DEFECT ANALYSIS OF REINFORCED CONCRETE SLABS FOR EARTH DAM SLOPE PROTECTION

Raimondas Sadzevicius, Feliksas Mikuckis, Dainius Ramukevicius
Lithuanian University of Agriculture,
Department of Building Constructions
raimondas.sadzevicius@lzuu.lt; sk@lzuu.lt; dainius.ramukevicius@lzuu.lt

ABSTRACT

Many of hydraulic structures on Lithuania hydroschemes are older than 30 years; therefore, the ageing of building materials causes greater probability of deterioration and even failure. Every reinforced concrete construction of hydraulic structures is getting worse with time, but especially often there are deteriorated reinforced concrete slabs for earth dam slope protection. Due to environmental impacts some deteriorations of the slabs take place, which influence negatively not only some slabs, but after their failure the danger arises for the whole slope protection, for the reliability, durability and safety of the hydraulic structure in general. If dangerous defects and deteriorations are not repaired in time, big technical and ecological loss may occur. From the economic point of view execution of new slope protection is more expensive; therefore, a more topical problem is to preserve the present reinforced concrete slabs by means of restoration and/or reconstruction. The main defects and deterioration of reinforced concrete slabs for earth dam slope protection, the character and causes of ones are described in the article; the technical state of strengthening slabs was estimated by points. It is established that rupture of slabs of hydroschemes in the time being was caused in many cases by unfit manufactured concrete, which properties do not satisfy the requirements of usage; the influence of aggressive environments, unfit exploitation. The data of the investigations published in the article are given for improvement in designing new strengthening slabs, repairing the damaged part of the construction timely.

Key words. Defects, reinforced concrete slabs, technical state.

INTRODUCTION

The slopes of earth dams are effected by external climatic and other factors (Building standards STR 2.05.15:2004): water, waves, ice, wind, atmospheric conditions (high and low temperature, solar radiation, humidity, frost cycles, etc.), ground, vegetation and even burrow animals, livestock and so on.

Earth dam slopes protection methods involve such structural approaches as rip-rap, stone pitching, concrete (slabs, concrete filled bags), dikes, fences, asphalt, gabions, matting, bulkheads, geosynthetic lining systems etc. Reinforced concrete strengthening slabs are the most popular coverage of earth dam slopes in Lithuania. The covering of earth dam slopes were constructed and arranged in accordance with the building standards and regulations (STR 2.05.17:2005; ST 2079337.09:2000).

The main slope coverage is in the most intensive ice and water wave impact zone. The monolithic, precast or combine (cast in place - precast) reinforced concrete slabs were used. The reinforced concrete coverage of earth dams was divided in separate sections by contraction joints (Webber et al., 1987). At present the state of every reinforced concrete strengthening slab in functioning hydraulic structure (here and after HS) is unequal. There is a number of strengthening slabs functioning almost well, others are more or less deteriorated (Damulevicius et al., 2001; Damulevicius, Vycius, 2007; Sadzevicius, 2002). The regulations (Building standards STR.1.12.03:2006) briefly describe the state of upstream slopes and discount the condition of reinforced structures. In order to evaluate the type of physical deterioration and the technical state of strengthening slabs, a mass of initial data must be collected. Reinforced concrete is a durable material, but like any other it is deteriorated in time. Deteriorations of constructions create not only favorable conditions for rapid destruction of the structure, but can cause crash of the whole construction as well (Vaišvila, Vilkas, 1998; Vaisvila et al., 1999).

The purpose of these investigations, based on the research in the field, is to identify the shortcomings during the construction aging, to clarify characteristic breakdowns, failures, to establish the character and causes of the main defects in the reinforced concrete strengthening slabs.

MATERIALS AND METHODS

In 1998-2011 the reinforced concrete strengthening slabs of 30 HS were investigated in the field. The actual quantities of the main physical-mechanical properties of concrete, defects and deteriorations of

the structures were established. The principal attention was located to establish the actual quantities of the compressive strength, main deteriorations and ruptures in reinforced concrete strengthening slabs.

The compressive strength of concrete of the structures was estimated by nondestructive methods in accordance with the Standard and instructional manual of instrument devices requirements (Building standards LST ISO 4012:1995; LST 1428.11.1996; LST 1428.14:1997).

