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MAIN PHYSICAL-MECHANIC PROPERTIES OF CONCRETE SAMPLES TAKEN FROM BRAŽUOLĖ – FIRST REMOVED DAM IN LITHUANIA

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ABSTRACT

According to historical records, the dam was first built in the 19th century to power a water mill. In this article, the main attention focused on the main physical-mechanic properties of concrete samples taken from Bražuolė dam – first officially removed dam in Lithuania (in 2020). The purpose of these investigations based on field research is to establish actual quantities of compression strength, density, and water absorption by weight of concrete used in the retaining walls of Bražuolė dam. The concrete water absorption by mass (W_m) and compression strength (f_{ck}) testing results based on research data of concrete samples from Bražuolė hydroscheme retaining walls do not meet the requirements of currently valid technical construction regulation.

Key words: concrete samples, dam removal, concrete compression strength, density, water absorption by weight

INTRODUCTION

Fifty eight thousand and seven hundred dams are registered in the International Commission on Large Dams database. A large dam is defined as above 15 m in height, measured from lowest foundation to a crest, or between 5 and 15 m impounding more than 3 million m^3 (0.003 km^3). Within the total amount of large dams, roughly one in eight has a 100 million m^3 (0.1 km^3) capacity (World Register of Dams [WRD], 2020). Design life 50 to 100 years of dams constructed between 1930 and 1970 (when most existing large dams were built) (Perera, Smakhtin, Williams, North & Curry, 2021).

Annual construction of middle and small dams constructed in Lithuania (between 1950 and 1991) is illustrated in Figure 1.

Large, middle size and small dams worldwide were constructed for energetics, irrigation, recreation, fishing, antierosion, etc.

In the 20th century in Lithuania construction of the dams for hydropower stations started with the purpose to use water energy. Some small dams were constructed for the prevention of flooding. In 1926 there were 616 mixed hydropower stations in the country, and in 1939 this number reached 640. During World War II hydropower plants were devastated. However, in the post-war period in Soviet times, dams on small rivers were constructed intensively and mostly in the places of former sites for electricity production. In 1958 there were 100 small hydropower plants in Lithuania. From 1970 to 1989 there was a tradition almost in every collective or state farm to construct a dam and equip reservoir for irrigation,

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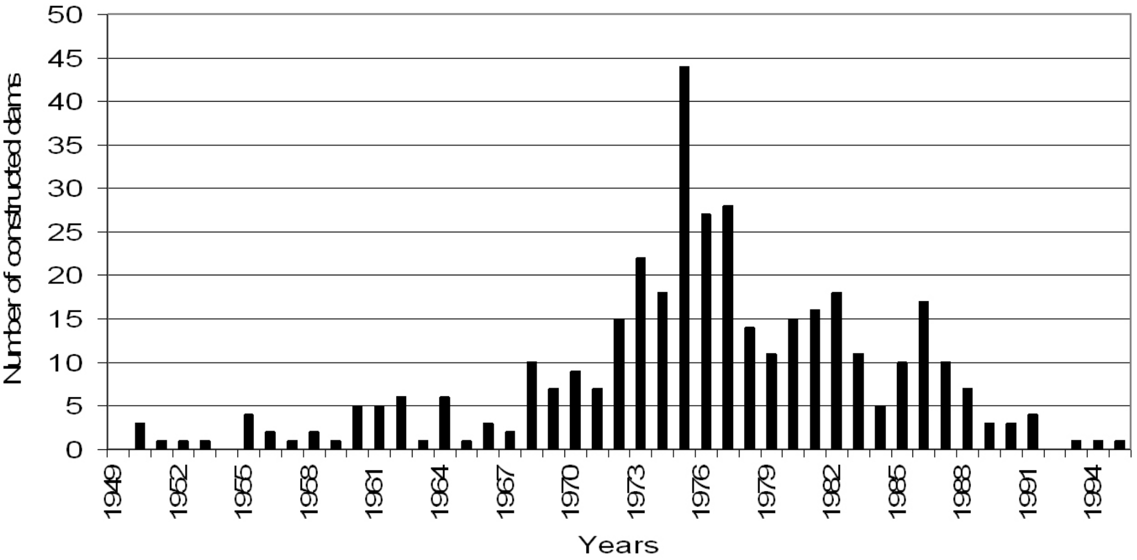

Fig. 1. Annual construction of dams construction in Lithuania (Damulevičius, Rimkus & Vyčius, 2001)

fishery, or recreation. At present, there are more than 1,100 dams with a reservoir area larger than 0.5 ha.

