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Математика та статистика
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Зміст

Evaluating parameters of econometric models with linear limitations and a rank deficient observation matrix

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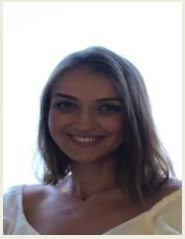
Abstract. There considered the approach of the linear econometric dependences parameters estimating for the case of combining a set of special conditions arising in the simulation process. These conditions address the most important problems met in practice when implementing a series of classes of mathematical models, for the construction of which the matrix of explanatory variables can be used. In most cases the vectors that make up the matrix have a close correlation relationship; this leads to the need of performing calculations using a rank deficient matrix. There are also take place violations of the Gauss-Markov theorem condition. The list of above mentioned special conditions is augmented by the additional model parameters constraints. Cobb-Douglas's production function and the Solow model are known economic problems of this type. In this research the need to impose additional constraints on the model parameters is extended to a wider range of tasks. In general, the economic formulation of the problem with the specified features is presented.

Known ways to solve these tasks are discussed. The authors' approach proposed takes into account the whole spectrum of these features. This approach is based on the application of pseudorandom matrices and the use of singular matrix decomposition. The use of proposed mathematical tools makes it possible to improve the quality of estimating model parameters while using real economic processes data. The analytical definition is found for the parameter evaluating vector of a linear econometric model with all the above mentioned features. Analysis of the used definition provides determination of the conditions that the matrix must satisfy; this describes additional model parameters constraints. The term was also obtained to estimate the variance of a linear econometric model parameters vector.

The results obtained can be used in machine learning systems in the implementation of problems of econometric dependencies or discriminant models.



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Key words: econometric models, rank deficient matrix, multicollinearity, Gauss-Markov conditions, pseudorandom matrix.

FORMULATION OF THE PROBLEM

The current state of society as a whole and the economy in particular is characterized by a digital information drastic increase. Therefore, in recent decades, the most urgent issue has been the search for adequate methods of vast data sets analysis and processing. Generalizing existing data analysis developments has led to the creation of Data Mining techniques. In most cases, Data Mining refers to a set of procedures for finding useful, non-trivial information that is understandable and can be applied in decision-making processes. There are several conditional options for Data Mining tasks classifying. As a rule, among the basic Data Mining tasks classes are the regression construction and the classification of economic objects. The tasks of regression constructing establish a relation between a continuous variable, which describes the behavior of an economic indicator, depending on the selected list of factors influence. The classification tasks also determine the dependence of a particular variable on the selected list of factors. However, unlike regressions, the dependent variable accepts only discrete values and can describe, for example, some characteristics of economic objects. For both specified task classes, the initial data is a dimension matrix $n \times m$ consisting of values for the m explanatory variables for each n object. Therefore, the implementation of methods for constructing mathematical models of both classes of problems has a common problem that is associated with the requirements for the initial data array. The problem is that there is a strong correlation between two or more explanatory variables (the multicollinearity phenomenon). Construction of mathematical models if such connection is neglected leads to significant negative consequences, that is why special algorithms have been developed to check for multicollinearity. In most cases, if there are close correlation relationships between the explanatory variables, some variables are removed from the initial data matrix so as to eliminate multicollinearity. However, maintaining a complete list of factors when constructing a model can provide more valuable information, so very important are the approaches that allow an arbitrary matrix of explanatory variables to be used to construct mathematical models. This research describes the approach of constructing linear econometric models for the case where the matrix of explanatory variables is a deficient one.

Let there be a linear relationship between the variable Y explaining variables $X_j\ (j = 1,2,\dots,m)$, m - the number of explanatory variables and ε perturbation. Suppose that there is a sample n of observations for the variables Y and $X_j\ (j = 1,2,\dots,m)$ that each observation for each explanatory variable corresponds $x_{ij}\ (i = \overline{1,n})$ - the value for *i* observation of *j* variable.

Then the linear relationship between Y and $X_j\ (j = 1,2,\dots,m)$ can be represented as:

$$y_i = \sum_{j=1}^{m} x_{ij}\beta_j + \varepsilon_i, i = 1,2,\dots,n. \quad (1)$$

Expression (1) in matrix form has the form:

$$Y = X\beta + \varepsilon \quad (2)$$

where $Y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix}, X = \begin{pmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n1} & \dots & x_{nm} \end{pmatrix}$

$$\beta = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_m \end{pmatrix}, \varepsilon = \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{pmatrix}$$

Denote also the X^T and ε^T matrices transposed to X and ε, respectively.

Let the following conditions be met:

1. $M(\varepsilon) = 0$ (3)

2. $M(\varepsilon\varepsilon') = \sigma^2 \cdot E$, E is a single matrix, (4)

3. – X is a matrix whose elements are determined numbers, (5)

4. *rang* $X = m$ (where matrix X is a full rank matrix). (6)

ANALYSIS OF THE RECENT RESEARCHES AND PUBLICATIONS

There is virtually no doubt that only a slight modification of the already known numerical methods is required to solve the system of general contravention (6). These modifications are based on the following idea.

Let us solve system (1), (2) by any direct method, let it be the Gauss method with the choice of the principal element. If the matrix X has an incomplete rank, then in the process of real transformations we obtain a system in which all the elements of the last rows will be minor. We reject these equations and find the solutions of the resulting system. They will serve as an approximation, good enough to the exact system.

On the basis of this idea a considerable number of works was published [1-4]. All their differences are related only to the use of various transformations of the initial system and the use of various criteria for the replacement of "small" elements of the transformed zero system. However, this idea did not immediately lead to the effective solution of systems of algebraic equations linear of general form. Moreover, the issue of the possibility of constructing a stable process of solving systems with incomplete matrices in the conditions of perturbation of the input data and the influence of rounding errors has not been finally resolved recently. A positive result was obtained only after a thorough study of the instability mechanism and finding guaranteed means of reducing its impact [3].

It is advisable to use unitary transformations of the initial system to find a normal pseudo solution. But, unlike full-rank matrices systems, the application of these transformations will no longer entail overall stability.

Thus, if the exact system matrix is incomplete, then the small values of the input data perturbations and rounding errors will not necessarily lead to the appearance in the system transformation process of any rows or columns, which consist entirely of the same small elements. This is the main, but not the only, difficulty in developing numerical methods for solving systems with rank deficient matrices, built on equivalent transformations of the original system.

Another obstacle is the reasoning for further transformations of those systems whose matrices have rows or columns with small elements.

