Assessment on the Technical State of Spillway Concrete Gravity Dams in Lithuania

Raimondas Šadzevičius*, Rytis Skominas, Algirdas Radzevičius

Vytautas Magnus University, Institute of Hydraulic Engineering, Universiteto 10, LT–53361, Akademija, Kaunas district, Lithuania

*Corresponding author: raimondas.sadzevicius@vdu.lt

Spillway concrete gravity dams are exposed to loads and environment causing deterioration process. The article presents the concrete structure deteriorations, defects and technical state evaluation results of 34 Lithuanian spillway concrete gravity dams performed in 2006–2018. The typical deteriorations are: in piers—crumbled protective layer of concrete, its corrosion, reinforcement corrosion, cracks in concrete, chipped edges; in spillway constructions—concrete corrosion, bio-corrosion, concrete corrosion caused by cavitation; in outflow constructions—concrete corrosion, bigger cracks and deformations. According to results of technical state research, it was found that only 3% (1 SCGD) dams are in good technical state, 27% (9 SCGD) – moderate, 47% (16 SCGD) – satisfactory, 12% (4 SCGD) – unsatisfactory and 12% (4 SCGD) – in critical state.

Keywords: deterioration, environmental impact assessment, spillway concrete gravity dams, technical state.

Introduction

Spillway concrete gravity dams (hereinafter – SCGD) are rather popular because they are good enough to pass a greater floodwater discharges and ice. In Lithuania’s conditions such discharges are over 100–150 m³/s (Damulevičius and Vyčius 2008, Damulevičius et al. 2009, Ruplys 1988). Abroad various propositions are presented (Hydraulics of Dams and River Structures 2004, Novak et al. 2007, Tanchev 2005).


SCGDs are usually included into the combined hydroscheme, which include, for example, embankment dam, hydropower plant (hereinafter – HPP) structure and other hydraulic structures. Such and the most remarkable Lithuanian SCGD is in the hydroscheme of Kaunas HPP. Its maximum afflux (head difference) reaches 20 m, the design flood discharge is 3990 m³/s. Nowadays here are possibilities to build a navigation sluice or lift in Kaunas HPP hydroscheme and fish pass or fish lift.

Worldwide SCGDs that are more impressive are built. The tallest of them are: the Grande Dixence in Switzerland with 285m height (Grande Dixence dam 2020) and Diamer Basha (formerly called Basha) with 272m height (Big Dams 2020). Many rather large SCGDs are built in USA, Russia and in other countries which are mountainous and where strong, rocky soils prevail. These dams are designed in accordance with the requirements of construction technical regulations (EM 1110–2–1603 1990, EM 1110–2–2104 2003, EM 1110–2–2100 2005, EM 1110–2–2200 1995, EM 1110–2–2201
All the hydraulic structures (hereinafter – HS), including spillway concrete gravity dams, are used in complicated conditions of the environmental impact: they are affected by natural (atmosphere, freezing–thawing cycles, ice and swimming solids or sediments abrasive impact, atmospheric precipitation, wind and storm, wave blows; periodical wetting; solar radiation, collapsing impacts; rockslides, earthquakes, etc.) and various technological factors. Due to these factors, various deteriorations appear in the HS constructions; they reduce the bearing capacity of constructions (or spillway) to water pressure, technical state of SCGD constructions decreases. Causes of distress and deterioration of concrete are described very detail in Standard EM 1110–2–2002 (EM 1110–2–2002 1995). It is known, concrete ageing, vibrations in the foundations, accumulation of sediments, water erosion are main factors that reduces dams resistance to failure (Safety of Existing Dams – Evaluation and improvement 1983, ICOLD 1995). The threats (initiating events), 48 hazards, defined may lead to the different modes of failure, are described in work (Almog 2011), but some of them – for example, earthquake loading are not actual in Lithuania.

The numbers of large dams are growing - taking only the approximately 36 000 large dams listed in the World Register of Dams there have been around 300 reported accidents (ICOLD 1995), (ICOLD 2020, Chanson 2000). Some safety evaluation methods of HPP are described in scientific literature (Safety of Existing Dams – Evaluation and improvement 1983).