The technical state of dams in Lithuania has been periodically investigated by researchers from the Lithuanian Academy of Agriculture (now – the Vytautas Magnus University Agriculture Academy). The defect and technical state analysis of reinforced concrete hydraulic structures in Lithuania were presented in previous studies as follows: slabs for earth dam slope protection (Šadzevičius, Mikuckis & Ramukevičius, 2011), service bridges (Šadzevičius & Mikuckis, 2010), retaining walls (Šadzevičius, Patašius & Mikuckis, 2009; Šadzevičius, Sankauskienė & Mikuckis, 2013), spillway concrete gravity dams (Šadzevičius, Skominas & Radzevičius, 2021).

Many causes of dam failure have been identified by researchers (Zhang, Xu & Jia, 2009): overtopping, technical deficiencies, poor management, disaster, others, unknown. Researchers found that many public safety incidents occur in the first five years of a dam's operation (Chinese dam failures reported by He, Wang and Huang (2008)), a considerable number of failures (over 75%) have also occurred in dams over 50 years (an analysis of recorded USA's dam failures (Association of State Dam Safety Officials [ASDSO], 2021)). Overall, not all dam failures can be attributed to aging without more detailed data of failures across all ages and failure triggers.

The median age of large dams is higher across much of Europe and North America, between 50 and 100 years. In Lithuania many hydroschemes are older than 40 years, therefore the aging of building materials causes a greater probability of deterioration and even failure. Older dams combined with poor maintenance represent a higher risk to public safety, particularly for downstream areas. In Lithuania were recorded dam failures in 1998 Radviliškis District, in 2005 Kretinga District, in 2007 Telšiai District, in 2011 Plungė and Šilutė District, etc.

Ageing signs include increasing cases of dam failures, progressively increasing costs of dam repair and maintenance, increasing reservoir sedimentation, and loss of a dam's functionality and effectiveness. Public safety, escalating maintenance costs, reservoir sedimentation, and restoration of a natural river ecosystem are among the reasons driving dam decommissioning. Even removing a small dam requires years (often decades) of continuous expert and public involvement and lengthy regulatory reviews. Decommissioning will also have various positive and negative economic, social, and ecological impacts to be considered in a local and regional social, economic, and geographic context that is critical to protect the broader, sustainable development objectives for a region – fisheries, agriculture, tourism, and hydropower will be affected by dam removal and, in turn, impact employment opportunities and livelihoods (Perera et al., 2021).

In this article, the main attention focused on the first official dam removal in Lithuania – the main physical-mechanic properties of concrete samples taken from Bražuolė dam.

The purpose of these investigations based on field research is to establish actual quantities of compression strength, density, and water absorption by weight of concrete used in the retaining walls of Bražuolė dam.

MATERIAL AND METHODS

The object of investigation

According to historical records, the dam was first built in the 19th century to power a water mill. The stone step was 1 m high and 1 m wide and the total length of the dam was nearly 8 m. Initially, it was constructed from large boulders and wood but was rebuilt during the mid-20th century using mainly concrete. It eventually became obsolete and, without a registered owner, was abandoned for decades. The dam was situated on the 22.7-kilometer long river Bražuolė, which has an important role to play in the ecology of the area as it forms part of the Neris Regional Park, a Natura 2000 site. The dam was finally removed in July 2020 (Dam Removal Europe, 2021; Fig. 2).

The tests

The samples from concrete hydraulic structures in Bražuolė hydroscheme (Fig. 3) were taken for a detailed investigation of the main physical-mechanic properties of concrete structures.

By the field investigations and laboratory tests were determined and statistically evaluated main physical-mechanic properties of hydraulic structures – their concrete compression strength, density, and water absorption by weight. Mentioned tests were performed according to building regulations: EN 13791:2007 (European Standard European Committee for Standardization [CEN], 2007), EN 12390-3:2009 (CEN, 2009a), EN 12390-8:2009 (CEN, 2009b), EN 206:2013+A2:2021 (CEN, 2013), LST 1413.10:1997/P:2020 (Lithuanian Standards Board [LST], 2020). These properties are necessary for the

Fig. 2. Dam before and after removal

Fig. 3. Samples from concrete structures in Bražuolė hydroscheme

evaluation of changes in concrete properties under freezing and thawing cycles impact and other durability indices.

The samples from concrete hydraulic structures for evaluation of the concrete water absorption by weight (W_m) were tested using methodology according to LST 1413.10:1997/P:2020 and EN 12390-8:2009 (Fig. 4).