If the system input data with a rank deficient matrix is given with errors, no increase in the accuracy of calculations and no transformations will guarantee the desired accuracy of a normal pseudo-solution [3]. This requires the involvement of additional information on the exact task. But suppose, after the unitary transformations, a system with small rows or columns is obtained. Replacing these rows and columns with zero is equivalent to a small perturbation of the initial system matrix. If we can accurately find the normal pseudo-solution of the resulting system, it will mean that the projection of the normal pseudo-solution of the exact system on one of the subspaces drawn on singular vectors will be calculated sufficiently accurately. There is no reason to expect a better result without additional information.

The need to use additional information to solve unstable systems is interconnected with some difficulties in designing the appropriate computational algorithms.

TASK SETTING

When solving certain economic problems on the basis of econometric models, it is necessary to consider conditions that impose additional regression coefficients constraints.

Let us have an enterprise that produces goods and uses m types of resources. The enterprise is characterized by a technological set $Z \subset R_+^n$ that describes all the possible sets of resources needed to produce a given product.

For example, the plural $M \subset Z$ may be conditioned by

$$x_1 \geq 0, \quad a_i x_1 \leq x_i \leq b_i x_1, \quad i = 1, 2, \ldots m$$

where a_i, b_i – are given numbers $0 \leq a_i \leq b_i$, that is, the proportions of resources must be within certain limits.

Let's have a production function

$$Y(X) = \gamma \prod_{i=1}^{m} x_i^{\lambda_i} \qquad (7)$$

where $\gamma > 0$, $\lambda_1 \geq 0, \lambda_2 \geq 0, \ldots$, are unknown parameters for which $\sum_{i=1}^{m} \lambda_i = 1$.

Suppose $\hat{Y}(X)$ - the amount of goods produced by the enterprise in the set of resources $X = (x_1, x_2, \ldots, x_m)$. One can consider the task of determining $\gamma > 0, \lambda_1 \geq 0, \ldots, \lambda_m \geq 0$

$$\sum_{X \in M \subset Z} (\hat{Y}(X) - \gamma \prod_{i=1}^{m} x_i^{\lambda_i})^2 \to \min_{\gamma, \lambda} \Leftrightarrow$$

$$\sum_{X \in M \subset Z} (\ln \hat{Y}(X) - \ln y - \sum_{i=1}^{m} \lambda_i \ln x_i)^2 \to \min_{\gamma, \lambda}$$

with additional conditions

$$\begin{cases} \sum\limits_{i=1}^{k_1} \lambda_i = z_1, \\ \sum\limits_{i=k_1+1}^{k_2} \lambda_i = z_2, \\ \cdots \\ \sum\limits_{i=k_m+1}^{k_{m+1}} \lambda_i = z_{k_{m+1}}, \\ z_1 + z_2 + \cdots + z_{k_{m+1}} = 1. \end{cases}$$

For example, [1] when applying the classical Cobb-Douglas production function of a form

$$Y = b_0 L^{\alpha} K^{\beta} \qquad (8)$$

where Y – production volumes, L – labor costs, K – capital costs, α, β, b_0 – model parameters, the need that considers the constant production scale feedback is realized by introducing a $\alpha + \beta = 1$ constraint type.

PRESENTING THE MAIN CONTENT

There are two ways of considering such limitations [1]. The first is to solve the problem without additional constraints. For the result obtained, we test the hypothesis that the estimated coefficients satisfy the required conditions.

The hypothesis is formulated as follows: for the true values of the coefficients of the model, a condition $C^T \hat{\beta} = r$ is fulfilled, where C is a vector of constants, which allows to describe the existing additional conditions, $\hat{\beta}$ - the estimates of the model parameters found without taking into account additional conditions, r - the constant is given by the condition.

Using model parameter estimates, the value $C^T \hat{\beta}$ for which the value is checked is calculated

$$t = \frac{C^T \hat{\beta} - C^T \beta}{s \sqrt{C^T (X^T X)^{-1} C}} \qquad (9)$$

where s is the standard error of the model perturbation.

To test the hypothesis in (9), r is substituted instead of $C^T \beta$. The obtained value is compared to the critical t-distribution value with $n - k$ degrees of freedom.

The second way is to take into account the additional constraint directly in the model parameter estimation process. In the simplest cases, the regression equation can be transformed so that an additional constraint will be taken into account in the model structure itself.

Consider the case [1] of estimating the parameters (8) provided by $\alpha + \beta = 1$.

Logarithm (8) leads down to a linear dependence of the form:

$$y = b_0 + \alpha X_1 + \beta X_2 + \varepsilon,$$

where $y = \ln Y, X_1 = \ln L, X_2 = \ln K$.

Limitation $\alpha + \beta = 1$ can be represented in the form and directly included in the model:

$$y = b_0 + \alpha X_1 + (1-\alpha) X_2 + \varepsilon \qquad (10)$$

For (10), we find the estimates of the parameters $\hat{b}_0$ and $\hat{\alpha}$ provided that the sum of the squares of deviations is minimized [1].

$$\sum_{i=1}^{n} (y_i - \hat{b}_0 - \hat{\alpha} X_1 - (1-\hat{\alpha}) X_2)^2 \qquad (11)$$

If any of the methods does not provide the necessary accuracy for solving a system of linear algebraic equations, there is no reason to expect that another method will produce better results for the same system. Most likely, such a system should be considered unstable. It is known [1-4] that the redefined system pseudo-solution (2) with a full rank matrix is the usual solution of the system

$$X^T X \hat{\beta} = X^T Y$$

with a square non-degenerate $X^T X$ order matrix $m \times m$. Normal System Solution (1-2)

$$\hat{\beta} = (X^T X)^{-1} X^T Y$$

It should be required $\sum_{i=1}^{n} \beta_i^2 \to \min$.

Definition 1. The matrix X^+ $(m \times n)$ is called the Moore-Penrose pseudorandom for a matrix X if it satisfies the following four conditions:

1. $X^+ X X^+ = X^+$ (12)
2. $X X^+ X = X$ (13)
3. $X X^+$ – symmetric (14)
4. $X^+ X$ – symmetric (15)

