LITHUANIAN UNIVERSITY OF AGRICULTURE

Raimondas Šadzevičius

MODELLING AND ANALYSIS OF ENVIRONMENTAL IMPACT ON REINFORCED CONCRETE SLABS FOR EARTH DAM SLOPE PROTECTION

Summary of Doctoral Dissertation
Technological Sciences,
Environmental Engineering and Land Management (04T)

Kaunas, 2005

Doctoral dissertation was preparied at the Lithuanian University of Agriculture in 1998–2004.
Dissertation is being externally defended at the Lithuanian University of Agriculture.

Scientific supervisor:
Assoc. Prof. Dr. Juozapas VYČIUS, Lithuanian University of Agriculture (Technological Sciences, Environmental Engineering and Land Management– 04T).

Council Environmental Engineering and Land Management Sciences trend:

Chairman:
Assoc. Prof. Dr. Arvydas POVILAITIS, Lithuanian University of Agriculture (Technological Sciences, Environmental Engineering and Land Management– 04T).

Members:
Prof. Dr. Habil. Povilas Algimantas SIRVYDAS, Lithuanian University of Agriculture (Technological Sciences, Environmental Engineering and Land Management– 04T);
Prof. Dr. Habil. Juozas ATKOČIŪNAS, Vilnius Gediminas Technical University (Technological Sciences, Building Engineering – 02T);
Prof. Dr. Habil. Jurgis Kazimieras STANIŠKIS, Kaunas University of Technology (Technological Sciences, Environmental Engineering and Land Management– 04T);
Assoc. Prof. Dr. Petras PUNYS, Lithuanian University of Agriculture (Technological Sciences, Environmental Engineering and Land Management– 04T).

Official opponents:
Prof. Dr. Habil. Brunonas GAILIUŠIS, Lithuanian Energy Institute (Technological Sciences, Environmental Engineering and Land Management– 04T);
Dr. Habil. Saulius VAIKASAS, Water Management Institute of Lithuanian University of Agriculture (Technological Sciences, Environmental Engineering and Land Management– 04T).

The official defence of the dissertation will be held at the public session of the Council of Environmental Engineering and Land Management science trend at 11 p.m. on 24th November, 2005 at Lithuanian University of Agriculture III house 610 audience.
Address: Universiteto 10, LT–53361, Akademija place, Kaunas district.

Summary of the doctoral dissertation was distributed on 24th October, 2005.
The dissertation can be revised at libraries of Lithuanian University of Agriculture (Studentu 11, Akademija place, Kaunas district) and Water Management Institute of Lithuanian University of Agriculture (Parko st. 3, Vilainiai, Kėdainiai district).

LIETUVOS ŽEMĖS ŪKIO UNIVERSITETAS

Raimondas Šadzevičius

APLINKOS POVEIKIO ŽEMIŲ UŽTVANKŲ ŠLAITŲ TVIRTINIMO GELŽBETONINĖMS PLOKŠTĖMS MODELIAVIMAS IR ANALIZĖ

Daktaro disertacijos santrauka
Technologijos mokslai, aplinkos inžinerija ir kraštotvarka (04T)

Kaunas, 2005

Disertacija rengta 1998–2004m. Lietuvos žemės ūkio universitete Statybinių konstrukcijų katedroje.

Disertacija ginama eksternu Lietuvos žemės ūkio universitete.

Mokslinis konsultantas:

doc.dr. Juozapas VYČIUS, (Lietuvos žemės ūkio universitetas, technologijos mokslai, aplinkos inžinerija ir kraštotvarka – 04 T)

Disertacija ginama Lietuvos žemės ūkio universiteto Aplinkos inžinerijos ir kraštotvarkos mokslo krypties taryboje:

Pirmininkas:

doc. dr. Arvydas POVILAITIS, (Lietuvos žemės ūkio universitetas, technologijos mokslai, aplinkos inžinerija ir kraštotvarka – 04 T)

Nariai:

prof. habil. dr. Povilas Algimantas SIRVYDAS, (Lietuvos žemės ūkio universitetas, technologijos mokslai, aplinkos inžinerija ir kraštotvarka 04T);

prof. habil. dr. Juozas ATKOČIŪNAS, (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija 02T);

prof. habil. dr. Jurgis Kazimieras STANIŠKIS, (Kauno technologijos universitetas, technologijos mokslai, aplinkos inžinerija ir kraštotvarka 04T);

doc. dr. Petras PUNYS, (Lietuvos žemės ūkio universitetas, technologijos mokslai, aplinkos inžinerija ir kraštotvarka 04T).

Oponentai:

prof. habil. dr. Brunonas GAILIUŠIS, (Lietuvos energetikos institutas, technologijos mokslai, aplinkos inžinerija ir kraštotvarka 04T);

habil. dr. Saulius VAIKASAS, (Lietuvos žemės ūkio universitetas Vandens ūkio institutas, technologijos mokslai, aplinkos inžinerija ir kraštotvarka 04T).

Disertacija bus ginama viešame Aplinkos inžinerijos ir kraštotvarkos mokslo krypties tarybos posėdyje 2005 m. lapkričio mėn. 24 d. 11 val. Lietuvos žemės ūkio universiteto III rūmų 610 auditorijoje.
Adresas: Universiteto g. 10 LT-53361 Akademijos mst., Kauno r.

Disertacijos santrauka išsiųsta 2005 m. spalio 24 d.

Disertaciją galima peržiūrėti Lietuvos žemės ūkio universiteto (Studentų 11, Akademijos mst., Kauno r.) ir LŽŪU vandens ūkio instituto (Parko g. 3, Vilainiai, Kėdainių r.) bibliotekose.

INTRODUCTION

Actuality of the work. There are over 1100 dams in Lithuania presently, that have created ponds bigger than 0,5 ha with. Among them there are 414 ponds, which are bigger than 5 ha. There are also 165 impounded lakes with various types of hydraulic structures (spillways, earth dams, etc.). Water accumulated in ponds presents a danger for the community and the environment both by the water head and by accumulated water volume. In Lithuania there are 617 ponds evaluated as potentially dangerous hydraulic structures. These structures are maintained in the complex circumstances and therefore should be reliable and of long durability. Durability depends on maintenance circumstances, surveillance, timely repair of structures or reconstructions. Many of hydraulic structures on our 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* 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, a big technical and ecological loss may occur. From economic point of view execution of new slope protection is more expensive, therefore more actual problem is to preserve the present reinforced concrete slabs by means of time by restoration and/or reconstruction.

Meantime the state of hydraulic structures in service is evaluated in points according to the Lithuanian technical construction regulations STR 1.12.03:2000.
But in the latter regulations some hydraulic structures are omitted. Among them is the protection of the downstream slopes by reinforced concrete slabs is not mentioned, evaluation of their state is not discussed.

It is clear there is the necessity in practice – oriented scientifically based algorithms for the evaluation of the state of reinforced concrete slabs for earth dam slope protection. In the evaluation process the influence of environmental factors on the technical state, reliability and durability of reinforced concrete slabs should be stressed. In the dissertation the main attention is paid just for the above questions.

