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DEVELOPMENT OF THE ONTOLOGY MODEL FOR THE TECHNICAL CONDITION OF HYDRAULIC STRUCTURES

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ABSTRACT

Hydrotechnical constructures are complex structures that represent the interaction between soil-, water- and technological environment. For trouble-free and safe operation of hydrotechnical constructures, as well as maintaining them in operational mode, by the operating organization, as well as by organizations that conduct technical supervision, constant technical inspections are carried out to fix the damage (defects). This allows you to determine the actual technical condition of structures. Currently, building information modelling (BIM) methodology is most widely used for modelling structures. This methodology supports the seamless exchange of all information between relevant participants using digital technology. However, IFC files are mainly used to store data on structures. The evolution of this methodology provides for interoperability based on the network. The W3C LBD-CG community group presented an adapt extensible ontology called Building Topology Ontology (BOT), which provides a high-level description of the topology of structures, including the natures and types of hydrotechnical constructures depending on the purpose and operating conditions of structural elements of different levels. Authors have created an adapted ontology that does not have the same disadvantages as the IFC in terms of size and complexity. Reuse of existing ontologies has been an important priority, which allows the inclusion of ontologies for specialized areas. The issue of describing the technical condition of hydrotechnical constructures is considered. Basic terms and statements are introduced that extend the multi-sorted language of applied logic to describe the knowledge of this subject area. The ontology model provides terminology for defining damage associated with hydrotechnical constructures. The ontology model makes it possible to introduce into the developed ontologies the relationship of damages with structural elements and spatial zones of their location. The ontology can also be used to represent observations of the technical state of damage in a machine-interpreted format.

Keywords: Hydrotechnical constructures; building information modelling; topology; damage; ontology; multi-sorted language; applied logic; determination of depths; ontology web language; complete orthogonal semantic spaces; sediment accumulation

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INTRODUCTION

Building Information Modeling (BIM) is a methodology that has been used in recent decades [1-2] for the unhindered flow of information between users through the use of digital technologies. The operation of hydrotechnical constructures (HS) implies a set of measures to ensure safe and trouble condition of the structure. To solve this problem, free operation. One of the most important issues in the operation of existing structures is the task of determining the technical extremely large volumes of information of various nature are required. Moreover, information resources, as a rule, are located in geographically distributed nodes. Here, the technical condition is understood as a set of values of parameters (attributes) of a structure that change in the course of design, production, testing and operation, which characterize its functional suitability under given conditions of use [3].

During the technical operation of structures, the following documents are used: technical supervision logs of the hydrotechnical constructure, inspection reports, diving surveys of the underwater part of the structure, as well as the operating water area near the structure, certificates of technical condition, reports of control and inspection surveys of the structure, surveying works to determine the actual depths, as

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well as identifying items lying on the bottom that can cause accidents, photographs of defects, defective statements, supervisory documents, etc.

In the process of BIM modelling of a structure, users of different specialities participate, and each of them uses its own special software tools [4-5]. The fragmented structure of the industry, as it is made up of many small and medium-sized companies, makes particular demands on the exchange of information. Information exchange approaches rely on files such as Industry Foundation Classes (IFC) [6] and file containers [7]. Recently, the Common Data Environments (CDE) – based approach has been proposed for centralized web storage and file-sharing related to structures. The use of CDE is also stipulated in the European guidelines for the implementation of BIM [8]. However, a common disadvantage of these approaches is that linking information at the data level is not possible by distributing information across files. Also, tracking changes is possible only at the file level, which is a serious limitation [9].

The exchange of information is expected to be purely web-based and fully integrated across companies. The approach taken to address this problem is that the introduction of Semantic Web technologies [10-11] in the building information modelling industry will help meet these requirements.

Currently, the classification of damages in hydrotechnical constructures is carried out manually by an expert. In addition, after the classification process is completed, it is necessary for an expert to assess the technical condition of the structure. For this purpose, Ukraine uses standards [12-13]. However, when using these standards, the assessment is simplified to the definition of a generalized technical condition class. Detailed classification and identification of the cause of damage are often recorded only in non-machine or even non-digital formats, such as handwritten protocols or images, which makes further processing of this data more difficult.

However, the approach based only on the use of descriptive logic when building an ontology in the Web Ontology Language (OWL) suffers from a number of disadvantages. For example, in OWL it is possible to specify only binary relationships between classes, but it is impossible to specify temporal relationships, mathematical formulas.

Therefore, the authors propose to use in the construction of ontologies a multi-sorted language of applied logic [14], which provides less limited possibilities.

LITERATURE REVIEW

In [15-16], the mapping of the EXPRESS schema within Ontology Web Language (OWL) is implemented to create the ifcOWL ontology [17]. The resulting ontology was fully backward-compatible with the EXPRESS IFC schema. As a result, ifcOWL has two main disadvantages: complex structure and size.

Several ontologies have been developed to represent and classify damages. In [18], an ontology was developed, which is used to search for information about damages obtained from the BIM model. Several instances, called “cases”, are predefined in the ABox of the ontology. Each of these instances belongs to a certain number of classes that define defects and properties of the design (for example, component type or material). However, the ontology does not support damage topology modelling, nor does it link damage to structural components. As far as we know, the ontology presented in [18] is not publicly available on the Internet, which complicates its application. One of the most extensive approaches to representing damage in an ontological model was developed within the MONDIS project, which focuses on damage to cultural monuments [19]. The ontological model developed in [19] makes it possible to determine causal relationships and the corresponding properties of damage for historical structures. Thus, it can also be used to classify and assess the condition of structures.

Papers [20-21] present an adapted extensible ontology called Building Topology Ontology (BOT), which provides a high-level description of the topology of structures, including floors and rooms, and the building elements they may contain. The authors have created an adapted ontology that does not have the same disadvantages as the IFC in terms of size and complexity. Reuse of existing ontologies has been an important priority, which includes ontologies for specialized areas. Such detailed ontologies do not need to be included in the BOT, but they are intended to be associated with each generated BOT compliant RDF data item.