It follows from condition (12) $X^+ X X^+ = X^+ \Rightarrow X^+ X X^+ X = X^+ X$ if $X^+ X = P_1$, then $P_1^2 = P_1$. From condition (15) P_1 is symmetric. So P_1 is an orthoprojector. Similarly $X X^+ = P_2$ – orthoprojector. In addition, with $X^+ X X^+ = X^+ \Rightarrow P_1 X^+ = X^+$, $X^+ P_2 = X^+$. And from that $X X^+ X = X \Rightarrow X P_1 = X, P_2 X = X$, one can prove that such a matrix X^+ always exists and is unique [2]. If X is a non-degenerate square matrix, then $X^+ = X^{-1}$ obviously satisfies the conditions (12-15). If X is rectangular and has full rank, then $X^+ = (X^T X)^{-1} X^T$. One can check that pseudo-inverse of the diagonal matrix

$$\Sigma = \begin{pmatrix} \sigma_1 & 0 & \cdots & 0 \\ 0 & \sigma_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & \cdots & \sigma_m \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 \end{pmatrix}$$

is a diagonal $m \times n$ matrix

$$\Sigma^+ = \begin{pmatrix} \sigma_1' & 0 & \cdots & 0 & 0 & \cdots & 0 \\ 0 & \sigma_2' & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_m' & 0 & \cdots & 0 \end{pmatrix},$$

where $\sigma_i = \begin{cases} \dfrac{1}{\sigma_i}, & \sigma_i \neq 0 \\ 0, & \sigma_i = 0 \end{cases}$

Next, we use a singular matrix arrangement X [3].

$$X = U \Sigma V^T$$

where U is an orthogonal $n \times n$ matrix, V^T is an orthogonal $m \times m$ matrix, and Σ is a diagonal $m \times n$ matrix which has $\sigma_{ij} = 0$, if $i \neq j$, $\sigma_{ii} \geq 0$. The columns of the U matrix are eigenvectors of the XX^T matrix and the columns of the V matrix are eigenvectors $X^T X$. Using (13) [2,3] we obtain

$$X^+ = V\Sigma^+ U^T.$$

The least squares estimates of the parameter β in (2) are defined as the values $\beta_1, \beta_2, \ldots, \beta_m$, minimizing

$$L = \sum_{i=1}^{n} \sum_{k=1}^{n} (y_i - \sum_{j=1}^{m} x_{ij}\beta_j)(y_k - \sum_{j=1}^{m} x_{kj}\beta_j)\alpha_{ik} \to \min_{\beta} \quad (16)$$

where the matrix $A = \|\alpha_{ik}\|$ is a symmetric positively definite matrix. The solution (16) $\hat{\beta}_1, \hat{\beta}_2, \ldots, \hat{\beta}_m$ will be called the pseudo-solution of problem (1), (2). The solution will be linear with respect to y. In addition, provided (3) $P_1\hat{\beta}$ is an unbiased estimate $P_1\beta$ in (1). That is $M(P_1\hat{\beta}) = P_1\beta$.

The solution, generally speaking, will not be the only one. We will require that the minimum amount be $\sum_{j=1}^{m} \beta_j^2$. Then the solution (16) is unique. Generally speaking, when condition (4) is violated, unbiased estimates β cannot be obtained.

The case where for problem (1-2), without taking into account the linear constraints, condition (3) is not fulfilled is considered in [9] for $M(\varepsilon) \neq 0$. Some compromise was found between the bias value $\hat{\beta}$ and the value $D(\hat{\beta})$. The case where (2) is not fulfilled was considered by Aitken [10], who proposed the use of the generalized least squares method, provided that the matrix X is of complete rank. In this work, Aitken's method extends to problem (1-2), provided that there are linear constraints, as well as that (6) is not fulfilled, but takes place $rangX = t \leq m$ and simultaneously

$$M(\varepsilon\varepsilon^T) = D = \sigma^2 W, \quad (17)$$

where σ^2 is an unknown parameter, D, W are known symmetric positive definite order matrices $n \times n$. Then D makes it possible a representation $D = PP^T$ where the matrix P is non-degenerate positively defined. So, $D = PP^T$, so that $P^{-1}DP^{-1} = E$ and $P^{-1}P^{-1} = D^{-1}$. Let us denote $P^{-1} = B$. The matrix D commutes with B. From (17) it follows that $W^{-1} = D^{-1}\sigma^2$, $W^{-1} = \bar{B}\bar{B} = \sigma^2 BB$.

Hence the covariance matrix

$$M(\varepsilon\varepsilon^T) = \begin{bmatrix} \sigma_1^2 & \sigma_1\sigma_2\sigma_{12} & \ldots & \sigma_1\sigma_n\sigma_{1n} \\ \sigma_1\sigma_2\sigma_{12} & \sigma_2^2 & \ldots & \sigma_2\sigma_n\sigma_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_n\sigma_1\sigma_{n1} & \sigma_n\sigma_2\sigma_{n2} & \ldots & \sigma_n^2 \end{bmatrix} = \sigma^2 W,$$

where $\sigma_i^2 = M(\varepsilon_i^2) = D(y_i)$ is the dispersion $\sigma_i\sigma_j\rho_{ij} = M(\varepsilon_i\varepsilon_j) = \operatorname{cov} y_i y_j$, W is the known weight matrix.

In this article we consider the general case of linear constraints for problem (1), (2) in the form:

$$r = R\hat{\beta} \quad (18)$$

where r is a known vector column consisting of $g < m$ elements, $g - rangR$

R is a known order matrix $g \times m$.

It is important that the matrix R should have the following property:

$$RK^+K = R, \quad RP_1 = R$$

where $P_1 = K^+K$ – orthoprojector, $K = X^T\bar{B}\bar{B}X$.

It is necessary to find $Y = X\hat{\beta} + e$ model parameter estimates such that the constraints (18) to be satisfied. To do this, it is necessary to minimize the expression:

$$\hat{\hat{L}} = (Y - X\hat{\hat{\beta}})^T \bar{B}\bar{B}(Y - X\hat{\hat{\beta}}) + (R\hat{\hat{\beta}} - r)^T 2\lambda$$

where λ – is a vector column of g Lagrange multipliers.

$$\hat{\hat{L}} = (Y - X\hat{\hat{\beta}})^T \bar{B}\bar{B}(Y - X\hat{\hat{\beta}}) + (R\hat{\hat{\beta}} - r)^T =$$
$$Y^T \bar{B}\bar{B}Y - Y^T \bar{B}\bar{B}X\hat{\hat{\beta}} - \hat{\hat{\beta}}^T X^T \bar{B}\bar{B}Y + \hat{\hat{\beta}}^T X^T \bar{B}\bar{B}X\hat{\hat{\beta}} +$$
$$(R\hat{\hat{\beta}} - r)^T = Y^T \bar{B}\bar{B}Y - 2Y^T \bar{B}\bar{B}X\hat{\hat{\beta}} + \hat{\hat{\beta}}^T X^T \bar{B}\bar{B}X\hat{\hat{\beta}} +$$
$$(R\hat{\hat{\beta}} - r)^T 2\lambda$$

since $Y^T \bar{B}\bar{B}X\hat{\hat{\beta}}$ - the number transposed to $\hat{\hat{\beta}}^T X^T \bar{B}\bar{B}Y$, the second and third additions coincide.

