1 Sampling and characterization of the Centennial Hall

1.1 Information on the monument

General Information about the building

The structure of the object comprises a central dome, measuring 42 m in height with an internal span of 65 m. Four semi-circular apses adjoin the dome on its main axes. The maximum width of the space free of structural elements is 95 m along the main axes of the building. The surface area of this space is 5.500 m^2. The central part of the Hall is surrounded by single-storey side lobbies, comprising rooms which can be used as additional exhibition spaces. The entrances to the building are located along the main axes of the structure. The west entrance faces the centre of Wroclaw and was built as the main entrance. A reception hall with the access to the Emperor's Stand, is located over the entrance space. The Hall was designed to provide seating space for nearly 6.000 people or standing space for 10.000. The dome had a form which was very different from the generally accepted standards of the time. The surface surrounding the interior of the Hall is not spherical in shape but consists of descending horizontal circular terraces and vertical cylindrical window walls.

Bottom view of the ribbed dome

As the vertical window surfaces are not strongly affected by external weather conditions, they admit a great deal of natural light. The same feature was used in the apses. Only the groundfloor side lobbies make use of skylights, which were shaped in forms popular at the time.

The Centennial Hall comprises four main structural components:

1) **Lantern**, which crowns the ribbed dome. The lantern is supported by a keystone compression ring, which braces the 32 main arches of the dome at a height of approximately 36 m. The structure of the lantern consists of four rigid frames, which cross in the keystone block. The frames are firmly mounted in the compression ring, which has an internal diameter of 14.4 m and a cross-section of 150 cm (width) and 110 cm (height).
2) **Ribbed dome** consisting of 32 arches, inserted into the keystone ring at the top and anchored in the tension ring at the bottom. The main arches are divided into four segments with circumferential transoms along their length between the tension ring and the compression ring. The transoms stiffen the ribs of the dome and prevent them from torsion or buckling out of plane. They serve at the same time as supports for window walls and supports for ring ribs of the flat roofs. Terraced-glazed facade walls were placed on each of the transom rings.
3) **Cylinder,** which forms the base for the dome. It is 19 m high, with an internal diameter of 65 m, and walls varying in thickness (stiffness). Four arcades of apses were cut into the cylinder symmetrically on its axes. Each arcade is 16.7 m high with a span of 41 m. Each apse consists of six supporting arches, which carry two window walls and two terraced flat roofs.
4) **Side lobbies,** which constitute the external part of the groundfloor, which surround the arcades and the cylinder.

General internal view of the structure

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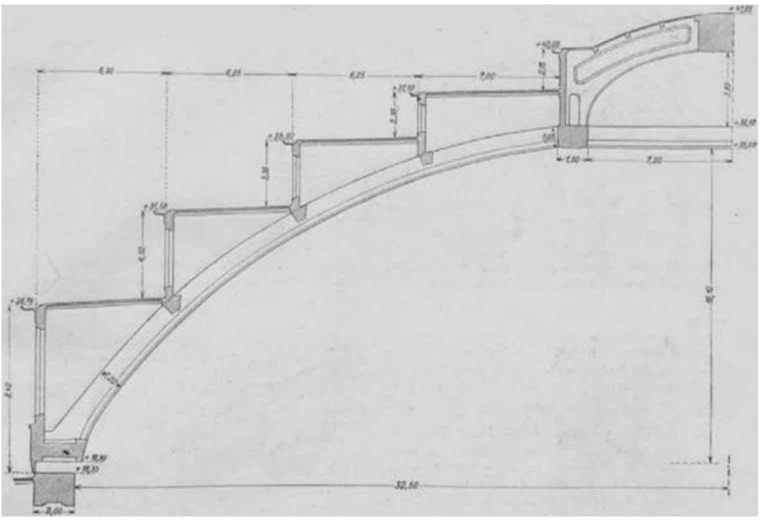
The load bearing structure of the dome consists of 32 ribs, which are braced at the top with a compression ring with an internal diameter of 14.4 m and supported at the bottom with a tension ring. The compression ring carries the load of the 5.75 m high lantern, which consists of four crossing trusses. The dome rests on a base by means of 32 bearings with tangent balancing mechanisms, which move in the radial direction and is not influenced by horizontal forces, which would have occurred as a consequence of disassembly of scaffolding and as a result of changes in the thermal load, if the dome had been permanently fixed to its base. The radial arrangement of rollers allows for the wind load to be transferred to the base in a tangential direction, in which the load-carrying capacity for horizontal forces of the dome is the highest.



Cross – section of the dome structure

From the static behaviour point of view, the structure of the base is very complex and is susceptible to unanticipated loading. For this reason, a number of elements additional to the bearings were introduced to support the overall stiffness of the structure.

Historical building documentation was modified, amended and updated also during the construction of the Hall. This observation concerns mainly the structure of the terraced roofs and facade walls, where significant discrepancies have been identified. They relate mainly to the arrangement of reinforcement, the length of lap joints and anchorage of reinforcing bars, and also to the density, homogeneity and structure of concrete. Archive information that the structural ceiling slabs and structural elements of the facade walls were prefabricated were not confirmed. The assumption is that only window posts and some of the lintels with small cross-sections were prefabricated. The remaining structures were made on-site and built using formwork. The principles of arranging reinforcement to assure homogeneity regimes and concrete density were not observed.

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The steel reinforcement is arranged at random and the quality of concrete (even within a single element) is highly variable.

Information about the materials used for the construction of the monument

The concrete of the foundations consists of 1 part cement to 7 parts gravel in the lower parts of the foundations, and 1 part cement to 5½ parts gravel in the upper parts. The proportion used for the sections with anchored steel rods is 1:4. The pillars were built with crushed stone concrete consisting of 1 part cement to 6 parts sand-gravel to 8 parts fine granite aggregate. Concrete was compacted with compressed air in all foundations and low-reinforced pillars with large sections. The proportion of the concrete mix used for setting steel elements on the surface of the arches was as follows: 1 part cement, 3 parts sand-gravel and 3 parts fine granite aggregate, whereas for the internal concrete core without steel fill, the loads carried were as follows: the proportion of 1:6:8 in the lower part, 1:5:6½ in the middle part and 1:4:5½ in the upper part. In the part at the very top of the dome measuring 1 m in length, the proportion was 1:2½:2½ and in the adjoining sections measuring 2.5 m the proportion was 1:3:3.

In the case of straining arches, it was necessary to use a concrete mixture with proportions of 1:3:3 with an increased moisture content, as application of concrete was possible only from the top as the sides were covered with formwork. The concrete used in formation of the load-bearing structure of the dome was relatively dry in order to ensure appropriate density of these elements, which undergo compression, and to prevent accidental ‘flowing down’ of concrete mixture, which could be the case if the concrete had been more liquid.

The technical parameters of the concrete produced for the construction of the Hall were not good. This resulted in numerous defects in the reinforced concrete elements, which have had to withstand the destructive impacts of unfavourable weather conditions. The concrete used for the construction of the Hall could be classified as C8/10 to C12/15 and of lower class in various places. According to contemporary sources the class of the structural concrete can in places be much higher and reach values equivalent to the C30/37 class.

Analysis of the concrete in the bottom tension ring of the Centennial Hall’s dome carried out to date confirms high concrete quality. The hardened cement paste in the tested concrete demonstrates excellent adhesion to crushed granite aggregate. It is characterised by a dense structure, with low absorbability. Low infiltration of the cement paste obstructs carbonation and diffusion of chlorides, providing a protective barrier for the steel reinforcement of the concrete.

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The reinforcement ratio in the section of elements at the top of the dome is 0.32% with the surface area of reinforcement measures 3.0 cm^2, whereas at the abutments, the reinforcement ratio in the section of elements is only 0.06% with the surface area of reinforcement equal to 21.0 cm^2. The small percentage of the steel reinforcement applied indicates that in the case of such structural elements, reinforced concrete is a suitable building material, and more cost-effective than steel structures. Several lateral bars were added in the planes of arches because of low value torsional stress. As the large sections did not require the use of common stirrups, the steel bars were anchored on the internal arch faces with 50 cm long 'S' shaped stirrups, which served to prevent delamination of the concrete layer from the steel reinforcement.

Construction period

It was probably as early as 1910 that Max Berg started to design the future Exhibition hall, in response on the ongoing discussion in the local press and Municipality. The earliest drawings of the hall date back to February and November 1910. Preparatory work began in early May 1911 while ground examination began on July 19, 1911. Earthwork started on August 31st with the laying out of the building's principal axes. In April 1912 work began on the scaffolding and formwork for the four monumental arcades, each spanning 40 metres and the four principal pillars. The concreting of the dome was completed by September 1, 1912 and celebrated in traditional fashion that involved putting up a decoration of branches, grass and flowers. By December 1912 the reinforced – concrete shell was finished and subsequently formally presented to the Municipal authorities by Dyckerhoff & Widmann construction company.

It is important to bear in mind that the Hall is one of the first buildings built at such a scale in Europe. It was designed and built in the years 1910 – 1912, when the theory of reinforced concrete construction was still being developed and a significant part of the design and planning decisions were made on the basis of the designers' intuition. Despite the fact that, at the time, calculation methods regarding the statics of the building based on advanced mechanics of the building were available, the designers used simplified models for calculations, which often generated results at odds with the actual situation. Graphic methods were an important element in reviewing and revising the static calculations. Such methods were also used by the designers of the Centennial Hall. It is important to remember that at the time, there were no analytical procedures for assessing the support (shearing) zone with stirrups. Designers were not familiar with the principles of reinforcing beams for torsion. They also neglected the role of stirrups in designing building structures. As a consequence, assessment of the structure of the Centennial Hall should take into consideration all the circumstances discussed above. The relatively small number of anomalies and defects in the

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building structure attests to the skill and intuition of the professionals who designed and built the Hall. Some insignificant mistakes which were made during the construction of the Hall and some design shortcomings were observed shortly after the completion of the building. In some places dilatations were planned to be introduced to counteract cracks, which appeared on the external walls.

Main degradation problems

The structure of the Hall comprises more than two thousand reinforced concrete elements, which were intended to perform a number of static, structural and functional tasks. It is only natural that the structural elements of the Centennial Hall, which were built over a hundred years ago when reinforced concrete construction was still being developed, display a number of defects, anomalies, irregularities and damage resulting from building use. The present condition of the building has also been influenced by the lack of sufficient renovation work following World War Two. Several thousand cubic meters of reinforced concrete structures were fabricated during less then eleven months. The damage to the Hall's elements is widespread and highly varied.