The concrete compressive strength of strengthening slabs evaluation was performed by using the standard Schmidt E. – hammer apparatus (Building standards LST 1428.11.1996). The sufficiency of quantity impact produced with nondestructive apparatus was controlled in accordance with the manual requirements. The calibration curves of the mentioned apparatus to calculate the strength of the tested concrete were used. We prepared split concrete pieces from the structure for testing the compressive strength of concrete by the destructive method. The split concrete pieces were placed in hermetically sealed polythene sacks and carried to the laboratory for tests. The structures on location were visually examined and their most deteriorated places, the character of defects, area and the depth of cracks and deteriorations were established.

On the basis of the field investigations the main deterioration and rupture of reinforced concrete strengthening slabs character and causes of ones are described, the technical state of the strengthening slabs was evaluated by defectiveness points (B_u,) in the ten point criterion system by the standing construction regulations STR 1.12.03:2006: 0 points – ideal condition, 10 points – emergency condition.

The detailed point determination is presented below:

- element condition meets the requirements of the construction regulations, irregularity is small — 0 < $B_u \leq 2.0$ points (good condition);
- deterioration of the element has no influence to the strength and normal maintenance of the dam, small deteriorations are recorded – $2.1 < B_u \leq 4.0$ points (moderate condition);
- deterioration of the element does not have important influence to the strength, reliability and the actual service life of the element, some defects and deteriorations are significant – $4.1 < B_u \leq 6.0$ points (satisfactory condition), the technical state can be improved by repairing;
- deterioration reduces the strength and reliability of the element very much, defects and deteriorations are significant – $6.1 < B_u \leq 8.0$ points (unsatisfactory condition), big repair needed;
- remarkable deterioration and maintenance of the element is impossible – $8.1 < B_u \leq 10.0$ points (critical condition), the dam should be reconstructed.

RESULTS AND DISCUSSION

In the paper the data and analysis of reinforced concrete strengthening slabs of 30 functioning HS are presented. The investigations were performed in 1998-2011.

For investigations hydraulic structures were selected in various regions of Lithuania. The investigated structures were built in different time. The selected ones are located in Alytus, Anyksciai, Birzai, Kaunas, Kedainiai, Marijampole, Joniskis, Pasvalys, Raseiniai, Ukmerge and Utena districts (Tvenkiniu katalogas, 1998).

The data of the investigated HS: the actual service life, the average compressive strength of concrete, deterioration and defects of reinforced concrete strengthening slabs, conditions of them in points are given in Table 1.

Table 1

Data of investigated strengthening slabs

No	HS, Age of constr., years	Compressive strength, MPa	Character of deterioration and defects	Causes of deterioration rising	Condition, points
1	2	3	4	5	6
			Alytus district		
1.	Krokialaukis 26	14.7±1.4	Scour, deformation of dam slope protection slabs, collapsing of joints	Mounting inaccuracy, damaged joints, wave blows	8.7
			Anyksciai district		
2.	Elmininkai 24	16.0±0.8	Scour, deformation of dam slope protection slabs	Damaged joints by grass, bushes roots, wave blows	8.5
3.	Leliunai 11	19.8±1.0	Deformation of dam slope protection slabs	Damaged joints, wave blows	6.0

