# ANALYSIS OF ENVIRONMENTAL IMPACT ON SLOPE PROTECTION CONSTRUCTIONS AND ENVIRONMENTAL FRIENDLY SOLUTIONS OF SLOPE PROTECTION REHABILITATION

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**ABSTRACT**
There were investigated 32 Lithuanian earth dam slopes protected with concrete in the years 1998–2011. The purpose of these investigations, based on research in the field, is to evaluate the impacts of environment on reinforced concrete slabs for earth dam slope protection by establishing character and causes of the main deteriorations and ruptures in the slabs. Further goal is to evaluate frost impact on the change of concrete properties and durability of covering layer of the slabs and to suggest environmental friendly solutions of slope protection rehabilitation. During expeditions the structures were visually examined on location and their most deteriorated places were detected, typical defects and deteriorations were measured. Furthermore, regularities of concrete compression strength and water absorbability of reinforced concrete slabs for earth dam slope protection under the influence of freezing–thawing cycles and other environmental factors were determined. Using the durability evaluation method of reinforced concrete slabs for earth dam slope protection created by us, the period left to use the construction till the probable deterioration start ($T_{5\%}$) or end ($T_{50\%}$) may be calculated. Environmental friendly solution for the rehabilitation of slope protection structures is proposed.

**Keywords**: reinforced concrete slabs, frost cycles, concrete compression strength, durability

## INTRODUCTION

There are over 1100 dams in Lithuania presently, that have created ponds bigger than 0.5ha with. Water accumulated in ponds presents a danger for the community and the environment both by the water head and by the accumulated water volume. In Lithuania there are 617 ponds evaluated as potentially dangerous hydraulic structures. The reinforced concrete strengthening slabs (hereinafter - RCSS) are the most popular main coverage of slopes. The monolitic, precast or combine (cast in place - precast) reinforced concrete slabs were used. The reinforced concrete coverage of earth dams were divided in separate section by contraction joints. The covering of earth dams slopes was constructed and arranged in accordance with building standards and regulations. Reinforced concrete strengthening slab constructions are exploited in rather hard conditions. They are under the impacts of various loads and aggressive environment: atmosphere, water medium (surroundings), ice, etc. The main slope coverage is in the most intensive ice and water waves impact zone B (*Figure 1*), the reinforced concrete slabs for earth dam slope protection deteriorate and lose their durability.

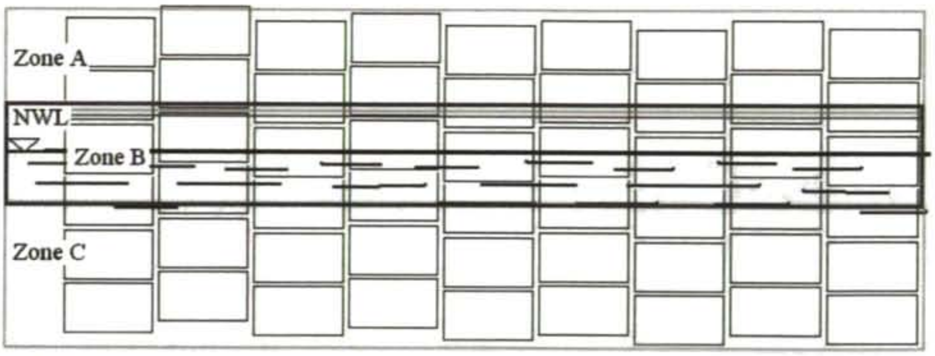


**Figure 1. The zones of reinforced concrete coverage of earth dams**

Durability depends on the maintenance circumstances, surveillance, timely repair of structures or reconstructions. The reinforced concrete is a durable material, but like any other one it is deteriorated in time. Many hydraulic structures on hydroschemes in Lithuania are older than 30 years, therefore the ageing of building materials causes greater probability of deterioration. Deteriorations of constructions create not only favorable conditions for rapid destruction of the structure, but can cause crash of the whole construction as well. Evaluation of environmental factors [freezing–thawing (hereinafter – frost) cycles, ice loads] and the deterioration process (erosion, construction defects and deterioration development) speed of slabs caused by them, and slabs durability prognosis is the main problem. Level of its research is inadequate.