Therefore, the damage topology ontology (DOT) [22] was developed as a modular web ontology for defining damage objects and their topology. In addition to defining the topology of damage, DOT also serves as a basic ontology for the digital representation of degradation. Thus, DOT can be extended with additional ontologies that allow more detailed damage classifications and structural damage mechanics to be added.

Despite these various changes in the area of damage classification and assessment, there is no approach at the time of publication that provides a detailed description of damage parameters with damage related to structural components. At the same time, a model should be determined that could be best suited for assessing the technical condition of a structure over a certain period of time.

When constructing an ontology model, a multi-sorted language of applied logic is used in the work.

Currently, ontology models have been developed for various subject areas using a multi-sorted language of applied logic. Examples of ontology models are: chemistry [23], program transformation [24], medical diagnostics [25], diagnostics of distributed networks [26-27] and environmental monitoring [28]. Note that the practical implementation of such systems is possible using knowledge bases in the RDF format and inference engines similar to BaseVISor [29].

PURPOSE AND OBJECTIVES OF THE RESEARCH

In this paper, an approach is proposed to create a module for describing the technical state of structures using a multi-sorted language of applied logic. This approach allows a detailed description of the damage parameters with the linkage of damage to structural components and is suitable for assessing the technical condition of a structure over a certain period of time.

To achieve this goal, it is necessary to solve the following tasks:

– introduce the basic concepts of the module for describing structures using IFC terms;

– introduce the basic concepts of the damage description module using IFC terms;

– introduce the basic concepts of the module for describing the technical condition of structures;

– to develop an ontology model for describing the technical state of HS's.

The work is structured as follows:

1) The basic concepts of the module for describing structures using the Building Topology Ontology (BOT) have been introduced.

2) The basic concepts of the damage description module using the Damage Topology Ontology (DOT) have been introduced.

3) A linguistic model for describing the technical state of damage has been developed.

4) The linguistic variables that are necessary to describe the technical state of specific damages have been introduced.

5) An ontology model for describing the technical state of damage in the language of multi-sorted logic is being developed.

6) The application of the ontology model for describing the technical state of damage to describe specific damage and their causes in the language of multi-sorted logic is demonstrated.

MULTILEVEL MODEL OF ONTOLOGY

This paper presents a modular approach developed by the authors for creating ontology models for describing the technical state of hydrotechnical constructures. The developed approach provides for the creation of a multilevel ontology model in the form of a set of modules, presented in Fig. 1.

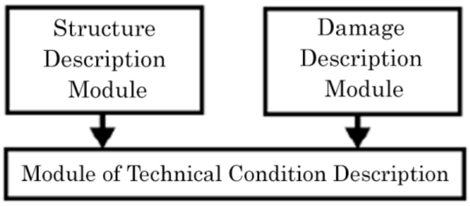

Fig. 1. **Multilevel ontology model**
***Source*: compiled by the author**

Each module of the second level describes the terminology of the corresponding section of the subject area. A structure description module and a damage description module are presented.

This description allows expanding the multilevel ontology model for describing the technical state of hydrotechnical constructures by introducing new modules.

New modules can correspond to other sections of such a complex and structured subject area as the description of the technical condition of structures.

STRUCTURE DESCRIPTION MODULE

The structure description module contains terms and relationships similar to the classes in the Building Topology Ontology (BOT) [20-21]. This allows this ontology to be used as a separate module.

The purpose of the BOT ontology is to explicitly define the necessary relationships between the subcomponents of a structure. For this, three main classes are introduced in the BOT ontology: bot:Zone, bot:Element, and bot:Interface. bot:Zone is an area in 3D space. bot:Element is an integral part of a structure with a specific shape or position. It can be a product, device, structural element, etc. bot:Interface is a limited surface that is common to some specific zones and elements and is located on the border of at least one of them. The bot:Zone class has four subclasses: bot:Site, bot:Building, bot:Storey, and bot:Space.

A 3D model can be assigned to the bot:Zone or bot:Element classes in two ways:

1) using the bot object property: has3DModel;

2) using the bot datatype property: hasSimple3DModel.

The bot:Element class describing structural elements of structures can contain subelements. This relationship is defined using the bot:hasSubElement property. The bot:hasElement property is defined to indicate the general relationship between bot:Zone and bot:Element.

The mathematical model of the ontology for describing structures is based on a multi-sorted language of applied logic. Each particular application logic language includes a kernel, as well as usually a standard extension and some specialized extensions.

As a result, a set of statements were formulated that make up the module for describing structures using a multi-sorted language of applied logic.

Here are some of the statements of this module:

– the term *Elements* denotes a set of structural elements of a structure.

sort $Elements = \{\}N \setminus \{\ \}$.

– the term *Zones* denotes a collection of three-dimensional areas that are used to describe a structure.

sort $Zones = \{\}N \setminus \{\ \}$.

– the term *Sites* denotes a collection of three-dimensional areas that contain one or more objects used to describe a structure.

sort $Sites = \{\}N \setminus \{\ \}$.

– the term *Buildings* denotes a set of specific hydrotechnical constructures, which may consist of individual structural elements.

sort $Buildings = \{\}N \setminus \{\ \}$.

– the term *Storeys* denotes a set of vertically connected modules of hydrotechnical constructures, which may consist of separate structural elements.

sort $Storeys = \{\}N \setminus \{\ \}$.

– the term *Spaces* denotes a three-dimensional area within the area in which it is contained.

sort $Spaces = \{\}N \setminus \{\ \}$.

– the term *hasElements* denotes a function that assigns an element of the *Zones* set to each structural element of the *Elements* structure.

sort $hasElements = Zones \rightarrow Elements$.

– the term *hasSubElements* denotes a function that assigns to each structural element of the *Elements* structure an element of the set of *Elements* that it contains..

sort $hasSubElements = Elements \rightarrow Elements$.

– the names of all *Elements* and *Zones* are different.

$Elements \cap Zones = \varnothing$.

