonstigen Kosten (brutto) 34,31 € | 48,03 € | 68,62 € | 68,62 € | 96.068,51 € |
Baubeschreibung nach Elementen

Bauvorhaben: 3 - Reparation
Bearbeiter: Stephan Kroll

Aufstellung der im Projekt vorhandenen Elemente

<table>
<thead>
<tr>
<th>Nr.</th>
<th>DIN276.08</th>
<th>Langtext</th>
<th>Menge</th>
<th>Einh.</th>
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<tr>
<td></td>
<td></td>
<td>exsisting basin</td>
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<tr>
<td>B32421114</td>
<td>324.2</td>
<td>Bestand, Gründung, Bodenplatte Stahlbeton B25 (C 20/25), d=25 cm</td>
<td>402,000</td>
<td>m²</td>
</tr>
<tr>
<td>B32511113</td>
<td>325.1</td>
<td>Bestand, Gründung, Verbundestrich C 20, d=40 mm</td>
<td>402,000</td>
<td>m²</td>
</tr>
<tr>
<td>B32531112</td>
<td>325.3</td>
<td>Bestand, Gründung, Bodenfliesen, glasiert, 10/10 cm, mit Sockelfliesen auf Abdichtung</td>
<td>402,000</td>
<td>m²</td>
</tr>
<tr>
<td>B33125213</td>
<td>331.2</td>
<td>Bestand, Außenwand aus Stahlbeton B25 (C 20/25), wasserundurchlässig, mit glatter Schalung, d=25 cm</td>
<td>135,960</td>
<td>m²</td>
</tr>
<tr>
<td>B32531112</td>
<td>325.3</td>
<td>Bestand, Gründung, Bodenfliesen, glasiert, 10/10 cm, mit Sockelfliesen auf Abdichtung</td>
<td>135,960</td>
<td>m²</td>
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<tr>
<td>B32422114</td>
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<td>Bestand, Gründung, Bodenplatte Stahlbeton B25 (C 20/25), d=25 cm</td>
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<td>m²</td>
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<tr>
<td>B32511113</td>
<td>325.1</td>
<td>Bestand, Gründung, Verbundestrich C 20, d=40 mm</td>
<td>164,000</td>
<td>m²</td>
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<tr>
<td>B32531252</td>
<td>325.3</td>
<td>Bestand, Gründung, Bodenfliesen, rutschhemmend R 11, 15/15 cm, auf Abdichtung</td>
<td>164,000</td>
<td>m²</td>
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<tr>
<td></td>
<td></td>
<td>repair work 2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>121211111</td>
<td>212</td>
<td>Gebäudeabbruch nach umbautem Raum, komplett, ohne Vorsortieren, jedoch ohne Deponierung von Baurestmassen sowie Entsorgung von Problemmüll</td>
<td>15,000</td>
<td>m³</td>
</tr>
<tr>
<td>139111111</td>
<td>391</td>
<td>Baustelleneinrichtung für ein Einfamilienhaus bzw. Doppelhaushälfte, m² BGF</td>
<td>200,000</td>
<td>m²</td>
</tr>
<tr>
<td>33312S120</td>
<td>394</td>
<td>Instandsetzung von Betonflächen im Ingenieurbau mit 30 % Schadstellen durch Repassivierung, Untergrundvorbereitung, Strahlen der Bewehrung und Auftragen von PCC-Mörtel und Feinspachtelung mit 5 cm</td>
<td>50,000</td>
<td>m²</td>
</tr>
<tr>
<td>Code</td>
<td>Art.</td>
<td>Description</td>
<td>Menge/Betr.</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>33359S120</td>
<td>394</td>
<td>Bewegungsfuge in Außenwand, Fugenbreite 20 mm, mit vorkomprimiertem Fugenband erneuern, entfernen der alten Dichtungsmasse mit Hinterfüllung und vorkomprimiertes Fugenband instand setzen</td>
<td>20,000 m</td>
<td></td>
</tr>
<tr>
<td>135121333</td>
<td>351.2</td>
<td>Decke, Unterzug C 30/37 (B 35), Sichtschalung, 30/50 cm</td>
<td>20,000 m</td>
<td></td>
</tr>
<tr>
<td>132531112</td>
<td>325.3</td>
<td>Gründung, Bodenfliesen, glasiert, 10/10 cm, mit Sockelfliesen</td>
<td>430,080 m²</td>
<td></td>
</tr>
<tr>
<td>132531253</td>
<td>325.3</td>
<td>Gründung, Bodenfliesen, rutschhemmend R 11, 15/15 cm, Epoxidharzverfügung, Kehlsockel</td>
<td>140,000 m²</td>
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</table>

