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THE TECHNICAL STATE OF EARTH DAMS IN LITHUANIA

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Abstract. Dams are ageing out as all constructions do, and inaccuracies during the field survey, designing and construction, as well as defects of building materials and deterioration due to environmental impacts accelerate the aging process. The article presents the technical state assessment comparable results of 260 Lithuanian earth dams performed in 2002–2009 and 368 dams in 1997; the analysis of character and causes of the main deteriorations and defects. The typical causes of failure (according to their danger to the stability of the entire hydroscheme) are: diverse intensity of seepage water leakage at the downstream slope and the tailwater of dam; landslides and deformation of the slopes of the dams; bigger cracks, deformation, tilt in shaft spillway; scour, deformation of dam slope protection slabs, concrete cover layer deterioration, collapsing of junctures are mainly caused by the environmental (frost cycles; ice, wave blows; moss, grass, bushes roots; periodical wetting, etc.) impacts.

Keywords: environmental impact assessment, earth dams, deterioration, technical state.

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Introduction

Dams, dikes, water plants (near fleece wool carding factories and mills) as first hydraulic structures (hereinafter – HS) appeared in Lithuania in the 13th–14th centuries AD. The period of 1972–1982 was most intensive for dam construction; every year 20–25 new dams were built; and even 44 dams were constructed in 1975. In most cases they were constructed from the local soil and named "earth dams" (hereinafter – ED). By 1990, in Lithuania there were 1100 ED with a pond area of more than 0.5 ha; among them there were 414 ED with a pond area of more than 5.0 ha. Water accumulated in ponds presents a danger for the community and the environment both due to water head (3 m or higher) and due to accumulated water volume (in ponds with area 5 ha and larger) (Gailiušis *et al.* 2001; Tvenkinių katalogas 1998). There are 617 ponds with potentially dangerous hydraulic structures in Lithuania. Many of hydraulic structures in our hydroschemes are older than 35–40 years, therefore the ageing of building materials causes greater probability of deterioration and even failure. Hydraulic structures exist in rather hard conditions. They are affected by atmosphere, water medium, ice, high and low temperature, precipitation, wind, etc. Due to environmental impacts (freezing–thawing cycles, ice, wave blows; moss, grass, bushes roots, collapsing impacts; periodical wetting, swimming solids or sediments abrasive impact, etc.) some deteriorations of the hydraulic structures occur, surfaces of reinforced concrete structures are especially often deteriorated. If dangerous defects and deteriorations are not repaired in time the danger arises for the reliability, durability and safety of the hydraulic structure and a big threat of technical, ecological, economical and human lives loss. A lot of methods for evaluation of safety, reliability of hydraulic structures are created and developed in worldwide. Main categories of methods for safety evaluation are described in Putcha (2000). There are over 60 methods presented in this paper, the main methods for risk assessment are: The method of Kreuzer and Bury (1984) is one of the methods of risk assessment because their paper provided a systematic presentation for probability of failure for a dam with available information from a dam safety inspection. The method of Cheng *et al.* (1986) is used for risk assessment because of its use of a well-known reliability method (AFOSM for reliability calculation) for any given performance function. The

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method of Lafitte (1993) is a potential method for risk assessment because of its usage of fault-tree analysis and event-tree analysis for probability of failure calculation. This method has an extra advantage because of a simple relation for risk calculation using probability of failure values. The method of Dekay and McClelland (1993) – a potential method for risk assessment because of its easy usage of calculation of Loss of Life (LOL) in case of dam failure. Another method of Lafitte (1996) is method for risk assessment for classifying the dams based on the global factors. Based on the extensive literature review about the main methods for risk assessment, it is decided about necessity to perform visual observations and field investigations of Lithuanian dams in order to collect data about main defects, deteriorations raised under the environmental impacts.