There are about 620 potentially dangerous ponds with hydraulic structures (if water head is 4 m or more or in ponds accumulated water volume is more then 100000m³) in Lithuania (Tvenkinių katalogas 1998). In Lithuania, dams’ observations and, to a certain extent, researches have been carried out since the dams were built, nevertheless the greatest attention has been focused on the field observations of earthfill dams (Damulevičius 2001, Damulevičius and Vyčius 2007, Šadzevičius et al. 2013). The biggest hydroschemes in Lithuania are: Kruonis PSHEP and Kaunas HEP. The technical state of these objects is monitored, controlled using regulations for maintenance (Šikšnys 2007, Skripkiūnas et al. 2006).

Technical state over 300 dams in Lithuania were investigated by the specialists of Water and Land Management Faculty at the Vytautas Magnus University (hereinafter – VDU). Main attention has been paid to these reinforced concrete (hereinafter –RC) hydraulic structures and constructions: RC slabs for earthfill dams slope protection (Damulevičius and Vyčius 2007), (Šadzevičius 2002, Šadzevičius et al. 2011); culverts and service bridges (Natūrinių ir anketinių duomenų… 2009); service bridges in spillways (Šadzevičius and Mikuckis 2010); retaining (wing) walls (Šadzevičius et al. 2009). At the same time studies of HS technical state evaluation were carried out (Damulevičius et al. 2001, Damulevičius and Vyčius 2007, Šadzevičius et al. 2013, Šadzevičius et al. 2001, Patašius et al. 2009). The researches of the SCGD reinforced concrete constructions state were carried out in 1999–2005 by the specialists of the Department of Building Constructions in Lithuanian University of Agriculture; the results were generalized in the report (Natūrinių ir anketinių duomenų… 2009) and in the paper’s (Damulevičius et al. 2009), (Šadzevičius et al. 2013). Analysis of these, early performed investigations results, shows that currently valid dams’ maintenance regulations should be improved, because of insufficient information about the technical state evaluation process, deterioration of concrete on the safety and reliability of RC hydraulic structures.

The purpose of this research is to describe the main indices and causes of deteriorations appearing in Lithuanian spillway concrete gravity dams, to evaluate the changes of technical state of dams and according to the results of investigation propose the expressions for selecting proper covering concrete layer of designing new reinforced concrete spillways.

In 2006–2018 the spillway concrete gravity dams were inspected in 15 districts of Lithuania: Kėdainiai (8 dams), Marijampolė (6 dams) and in some other regions of Lithuania. Taking into account the materials used for construction, the acting head and ground soil, the investigated objects belong to the consequence classes CC1 and CC2 (STR 2.02.06:2004 2004).
The following constructions’ diagnostic methods were used during the investigation of deteriorations’ state changes in spillways:

1. documentation review;
2. visual–instrumental method;

**Documentation review** – the analysis of design (work drawings and construction projects) and other archival documentation (technical maintenance records, rules of dam maintenance, inspections reports).

**Visual–instrumental method** (Durcheva 1988, Malakhanov 1990) is applied for SCGD field investigations. Noticed defects (broken corners or edges of surface, stratified concrete, etc.) and deteriorations (deteriorated and destroyed concrete covering layer, steel corrosion, etc.) and their intensity were analyzed according to dams’ maintenance regulations (EM 1110–2–2002 1995, The Norwegian regulations for planning... 1996, EM 1110–2–4300 1987). During expeditions and field investigations the location of damaged constructions, the types of deteriorations and their geometrical data (area, depth) were determined. Using simple instruments (a ruler, sliding caliper, etc.) the deterioration of concrete surfaces, depths and patterns of cracks, deformations, scour, pittings, etc. were established. The photos of typical deteriorations of SCGD were taken.