Similarly, it is determined that the names of all elements of the sets *Elements*, *Zones*, *Buildings*, *Storeys*, *Spaces*, *Sites*, *hasElements*, and *hasSubElements* are pairwise different.

DAMAGE DESCRIPTION MODULE

The damage description module contains terms and relationships similar to the classes in the Damage Topology Ontology (DOT) ontology [22], which allows using this ontology as a separate module. DOT acts as a base ontology and is designed to define and link damage representations to other web ontologies that define the construct (for example, instances of BOT classes).

Damages Dot:Damage can be described using one of two subclasses. Individual damage representations can be described using the dot:DamageElement class. At the same time, they are connected with the components of the described bot:Element constructs using the dot:hasDamageElement relationship. Detailed damage geometry can be associated with a dot:DamageElement instance at a later point in time using, for example, an information data container (ICDD) [30].

However, in practice, detailed damage modelling is not always possible. For example, modelling complex damage, such as an accumulation of microfractures, is time-consuming. In this case, the damaged area can be modelled using dot:DamageArea. Instances of the dot:DamageArea class can be associated with damaged structure components using the dot:hasDamageArea relationship. To assign instances of the dot:DamageElement class to an instance of the dot:DamageArea class, the dot:aggregatesDamageElement relationship is used.

To define physically related damages, such as adjacent fractures, multiple instances of the dot:DamageElement class can be associated with a dot:adjacentDamageElement relationship. Using this relationship, complex damage models can be modelled. A sample of physically related damage is represented by an instance of the dot:DamagePattern class, in which instances of the dot:DamageElement class can be grouped through the dot:groupsDamageElement relation. Then dot:DamagePattern connects to the dot:DamageArea instance through the dot:aggregatesDamagePattern relationship.

The mathematical model of the damage description ontology is also built on the basis of a multi-sorted language of applied logic. As a result, many statements were formulated that make up the damage description module.

Here are some of the statements of this module:

– the term *Damages* denotes a collection of objects of damage. Instead of using *Damages*, it is recommended to use one *Damages* subclass for the respective damage topology (*DamageAreas* or *DamageElements*).

sort $Damages = \{\}N \setminus \{\varnothing\}$.

– the term *DamageElements* denotes a set of damages to structural elements. The knowledge must describe at least one damage to a structural element.

sort $DamageElements = \{\}N \setminus \{\varnothing\}$.

– the term *DamageAreas* denotes a collection of damage surfaces. The knowledge must describe at least one surface of the damage.

sort *DamageAreas* = {}N \ { $\varnothing$ } .

– The term *adjacentDamageElements* denotes a function that defines a relationship between two *DamageElements* instances that are physically connected to each other.

sort *adjacentDamageElements* = *DamageElements* $\rightarrow$ *DamageElements.*

– the names of all *DamageElements* and *DamageAreas* are different.

DamageElements $\cap$ *DamageAreas* = $\varnothing$.

– The term *aggregatesDamageElement* denotes a function that defines a relationship between a *DamageAreas* instance containing *DamageElements* instances.

sort *aggregatesDamageElement* = *DamageAreas* $\rightarrow$ *DamageElements*.

– The term *DamagePatterns* is used to define a set of related or physically related instances of *DamageElements*. It's used as a grouping class within a *DamageAreas* instance.

sort *DamagePatterns* = {} N.

– The term *aggregatesDamagePatterns* denotes a function that defines the relationship between a *DamageAreas* instance and a *DamagePatterns* instance.

sort *aggregatesDamagePatterns* = *DamageAreas* $\rightarrow$ *DamagePatterns*.

– the group of the names of all *DamageElements* and *DamageAreas* matches the set of *Damages*.

Damages $\equiv$ *DamageElements* $\cup$ *DamageAreas*.

LINGUISTIC MODEL FOR DESCRIPTION OF TECHNICAL STATE

The model being developed is based on the representation of the structure as a set of structural elements.

$$E=\{e_l\}_{l=1}^{L}, \tag{1}$$

where L is the total number of structural elements.

The assemblage of defects is represented as a set

$$A=\{a_i\}_{i=1}^{I}, \tag{2}$$

where I is the total number of damages in the structure under consideration.

We represent the set of observed parameters of some damage $a_i \in A, i=1,...,I$ in the form

$$P(a_i)=\left\{p_j(a_i)\right\}_{j=1}^{J(a_i)}, i=1,...,I, \tag{3}$$

where $J(a_i)$ is the total number of observed parameters of the defect $a_i \in A, i=1,...,I$.

From the sets $P(a_i)$, $i=1,...,I$ expertly identifies sets of parameters $B(e_l)$, the values of which must be taken into account in the future in the process of observing the technical state of a certain structural element $e_l, l=1,...,L$.

In this work, the set of parameters $B(e_l), l=1,...,L$ is denoted as

$$B(e_l)=\{b_m(e_l)\}_{m=1}^{M(e_l)}, \tag{4}$$

where $M(e_l)$ is the total number of diagnostic parameters that must be taken into account in the process of identifying the technical state of a certain structural element $e_l \in E, l=1,...,L$.

It is assumed that the values $b_m(e_l)$, $l=1,...,L, m=1,...,M(e_l)$ are determined inaccurately. Therefore, in the work, the value of the parameter $b_m(e_l)$ is determined on a certain segment of the set of real numbers as a fuzzy set $t(v_{l,m},\varepsilon_{l,m})$ with the following membership function

$$\mu(x,v_{l,m},\varepsilon_{l,m})=\begin{cases}0, x<v_{l,m}-\varepsilon_{l,m}\\ 1, v_{l,m}-\varepsilon_{l,m}\le x\le v_{l,m}+\varepsilon_{l,m}\\ 0, x>v_{l,m}+\varepsilon_{l,m}\end{cases} \tag{5}$$

where $v_{l,m},\varepsilon_{l,m}$ are some real numbers,

$$l=1,...,L, m=1,...,M(e_l).$$

When describing fuzzy parameters, it is necessary to describe the fuzzy values that they take. To avoid ambiguity in interpreting the semantic values of the same parameter in different situations, we construct complete orthogonal semantic spaces (COSS), which will serve as areas of fuzzy values of each of the parameters, regardless of the system under consideration.