Continuation of the Table 1

1	2	3	4	5	6
4.	Pagoje 10	12.7±0.6	Damaged joints, deteriorated surfaces	Concrete, which properties do not satisfy requirements of usage (weak concrete), damaged joints	5.0
			Birzai district		
5.	Ageniskis 32	11.8±0.4	Damaged joints	Damaged joints by grass	7.0
6.	Gulbinai 32	24.3±1.2	Damaged joints, corrosion of reinforcement and concrete,	Damaged joints by grass	7.0
			Kaunas district		
7.	Gailiusiai 29	9.1±0.4	Damaged joints, damaged surfaces	Weak concrete, damaged joints	5.9
8.	Grauze III 37	7.1±0.4	Damaged joints, damaged surfaces, corrosion of reinforcement and concrete,	Weak concrete, damaged joints by grass, bushes roots, thin covering layer	7.7
9.	Muniskiai 24	8.3±0.7	Deteriorated surfaces	Weak concrete, frost cycles	7.2
			Kedainiai district		
10.	Angiriai 34	7.9±0.6	Light irregularity		4.2
11.	Kruostas HPS 49	5.5±0.2	Damaged joints, deteriorated surfaces	Concrete, which properties do not satisfy requirements of usage (weak concrete), damaged joints, frost cycles	6.1
			Marijampole district		
12.	Antanavas HPS 51	6.0±0.4	Biocorrosion, deformation of dam slope protection slabs	Exploitation denormalization	8.6
13.	Marijam-pole 67	6.0±0.9	Damaged joints, deteriorated surfaces	Mechanical rupture	7.8
14.	Jure 23	9.8±0.5	Defects of surface, pittings, corrosion of reinforcement and concrete, damaged joints	Weak concrete, damaged joints, exploitation denormalization, thin covering layer	7.9
15.	Kazlai 18	7.7±0.4	Light irregularity		3.0
16.	Pilve-Vabalksnis 45	9.6±1.4	Unallowable strain of elements, scour	Undercut basis of slabs, weak concrete	9.0
			Joniskis district		
17.	Berzenai	13.3±1.0	Damaged joints, deteriorated surfaces	Seepage, damaged joints by grass, frost cycles	5.1
18.	Linkaiciai	15.3±0.6	Deteriorated surfaces	Weak concrete, frost cycles	4.3
			Pasvalys district		
19.	Smilgiai 33	20.0±0.6	Biocorrosion, damaged joints	Damaged joints by grass	5.0

Continuation of the Table 1

1	2	3	4	5	6
20.	Svobiskis 89	29.3±1.2	Biocorrosion, damaged joints	Damaged joints by grass	4.0
21.	Paiesmenys 36	24.0±0.8	Biocorrosion, damaged joints	Damaged joints by grass	6.0
			Raseiniai district		
22.	Anulynas 20	6.2±0.7	Defects of surface, pittings, corrosion of reinforce and concrete, damaged joints	Weak concrete, damaged joints, exploitation denormalization, thin covering layer	8.1
23.	Kaulakiai 19	15.0±1.2	Damaged joints, deteriorated surfaces	Weak concrete damaged joints by grass, frost cycles	6.8
24.	Musia 17	23.1±1.2	Light irregularity		3.0
			Ukmerge district		
25.	Ukmerge 29	29.3±0.8	Damaged joints, deformation of dam slope protection slabs, deteriorated surfaces	Damaged joints by grass, wave blows, weak concrete	4.0
26.	Virksciai 33	13.8±0.7	Damaged joints	Damaged joints by grass	5.0
			Utena district		
27.	Utena 34	20.2±0.6	Damaged joints, deformation of dam slope protection slabs	Damaged joints by grass, wave blows	4.0
28.	Nemei-ksciai 28	22.9±0.9	Damaged joints	Damaged joints by grass	4.0
29.	Biliakiemis 29	17.1±0.6	Damaged joints	Moss, grass, bushes roots	7.0
30.	Packenai 34	22.9±0.6	Damaged joints	Moss, bushes roots	7.0

The most damaged reinforced concrete strengthening slabs (in critical condition) are in Krokialaukis, Elmininkai, Antanavas, Anulynas, Pilve –Vabalksnis hydroschemes. Rehabilitation of these hydroschemes is necessary.

The actual service life of the oldest hydraulic structure is 89 years and 10 years of the last one. The strongest concrete with average compressive strength 29.3 MPa was established in the slabs of Ukmerge HS, the weakest one – 5.5 MPa in the structures of Kruostas HPS. The surfaces of the structures manufactured with stronger concrete were less damaged. Concrete is affected in the changing water level most intensively. Pittings on the surface of the structures proceed rapidly in this zone. The possibility of damages of the covering layer is created by sufficient conditions for corrosion of reinforcement. Defects are in progress then joints are damaged (25 from 30 investigated objects). The bad exploited joints were damaged by the weeds or even scrubs. Roots of scrubs can break reinforced concrete strengthening slabs (Fig.1).

It was noticed during the expedition, that all the investigated surfaces of the earth dam slopes slabs in the zone of the changing water level are more or less deteriorated in form of pitting. There are several reasons of forming pitting, but the main is– erosion of concrete by the influence of frost cycles (Fig. 2). The surface of the structures on the changing water level zone is touched by ice, swimming solids or sediments (especially gravel) abrasive impact. After establishment, which impact is the most actual in separate ponds, there is a need to explore in more detail the pitting appearance reasons. Other reasons of concrete erosion presented in literature, for instance, cavitations, are less found in our researched structures, because in the researched ponds, the water flow pulsation speeds are small (<2m/s).