Since

$$d\hat{\hat{L}} = -2Y^T \bar{B}\bar{B}Xd\hat{\hat{\beta}} + d\hat{\hat{\beta}}^T X^T \bar{B}\bar{B}X\hat{\hat{\beta}} +$$
$$\hat{\hat{\beta}}^T X^T \bar{B}\bar{B}Xd\hat{\hat{\beta}} + 2\lambda R^T d\hat{\hat{\beta}}$$

$$(d\hat{\hat{\beta}}^T X^T \bar{B}\bar{B}X\hat{\hat{\beta}})^T = \hat{\hat{\beta}}^T X^T \bar{B}\bar{B}Xd\hat{\hat{\beta}} \quad (19)$$

From (19) we have:

$$2(-X\bar{B}\bar{B}Y + (X^T \bar{B}\bar{B}X)\hat{\hat{\beta}} + R^T\lambda) = 0$$

Let us denote $\hat{L} = (Y - X\hat{\beta})^T \bar{B}\bar{B}(Y - X\hat{\beta})$. Then the condition of minimization will be

$$(X^T \bar{B}\bar{B}X)\hat{\beta} = X^T \bar{B}\bar{B}Y \quad (20)$$

Then

$$\hat{\beta} = (X^T \bar{B}\bar{B}X)^+ X^T \bar{B}\bar{B}Y \quad (21)$$

Using λ Lagrange multipliers, let us consider

$$\hat{\hat{L}} = \hat{L} + 2(R\hat{\hat{\beta}} - r)^T\lambda$$

We estimate the vector $\hat{\hat{\beta}}$ so that the condition $(R\hat{\hat{\beta}} - r) = 0$ be satisfied. To do this, select $\hat{\hat{\beta}}$ in such a way as to minimize $\hat{\hat{L}}$ under condition $R\hat{\hat{\beta}} = r$.

The condition min $\hat{\hat{L}}$ will be

$$d\hat{\hat{L}} = 0 \Rightarrow -2X^T \bar{B}\bar{B}Y + 2(X^T \bar{B}\bar{B}X)\hat{\hat{\beta}} - 2R^T\lambda = 0 \quad (22)$$

From (20), (21), (22) we obtain:

$$R^T\lambda = K(\hat{\hat{\beta}} - \hat{\beta}) \quad (23)$$

where $K = X\bar{B}\bar{B}X$.

Multiply on the left on RK^+

$$RK^+R^T\lambda = RK^+K(\hat{\hat{\beta}} - \hat{\beta}) = RK^+K\hat{\hat{\beta}} - RK^+K\hat{\beta} \quad (24)$$

Solve (24) pertaining to λ, using the pseudorandom matrix, we have:

$$\lambda = (RK^+R^T)^+(RK^+K\hat{\hat{\beta}} - RK^+K\hat{\beta}) \quad (25)$$

Substitute the resulting expression for λ (25) into (23):

$$R^T(RK^+R^T)^+(RK^+K\hat{\hat{\beta}} - RK^+K\hat{\beta}) = K(\hat{\hat{\beta}} - \hat{\beta})$$

Solve for $(\hat{\hat{\beta}} - \hat{\beta})$:

$$(\hat{\hat{\beta}} - \hat{\beta}) = K^+R^T(RK^+R^T)^+(RK^+K\hat{\hat{\beta}} - RK^+K\hat{\beta}) \quad (26)$$

Since $K^+K = P_1$ – orthoprojector [20] and $RK^+K\hat{\hat{\beta}} = RP_1\hat{\hat{\beta}} = R\hat{\hat{\beta}} = r$, then

$$\hat{\hat{\beta}} = \hat{\beta} - K^+R^T(RK^+R^T)^+(RK^+K\hat{\beta}) + K^+R^T(RK^+R^T)^+r = \hat{\beta} - K^+R^T(RK^+R^T)^+(R\hat{\beta}) + K^+R^T(RK^+R^T)^+r \quad (27)$$

The second supplement is independent of β, therefore $D(K^+R^T(RK^+R^T)^+r) = 0$.

Besides, it is known that [20]

$$D(\hat{\beta}) = K^+ \quad (28)$$

Applying (28) and (27) we get

$$D(\hat{\hat{\beta}}) = K^+ - K^+R^T(RK^+R^T)^+RD(\hat{\beta})$$
$$(K^+R^T(RK^+R^T)^+R)^T = K^+ - K^+R^T \quad (29)$$
$$(RK^+R^T)^+RK^+R^T(RK^+R^T)^+RK^+$$

Using the Moore-Penrose conditions (12) - (15), we have:

$$K^+R^T(RK^+R^T)^+(RK^+R^T)(RK^+R^T)^+RK^+ = K^+R^T(RK^+R^T)^+RK^+$$

So

$$D(\hat{\hat{\beta}}) = D(\hat{\beta}) - K^+R^T(RK^+R^T)^+RK^+$$
$$D(\hat{\hat{\beta}}) = K^+ - K^+R^T(RK^+R^T)^+RK^+$$

In addition

$$e^TD^{-1}e = (Y - X\hat{\hat{\beta}})^TD^{-1}(Y - X\hat{\hat{\beta}}) =$$
$$(Y^T - \hat{\hat{\beta}}^TX^T)D^{-1}(Y - X\hat{\hat{\beta}}) = Y^TD^{-1}Y +$$
$$\hat{\hat{\beta}}^TX^TD^{-1}X\hat{\hat{\beta}} - Y^TD^{-1}X\hat{\hat{\beta}} - \hat{\hat{\beta}}^TX^TD^{-1}Y = Y^TD^{-1}Y +$$
$$2\hat{\hat{\beta}}^TX^TD^{-1}Y + \hat{\hat{\beta}}^TX^TD^{-1}X\hat{\hat{\beta}} = Y^TD^{-1}Y +$$
$$\hat{\hat{\beta}}^T(X^TD^{-1}X\hat{\hat{\beta}} - 2X^TD^{-1}Y);$$
$$e^TD^{-1}e = Y^TD^{-1}Y + \hat{\hat{\beta}}^T(X^TD^{-1}X\hat{\hat{\beta}} -$$
$$2X^TD^{-1}(X\hat{\hat{\beta}} + e)) = Y^TD^{-1}Y - \hat{\hat{\beta}}^TK\hat{\hat{\beta}}.$$

Since $(Y - Y_0)$, $(\hat{\hat{\beta}} - \beta_0)$ are values with zero mathematical expectations, then the residual sum of squares in the presence of additional conditions for the model parameters have the form:

$$\hat{\hat{H}}_R = \sigma^2(e^TW^{-1}e + (\hat{\hat{\beta}} - \hat{\beta})^T(X^TW^{-1}X)(\hat{\hat{\beta}} - \hat{\beta}))$$

Where

$$(X\hat{\beta} - Y) = e$$
$$M(\hat{\hat{H}}_R) = n - t + g,$$
$$\hat{H}_R = \hat{\hat{H}}_R - H_0$$

where H_0 is the residual sum of squares in the absence of a relation between the parameters and is equal.