Fig. 4. Samples for the concrete water absorption by weight (W_m)

The concrete water absorption by weight (W_m) calculated according to formula (1):

$$W_m = \frac{m_d - m_s}{m_s} 100 \qquad (1)$$

where:

W_m – water absorption by weight [%],

m_d – mass of the saturated sample [g],

m_s – mass of the dry sample [g].

The concrete samples volume (V) calculated according to formula (2):

$$V = \frac{m_d - m_w}{\rho_w} \qquad (2)$$

where:

V – volume [cm^3],

m_w – mass of sample in the water [g],

ρ_w – density of water [g·cm^{-3}].

The concrete samples density (ρ) calculated according to formula (3):

$$\rho = \frac{m_d}{V} \qquad (3)$$

where ρ is a density of concrete [t·m^{-3}].

We used a non-standard concrete compression strength determination method, worked out by the employees (Vaišvila & Mikuckis, 2005) of the Vytautas Magnus University Agriculture Academy (former the Aleksandras Stulginskis University of Lithuanian University of Agriculture).

Fig. 5. Preparation for compression test of concrete irregular shape samples by concave punches and compression test of concrete by punches

The concrete samples were carefully inspected before the test. Cracked, layered, and with bubbles or pores samples were rejected. The test results are affected by the punches' diameter and the specimen height. Most of the concrete samples were of such a size that they could be tested with punches with the largest diameter ($d = 100$ mm). Before the test, the cavities of the punches of the selected diameter are filled with a leveling mortar with a compressive strength close to that of the concrete under test. The sample is placed on one punch and the second punch goes on top of the sample, in that way the axes of the two punches coincide approximately. The samples were centered in a special device. The concrete compression strength of samples is evaluated by an ordinary compression test. For this purpose, hydraulic compression machines are used (Fig. 5).

The concrete compressive strength of specimens (f_{nch}) is calculated according to formula (4):

$$f_{nch} = \frac{F}{A_n} \tag{4}$$

where:

f_{nch} – irregular shape 0.8–2.0 relative compressive strength of height specimens, evaluated by testing the selected diameter (number) concave punches N·mm^{-2} [MPa],

F – destructive load [kN],

A_n – cross-sectional area of the specimen subjected to the compressive force [mm^2]. This area is equal to the used punch area, as shown in Table 1.

Table 1. Dimensions of punches (Vaišvila & Mikuckis, 2005)

Number of punches	Diameter [mm]	Area [mm^2]
1	35.7	1 000
2	50.5	2 000
3	71.4	4 000
4	100.0	7 850

The concrete compression strength of the samples of irregular shape was calculated into concrete compressive strength of standard cubes of 100 × 100 × 100 mm. Such an evaluation was accomplished using the proposed formulae and corresponding coefficients:

$$f_{4ch} = f_{nch}\,\alpha \tag{5}$$

where:

f_{4ch} – irregular shape 0.8–2.0 relative compressive strength of height specimens, evaluated by testing the selected 100.0 mm diameter (number 4) concave punches N·mm^{-2} [MPa],

$$f_{ck} = f_{nch}\,\alpha\,\eta\,\gamma \tag{6}$$

where:

f_{ck} – standard 100 mm edge length cubes compressive strength of concrete N·mm^{-2} [MPa],

f_{nch} – irregular shape 0.8–2.0 relative compressive strength of height specimens, evaluated by testing the selected diameter (number) concave punches N·mm^{-2} [MPa],

α – irregularly shaped specimens tested concave punches of selected diameter, concrete compressive strength to specimens, tested with concave diameters of 100.0 mm punches, the coefficient of compressive strength of concrete, presented in Table 2.

Table 2. Dependency of coefficient αn on diameter of punches (Vaišvila & Mikuckis, 2005)

Diameter of punches [mm]	35.7	50.5	71.4	100.0
α	0.85	0.93	0.98	1.00

η – irregular shape 0.8–2.0 relative the coefficient of conversion of the compressive strength of the height of concrete tested with concave dies of the selected diameter into that of specimens with a relative height equal to 1 of the concrete strength compressed by concave dies, calculated according to formula (7):

$$\eta = 1.0007(h/d)^{0.1801} \tag{7}$$

γ – irregularly shaped specimens of relative height equal to 1, tested with 100.0 mm diameter concave punches, coefficient of conversion of concrete compressive strength to 100 mm edge length cubes tested in the standard way, concrete compressive strength, for samples with compressive strength up to 10 MPa (for practical calculations = 1).