It is important to consider also the level of concrete technology, which was much less developed at the time. The contractor building the Centennial Hall took measures to meet the technical parameters of concrete required by the designer by using basalt crushed-stone aggregate, but did not prevent the creation of localised discontinuities and cavities in concrete connections. The importance of concrete homogeneity was also not recognised (i.e. even aggregate content, especially with respect to coarse grain), nor the importance of assuring appropriate concrete density.

Contemporary knowledge on the subject indicates that weak concrete undergoes the process of carbonisation faster and so, provides poor protection for the steel reinforcement from external factors, thus facilitating corrosion of steel elements. This is why an appropriate thickness of the concrete casing and its integrity are highly significant.

The following features of the reinforced concrete structures analysed promote damage to the concrete casing and steel corrosion and result from low quality construction work:

- Excessive porosity of concrete, including the presence of numerous pores visible to the naked eye as well as cavities. This kind of concrete structure allows penetration of gases and liquids, including aggressive substances. Concrete with high absorbability is not resistant to freezing.

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- Varying thickness of the concrete casing covering the reinforcement (the casing thickness ranged from 0.5 cm to 4 cm), found to be insufficient in many places.

Cracks and fissures visible on the surface of the concrete can be attributed to a variety of causes:

- Cracks and fissures appearing along reinforcing bars resulting from reinforcement corrosion processes,
- Cracks and fissures in external walls, as well as in some lintels and cornice beams, which run almost vertically, as well as cracks appearing around window and door openings, are usually caused by the process of concrete contraction. They indicate insufficient care during the early stages of concrete curing and should be regarded as a deficiency on the part of the building contractor. This type of damage can be also influenced by changes in the external temperature, especially in places where there are large distances between dilatations or there is poor reinforcement of the walls. The archived static calculation documentation indicates that the Hall designers did not take into account thermal impact on the internal forces in the structural elements. Vertical cracks, as well as cracks running in different directions can be found on the Hall's facade walls where edges of the structural elements meet the monolithic walls of lower stiffness, which were built at the same time with poor reinforcement or without reinforcement altogether. This design defect is caused by differences in deformation of elements which carry heavy loads and elements which carry only their dead load, where there is no reinforcement joining them together,
- Some of the cracks (fissures) which can be found on the groundfloor walls in the northern part of the building may indicate localised of uneven settlement of soil substrate and foundations. There are cellars under the northern apse and side lobbies of the Hall. This would suggest a deficiency in design (assessment of the soil substrate), as well as in construction work (analysis of soil substrate conditions). The nature of these deficiencies indicates that they originated a long time ago – most definitely prior to the flood of 1997.

The façade elements include relatively numerous spots which indicate that the breaks in the laying of the concrete were incorrectly executed – leading to cracks and fissures in these spots, separation of concrete, extensive concrete surface discontinuities and even cavities. Some of the dilatations planned by the designers were carelessly implemented and their edges have sustained damage over time.

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Cracks and fissures where prefabricated facade elements (lintels, pillars) and monolithic elements (walls under window sills, cornice beams) meet are a consequence of the way the prefabricated elements were installed (rigid or flexible joints were not used at the time).

Infiltration spots of calcium hydroxide (from concrete corrosion from leaching) can be found in many places on the cornice beams. They appear much more frequently on the ceilings of terrace flat roofs above the level of the groundfloor. The calcium hydroxide leached from reinforced concrete flat roof slabs has migrated through cork tiles and the cement-bonded woodchip tiles. This is visible on the lower surfaces of tiles, suspended from the flat roofs.

The causes of this deficiency include leaks in the roof covering and the faulty operation of precipitation drainage systems prior to renovation and repair. They are the result of incorrect maintenance and functioning of building in past years.

The Centennial Hall is after external restoration process, but still we could find a places inside were deterioration of reinforced concrete is visible.

Environmental conditions that can affect the conservation status

A significant cause of corrosion damage of the reinforced concrete facade elements arises during the ongoing functioning of the building, where the building's facade is subjected to external impacts, such as precipitation, aggressive gases and liquids, as well as freezing. The low quality of concrete magnifies these impacts by allowing penetration into the interior of the element sections. The impact of so called acid rain has caused damage to the surface of the Hall's façade by turning it into a powdered form.

Localised damage in the connection areas of elements, which are made of different materials or separated from each other with dilatations, has been caused by thermal factors, which can seldom be prevented. Such damage can generate cracking in the adjoining elements, e.g. structural ceiling slabs or walls. Appearance and development of such damage may have also resulted from vibrations caused by the operation of various machines or equipment, such as ventilation fans. Mistakes in design, construction and building use are the most frequent causes of damage to the concrete casing, the corrosion of steel reinforcement and localised damage to areas of unreinforced concrete.

It was concluded, however, that the causes listed above cannot be blamed on the structural designers of the Hall, as they reflected the state of knowledge of concrete and reinforced concrete construction which prevailed at the time. This refers in particular to the problems of corrosion of reinforced concrete structures and prevention of corrosion advancement. The B12.5 class concrete

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was regarded at the time as structural concrete and so its application in the Centennial Hall designed in the years 1911 – 1912 did not generate any reservations. The thickness of the concrete casing was not a design parameter, but rather a result of the building construction process. Structural concrete was regarded as an extremely durable material, not prone to corrosion and thus providing a sufficient protection for the steel reinforcement. There was no detailed analysis of the role of the concrete casing and the impact of the building's external surroundings.

The overall advance of corrosion of the reinforced concrete structural elements of the Centennial Hall has been facilitated by the lack of proper protection and maintenance repairs of the external elements, which have been the most exposed to the influence of aggressive external conditions.

Information on the previous conservation interventions

In a historical perspective, World War Two should have been the most difficult time for the Centennial Hall. But the building did not suffer during the bombing campaign in 1945, even though some of the other Max Berg designed buildings in the Exhibition Grounds were destroyed. Both the Hall and the Exhibition Grounds have functioned continuously right up to the present day. There have been only a few changes in the structure of the Centennial Hall since it was built. The most important changes include:

1937 – construction of an external service staircase for the organ, renovation of the interiors and the roof terrace, installation of chipboards and cement boards to improve the acoustics of the Hall. This was a temporary solution, which was implemented due to the lack of funds for a more permanent solution;

1947 – 1948 – repair of war damage, roof repair, installation of transparent glass panes, disassembly of the damaged organ, removal of roof covering, renovation of damaged skylights over the passage way, replacement of electric and heating installations;

Several interventions have been undertaken that times to protect some of damaged fragments of the external walls above the level of the side lobbies during the years the Hall has been in use. These included reprofiling and filling in cavities and covering repaired fragments with various protective coats. The repairs were carried out incorrectly as the corroded reinforcement was not cleared of corrosive deposits in a proper way and the substrate was not prepared appropriately. The wrong reprofiling materials were used. This resulted in further reinforcement corrosion and concrete damage.

1996 – renovation of the Hall auditorium, including seat replacement;

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2009 – 2011 – the most comprehensive renovation of the Hall since it was built.

The renovation work completed in the years 2009 – 2011, was preceded by preparatory work, which included securing financing and carrying out several analyses and surveys to assess the technical condition of the building as a whole and its constituent elements. Several reports were prepared, including: conservation documentation for the window woodwork, expert opinion on the technical condition of the building structure, dendrological analysis concerning the vegetation covering the building façades and the requirements for temporary protection of the vegetation during renovation work of the facade, assessment of the conservation condition and analysis of the colour scheme of the external walls, technical opinion concerning the strengthening of the main tension ring, metallographic examination of the condition and parameters of steel lattice-work elements of the tension ring, comprehensive assessment of the mechanical properties of the concrete in the tension ring, documentation relating to the conservation condition and exposed excavations in the Emperor's Room. The documents and reports listed above and consultations with a group of outstanding experts in heritage monument conservation, history of art and construction, provided the basis for developing designs and plans for the renovation of the Centennial Hall and for obtaining the planning permission required. Renovation work was divided into two stages due to the specific character of the financial support secured. The first stage involved renovation of the building's façades, whereas the second stage was related to the renovation and modernisation of the interiors.

Stage one – the renovation of the façades began in February 2009, when planning permission was granted for renovation of the façades, window woodwork and the roof covering the Hall. The work started in March 2009 by ensuring protection for the vegetation growing next to the building walls so as to allow the process of cleaning the concrete façade surface. At the same time, windows were disassembled for comprehensive conservation in a specialist woodworking workshop and layers of roof covering were removed.

The original façade was repaired using concrete prepared on-site in wooden formwork. The pattern of formwork used, included varied heterogeneous texture with aggregates of various sizes, which allowed application of concrete varying in strength. The façade had sustained damage and was dirty with a layer of grime from exposure to destructive weather conditions.

The concrete façade had numerous cracks and fissures. The defects and cavities were the result of concrete degradation. The concrete casing of the steel reinforcement had lost its protective properties, causing corrosion of steel elements, which brought about further cracking and

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delamination of concrete fragments in window posts. The whole surface of the façade was in need of comprehensive conservation and renovation work.

The renovation work of the façades involved cleaning all the concrete elements, carrying out all necessary repairs to the damaged concrete and reinforcement, reprofiling of concrete cavities, injections of fill to secure cracks and fissures in the concrete structure, which had sustained damage from rain and wind.

Renovation work of concrete surfaces was completed as follows:

- the whole concrete surface of the façade was cleaned using low-pressure streaming of fine-grained abradent (quartz dust) protected by a water mist in accordance with the JOS method;
- cavities, honeycombing and corrosion delamination were repaired (reprofiled), and the corroded reinforcing bars were replaced;
- in the case of large cavities and delaminations, the missing surface was recreated in line with adjoining surfaces or surfaces of similar elements;
- small cavities and defects resulting from washing-out of the concrete texture were left without reprofiling, where they did not stand out from the adjoining surfaces or other elements of similar character, and where they did not affect concrete strength;
- injections of material to fill all cracks and fissures to secure the internal concrete structure;
- the concrete surface of the façade was secured with a water vapour-permeable impregnating agent.

