Vol. 12, 2023, 116-123

sciendo

DOI: 10.17512/bozpe.2023.12.13

Construction of optimized energy potential

Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Repair of concretes in the underwater part of a water barrage

Wacław Brachaczek[1] (*orcid id: 0000-0002-4782-8409*)
Agnieszka Gałuszka[1*] (*orcid id: 0009-0003-9915-2628*)
[1] University of Bielsko-Biała, Poland

Abstract: The article discusses a technological solution typical for the renovation of hydrotechnical structures. Factors posing a threat to the safety of such structures are presented through the example of the renovation of a barrage. The methodology and the general scope of diagnostic activities necessary for the development of the technical condition assessment were proposed. Exemplary test results and technological solutions for repairing the concrete surface, carried out in the underwater part of the hydrotechnical structure without the need to shut down the facility, are presented. The specificity, the validity of the selection of technology and the beneficial properties of self-compacting concrete laid under water are described.

Keywords: concrete, construction, hydrotechnical engineering, underwater, repair

Please, quote this article as follows:

Brachaczek W., Gałuszka A., Repair of concretes of the underwater part of the water barrage, Construction of Optimized Energy Potential (CoOEP), Vol. 12, 2023, 116-123, DOI: 10.17512/bozpe.2023.12.13

Introduction

Hydrotechnical structures together with devices and technical installations serve and shape water resources and the way they are used and stored. They also protect against the destructive power of water (Act, 2017) The barrage, as an example of a hydrotechnical structure, consists of a transverse dam usually placed on the floodplain of a river. Its task is to accumulate water and create a reservoir. The height and length of the barrage depends on the designed capacity of the reservoir, as well as on the width of the valley, the depth of the river, and the inclination of slopes. The barrage is equipped with bleed devices to regulate the flow. These

* Corresponding author: agnieszkagaluszka@hotmail.com

devices are most exposed to damage because their task is to pass water in a safe way for the damming elements and to ensure the passage of ice, sludge, floating bodies, or rubble (Nowak & Ptak, 2018). In addition, the barrage can be supplemented with a hydroelectric power plant or a navigation lock. Elements of the water barrage include: separation pillars, abutments, fish passes, fish locks and retaining walls (Depczyński & Szamowski, 1999).

1. Factors affecting the durability of water structures

Elements of hydrotechnical structures (Fig. 1), after completion of construction and commencement of operation, mostly remain in constant contact with the water. This poses many difficulties in maintaining proper durability of the structure. Durability is a feature of a structure expressing its ability to maintain stability in the assumed period of use and load-bearing capacity without a significant reduction in performance properties. Degradation and aging processes progress along with the lengthening of the operating period (Hanson & Åke, 1986; Runkiewicz & Hoła, 2018). Physical degradation is caused by the wear and tear of materials and the aging of concrete structures. In the case of water structures, periods of high water and the passage of large amount water through the damming structure are important. These are often the result of extreme events and can cause catastrophic consequences. Each accumulation of water causes filtration through the body of the structure, the ground and abutments (Kańka & Sołtysik, 2009; 2010). However, water flow through the concrete structure is limited to the permeable parts of the structure, for example, the expansion joints, working seams, and the contact between the substrate and concrete. Water in the ground causes a pressure effect on the base of a concrete structure, impairing its stability.

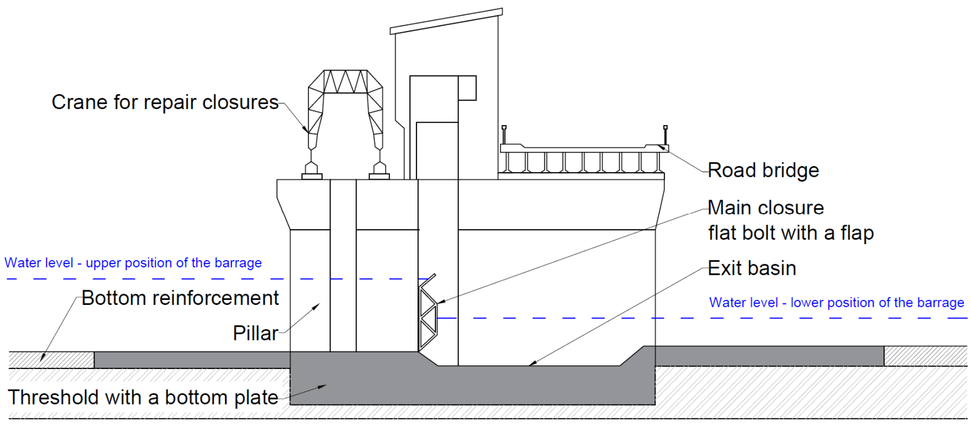


Fig. 1. Schematic cross-section of the barrage (*own research*)