We can prove that

$$\hat{H}_R = (r - R\hat{\beta})^T(RK^+R^T)^+(r - R\hat{\beta})$$
$$\hat{H}_R = \sigma^2(r - R\hat{\beta})^T(R(X^TW^{-1}X)^+R^T)^+(r - R\hat{\beta})$$

Indeed, according to (25), (26)

$$K(\hat{\hat{\beta}} - \hat{\beta}) = R(RK^+R^T)^+(r - R\hat{\beta})$$

$$(\hat{\hat{\beta}} - \hat{\beta})^T = (r - R\hat{\beta})^T(RK^+R^T)^+RK^+$$

$$\hat{H}_R = (\hat{\hat{\beta}} - \hat{\beta})^TK(\hat{\hat{\beta}} - \hat{\beta}) = (r^T - \hat{\beta}^TR^T)$$
$$(RK^+R^T)^+RK^+R^T(RK^+R^T)^+(r - R\hat{\beta}) =$$
$$(r^T - \hat{\beta}^TR^T)(RK^+R^T)^+(r - R\hat{\beta})$$

Hence we will be able to evaluate the hypothesis of the relationship between the parameters β by the criterion $\frac{\hat{H}_R - H_0}{H_0} = \frac{\hat{H}_R}{H_0}$

where $\frac{\hat{H}_R}{H_0}$ distributed as $\frac{g}{n-t}F_{g,n-t}$.

CONCLUSIONS FROM THIS STUDY AND PROSPECTS FOR FURTHER EXPLORATION IN THIS AREA

The complexity of real economic processes requires the continuous improvement of existing mathematical tools to enable the construc-

tion of adequate mathematical models. It is necessary to constantly search for new approaches in mathematical modeling, which will allow expanding the possibilities of constructing models of real economic processes. Known methods may have quite limited applications. Thus, a detailed method of estimating the parameters of linear econometric models may be unsuitable in some cases for its application in modeling real economic processes. The classical least-squares method gives stable and effective evaluation only if the conditions of the Gauss-Markov theorem are fulfilled, whereas in most studies such conditions are not fulfilled. Therefore, developments that allow the adaptation of existing mathematical modeling approaches to a wider range of problems are important. In addition, the modern dissemination of digital information necessitates its automated processing. Machine learning technology to build mathematical models is becoming more commonplace, and so approaches that can be used to solve common problem classes are becoming more relevant. The approach considered in this paper meets these requirements. It extends the ability to solve the problem of evaluating parameters of linear econometric models for cases of a number of problematic issues that may arise in the construction of models and can be conveniently implemented in machine learning systems.

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Оценивание параметров эконометрических моделей с линейными ограничениями и матрицей наблюдений неполного ранга

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Аннотация. Рассмотрен подход оценивания параметров линейных эконометрических зависимостей для случая совмещения ряда особых условий, возникающих в процессе моделирования. Эти условия касаются наиболее важных проблем, возникающих на практике при реализации ряда классов математических моделей, для построения которых используется матрица объясняющих переменных. В большинстве случаев векторы, из которых составляется матрица, имеют тесную корреляционную связь, что приводит к необходимости выполнять вычисления с использованием матрицы неполного ранга. Также имеют место нарушения условия теоремы Гаусса-Маркова. В перечень указанных особых условий добавляется наличие дополнительных ограничений на параметры модели. К известным экономическим постановкам задач данного типа относятся производственная функция Кобба-Дугласа и модель Солоу. В работе необходимость наложения дополнительных ограничений на параметры модели распространено для более широкого спектра задач. В общем виде приведено экономическую постановку задачи с указанными особенностями.

Рассмотрены известные способы решения таких задач. Предложен авторский подход, учитывающий весь перечень указанных особенностей. Подход основывается на применении псевдообратных матриц и использовании сингулярного разложения матриц. Применение такого математического инструментария позволяет повысить качество оценки параметров моделей при использовании данных реальных экономических процессов. Найдено аналитическое выражение для вектора оценок параметров линейной эконометрической модели с учетом всех указанных особенностей. Анализ полученного выражения позволил определить условия, которым должна удовлетворять матрица, описывающая дополнительные ограничения на параметры модели. Также получено выражение для оценки дисперсии вектора параметров линейной эконометрической модели.

Полученные результаты могут быть использованы в системах машинного обучения при реализации задач построения эконометрических зависимостей или дискриминантных моделей.

Ключевые слова: эконометрические модели, матрица неполного ранга, мультиколинеарность, условия Гаусса-Маркова, псевдообратная матрица.

A formal model of the human psyche life-supporting functions dialectic logic control

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Abstract. A lot of research in the field of artificial intelligence cannot be completed, or carried out at all, due to the lack of at the moment a correct theory of the human brain functioning associated with its intellectual activity, at least at a conceptual level. So far, there are no comprehensive proposals by researchers on what principles should be based on models of elementary and structured meanings processed by the brain in the course of human life, not to mention formal languages and their grammars, or, especially, formal theories designed for these purposes. The purpose of this article is to fill the gap in scientific knowledge about the human brain. Academician P.K. Anokhin in 1984 proposed the concept of a model for organizing and regulating a behavioral act, in which there is a place for all basic processes and conditions. It was called the functional system model. With such a model, it becomes possible in the same vein, using axiomatic statements, to create a logical-dialectical model of the functioning process at the physiological level of any of the higher mental functions. The dialectical logic of controlling any human body functional systems follows from the conceptual knowledge of the vital functions of these functional systems, obtained exclusively by natural experimenting. Therefore, the conceptual knowledge of the vital functions of each studied functional system of a person should precede the description of the logic essence of its control. The human psyche is one of the most important functional systems of the human body. The article presents the fundamental concepts of the vital functions of this system, which allow revealing the essence of the dialectical logic of life-supporting functions control and a formal model of the dialectic logic of the human psyche functional system control.

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INTRODUCTION

Relevance of the topic. The existence of a living matter, including complexly organized animals having nervous system (COAHNS) [1,2,3,4], in a state of continuous and perpetual motion, caused not only the appearance of the psyche in the matter of these COAHNS, but also the possibility of creating various **mental images** based on this matter.

Mental images are used as reflections in the minds of an interacting pair of COAHNS individuals.