After the façade surfaces had been cleaned, it was decided to test different colour hues of the paint coatings that were to be applied. An additional conservation assessment was conducted in order to determine the right colour scheme for the external walls: photographic documentation was prepared, places for extracting samples for laboratory testing were selected, and analysis of the preservation of tested fragments was carried out together with the analysis of the impact of destructive agents on the original colouring. Samples were extracted and specialist laboratory and stratigraphic tests were carried out, followed by analysis of the material gathered and test results. The final colour scheme for the façade walls was determined on the basis of these test results

The tests which were carried out indicated that the oldest ochre colour coating of paint had been applied directly onto the concrete surface. In addition to the ochre, the coating was found to contain an unidentified white. No organic binder or carbonates were found in the samples. The paint layers were brittle. Most probably, the original binder had disintegrated as a result of weather impacts.

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Light yellow paint layers were visible on the surface of five samples. These were all well connected to the substrate and some of them were shiny. The pigment used for this paint was also ochre, most probably with a silicate binder.

The overall colour scheme of the façade was varied and depended on several factors. Weather conditions have influenced the colouring of the paint coatings in various places. Rainfall has washed out pigments, whereas strong sunshine has turned natural ochre into a burnt ochre colouring, additional salt precipitation and repainting of some layers has resulted in a colour drizzle effect.

This effect resulted also from adding various types of aggregate to the concrete paste (basalts, granites, gravel and sand) and the application of different arrangements of formwork boards, accentuating individual elements of the façades. In the final analysis, it was concluded that it was not possible to identify unambiguously one colour for the whole surface of the façade. This was because the paints used originally had been applied in relatively thin layers and glazed in a particular way. The final decision on colour selection was preceded with several tests, which were carried out on clean concrete surfaces to assist in selecting the right paint coating. The basic colour selected was the S 0520-Y20R colour in accordance with the NCS colour classification model or colour number 35 H 54 (Farbreihe 35 Goldocker) in the KEIM historisch colour model.

Colour testing was carried out on specially prepared surfaces of the façade. The test results were assessed by a team of conservation experts, designers and contractors. The colour experimental testing led to the decision to use a non-standard colour. The colour of the paint and its concentration was determined through individualised test applications.

KEIM paints were used in order to ensure the integrity of the colour scheme. First of all, surfaces were grounded with a primer containing a sol-silicate binder. Then a glazing coat of a sol-silicate paint was applied. The glazing coat consisted of a diluted mix of four base colours. The colour composition obtained in this way was marked as 27/9 HS.

The second stage – renovation work of the interiors began in January 2011 and was completed in August of the same year. It was a very short period of time for a complex renovation intervention.

The aim of the renovation was to adapt the building to the modern requirements which have to be met by any sports and entertainment arena. As a result, the Hall could be still used for the purposes it had originally been designed for. Work essential for allowing the Hall to serve as a venue for concerts, sport events, conferences and congresses, artistic performances, trade fairs and exhibitions, which was carried out, included:

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- a complete replacement of the auditorium with a new one, which provides seating for a maximum number of seven thousand people or standing room for ten thousand.
- four dressing room complexes were built for teams participating in sports events, along with rooms for trainers and team support staff;
- all office and ancillary rooms in the side lobbies were dismantled;
- the bathrooms were extended to accommodate the increased number of Hall users;
- a Discovery Centre was organised in a separated part of the side lobbies (in the south west part of the building) and the space was adapted to its needs;
- the suspended ceiling in the hallway of the main entrance was disassembled, uncovering the original reinforced concrete coffer ceiling;
- the concrete surfaces inside the Hall were cleaned using a closed system water streaming method, which included detergent additive;
- the structure of the lantern was secured and strengthened using carbon fibre C-FRP strips,
- repair (reprofiling) of structural reinforced concrete elements inside the Hall,

The renovation work carried out included a securing of the main structural element, which is the bottom tension ring situated below the ribbed dome. The Centennial Hall's designers disregarded somewhat the bottom tension ring, which constitutes a very important structural element. They did recognise its critical role in providing for the overall structural security of the building. This element was one of only a few cases in which, not only did the design not allow an appropriate safety margin for the load-bearing capacity of the element, but it was also found to be deficient in its load-bearing capacity as has been demonstrated by computer calculations. This deficiency resulted from the application of simplified static schemes. This, along with the other defects describe, may call for strengthening of the ring structure. The length of the ring perimeter is 218 m and the element is located 19 m above ground level. Intervention was necessary because the lighting and sound system equipment used for public events held in the Hall would have to be temporarily suspended from the structural ribs of the dome. The general contractor suggested securing the tension ring by surrounding the element on the outside with unbounded cords (27 cords, each with a diameter of 15.5 mm), grouped into nine cables, and each one comprising three cords. Cables were placed in PEHD tube covers and were laid on the external surface of the tension ring of the dome with a spacing of 140 mm between them. Prior to anchoring, the cables were also tightened using an even force equal to 15% of the load-bearing capacity of the cords, which ensured proper functioning of the anchors. After tightening, the cords were injected with cement paste and secured from their external side with a layer of low-shrinkage mineral mortar with a texture and colour compliant with

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recommendations of the heritage conservation officer and similar to that used on the other surfaces of the Hall's façade.

1.2 Sampling activities

On the 2nd of August 2018 the sampling of the Centennial Hall, selected as case study in Wroclaw (Poland), was carried out in collaboration with Wroclaw University of Science and Technology. Representative concrete samples have been taken from the Centennial Hall, which was chosen for being a significant monument and an outstanding example of early Modernism.

The main purpose of the material characterization is understanding the properties that define the concrete with which the structure was built as well as identifying the decay processes that could be currently active or that can activate in the near future due to the material composition and environmental conditions to which is exposed to.

The sampling activities were led by the structural engineer and architect Krzysztof Raszczuk. In addition, apart from sampling, several non – destructive tests were carried out such as: ultrasonic tests, electromagnetic tests and sclerometric test (Schmidt hammer method). Ultrasonic method was used for quality control of concrete materials, and detecting damages in structural components. Electromagnetic method was used to assess concrete conditions and identify arrangement of reinforcement. Schmidt hammer measurements was used to check the hardness of concrete surface in area of testing.

Various boreholes were made with a ∅35, ∅50, ∅80 and ∅100 drill. In the case of some long core samples the ends crumbled before they were extracted from the borehole.

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Sampling process

Sampling process – detecting rebar in reinforced concrete

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Sampling process – Rebound Hammer test

Sampling process – Ultrasonic pulse velocity test

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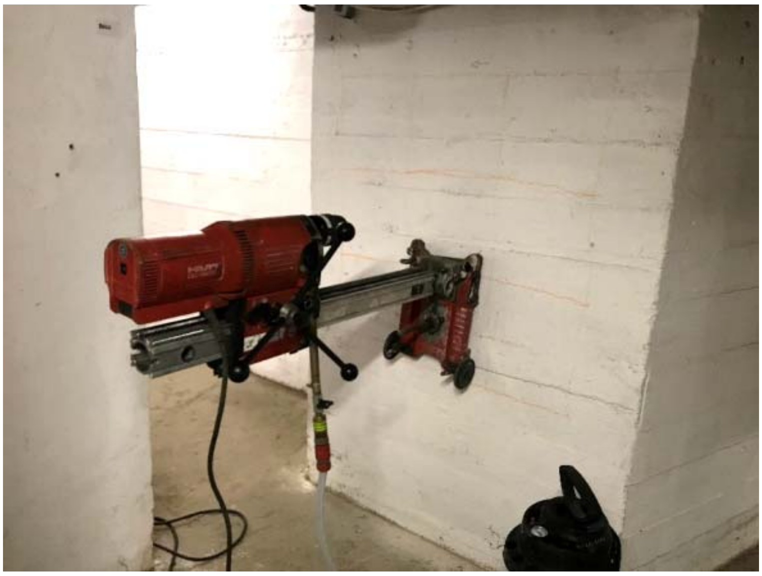

Sampling process – Core Drill Rig

Sample P1/1 extracted from the structure

In the year 2018 following samples were extracted from the building:

P1 – external area in south part of the building	P1/1, P1/2, P1/3, P1/4
P2 – external area in north part of the building	P2/1, P2/2, P2/3, P2/4
P3 - basement	P3/1, P3/2, P3/3, P3/4, P3/5
P4 – entrance roof	P4/1, P4/2

The localisation of samples from region P1 to P4 is shown below with additional region P5 where only surface pattern was analysed and NDT tests were carried out.

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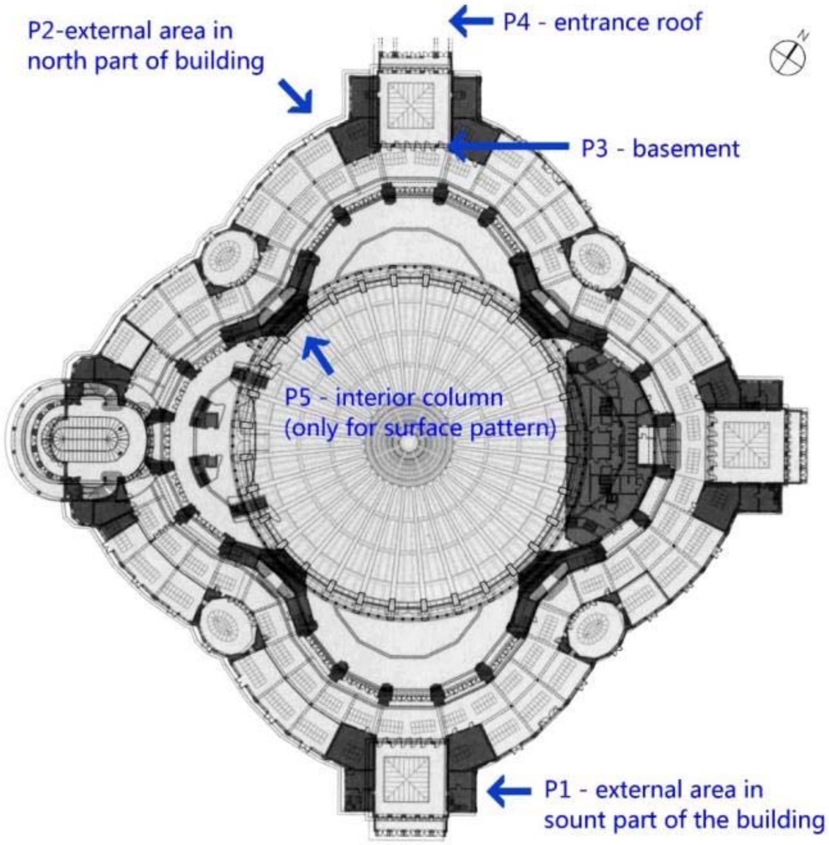