In 1970–1990, the dams were supervised at a minimum, each region had a land reclamation services with resources for necessary maintenance, repair of the dams and other hydraulic structures. Rural economic organizations often had a land reclamation specialist for drainage, irrigation systems and maintenance of hydraulic structures. After restoring the Independence of the country, many of reservoirs and dams lost their former destination and became less necessary. At the same time ruined a lot of rural farms and other organizations in which disposition were dams and other hydraulic structures. When the number of land reclamation professionals decreased, the resources for maintenance of the dams was reduced, then the dams began to deteriorate faster than during normal supervision of such structures. Some dams were leased or privatized due increased interest (from 1990) for construction of small hydropower plants (hereinafter – SHPP) in hydroschemes. In 2009 there were 88 SHPP constructed on existing dams (in 1995 there were only 13 SHPP). In this way, over the last 15 years 75 dams had got owners and more or less normal maintenance. Some dams and reservoirs have been leased to country tourism. Maintenance of leased or privatized dams usually is better and fits the HS maintenance regulations. The biggest Lithuanian HS (Kruonis PSHEP and Kaunas HEP) are well maintained, because the technical state of these structures is constantly monitored (Ždankus *et al.* 2008) and controlled in accordance with the maintenance regulations (Šiksnys 2007; Skripkiūnas *et al*. 2006).

Investigations of earth dams' state (mostly visual observations) were carried out since dams erection, especially in cases, when damages were noticed. These works were more intensive in 1997–1999 when Ministry of Agriculture ordered to elaborate the system of technical state evaluation and maintenance regulations of earth dams (Lindišas *et al.* 1997). Using visual observations and field investigations (instrumental methods) over 110 dams have been investigated. Considering the noticed defects and deteriorations of structures their technical states were assessed. Based on the results of this study the first HS technical state assessment methodology was developed (STR 1.12.03:2000 2000). All the necessary documents for earth dam design, construction and maintenance are now developed and adopted, but due to lack of finances, many of dams are not properly maintained and their condition is getting worse in time.

In the Water and Land Management Faculty at the Lithuanian University of Agriculture in 2002–2003 investigations of reinforced concrete slabs for ED slope protection (Vyčius 2002; Šadzevičius 2002) were performed and the studies of hydraulic structures technical state evaluation were carried out (Šadzevičius *et al.* 2001; Damulevičius *et al.* 2001). The period of 1970–1980 was most intensive for drainage systems construction – it was build 2 millions hectare (Lukianas, Ruminaitė 2009). Evaluation of the technical state of reinforced concrete structures (culverts and bridges) in drainage systems was performed by Water and Land Management Faculty group (Gurskis *et al.* 2004). Visual observations and field investigations of 150 Lithuanian dams were continued in 2007–2009 (Damulevičius, Vyčius 2007; Patašius *et al.* 2009). Analysis of investigations results shows that there is the necessity to improve currently valid dams' maintenance regulations, because of lack of information about evaluation process concerning the influence of environmental factors on the technical state, reliability and durability of reinforced concrete HS.

The purpose of this work is to establish character and causes of the main deteriorations and defects of Lithuanian earth dams (due to environmental impact) on the basis of 2002–2009 performed field investigations and to estimate changes of the technical state of dams in comparison with results of field investigation executed in 1997.

1. Methods

In 2002–2009 the earth dams were investigated in 31 region of Lithuania. Main attention was paid to Raseiniai ED (20 ED), Kretinga (17), Mažeikiai (16), Panevėžys (15), Kėdainiai (13), Kaišiadoriai (13), Kaunas (12), Kelmė, Radviliškis, Šiauliai and in some other regions of Lithuania. In 2008–2009, during scientific research (Patašius *et al.* 2009) ordered by the Ministry of Agriculture 155 ED were investigated. Earth dams complex (hydroscheme) were analyzed as the whole of constructive and functional elements choosing principal dam stability determining and secondary less important ones. Their technical state was determined according to quantitative indices – scale of defectiveness and calculated averages of defectiveness points for each investigated dam. In the article also is used data from earlier (in 1997 and 2002–2006) investigations performed by employees of Hydraulic Engineering and Building Construction Departments concerning 260 ED. Some dams have been investigated more in detail (using instrumental methods) for preparing of ED reconstruction projects. Such investigations in 2008 have been carried out in Naudvaris ED on Varmė River (Kelmė region) and in Totorvietis ED on Penta River (Šakiai region). Previously (in 2000–2006), detailed investigations were carried out at following ED: in Šiauliai region – 4 objects, Joniškis region – 3 objects, Pakruojis and Radviliškis regions – 1 + 1 object.