The psyche is defined as the feature of highly organized matter of a particular subject to reflect the objective reality of the universe and, based on the mental image of this reality formed at the same time, to carry out not only operational, but also current and long-term management of the activity of this subject and its behavior. Reflection fixes in the memory of its consciousness the mental image formed by it (reflection) of the environmental impacts on it, which certainly agrees (image) with the worldview of the reflecting subject. The form of reflection depends on the form of existence of matter. In nature, there are three main forms of reflection. The lower life organization level corresponds to the physical form of reflection, characteristic of the interaction of inanimate nature objects.

Physiological form of reflection corresponds to the living matter.

The highest level of reflection in living matter takes the form of the most complex and perfect reflection - mental reflection.

The consciousness of a particular person integrates the diverse phenomena of human reality, transforming them into a truly holistic way of life of this person.

Consciousness is an integrated complex (system!) **of higher mental functions (HMF)** [4, 5, 6, 7], in which there are no fundamental and secondary functions. This is a set of 40-60 pcs equally important functions, implementing the highest level of the human psyche. Psychology professionals attribute them to artificial, instrumental, arbitrarily functions, controlled by a person, **that have a social formation**. But professionals in the area of neurophysiology, neuropsychology and biochemistry argue that HMF are implemented:

• Either on the genetic foundation of the neural networks fragments stereotypical architecture specifically designed for these purposes.

• Or, the human brain has a genetic neural structure loaded with the functions of a Universal Biological Architect, capable, in the space of its own population of **neural stem cells by differentiating these cells**, to create arbitrary neural network architectures designed to implement each of the HMFs.

The last two statements have yet to be clarified by natural scientists in the near future.

The vital activity of consciousness and HMF ceases with the death of a person.

For newborns, the process of HMF formation and consciousness begins from the moment they are born.

The approximate HMF list is as follows:

- reflection
- physical reflection
- physiological reflection,
- mental reflection,
- perception,
- presentation
- arbitrary attention,
- arbitrary memory,
- rational activity (extrapolation reflex),
- speech,
- writing
- logical thinking,
- imagination
- consciousness
- nine gnostic functions,
- twenty to forty intellectual functions.

It should be noted that the given approximate HMF list of is very far from perfect, due to the fact that so far psychologists, specialists in normal physiology, neurophysiologists, neuropsychologists, biochemists and cognitive specialists have no consensus and, moreover, a consensus:

• on the leading role of one of the HMF;

• on the classification of these functions and the algorithm of their interactions;

• about the tasks solved by each of them;

• about physiological processes that realize them;

• on the cerebral globe of the brain and spinal cord, fragments of which realize the function of the substrates of each of the HMF;

• on the unity of the mental, material and information functions in each of the substrates of living matter.

We will consider this phenomenon temporary, and that very soon it will be qualified by natural scientists. In the meantime, all professionals mentioned in the context attribute the leading role to consciousness, in spite of the HMF of logical thinking, not being embar-

rassed by the fact that consciousness combines dozens of HMF.

If, yet, adhere to the rules of the protocol of agreements already reached in the field of reflection of knowledge about living matter in textbooks for biological and medical universities, then logical thinking, both of a mentor and a student, suggests the need to recognize the leading role of the HMF rational activity of a person. Although if only because it has, by universal admission of natural scientists, a genetic beginning and was first discovered experimentally as a sign of a psychic beginning in a person.

The discussions activity on the topics mentioned above has not subsided for at least the last three decades, but no noticeable progress in cognition of the human psyche has been observed.

The purpose of the article is to focus the attention of natural biologists on the lack of necessary knowledge in the field of dialectic logic of controlling the functional system of the human psyche, which, due to their fundamental nature, inhibits the knowledge of the neurophysiological processes secrets that realize his (person's) mental life. In particular, the knowledge formalization process in the field of theoretical medicine concerning the life of the functional system of the human psyche suffers to the maximum extent. It is these specialists who, like no one better, can see what knowledge and in what way can be obtained in a minimum amount of time. The article is devoted to the coverage of these problems.

The dialectical logic of controlling any functional systems of the human body follows from the conceptual knowledge of the vital functions of these functional systems, obtained exclusively through field experimentation. Therefore, the conceptual knowledge of the vital functions of each studied functional system of a person should precede the description of the essence of the management logic.

The problem formulation. The human psyche is one of the most important functional systems of the body, therefore, we will present the fundamental concepts of the vital activity of this system, which will allow us to identify the essence of the dialectical managing of life-supporting functions logic [8 – 11].

Human psyche life concepts

Concept No 1. The psyche essence and the HMF role in human life.

The psyche (mental (from Greek)) is a genetically determined property of highly organized matter of the human body, consisting in its (matter) ability to reflect (subjectively reproduce!) using its own sensory organs and to fix a mental image in the memory of its nervous system (scene + scenario)), interacting with it the objective reality of the environment. The adjective “mental” focuses on the fact that the image (scene + script) is formed in the perception environment, due to the complex of knowledge about this environment, called the worldview of the reflector.

The mental images accumulated by the subject about the life of the universe are used throughout his life, both for the operational and for the current and long-term management of his own life and his behavior.

The HMF control algorithm as a part of a functional system called the psyche is not yet known to natural scientists. And according to my ideas, no one has yet studied this topic in the international scientific community, since publications on it have not yet been encountered in international scientific journals.

As well as the list of HMF specific functional capabilities of human rational activity is thoroughly known to no one. Although for the leading role among all HMF, it is objectively the number one contender.

It remains nothing but hope that this publication will arouse interest in the announced research topics and the results will not be long in coming.

In the meantime, in addition to the HMF presented above, it is possible to reveal generalized names of Gnostic and intellectual functions.

Gnostic (underlying) functions of natural phenomena cognition:

- purpose of functioning;
- motivation for functioning;

• morphology of a cognizable phenomenon;
• assessment of operation accuracy and reliability;
• identification of energy sources necessary for functioning;
• assessment of energy required for operation;
• physical forces that ensure the functioning process;
• types of movements of matter on which functioning is based;
• relation between physical variables that are functionally fully characterizing the functioning of the phenomenon under study.

Smart features

Intelligence (from the Latin intellectus – understanding, cognition) is **the main form of human cognition of reality**. In a broad sense, this is the totality of all individual cognitive mental functions: from sensation and perception to thinking and imagination; in a narrower sense, it is thinking. This definition of intelligence is accepted in modern national psychology.