Sampling areas

Table: List of samples

Symbol	Dimensions	Location
P1/1	Ø 35, l = 90 mm	external area in south part of building
P1/2	Ø 35, l = 120 mm	
P1/3	Ø 35, l = 140 mm	
P1/4	Ø 35, l = 140 mm	
P2/1	Ø 35, l = 100 mm	external area in north part of building
P2/2	Ø 35, l = 130 mm	
P2/3	Ø 35, l = 140 mm	
P2/4	Ø 50, l = 180 mm	
P3/1	Ø 35, l = 100 mm	basement
P3/2	Ø 50, l = 95 mm	
P3/3	Ø 35, l = 115 mm	
P3/4	Ø 100, l = 250 mm	
P3/5	Ø 100, l = 250 mm	
P4/1	-	entrance roof
P4/2	-	

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1.3 Results of the characterization

Introduction

The following results of characterization include also testing, which were carried out in previous years in following periods: a) 2007 – 2012, b) 2015, c) 2018. The tests which were carried out during InnovaConcrete project were planned as a complementary test. Some tests were also published in different papers:

- Ekspertyza stanu technicznego konstrukcji budynku Hali Ludowej we Wrocławiu. Część I i II, (2007, 2008), MBM Firma Konsultingowa i projektowo-badawczo-budowlana sp. z o.o.
- Jasieńko J., Moczko M., Moczko A., Dżugaj R., (2011) Badanie cech mechaniczno-fizycznych betonu w dolnym pierścieniu obwodowym kopuły Hali Stulecia we Wrocławiu, Wiadomości konserwatorskie, Nr 28/2011.
- Jasieńko J., Moczko M., Moczko A., Wala D., (2011) Beton Hali Stulecia (UNESCO List) we Wrocławiu, Wiadomości konserwatorskie, Nr 30/2011.

2007 – 2012

set of specimen (different parts): LOK/926/H1 to LOK-926/H11

set of specimen (tensile ring): O -1/A to O -9/A and O -10/B ÷ O -19/B

2015

set of specimen (ribs): RIB Ł1 to RIB Ł29

set of specimen (pillars): O-A1 to O-D2

2018

set of specimen (external walls and cellar): P1/1 to P4/2

Petrographic study

The macroscopic evaluation of the concrete indicates that the following types of aggregate were used in the structural concrete of the Hall: granites (locally with a small amount of haematite) and feldspars dominate, with smaller amounts of marble, quartzite, basalt and slate. The maximum diameter of the aggregate grain is more than 20 mm.

The sieve analysis indicated that all of the tested aggregate complies with the recommended content of aggregate grain-size of dimensions of less than 32 mm. The tested aggregate consists of crushed granite. Grain-size fractions of 31.5 ÷ 16 mm comprise more than 92 % granite, which in

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more than 47% consists of elongated and flat grains. The smaller the grain-size of the aggregate, the lower the content of granite and irregular grains. The fraction of 4 -2 mm contains approximately 50 % granite, whereas the remaining part consists of natural quartz aggregate or other additives.

A visual inspection of extracted core samples indicated that the tested concrete was based on granite aggregate with an addition of natural aggregate, in amounts which vary in individual ribs of the dome. In the majority of cases, the granite aggregate dominates, with a small addition of natural aggregate.

Core sample extracted from the Ł 17 rib (high content of granite aggregate)

Core sample extracted from the Ł 20 rib (composition dominated by natural aggregate)

The curve of grain size for the aggregate was determined in tests in 2009 and 2015. Test results are presented in Table below.

Table: Aggregate grain composition.

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Sieve	Remaining on the sieve [%]		Passing through the sieve [%]	
	specimen 3	specimen 4	specimen 3	specimen 4
31.5	0	0	100	100
16	2.8	17.35	97.2	82.65
8	26.6	25.7	70.6	56.95
4	16,5	10.87	54	46.08
2	10	6.1	44	39.98
1	6.5	6.27	37.5	33.71
0.5	8,9	16.14	28.6	17.57
0.25	23	13.58	5.7	3.99
0.125	3.7	2.86	2	1.13
less	2	1.13	0	0

The tested aggregate can be classified as 'well-grained' in line with the recommended grain size of less than 32 mm. In both specimens, fine grains were found to constitute approximately 40% of the aggregate. It can be assumed that the aggregate was enriched through addition of stone dust. The aggregate in the tested specimens comprised mainly crushed granite. For the fraction of 2 – 4 mm, half of the aggregate in both specimens was granite. The smaller the fraction of the aggregate, the lower the content of granite.

Table: Content of granite aggregate in 2 – 31.5 mm fractions.

Aggregate fraction [mm]	Content of granite aggregate in the fraction [%]	
	disc 3	disc 4
31.5 - 16	92.79	45.9
8 - 16	88.77	79.6
4 - 8	83.45	69.5
2 - 4	50.5	47

Microscopic analysis of grain composition was carried out in 2015. The content of aggregate with grains larger than 2 mm was investigated along 6 straight lines. They constituted the diameter of a flat surface and the angle between two immediate lines was 30°. The test results are presented in table below:

Disc number	Aggregate [%]	Granite [%]	Other aggregate [%]

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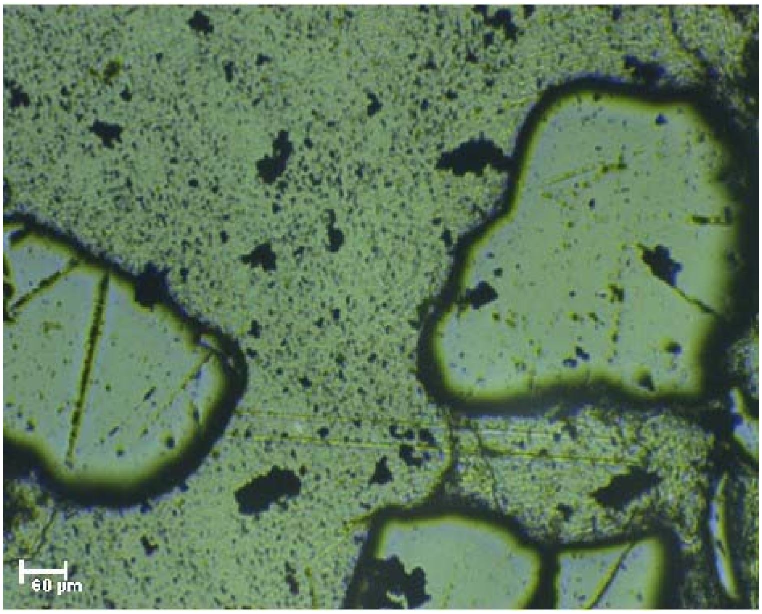
1	46.8	35.7	11.1
2	49.4	35.8	13.6
3	54.4	48.6	5.8
4	61.6	53.7	7.9

In aggregate fractions lower than 8 mm, the presence of high porosity slag and wood chip inclusions was observed. The presence of fine black inclusions was also confirmed by images taken with the TTX-NHT nano-indentation tester.



The tested concrete – image obtained with the TTX-NHT nano-indentation tester

It can be assumed that the slag was intentionally added to the concrete mix in order to improve concrete mechanical properties. High concentration of the C-S-H phase, which is a product of the process of hydration of slag and reaction of calcium hydroxide with silicate anions resulting from the slag hydration, is responsible for a much lower content of calcium hydroxide and higher concentration of the C-S-H phase in the hardened cement paste. The high content of the C-S-H phase, in the form of a dense gel, results in a very dense concrete microstructure. This leads to lower capillary porosity of the hardened cement paste, which obstructs diffusion of aggressive agents into the cement matrix. This in turn translates into a smaller content of portlandite and calcium aluminates, which are not resistant to corrosion. The described changes to microstructure of slag cement pastes are responsible for the fact that slag cements are characterised by a number of more favourable properties than Portland cements without additives.

Mineralogical composition

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Data available in the literature and other documents suggest that concrete for the construction of the Hall was made from a special cement from the Silesia cement mill in Opole. The highest quality Strzegom granite was used for the aggregate. Concrete mixing stations and aggregate grinding mills were located on the construction site of the Centennial Hall.

The concrete composition assessment involves determining concrete density by volume, the quantity of fractions insoluble in HCL (1:3) and the content of components which attach during the processes of hydrolysis, hydratation and carbonation of the cement binder.

1 m^3 of concrete contains 1,941.5 kg of aggregate and 215.0 kg of cement in one of the specimen and 1895 kg of aggregate and 240 kg of cement. The ratio of aggregate to cement is approximately 9:1. Thus, the amount of cement is relatively low.

The assessment of mineral content of the tested concrete was carried out based on the results of the oxide composition analysis. The content of the following oxides: CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, Na_2O, K_2O, was determined using Atomic Absorption Spectroscopy (AAS) method. The composition of the tested binder differed from the oxide composition of Portland cement. Its oxide composition was similar to the composition of Roman cement or blast-furnace cement on account of a lower content of CaO.

Components	Content [%]	Determination method
CaO	32.2	AAS
SiO_2	24.3	AAS
Al_2O_3	6.1	AAS
Fe_2O_3	6.3	AAS
MgO	1.2	AAS
Na_2O	0.2	AAS
K_2O	1.0	AAS
CO_2	5.9	Roasting losses
H_2O	16.4	Roasting losses
SO_3	0.8	Gravimetric analysis

Additional analysis of the mineral composition of the tested concrete was carried out using X-ray diffraction. The presence of calcium carbonate in the form of calcite and crystal phase in the form of portlandite Ca (OH)2 was discovered in tested samples of cement paste, which had been separated out. The X-ray diffraction analysis did not indicate any presence of hydrated calcium aluminium sulphate in the form of ettringite C6AH32, calcium mono-sulphate C4AH12 and hydrated calcium silicates C-S-H, which occur in an amorphous form.

