CENTENNIAL HALL IN WROCŁAW (POLAND) –
UNIQUE, HUNDRED YEARS OLD CONCRETE
STRUCTURE OF MAX BERG

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ABSTRACT

The paper presents results of the research focused on the determination of actual mechanical and physical properties of concrete structure of the dome of the Centennial Hall in Wroclaw. The tests were carried out on the three main elements of the dome: main bottom perimeter ring, top ring of dome and concrete ribs connecting both rings. Research program comprised, among other things, determination of actual compressive strength by means of testing cores and „pull-out” measurements and assessment of „in-situ” tensile strength using „pull-off” method. Concrete absorbability and carbonation depth was determined as well by means of phenolphthalein test and „Rainbow-Test”. In-depth physicochemical studies, containing X-ray radiographic analysis, differential thermal analysis and determination of the oxide composition of concrete, were also performed for determining details of phase composition and microstructure of the concrete after about 100 years of its service. The obtained results document current mechanical and physical properties of examined concrete. Considering the level of concrete technology at the beginning of the XX century and actual age of tested concrete, its current technical condition should be considered as surprisingly good. On the one hand, they are a unique source of information about the quality of concrete from the beginning of the 20th century, while on the other, they allow for evaluation of durability conditions of the material after a century.

Keywords: Centennial Hall in Wroclaw, Dome, Concrete, Compressive strength, Tensile strength, Absorbability, Carbonation depth, Concrete phase composition

1. INTRODUCTION

The Centennial Hall in Wroclaw is considered as one of the most famous milestones of reinforced concrete structures in Europe. This unique concrete structure was build in Wroclaw (in this time known as Breslau) in 1912, by the German construction company „Dyckerhoff & Widmann”. The object was opened to the public in 1913, in the presence of the heir to the imperial throne, Prince Wilhelm, as the main attraction of the Centennial Exhibition which was to celebrate the one hundredth anniversary of victory over Napoleon [1, 2]. On July 13, 2006, the Centennial Hall was entered into the UNESCO World Heritage List as a pioneer achievement of engineering and architecture of the 20th century (Fig. 1 and Fig. 2).

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This an unusual project was proposed by Max Berg (Fig. 3), the German architect, urban planner and constructor (Fig. 3) in collaboration with engineer Günther Trauer, responsible of structural calculations, and professor Heinrich Müller who supervised static calculations [1].

Max Berg was born in 1870 in Szczecin (then known as Stettin). He attended the Technische Hochschule Charlottenburg in Berlin. After graduation He worked In Szczecin and after that he moved to Frankfurt am Main to become the building inspector. Berg stayed there until 1909. In December 1909 he was elected to the twelve year term of office of chief architect of Wroclaw. During this time he designed several innovative reinforced concrete structures. Among other things, it is worth of mention hydroelectric power station, water tower for Wroclaw’s northern districts, public baths and finally his biggest engineering achievement – Centennial Hall. This very original concrete structure is 42 m high, out of which substructure measures 19 m, and the proper dome measures 23 m. The dome diameter equals 65 m. The whole structure consists of two basic parts (Fig. 4).

The basis comprises a set of four main supports creating four arcades of apses with the span of 41 m and the height of 16.7 m. The main part of the structure is the dome consisting of 32 reinforced concrete ribs supported in the bottom by a main perimeter ring measuring 65 m in diameter, and at the top bound in a compressed concrete ring measuring 14.4 m in diameter. The basic element of the main ring compensating tension from the dome ribs, are two steel trusses (Fig. 5) located horizontally one over the other and concreted.

The concrete perimeter ring created in this way and supporting the dome of the Centennial Hall lies on steel movable bearings (Fig. 6) which provide a natural expansion joint separating the dome from the substructure [1, 2].
2. TESTING PROGRAM

On-side tests were carried out on the three main elements of the dome of the Centennial Hall in Wroclaw: main bottom perimeter ring, top ring of dome and concrete ribs connecting both rings. For proper evaluation of the actual technical condition of examined concrete comprehensive testing program has been proposed. Following tests were carried out:

- determination of actual compressive strength by means of testing cores and „pull-out” measurements (Fig. 7),
- assessment of „in-situ” tensile strength using „pull-off” measurements (Fig. 8),
- determination of concrete absorbability,
- measurements of carbonation depth, which was performed as well by means of phenolphthalein test and „Rainbow-Test” (Fig. 10),
- determination of the phase composition, mix design and microstructure of the concrete were performed using X-ray radiographic analysis, differential thermal analysis and determination of the oxide composition of concrete.