The safety and reliability of existing reinforced concrete structures is assessed using a series of diagnostic activities (Kledyński, 2006; 2011a; 2011b). During operation, hydrotechnical structures are subject to heterogeneous weakening and destruction as a result of the corrosion of elements, load changes, random factors, and other processes. Diagnostic procedures may be applied to entire reinforced concrete structures or only to selected elements, such as damaged elements or elements intended for structural changes or repairs and modernization. In such cases, diagnostic procedures should also cover other structural elements where there is a suspicion that their required levels of reliability and safety of use may have been reduced. (Bień, 2010; IMGW, 2020). The selection of diagnostic methods and techniques should be adapted to the conditions and technical requirements of the diagnosed structures. Non-destructive and semi-non-destructive methods are particularly recommended (Czarnecki et al., 2017). For this reason, the damming structure should be equipped with measuring and control devices appropriate for its class. The technical and safety inspection includes measurements and analysis, as well as ongoing observations and site inspections.

2. Diagnostics of damage to concrete hydrotechnical structures

An important element of controlling the technical condition and safety of a hydrotechnical structure is its regular inspection. Identified and documented irregularities may cause deterioration of the structure's technical condition and safety. Due to the wide spectrum of research and analysis on various types of water objects, selected methods will be discussed that relate to certain parts of concrete damming structures (concrete surface condition, leaks and deformations).

The durability of technical structures is assessed by testing the strength of the concrete elements of the structure. Strength tests are mainly carried out on elements located below ground level, which are in direct contact with water. The tests are usually carried out using the sclerometric method, a method that utilizes a Schmidt hammer and confirms the obtained results with strength tests on core boreholes. In the sclerometric method, it is required to specify the parameter in the form of the so-called reflection number R and correlate it with the compressive strength fc by selecting the appropriate correlation or hypothetical relationship fc-R. The correct application of this method ensures reliable results and requires the absolute application of the test principles given in the works. To ensure and obtain reliable results, the measurement is made in the upper and lower zones of the test subject. When designing hydrotechnical structures, a 40% strength reserve is assumed (Rubin et al., 2017).

The consequence of the degradation processes is the appearance of varying levels of severity of damage that require repair or strengthening. In order to determine the shape of the bottom of the tanks, bathymetric tests are carried out. The purpose of the measurements may be maps of the bottom of water bodies for the purpose of determining the degree of loading of retention and sedimentary reservoirs, determining the available amount of water in reservoirs, locating objects lying on the bottom, and many more. Most often, in the case of the analyzed barrage, the measurements were carried out using a single-beam probe connected to a GPS receiver on the upper position. The measurements made it possible to determine the capacity of the reservoir, the degree of silting and edge abrasion. Measurements of the lower station are used primarily to study the intensity of erosion processes and the degree of washout, and then to identify damage to, for example, structural elements of the exit basin.

3. Measurement results and design assumptions

As a result of bathymetric assessments, serious damage was found on the surface of underwater elements requiring repair or strengthening. The survey showed defects in the concrete of the footings of the pillars and the bottom slabs of the dam up to 15 cm deep, together with the protruding reinforcement. Significant losses in the bottom concrete reinforcements and numerous collapsed and washed away slabs were noted. Washouts and sinkholes are the result of filtration flows. Damage to the expansion joint and concrete slabs in its area was found. The slabs at the lower and upper station were clearly keyed. Figure 2 shows a bathymetric map of the bottom of the reservoir. Changing the elevation of the bottom corresponds to a greater colour intensity on the map.