On the basis of field investigations of reinforced concrete slabs for earth dam slope protection in Lithuania we conclude, that slabs suffer most of all from the ice impacts. Ice load calculation methods are worked out in various countries, but how do they meet Lithuania's climate states – the problem is open up to now.

Scientific problem and level of its research. Reinforced concrete slabs for earth dam slope protection are under the impacts of various loads and aggressive environment, therefore they deteriorate and lose their durability. Evaluation of environmental factors (***freezing–thawing*** (hereinafter – ***frost***) ***cycles, ice loads***) and caused by them slabs' deterioration process (***erosion, construction defects and deteriorations development***), speed and slabs durability prognosis is the main problem. Level of it's research is inadequate.

The purpose of work

To evaluate the impacts of environment on reinforced concrete slabs for earth dam slope protection.

To achieve the purpose following **tasks** must be solved:

- To work out the method for evaluation of the durability of reinforced concrete slabs for earth dam slope protection under actions of frost cycles.
- To establish (in Lithuanian states) the archetypal type of ice load and design standards, which evaluate most exactly these loads.
- To establish main indices for evaluation of the deterioration process of reinforced concrete slabs for earth dam slope protection and to evaluate the durability of outside layer of slabs' concrete.
- To substantiate by results of the field investigations of reinforced concrete slabs for earth dam slope protection the reliability of currently used methods for slabs' state evaluation.

Scientific novelty

- Based on the field investigations results the modelling and analysis of environmental impact to reinforced concrete slabs for earth dam slope protection durability, not mentioned in scientific publications, was carried out.
- Based on analysis of deterioration of reinforced concrete slabs for earth dam slope protection, for the first time in Lithuanian states the linear load of thermal expansion of ice formed in a pond was evaluated.
- Regularities of concrete compression strength of reinforced concrete slabs for earth dam slope protection under the influence of freezing–thawing cycles and other environmental factors were established.

Theoretical approach

- An indirect method to establish the concrete frost resistance mark was fitted for evaluating of frost resistance of reinforced concrete slabs for earth dam slope protection.
- Established the most suitable commercial programme for structural calculation of reinforced concrete slabs for earth dam slope protection.
- The computer programme "*SIJA*" for calculation of slabs on the elastic foundation is worked out.
- Established the most suitable calculation method of ice loads in Lithuanian states.
- Established one of the main degradation indices – constant of degradation.
- Established additional criteria for the Regulations STR 1.12.03:2000 for the evaluation of the state of reinforced concrete slabs for earth dam slope protection.
- Developed durability evaluation method of reinforced concrete slabs for earth dam slope protection.
- Practical reports and codifiers for the evaluation of technical state of ponds' slopes protection slabs are worked out.

Practical value of the results

- Having estimated by field investigations physical – mechanical properties of reinforced concrete slabs for earth dam slope protection and using models of slabs worked out by us it is possible to evaluate loads of ice formed in a pond.
- Using estimated constant of degradation for designed reinforced concrete slabs for earth dam slope protection, present on in changing level of water, there is a possibility to choose such strength concrete, that during the intended period the reinforcement of these constructions wouldn't uncover. This constant also can be used for the state evaluation of used reinforced concrete slabs for earth dam slope

protection.

- Established additional criteria of the STR 1.12.03:2000 for the reinforced concrete slabs for earth dam slope protection state evaluation and the proposed reports and codifiers of technical state help to evaluate better the usable slabs' state.
- Using the created by us durability evaluation method of reinforced concrete slabs for earth dam slope protection may be calculated the period left to use the construction till the probable deterioration start ($T_{5\ \%}$) or end ($T_{50\ \%}$), and also evaluate the time ($T_{ap.sl.}$), during which the reinforcement of usable reinforced concrete constructions uncovers.

Research time, objects and states

There were investigated 32 earth dam slopes protected with reinforced concrete slabs for the year 1998–2004.

The author defends

- Method for determination of durability indices $T_{5\ \%}$ and $T_{50\ \%}$ of reinforced concrete slabs for earth dam slope protection under the influence of freezing–thawing cycles (by the slabs concrete compression strength and water absorbability research results).
- Method for determination of linear loads caused by thermal expansion of ice formed in a pond and acting on the reinforced concrete slabs of earth dam slope protection. The method is worked out by evaluation of the slabs' deterioration parameters.
- Deterioration indices' impact to research results of the durability of reinforced concrete slabs for earth dam slope protection.

Approbation of research results

The main work propositions of the dissertation were discussed in 7 scientific conferences. The information presented in the work is published in 3 articles (in accepted scientific publications).

Composition and size of the dissertation. The dissertation consists of introduction, 4 chapters, conclusions, 36 figures (there are 11 figures in the appendixes), 23 tables (there are 37 tables in the appendixes), list of 153 literature sources, list of author's publications on the dissertation subject and scientific research works, 4 appendixes. The used arbitrary notations, symbols and abbreviations are also presented. Size – 130 pages.

Principal concepts and definitions

Covering layer **–** 30 – 40 mm concrete surface layer, protecting reinforcement from corrosion.

Defects – quality parameters indices deflection of the construction (or building materials) from the standard or project requirements, appearing in the process of their manufacturing, transporting or in construction and mounting works.

Physical deterioration of reinforced concrete constructions of hydraulic structures **–** caused by environmental impact erosion and corrosion processes resulting in worsening strength and water proofing properties of the construction development of defects and deteriorations.

Percentage of physical deterioration – the quantitative evaluation of the technical state, showing deterioration level, (by the construction's technical and maintenance

properties loss during usage period comparing with primary state).
Durability – property of the structure to keep efficiency up to the limit state, including brakes for surveillance, repair or reconstructions.
Deterioration – unconformity of structure element to requirements of the project or normative documents, appearing due to the outside impacts in usage period.
Frost cycles – laboratory freezing–thawing cycles (from -18^{o} C to +18^{o} C).
Technical remainder Δt **–** residual life term.

Indexes used in the dissertation:

Deterioration is described by**:** 1) the constant of deterioration υ; 2) the deterioration percentage; 3) the main defects (deteriorations) of reinforced concrete slabs for earth dam slope protection and the defects causes.
Durability is described by: 1) the probable deterioration start time $T_{5\,\%}$, 2) the probable deterioration end time $T_{50\_\%}$, 3) by the time ($T_{ap.sl}$), through which usable reinforced concrete construction reinforcement uncovers; 4) by technical remainder Δt.
According to the recommendations of literature, **constant of deterioration** is by the research approved deepening speed of pitting υ ^{mm}/ *year*.
The probable deterioration start time $T_{5\,\%}$ characterizes deterioration starting, when the compression strength f_c of concrete covering layer lowers in 5 % comparing with the strength determined during research time.
The probable deterioration end time $T_{50\,\%}$ – the end of safe use, when the strength f_c of concrete covering layer lowers in 50 % comparing with the strength determined during research time.