The field investigations were done and the state of ED and associated hydraulic structures in earth dams was evaluated in accordance to the Lithuanian construction technical regulations: "Regulations of Maintenance of Hydraulic Structures (STR 1.12.03:2006 2007)", "Hydraulic Structures. The Main Rules (STR 2.02.06:2004 2004)", "Ground Material Dams (STR 2.05.17:2005 2006)", "The Impacts and Loads on Hydraulic Structures (STR 2.05.15:2004 2004)".

Hydraulic structures in accordance with their importance to the hydroscheme construction may be divided into two groups: the main structures and auxiliary ones. The technical state of elements in ED was evaluated by defectiveness points (B_u,) in ten points criterion system by standing construction regulations STR 1.12.03:2006: 0 point – ideal condition, 10 points – emergency condition. The detailed points' determination is presented below:

- element's condition meets requirements of construction regulations, irregularity is small – $0 < B_u \leq 2.0$ points (good condition);
- deterioration of element has no influence to strength and normal maintenance of 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 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), technical state can be improved by repairing;
- deterioration greatly reduces the strength and reliability of element, defects and deteriorations are significant – $6.1 < B_u \leq 8.0$ points (unsatisfactory condition), big repair is needed;
- remarkable deterioration and maintenance of element is impossible – $8.1 < B_u \leq 10.0$ points (critical condition), the dam should be reconstructed.

If any one of the main elements of ED is evaluated by 8.1 to 10 defectiveness points, the whole ED state is evaluated by the same point. In other cases, averages of structures defectiveness points are calculated in order to determine total ED defectiveness points. Visual–instrumental method (Malakhanov 1990) is applied for ED field investigations as quite effective and productive, because it requires a minimum of time and money. Defects and deteriorations causes and their magnitude were analyzed according to project solutions described in regulations (The Norwegian … 1996).

The visual method enables to evaluate such surface defects of structures as broken corners, edges, deteriorated concrete covering layer, stratified concrete, cracks, bad concrete pouring and steel corrosion. During field investigations smoothness of concrete surfaces, cracks, deflection, character and causes of defects, areas and the depths of cracks, deteriorations, deformations and scour were established.

Simple instruments (tape–measure, tape, levels) were used during visual dam examination, for drainage, reinforced concrete plates for slope protection and their joint inspections – manual and mechanical tools for resurrection. Water levels in several ED were monitored by means of the piezometers installed in the dams. In some objects the technical state was observed during the repair work – before reconstruction and after it. Defects and deteriorations of ED were documented by photography methods.

2. The results and discussion concerning investigation of the technical state of earths dams

The technical state of Lithuania dams was observed and investigated just from the erection of the first dams. Hydroschemes in which deteriorations or defects were most visible are mostly monitored and analyzed. Dams investigations (performed by the employees of Water and Land Management Faculty at the Lithuanian University of Agriculture) became more intensive and acquired a systematic trend in 1997–1999. The purpose was to work out a methodology for assessing the state of hydroschemes (Lindišas *et al.* 1997). The first such methodology has been approved in 2000 – it was "STR 1.12.03:2000. The technical evaluation of the state of potentially dangerous hydraulic structures" (2000). Later, in 2006, it was slightly improved in 2006 and released as a new version of the methodology (STR 1.12.03:2006 2007). But it did not take sufficient attention to the comments of the hydraulic scientists and managers, especially concerning degradation indices of concrete and reinforced concrete elements of hydroschemes. This paper presents the investigations carried out in accordance with requirements of above mentioned methodologies.