To construct a complete orthogonal semantic space of some fuzzy parameter t we define a set of fuzzy values $T=\{T^k\}_{k=1..K}$, where K is the number of fuzzy values taken by the parameter t. Each fuzzy value T^k is a fuzzy number with a membership function μ^k, that is positively defined on some interval (d_b^k,d_e^k), where $d_b^k,d_e^k \in D$ are the values of the beginning and end of the interval, respectively, and D is the base set of fuzzy parameter t values. In order for the constructed sets $T=\{T^k\}_{k=1..K}$ to be COSS, it is necessary that they satisfy the following axioms [27].

Axiom 1 -- normality: each membership function μ^k of fuzzy values T^k reaches the value of *one* on the base set D.

Axiom 2 -- the function μ^k does not decrease to the left of d_b^k and does not increase to the right of d_e^k, i.e:

$$\begin{aligned} \mu^k(d) \ge \mu^k(d_b^k), \quad & d < d_b^k \\ \mu^k(d) \le \mu^k(d_e^k), \quad & d > d_e^k \end{aligned}.$$

Axiom 3 – functions μ^k cannot have more than two discontinuity points of the first kind.

Axiom 4 – completeness: for any value d from the base set D there is a fuzzy value $T^k \in T$ with a nonzero value of the membership function $\mu^k(d)$ at a given point, i.e.

$$\forall d \in D \quad \exists k \in [1, K]: \quad \mu^k(d) \ne 0$$

Axiom 5 – orthogonality: the sum of all values of the membership functions $\mu^k(d)$ at some point d of the base set D must be equal to *one*, i.e.

$$\sum_{k=1}^{K} \mu^k(d) = 1, \qquad d \in D.$$

Thereat, if a strictly order relation $\prec_T$ is introduced on the set of fuzzy values of the parameter t, then the following conditions must be satisfied:

$$\begin{cases} \mu^k(d) = 1 - \mu^{k-1}(d), d_b^k < d < b^k \\ \mu^k(d) = 1 - \mu^{k+1}(d), e^k < d < p_e^k \end{cases}, \tag{6}$$

$$k = 2..(K-1)$$

$$\begin{cases} d_b^1 = b^1 = \min\limits_D(d) \\ d_e^K = e^K = \max\limits_D(d) \end{cases}, \tag{7}$$

where d is some point of the base set D of the fuzzy parameter t, b^k, e^k are the initial and final values, respectively, of the interval of values of the base set D, on which the membership function $T^k \in T$ is equal to *one*.

Let us now set some constructive element $e \in E$ and parameter $b(e) \in B(e)$. For the linguistic description of the parameter $b(e) \in B(e)$ values, we construct a COSS, which will serve as the domain of the linguistic parameter values.

The COSS of some parameter $b(e)$ is defined as a set of fuzzy values $\Omega(b,e) = \{b^k(e)\}_{k=0..K(b,e)-1}$, where $K(b,e)$ is the number of fuzzy values accepted by the parameter. Here the fuzzy set $b^k(e)$ is a fuzzy number with a triangular membership function that is positively defined on some segment $[D_0(b,e), D_1(b,e)]$.

We define each fuzzy number $b^k(e) \in \Omega(b,e), k = 0..K(b,e)-1$ through the membership function of the following form:

$$\mu_0(b,e,x) = \begin{cases} \dfrac{x_1(b,e) - x}{\Delta(b,e)}, x_0 \le x \le x_1 \\ 0, x \ge x_1 \end{cases},$$

$$\mu_i(x,b,e) = \begin{cases} 0, x \le x_{i-1} \\ \dfrac{x - x_{i-1}}{\Delta(b,e)}, x_{i-1} \le x \le x_i \\ \dfrac{x_{i+1} - x}{\Delta(b,e)}, x_i \le x \le x_{i+1} \\ 0, x \ge x_{i+1} \end{cases}, \tag{8}$$

$$\mu_{K-1}(x,b,e) = \begin{cases} 0, x \le x_{K-2} \\ \dfrac{x - x_{K-2}}{\Delta(b,e)}, x_{K-2} \le x \le D_1(b,e) \end{cases}.$$

where x – is some clear value of the parameter,

$$K = K(b,e), \; x_i = D_0(b,e) + \Delta(b,e)i,$$

$$i = 0...K(b,e)-1,$$

$$\Delta(b,e) = \frac{D_1(b,e) - D_0(b,e)}{K-1}.$$

The following statement can be shown to be true:

Statement. If the set of fuzzy values $\Omega(b,e)$ satisfies relations (6), then it is COSS.

The proof. Axiom 1 – Normality:

– the membership function $\mu_0(b,e,x)$ is equal to *one* at the point $x_0 = D_0(b,e)$;

– the membership function $\mu_i(b,e,x)$ is equal to *one* at the point x_i;

– the membership function $\mu_{K-1}(b,e,x)$ is equal to *one* at the point x_{K-1}.

Axiom 2. The function $\mu_i = 0$ to the left of x_{i-1} and to the right of x_{i+1}, i.e. the conditions of the axiom are fulfilled.

Axiom 3. The functions μ_i, $i=0..K-1$ are continuous, therefore the conditions of the axiom are fulfilled.

Axiom 4 and Axiom 5. Suppose that $x\in[x_n,x_{n+1}]$. Then the following conditions are met:

$$\mu_i(b,e,x)=0,\ i=0..n-1,$$

$$\mu_i(b,e,x)=0,\ i=n+2..K-1,$$

$$\mu_n(b,e,x)=\frac{x_{n+1}-x}{\Delta},$$

$$\mu_{n+1}(b,e,x)=\frac{x-x_n}{\Delta},$$

$$\mu_n(b,e,x)+\mu_{n+1}(b,e,x)=1.$$

Therefore, the conditions of the axioms are fulfilled. The statement is proven.