**Frost cycles.** Analysis of various researchers' works (RAMONAS, 1995; GURSKIS, 1996) about the influence of frost cycles on the concrete of hydraulic structures showed, that so far, in the scientific literature the method for the determination of slab durability based on the evaluation of change of main physical–mechanical properties of the concrete under the influence of frost cycles is not sufficiently discussed.

**Defects and deteriorations.** For the classification of defects and deterioration of civil, industrial and hydraulic structures, for their state evaluation there is paid much attention in Lithuanian and foreign scientists' works (КАВЕШНИКОВ, 1989; KAMAITIS, 2000; JOKŪBAITIS AND KAMAITIS, 2000; VAIŠVILA ET AL., 2001). The state of structures and constructions is evaluated according to the main indices of defects and deterioration and is expressed by the method of grades (points, sorts, categories). Analysis of the literature and the currently used building standards and regulations shows that archetypical defects and technical state of RCSS is not described very strictly. There is a lack of information about the impact of defects on the durability of these structures.

The purpose of these investigations, based on research in the field, is to evaluate the impacts of environment on reinforced concrete slabs for earth dam slope protection by establishing character and causes of the main deteriorations and ruptures in the slabs. Further goal is to evaluate frost impact n the change of concrete properties and durability of the covering layer of the slabs and to suggest environmental friendly solutions of slope protection rehabilitation.

## MATERIAL AND METHOD

There were investigated 32 earth dam slopes protected with reinforced concrete slabs for the years 1998–2011. The structures were visually examined on location and their most deteriorated places were established, typical defects and deteriorations were measured. By the field investigations and laboratory tests (by standard methods) the main physical–mechanical properties of RCSS – their concrete compression strength and water absorbability were determined and statistically evaluated. The compression strength of concrete structures was estimated by nondestructive and destructive methods in accordance with the standard and instructional manual of the instrument devices.

By the statistically evaluated research results of RCSS, concrete compression strength and water absorbability were calculated rates of concrete resistance to frost. We used a new, nonstandard concrete frost resistance mark determination method worked out by the employees of the Department of Building Constructions at the Lithuanian University of Agriculture (hereinafter – Dept. of Building Constructions), where this property is approximately evaluated by concrete compression strength and water absorbability (VAIŠVILA ET AL., 2002; VAIŠVILA ET AL., 2003; VAIŠVILA ET AL., 2004).

Knowing compression strength $f_c$ of the concrete (LST EN 12504-2:2003, LST EN 12390-3:2003-12), water absorbability by mass $W_m$ (LST 1428.18:1997) and allowed or forecasted loss of the concrete strength $\Delta f_c$, it is possible to estimate laboratory frost cycles number $n_{50}$ (ГОСТ 10060–87):

$$n_{50} = c \cdot \Delta f_c^{-d}, \quad (1)$$

where

$n_{50}$ – numbers of laboratory frost cycles freezing samples until –55±2° C by ГОСТ 10060–87,

$\Delta f_c$ – concrete strength loss in % due the influence of frost cycles, calculated by LST 1428.17:2005,

$c,d$ – coefficients found in the tables made by employees of Dept. of Building Constructions (VAIŠVILA et al, 2002).

As far as concrete frost resistance mark $F$ shows the number of frost cycles $n_f$ when samples are freezed in –18±2° C, the number of standard cycles is calculated by Dept. of Building Constructions employees' formula (VAIŠVILA ET AL., 2004):

$$n_F = 34.848 \cdot n_{50}^{\,0.6157}. \quad (2)$$

Evaluating the impact of frost cycles on the change of investigated RCSS concrete physical–mechanical properties the frost resistant indices $F_{50\,\%}$ were used.

According to the construction regulations (Рекомендации …, 1990), deterioration end was fixed by the number of cycles $F_{50\,\%}$, where the concrete compression strength of the 25–30 mm thick outer concrete layer (hereinafter – covering) shrinks twice, i.e. to 50% of the estimated strength during the research.