According to the results of field investigations the technical state of SCGD and whole hydroscheme was evaluated in accordance with deteriorations registered during the field observation and using the methodology given in the Lithuanian construction technical regulations (STR 1.03.07:2017 2017): SCGD and hydroscheme were evaluated as functionally related elements – main structures and auxiliary structures. Technical state evaluation was performed using quantitative indices and calculating averages of defectiveness points (Bu,) in ten points criterion system (0 points – ideal state, 10 points – element’s emergency state) following evaluation criteria given in Lithuanian construction technical regulations (STR 1.03.07:2017 2017). If one of main elements which determines SCGD reliability is evaluated from 8.1 to 10.0 defectiveness points, then the technical state of the whole hydraulic structure is evaluated by the same points. If the main elements with defectiveness points from 8.1 to 10.0 are absent, overall (total) points (Bu) of HS technical state are calculated according to the following formula:

\[
B_u = \frac{B_1 + B_2 + \ldots + B_n}{n}
\]

where: B₁, B₂, ..., Bₙ – evaluation points of separate HS elements; n – number of evaluated HS elements.

The calculated points of HS technical state (Bu) are rounded up or down in limits of 0.1 (STR 1.03.07:2017 2017).

**Results**

In this paper the results of research and analysis of 34 SCGD technical state in 15 districts of Lithuania are presented.

The oldest SCGD was built in 1847, the last one in 1997. The investigations were performed in 2006–2018. During the field observation, the main SCGD defects were determined; the general evaluation of SCGD technical state in defectiveness points were calculated (Table 2) in accordance Lithuanian construction technical regulations (STR 1.03.07:2017 2017). The data of investigated SCGD are presented in Table 1 and Fig. 1.
<table>
<thead>
<tr>
<th>No.</th>
<th>Name of hydroscheme</th>
<th>Year of construction (* year of reconstruction works)</th>
<th>Year of research</th>
<th>General evaluation of SCGD state Bu, points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alytus district</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Kumečiai</td>
<td>1968</td>
<td>2009</td>
<td>4.4</td>
</tr>
<tr>
<td>2</td>
<td>Jonava district</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Lokys</td>
<td>1988</td>
<td>2011</td>
<td>5.4</td>
</tr>
<tr>
<td>3</td>
<td>Markutiškių</td>
<td>1989</td>
<td>2011</td>
<td>6.7</td>
</tr>
<tr>
<td>4</td>
<td>Kėdainiai district</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Akademija – Dotnuva</td>
<td>1968</td>
<td>2011</td>
<td>4.6</td>
</tr>
<tr>
<td>5</td>
<td>Angiriai</td>
<td>1980</td>
<td>2006</td>
<td>3.2</td>
</tr>
<tr>
<td>6</td>
<td>Kruostas</td>
<td>1953</td>
<td>2013</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Labūnava I</td>
<td>1977</td>
<td>2012</td>
<td>4.7</td>
</tr>
<tr>
<td>8</td>
<td>Labūnava II</td>
<td>1991</td>
<td>2010</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>Kėdainiai city</td>
<td>1972</td>
<td>2012</td>
<td>4.0</td>
</tr>
<tr>
<td>11</td>
<td>Urkos</td>
<td>1997</td>
<td>2010</td>
<td>9</td>
</tr>
<tr>
<td>12</td>
<td>Kėtinga district</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Darbėnai</td>
<td>1932</td>
<td>2009</td>
<td>3.2</td>
</tr>
<tr>
<td>13</td>
<td>Kretinga park I</td>
<td>1878, 1987</td>
<td>2006</td>
<td>3.9</td>
</tr>
<tr>
<td>14</td>
<td>Lazdijai district</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Kapčiamiestis</td>
<td>1956</td>
<td>2007</td>
<td>4.1</td>
</tr>
<tr>
<td>15</td>
<td>Marijampolė district</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Kazlai I</td>
<td>1991</td>
<td>2009</td>
<td>3.8</td>
</tr>
<tr>
<td>17</td>
<td>Kazlai II</td>
<td>1935</td>
<td>2006</td>
<td>7.8</td>
</tr>
<tr>
<td>18</td>
<td>Marijampolė I</td>
<td>1957, 2008*</td>
<td>2011</td>
<td>4.5</td>
</tr>
<tr>
<td>19</td>
<td>Marijampolė II</td>
<td>1974, 2004*</td>
<td>2011</td>
<td>4.4</td>
</tr>
<tr>
<td>20</td>
<td>Netiškampis</td>
<td>1951, 1991*</td>
<td>2009</td>
<td>7.3</td>
</tr>
<tr>
<td>21</td>
<td>Pakruojis district</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Dvariukai</td>
<td>1982</td>
<td>2011</td>
<td>3.7</td>
</tr>
<tr>
<td>22</td>
<td>Panevėžys district</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Factory „Ekranas“</td>
<td>1980</td>
<td>2018</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Table 1
The data of spillway concrete gravity dams
<table>
<thead>
<tr>
<th>No.</th>
<th>Name of hydroscheme</th>
<th>Year of construction (* year of reconstruction works)</th>
<th>Year of research</th>
<th>General evaluation of SCGD state ( B_u ), points</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Jotainiai</td>
<td>1987</td>
<td>2008</td>
<td>4.5</td>
</tr>
<tr>
<td>24</td>
<td>Pasvalys city</td>
<td>1895</td>
<td>2008</td>
<td>5.1</td>
</tr>
<tr>
<td>25</td>
<td>Švobiskis</td>
<td>1919</td>
<td>2008</td>
<td>5.2</td>
</tr>
<tr>
<td>26</td>
<td>Jundeliškes</td>
<td>1958</td>
<td>2011</td>
<td>6.1</td>
</tr>
<tr>
<td>27</td>
<td>Paupys</td>
<td>1972</td>
<td>2012</td>
<td>5.5</td>
</tr>
<tr>
<td>28</td>
<td>Vilkenai</td>
<td>1847</td>
<td>2007</td>
<td>2.8</td>
</tr>
<tr>
<td>29</td>
<td>Taujēnai</td>
<td>1985</td>
<td>2010</td>
<td>4.0</td>
</tr>
<tr>
<td>30</td>
<td>Vepriai</td>
<td>1974</td>
<td>2010</td>
<td>5.6</td>
</tr>
<tr>
<td>31</td>
<td>Satarečius</td>
<td>1975</td>
<td>2008*</td>
<td>1.0</td>
</tr>
<tr>
<td>32</td>
<td>Pasruojė</td>
<td>1964</td>
<td>2012</td>
<td>9.0</td>
</tr>
<tr>
<td>33</td>
<td>Sukončiai</td>
<td>1953</td>
<td>2012</td>
<td>4.2</td>
</tr>
<tr>
<td>34</td>
<td>Ubiškė</td>
<td>1977</td>
<td>2012</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Fig. 1**
The histogram of construction years of investigated objects