Description of work content

The analysis of the methods for evaluation of the durability of usable reinforced concrete slabs for earth dam slope protection (hereinafter – *slabs*) influenced by environmental factors is given in the first chapter. Analysis shows that the state, the bearing capacity and the durability of reinforced concrete constructions of hydraulic structures (hereinafter – *HS*) most of all influence aggressive environmental impacts (***freezing–thawing cycles***, ***ice loads***) and caused by them deterioration processes (***erosion, development of defects and deteriorations of structures***).
Frost cycles. Analysis of various researchers' works about frost cycles influence to the concrete of HS showed, that so far in the scientific literature is not sufficiently discussed the method for slabs durability determination based on evaluation of change of main physical– mechanical properties of the concrete under the influence of frost cycles.
Ice load. Building standards and regulations of different countries such as Russia, Canada, Finland, USA, Lithuania, state that slabs are mostly eroded by ***ice*** *impact* (static, dynamic or friction). Ice loads influencing reinforced concrete slabs in ponds in Lithuania are investigated only a little and it is not clear which type of load mostly erodes slabs. It was noticed during the expedition, that slabs are mostly eroded by the ice thermal expansion load. Calculating principles of this load are given in different building standards and regulations. In Lithuania usable reinforced concrete slabs most often are designed by the rules and regulations of that time, but it's not examined if those rules evaluate well above mentioned loads.
Deterioration. After the analysis of deterioration models was made a conclusion, that slabs deterioration process is not discussed fairly in literature. Wishing to evaluate this

process better it is necessary to investigate physical – mechanical properties of these structures, also their change under the influence of environment and estimate deterioration indices. As far as in the literature described deterioration models not all factors are often well estimated, for the tentative evaluation must be worked out simpler, not mentioned in the literature, slabs deterioration model, which needs lesser amount of original data. After the analysis of physical deterioration evaluation methods, presented in scientific works, was founded that wanting to describe more precisely the deterioration of structure it is necessary to substantiate the constant of deterioration by field investigations.

Defects and deteriorations. For classification of defects and deterioration of civil, industrial and hydraulic structures, for their state evaluation there's paid much attention in Lithuanian and foreign scientists works. The state of structures and constructions is evaluated according to the main indices of defects and deterioration and is expressed by method of grades (points, sorts, categories). Analysis the literature and currently used building standards and regulations shows, that archetypical defects and technical state of reinforced concrete slabs isn't described very strictly, there's a lack of information about impact of defects to the durability of these structures.

Methods of analytic calculations, field investigations and laboratory tests are presented in the **second chapter.**

Methods of field investigations and laboratory tests.

By the field investigations and laboratory tests (by standard methods) were determined and statistically evaluated main physical – mechanic properties of slabs – their concrete compression strength and water absorbability. These properties are necessary for the evaluation of changes in concrete properties under frost impact, for the calculations of the constant of deterioration and durability of structures indices, for the estimation of the ice thermal expansion loads by slabs deterioration parameters. Technical state and durability of slabs was assessed considering the noticed defects and deteriorations of structures.

By the statistically evaluated research results of slabs 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 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.

Knowing compression strength f_c of the concrete (LST ISO 4012:1995), water absorbability by mass W_m (LST 1428.18:1997) and allowed or forecasted loss of the concrete strength Δf_c, it is possible to estimate laboratory frost cycles number n_{50} (GOST 10060–87):

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

where n_{50} – numbers of laboratory frost cycles freezing samples until –55±2^o C by GOST 10060–87 ,

Δf_c – concrete strength loss in % due the influence of frost cycles, calculated by LST 1428.17:1997,

c,d – coefficients found in the tables made by employees of Dept. of Building

Structures.

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 Structures employees formula:

$$n_F = 34{,}848 \cdot n_{50}^{\ 0{,}6157}. \quad (2)$$

Function determination coefficient $R^2 = 0{,}9947$.

Evaluating the impact of frost cycles to the change of investigated slabs concrete physical– mechanic properties the frost resistant indices $F_{5\,\%}$ and $F_{50\,\%}$. were used.

According to the LST 1428.17:1997 deterioration beginning was fixed by number of cycles, when from freezing sample surface deteriorate 5 % of sample mass (frost resistance index $F_{5\%}$). From the first seen deterioration symptoms till absolute deterioration of the surface passes some time.

According to the construction regulations (Рекомендации по обеспечению надежности и долговечности железобетных конструкций .., 1990) deterioration end was fixed by 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 Structures employees made graph), were recounted into laboratory cycles and further recalculated to the indices of structures durability – probable deterioration times $T_{5\,\%}$ or $T_{50\,\%}$.

Dependency between established by field investigations concrete physical–mechanical properties and calculated indices of structures durability $T_{5\,\%}$ and $T_{50\,\%}$ were examined by methods of correlation analysis. Formulae of dependences were established correlation coefficients calculated and their reliability evaluated.

Main defects of reinforced concrete slabs were established and registered during the scientific expeditions.

Method of analytical research

Loads caused by ice fields were calculated according to the building standards and regulations of Lithuania, Russia, Canada, America and Finland. Load caused by ice thermal expansion was estimated by analytic calculations, using field investigations data of slabs and analyzing acting stress, which were calculated by the means of computer programmes (*"ALGOR"*, *"STAAD/Pro 2000"*, *"PLOKŠTĖ"*, *"SIJA"*).

Deterioration percentage of slabs was calculated using the formula recommended by literature (Kamaitis, 2000)

$$g_{fi} = [\,T(T+t)/2t^2\,]100\,\%, \quad (3)$$

where g_{fi} –deterioration percentage of slab,
T – standard life term in years,
t– functioning period in years.

Remainder of technical resource Δt is expressed by formula recommended by literature (Kamaitis, 2000)

$$\Delta t = t_{res} - t_i, \quad (4)$$

where t_{res} – slabs standard life term (by norms and results of research t_{res} =30 years),
t_i, – functioning period in years.

Method of the state evaluation of reinforced concrete slabs for earth dam slope protection

Main defects and deterioration of reinforced concrete slabs origin of their causes and the state of constructions were evaluated in the system of 10 points by valid building standards and regulations.

Research results and their analysis is presented in the **third and forth chapter** in such order:

1. Frost impact to the change of concrete properties and durability of reinforced concrete slabs.
2. Ice loads acting the reinforced concrete slabs.
3. The influence of slabs deterioration indices and defects to the constructions durability and state.
4. Improvement of the accuracy of reinforced concrete slabs state evaluation methods.

1. Durability indices research of reinforced concrete slabs for earth dam slope protection under the influence of frost cycles, results and its analysis

In 1998–2004 we investigated the mean compression strength and water absorbability of the cement coarse – grained without additives concrete of slabs in 32 Lithuania's earth dams. Using the research results of concrete compression strength and water absorbability by formulae (1,2) were calculated concrete frost resistance indices $F_{5\,\%}$ and $F_{50\,\%}$ and from them – durability indices – probable deterioration times $T_{5\,\%}$ and $T_{50\,\%}$.