Comparative analysis was made in order to assess how the technical state of Lithuania ED changed from 1997. The technical state of 368 dams (owned by Reclamation Service) investigated by group of LAU researchers in 1997 (Lindišas *et al.* 1997) was evaluated as follows:

good – 143 dams (38.9%);
satisfactory – 120 dams (32.6%);
unsatisfactory – 58 dams (15.8%).

The data are absent about the state of 45 dams (in Raseiniai, Šalčininkai, Utena, Varėna districts). Two dams are in critical state:

- Daunorava dam in Satkūnai municipality, Joniškis region (the structure in critical state – the drop inlet spillway, erected in 1970),
- Didžiulis lake in Onuškis municipality, Trakai region (the structure in critical state – drop inlet spillway, erected in 1972).

Graphically research results of the state of ED (in 1997) by county are shown in Figure 1.

Summarized data of ED investigation performed in 2002–2009 are presented in Table 1. Most of the dams investigations were carried out during the last three years, some hydroschemes were inspected several times. The technical state of ED was periodically evaluated in order to establish changes of the state and establish trends of deterioration process.

The analysis of the data presented in Table 1 showed that only 6% (15 ED) dams were in good condition, 42% (109 ED) – moderate, 34% (87 ED) – satisfactory, 8% (22 ED) – unsatisfactory and 10% (27 ED) – in critical state. Unsatisfactory and critical state of the dam can provoke risk for the dam surroundings and must be repaired immediately. Some ponds in this category are empty: Gyliai II, III and IV, Blinstrubiškis I and II dams in Raseiniai district, as well as the Kruostas dam pond in Kėdainiai district. The results of ED technical state research are shown in Figure 2.

The analysis of ED state investigation carried out in 2002–2009 results (presented in Fig. 1 and Table 1) shows that ED in the critical state are mainly in the Kaunas county (15 objects). The biggest number of dams in unsatisfactory and critical condition is also in Kaunas County (total number of these state categories ED is 37). These hydroschemes are dangerous to the surrounding and must be repaired immediately.

The analysis of ED technical state research (in 1997) results (in Fig. 2) shows that most of dams of unsatisfactory condition (30 ED) was found in Šiauliai County. This county has a maximum total number of unsatisfactory and satisfactory ED (69).

ED technical status as it was evaluated in 1997 and 2002–2009 is graphically presented in Fig. 3.

Summarized results of ED technical state investigations carried out in recent years show, that in most regions of Lithuania state of dams is unacceptably getting worse, because of insufficient supervision, as well as the natural aging and deterioration of these structures due to environmental impacts. It was found comparing the ED state assessment results obtained in 1997 and 2002–2009 (shown in Fig. 3), that the state has worsened – 1997 study showed that in unsatisfactory condition are 58 ED (16% of 368 investigated objects), and the 2002–2009 study showed that in unsatisfactory and emergency conditions are 47 ED (19% of 260 investigated objects). It is known, that in normal maintenance of structure, slow deterioration process takes longer period. During this deterioration