Graphically the results of the SCGD erection are presented in Fig. 1. The most intensive period of SCGD constructing was in 1960–1980. During this period were built 13 investigated objects. According to the data presented in Fig. 1 main part of investigated SCGD are more than 40 years old, only few objects are exploited less than 30 years.

The distribution of the number of investigated SCGD in Lithuania by district is shown in Fig. 2. The results of 34 SCGD technical state investigations are presented graphically in Fig. 3. Summarized results showed that only 3% (1 SCGD) dams are in good technical state, 26% (9 SCGD) – moderate, 47% (16 SCGD) – satisfactory, 12% (4 SCGD) – unsatisfactory and 12% (4 SCGD) – in critical state.
The maximum of dams in critical state (3) was founded in Kėdainiai district. SCGD in unsatisfactory or critical state can be potentially dangerous for the dam surroundings and repair works must be performed immediately. Kruostas, Labūnava II, Urkos SCGD in Kėdainiai district and Pasruojė SCGD in Telšiai district must be rehabilitated or demolished as quick as possible.

Analysing results of pier constructions’ technical state research it was established that after reconstruction, the state of piers’ constructions in Akademija–Dotnuva, Antanavas, Marijampolė I and Marijampolė II and another SCGDs improved, however in hydro-schemes, where the reconstruction haven’t taken place, the state of piers worsens, it has especially worsened in Kruostas, Netičkampis SCGD. Main piers’ deteriorations in the investigated SCGDs are the following: crumbled protective layer of concrete, its corrosion, reinforcement corrosion, cracks in concrete, chipped edges, etc.

Analysing the results of spillway base technical state research, it was established that before reconstruction in Akademija–Dotnuva and Antanavas SCGDs, these constructions had been in an unsatisfactory (bad) technical state (6.5 – 7.0 points). The technical state of spillway base was evaluated as average in those SCGDs, where the reconstruction haven’t taken place, still, the technical state of these constructions has especially worsened in Netičkampis SCGD (7.5 points, unsatisfactory (bad) state) and Kruostas SCGD where it has worsened from 5.5 points in 1999 to 10.0 points in 2005–2011. Main spillway constructions’ deteriorations in the investigated SCGDs are the following: concrete corrosion, bio-corrosion, concrete corrosion caused by cavitation etc.