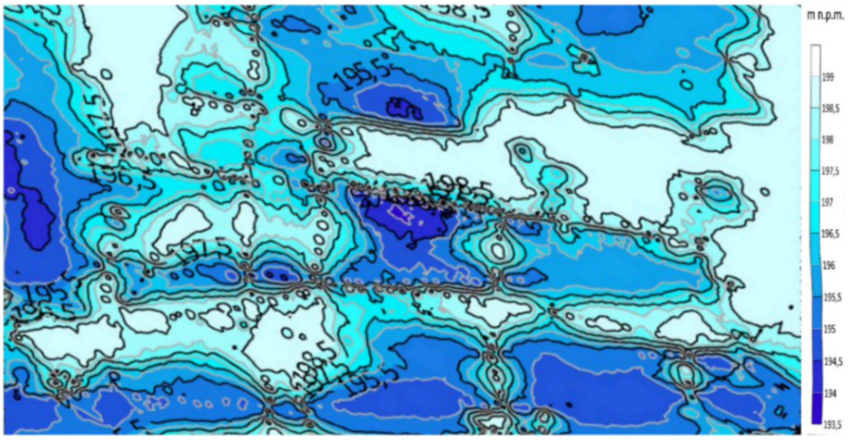


Fig. 2. Bathymetric map of the bottom (*own research*)

On the basis of strength tests carried out using the sclerometric method and laboratory tests on five core boreholes, significant differences in strength were found. In the case of the bottom of the reservoir, the highest strength was found in well-preserved places and it ranged from 25 to 35 MPa, and in degraded areas it was 15 MPa. It was originally assumed that the strength was in the range of 25 to 35 MPa. Based on the results of strength tests, it was found that the strength of concrete for repairs (with a 40% strength reserve added) should be 49.3 MPa, and after 28 days 67.0 MPa, reaching a bulk density of fresh concrete of 2388.00 kg/m^3, a consistency of 590 mm, and a sand point of approx. 40.

To ensure proper stability and safe use of the facility, it is necessary to repair any damaged elements. A renovation project was prepared, which provided for all planned repair activities on the over 60-year-old facility.

4. Formulation and tests

The subject of the discussed repair on the barrage is the concrete bottom slabs (concreting was performed each time on every second slab with dimensions of 6.0 x 8.0 m). In unit formwork, it is necessary to provide for the possibility of making "traps", which will later be chipped and ground). Underwater concrete was used for their construction. The mixture and technology of laying under water were developed on the basis of close cooperation with a construction laboratory and authorized and experienced engineers (Jamroży, 2015; Łukowski, 2003; Owsiak, 2022). For output:

– exposure class XC2 (wet, occasionally dry parts of hydrotechnical structures),
– compressive strength class min. C30/37,
– SF1 consistency (flow diameter 550-650 mm),
– cement strength class 42.5 N,
– W/C (water/cement) = 0.4,

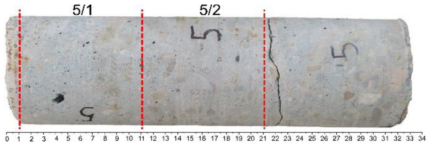
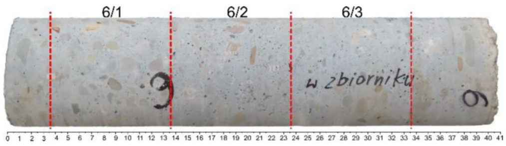
the following composition of the concrete mix was selected for the batch V = 1000 L

– gravel 2/16 (1139.00 kg),
– sand 0/2 (652.00 kg),
– Portland cement CEM I 42.5 N (450.00 kg),
– water (138.00 L),
– superplasticizer strongly reducing mixing water (4.00 kg),
– AWA stabilizing admixture (5.00 kg).

Prior to the commencement of the main works related to placing the concrete mix, experimental concreting was carried out, giving a picture of the adopted solution in real conditions. The container was immersed in water at the site at the depth of the targeted works (Kańka & Sołtysik, 2011). After 28 days, the container was surfaced and Ø100 mm core boreholes were taken for testing (Table 1).