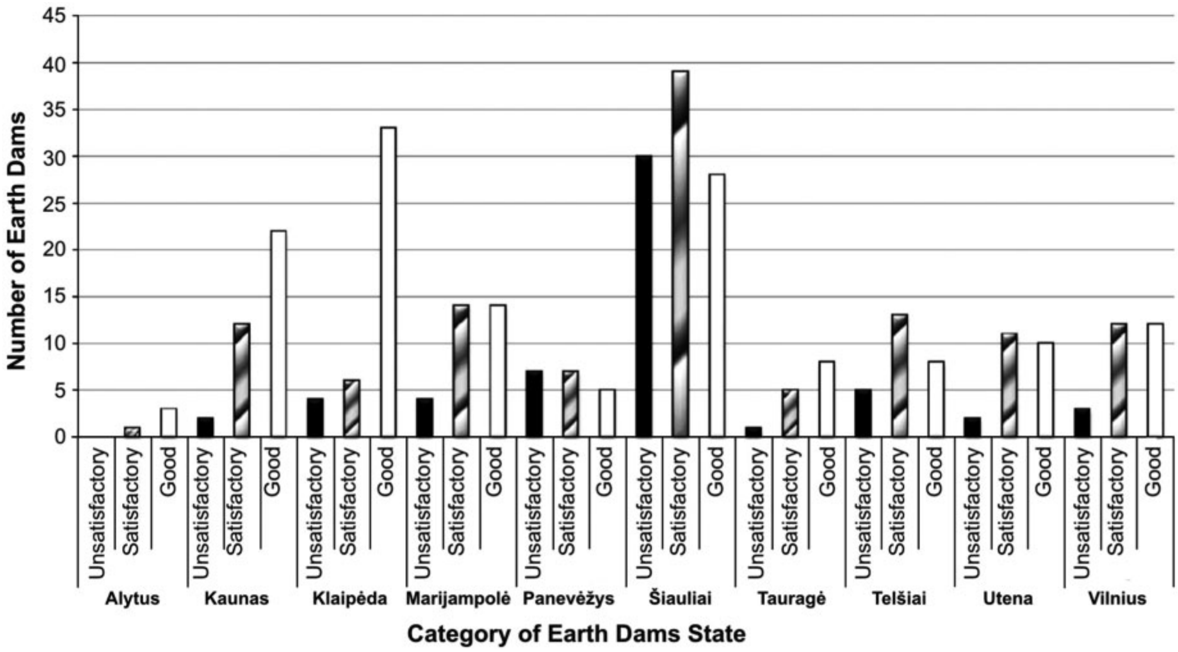

Fig. 1. Distribution of the category of dams' technical state in 1997 by county

Table 1. Evaluation of technical state of investigated earth dams in 2002–2009

No.	District	The number of investigated ED	Category of ED state, in points: 0 … 2.0 Good	2.1 … 4.0 Moderate	4.1 … 6.0 Satisfactory	6.1 … 8.0 Unsatisfactory	8.1 … 10.0 Critical	County
1	Akmenė	3	1	1	1			Šiauliai
2	Alytus	10			5	3	2	Alytus
3	Anykščiai	8		2	4	1	1	Utena
4	Biržai	3			3			Panevėžys
5	Jonava	4		2	2			Kaunas
6	Joniškis	11	2	8	1			Šiauliai
7	Kaunas	12		7	2		3	Kaunas
8	Kaišiadorys	13		3	8	1	1	Kaunas
9	Kėdainiai	13		10	2		1	Kaunas
10	Kelmė	12	3	7	1	1		Šiauliai
11	Klaipėda	3			2		1	Klaipėda
12	Kretinga	17		9	5	1	2	Klaipėda
13	Kupiškis	12		7	5			Panevėžys
14	Lazdijai	2		1	1			Alytus
15	Marijampolė	10	2	1	2	4	1	Marijampolė
16	Mažeikiai	16	1	12		1	2	Telšiai
17	Pakruojis	8	1	1	5	1		Šiauliai
18	Panevėžys	15		1	14			Panevėžys
19	Pasvalys	4			4			Panevėžys
20	Prienai	8		2	3		3	Kaunas
21	Radviliškis	13	1	12				Šiauliai
22	Raseiniai	20		6	5	2	7	Kaunas
23	Rokiškis	3			3			Panevėžys
24	Šalcininkai	9		3	1	4	1	Vilnius
25	Šakiai	1					1	Marijampolė
26	Šiauliai	6	3	1	2			Šiauliai
27	Šilutė	5		5				Klaipėda
28	Ukmergė	7		2	5			Vilnius
29	Utena	10	1	6		2	1	Utena
30	Vilkaviškis	1			1			Marijampolė
31	Vilnius	1				1		Vilnius
	Total GMD	260	15	109	87	22	27	
	Total %	100	6	42	34	8	10	

time the damages accumulate slowly, so ED number in satisfactory condition has remained unchanged (33% of the total amount of investigated objects). In some ED, the deterioration process was accelerated by:

– very aggressive environment (e.g. acidic water from peatbog in Dubuliai hydroscheme);
– insufficient exploitation of structures (e.g. Butrimonys, Giliai hydroschemes);
– improper repairing (e.g. Pajiesys, Janušoniai hydroschemes), where dams are only equipped with new hydropower stations, but during their installation deteriorated structures – shaft spillways or retaining walls, – were not repaired;
– faulty technical solutions causes itself further damage and defects (e.g. Pabaudos, Šarkiskiai hydroschemes) where the construction of civil structures was used in erecting hydraulic structures.

During this accelerated accumulation of damage in very intensive deterioration period the state of ED is rapidly moving from satisfactory to unsatisfactory or even critical.

The statistical analysis was performed in order to evaluate the changes of technical state by various regions of Lithuania. The results of statistical analysis are presented in Table 2.

Summarized results of analysis shows, that in 1997 most regions of Lithuania state of dams was less, than average of Lithuania (4.5 defectiveness points) (except Panevėžys, Šiauliai, Telšiai county), but in period 2002–2009 was unacceptably getting worse in all regions (except Panevėžys, Šiauliai county – reconstruction of some dams reduced average of defectiveness points). Especially worsted the state of ED in Alytus County – from 3.5 defectiveness points (in 1997) to 7.0 defectiveness points (in 2002–2009).

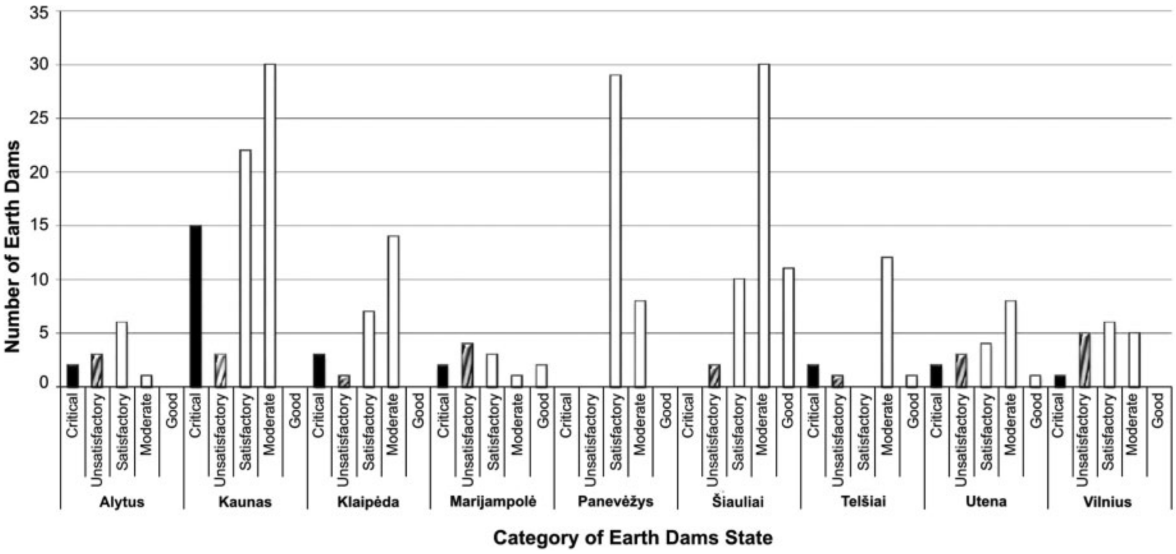

Fig. 2. Distribution of the technical state category of investigated dams in 2002–2009

The analysis of the data of Lithuania dams field investigations performed in 2002–2009 shows that the typical failure of dams (according to their danger to the stability of the entire hydroscheme) are:

- diverse intensity of seepage water leakage at the downstream slope and the tailwater of dam – 17 ED (6.5%);
- landslides and deformation of the slopes of the dams – 29 ED (11%);
- bigger cracks, deformation, tilt in shaft spillway – 33 ED (12.7%);
- scour, deformation of dam slope protection slabs, collapsing of junctures – 108 ED (41.5%).