Cores with the diameter approaching 100 mm were cut out from the concrete elements and used for determination of concrete compressive strength, concrete absorbability and also for further in-depth physicochemical studies. Strength tests were conducted according to [3, 4] in the Accredited Laboratory of the Building Institute of the Wroclaw University of Technology. Simultaneously the „pull-out” technique was applied for determining on site compressive strength of existing concrete structures. The principle behind this test method is that the force required to pull special steel ring out of concrete can be correlated with the concrete’s compressive strength (Fig. 9). Such split ring is inserted and expanded in the recess (slot) made in the hole previously cored perpendicularly to the concrete surface. This recess is routed inside the hole to a diameter 25 mm and at a depth of 25 mm. Finally, the ring is pulled against a counter pressure 55 mm in diameter. A load is applied through a manually operated hydraulic pull-machine (Fig. 7).
The tensile strength measurements were carried according to [5] using metal discs with diameter of 50 mm. The „pull-off” force was recorded and correlated to tensile/adhesion strength by dividing the value of measured force by the cross-sectional area of the disk. According to standard recommendation, it has been assumed that in the case of applying modern surface repairs like PCC renovation materials, the tensile strength of concrete should be at least 1.5 MPa. Absorbability of examined concrete was determined in accordance with the procedures formulated in [6].

![Graph showing compressive strength vs pullout load](image)

**Fig. 9** „Pull-out” measurements – general correlations

The range of carbonation process in the concrete cover layer was evaluated using the phenolphthalein test and the „Rainbow-Test” (Fig.10). In both cases the tests were conducted on the surface of concrete, directly after it had been fractured. Though the phenolphthalein test is commonly known, the idea of measuring carbonation depth using the „Rainbow-Test” requires some comments. This test involves spraying the examined concrete surface with an aerosol solution of a specially selected composition of chemical reagents, identifying particular values of pH coefficient within the range from 5 to 13.

![Image of rainbow test reagents](image)

**Fig. 10** Carbonation depth measurements (Rainbow-Test)

High value of pH coefficient, more than about 11 (violet or dark blue colour), results in a passive film protecting steel from rapid corrosion. When pH drops below this value, in particular if is lower than about 9.5 (green colour), passive iron-oxide film breaks down and as a result rapid corrosion occurs in the presence of moisture and oxygen.
3. TEST RESULTS

3.1. Bottom perimeter ring
The tests carried out on the concrete from which the bottom ring of the dome of the Centennial Hall was made, indicated that its current technical condition, despite the passing of almost 100 years, should be regarded as very good. Visual inspection of the obtained cores and relevant structural tests showed that the examined concrete was made using crushed granite aggregate with addition of some natural quartz aggregate (Fig.11). Average weight by volume for this concrete equals 2236 kg/m³.

![Fig. 11 View of the concrete macro structure (granite aggregate content is dominant)](image1)

The evaluation of the aggregate composition revealed that tested aggregate falls into the area of the grain size distribution recommended for aggregate with a grading below 32 mm. The mineralogical composition of the concrete was evaluated using the results of the X-ray diffraction analysis, the thermal analysis and the oxide composition. This investigation showed that the binder composition in the tested concrete significantly differs (lower CaO content, higher SiO₂, Al₂O₃, Fe₂O₃ content) from the oxide composition of Portland cement and is similar to that of Roman cement or blast-furnace cement. More details concerning this research can be found in [7].

Further investigation demonstrated that the hardened cement paste in the tested concrete shows excellent adhesion to the crushed-granite aggregate. It has a compact, dense structure characterized by very low water absorption.

![Fig. 12 Core O-11 – no carbonation (pH ≥ 13)](image2)
This observation has been proved by the results of absorbability measurements which reveal values between 3.9% and 4.8% with the variation coefficient equal to 8% which confirms high structural homogeneity of this concrete.

The test carried out showed also that carbonation of the concrete cover layer is quite significant and in general is not smaller than 35 mm, although in several cases actual carbonation depth has been found considerable larger, reaching even 100 mm. At the same time, it should be emphasized that in some cases it was found that process of carbonation did not undergo at all (Fig. 12), what is quite unexpected considering age of tested concrete.