In general, a fuzzy estimate $t(v,\varepsilon)$ of the parameter $b(e)$ will not match any of the fuzzy values $b^k(e)$ from COSS $\Omega(b(e),e)$.To determine the correspondence of the obtained value to one of the terms defined in $\Omega(b(e),e)$, the relation is used (it is assumed in the work that $\varepsilon<\Delta$):

$$t(e)=\arg\min_{k=0..K-1} S(z_k,\varepsilon,\Delta(b,e)) \qquad (9)$$

where $z_k=\left|v-D_0(b)-k\Delta(b,e)\right|$,

$$S(z,\varepsilon,\Delta)=\begin{cases}\dfrac{2\varepsilon\Delta-z^2-\varepsilon^2}{\Delta}0,0\le z\le\varepsilon\\ \dfrac{2\varepsilon(\Delta-z)}{\Delta},\varepsilon<z\le\Delta-\varepsilon\\ \dfrac{(\Delta+\varepsilon-z)^2}{2\Delta},\Delta-\varepsilon<z\le\Delta+\varepsilon\\ 0,\Delta+\varepsilon<z\end{cases},$$

if $\Delta>2\varepsilon$ and

$$S(z,\varepsilon,\Delta)=\begin{cases}\dfrac{2\varepsilon\Delta-z^2-\varepsilon^2}{\Delta}0,0\le z\le\varepsilon\\ \dfrac{(\Delta+\varepsilon-z)^2}{2\Delta},\Delta-\varepsilon<z\le\Delta+\varepsilon,\\ 0,\Delta+\varepsilon<z\end{cases}$$

if $\varepsilon<\Delta\le2\varepsilon$.

Thus, to set the values of the system parameters, linguistic variables are defined:

$$p_m^l=<n_m^l,\Omega(b_m(e_l),e_l),D_{m,l}>,\quad l=1,...,L,\ m=1,...,M(e_l) \qquad (10)$$

where n_m^l is the name of the linguistic variable, $\Omega(b_m(e_l),e_l)$ is the COSS, which determines the term-set of the linguistic variable, and $D_{m,l}=(D_0(b_m(e_l),e_l),D_1(b_m(e_l),e_l))$ is the base set of the *m*-th parameter of the *l*-th structural element.

MODULE OF TECHNICAL CONDITION DESCRIPTION

The paper presents a mathematical model of the ontology for describing the technical condition of structural elements, which contains observations of the specified parameters that depend on the observation time.

The developed model made it possible to formulate a set of statements that make up the module for describing the technical condition.

Part of these statements, described using the multi-sorted applied logic language, is represented in the form:

– the term *partitions* means the set of all possible partitions of the set of non-negative integers; each partition is a finite strictly increasing sequence.

$$partitions\equiv(\cup(n:I[1,\infty])$$

$$\left\{\left(v:R\Uparrow(n+1))(\wedge(i:I[1,n])\pi(i,v)<\pi(i+1,v)\right)\right\})$$

– the term *el* denotes a function whose arguments are some partition and an integer in the range from 0 to the number of elements in this partition, and the result is an element of this partition, the number of which is equal to the second argument

$$el\equiv\begin{pmatrix}\lambda(v:\textit{разбиения})\\ (i:I[0,length(v)-1])\pi(i+1,v)\end{pmatrix}.$$

– The term *interval* (inv) is a set of elements of structural values with the attributes lower bound (*lb*) and upper bound (*ub*). Their values are natural numbers – the minimum and maximum duration of the interval and the upper bound is greater than the lower one.

$$inv\equiv\left(\textit{нг}\to I[1,\infty),\textit{вг}\to I[\textit{нг}+1,\infty)\right).$$

– The term *hasDamage* denotes a function that associates a structural element of a structure with each damage.

sort *hasDamage*= *DamageElements* → *Elements*.

– The term *hasDamageElement* denotes a function that associates a structural element of a structure with each damage element.

sort *hasDamageElement*=*DamageElements* → *Elements*.

– The term *hasDamageArea* denotes a function that associates a structural element of a structure with each damage surface.

sort $hasDamageArea = DamageAreas \rightarrow Elements$.

– The names of all *hasDamageElement* and *hasDamageArea* are different.

$hasDamageElement \cap hasDamageArea = \varnothing$.

– The union of the names of all *hasDamageElement* and *hasDamageArea* matches the set of *hasDamage*.

$hasDamage \equiv hasDamageElement \cup hasDamageArea$.

– The term *Parameters* denotes a class of concepts corresponding to the observed parameters. The knowledge must describe at least one parameter.

sort $Parameters = \{\}N \setminus \{\varnothing\}$.

– The term *ParametersDamageElement* denotes a class of concepts corresponding to linguistic variables to be used in assessing the technical state of damage.

sort $ParametersDamageElement = \{\}N \setminus \{\varnothing\}$.

– Each term in the *ParametersDamageElement* term class denotes a structural value with two attributes: $s \rightarrow DamageElements,\ p \rightarrow Parameters$.

The value of the first is the name of the damage; the second attribute is the set of observed parameters.

$(d: ParametersDamageElement)\ d: (s \rightarrow DamageElements,\ p \rightarrow \{\}Parameters)$.

– The term *SetsOfValues* denotes the set of all valid value sets.

$SetsOfValues \equiv \{\}N \setminus \{\varnothing\}$.

– The *SetsOfValues* values do not match the parameter names.

$Parameters \cap (\cup(x: SetsOfValues)\ x) = \varnothing$.

– The term *PossibleValues* denotes a function that maps parameters to their set of values.

sort $PossibleValues: Parameters \rightarrow SetsOfValues$.

– Each parameter has at least two possible values.

$(x: Parameters)\ \mu(PossibleValues(x)) \geq 2$.

– The term *Causations* denotes a class of concepts for the causes of damage. The knowledge must contain a description of at least one reason for the deviations.

sort $Causations = \{\}N \setminus \{\varnothing\}$.