Analysing the results of outflow constructions’ state research it was found out that before reconstruction in Akademija–Dotnuva and Antanavas SCGDs, these constructions had been in a very bad state (9.0 points) the failure of the whole structure was possible due to considerable deteriorations of the constructions. The technical state of outflow constructions in other SCGDs was evaluated as unsatisfactory (6.1–8.0 points) and only in Labūnava and Kazlai SCGDs the technical state of these constructions was evaluated as satisfactory (4.1–6.0 points). The main deteriorations of outflow constructions are the signs of concrete corrosion, noticed in all the investigated SCGDs. Deformations of retaining walls were noticed in Kėdainiai city, Kruostas, Marijampolė I, Netičkampis SCGDs. Main
causes of SCGDs deformations and deteriorations are: insufficient supervision (Antanavas and Kudirkos Naumiestis SCGD), poor quality of work and low quality of used construction materials (Kruostas SCGD). Relatively rapid deterioration of Kruostas HS was due to low quality of materials – after the core drilling was found clay in some samples (specimen No.7) and laboratory testing of core samples showed the small compressive strength of concrete (Table 2).

During increased accumulation of deteriorations (in some cases of very aggressive environment (acidic brown water from exploited peatbog), insufficient supervision of HS (e.g. Kruostas, Kudirkos Naumiestis SCGD) the SCGDs technical state changing from unsatisfactory to critical.

### Table 2

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Description and location of investigated part</th>
<th>Compression Strength of Specimen $f_{cube}$ (MPa)</th>
<th>Density of hardened concrete $\rho$, kg/m$^3$</th>
<th>Water absorption, $w$, %</th>
<th>Frost resistance $F$, cycles</th>
<th>Thickness of damaged, surface layer, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wall of turbine hall</td>
<td>19.5</td>
<td>2227</td>
<td>8.32</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Wall of HPP from LP side</td>
<td>20.8</td>
<td>2146</td>
<td>9.23</td>
<td>16</td>
<td>3-5</td>
</tr>
<tr>
<td>3</td>
<td>Right wall of HPP from LP side</td>
<td>25.0</td>
<td>2235</td>
<td>8.45</td>
<td>31</td>
<td>1-2</td>
</tr>
<tr>
<td>4 L</td>
<td>Left side of fish pass wall from LP near gates</td>
<td>33.6</td>
<td>2211</td>
<td>9.37</td>
<td>14</td>
<td>&lt;1</td>
</tr>
<tr>
<td>4 R</td>
<td>The right side of fish pass wall from LP</td>
<td>30.2</td>
<td>2071</td>
<td>10.99</td>
<td>-</td>
<td>1-2</td>
</tr>
<tr>
<td>5</td>
<td>II pier from LP, left side</td>
<td>49.2</td>
<td>2282</td>
<td>6.14</td>
<td>118</td>
<td>&lt;1</td>
</tr>
<tr>
<td>6</td>
<td>III pier from LP, left side</td>
<td>49.1</td>
<td>2245</td>
<td>7.04</td>
<td>75</td>
<td>&lt;1</td>
</tr>
<tr>
<td>7</td>
<td>Abutment left side, external 20 cm layer</td>
<td>46.0</td>
<td>2204</td>
<td>9.32</td>
<td>29</td>
<td>1-10</td>
</tr>
<tr>
<td>7</td>
<td>Abutment left side, internal layer *</td>
<td>12.4</td>
<td>5.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Remarks:
* Core No.7 made from two different composition of concrete
HPP – hydropower plant,
LP – lower pool side.
The results of non-destructive testing (Table 2) shows that the highest concrete compression strength was determined in the structures of II and III piers $f_{\text{cube}} = 49.2$ MPa, the lowest concrete compression strength was found in the left abutment $f_{\text{cube}} = 12.4$ MPa. The results of destructive testing shows the lower values of concrete compression strength at the same structures – II pier $f_{\text{cube}} = 42.1$ MPa and III pier $f_{\text{cube}} = 23.4$ MPa, left abutment $f_{\text{cube}} = 5.8$ MPa. It is known (Šadzevičius et al 2015), that the rebound hammer test shows only the state of the surface of concrete. The surface of concrete has higher values (due carbonisation), so the result of compressive strength obtained by examining the drilled cores is more reliable.