Results obtained from the compressive strength tests indicate that there exist significant differences in the strength parameters of the examined concrete in its outer layer (about 10 cm) in comparison with the layers located deeper (from 10 to 30 cm). It was also found out that compressive strength reaches highest values close to the surface layer and successively decreases for layers located deeper. The above observation refers both to the tests conducted following the direction of concreting, and those perpendicular to it. It is interesting to notice that obtained results did not show significant differences in values of concrete strength achieved during tests carried out in the direction following the direction of concreting, in relation to the tests conducted in the direction perpendicular to the direction of concreting. A detailed description of the tests and their results can be found in [8]. Considering all the obtained results and taking into account the variability of the strength parameters of concrete, it should be assumed that the concrete from which the examined perimeter ring had been made fulfills the requirements for strength class C20/25 according to relevant European standard [4]. High quality of the tested concrete was confirmed by the tensile strength tests results, which indicated its average value at the level of approximately 3.6 MPa.

3.2. Top ring of the dome

In order to obtain information about the strength parameters of the concrete from which the top ring of the dome had been made, 6 cores with the diameter approaching 100 mm were cut out from the existing structure. Laboratory samples measuring \( h \approx \varphi \approx 100 \text{ mm} \), cut out from the obtained cores, were subjected to compressive tests which have been performed at Accredited Laboratory of the Building Institute of the Wroclaw University of Technology.

Before the mechanical tests were carried out, macro structure of concrete has been evaluated. Among other things, it was revealed that concrete used for making top ring was made on the base of crushed basalt aggregate with addition of some natural quartz aggregate (Fig.13). It has been also found that aggregate composition is characterized by good grading and that average concrete weight by volume equals 2339 kg/m³.

The obtained results of absorbability measurements showed the values between 4.2% and 5.4%, with the coefficient of variation equaling 9%.

![Fig. 13 Concrete macro structure (basalt aggregate content is dominant)](image)
### Table 1 Results of concrete compressive strength obtained for top ring of the dome

<table>
<thead>
<tr>
<th>Specimen identification</th>
<th>Cross section [mm²]</th>
<th>Force [kN]</th>
<th>Weight by volume [kg/m³]</th>
<th>Compressive strength [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>specimen O-1/2</td>
<td>7003</td>
<td>170</td>
<td>2313</td>
<td>24.3</td>
</tr>
<tr>
<td>specimen O-2/1</td>
<td>7028</td>
<td>244</td>
<td>2383</td>
<td>34.7</td>
</tr>
<tr>
<td>specimen O-4/1</td>
<td>7018</td>
<td>152</td>
<td>2346</td>
<td>21.7</td>
</tr>
<tr>
<td>specimen O-7/1</td>
<td>7020</td>
<td>202</td>
<td>2345</td>
<td>28.8</td>
</tr>
<tr>
<td>specimen O-8/1</td>
<td>7006</td>
<td>202</td>
<td>2346</td>
<td>28.8</td>
</tr>
<tr>
<td>specimen O-10/1</td>
<td>7013</td>
<td>195</td>
<td>2302</td>
<td>27.8</td>
</tr>
</tbody>
</table>

Results obtained from the compressive strength tests are shown in Table 1. According to conducted analysis of presented test results it has been found that average value of cube compressive strength determined by testing of cores is equal to 27.7 MPa, with the coefficient of variation be equal to 16.1%. It can be also assumed that the concrete from which the examined top ring had been made fulfils the requirements for strength class C20/25 according to the relevant European standard [4]. Such result is similar to the concrete compressive strength class obtained for bottom perimeter ring. Good quality of the tested concrete was also confirmed by obtained tensile strength tests results, which revealed its average value at the level of approximately 2.9 MPa. The details of these measurements are presented in Table 2.

### Table 2 Results of „pull-off” measurements obtained for top ring of the dome

<table>
<thead>
<tr>
<th>Direct reading of „pull-off” force [kN]</th>
<th>Tensile strength [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>measurement point B-1</td>
<td>6.40</td>
</tr>
<tr>
<td>measurement point B-2</td>
<td>5.50</td>
</tr>
<tr>
<td>measurement point B-3</td>
<td>5.20</td>
</tr>
<tr>
<td>measurement point B-4</td>
<td>6.10</td>
</tr>
<tr>
<td>measurement point B-5</td>
<td>5.30</td>
</tr>
</tbody>
</table>

Complementary measurements of carbonation indicated that values of its depth, obtained for different specimens, are in general comparable and in average equal to around 35 mm (Fig. 14, 15).