– The term *Causation* denotes a function that assigns to each element of the set *Damages* a set of damage causes, the descriptions of which are presented in knowledge. The knowledge must contain a description of at least one cause of damage.

sort $Causation: Damages \rightarrow Causations$.

– The term *Measurements* denotes a class of concepts corresponding to measurements of parameters that must be taken into account when assessing the technical condition of structural elements.

sort $Measurements: \{\}N \setminus \{\varnothing\}$.

– The names of all parameters and measurements are different.

$Parameters \cap Measurements = \varnothing$.

– Each term in the Measurements term class denotes a structural value with three attributes: *Elements* (*e*), *Parameters* (*p*), *DamageElements* (*a*). The value of the first is the name of the structural element of the structure, the second attribute is the name of the parameter, the third attribute is the name of the damage of the structural element.

$(m: Measurements)\ m: (e \rightarrow Elements,\ p \rightarrow Parameters,\ a \rightarrow DamageElements)$.

– The term *moments* (*t*) denote a function that associates each parameter and measurement with a set of non-negative integers – time instants within a situation when this parameter was observed. If for some parameter the value of this function is an empty set, it means that this parameter was not observed.

sort $t : Parameters \cup \mathrm{Measurements} \rightarrow \{\}I[0,\infty)$.

– Each term included in the class of terms *Parameters* denotes a function that matches the moments of observation of this parameter (*p*) its values at these moments.

$(p: Parameters)\ copmp: t(p) \rightarrow PossibleValues\ (p)$.

APPLICATION OF THE DEVELOPED ONTOLOGY MODEL

When designing ports, one of the important tasks is to forecast sediment accumulation of port waters and approach channels of sandy, silty or pebble sediments.

When assessing the technical condition of the port water area, the following values are used:

– L_p is the navigation depth of the water area;

– L is the actual depth of the water area;

– V is the velocity of sediment accumulation of a section of the water area.

Consider a section of the water area near the pier, Fig. 2.

As a result of determination of depths in 2019, a dataset $L - L_p$ which is presented in Table 1.

At the same time, the navigation depth of the water area is 11 m.

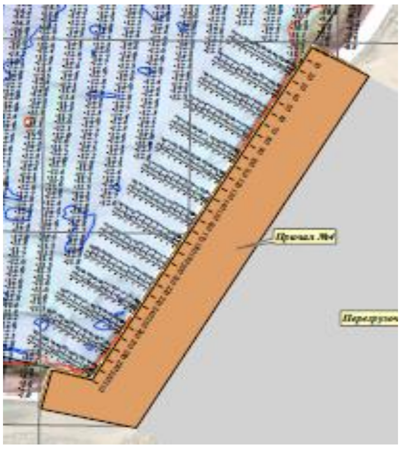

Fig. 2. **Water area at the pier with depth measurements**

***Source*: compiled by the author**

***Table 1*. Results of determination of depths in the water area at the pier in 2019**

Distance from the start point of pier line, m	Pegging out				
	Pg4	Pg8	Pg12	Pg16	Pg20
0	0.60	0.60	0.60	1.00	1.20
40	1.10	1.10	1.00	1.20	1.20
80	0.80	1.00	0.90	1.30	1.30
120	1.00	1.00	1.00	1.30	1.30
160	1.10	1.20	1.10	1.40	1.40

***Source*: compiled by the author**

Similarly, as a result of determination of depths in 2020, a set of data is determined, which is presented in Table 2.

***Table 2*. Results of determination of depths in the water area in 2020**

Distance from the start point of pier line, m	Pegging out				
	Pg4	Pg8	Pg12	Pg16	Pg20
0	0.50	0.50	0.60	0.90	1.10
40	1.10	1.10	0.90	1.20	1.20
80	0.80	1.00	0.90	1.30	1.30
120	1.00	1.00	0.90	1.30	1.30
160	1.10	1.20	1.00	1.40	1.30

***Source*: compiled by the author**

Using Table 1 and Table 2, it is possible to determine the sediment accumulation velocity of this section of the water area. The results are presented in Table 3.

The analysis of the results obtained in Table 1, Table 2 and Table 3 makes it possible to distinguish three areas in this water area (Fig. 3), which must be monitored in the current time interval. Let's designate the selected areas as D_1, D_2, D_3. Note that in the BIM model of the water area, an accurate description of the location of these areas is possible.

***Table 3*. The sediment accumulation velocity of the water area section**

Distance from the start point of pier line, m	Pegging out				
	Pg4	Pg8	Pg12	Pg16	Pg20
0	0.1	0.1	0.0	0.1	0.1
40	0.0	0.0	0.1	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0
120	0.0	0.0	0.1	0.0	0.0
160	0.0	0.0	0.1	0.0	0.0

***Source*: compiled by the author**

We will introduce COSS, which will allow us to switch to a linguistic model for describing the technical condition of the selected areas of the water area.

For the value $\Delta_L(ch) = L - L_p$ we define COSS $\Omega_L = \{TL_k\}_{k=0}^{7}$, where $\{TL_k\}_{k=0}^{7}$ is a term-set of linguistic values.

Moreover, the terms are fuzzy sets, the membership functions of which are defined by formulas (8). The scope is the segment [0; 1.05].

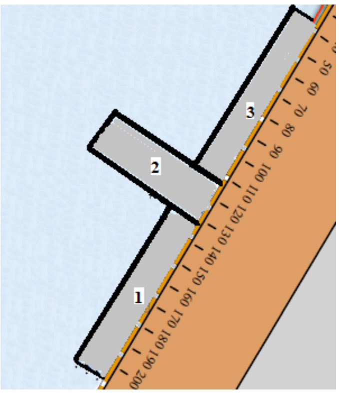

Fig. 3. **Designated areas of the water area at the pier**

***Source*: compiled by the author**

The introduced terms take the following linguistic values:

TL_0 - <vl> – the deviation value is *very low*

TL_1 - <cl> – the deviation value is *criticallylow*

TL_2 - <l> – the deviation value is *low*

TL_3 - <ba> – the deviation value is *below average*

TL_4 - <a> – the deviation value is *average*

TL_5 - <ha> – the deviation value is *higher than average*

TL_6 - <h> – the deviation value is *high*

TL_7 - <vh> – the deviation value is *very high*.