The analysis of results of Lithuania SCGD technical state evaluation performed in our research shows, that in investigated regions SCGD technical state is getting worse, due to insufficient supervision, ageing and deterioration of structures. During normal maintenance of HS the damages are accumulate slowly, so the technical state has remained unchanged than repair works performed in some SCGD.

Analysing the results of SCGDs constructions’ technical state research it was established that, similar deteriorations are mentioned in the generalized report of state researches of 287 SCGDs in Norway, which can be found in scientific literature (Jensen 2001). On the basis of these researches, the main reinforced concrete deteriorations in the investigated dams and their causes were established: reinforcement corrosion (noticed in 19 % of researched dams), concrete corrosion (18 %), deteriorations caused by frost (50 %), concrete erosion (47 %), water leakage (21 %), deformations (20 %), concreting defects (43 %), vertical and horizontal cracks noticed in 53% to 56% of the investigated dams; 36% have map cracking and damages in the dam arches.

Above listed main causes of HS defects and deteriorations in Norway SCGD are typical and founded in reinforced concrete HS of Lithuania SCGD too.

The results of field investigations performed on 32 earthfill dams shows, that main damages of RC slabs for slope protection are deterioration of cover layer and collapsing of junctures, noticed in 30% and 50% of objects. (Damulevičius, V.; Vyčius 2007, Šadzevičius 2002, Šadzevičius et al. 2011).

Comparing the research results carried out in 2006–2018 with the results of previous researches (1999–2005) it was found out that the technical state has hardly changed in Kruostas, Labūnava II, Urkos Marijampolė II, Antanavas, Pasruojė SCGDs; the technical state has worsened in Akademija–Dotnuva, Juodkiškis, Kazlai, Jundeliškes, Markutiškiai and Netičkampis SCGDs; the state has improved due to reconstruction in Marijampolė I SCGD. The worst technical state was established in Kruostas and Labūnava II (10.0 points), Urkos and Pasruojė (9.0 points) SCGDs.

The data of research presented are given for designing new reinforced concrete (hereinafter –RC) spillways or repairing the deteriorated parts of structures timely. 30 - 40 mm concrete covering layer, protecting reinforcement from corrosion and its condition shows the durability of whole structure. During research it was noticed the 30 mm concrete covering layer (constructed according design norms of former USSR) of reinforced concrete structures was deteriorated very often. If HS are made from concrete with low quality of materials RC surfaces are damaged much more (Šadzevičius 2007). The maximum speed of deterioration (pitting) deepening (3.67 ÷ 5.06 mm/year) was noticed in structures made of concrete with low average concrete compression strength $f_c = 5.1 ÷ 7.1$ MPa from Antanavas and Kazlai old SCGD. Nowadays covering layer of RC structures must be 40 mm and made from concrete, which compression strength 37 MPa (STR 2.05.18:2005 2006). Using our estimated durability indices $T_{\text{dmm}}$ (Šadzevičius et al. 2010) for designed reinforced concrete spillways, can be chosen concrete covering layer of RC structures, that reinforcement won’t uncover during foreseen time:

**Discussion**
Fig. 4

The relationship between Concrete compression strength $f_c$ - Frost resistance $F$ and Durability indices $T_{40\text{ mm}}$ based on Kruostas SCGD technical state investigations

According to the data presented in Fig. 4, a 40 mm covering layer made of weak concrete ($f_c = 5.8$ MPa) will be deteriorated in 5 years of functioning, while the one made of strong concrete ($f_c = 42.1$ MPa) will be deteriorated in 122.6 years of functioning.

The relationship between frost resistance $F$ and average compression strength of concrete $f_c$ could be expressed:

$$F = 0.0607f_c^2 - 0.3827f_c + 5.0118$$  \hspace{1cm} (3)

where $F$ – frost resistance expressed in cycles; $f_c$ – average compression strength of concrete, MPa.