Natural frost cycles, by means of corrective coefficients (chosen by Dept. of Building Constructions employees made graph), were recounted into laboratory freezing–thawing cycles (from –18° C to +18° C) and further recalculated to the indices of structures durability – probable deterioration end time $T_{50\,\%}$.

## RESULTS

At present time the technical state of reinforced concrete structures of functioning hydraulic structures in Lithuania is not the same. There is a number of earth dam slope covering structures being in almost good condition, others are less or more deteriorated. The results of field investigations of 32 earth dam slope protection slabs show that the mostly occurred defects and deteriorations of slab were: deterioration of cover layer (11 from 32 objects) and collapsing of junctures (16 from 32 objects) at 34% and 50% of the researched objects, respectively. It was established, that cover layer and juncture defects are caused by the environmental (frost cycles; ice, wave blows; moss, grass, bushes roots, collapsing impacts; periodical wetting, etc.) impacts, appearing in degradation processes (concrete and reinforcement corrosion, erosion, biological actions). It was noticed during the expedition, that RCSS are mostly eroded by the ice thermal expansion load.

Deterioration processes mostly break the badly made covering layer (small concrete strength and frost resistance) which, being under the influence of frost cycles, crumbles. Its physical–mechanical properties change, form deteriorations, pitting. Most intensively, the concrete is destroyed due to the impact of ice and waves (changing water level) on zone B. Also main attention must be paid to the zones where deterioration and defects are often formed – pitting is formed in the changing water level in flow compression zone: the inflow part of shaft spillways or in the flow parts of overflow spillways. The rate of erosion is dependent on a number of factors including the size, shape, quantity, and hardness of particles being transported, the velocity of the water, and the quality of the concrete. While high–quality concrete is capable of resisting high water velocities for many years with little or no damage, the concrete cannot withstand the abrasive action of debris grinding or repeatedly impacting on its surface. In such cases, abrasive erosion, ranging in depth from a few millimeters to a meter or more, can happen depending on the flow conditions. There are several reasons (mentioned above) forming pitting, but we focused the main attention on the erosion of concrete by the influence of frost cycles (ŠADZEVIČIUS, 2007).
By the statistically evaluated research results of RCSS, concrete compression strength and water absorbability were calculated rates of concrete resistance to frost and further recalculated to the indices of structures durability – probable starting ($T_{5\,\%}$) and ending time ($T_{50\,\%}$) of deterioration. Relationship between durability indices $T_{50\%}$ and average compression strength of concrete $f_c$ and water absorbability $W_m$ is shown in *Figure 2*.