Membership functions of fuzzy sets $\{TL_k\}_{k=0}^{7}$ are shown in Fig. 4.

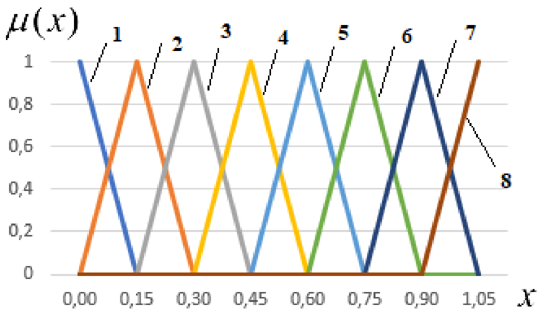

Fig. 4. **Membership functions of fuzzy sets** $\{TL_k\}_{k=0}^{7}$ **:**

1 – term TL_0; 2 – term TL_1; 3 – term TL_2;
4 – term TL_3; 5 – term TL_4; 6 – term TL_5;
7 – term TL_6; 8 – term TL_7

***Source*: compiled by the author**

For the value V we define COSS $\Omega_V = \{TV_k\}_{k=0}^{4}$, where $\{TV_k\}_{k=0}^{4}$ is a term-set of linguistic meanings. Moreover, the terms are fuzzy sets, the membership functions of which are defined by formulas (8). The scope is the segmentт [0, 0.4].

The introduced terms take the following linguistic meanings:

TV_0 - <l> – the sediment accumulation velocity is*low*

TV_1- <ba> – the sediment accumulation velocity is *below average*

TV_2 - <a> – the sediment accumulation velocity is*average*

TV_3-<ha> – the sediment accumulation velocity is *higher than average*

TV_4 - <h> – the sediment accumulation velocity is *high*.

Membership functions of fuzzy sets $\{TV_k\}_{k=0}^{4}$ are shown in Fig. 5.

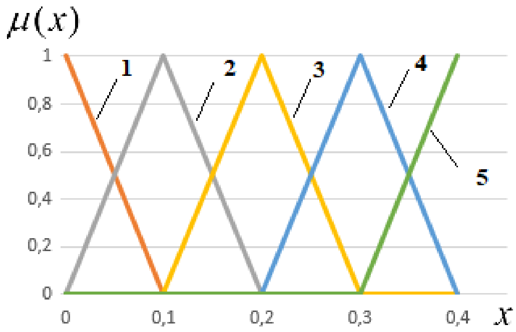

Fig. 5. **Membership functions of fuzzy sets:** $\{TV_k\}_{k=0}^{4}$**:**

1 – term TV_0; 2 – term TV_1; 3 – term TV_2;
4 – term TV_3; 5 – term TV_4

***Source*: compiled by the author**

Let us introduce into consideration the following linguistic variables in accordance with relation (10).

– Δ_L – deviation of the water area depth from the navigation one..

This linguistic variable is defined on the introduced COSS Ω_L.

– Δ_V is the sediment accumulation velocity of a section of the water area. This linguistic variable is defined on the introduced COSS Ω_V.

Thus, for a linguistic variable Δ_L the term-set of a linguistic variable is defined as follows {*vl, cl, l, ba, a, ha, h, vh*}. The term-set {*l, ba, a, ha, h*} of a linguistic variable Δ_V is defined in a similar way.

Then the linguistic description of the sections D_1, D_2, D_3, using formulas (6-7) and (9) can be presented as follows:

– for section D_1

$\Delta_L = a$, surveying periodis 2019 year;

$\Delta_L = ba$, surveying period is 2020 year;

$\Delta_V = ba$ surveying period is 2020 year,

– for section D_2

$\Delta_L = vh$, surveying period is 2019 year;

$\Delta_L = h$, surveying period is 2020 year;

$\Delta_V = ba$, surveying period is 2020 year,

– for section D_3

$\Delta_L = vh$, surveying period is 2019 year;

$\Delta_L = h$, surveying period is 2020 year;

$\Delta_V = ba$, surveying period is 2020 year.

Let's designate the port water area as S. Then we can introduce the following set of sentences:

$Elements \equiv \{S\}$,

$DamageElements \equiv \{D_1, D_2, D_3\}$,

$Parameters \equiv \{\Delta_L(1), \Delta_V(1), \Delta_L(2), \Delta_V(2),$
$\Delta_L(3), \Delta_V(3)\}$,

$ParametersDamageElement \equiv (D_1 \Rightarrow \{\Delta_L(1), \Delta_V(1)\},$
$D_2 \Rightarrow \{\Delta_L(2), \Delta_V(2)\}, D_3 \Rightarrow \{\Delta_L(3), \Delta_V(3)\})$,

$SetsOfValues \equiv \{\ vl,\ cl,\ l,\ ba,\ a,\ ha,\ h,\ vh\ \}$,

$$PossibleValues \equiv$$
$$\equiv (\lambda(v : \{\Delta_L(1), \Delta_V(1), \Delta_L(2), \Delta_V(2), \Delta_L(3), \Delta_V(3)\}) /$$
$$v(\Delta_L(1)) \Rightarrow \{\ vl,\ cl,\ l,\ ba,\ a,\ ha,\ h,\ vh\},$$
$$v(\Delta_V(1)) \Rightarrow \{\ l,\ ba,\ a,\ ha,\ h\},$$
$$v(\Delta_L(2)) \Rightarrow \{\ vl,\ cl,\ l,\ ba,\ a,\ ha,\ h,\ vh\},$$
$$v(\Delta_V(2)) \Rightarrow \{\ l,\ ba,\ a,\ ha,\ h\},$$
$$v(\Delta_L(3)) \Rightarrow \{\ vl,\ cl,\ l,\ ba,\ a,\ ha,\ h,\ vh\},$$
$$v(\Delta_V(3)) \Rightarrow \{\ l,\ ba,\ a,\ ha,\ h\})$$

Let us introduce into consideration one of the possible causes of damage - the sediment accumulation in a section of the water area(h).