Main causes of hydraulic structures deformations are:

- lack of supervision (e.g. Antanavas HPP, Kudirkos Naumiestis HPP, Varėna HPP);
- low quality of materials (e.g. Molainiai, Panevėžiukas hydroschemes, Kruostas HPP);
- poor quality of work and, in some cases, a wrong design solutions, including unsufficient investigation of geological situation (e.g. Savičiūnai ED is built without the clay core and due seepage headwater level could not be reached).

The results of 32 earth dam slope protection slabs field investigations shows, that mostly occurred defects

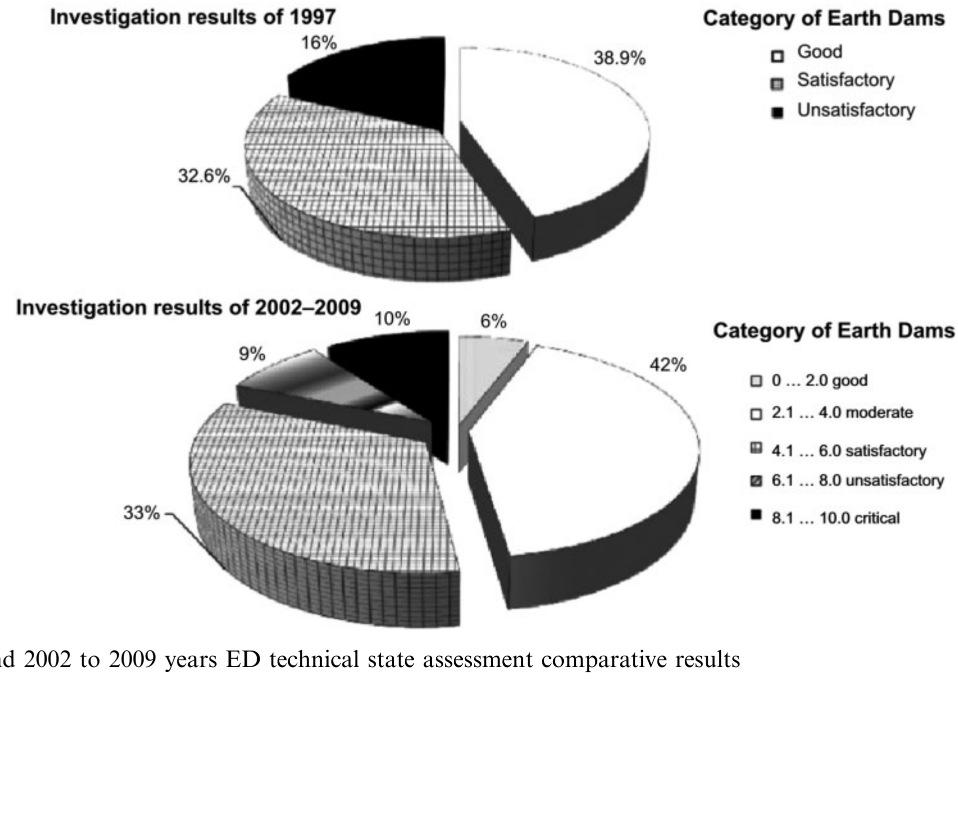

Fig. 3. 1997 and 2002 to 2009 years ED technical state assessment comparative results

Table 2. Results of statistical analysis of technical state of investigated earth dams in 1997–2009