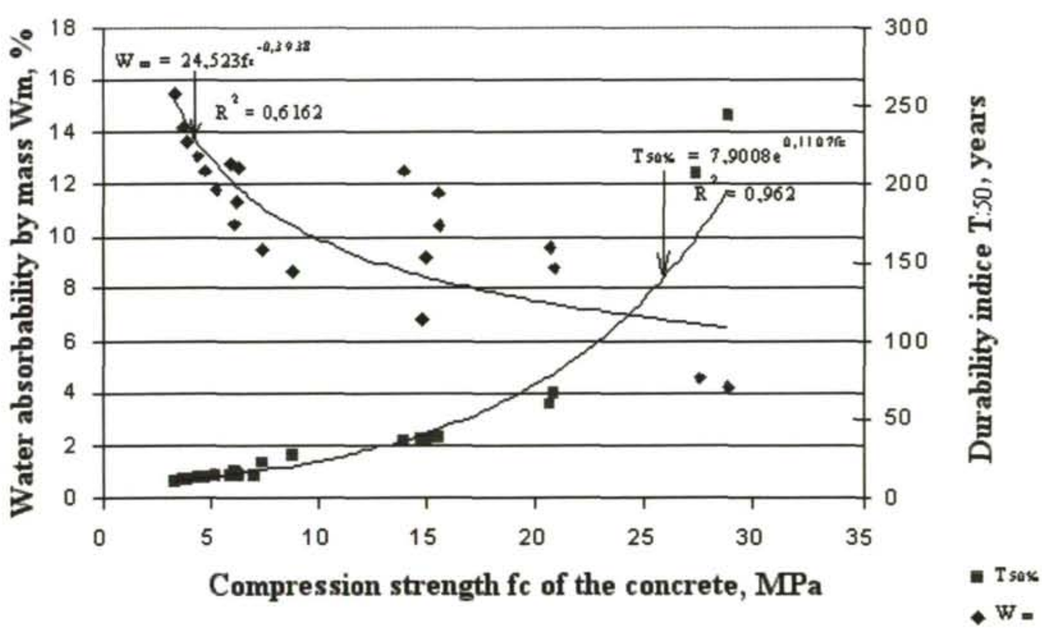


**Figure 2. Relationship between durability indices $T_{50\%}$ and average compression strength of concrete $f_c$ and water absorbability $W_m$**

The probable deterioration end time $T_{50\%}$ (covering layer strength $f_c$ loss under the frost influence by 50%) may be expressed by

$$T_{50\%} = 7{,}9008\ e^{0{,}1107 fc}, \qquad (3)$$

To illustrate how fast concrete covering layer losing the strength under the frost influence were calculated indices of structures durability – probable deterioration end time $T_{50}$ in Grauzes hydroscheme (Kaunas distr.). The calculation results are shown in *Table 1*.

**Table 1. The calculation results of durability indices based on determined and statistically evaluated main physical–mechanical properties of RCSS**

| Date | 2011.04 | | | | |
|---|---|---|---|---|---|
| Indices | $f_c$, MPa<br>$W_m$, % | $F_{5\%}$, cycles | $F_{50\%}$, cycles | $T_{5\%}$, years | $T_{50\%}$, years |
| Zone B | 18.0<br>7.7 | 66.2 | 249.7 | 13.2 | 50.0 |
| Zone A | 30.4<br>5.6 | 113.8 | 558.3 | 22.8 | 111.7 |

$f_c$: compression strength of the concrete;
$W_m$: water absorbability by mass;
$F_{5\%}$ and $F_{50\%}$: number of cycles, where the concrete compression strength of the 25–30 mm thick concrete covering layer shrinks 5% and 50%;
$T_{5\%}$ and $T_{50\%}$: the period left to use the construction till the probable deterioration start or end, respectively.

According to the data presented, a 30 mm covering layer made of weaken concrete ($f_c$ = 18.0 MPa) will be destroyed in 50.0 years of functioning, while the one made of stronger concrete ($f_c$ = 30.4 MPa) will be destroyed in 111.7 years of functioning. As it can be seen in *Table 1*, concrete is weakening under ice and waves impact (changing water level) in zone B, so this zone should be protected with structure of higher strength, or should be protected with environmental friendly solutions of slope protection.
Usually, in Lithuania streambank protection methods involve such rigid structural approaches as rip-rap, concrete, dikes, fences, asphalt, gabions, matting, and bulkheads which, directly and indirectly, have influenced the characteristics of riparian areas.
In the last years, the application of bioengineering techniques has favoured the planning of protective structures with a lowered environmental impact: sunken fascine rolls, anterior stakes, wattle work, live brush mattresses, brushlayers, crib groynes with cuttings (living groynes), etc. Today in Lithuania has just been started the application of one of the environmental friendly methods, the earth dam slope protection using flexible solutions – geocells (geogrids).

## CONCLUSIONS

The results of field investigations of 32 earth dam slope protection slabs show that the mostly occurring defects and deteriorations of slabs are: deterioration of cover layer and collapsing of junctures at 30% and 50% of the researched objects, respectively.
The influence of frost on the change of physical–mechanical properties and on the durability of covering layer of reinforced concrete slabs was evaluated. By means of the evaluation, knowing values of structures concrete strength $f_c$, water absorbability $W_m$ and allowed or forecasted loss of the concrete strength $\Delta f_c$, using function (3) the main indices of reinforced concrete slab durability can be calculated – the probable deterioration end time $T_{50\%}$ (covering layer strength $f_c$ loss under the frost influence by 50%).
Using function (3) for designed reinforced concrete strengthening slabs which are on the changing water level, concrete of such strength can be chosen, that reinforcement of these structures will not uncover during the foreseen time.

For the rehabilitation of slope protection structures in Lithuania, it is suggested to use environmental friendly solutions such as geocells (geogrids).

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