Dependences established between concrete physical-mechanical properties obtained by the field investigations and laboratory tests were examined by methods of correlation analysis. Formulae of dependences were established, correlation coefficients calculated and their reliability evaluated.

RESULTS AND DISCUSSION

The concrete water absorption by mass (W_m), concrete density (ρ), and compression strength (f_{ck}) testing results based on research data of concrete samples from Bražuolė hydroscheme retaining walls are given in Tables 3 and 4.

Table 3. Determination of water absorption by weight (W_m) and density (ρ)

Sample	Weight of air dry [g]	Weight of dry [g]	Weight of wet [g]	Natural moisture [%]	Water absorption by weight (W_m) [%]	Volume (V) [ml]	Density (ρ) [g·cm^{-3}]
1	2 499.0	2 307.0	2 543.0	8.32	10.23	1 150	2 211
2	3 745.5	3 422.6	3 788.6	9.43	10.69	1 640	2 310
3	3 412.2	3 204.0	3 422.9	6.50	6.83	1 490	2 297
4	2 251.0	2 051.7	2 271.9	9.71	10.73	990	2 295

Table 4. Determination of compressive strength

Sample	F [N]	A_n [mm^2]	f_{nch} [MPa]	α	f_{ck} [MPa]
1	69 200	7 850	8.8	1.0	8.8
2	20 400	4 000	5.1	0.98	5.0
3	22 800	2 000	11.4	0.93	10.6
4	61 000	7 850	7.8	1.0	7.8

Notes: F – destructive load [N]; A_n – cross-sectional area of the specimen subjected to the compressive force [mm^2]; f_{nch} – irregular shape 0.8–2.0 relative compressive strength of height specimens, evaluated by testing the selected diameter (number) concave punches N·mm^{-2} [MPa]; α – irregularly shaped specimens tested concave punches of selected diameter, concrete compressive strength to specimens, tested with concave diameters of 100.0 mm punches, the coefficient of compressive strength of concrete, presented in Table 2; f_{ck} – standard 100 mm edge length cubes compressive strength of concrete N·mm^{-2} [MPa].

According to the analysis of testing results (Table 4), the highest concrete density of 2.31 t·m^{-3} was established in Sample 2, the lowest one (2.21 t·m^{-3}) was observed in Sample 1.

Water absorption in three of four specimens (10.23, 10.69 and 10.73%) was exceeded the 7% limit for hydraulic structures above changing water level and water absorption in all specimens were exceeded the 5% limit for hydraulic structures in changing water levels.

Following earlier valid requirements of regulations, the class of compressive strength of concrete in these structures should have been no lower than B15, these days it would correspond to the C12/15 class. None of investigated Bražuolė hydroscheme concrete samples meets the requirements of these standards.

By currently valid Lithuanian Building Technical Regulation STR 2.05.05:2005 structures, used in the aggressive environmental conditions of XC4 and XF3 exposure classes, must be designed from the concrete whose least strength class is C30/37. None of investigated Bražuolė hydroscheme concrete samples meets the requirements of these regulations.

Concrete average compression strength's (f_{ck}), density (ρ), and water absorption by mass (W_m) functional dependencies were created (Fig. 6).

Concrete average compression strength's (f_{ck}), concrete density (ρ), and water absorption by mass (W_m) reliability of functional dependencies were checked by double correlation. It was found, that dependences are strong ($r_{xy} = 0.98$) and medium ($r_{xy} = 0.4$). Calculated correlation coefficients are reliable, their importance level $p < 0.05$. The established determination coefficient $R^2 = 0.9899$, therefore can be stated that examined strength parameters influence investigated water absorption by 98.99%, another part belongs to the influence of less important parameters. The established determination coefficient $R^2 = 0.3937$ shows strength parameters influence density by 39.37%.