The basic HMF list (**higher mental functions**) that make up the intellect is as follows:
• consciousness;
• perception;
• memory;
• thinking;
• speech;
• writing;
• score;
• arbitrary movements;
• understanding of relative movements;
• understanding of rhythms in movement and in sensory perceptions;
• imagination;
• recognition of familiar sensory images;
• recognition of familiar compositions (scenes) of sensory images;
• understanding the structure of sign systems (solving the problems of semiology);
• solving logical problems;
• solving problems of spatial geometric constructions;
• solving game problems with the antagonistic warring goals;
• reproduction of graphic or pictorial copies of the observed phenomena;
• fine art, literary and musical creativity;
• scientific creativity;
• substantial evidence of predictive logical statements;
• control and management of the autonomic nervous system.

However, you must admit that without the HMF control algorithm, which is part of the human body psyche functional system (HBPFS), known only through HBPFS full-scale experimentation, it is fundamentally impossible to understand the control logic of it (the psyche) by life-supporting functions.

Therefore, based on the knowledge of the human psyche set forth in this concept, we formulate the following axiom:

Axiom No.1. The human **psyche** as a whole, with all its HMF, from the point of view of a natural scientist-neurophysiologist, is a script generator, **reflected in the format of the second signal system symbols**, all admissible states of its nervous system, and, at the same time, the director of the implementation of these scenarios, guided by: environmental influences, interactions with the environment and a mental imitation of the "self" interaction with its own psyche.

This generator and director provides the solution to the following human life support tasks:
• active, but at the same time subjective reflection by this real universe individual;
• adaptive regulation of the one's own body state in accordance with the current environmental influences and current interactions;
• adaptive operational behavior management and reactions in accordance with the current environmental impacts and current interactions;
• the possibility of a mental imitation of the "self" interaction with his own psyche.

Guided by the ultimate goal of knowing the human psyche, and knowing the real state of this knowledge from the point of view of the psyche integrity **as a functional system of the human body**, I believe that we stay without answers to two questions:

- constructing (on the basis of the facts of full-scale experimentation with the functional system of the psyche) a HMF network management model of this system when solving the tasks just listed for the life support of the human body;
- on the basis of the HMF network model of management to identify the dialectic logic of its management (psyche) of life-supporting functions;

the psyche cognition cannot be considered successful. Such a level of cognition cannot be called failure otherwise. And, of course, there is a need for its urgent completion, but according to the program proposed in the article. Such actions determine the purpose of publishing the article. However, we must not forget that the psyche functional system, of course, being the most important in the environment of many other functional systems of the human body, continuously interacts with these other systems, and the quality of its functioning directly depends on this interaction. This will be discussed in the following concepts about some related HMF functional systems and the features [12, 13-18].

Concept No 2. The HMF leading role of rational activity in the sphere of the functional system action of the human psyche can be recognized only after exhaustive scientific knowledge of the biological tools that implement it. Including its functional capabilities, an algorithm for implementing these capabilities, plus the architecture of fragments of a neural network in the brain globe of the brain and spinal cord, which implement the full HMF functionality of rational activity. We identify this concept as **Axiom No.2.**

Concept No.3. Human evolution of the second signal system (speech, writing, reading) in addition to the first signal system (sensory), led to the generation in the body of the psyche as a separate body functional system, the material carrier (substrate) of which is the central nervous system (CNS). The psyche provides:

• interpretation of the universe phenomena reflected by it in human memory, in the format of functional information about this phenomenon, but not related to the substrate and its properties;

• interpretation of any functionality of the human body in the format of a controlled information process of movement and processing of the following types of information: 1) stored in its memory; 2) outgoing from the external environment (sensory); 3) coming from the analytical and associative centers of the cerebral cortex and its centers of motivation, will and emotions; 4) as well as coming from all feedback sources.

We identify this concept as Axiom No 3.

Concept No 4. The basis of the human body vital functions are the unconditioned reflex reactions of the organism to disturbances in the living environment, or disturbances in the internal environment of the organism. We identify this concept as **Axiom No 4.**

Concept No 5. The conditioned human body reflex activity is based on unconditioned reflex activity. We identify this concept as **Axiom No 5.**

Concept No 6. The human cerebral cortex activity has the most developed ability to analyze and synthesize signals from the surrounding and internal environment of the body. The analytical activity of the cortex is: a subtle distinction (differentiation) in the nature and intensity of the action of many stimuli acting on the body and reaching in the form of nerve impulses to the cerebral cortex. Due to internal inhibition in the cortex, differentiation of stimuli by the degree of their biological significance is carried out. This differentiation is analogous to the logical summation operation performed by the processor of the analytical zone.

The synthetic cortex activity is manifested in the binding, association of excitations that arise in different zones of the cortex, which forms complex forms of human behavior. This binding is an analogue of the logical multiplication operation, which is performed by the processor of the associative zone in the cerebral cortex. The neurons of the associative zone are not connected with the sensory organs or muscles, they communicate between different areas of the cortex, integrating, com-

bining all the impulses entering the cortex into integral acts of learning (reading, speech, writing), logical thinking, memory and providing the possibility of appropriate behavior reactions. We identify this concept as **Axiom No.6.**

Concept No 7. All anatomical components of the human body, external and internal, are permeated with various types of receptors, which are designed to control and regulate the permissible states of these components. We identify this concept as **Axiom No 7.**

Concept No 8. Conscious human activity is realized solely by the functional system of the human psyche, which includes the central and peripheral nervous system of a person. In this case, it is carried out:

• coding of processed information (engrams);

• associative information retrieval (engram);

• addressing of engrams during writing and reading;

• synchronization of writing and reading engrams;

• transformation of complex multimodal perceptions formats (unconscious memory) into conscious information formats (glosses, meanings);

• logical analysis of engrams performed in the analytical zone of the cortex;

• logical synthesis of engrams performed in the associative zone of the cortex.

We identify this concept as **Axiom No 8.**

Concept No 9. HMF of consciousness implements the list of functional capabilities identified in the process of exclusively full-scale experimentation [19 – 22]:

Model (in the form of sensory, speech, written, graphic, and engineering-graphic images) of subjective reflection in a person's memory of his interaction with environmental realities, which are the components of the universe.

Model subjective reflection in human memory of the accumulative knowledge results of the universe new fragments.

Providing the generating based on the accumulated knowledge of behavioral functions that allow a person to:

adequately navigate in space and time of the universe;

adequately assess the personal status in the environment;

adequately be guided by the laws of life in the environment;

ensure in time the systematic and integrity of the laws of life;

make the work socially useful, associated with the production of goods necessary for the life of society;

carry out an internal mental dialogue, which is the basis of the fruitful thinking of this person.

We identify this concept as **Axiom No 9.**

Axiom No 10. The spiritual life of a person is mediated by the dialectical logic of controlling his psyche functional system.

A formal model of the human psyche life-supporting functions dialectic logic control.