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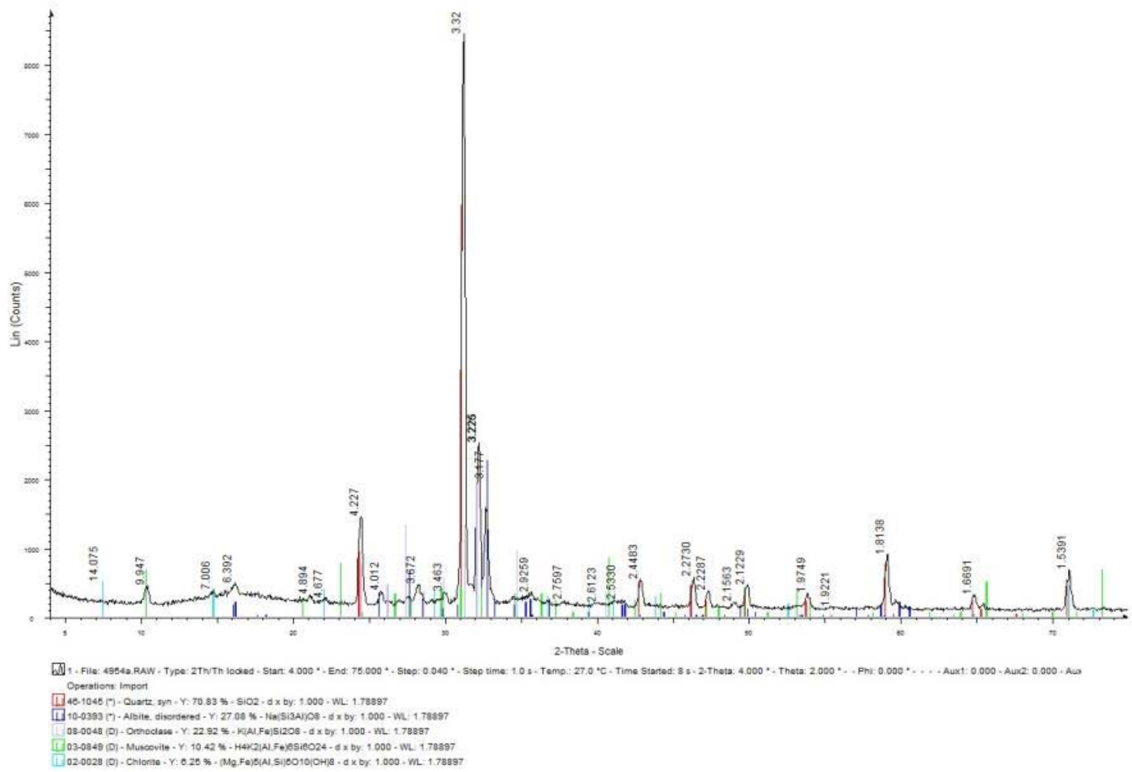

Phase analysis of the tested concrete – X-ray diffractometry

Porosity and pore size distribution

The analysis of the concrete microstructure was carried out using a computer tomograph. SkyScan 1172 micro-tomograph with a 11 Mp resolution camera made by the Bruker company was used.

Testing station - SkySkan 1172 micro-CT made by the Bruker company

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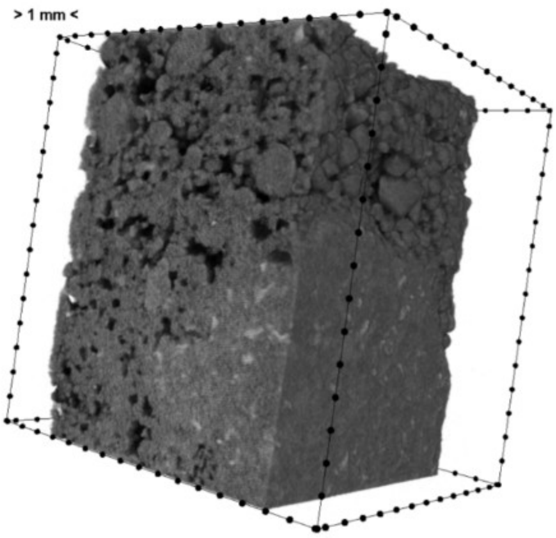
X-ray micro-CT method provides for a sharp contrast between the solid phase and air. The method involves a 3D reconstructed image of a tested element, which is based on two-dimension projections obtained through X-ray scanning of the specimen. The source of radiation is usually an X-ray tube which comprises two electrodes: cathode and anode, made of material with a high atomic number. A beam of rays passes through the specimen placed on a mobile hoist. Images are registered by a scintillator, which transforms the energy of radiation molecules into visible light. The scintillator is connected to the matrix of the Charge Coupled Device (CCD), which transforms light into a digital signal. The result of scanning is a set of images (projections) which can be subsequently reconstructed into a series of specimen sections. On the basis of this data, a 3D visualisation of the material can be obtained. All scans were carried out with maximum lamp voltage (100 kV) and a constant power of the source of 10 W. An Al+Cu (aluminium – 1 mm, copper – 0.05 mm) screen was used for scanning all elements due to the properties of samples (high density material). The individual rate of specimen rotation was equal to 0.15°. The images were reconstructed with the NRecon software using the Feldkamp algorithm. The test resulted in a series of images with a resolution of 6.8 µm per 1 pixel.

Results enabled analysis of the patterns, shape, size and diameter of pores. The images of specimens analysed with the micro CT device include the distribution, marked in red for each tested specimen. They are uniformly spread in the volume of the tested concrete. The analysis gives us also the information about the sphericity of pores in the tested samples. The most frequent value of the pore sphericity is 0.6-0.7, which means that the pores shape is not close to spherical but slightly elongated.



3D images of concrete specimen A obtained with micro-CT – solid view reduced by pore space

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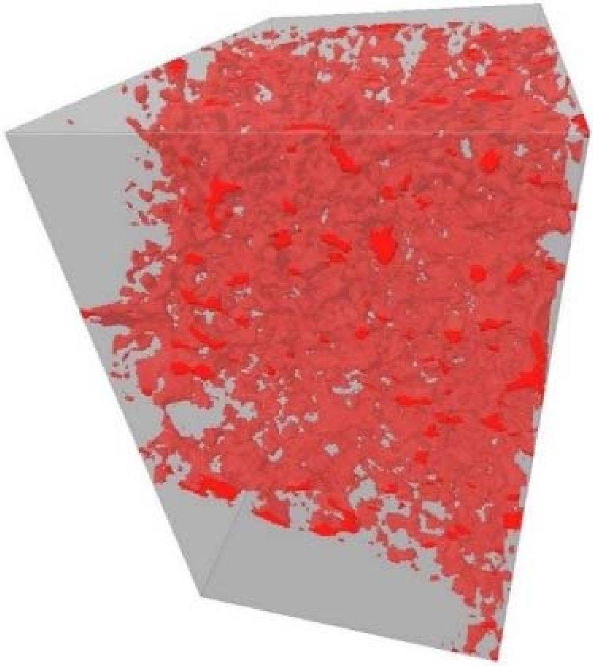
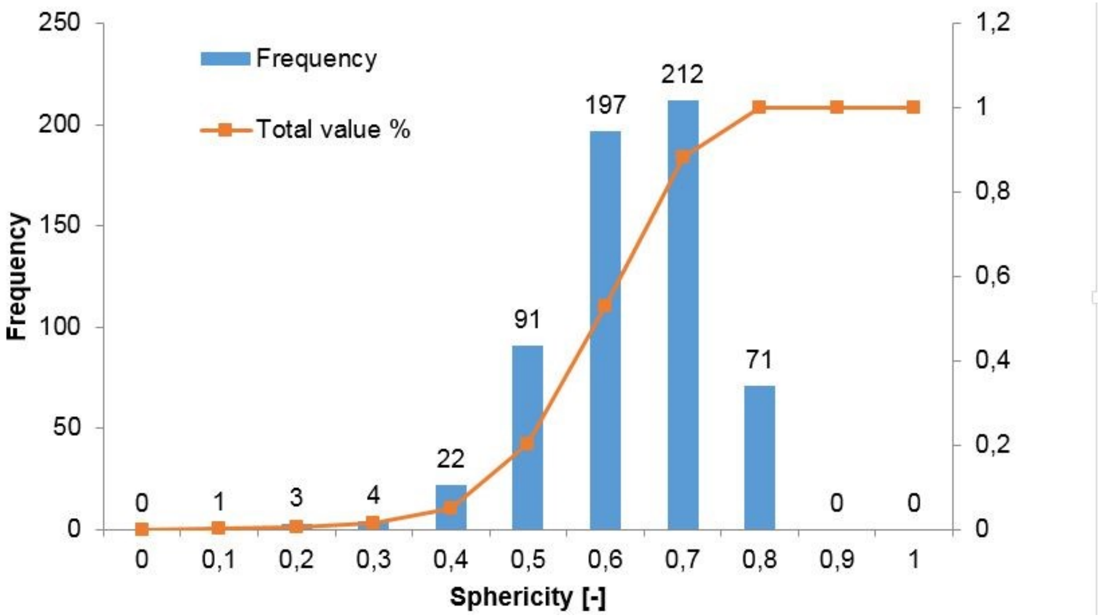


3D images of concrete specimen A obtained with micro-CT – isolated pore space

Concrete properties depend on the following: total volume of pores, spread of their sizes, uniformity of distribution and shape. The air pore structure can be characterised by the following parameters: total air content, specific surface area of the air pore system, spread of the air pore sizes and the content of micropores <300µm.