The boreholes were taken using the diamond crown drilling technique. In this way, concrete cores with a diameter of 100 mm were obtained. For compressive strength tests, cylinders with a height equal to their diameter were cut out of the collected cores. Prior to testing, the opposite planes after cutting were ground to obtain smooth and parallel planes. The samples prepared in this way were compressed in a testing machine and the value of the destructive force was determined. The tests were carried out in accordance with the standard (PN-EN 12504-1:2019-08). On the samples that were intended for the compressive strength tests, before their destruction, the bulk density in the state of natural (real) humidity was determined. Based on the obtained results, it was found that the concrete met the requirements for strength class C40/50 (PN-EN 206:2014-04).

Table 1. A summary of the results of concrete tests performed on core boreholes taken from the reservoir (concrete testing report provided free of charge by the PGW Wody Polskie)

No.	The core boreholes with division into laboratory samples	Bulk density [kg/m^3]	Compressive strength f_{is} [MPa]
1		2221 2207	63.0 59.4
2		2285 2287 2250	42.7 59.7 48.1
	Average strength f_{cm} Minimum strength $f_{ci,lowest}$ Characteristic strength $f_{ck,is}$ Strength class	54.6 MPa 42.7 MPa 46.7 MPa C40/50	

A consistency test was carried out on site using the inverted Abrams cone flow method. The test is carried out according to the PN-EN 12350-2: 2019-07 standard – Polish version. It consisted of placing a self-compacting concrete mix in the shape of a truncated cone. The result of the test is the flow diameter of the concrete mix under its own weight after removing the form. Based on the measurement, the consistency class is determined.

After the preparatory works were completed, the main concreting of the bottom slabs began. Approximately 570 m^3 of concrete mix was placed under water. This process was controlled and performed by a team of professional divers. To ensure the reliability of the test results, 60 cubic samples of basic concrete with dimensions of 150 x 150 x 150 mm were tested after 28 days of being under water (Table 2).

The assumed technological properties checked during experimental concreting showed high compliance with the tested samples from the main concreting. The tests showed that the design assumptions were met. The concrete met the minimum requirements of class C30/37 and showed adequate durability required for operation in water conditions (Horszczaruk, 2022; Horszczaruk & Brzozowski, 2013; Horszczaruk & Łukowski, 2006; Horszczaruk et al., 2004; Tracz et al., 2006).

Table 2. List of results of the concrete tests performed on cubic samples (concrete testing report provided free of charge by the PGW Wody Polskie)

Average strength f_{cm} Minimum strength $f_{ci,lowest}$ Characteristic strength $f_{ck,is}$ Strength class	47.9 46.0 45.5 C35/45

Conclusions

The article presents the issues related to the diagnostics and repairs of hydrotechnical structures using the example of a barrage in Krakow. In the diagnostics of the technical condition, the results of measurements using the sclerometric method turned out to be extremely useful. In places immersed in water, it was necessary to take boreholes and conduct a laboratory strength assessment. In the aspect of assessing damage to the existing structure, a useful method was the bathymetric analysis using a single-beam probe connected to a GPS receiver. The introduction of concrete admixtures and plasticizers into general use expanded the area of operation, facilitated the work of contractors and reduced the implementation costs. The tests carried out indicate that the properties of concrete laid under water meet the design assumptions and show satisfactory properties.

Another advantage of this technology is that there is no need to stop the operation of the facility. The issue of repairs of hydrotechnical facilities is very complex and extensive. The topic of innovative technologies is creative and developmental. The progress in engineering materials allows us to discover new areas of activity and effectively replace the previously selected solutions, although it may often seem contrary to logic. This determines the long-term durability and safety of all hydrotechnical structures.

Bibliography

Act of July 20, 2017 Water Law, Journal of Laws 2022.2625, Dz.U. 2017 poz. 1566.

Bień, J. (2010) *Uszkodzenia i diagnostyka obiektów mostowych*. Warszawa, Wydawnictwo Komunikacji i Łączności.

Czarnecki, L., Łukowski, P. & Garbacz, A. (2017) *Naprawa i ochrona konstrukcji z betonu. Komentarz do PN-EN 1504*. Warszawa, Wydawnictwo Naukowe PWN.

Depczyński, W. & Szamowski, A. (1999) *Budowle i zbiorniki wodne*. Warszawa, Oficyna Wydawnicza Politechniki Warszawskiej.