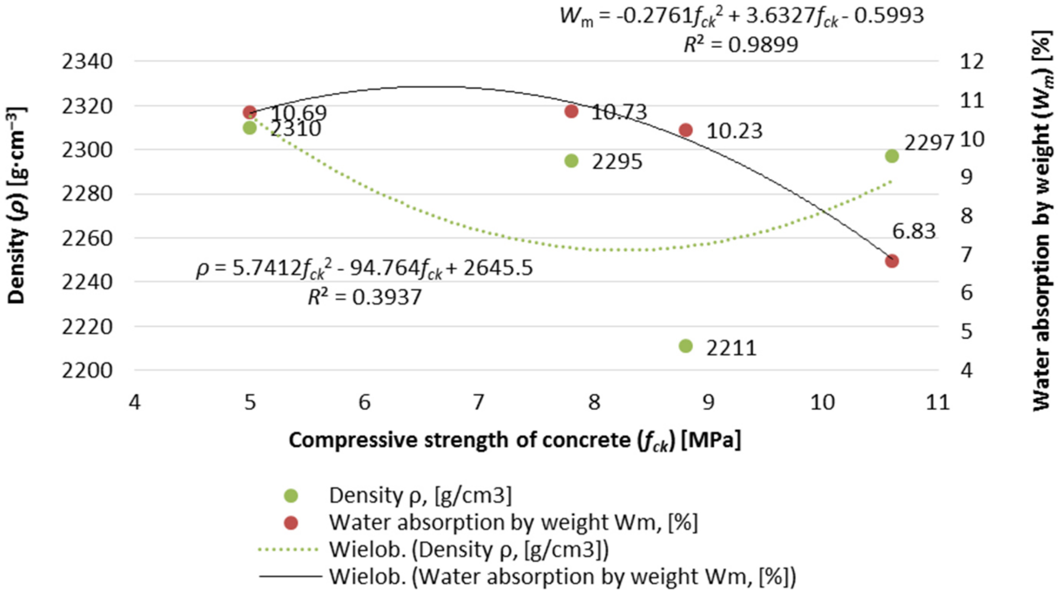

Fig. 6. Relationships between concrete samples water absorption by mass (W_m) and average compression strength of concrete (f_{ck}) and density (ρ) – compression strength of concrete (f_{ck})

CONCLUSIONS

None of investigated Bražuolė hydroscheme concrete samples meets the requirements of currently valid Lithuanian Technical Building Regulation STR 2.05.05:2005.

Assessing the water absorption of concrete specimens from Bražuolė dam it was found that water absorption in three of four specimens (10.23, 10.69 and 10.73%) was exceeded the 7% limit for hydraulic structures in above-changing water level and water absorption in all tested specimens were exceeded 5% limit for hydraulic structures in changing water level.

Analyzing the results of compressive strength of concrete specimens from Bražuolė dam shows that structures were made of weak concrete (the highest value f_{ck} = 10.6 MPa). Nowadays covering layer of reinforced concrete hydraulic structures must be 40 mm and made from concrete with a compression strength of 37 MPa.

The concrete used in the retaining walls of Bražuolė dam was exploited more then 100 years, due to environmental (freezing and thawing cycles, periodically wetting, etc.) impacts and ageing of materials arose defects and deteriorations in the structures. In order to improve the dam's poor technical state – repair or reconstruction should be done these works extends life cycle of dam, but in the Bražuolė dam case another solution was selected – the deteriorated and potentially dangerous for humans retaining walls were demolished and life cycle of this dam was closed.

Authors' contributions

Conceptualization: R.Š. and I.A.; methodology: R.Š.; validation: R.Š., I.A. and K.G.; formal analysis: R.Š. and M.K.; investigation: R.Š.; resources: I.A. and M.K.; data curation: K.G. and M.K.; writing – original draft preparation: R.Š.; writing – review and editing: I.A. and M.K.; visualization: K.G.; supervision: R.Š.

All authors have read and agreed to the published version of the manuscript.

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GŁÓWNE WŁAŚCIWOŚCI FIZYKOMECHANICZNE PRÓBEK BETONU POBRANYCH Z BRAŽUOLĖ – PIERWSZEJ USUNIĘTEJ ZAPORY NA LITWIE

STRESZCZENIE

Według zapisów historycznych zapora została zbudowana w XIX wieku w celu zasilania młyna wodnego. W niniejszym artykule główną uwagę skupiono na podstawowych właściwościach fizykomechanicznych próbek betonu pobranych z zapory Bražuolė – pierwszej oficjalnie usuniętej zapory na Litwie (w 2020 r.). Celem tych opartych na pomiarach terenowych badań jest ustalenie rzeczywistych wartości wytrzymałości na ściskanie, gęstości i nasiąkliwości wagowej betonu zastosowanego w ścianach oporowych zapory Bražuolė. Wyniki badań nasiąkliwości betonu według masy (W_m) i wytrzymałości na ściskanie (f_{ck}) na podstawie danych z badań próbek betonu ze ścian oporowych hydroschematu Bražuolė nie spełniają wymagań aktualnie obowiązujących przepisów techniczno-budowlanych.

Słowa kluczowe: próbki betonu, usuwanie zapór, wytrzymałość betonu na ściskanie, gęstość, absorpcja wody przez masę