**Sonstige Baumassnahmen**

<table>
<thead>
<tr>
<th>Code</th>
<th>Art.</th>
<th>Description</th>
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<tbody>
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<table>
<thead>
<tr>
<th>Code</th>
<th>Art.</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td></td>
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1,000
## Costs for repair work

<table>
<thead>
<tr>
<th>Name</th>
<th>Material</th>
<th>Abmessungen</th>
<th>Menge</th>
<th>Preisklassen</th>
<th>Faktor</th>
<th>Einzelpreis</th>
<th>KG</th>
<th>Gesamtpreis</th>
<th>Variante</th>
<th>Z</th>
<th>Zeile</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DGR Bodenplatte Stb, D250, d=25 cm</td>
<td></td>
<td>400,000 m³</td>
<td>324</td>
<td>96,251,04€</td>
<td>0,00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DGR Bodenplatte, d=10 cm, Sackflecten, a. Abdeckung</td>
<td></td>
<td>400,000 m³</td>
<td>325</td>
<td>96,251,04€</td>
<td>0,00</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>DGR Zementband CT 36, Naturstein, an Abdeckung, d=45 mm</td>
<td></td>
<td>400,000 m³</td>
<td>325</td>
<td>96,251,04€</td>
<td>0,00</td>
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<td></td>
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<tr>
<td>DBM D25, gelee, glatte Schale, d=25 cm</td>
<td></td>
<td>329,940 m³</td>
<td>331</td>
<td>35</td>
<td>0,00</td>
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<tr>
<td>DGR Bodenplatte, d=10 cm, Sackflecten, a. Abdeckung</td>
<td></td>
<td>135,960 m³</td>
<td>325</td>
<td>96,251,04€</td>
<td>0,00</td>
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</tr>
<tr>
<td>DGR Bodenplatte Stb, D250, d=25 cm</td>
<td></td>
<td>164,000 m³</td>
<td>325</td>
<td>96,251,04€</td>
<td>0,00</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>DGR Bodenplatte, netzschirmend R: 11, 15/25 cm, auf Abdeckung</td>
<td></td>
<td>164,000 m³</td>
<td>325</td>
<td>96,251,04€</td>
<td>0,00</td>
<td></td>
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### Repair work 2012

<table>
<thead>
<tr>
<th>Name</th>
<th>Material</th>
<th>Abmessungen</th>
<th>Menge</th>
<th>Preisklassen</th>
<th>Faktor</th>
<th>Einzelpreis</th>
<th>KG</th>
<th>Gesamtpreis</th>
<th>Variante</th>
<th>Z</th>
<th>Zeile</th>
<th></th>
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<tbody>
<tr>
<td>Abdich. Unterzüge, komplett, ohne Vorsortierung</td>
<td></td>
<td>15,000 m³</td>
<td>14,86</td>
<td>222,95 €</td>
<td>0,00</td>
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<td></td>
<td></td>
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<tr>
<td>Bauwerksausbaustrecke, Riff/Dichter, mit DGR</td>
<td></td>
<td>200,000 m³</td>
<td>35,16</td>
<td>9,032,16 €</td>
<td>0,00</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>AR Stb, Instandsetzung R1, Ingenieurbauwerk, 30 %, Säulen mit AR</td>
<td></td>
<td>50,000 m³</td>
<td>210,39</td>
<td>10,023,48 €</td>
<td>0,00</td>
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<td></td>
</tr>
<tr>
<td>AR Bewegungsfuge, mit vorkonstruierter Band/Fuge 20 mm, instand setzen</td>
<td></td>
<td>20,000 m</td>
<td>59,29</td>
<td>1,186,72 €</td>
<td>0,00</td>
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<tr>
<td>DGR-Unterzug C30/37, Sichteinfassung, 30/10 cm</td>
<td></td>
<td>20,000 m</td>
<td>160,79</td>
<td>3,285,98 €</td>
<td>0,00</td>
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<tr>
<td>DGR Bodenplatte, d=10 cm, Sackflecten, auf Abdeckung</td>
<td></td>
<td>420,000 m³</td>
<td>325,02</td>
<td>55,993,18 €</td>
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<tr>
<td>DGR Bodenplatte, netzschirmend R: 11, 15/25 cm, auf Abdeckung</td>
<td></td>
<td>140,000 m³</td>
<td>157,61</td>
<td>17,651,19 €</td>
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</tbody>
</table>