Functional reliability of concrete compression strength f_c, water absorbability by mass W_m, and probable deterioration times $T_{5\,\%}$ and $T_{50\,\%}$ of slabs checked by double correlation. It was found that dependence strength ranges from very strong (when r_{xy} > 0,9) to strong (when r_{xy} from 0,7 to 0,9). Calculated correlation coefficients are reliable, their importance level p<0,05. Estimated determination coefficients R^2 range from 0,804 to 0,993, so it's true to say that researched strength and water absorbability parameters from 80,4 to 99,3% influence investigated durability indices (other part – influence of other parameters).

For a practical use proposed dependences equations are presented in the table 1.

Table 1. Equations dependences of slabs concrete compression strength f_c, water absorbability by mass W_m, and probable deterioration times $T_{5\,\%}$ and $T_{50\,\%}$

Equations dependences			
$T_{5\,\%}$(years)– f_c(MPa)	$T_{50\,\%}$(years) – f_c(MPa)	$T_{5\,\%}$(years) – W_m(%)	$T_{5\,0\%}$(years) – W_m(%)
$T_{5\%} = 1{,}4004 f_c^{0{,}7886}$	$T_{50\%} = 2{,}1051 f_c^{1{,}1014}$	$T_{5\%} = 366{,}38\, W_m^{-1{,}6429}$	$T_{50\%} = 5195{,}5 W_m^{-2{,}3103}$

Using the proposed equations dependences a calculation can be made for how many years are left for structure use till probable deterioration starts ($T_{5\,\%}$.) or ends ($T_{50\,\%}$.).

These equations may be used for the evaluation of state and durability of used reinforced concrete slabs by the probable deterioration time. Calculations by the formulae need to know values of concrete compression strength $f_{c,}$ water absorbability W_m and size of concrete strength loss Δf_c because of frost impact.

By the proposed method were calculated reinforced concrete slabs durability indices ($T_{5\%}$ and $T_{50\%}$) of 32 Lithuania's earth dam. It was found, that the structure at f_c=28,9±1,4MPa (one of the biggest in researched structures) and at W_m=4,24 %, influenced of 5 laboratory frost cycles during the year, can be used till probable deterioration start $T_{5\ \%}$ =37,5 years and till probable deterioration end $T_{50\ \%}$ = 237,0 years. Under f_c =3,36±0,11 MPa (one of the smallest researched structures) and W_m =15,5 % such slab could be used accordingly: $T_{5\ \%}$ =4,53 years and $T_{50\ \%}$ =10,8 years.

2.Determination of loads made by ice in Lithuania's conditions (according to the research results of reinforced concrete slabs for earth dam slope protection deterioration)

The scientific publications analysis shows, that during construction and examination of reinforced concrete slabs for earth dam slope protection the attention must be paid to ice loads.

Ice created loads acting on slabs of ponds in Lithuania are little researched.

There's indicated in the construction regulations of different countries, that main factors influencing ice loads are ice thickness and environmental temperature, but in the slab and ice contact zone also are acting static, dynamic, elastic, rising and attraction powers. Dependence of ice loads from ice thickness, calculated by construction regulations of Lithuania, Russia and Canada is presented in table 2.

Table 2. Relationship between ice thickness and ice load

Ice thickness, m	Horizontal, kN	Thermal expansion, kN/m	Dynamic, kN	Vertical, kN	Bending moment, kNm
0,4	12,1	24	773	25,4	42,6
0,3	11,3	18	580	20,5	16,6
0,2	3,02	12	386	15,1	9,04

After analysis of ice loads calculating methods practised in Russia, Canada, Finland, USA and Lithuania and calculating by them 0,4 m thick ice (1% probability ice thickness in Lithuania in winter time) load, acting on slabs, it was found that the results of ice loads, calculated by different methods, differ from several to some tens of times (Fig. 1). We think that these differences of calculations results are depend on ice mechanic properties, which are different considering the local climate states.

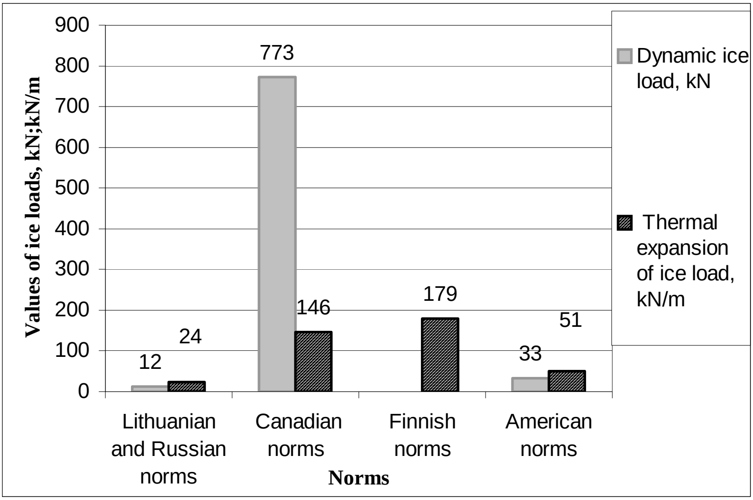

Fig 1. Calculated values of ice loads by different countries' norms

There were made notices during the expeditions, that reinforced concrete slabs for earth dam slope protection are mostly eroded by the linear load of ice thermal expansion. Load values calculated by normative documents of Lithuania (STR 2.05.15:2004), Russia (СНиП 2.06.04–82*), USA (EM 1110–2–2200.58), Canada (EM 1110–2–1612.99), Finland (Fransson L., 1988) are as follows: *q*=24 *kN/m*, *q*=24 *kN/m*, *q*=51 *kN/m*, *q*=146 *kN/m*, *q*=178,9 *kN/m* (Fig. 1).

Calculating method for ice thermal expansion load in Lithuania's conditions was choosed by results of slabs field investigations and control calculations.

Calculations were made by means of commercial programmes *"ALGOR"*, *"STAAD/Pro 2000"*, by the programme *"PLOKŠTĖ"*, worked out by Dr. Assoc. Prof. L. Lindišas of the Dept. of Building Constructions. Further for static calculations was used most suitable commercial programme "*STAAD/Pro2000*", which was choosed after solving the test problem.

During the field investigations we noticed, that reinforced concrete slabs loaded by destroying ice and other environmental impacts mostly collapse as shown in Fig.2.

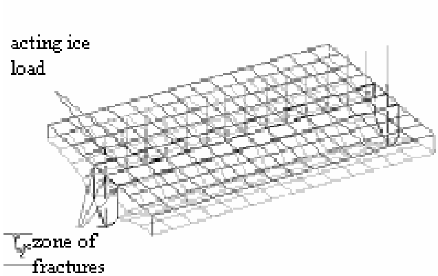

Fig. 2. Reinforced concrete slab collapse scheme under the influence of destroying ice impact

In the field observations noticed longitudinal cracks in parallel with long slab sides (Fig. 2) show the possible impact place of the ice thermal expansion load.