$Causations \equiv \{h\}$.

Thesentence

$$moments \equiv (\lambda(v : \{\Delta_L(1), \Delta_V(1), \Delta_L(2),$$
$$\Delta_V(2), \Delta_L(3), \Delta_V(3)\})$$
$$/(v = \Delta_L(1) \Rightarrow \{1,13\}), v = \Delta_V(1) \Rightarrow \{13\},$$
$$v = \Delta_L(2) \Rightarrow \{1,13\}), v = \Delta_V(2) \Rightarrow \{13\}),$$
$$v = \Delta_L(3) \Rightarrow \{1,13\}), v = \Delta_V(3) \Rightarrow \{13\}/)$$

describes that the parameters $\Delta_L(1), \Delta_L(2), \Delta_L(3)$ were observed after the first and thirteenth months from the beginning of the surveying, and the parameters $\Delta_V(1), \Delta_V(2), \Delta_V(3)$ after the thirteenth month from the beginning of the surveying.

The sentences

$$\Delta_L(1) \equiv (\lambda(v : \{1,13\}) / (v(1) \Rightarrow a), (v(13) \Rightarrow ba)/),$$
$$\Delta_V(1) \equiv (\lambda(v : \{13\}) / (v(13) \Rightarrow ba)/).$$
$$\Delta_L(2) \equiv (\lambda(v : \{1,13\}) / (v(1) \Rightarrow vh), (v(13) \Rightarrow h)/),$$
$$\Delta_V(2) \equiv (\lambda(v : \{13\}) / (v(13) \Rightarrow ba)/).$$
$$\Delta_L(3) \equiv (\lambda(v : \{1,13\}) / (v(1) \Rightarrow vh), (v(13) \Rightarrow h)/),$$
$$\Delta_V(3) \equiv (\lambda(v : \{13\}) / (v(13) \Rightarrow ba)/).$$

Describe the results of observing parameters $\Delta_L(1), \Delta_L(2), \Delta_L(3)$ и $\Delta_V(1), \Delta_V(2), \Delta_V(3)$.

CONCLUSIONS

In this paper, the basic concepts are introduced and an ontology model for describing the technical condition of hydrotechnical constructures (water area) is developed. The basic concepts introduced for the ontology model allow us to describe the subject domain within the framework of the building information modelling (BIM) methodology.

At the same time, the proposed approach allows us to describe:

– design features of hydrotechnical constructures;

– damage to structural elements of ones;

– a set of parameters that are used to monitor the change in damage (defect) over time;

– knowledge about the technical condition of hydrotechnical constructures, depending on the periods of the dynamics of the parameters.

As a result, the ontology for describing the technical state of hydrotechnical constructures can be used in approaches aimed at ensuring the availability of data on structures via the Internet for all participants involved in the operation of hydrotechnical constructures. A single work environment for all participants makes it possible to respond quickly when factors appear that can lead to a change in the actual state of structures or the occurrence of an emergency.

The developed approach allows the direct inclusion of knowledge about the technical condition of hydrotechnical constructures, depending on the periods of the dynamics of parameters, in the documents of building information modelling (BIM).

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РОЗРОБКА МОДЕЛІ ОНТОЛОГІЇ ТЕХНІЧНОГО СТАНУ ГІДРОТЕХНІЧНИХ СПОРУД

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АНОТАЦІЯ

Гідротехнічні споруди – це комплексні споруди, які представляють собою взаємодію між ґрунтовим, воднимта технологічним середовищем. Для безаварійної і безпечної експлуатації гідротехнічних споруд, а також підтримання їх в експлуатаційному режимі силами експлуатуючої організації, а також організаціями, які проводять технічний нагляд проводяться постійні технічні огляди для фіксації ушкоджень (дефектів). Це дозволяє визначати фактичний технічний стан споруд. В даний час для моделювання споруд найбільш широко застосовується методологія інформаційного моделювання будівель (BIM). В рамках даної методології підтримується безперешкодний обмін всією інформацією між відповідними зацікавленими сторонами з використанням цифрових технологій. Однак, для зберігання даних про споруди в основному використовуються файли формату IFC. Еволюція даної методології передбачає можливість взаємодії, заснованої на мережі. Групою спільноти W3C LBD-CG представлена полегшена онтологія, що розширюється, під назвою Building Topology Ontology (BOT), яка забезпечує високорівневий опис топології споруд, включаючи види та типи гідротехнічних споруд в залежності від призначення і умов експлуатації, конструктивних елементів споруд різного рівня. Автори створили полегшену онтологію, яка не має тих же недоліків, що і IFC, з точки зору розміру і складності. Повторне використання існуючих онтологій було важливим пріоритетом, який дозволяє включати онтології для спеціалізованих областей. Розглянуто питання опису технічного стану гідротехнічних споруд. Введено базові терміни і затвердження, що розширюють многосортну мову прикладної логіки для опису знань цієї предметної області. Модель онтології надає термінологію для визначення пошкоджень, пов'язаних з гідротехнічними спорудами. Модель онтології дозволяє вводити в розроблювані онтології зв'язок ушкоджень з конструктивними елементами споруд та просторовими зонами їх розташування. Онтологія також може застосовуватися для подання спостережень за технічним станом пошкоджень в машинному форматі, що інтерпретується.

Ключові слова: гідротехнічні сооруження; інформаційне моделювання зданий; топология; пошкодження; онтологія; многосортный язык; прикладная логіка; определение глубин; онтологічний веб-мова; повні ортогональні семантичні простори; замулювання

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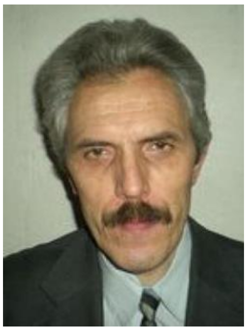

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