### Summe Projekt (Netto)

Summe Projekt (Netto) | 84,114,84 €

### Umsatzsteuer 19%

Umsatzsteuer 19% | 15,908,82 €

### Summe Projekt (Brutto)

Summe Projekt (Brutto) | 100,023,66 €

---

## Costs for replacing chloride contaminated concrete

<table>
<thead>
<tr>
<th>Nr</th>
<th>Info</th>
<th>Kurz</th>
<th>KG</th>
<th>PS</th>
<th>Faktor</th>
<th>ME</th>
<th>EP</th>
<th>GP</th>
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<tbody>
<tr>
<td>1013096540</td>
<td>Strahlen, Strahmittel-Wasser-Gemisch</td>
<td>395</td>
<td>1,000 m²</td>
<td>11,60</td>
<td>11,60</td>
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<tr>
<td>1013096565</td>
<td>Betonabrieb/Bewehrung</td>
<td>395</td>
<td>1,000 m²</td>
<td>74,60</td>
<td>74,60</td>
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<tr>
<td>1013096510</td>
<td>Instandsetzungsmörtel PCC, pro cm Mehrl.</td>
<td>395 E</td>
<td>1,000 m²</td>
<td>15,10</td>
<td>15,10</td>
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<tr>
<td>1013096575</td>
<td>Bewehrung strahlen: Sa 2</td>
<td>395</td>
<td>1,000 m²</td>
<td>14,60</td>
<td>4,14</td>
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### Reprofillierung

<table>
<thead>
<tr>
<th>Nr</th>
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<th>KG</th>
<th>PS</th>
<th>Faktor</th>
<th>ME</th>
<th>EP</th>
<th>GP</th>
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<tbody>
<tr>
<td>1013096510</td>
<td>Instandsetzungsmörtel PCC, 5 cm</td>
<td>395</td>
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<td>78,30</td>
<td>78,30</td>
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<tr>
<td>1013096510</td>
<td>Instandsetzungsmörtel PCC, pro cm Mehrl.</td>
<td>395 E</td>
<td>1,000 m²</td>
<td>15,10</td>
<td>15,10</td>
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<tr>
<td>1013096510</td>
<td>Feinspachtelung, 2 mm</td>
<td>395</td>
<td>1,000 m²</td>
<td>12,90</td>
<td>12,90</td>
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### Hefteinsatz

Hefteinsatz | 161,64 €
Übersicht Lebenszykluskosten (LCC)

Betrachtungszeitraum 70

Gesamtkosten nach DIN 18960
Bauwerkskosten (Kgr. 300 und 400) (netto) 80.729,84 €

<table>
<thead>
<tr>
<th>Folgekosten</th>
<th>Netto</th>
<th>% der Herstellungkosten</th>
<th>Brutto</th>
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</thead>
<tbody>
<tr>
<td>Reinigung pro Jahr</td>
<td>3.134,52 €</td>
<td>3,54 %</td>
<td>3.730,08 €</td>
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<tr>
<td>Ver- und Entsorgung pro Jahr</td>
<td>0,00 €</td>
<td>0,00 %</td>
<td>0,00 €</td>
</tr>
<tr>
<td>Wartung pro Jahr</td>
<td>192,70 €</td>
<td>0,22 %</td>
<td>229,31 €</td>
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<tr>
<td>Instandsetzung pro Jahr</td>
<td>2.148,74 €</td>
<td>2,43 %</td>
<td>2.557,00 €</td>
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<tr>
<td>Rückbau (Austausch) pro Jahr</td>
<td>0,00 €</td>
<td>0,00 %</td>
<td>0,00 €</td>
</tr>
</tbody>
</table>