The linear load of ice thermal expansion we established by the bearing capacity of destroyed and non destroyed slabs lagging in the same conditions. The factual bearing capacity of slabs was calculated using by field investigations established physical–mechanic characteristics of slabs. Ice load q which caused factual stress M had to be less for non collapsing slabs, and for collapsing slabs bigger than factual bearing capacity stress $M_{lg.}$ Factual bearing capacities and working stresses of slabs, with maximum values taken with the probability p=0,001, are presented in table 3.

Table 3. Research results of Graužė III earth dam of slopes protection slabs

Factual bearing capacity of slabs $M_{l.g}$		*Factual working stress M*
Non collapsed	*Collapsed*	
2,52±0,15 kNm	2,28±0,03 kNm	$M=M_{vid}+3\sigma$=2,45 kNm

By creation discrete models of structures on the elastic foundation, use computer programme "*SIJA*" worked out by us and commercial programme "*STAAD Pro 2000*" working stresses M were calculated. Under the load – q= 23 kN/m, maximum working stress in the collapsed slabs was M_{suard} = 2,41 kN/m, and in non collapsed $M_{nesuard}$ =2,45 kN/m. Analyzing calculation results of ice thermal expansion load obtained from various countries' norms we can see, that the closest load value is received by STR 2.05.15:2004 and СНиП 2.06.04–82*.

Under the load – q = 24 kN/m were estimated such maximum stresses: 1) by programme "*STAAD/Pro 2000*" $M_{suardytų}$=2,68 kNm, 2) by programme "*SIJA*" M_{suard}=2,52 kNm and $M_{nesuard}$=2,56 kNm..

Having in mind that received calculating results are the closest to our field investigations results, we propose to calculate ice thermal expansion linear loads on slabs of small ponds (with area < 5ha) by STR 2.05.15:2004.

Established ice thermal expansion load has a great influence to durability of pond slabs. Multiplex periodic action of ice thermal expansion load in slabs, which are made from lower quality concrete, calls cracking. Further, when ice widens in the zone of contact with slab due to friction form pitting. The influence of ice thermal expansion load to slabs deterioration process we presented in the "tree of failure" (in the dissertation). Due to this "failure tree" the forecast can be made what deteriorations are menaced to the Gaužė III earth dam slabs. During the research time were destroyed single slabs of ponds. This "failure tree" is usable in other (with similar properties) ponds in the future.

3. Analysis of durability(of the period during which reinforcement of slabs will uncover) and deterioration (constants of degradation) indices of reinforced concrete slabs for earth dam slope protection calculation results

It was noticed during the expedition, that all the investigated surfaces of earth dam slopes slabs in the zone of 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 influence of frost cycles (Fig. 3).

Fig. 3. Erosion of surface on concrete slabs by influence of frost cycles

Surface of 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's a need to explore in more detail pitting appearing reasons. Other reasons of concrete erosion presented in the literature, for instance, cavitation, is less found in our researched structures, because in researched ponds, water flow pulsation speeds are small (<2m/s).

According to the analysis of 12 earth dams slopes protection with reinforced concrete slabs testing results, the surfaces of structures made of weak concrete were damaged much more. The top speed of pitting deepening was established in slabs made of weak concrete (f_c = 4,2÷6,3 MPa) at Pilvė–Vabalkšnis, Kazlai HS. The average deepening speed of a pitting was 4,6 mm and 4,1 mm per year in the structures of Pilvė – Vabalkšnis and Kazlai respectively.

The average deepening speed of pitting in the structures made of concrete with average compression strength f_c = 15,5 MPa (at Anulynas HS) was the smallest – only 0,39 mm per year.

The deepening speed of a pitting *v (constant of degradation)* – in relation to the average compression strength of slabs' concrete f_c may be expressed by equation

$$v = 45{,}813 f_c^{\,-1{,}723}, \qquad (5)$$

where v – average deepening speed of pitting in structures, mm per year,

f_c – average compression strength of concrete, MPa.

Determination coefficient of the function R^2 =0,6747.

Using the formula (5), can be estimated the time ($T_{ap.sl.}$), through which pitting will reach dangerous depth for structure. This depth is to be equal to thickness of the covering layer of the structure concrete (according to the former design norms it had to be no smaller than 30 mm, and due to the currently used design norms it must be 40 mm).

Time ($T_{ap.sl.}$), during which reinforcement of the reinforced concrete slab will uncover in dependence from concrete compression strength f_c may be expressed by

$$T_{30mm\ ap.sl.} = 5{,}789 f_c - 20{,}139, \quad (6)$$

$$T_{40mm\ ap.sl.} = 7{,}7187 f_c - 26{,}852, \quad (7)$$

where $T_{30\ mm\ ap.sl}$ – functioning period of a 30 mm thick covering layer of the structure expressed in years,

$T_{40\ mm\ ap.sl}$ – functioning period of a 40 mm thick covering layer of the structure expressed in years,

f_c – average compression strength of concrete, MPa.

Determination coefficient of the function R^2 =0,7956.

By the constant of degradation and concrete compression strength calculated durability time $T_{ap.sl}$ shows, that structures, manufactured in Lithuania from weak concrete (f_c = 4,4 MPa), when concrete covering layer is 30–40 mm thick, reinforcement had to be uncovered accordingly after 6,5 and 8,7 years of use. In structures, manufactured from stronger concrete (f_c = 15,5 MPa) will be uncovered accordingly after 76,8 and 102,4 years of use.

Using dependences (5) and (6 or 7) for designed earth dam slabs, which are on the changing water level, can be chosen concrete of such strength, that reinforcement of these structures won't uncover during foreseen time.

For example, we calculated, that 30 mm covering concrete layer of slab (under changing water level) would collapse just after 100 years, if it was made from concrete, which compression strength was 20,8 MPa. For the 40mm covering layer compression strength would be enough 16,4 MPa.

Empirical dependences (5) and (6 or 7) may be used for tentative evaluation of properties of cement, coarse–grained, without additives concrete, during the evaluation of used earth dam slopes slabs state.

Concrete compression strength's f_c and times' $T_{30\ aps.sl,}$ and $T_{40\ aps.sl}$, during which reinforcement of reinforced concrete slab will uncover, reliability of functional dependences was checked by double correlation. It was found, that dependences are strong (r_{xy} 0,7…0,9). Calculated correlation coefficients are reliable, their importance level p<0,05. The established determination coefficient R^2 =0,7956, therefore can be stated that examined strength parameters influence investigated indices of durability by 79,6%, other part belongs to the influence of less important parameters.

Analysis of durability (of technical resource remainder) indices and deterioration (percentage of deterioration) of reinforced concrete slabs for earth dam slope protection calculation results

Based on the results of 32 earth dam slabs deterioration percentage, by the real usage and normative life time and by formula (3), calculations of deterioration percentage of slab were carried out. Calculation results showed that they do not correspond to the field observation data. After the analysis of the process of earth dam slab deterioration and summarizing field investigations results, we propose to evaluate slab deterioration by the formula

$$g_{fi} = t_f / t_u \cdot 100\ \%, \quad (8)$$

where g_{fi} – percentage of slab deterioration,

t_f – factual life time of slab in years,

t_u – normative lifetime of slab in years (by norms and research results t_u = 30 years). In calculating cases, when factual lifetime of lab $t_f \geq 30$ years, deterioration of slabs is appreciated in 100%.