Hanson, G. & Åke, N. (1986) Ground-water dams for rural-water supplies in developing countries. *Groundwater*, 24.4, 497-506.

Horszczaruk, E. (2022) Właściwości reologiczne betonów podwodnych z domieszkami stabilizującymi. *Materiały Budowlane*, 4, 2-4.

Horszczaruk, E. & Brzozowski, P. (2013) *Wpływ przygotowania powierzchni na przyczepność betonów naprawczych układanych pod wodą*. XXVI Konferencja Naukowo-Techniczna, Szczecin.

Horszczaruk, E., Flis, I. & Wąż, S. (2004) *Betony podwodne – właściwości, projektowanie, technologie*. Dni Betonu, Wisła, Stowarzyszenie Producentów Cementu Polski Cement.

Horszczaruk, E. & Łukowski, P. (2006) *Betony podwodne nowej generacji modyfikowane domieszkami kompleksowymi*. Dni Betonu, Wisła.

Instytut Meteorologii i Gospodarki Wodnej, Państwowy Instytut Badawczy (2020) *Wytyczne wykonywania badań, pomiarów, ocen stanu technicznego oraz ocen stanu bezpieczeństwa budowli piętrzących wodę*, Warszawa, Seria publikacji naukowo-badawczych IMGW-PIB.

Jamroży, Z. (2015) *Beton i jego technologie*. Warszawa, Wydawnictwo Naukowe PWN.

Owsiak, D. (2022) https://inzynierbudownictwa.pl/domieszki-do-betonow-podwodnych/ (11.04.2023).

Kańka, S. & Sołtysik, R. (2009) *Przykłady napraw i wzmocnień budowli hydrotechnicznych wykonywanych w technologii betonowania pod wodą*. XXVI Konferencja Naukowo-Techniczna Awarie Budowlane, Międzyzdroje.

Kańka, S. & Sołtysik, R. (2010) Przykłady zastosowania technologii betonowania pod wodą w remontach budowli hydrotechnicznych. *Przegląd Budowlany*, 7-8, 54-57.

Kańka, S. & Sołtysik, R. (2011) https://inzynierbudownictwa.pl/nietypowa-realizacja-fundamentu-pod-woda/ (11.04.2023).

Kledyński, Z. (2006) *Remonty budowli wodnych*. Warszawa, Oficyna Wydawnicza Politechniki Warszawskiej.

Kledyński, Z. (2011a) Monitoring i diagnostyka budowli hydrotechnicznych, cz. 1. *Nowoczesne Budownictwo Inżynieryjne*, Marzec – Kwiecień, 54-61.

Kledyński, Z. (2011b) Monitoring i diagnostyka budowli hydrotechnicznych, cz. 2. *Nowoczesne Budownictwo Inżynieryjne*, Maj – Czerwiec, 36-38.

Łukowski, P. (2003) *Domieszki do zapraw i betonów*. Kraków, Polski Cement.

Nowak, B.M. & Ptak, M. (2018) The effect of a water dam on Lake Powidzkie and its vicinity. *Bulletin of Geography. Physical Geography Series*, 15.1, 5-13.

PN-EN 206+A1:2016-12 Concrete -- Requirements, properties, production and compliance.

PN-EN 12350-2:2019-07 Concrete mix testing - Part 2: Consistency testing using the cone slump method, polish version.

PN-EN 12504-1:2019-08 Testing of concrete in structures - Part 1: Core samples - Collection, evaluation and testing of compressive strength, polish version.

Rubin, O.D., Lisichkin, S.E. & Frolov, K.E. (2017) Methodology for durability calculation of reinforced concrete structures of hydrotechnical erections strengthened by composite materials, *Structural Mechanics of Engineering Constructions and Buildings*, 1, 42-48.

Runkiewicz, L. & Hoła, J. (2018) Diagnostyka techniczna konstrukcji żelbetowych. *Inżynieria i Budownictwo*, 74, 7-8, 397-405.

Tracz, T., Kańka, S. & Radło, W. (2006) *Betonowanie podwodne betonem samozagęszczalnym jako jeden z etapów remontu zapory w Porąbce*. Dni Betonu, Wisła.