Folgekosten (netto)

<table>
<thead>
<tr>
<th>Folgekosten (netto)</th>
<th>BRI</th>
<th>BGF</th>
<th>NGF</th>
<th>NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinigung pro Jahr (netto)</td>
<td>1,12 €</td>
<td>1,57 €</td>
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<tr>
<td>Ver- und Entsorgung pro Jahr (netto)</td>
<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
</tr>
<tr>
<td>Wartung pro Jahr (netto)</td>
<td>0,07 €</td>
<td>0,10 €</td>
<td>0,14 €</td>
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<td>Instandsetzung pro Jahr (netto)</td>
<td>0,77 €</td>
<td>1,07 €</td>
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<td>1,53 €</td>
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<tr>
<td>Rückbau (Austausch) pro Jahr (netto)</td>
<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
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</table>

Folgekosten (brutto)

<table>
<thead>
<tr>
<th>Folgekosten (brutto)</th>
<th>BRI</th>
<th>BGF</th>
<th>NGF</th>
<th>NF</th>
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</thead>
<tbody>
<tr>
<td>Reinigung pro Jahr (brutto)</td>
<td>1,33 €</td>
<td>1,87 €</td>
<td>2,66 €</td>
<td>2,66 €</td>
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<tr>
<td>Ver- und Entsorgung pro Jahr (brutto)</td>
<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
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<tr>
<td>Wartung pro Jahr (brutto)</td>
<td>0,08 €</td>
<td>0,11 €</td>
<td>0,16 €</td>
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<tr>
<td>Instandsetzung pro Jahr (brutto)</td>
<td>0,91 €</td>
<td>1,28 €</td>
<td>1,83 €</td>
<td>1,83 €</td>
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<tr>
<td>Rückbau (Austausch) pro Jahr (brutto)</td>
<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
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Lebenszykluskosten (Mit sonstigen Kosten) (Netto)

€ 99.000
90.000
81.000
72.000
63.000
54.000
45.000
36.000
27.000
18.000
9.000
0


Netbau
Instandsetzung
Reinigung
Wartung
Rückbau
Betrieb
Jahr
Lebenszykluskosten kumuliert (Mit sonstigen Kosten) (Netto/dynamisch)
Spannbetonbecken

Übersicht Kosten

**Gesamtkosten**
- Bauwerkskosten (Kgr. 300 und 400) netto: 205.165,96 €
- Gesamtkosten (netto) MwSt-frei: 0,00 €
- Gesamtkosten (netto): 207.911,56 €
- Mehrwertsteuer (19,0 %): 39.503,20 €
- Gesamtkosten (brutto): 247.414,76 €

Davon Bauwerkskosten (Kgr. 300 und 400) (netto): 205.165,96 €

Kostenkennwert nach BRI: 2.800,00 €/m³

**Herstellungskosten**

<table>
<thead>
<tr>
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<th>BRI</th>
<th>BGF</th>
<th>NGF</th>
<th>NF</th>
<th>WF</th>
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<tr>
<td>Neubaukosten KGR 100 bis 700 (netto)</td>
<td>74,25 €</td>
<td>103,96 €</td>
<td>148,51 €</td>
<td>148,51 €</td>
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<td>Neubaukosten KGR 100 bis 700 mit sonstigen Kosten (netto)</td>
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<td>103,96 €</td>
<td>148,51 €</td>
<td>148,51 €</td>
<td>207.911,56 €</td>
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<tr>
<td>Neubaukosten KGR 100 bis 700 mit sonstigen Kosten (brutto)</td>
<td>88,36 €</td>
<td>123,71 €</td>
<td>176,72 €</td>
<td>176,72 €</td>
<td>247.414,76 €</td>
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<th>NGF</th>
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<td>Neubaukosten KGR 300 und 400 (netto)</td>
<td>73,27 €</td>
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<td>122,07 €</td>
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<td>174,39 €</td>
<td>244.147,49 €</td>
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<td>102,58 €</td>
<td>146,55 €</td>
<td>146,55 €</td>
<td>205.165,96 €</td>
</tr>
<tr>
<td>Neubaukosten mit sonstigen Kosten (brutto)</td>
<td>87,20 €</td>
<td>122,07 €</td>
<td>174,39 €</td>
<td>174,39 €</td>
<td>244.147,49 €</td>
</tr>
</tbody>
</table>
Spannbetonbecken