We suppose that use of the formula (8) for deterioration percentage calculations more reliable evaluates factual lifetime of slab (in 95% reliability level) the formula (3). (Illustration is given in the dissertation).

It's known that average lifetime of structure conditionally characterizes its durability, but remainder of technical recourse specifies the left service time of structure. According to the results of slab field investigations, by real and normative lifetimes and use calculation formula (4) for technical resource remainder we can plan repair and reconstruction works of slabs.

For the evaluation on how technical resource remainder Δt calculation results correlate with the results of other durability indices ($T_{ap.sl,}$ $T_{5\,\%,}$ $T_{50\,\%}$) calculation results, were made comparative calculations, which results are given in the dissertation. It was noticed that evaluating durability by the formula (4) for technical resource remainder Δt, given in the literature, and by our proposed durability indices– reinforcement uncovering time $T_{ap.sl,}$ and probable deterioration times $T_{5\,\%,}$ $T_{50\,\%}$ –received calculation results differ in 25,4 to 432,3 %. We think, that this difference is received due to the fact, that calculation of the remainder of technical resource Δt by formula (4) attention is paid only to lifetimes of structures, but no attention is taken to factual physical–mechanical properties of concrete slab. Therefore we propose to use the calculating formula (4) only for the tentative probable durability evaluation of slabs.

Defects' analysis of reinforced concrete slabs for earth dam slope protection

The results of 32 earth dam slope protection slabs field investigations shows, that mostly occurred defects 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 and 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.
(Detailed analysis of slabs defects and deteriorations is given in the dissertation).

There's a need to supplement the slabs' defects classification given in the literature by our established earth dam slabs defects and deteriorations. Also main attention must be paid to the zones where deterioration and defects are often formed – pitting are formed in the changing water level in flow compression zone – in slabs, which are not far from the inflow part of shaft spillways or in the flow parts of overflow spillways.

4. Revised method of usable reinforced concrete slabs for earth dam slope protection state evaluation

According to the accumulated field investigations material and analysis of research results, the generalizations of analytical calculations and experience in evaluation the state by rates system, we propose to improve currently valid regulation STR.1.12.03:2000 for earth dam slopes state evaluation – to introduce additional evaluation criteria of *state* (evaluated by extra indices of defects and deterioration), *deterioration* (evaluated by deterioration percentage) and *durability* (evaluated by technical resource remainder).

We recommend to complement the method given in STR.1.12.03: 2000 for the evaluation of the technical state reinforced concrete structures of hydro schemes in this way:

During the field investigations time reinforced concrete slabs defects and deterioration, we propose to record by the scheme of N. Kavešnikovas (1989) and fill in proposed tentative evaluation report of earth dam slabs state and defects' table. After establishment of factual physical–mechanical properties of slabs concrete (method is given in chapter 2) by them are evaluated indices of durability $T_{5\ \%}$ and $T_{50\ \%}$ (by the formulae, presented in the table 1 are calculated probable deterioration times; (calculation illustration is in the dissertation and in its chapters of analysis)) and also $T_{ap.sl,}$(time through which reinforced concrete structures reinforcement will uncover, calculated by formulae (6) or (7); calculation illustration is given in affixes of dissertation and research results are analysed in the chapter of analysis). These indices should exceed minimum values of technical resource remainder Δt (calculated by the formula (4). If only one of durability indices doesn't exceed minimum values of technical remainder given in table 5, the state of slab is evaluated by lower category.

Deterioration indices of earth dam slabs we propose to evaluate by the deterioration percent calculated by the formula (8) from field investigations, which of 95 % probability level evaluate factual lifetime of slab. Additional criteria of the proposed method are given in table 5, where more data are presented.

About mostly in Lithuania occurred reinforced concrete strengthening slabs defects, deterioration and breakdowns typical for all categories of structure state, their physical deterioration or durability level. (Mostly occurred slabs defects were recorded during the expedition and research results were analysed in the dissertation chapter of analysis).

Table 5. State, deterioration and durability indices of reinforced concrete slabs earth dam slope protection

Category of structure state, in points Deterioration, in % Remainder of technical resource Δt, in years				
I Good 0–2,0 points 0–20 % Δt=25–30 years	II Moderate 2,1–4,0 points 20–35 % Δt =20–25 years	III Satisfactory 4,1–6,0 points 35–50 % Δt =15–20 years	IVUnsatisfactory 6,1–8,0 points 50–60 % Δt =10–15 years	V Critical 8,1–10 points 60–80 % Δt <10 years

* data of the table 5 are valid for slabs both on the upstream and on the downstream slope of the earth dam.

Worked out questions in the dissertation:

1. Evaluated frost influence to the change of physical–mechanical properties of the reinforced concrete slabs for earth dam slope protection.
2. Established ice thermal expansion linear load acting the slabs and proposed more exact calculation of this load.
3. Evaluated deterioration indices and defects influence to slabs state and durability.

Concluding remarks and suggestions

1. The method for durability evaluation of reinforced concrete slabs for earth dam slope protection is worked out. By means of the method, knowing values of structures concrete strength, water absorbability and allowed concrete strength loss due to frost action, can be calculated main indices of slabs durability – the probable deterioration start time $T_{5\,\%}$, (covering layer strength f_c loss under the frost influence by 5%) and final the probable deterioration end time $T_{50\,\%}$ (covering layer strength f_c loss under the frost influence by 50%).
2. It is established that reinforced concrete slabs of earth dam slopes protection are mostly damaged by ice thermal expansion load. Principles of this load calculation are given in normative documents of Russia (СНиП 2.06.04–82*), Canada (EM 1110–2–1612.99), USA (EM 1110–2–2200.58) and Lithuania (STR 2.05.15:2004). After checking indicated values in the norms by our method (considering physical–mechanical properties of slabs concrete) it was found, that ice thermal expansion load acting slabs best correspond to the calculated by STR 2.05.15:2004.
3. The main indices of the deterioration process of reinforced concrete slabs for earth dam slope protection are: 1) constant of degradation υ (expressed by pitting depth process dependence from concrete compression average strength), 2) percentage of deterioration, 3) main defects of slabs. Durability of slabs covering layer can be evaluated by time ($T_{ap.sl}$), which equals to reinforcement uncover of reinforced concrete structure.
4. It was found the need to improve evaluation method presented in currently valid regulation STR.1.12.03:2000 for earth dam slopes protection technical state, by complementing indices of physical–mechanical properties and defects of concrete and reinforcement with and main of deterioration and durability indices. The improved method can be also used for evaluation of earth dam downstream slope slabs state.