Pore shape spread in specimen A

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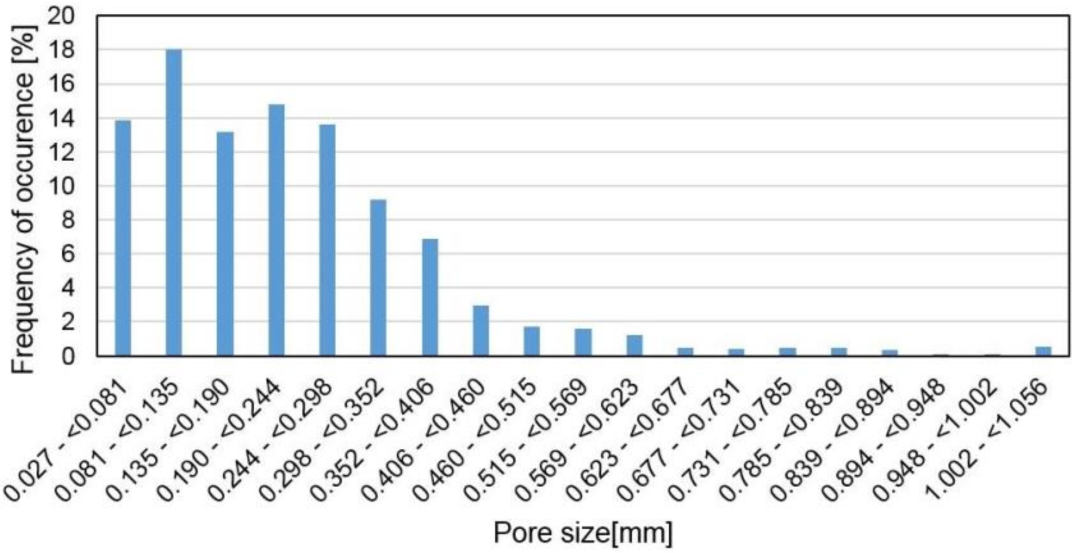
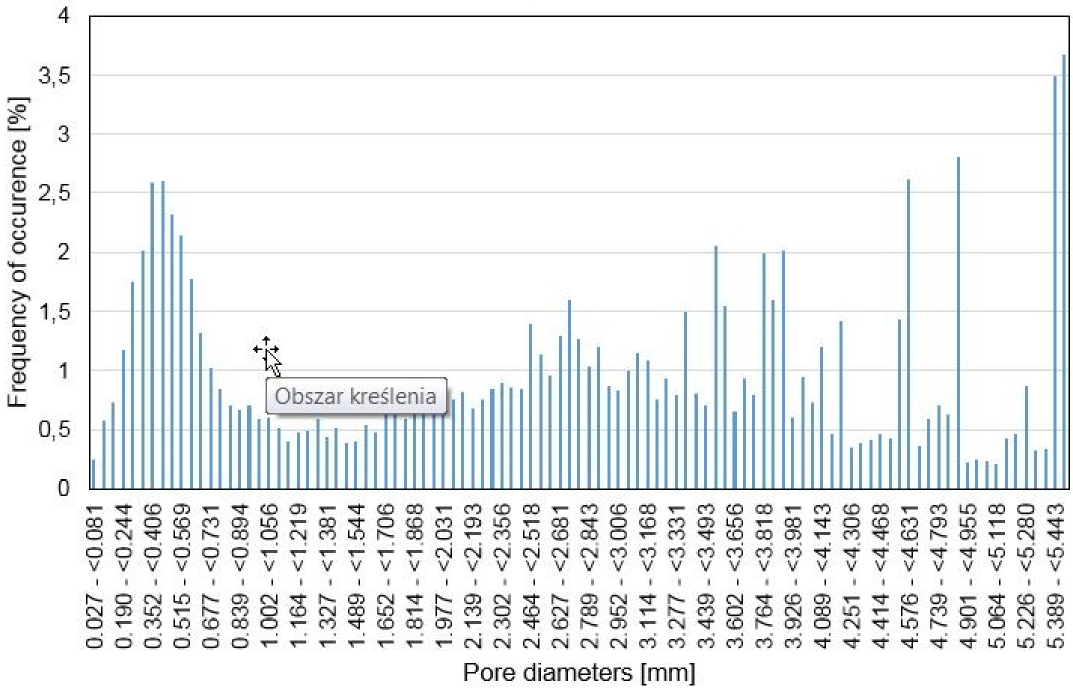
Porosity structure, pore size, shape and distribution influence concrete properties such as: thermal conductivity, frost resistance, absorbability and percolation, capillarity and strength. Based on the graphs presented, it can be concluded that fine-sized capillary pores prevail in the tested concrete.



Pore size spread in specimen A



Pore diameter spread in specimen A

In the case of specimens B-D, the total air content was approximately 10%, but it was half of this value for specimen A. The specific surface area of the air pores system in all tested specimens

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amounted to approximately 40 mm^2/mm^3. Fine-sized, regularly distributed air pores with dimensions ranging between 10μm and 300μm improve the frost resistance properties of concrete.

Table: Concrete porosity

	A	B	C	D
Total air content [%]	5.82	10.15	9.36	10.84
Specific surface area of the air pores system [mm^2/mm^3]	41.73	32.87	45.42	37.65
Micropores < 300μm content [%]	73.45	61.53	67.12	90.68

Using traditional approach in laboratory testing, following results were reached:

The average weight of concrete by volume is **ρ = 2236 kg/m³** base on 10 specimen (0-1 to 0-19) from the bottom tensile ring.

The average weight of concrete by volume is **ρ = 2261 kg/m³** base on 7 specimen (0-1 to 0-29) from the ribs.

The average weight of concrete by volume is **ρ = 2252 kg/m³** base on 7 specimen (0-A1 to 0-D1) from the ribs.

Concrete density was determined using a crushed sample of concrete in a Le Chatelier flask. The concrete density in 2009 tests was equal to **2560 kg/m³**. A similar value **2520 kg/m³** was obtained for one of the specimen in 2015.

Total porosity for concrete was calculated as equal to **12.6%.** Closed porosity was equal to **4.52%.**

Electrochemistry data

Merlin is used to measure the bulk electrical conductivity, or its inverse, the bulk electrical resistivity, of saturated 100 mm diameter concrete cylinders or cores with lengths up to 200 mm. The test is simple to perform and a measurement is obtained within two seconds. The conductivity of a saturated concrete specimen provides information on the resistance of the concrete to penetration of ionic species by diffusion. The term bulk is used to indicate that the measurement is made through the specimen as opposed to a surface-based measurement.

Merlin can be used for the following purposes:

- Research and development to characterize the influence of new materials on the electrical conductivity of concrete
- Optimizing mixture proportions and blends of supplementary cementitious materials to increase concrete service life

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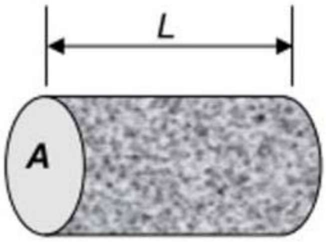
- On-site quality control and quality assurance
- Evaluation of in-place concrete (using cores).



$$R = \rho \frac{L}{A}$$

Principle of method and shape of sample

The electrical resistance *R* of a conductor of length *L* and uniform cross-sectional area *A* is given by the equation shown in the figure to the right. The quantity ρ is the electrical resistivity and is a material property, with units of resistance multiplied by length, such as ohm·m. If the electrical resistance *R* of a specimen of length *L* and area *A* is measured, the resistivity can be calculated from the relationship ρ = R A/L. The inverse of electrical resistivity is the electrical conductivity, σ. The inverse of ohms is a unit called siemens (S). Therefore, electrical conductivity has units of S/m. For concrete, it is convenient to express electrical conductivity in millisiemens per meter or mS/m.

In assessing the ability of a concrete mixture to resist penetration of a particular type of ion, one of the key properties is the **diffusivity**, which defines how readily the given type of ion will migrate through saturated concrete in the presence of a concentration gradient. For a saturated porous material, such as hardened concrete, the diffusion coefficient of a give type of ion can be related to electrical conductivity through the Nernst-Einstein equation as follows (Snyder et al. 2000; Nokken and Hooton 2006):

$$\frac{\sigma}{\sigma_p} = \frac{D}{D_w}$$

Nernst-Einstein equation

where:

σ = bulk electrical conductivity of the saturated porous material
σp = conductivity of the pore fluid
D = bulk diffusion coefficient of the specific type of ion through the porous material
Dw = diffusion coefficient of the specific ion through water (Mills and Lobo 1989).

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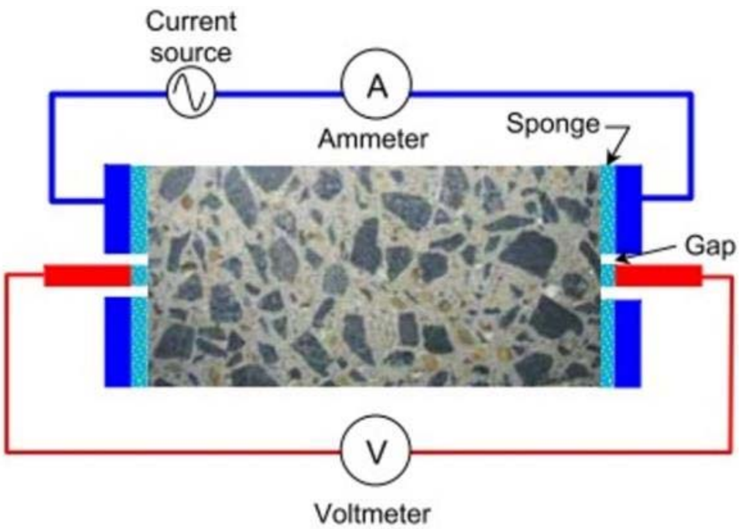
If the conductivity of the pore fluid is assumed to be similar among different concretes, the measured bulk electrical conductivity is related directly to the bulk diffusion coefficient (Berke and Hicks 1992). Measurement of the bulk diffusion coefficient of a particular type of ion through concrete is a time consuming process, while electrical conductivity can be measured in a matter of seconds.

The electrical conductivity of saturated cement paste is related to the volume of pores and how they are connected within the paste. The paste porosity is related to the water-cementitious materials *(w/cm)* ratio, the types of supplementary cementitious materials (SCMs), and the degree of hydration. For the same *w/cm* and degree of hydration, the use SCMs reduces pore size and increases the tortuosity of the pores and, thereby, reduces electrical conductivity and the ease of fluid penetration.

The following is a schematic of the measurement method incorporated in Merlin. The four-point measurement method that is used provides an accurate measure of specimen resistance by minimizing the effects of the conductive sponges and the pressure applied to the electrodes. The specimen must be in a water-saturated condition to obtain a meaningful measurement.