County	Average of defectiveness points (in 1997)	Average of defectiveness points (in 2002–2009)
Alytus	3.5	7.0
Kaunas	3.9	6.1
Klaipėda	3.7	5.4
Marijampolė	4.4	6.5
Panevėžys	5.2	5.6
Šiauliai	5.0	4.1
Telšiai	4.8	4.9
Utena	4.3	5.7
Vilnius	4.3	6.2
Average of defectiveness points (in Lithuania)	**4.5**	**5.5**
Standart deviation	0.58	0.87
Standart error	0.19	0.29
Variation coeff.,%	4.22	5.14

and deteriorations of slab are: deterioration of cover layer (11 from 32 objects) and collapsing of junctures (16 from 32 objects), accordingly 30% and 50% of researched objects. It was established, that cover layer and junctures 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). 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 changes, forms deteriorations – pitting. Most intensively concrete is destroyed in ice and waves impact (changing water level) zone. Surface of structures on this zone is touched by ice, swimming solids or sediments (especially gravel) abrasive impact.

Norwegian concrete dams' technical state evaluation (Jensen 2001) is made in order to compare results of Lithuania dams technical state evaluation with results obtained of foreign countries researchers. Survey about damage of 287 Norwegian concrete dams (432 including combination dams) (Jensen 2001) shows – in 53% to 56% of the dams it has been observed horizontal and vertical cracks; 36% of the dams have map cracking; water leakage through the dam has been registered in 32% of the dams; 36% have damages in the dam plates/arches and 6% to 7% that delamination, disintegration and cracking have increased during the last years.

Deformation has been observed in 14% of the dams. The same amount of deformation, tilt in shaft spillway has been registered in Lithuanian dams (12.7%).

Damage in joints has been registered in investigated dams: squeezed joint material (noticed in 24% of the dams), reduced joint width (15%), water leakage (25%), movement/crushing (12%), reduced ground contact (3%). Lithuanian earth dam slope protection slabs field investigations shows that mostly occurring damages of slab are: collapsing of junctures (41.5% of researched objects).

Main damages of 287 Norwegian concrete dams (Jensen 2001) caused by processes/reasons: reinforcement corrosion (noticed in 19% of the dams); alkali aggregate reaction (18%); freeze – thaw (50%); erosion (47%); leaching (21%); deformation/expansion (20%); bad concrete work (43%). The listed main causes of hydraulic structures damages in Norway are characteric and detected in concrete structures of Lithuania dams too.

Conclusions

1. According to the technical state investigation of 260 Lithuanian ED performed in 2002–2009, the typical causes of failure (according to their danger to the stability of the entire hydroscheme) are:
   - diverse intensity of seepage water leakage at the downstream slope and the tailwater of dam – (noticed in 6.5% of investigated objects);
   - landslides and deformation of the slopes of the dams – (noticed in 11% of investigated objects);
   - bigger cracks, deformation, tilt in shaft spillway – (noticed in 12.7% of investigated objects);
   - scour, deformation of dam slope protection slabs, concrete cover layer deterioration, collapsing of junctures – (noticed in 41.5% of investigated objects).
2. The main factors that cause deterioration and deformations are as follows:
   - lack of supervision;
   - low quality of building materials;
   - poor quality of work and in some cases a wrong design decisions, including unsufficient investigation of geological situation;
   - it was established, that concrete cover layer and junctures defects are caused by the environmental (frost cycles; ice, wave blows; moss, grass, bushes roots, collapsing impacts; periodical wetting, etc.) impacts.
3. According to the technical state investigation of 260 Lithuanian ED performed in 2002–2009 by LAU Hydraulic Engineering and Building Construction Departments researchers results, it was found that 15 ED (6%) are in good condition, 109 (42%) – moderate, 87 (34%) – satisfactory, 22 (8%) – unsatisfactory and 27 ED (10%) are in critical state.
4. Comparing the ED state assessment obtained in 1997 and 2002–2009 results it was found that ED state

has worsened – in 1997 in unsatisfactory condition were 16% of the total amount of investigated objects, and the 2002–2009 investigations showed that the number of objects in unsatisfactory and critical state increased up to 19% of the total amount of investigated objects.

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