Baubeschreibung nach Elementen

Bauvorhaben 1 - Spannbetonbecken

Bearbeiter Stephan Kroll

Aufstellung der im Projekt vorhandenen Elemente

<table>
<thead>
<tr>
<th>Nr.</th>
<th>DIN276.08</th>
<th>Langtext</th>
<th>Menge</th>
<th>Einh.</th>
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<tr>
<td>Baukonstruktion</td>
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<td></td>
<td></td>
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<tr>
<td>Demolish old basin</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>121211111 212</td>
<td>Gemüse in der Baustelle, komplett, ohne Vorsortieren, jedoch ohne Deponierung von Baurestmassen sowie Entsorgung von Problemmüll</td>
<td>220,000  m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>foundation</td>
<td></td>
<td></td>
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<tr>
<td>132425114 324.2</td>
<td>Gründung, Bodenplatte Stahlbeton C 20/25 wu (B 25), inkl. Sauberkeitsschicht, d=30 cm auf Kiesfilter</td>
<td>402,000  m²</td>
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<td></td>
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<tr>
<td>132511111 325.1</td>
<td>Verbundestrich auf Gründungsbodenplatte mit Zementestrich als Nutzestrich CT 20, d=40 mm</td>
<td>402,000  m²</td>
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<tr>
<td>132531132 325.3</td>
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<td>402,000  m²</td>
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<tr>
<td>walls</td>
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<tr>
<td>132531132 325.3</td>
<td>Gründung, Bodenfliesen, glasiert, 10/10 cm, Kehlsockel 10 cm</td>
<td>135,960  m²</td>
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<tr>
<td>133125214 331.2</td>
<td>Außenwand aus Stahlbeton C 20/25 (B 25), wasserundurchlässig, mit glatter Schalung, d=30 cm</td>
<td>135,960  m²</td>
<td></td>
<td></td>
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<td>path</td>
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<tr>
<td>132425114 324.2</td>
<td>Gründung, Bodenplatte Stahlbeton C 20/25 wu (B 25), inkl. Sauberkeitsschicht, d=30 cm auf Kiesfilter</td>
<td>164,000  m²</td>
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<tr>
<td>132511111 325.1</td>
<td>Verbundestrich auf Gründungsbodenplatte mit Zementestrich als Nutzestrich CT 20, d=40 mm</td>
<td>164,000  m²</td>
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<td></td>
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<tr>
<td>132531132 325.3</td>
<td>Gründung, Bodenfliesen, glasiert, 10/10 cm, Kehlsockel 10 cm</td>
<td>164,000  m²</td>
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<tr>
<td>Dach</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sonstige Baumassnahmen</td>
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</tbody>
</table>

Appendix H

40
| 139111111 | 391 | Baustelleneinrichtung für ein Einfamilienhaus bzw. Doppelhaushälfte, m² BGF | 600,000 m² |
## Costs for a new post tensioned swimming pool

<table>
<thead>
<tr>
<th>Name</th>
<th>Menge</th>
<th>Preise</th>
<th>Einheitspreis</th>
<th>Gesamtpreis</th>
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<tr>
<td>Baukonstruktion</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grundmauer</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>GR. Gebaudeebaukomplett, komplett ohne Vorsortierung</td>
<td>220,000 m³</td>
<td>27,48 232</td>
<td>52,749,60</td>
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<tr>
<td>Tagungsbauplanen, C 20/25 wu, d=30 cm</td>
<td>420,000 m³</td>
<td>87,94 304</td>
<td>430,911,56</td>
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<tr>
<td>GR. Verbundstrich CT 20, Nussstrich, d=60 mm</td>
<td>482,000 m³</td>
<td>21,76 325</td>
<td>98,747,90</td>
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<tr>
<td>GR. Bodenfliesen, glasiert, 10/10 cm, hohlsockel 10 cm, auf Abdruckf</td>
<td>482,000 m³</td>
<td>137,39 325</td>
<td>119,226,70</td>
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<td>GR. Bodenfliesen, glasiert, 10/10 cm, hohlsockel 10 cm, auf Abdruckf</td>
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<td>137,39 325</td>
<td>18,676,39</td>
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</tr>
<tr>
<td>GR. Verbundstrich CT 20, Nussstrich, d=60 mm</td>
<td>482,000 m³</td>
<td>21,76 325</td>
<td>108,730,50</td>
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<tr>
<td>GR. Bodenfliesen, glasiert, 10/10 cm, hohlsockel 10 cm, auf Abdruckf</td>
<td>135,960 m³</td>
<td>137,39 325</td>
<td>18,676,39</td>
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<tr>
<td>GR. Verbundstrich CT 20, Nussstrich, d=60 mm</td>
<td>482,000 m³</td>
<td>21,76 325</td>
<td>108,730,50</td>
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</tr>
<tr>
<td>GR. Bodenfliesen, glasiert, 10/10 cm, hohlsockel 10 cm, auf Abdruckf</td>
<td>135,960 m³</td>
<td>137,39 325</td>
<td>18,676,39</td>
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</tr>
<tr>
<td>Dach</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Baustellenversicherung, EUR 1/1/1, m² BGF</td>
<td>680,000 m²</td>
<td>37,95 399</td>
<td>22,770,00</td>
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</table>