Merlin Method of Operation

An alternating current source (325 Hz) is used to apply current through the saturated cylinder or core. A voltmeter measures the voltage drop across the specimen, and an ammeter measures the current through the specimen. From the measured current I and voltage V, the bulk conductivity is calculated as follows:

$$\sigma = \frac{I}{V}\frac{L}{A}$$

Bulk conductivity equation

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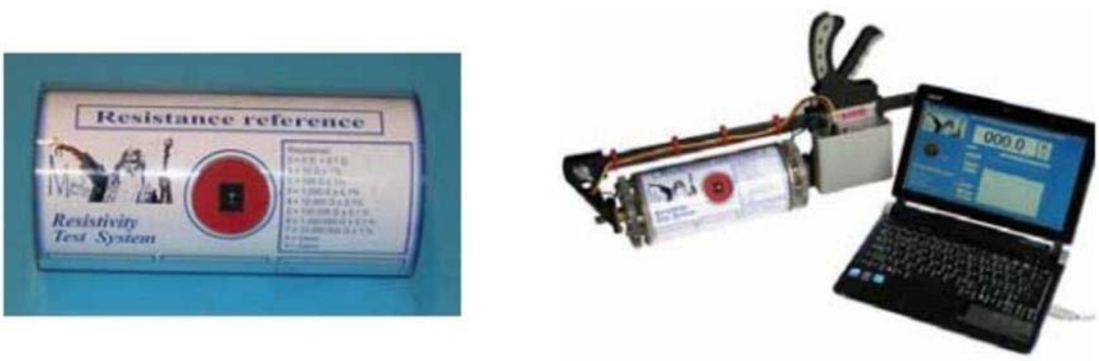
where,

L = the specimen length

A = the specimen cross-sectional area.

The bulk resistivity is the inverse of the bulk conductivity, that is, $\rho = 1/\sigma$. A 100 by 200 mm verification cylinder is provided to check that the Merlin system is operating correctly. The cylinder includes a push button switch than can be used to select one of several precision resistors from 10Ω to 1 MΩ. For example, if the 1000 Ω resistor is selected and the system is functioning correctly, the displayed conductivity of the verification cylinder should be 25.46 mS/m and the resistivity should be 39.27 Ω•m.



Merlin equipment

Merlin equipment during investigation

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Sample during testing using Merlin Method

Table: Merlin test results:

Sample	Electrical bulk resistivity	Average electrical bulk resistivity
(Near surface)	*Ωm*	*Ωm*
P3/5	585.41	584.53
	581.40	
	586.20	
	586.20	
	585.12	
P4/7	477.06	484.38
	489.10	
	480.15	
	491.20	

Absorbability

The concrete absorbability by weight ranging between **3.0% to 5.9 %,** based on specimen from LOK/926/H1 to LOK-926/H11.

The concrete absorbability by weight ranging between **3.9% to 4.8 %,** based on specimen form 0-2/B to 0-17/B.

The concrete absorbability by weight obtained in testing range from **4.08% to 5.45 %,** based on specimen form RIB Ł1 to RIB Ł29, with the absorbability coefficient of variation equal to 11.2%, which indicates a high homogeneity of this parameter of concrete.

The concrete absorbability by weight obtained in testing range from **3.47% to 5.51 %,** based on specimen form O-A1 to O-D2, with the absorbability coefficient of variation equal to 12.4%.

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This very low value is a result difficult to achieve even today, with the availability of much more advanced concrete technologies.

Surface pattern

The concrete surface is various, depending on the sampling place. Outside elevation was renovated several years ago. Exterior surfaces were covered with renovation, mineral coating (KEIM), with yellow hue. Interior surfaces are raw. In the basement surface is covered with white lime coating. Surface is homogeneous, which is characteristic of well-compacted concrete. All surfaces have a various but homogeneous on each element texture. Texture of surface depends on the type of formwork.

Surface pattern of concrete in external area in south part of the building (P1)

Surface pattern of concrete in external area in south part of the building (P1) - close-up

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Surface pattern of concrete in external area in north part of the building (P2)

Surface pattern of concrete in external area in north part of the building (P2) - close-up

Surface pattern of concrete in basement (P3)

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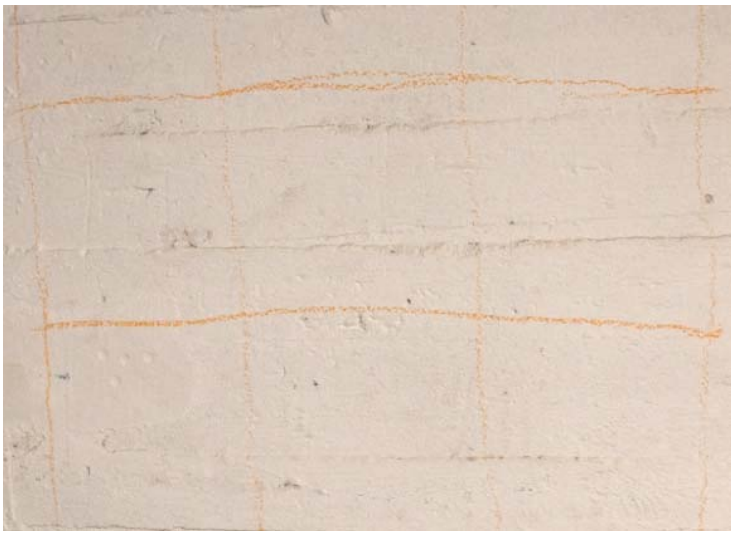

Surface pattern of concrete in basement (P3) - close-up

Surface pattern of concrete of interior pillar (P5)

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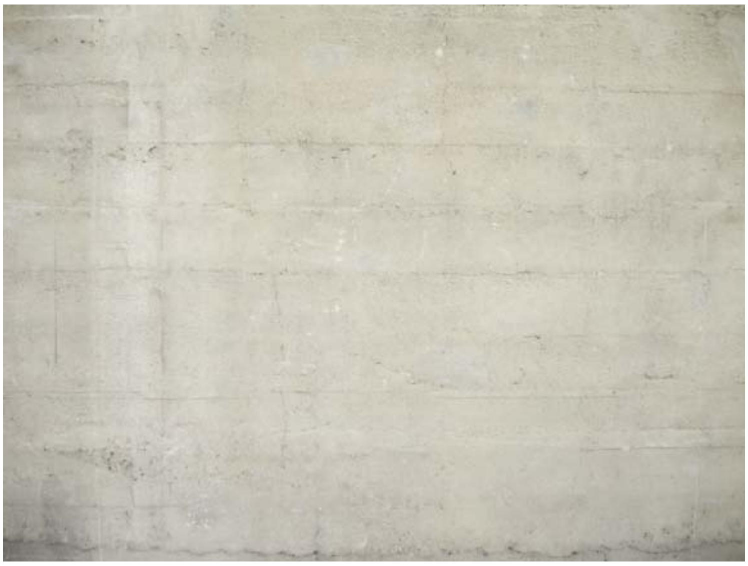

Surface pattern of concrete of interior column (P5) - close-up

Bonded water and carbonation of cement paste in the concrete

The composition of cement in the tested concrete differs significantly from the oxide composition of Portland cement (lower content of CaO, higher content of SiO_2) and has a composition more like Roman cement or blast-furnace cement. The colour of the cement paste (cream) of the tested concrete differs considerably from the colour of Portland cement paste. This may indicate that the cement used in construction of the Hall was produced with the addition of metallurgical slags.

The range of carbonation of the surface concrete layer was assessed using phenolphthalein and Rainbow tests. In both cases, testing is carried out on surfaces of core samples, immediately after extracting them from a structure. The phenolphthalein test method is well known in contrast to the Rainbow test method, which requires some explanation. The test involves spraying the surface of the tested concrete with a solution composed of specially selected chemical reagents, capable of identifying various pH values ranging from 5 to 13.

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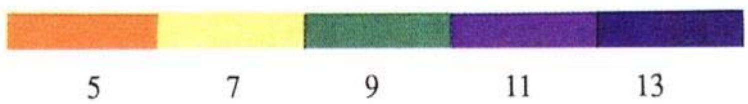
Rainbow and phenolphthalein tests



Rainbow Test method –colour scale adopted for testing

The pH reaction of 11 is commonly regarded as a border value, below which the natural capacity of concrete for passivation of reinforcement decreases and corresponds to the concrete staining purple. If the stain colour is green (pH = 9) it represents a pH being lower than the border value and indicates potential corrosion of reinforcement.

For specimen from H1 to H11 the carbonation depth is from 71 mm to 105 mm. The average depth of carbonation was 85 mm.

For specimen from 0-1/A to 0-19/B. In the majority of tested locations, the thickness of the carbonated area is no less than 35 mm, although in a number of locations it was found to be much thicker.

Specimen 0-5 after phenolphthalein and Rainbow Test method

For specimen from RIB Ł1 to RIB Ł32 the carbonation depth is from 22 mm to 42 mm.

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For specimen from O-A1 to O-D2 the carbonation depth is from 25 mm to 70 mm.

Specimen 0-C2 after phenolphthalein test (carbonation depth 60 – 70 mm)

The differences in the range of carbonation are primarily caused by the type and condition of the structure of concrete (strength and integrity) and depend also on the location of a given measurement point.

In 2018 following samples were testes using Ranibow Test and phenolphtaleine:

Measure place P 1 (wall exposed to the sun):

- Sample P1/1 → the layer is carbonated over the entire length of the sample (pH≈5-6) carbonation depth at least **90 mm,**
- Sample P1/2 → the layer is carbonated over the entire length of the sample (pH≈5-6) carbonation depth at least **120 mm,**
- Sample P1/4 → the layer is carbonated over the entire length of the sample (pH≈5) carbonation depth at least **140 mm,**

Sample P1/1 – carbonation over the entire length of the sample (90 mm - pH≈5-6)

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Sample P1/2 – carbonation over the entire length of the sample (120 mm - pH≈5-6)

Measure place P2 (shaded wall):

- Sample P2/2 → the layer is carbonated over the entire length of the sample (pH≈ 5) carbonation depth at least **130 mm,**
- Sample P2/3 → the layer is carbonated over the entire length of the sample (pH≈ 5) carbonation depth at least **100 mm,**
- Sample P2/4 → the layer is carbonated over the entire length of the sample (pH≈5-6) carbonation depth at least **180 mm,**

Sample P2/3 – carbonation over the entire length of the sample (100 mm - pH≈5)

The presence of the C-S-H phase was determined by means of thermal analysis (DTA, DTG, TG). In specific temperature ranges, endothermic effects were observed, such as: dehydration of hydrates of silicates, aluminium silicates and calcium aluminium sulphates (temp. 50-350°C), $Ca(OH)_2$ dehydroxylation (490-510°C), disintegration of $CaCO_3$ resulting from the process of carbonation (795-815°C), disintegration of remaining $CaCO_3$ (temp. 800-900°C).