The main results of the dissertation work are published in scientific, reviewed periodic publications:

1. Šadzevičius R., 2002 a. “Gelžbetonines plokštes tvenkinių šlaitams tvirtinti veikiančių apkrovų analizė” // Vandens ūkio inžinerija: mokslo darbai / LŽŪU, Lietuvos vandens ūkio inst., 2002, Nr.21(43), p. 97–104.
2. Šadzevičius R., 2002 b. “Tvenkinių hidromazgų šlaitų tvirtinimo gelžbetoninėmis plokštėmis techninės būklės vertinimas” // Vandens ūkio inžinerija: mokslo darbai / LŽŪU, Lietuvos vandens ūkio inst., 2002, Nr.20(42), p. 88–93.
3. Šadzevičius R. Vaišvila K.A., Lindišas L., 2001. The research of deterioration of reinforced concrete stuctures functioning in the alternative level of water

engineering constructions // Vandens ūkio inžinerija: mokslo darbai / LŽŪU, Lietuvos vandens ūkio inst., 2001, vol. 18(40), p.47–52.

Information about author

RAIMONDAS Šadzevičius

1973.06.22	Born in Kaunas
1980–1991	Kaunas 38 secondary school
1991– 1998	Lithuanian University of Agriculture
1996	Qualification of hydrotechnic engineering
1998	Master degree of hydrotechnic
1998–2002	Environmental Engineering and Land Management science doctorate at the Lithuanian University of Agriculture
1998–2000	Supervisor Assoc. Prof., Dr. L. Lindišas
2000–2002	Supervisor Assoc. Prof., Dr. K.A.Vaišvila
2002–2004	Assistant at the Department of Building Constructions

Tel.: +370 37 752392
E–mail: raimondas.sadzevicius@lzuu.lt

Apie autorių

Raimondas Šadzevičius

1973.06.23	Kaune.
1980–1991	Kauno 38 vidurinė mokykla.
1991– 1998	Lietuvos žemės ūkio universitetas
1996	Inžinieriaus hidrotechnikos kvalifikacija
1998	Hidrotechnikos magistro laipsnis
1998–2002	LŽŪU Aplinkos inžinerijos ir kraštotvarkos doktorantūra
1998–2000	vadovas doc. dr. L. Lindišas
2000–2002	vadovas doc. dr. K.A.Vaišvila
2002–2004	asistentas Statybinių konstrukcijų katedroje

Tel.: +370 37 752392
E–mail: raimondas.sadzevicius@lzuu.lt

REZIUME

Darbo aktualumas. Šiuo metu Lietuvoje yra virš 1100 užtvankų, kuriomis sudarytų tvenkinių plotai didesni kaip 0,5 ha, iš jų 414 tvenkinių, kurių plotai didesni kaip 5 ha, ir 165 patvenkti ežerai su įvairaus tipo hidrotechnikos statiniais (perteklinio vandens pralaidomis, žemių užtvankomis). Dėl sukaupto tvenkiniuose vandens potencinės energijos keliamo pavojaus aplinkai pagal vandens slėgio aukštį arba sukaupto vandens tūrio 617 tvenkinių Lietuvoje yra priskirti potencialiai pavojingų hidrotechnikos statinių kategorijai. Šie statiniai naudojami sudėtingose sąlygose, todėl turi būti patikimi ir ilgaamžiai. Jų patikimumas ir ilgaamžiškumas priklauso nuo naudojimo sąlygų, statinių priežiūros, savalaikio remonto ar rekonstrukcijos. Daugelio hidrotechnikos statinių amžius yra virš 30 metų ir todėl vien dėl medžiagų senėjimo padidėja gedimų ir avarijų tikimybė. Visos hidrotechnikos statinių gelžbetoninės konstrukcijos veikiamos aplinkos genda, bet ypač *dažnai pažeidžiamos* žemių užtvankų šlaitų tvirtinimo gelžbetoninės plokštės. Aplinkos poveikio pasekoje plokštėse atsiranda pažeidų, kurios neigiamai įtakoja ne tik atskiras plokštes, bet suirus plokštėms kyla grėsmė visam šlaito tvirtinimui bei hidrotechnikos statinio patikimumui, saugumui bei ilgaamžiškumui. Laiku nepašalinus pavojingų defektų bei pažeidų gali būti padaryta milžiniška materialinė ir ekologinė žala. Vertinant ekonominiu požiūriu naujų dangų įrengimas susijęs su didesniais statybos kaštais, todėl aktualiau išsaugoti jau įrengtas žemių užtvankų šlaitų tvirtinimo gelžbetonines dangas, jas laiku remontuojant ar rekonstruojant.

Šiuo metu naudojamų hidrotechnikos statinių būklė vertinama balais (pagal galiojantį reglamentą STR.1.12.03:2000). Šiame reglamente *neminima* apie žemutinio bjefo krantų sustiprinimą gelžbetoninėmis plokštėmis, jų būklės vertinimą, todėl išsamių naudojamų hidrotechnikos statinių gelžbetoninių elementų tyrimų Lietuvos respublikoje nepakanka. Tampa aišku, kad reikalingi praktiški, moksliškai pagrįsti žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių būklės vertinimo algoritmai, įvertinantys dėl aplinkos poveikio susiformavusių pažeidų įtaką plokščių techninei būklei, patikimumui ir ilgaamžiškumui. Disertacijoje būtent šiems klausimams skiriamas didžiausias dėmesys.

Remiantis natūriniais žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių stebėjimais galime teigti, kad Lietuvoje šios konstrukcijos labiausiai ardomos dėl ledo poveikio. Ledo apkrovos skaičiavimo metodikos pagal įvairių šalių norminius dokumentus pasaulyje yra žinomos, bet kiek tos metodikos tinkamos Lietuvos klimato sąlygomis – klausimas spręstinas.

Mokslinė problema ir jos ištyrimo lygis. Naudojamos žemių užtvankų šlaitų tvirtinimo gelžbetoninės plokštės veikiamos įvairių apkrovų bei agresyvios aplinkos genda ir tampa nebetinkamos naudoti. Aplinkos veiksnių (***užšalimo – atšilimo ciklų, ledų apkrovų***) bei jų veikimo pasekoje vykstančio nudėvėjimo (***erozija, konstrukcijų defektų bei pažeidų vystymasis***) proceso spartai bei žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių ilgaamžiškumui įvertinimas ir yra pagrindinė problema.

Darbo tikslas

Įvertinti aplinkos įtaką žemių užtvankų šlaitų tvirtinimo gelžbetoninėms plokštėms.

Tikslui pasiekti reikia išspręsti šiuos **uždavinius**:

1. Sudaryti šalčio ciklų veikiamų žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių ilgaamžiškumo įvertinimo metodiką.

2. Nustatyti (Lietuvos sąlygom) būdingiausią ledo apkrovos tipą ir projektavimo normas, kurios tiksliausiai įvertina šias apkrovas.
3. Nustatyti žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių pagrindinius nudėvėjimo procesą apibūdinančius rodiklius bei įvertinti plokščių betono išorinio sluoksnio ilgaamžiškumą.
4. Žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių natūrinių tyrimų rezultatais pagrįsti šiuo metu naudojamų būklės vertinimo metodikų patikimumą.