According to the data presented in Fig. 4, the structures in Kruostas SCGD made from strong concrete ($f_c = 42.1$ MPa) has frost resistance $F=118$ cycles. These structures are less deteriorated.

The most suitable variant for the repair of reinforced concrete in HS is to use cement mortar modified with expansive admixture and to properly prepare the concrete surface (the minimum roughness index of concrete surface must be $R_{\text{min}}=2.92$) (Skominas et al. 2017).

1. According to the technical state investigation of 34 Lithuanian spillway concrete gravity dams performed in 2006–2018, the main deteriorations in the structures of investigated objects are:
   - in piers’– crumbled protective layer of concrete, its corrosion, reinforcement corrosion, cracks in concrete, chipped edges;
   - in spillway constructions’–bio–corrosion, concrete corrosion caused by cavitation;
   - in outflow constructions – concrete corrosion, bigger cracks and deformations.
2. The typical causes of deterioration and deformations of spillway concrete gravity dams are:
   
   - lack of maintenance and insufficient supervision,
   - poor quality of work and low quality of used construction materials,
   - it was established, that main deteriorations of concrete structures are rapidly in progress and caused by the environmental factors (periodical wetting, freezing–thawing cycles, ice and swimming solids or sediments abrasive impacts, wave blows, cavitation and etc.).

3. According to results of technical state investigations of 34 Lithuanian SCGD carried out in 2006–2018 by VDU researchers, it was found that only 3% (1 SCGD) dams were in good technical state, 27% (9 SCGD) – moderate, 47% (16 SCGD) – satisfactory, 12% (4 SCGD) – unsatisfactory and 12% (4 SCGD) – in critical state.

4. The worst technical state was established in Kruostas, Labūnava II, Urkos SCGD in Kėdainiai district and Pasruojė SCGD in Telšiai district, so these dams must be rehabilitated or demolished as quick as possible.

5. According to the results of investigation proposed expressions (2 and 3) for selecting proper covering concrete layer of designing new reinforced concrete spillways. The most suitable variant for the repair of the damaged parts of reinforced concrete spillways is to use cement mortar modified with expansive admixture and to properly prepare the concrete surface.

References


ICOLD. Dams’ safety is at the very origin of the foundation of ICOLD. Available online: URL: http://www.icold-cigb.org/GB/Dams/dams_safety.asp (accessed on 3 September 2020)
LST 1428-17:2016. Concrete - Test methods - Part 17: Determination of frost resistance to volumetric freezing and thawing.
Šadzevičius, R.; Vaišvila, K. A.; Lindišas, L. The research of deterioration of reinforced concrete structures functioning in the alternative level of water


RAIMONDAS ŠADZEVIČIUS
Assoc.prof. dr.
Vytautas Magnus University, Institute of Hydraulic Engineering

Main research area
The evaluation of technical state of hydraulic structures and agricultural buildings. Other directions of research – to evaluate the new principles of repairing or reconstruction, the application of new materials in the reconstruction of hydroshemes and agricultural buildings in Lithuania.

Address
Universiteto 10, LT–53361, Akademija, Kaunas district, Lithuania
Tel. +37060097176
E-mail: raimondas.sadzevicius@vdu.lt

RYTIS SKOMINAS
Assoc.prof. dr.
Vytautas Magnus University, Institute of Hydraulic Engineering

Main research area
Durability, repair and maintenance of hydraulic structures. Other directions of research – green concrete.

Address
Universiteto 10, LT–53361, Akademija, Kaunas district, Lithuania
Tel. +37060014067
E-mail: rytis.skominas@vdu.lt

ALGIRDAS RADZEVIČIUS
Assoc.prof. dr.
Vytautas Magnus University, Institute of Hydraulic Engineering

Main research area
The modelling of sewerage systems, hydraulic structures, application of nano technologies on the improvement of mortars properties.

Address
Universiteto 10, LT–53361, Akademija, Kaunas district, Lithuania
Tel. +37068736574
E-mail: algirdas.radzevicius@vdu.lt

About the Author

This article is an Open Access article distributed under the terms and conditions of the Creative Commons Attribution 4.0 (CC BY 4.0) License (http://creativecommons.org/licenses/by/4.0/).