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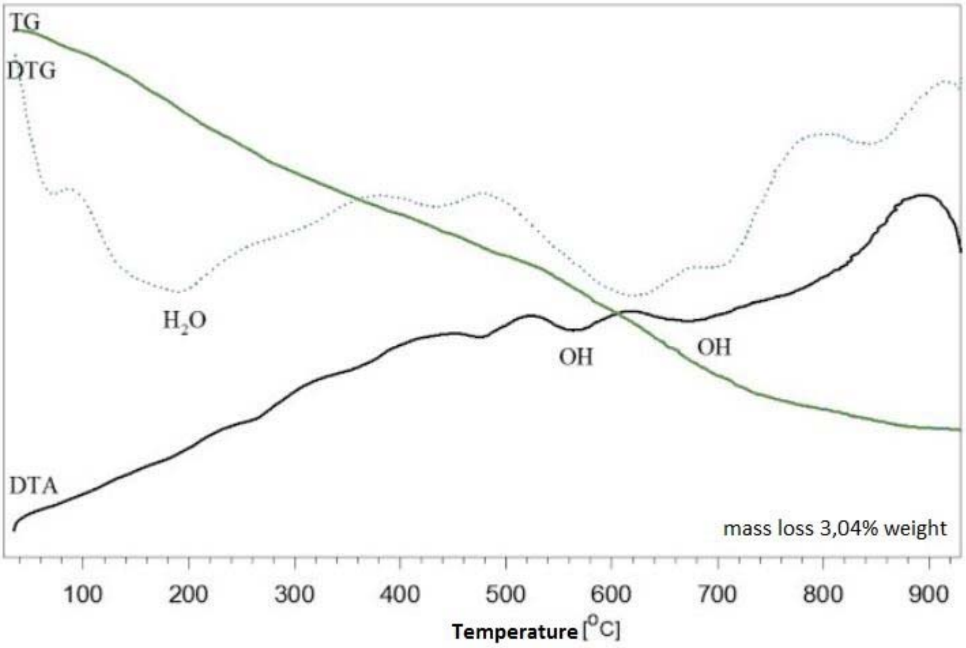

DTA, DTG, TG thermal analysis of the tested concrete

1.3.1 Compositional and textural properties of concrete

Regarding compositional properties of concrete, it should be underline that in the object, there are several "types" of concrete. The structural concrete which was used for structural (internal) elements like pillars, ribs and tension rings is characterised by an apparently high density, low overall porosity and low absorbability. Layers of concrete increase in porosity and absorbability with increasing distance from the external surface. This is a consequence of the carbonation process. Concrete samples differ also in relation to the aggregate content. The content of granite aggregate and the larger grain-size fraction is higher closer to the external surface. The closer to the external surface of the material, the lower the content of aggregate in concrete which results in higher content of cement. The ratio of aggregate to cement was 9:1 and 8:1, which can be regarded as relatively low. The analysis of grain composition of the aggregate indicated that the curve derived from the results for sieve testing, places the aggregate in the 'well-grained' category of aggregates with a fraction below 31.5 mm. Quartz aggregate along with crushed granite aggregate was found in the aggregate composition. The content of crushed granite aggregate increases for higher fractions of aggregate. It also increases closer to the external surface of the tested concrete.

A lower amount of CaO in the oxide composition of the cement and presence of fine black inclusions indicate that blast-furnace cement may have been used for construction purposes. Introduction of slag into the concrete mix resulted in a dense microstructure of the concrete. A high concentration

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of C-S-H phase is a product of slag hydration and reaction of calcium hydroxide with silicate anions coming from slag hydration. The amount of calcium hydroxide decreases, resulting in the presence of a C-S-H phase as a dense gel. This leads to lower capillary porosity of the hardened cement paste, which in turn obstructs the diffusion of aggressive agents to the cement matrix. The amount of portlandite and calcium aluminates, which are not resistant to corrosion, is lower in the cement paste. These changes to the microstructure of cement paste based on blast-furnace cement mean that such cements are characterised by a number of more favourable properties than Portland cements without additives.

Analysis of the microstructure allowed for porosity assessment of the material, as well as the structure and dimensions of pores. Porosity was determined with a micro-CT device for the tested samples, and found to be approximately 10%. The pores in the material are fine-sized, with a sphericity of 0.6-0.7. The majority are micropores smaller than 300μm. Such porosity of the tested concrete is responsible for its low absorbability (less than 5%) as well as good frost resistance.

The concrete surface is various, depending on the sampling place. Outside elevation was renovated several years ago. Exterior surfaces were covered with renovation, mineral coating (KEIM), with yellow hue. Interior surfaces are raw. In the basement surface is covered with white lime coating. Surface is homogeneous, which is characteristic of well-compacted concrete. All surfaces have a various but homogeneous on each element texture. Texture of surface depends also on the type of formwork.

The main causes of degradation process and mechanisms of decay are closely connected with carbonation process.

1.3.2 State of conservation of the monument

Centennial Hall is just after renovation process which took place several years ago (2009 – 2011). Following works were carried out regarding facade:

a) cleaning the concrete façade surface using low-pressure streaming of fine-grained abradent (quartz dust) protected by a water mist in accordance with the JOS method;
b) reprofiling of concrete cavities,
c) in the case of large cavities and delaminations, the missing surface was recreated in line with adjoining surfaces or surfaces of similar elements;

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d) small cavities and defects resulting from washing-out of the concrete texture were left without reprofiling, where they did not stand out from the adjoining surfaces or other elements of similar character, and where they did not affect concrete strength;
e) injections of material to fill all cracks and fissures to secure the internal concrete structure;
f) the concrete surface of the façade was secured with a water vapour-permeable impregnating agent,
g) surfaces grounding with a primer containing a sol-silicate binder
h) application of a sol-silicate paint
i) application of glazing coating
j) application of mineral paint coatings.

1.3.3 Mapping of the damages

In the sampling process it was possible to identify local damages, caused by various factors, for example:

- atmospheric impact (thermal effects and humidity);
- low reinforcement ratio;
- progress of concrete carbonation;
- reinforcement corrosion

Mapping of the damages is shown in the following figures and pictures.

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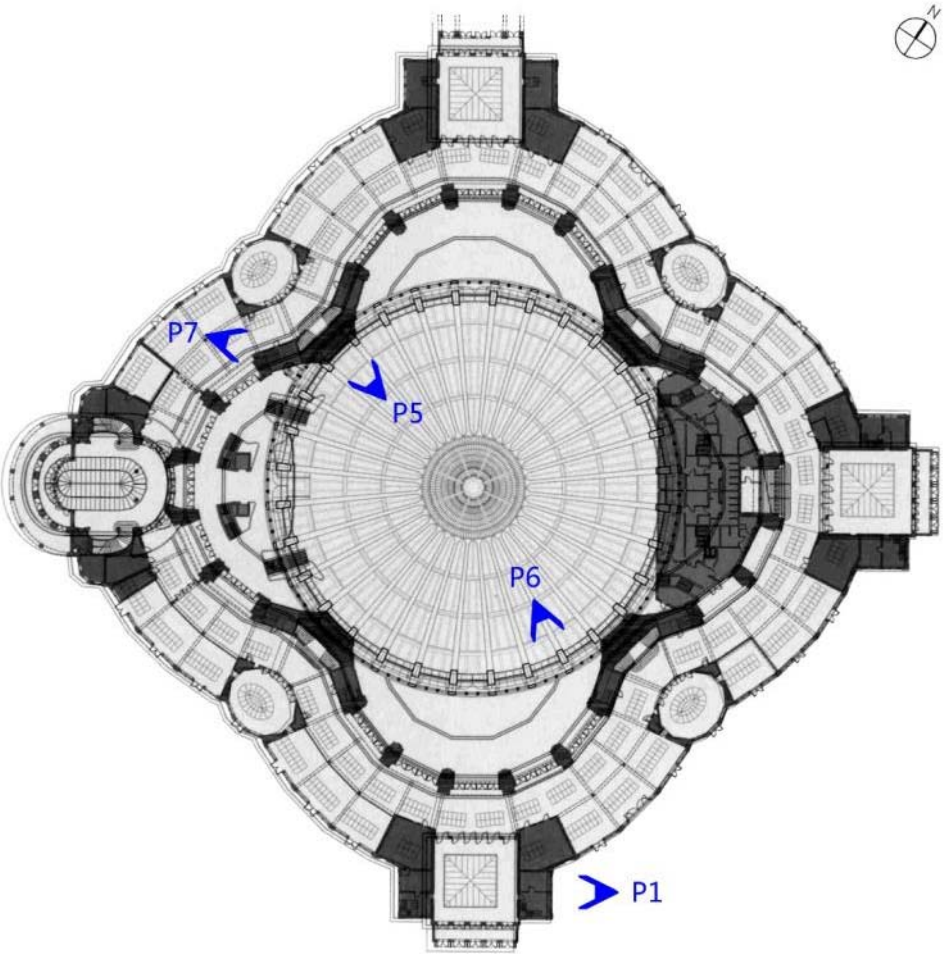

Mapping of the damages – location of photos

View of the cracking – P1

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View of the cracking – P5

View of the cracking – P6

View of the damages – P7

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1.4 Summary

Sampling and characterization process in Centennial Hall give us the general information about the concrete, which is a basic material for this building. Regarding compositional properties of concrete, it should be underline that in the object, there are several "types" of concrete. Concrete with different properties was observed for the structural elements, for the external walls and for the basement. During different testing, the following properties of concrete were determined:

a) absorbability,
b) density and density by volume
c) porosity
d) DTA/TG analysis
e) mineralogical composition
f) electrical bulk resistivity
g) sieve analysis
h) aggregate type and content

Because of renovation process in last years, the technical state of the building is satisfactory. However, there are still some places where cracking and damages are visible.

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