Mokslinis naujumas

- Pagal natūrinių tyrimų rezultatus atliktas mokslinėse publikacijose nepaminėtas aplinkos poveikio žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių ilgaamžiškumui modeliavimas ir analizė.
- Remiantis žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių irimo analize pirmą kartą Lietuvos sąlygomis įvertinta tvenkinyje susidariusio ledo temperatūrinio plėtimosi linijinė apkrova.
- Nustatyti užšalimo – atšilimų ciklų ir kt. aplinkos veiksnių veikiamų žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių betono gniuždomojo stiprio kitimo dėsningumai.

Teoriniai ir praktiniai rezultatai

- Nauja netiesioginio atsparumo šalčiui markės nustatymo metodika pritaikyta vertinant žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių atsparumą šalčiui.
- Nustatytas tinkamiausias programinis kompleksas žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių konstrukciniams skaičiavimams.
- Plokščių ant tampraus pagrindo skaičiavimams sukurta kompiuterinė programa *“SIJA”*.
- Nustatyta Lietuvos sąlygomis tinkamiausia ledo apkrovų skaičiavimo metodika.
- Nustatytas vienas iš pagrindinių nudėvėjimo rodiklių – nudėvėjimo konstanta.
- Nustatyti reglamentą STR.1.12.03:2000 papildantys žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių būklės vertinimo kriterijai.
- Sukurta žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių ilgaamžiškumo įvertinimo metodika.
- Sudaryti praktiški tvenkinių šlaitų tvirtinimo plokščių techninės būklės vertinimo protokolai bei klasifikatoriai.

Darbo rezultatų teorinė ir praktinė vertė

- Turint natūriniais tyrimais nustatytas žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių fizikines – mechanines savybes ir naudojant mūsų sudarytus plokščių modelius galima įvertinti tvenkinyje susidariusio ledo apkrovas.
- Naudojant nustatytą nudėvėjimo konstantą projektuojamoms žemių užtvankų šlaitų tvirtinimo plokštėms, esančioms kintamo vandens lygyje, galima parinkti tokio stiprio betoną, kad per numatytą laiką šių konstrukcijų armatūra neapsinuogintų. Taip pat ši konstanta naudotina vertinant naudojamų žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių būklę.
- Nustatytieji STR.1.12.03:2000 papildantys žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių būklės vertinimo kriterijai bei sudarytieji techninės būklės vertinimo protokolai bei klasifikatoriai padeda tiksliau įvertinti naudojamų plokščių būklę.
- Remiantis mūsų sukurta žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių

ilgaamžiškumo įvertinimo metodika galima apskaičiuoti kiek metų liko konstrukcijai naudoti iki tikimybinio suirimo pradžios ($T_{5\%}$) ar pabaigos ($T_{50\%}$), o taip pat įvertinti laiką ($T_{ap.sl.}$), per kurį naudojamų gelžbetoninių konstrukcijų armatūra apsinuogins.

Tyrimų laikas, objektai ir sąlygos

1998-2004 metais tyrinėtos 32 žemių užtvankų šlaitų tvirtinimo gelžbetoninės plokštės.

Autorius gina

- Užšalimo–atšilimo ciklų veikiamų žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių ilgaamžiškumo rodiklių $T_{5\%}$ ir $T_{50\%}$ nustatymo metodiką (pagal plokščių gniuždomojo betono stiprio ir vandens įgėrio tyrimų rezultatus).
- Tvenkinyje susidariusio ledo temperatūrinio plėtimosi linijinės apkrovos, veikiančios tvenkinių šlaitų tvirtinimo plokštes, nustatymo metodiką, pagrįstą plokščių suirimo parametrų įvertinimu.
- Nudėvėjimo rodiklių įtakos žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių ilgaamžiškumui tyrimų metodą.
- Papildomus žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių techninės būklės vertinimo kriterijus.

Išvados ir pasiūlymai

1. Sudaryta žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių (ŠTP) ilgaamžiškumo vertinimo metodika, pagal kurią žinant naudojamų konstrukcijų betono stiprio ir vandens įgėrio reikšmes bei leistiną betono stiprio sumažėjimo dydį dėl šalčio poveikio, galima nustatyti pagrindinius ŠTP ilgaamžiškumo rodiklius – teorinio suirimo pradžios laiką $T_{5\ \%}$ (šalčio veikiamo betono apsauginio sluoksnio stiprio f_c sumažėjimas 5 %) ir galutinio teorinio suirimo laiką $T_{50\ \%}$ (šalčio veikiamo betono apsauginio sluoksnio stiprio f_c sumažėjimas 50 %).

2. Nustatyta, kad žemių užtvankų šlaitų tvirtinimo gelžbetoninės plokštės dažniausiai ardomos dėl ledo temperatūrinio plėtimosi apkrovos. Šios apkrovos skaičiavimo principai pateikiami Rusijos (СНиП 2.06.04–82*), Kanados (EM 1110–2–1612.99), Jungtinių Amerikos Valstijų (EM 1110–2–2200.58) bei Lietuvos (STR 2.05.15:2004) norminiuose dokumentuose. Normose nurodytus dydžius patikrinus pagal mūsų sudarytą metodiką (remiantis nustatytomis ŠTP betono fizikinėmis – mechaninėmis savybėmis) nustatyta, kad žemių užtvankų šlaitų tvirtinimo plokštes veikiančių ledo temperatūrinio plėtimosi apkrovų dydžiai geriausiai atitinka apskaičiuotiems pagal STR 2.05.15:2004 ir СНиП 2.06.04–82*.

3. Žemių užtvankų šlaitų tvirtinimo gelžbetoninių plokščių nudėvėjimo procesą apibūdinantys pagrindiniai rodikliai yra: 1) nudėvėjimo konstanta v (išreikšta išgraužų gilėjimo spartos priklausomybe nuo gniuždomojo betono vidutinio stiprio), 2) nudėvėjimo procentai, 3) ŠTP pagrindiniai defektai.

ŠTP apsauginio sluoksnio ilgaamžiškumą galima įvertinti laiku ($T_{\text{ap.sl.}}$), per kurį naudojamos gelžbetoninės konstrukcijos armatūra apsinuogins.

4. Nustatyta kad reikia patikslinti dabar galiojančio reglamento STR.1.12.03:2000 žemių užtvankų šlaitų tvirtinimo techninės būklės įvertinimo metodiką, papildant betono ir armatūros fizikinių – mechaninių savybių, defektų, pagrindiniais nusidėvėjimo bei ilgaamžiškumo rodikliais. Patikslintą metodiką galima naudoti ir žemių užtvankų žemutinio bjefo ŠTP būklės vertinimui.

Rezultatų aprobavimas ir publikacijos

Pagrindiniai disertacinio darbo teiginiai buvo aptarti 7 mokslinėse konferencijose. Darbe išdėstyta medžiaga paskelbta 3 straipsniuose (pripažintuose mokslo leidiniuose).