![Fig. 14 Core O-8 – carbonation depth app. 39 mm](image1.png)

![Fig. 15 Core O-4 – carbonation depth app. 42 mm](image2.png)

### 3.3 Concrete ribs of the dome

In the case of concrete ribs of the dome „pull-out” technique has been applied for determination mechanical properties of examined concrete. Obtained results showed that average value of cube
Compressive strength determined by means of „pull-out” measurements is equal to 29.4 MPa, with the coefficient of variation be equal to 17.4% (details are shown in Table 3). According to European standard [4] it can be accepted that examined concrete fulfils the requirements for strength class C16/20. Additional research revealed that concrete ribs were made using concrete with the dominant content of granite crushed aggregate. This concrete average weight by volume equals 2250 kg/m³. Its average tensile strength, determined by means of „pull-off” tests, is equal to about 2.8 MPa.

**Table 3** Results of „pull-out” measurements obtained for concrete ribs of the dome

<table>
<thead>
<tr>
<th>Testing point</th>
<th>Direct reading of „pull-out” force [kN]</th>
<th>Actual „pull-out” force [kN]</th>
<th>Compressive strength [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1</td>
<td>28.0</td>
<td>27.8</td>
<td>36.3</td>
</tr>
<tr>
<td>C-2</td>
<td>26.3</td>
<td>26.1</td>
<td>33.9</td>
</tr>
<tr>
<td>C-3</td>
<td>27.4</td>
<td>27.2</td>
<td>35.5</td>
</tr>
<tr>
<td>C-4</td>
<td>20.8</td>
<td>20.6</td>
<td>26.2</td>
</tr>
<tr>
<td>C-5</td>
<td>21.9</td>
<td>21.7</td>
<td>27.7</td>
</tr>
<tr>
<td>C-6</td>
<td>19.7</td>
<td>19.5</td>
<td>24.7</td>
</tr>
<tr>
<td>C-7</td>
<td>21.4</td>
<td>21.2</td>
<td>27.1</td>
</tr>
<tr>
<td>C-8</td>
<td>18.8</td>
<td>18.6</td>
<td>23.4</td>
</tr>
</tbody>
</table>

Complementary measurements which have been carried out showed that depth of carbonation is in average equal to about 26 mm (Fig. 16) and that the concrete absorbability is varying between 4.9% and 5.1%.

![An example of „pull-out” fracture zone – carbonation depth around 26 mm (granite aggregate content is dominant)](image)

**Fig. 16** An example of „pull-out” fracture zone – carbonation depth around 26 mm (granite aggregate content is dominant)

### 4. CONCLUSIONS

The presented results document current mechanical and physical properties of concrete in main structural elements of the dome of the Centennial Hall in Wroclaw, after almost one hundred years have passed. On the one hand, they are unique source of information about the quality of concrete from the beginning of the 20th century while on the other, they allow for evaluation of durability conditions of the material after a century. This research have capital significance both from historic and conservation perspective because represents a first such comprehensive study focused on the evaluation of concrete quality applied in dome of the Centennial Hall in Wroclaw.
The obtained results revealed that the current technical condition of examined concrete, after about 100 years of its service, should be regarded as a very good. Its strength parameters meet the current European standard requirements for strength class C20/25 (bottom and top concrete rings) and C16/20 for concrete ribs connecting both rings. Considering the level of concrete technology at the beginning of the previous century it should be recognized as a surprisingly good result. High quality of the tested concrete was confirmed by the results of the concrete tensile strength tests, which indicated its average value at the level between 2.9 MPa (top ring) and 3.6 MPa (bottom ring).

Results of concrete absorbability measurements show the values between 3.9% and 5.4%, with the coefficient of variation equaling 8-9%, which proves significant density and structural homogeneity of the examined concrete. Further in-depth physicochemical studies confirmed that the hardened cement paste in the tested concrete shows excellent adhesion to the both granite and basalt crushed aggregate. Carbonation depth was determined as well. The test results showed that carbonation of the concrete cover layer is quite significant and in general is not smaller than 35 mm (bottom and top concrete rings) and not less than 26 mm in the case of concrete ribs. Nevertheless, in several cases actual carbonation depth has been found considerably larger, reaching even 100 mm. At the same time, it should be emphasized that in some cases it was found that process of carbonation did not undergo at all, what is quite unexpected considering age of tested concrete.

The work on full material identification of the concrete from the dome of the Centennial Hall in Wroclaw is still in progress and further research aimed at interrelating the material properties with the mechanics (static behaviour) of the Centennial Hall structure, taking into account the arrangement of reinforcing rods in the dome’s rings and ribs, is underway. It may lead to interesting conclusions concerning the durability of this unique structure and form the basis for comparative studies.

REFERENCES