It was established, that the cover layer and junctures defects are caused by 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). Deterioration processes mostly break badly made covering layer (small concrete strength and frost resistance), which being under the influence of frost cycles crumbles, its physical–mechanical properties change, forms deterioration – pitting. Most intensively concrete is destroyed in ice and wave impact (changing water level) zone.

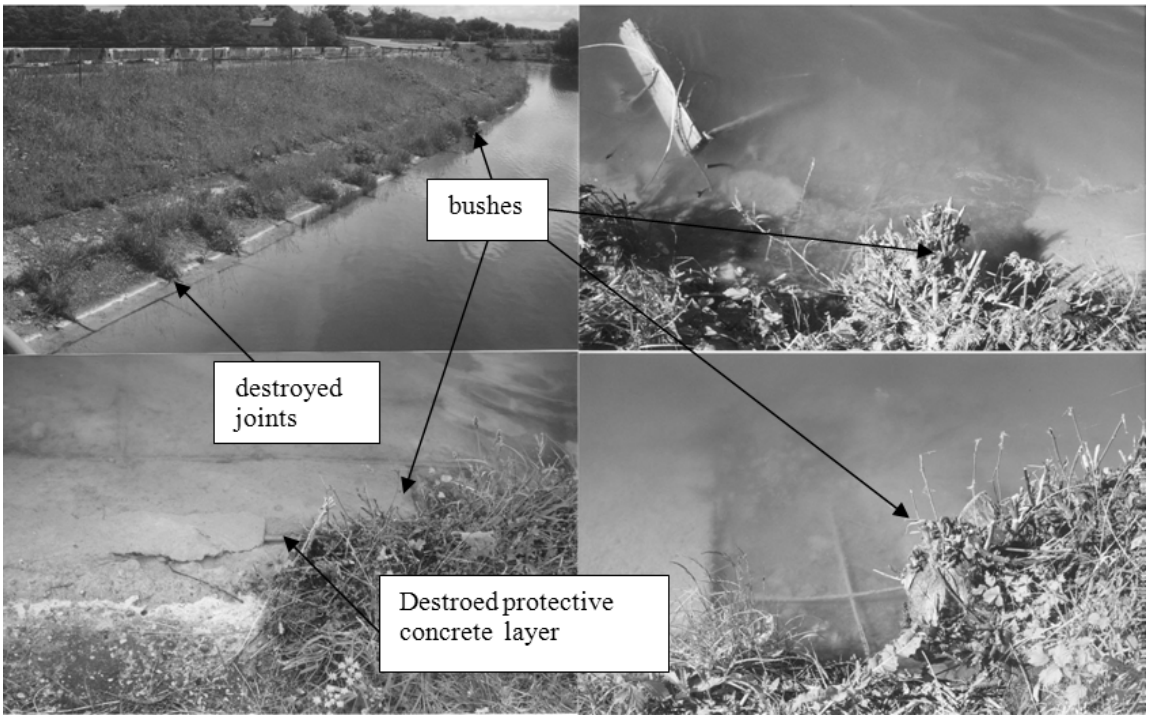

Figure 1. Destroyed joints by grass, bushes roots in Grauze pond (Kaunas district).

Figure 2. Erosion of surface on concrete slabs (Ageniskis pond) by influence of frost cycles.

The main attention should be paid to the zones where deterioration and defects are often formed – pitting is formed in the changing water level in the flow compression zone – in slabs, which are not far from the inflow part of shaft spillways or in the flow parts of overflow spillways.

CONCLUSIONS

1. The results of 30 earth dam slope protection slabs field investigations show, that mostly occurred defects and deteriorations of slab are: deterioration of the cover layer (12 from 30 objects) and collapsing of joints (25 from 30 objects), accordingly 40 % and 83 % of the researched objects.
2. The rupture and deterioration of the cover layer of reinforced concrete slabs in the time being were caused in many cases by unfit manufactured concrete, which properties do not satisfy the requirements of usage (weak concrete); unfit exploitation- bad exploited joints were damaged by the weeds or even scrubs.
3. The reinforced concrete strengthening slabs in Krokialaukis, Elmininkai, Antanavas, Anulynas, Pilve –Vabalksnis hydroschemes are in critical condition and should be repaired immediately.

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