### Appendix H

**Summe Projekt (Netto)**
- Kosten: 267,911,56
- Umsatzsteuer 19%
- Summe Projekt (Brutto): 329,583,20
- Summe Projekt (Brutto): 245,444,76

## Costs for a concrete slab

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<thead>
<tr>
<th>Nr.</th>
<th>Info</th>
<th>Kurz</th>
<th>KG</th>
<th>PS</th>
<th>Faktor</th>
<th>ME</th>
<th>EP</th>
<th>GP</th>
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<td>1013</td>
<td>Platte</td>
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<td>0,250</td>
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<td>Dämmung</td>
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<td>0,39</td>
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<td>1013</td>
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<td>1013</td>
<td>Trennlagen, Unterbeton</td>
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<td>1013</td>
<td>Trennlage, PS-Pore 0,2 mm</td>
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<td>1013</td>
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### Übersicht Lebenszykluskosten (LCC)

**Betrachtungszeitraum**

70

**Gesamtkosten nach DIN 18960**

Bauwerkskosten (Kgr. 300 und 400) (netto) 205.165,96 €

<table>
<thead>
<tr>
<th>Folgekosten</th>
<th>Netto</th>
<th>% der Herstellungskosten</th>
<th>Brutto</th>
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<td>1,76 %</td>
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<td>Wartung pro Jahr</td>
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<td>Instandsetzung pro Jahr</td>
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<td>Rückbau (Austausch) pro Jahr</td>
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<td>0,00 %</td>
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**Folgekosten (netto)**

<table>
<thead>
<tr>
<th>Folgekosten</th>
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<th>BGF</th>
<th>NGF</th>
<th>NF</th>
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<td>0,00 €</td>
<td>0,00 €</td>
<td>0,00 €</td>
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**Folgekosten (brutto)**

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<th>NGF</th>
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<td>0,00 €</td>
<td>0,00 €</td>
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Lebenszykluskosten Jahreswerte (Mit sonstigen Kosten) (Netto)

€

220.000
200.000
180.000
160.000
140.000
120.000
100.000
80.000
60.000
40.000
20.000
0

2020  2030  2040  2050  2060  2070  2080

Instandsetzung
Rückbau
Reinigung
Wartung
Betrieb
Jahr

Appendix H
Lebenszykluskosten kumuliert (Mit sonstigen Kosten) (Netto/dynamisch)
PROJEKTVERGLEICH

Spannbetonbecken
Reparation

3% discount rate
<table>
<thead>
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<th>Bezeichnung</th>
<th>Absolut</th>
<th>Absolut</th>
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<td>84.115,00</td>
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<td>Kosten Instandsetzung</td>
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<td>2.309,04</td>
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<td>Kosten Wartung</td>
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<td>Barwert</td>
<td>576.213,00</td>
<td>578.131,00</td>
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PROJEKTVERGLEICH

Spannbetonbecken
Reparation

0% discount rate
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<th>Absolut</th>
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<td>Projekname</td>
<td>Spannbetonbecken</td>
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<td>Kosten Instandsetzung</td>
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<td>Kosten Wartung</td>
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