If axioms A1 – A9 and their causal relations between themselves and axiom A10, which reflects one of the psyche modeling goals, are described in the formal language of first-order predicate logic, then we get the desired model of the dialectic logic of controlling the psyche functional system.

We proceed to the process of describing the first-order predicate logic the dialectic logic of controlling the functional system of the psyche, reflected in the context of the article using the axiomatic text A1 – A10.

Replace the axiom A_z with a logical function called the predicate:

A1 ≡ p1(X), in which the predicate symbol p1 is loaded with the meaning of the axiom A1, and the object variable X identifies the person in question.

A10 ≡ p10(X), in which the predicate symbol p10 is loaded with the meaning of the axiom A10, and the objective variable X identifies the person concerning the psyche.

Based on the axioms A1 – A10, one can formulate the following target theorem:

The logical product of the axiom premises A1 - A9 provides an adequate spiritual life of a person.

This theorem formally looks like this: A1ΛA2Λ…ΛA9═>A10**.**

What is reflected in the predicate form:

$$(\forall X)\,((p1(X)\ \Lambda\ p2(X)\Lambda\ \ldots\ \Lambda\ p9(X)) \Rightarrow p10(X)) \quad (1)$$

Understanding the physiological meaning of logical operations used to reflect physiological phenomena, for example, in formula (1), is achieved by combining this formula with the help of an implication operation with one of its interpretations [6–8], but obtained by natural experimentation, always with the knowledge of the person for whom the formula is applied (1).

As a result, the formal model of the dialectic logic of controlling the psyche functional system will have the following form:

$$((\forall X)\,((p1(X)\ \Lambda\ p2(X)\ \Lambda\ \ldots\ \Lambda\ p9(X)) \Rightarrow p10(X))) \Rightarrow ((\exists X)\,((p1(X)\ \Lambda\ p2(X)\ \Lambda\ \ldots\ \Lambda\ p9(X)) \Rightarrow p10(X))) \quad (2)$$

Transformation of the model of the theorem to the canonical form

If in the formula (2) the expression:

$$((p1(X)\ \Lambda\ p2(X)\ \Lambda\ \ldots\ \Lambda\ p9(X)) \equiv F1(X)$$

will be replaced by the formula F1 (X), then the formula (2) will take the following form:

$$(\forall X)\left(F1(X) \Rightarrow p10(X)\right) \Rightarrow (\exists X)\,(F1(X) \Rightarrow p10(X)) \quad (3)$$

In the theory of theorems automatic proof, in order to reduce logical formulas to a canonical format containing only axioms and three logical operations (conjunctions, disjunctions, and negations), 27 formal rules of equivalent transformations of first-order predicate logic formulas are defined and proved.

Two of them look like this:

$$(F1(X) \Rightarrow F2(X)) \equiv (\text{Í}F1(X)\ V\ F2(X))$$
$$(F1(X) \Rightarrow F2(X)) \equiv (F1(X)\ \Lambda\ \text{Í}F2(X))$$

One of the rules sets

$$\text{Í}\exists \equiv \forall$$

One of the rules prescribes to free a formula from all quantifiers of generality if there are no other quantifiers in the formula.

If you use these four last rules, then the formula (3) in the first step will take the following form:

$$(\forall X)\,(\text{Í}F1(X)\ V\ p10(X)) \Rightarrow (\exists X)\,(\text{Í}F1(X)\ V\ p10(X)). \quad (4)$$

And at the next step (4) it is converted to:

$$(\text{Í}F1(X)\ Vp10(X))\Lambda\ \text{Í}(\text{Í}F1(X)Vp10(X)) \quad (5)$$

Proof of the theorem

Formula (5) is a conjunction of only two counter-components.

This indicates its inconsistency, but also testifies to the truth of the theorem as a whole, since the methodology for the automatic proof of theorems is based on the conclusion that the formula of the theorem as a whole is inconsistent.

Therefore, the theorem is successfully proved.

CONCLUSION

The created model can be transformed, depending on the set goal of the human psyche cognition, it can be considered as an example of modeling and a demonstration of the modeling methodology used. As researchers gain new knowledge in various fields of science about the psyche functioning, the model can be supplemented with concepts, axioms, refined, etc. It is important that the resulting model preserves the knowledge heritability of the human psyche and, in the case of formal proofs, the truth of the statement of the theorem will be proved analytically and mathematically accurately.

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Формальная модель диалектической логики управления жизнеобеспечивающими функциями психики человека

Виктория Кондратенко

Аннотация. Множество исследований в области искусственного интеллекта не могут быть завершены, или проведены вообще, из-за отсутствия на текущий момент корректной теории функционирования человеческого мозга, связанного с его интеллектуальной деятельностью, хотя бы на концептуальном уровне. Нет

пока комплексных предложений исследователей, на каких принципах должны основываться модели элементарных и структурированных смыслов, обрабатываемых мозгом в процессе жизнедеятельности человека, не говоря уже о формальных языках и их грамматиках, или, тем более, о формальных теориях, предназначенных для этих целей. Цель статьи заключается в восполнении отмеченного пробела в научных знаниях о человеческом мозге. Академик П.К. Анохин в 1984 году предложил концепцию модели организации и регулирования поведенческого акта, в которой есть место для всех основных процессов и состояний. Она получила название модели функциональной системы. При наличии такой модели появляется возможность в том же ключе, с помощью аксиоматических утверждений, создать логико-диалектическую модель процесса функционирования на физиологическом уровне любой из высших психических функций. Диалектическая логика управления любыми функциональными системами организма человека вытекает из концептуальных знаний о жизнедеятельности этих функциональных систем, добытых исключительно путём натурного экспериментирования с ними. Поэтому концептуальные знания о жизнедеятельности каждой исследуемой функциональной системы человека должны предшествовать описанию сущности логики управления ею. Психика человека является одной из важнейших функциональных систем организма человека. В статье представлены основополагающие концепты жизнедеятельности этой системы, которые позволяют выявить сущность диалектической логики управления её жизнеобеспечивающими функциями, и формальная модель диалектической логики управления функциональной системой психики человека.

Ключевые слова: аксиоматическое моделирование, искусственный интеллект, математическая логика, мышление, формализация.

Щелевое резание грунта со свободным боковым оттоком

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Аннотация. В условиях резания грунта в глубине массива при ограничении оттока грунта по боковым сторонам широкого ножа эпюра давлений на его переднюю грань имеет приближенно треугольную форму. При малых углах резания деформирование и выдавливание грунта происходит, в основном, в своды щели в вертикальном направлении. Ранее автором были получены аналитические зависимости давления гранта на верхнюю кромку прямого плоского ножа. При образовании щели широким острым ножом, установленным под некоторым углом в плане относительно направления его движения (в случае отсутствия бокового выпора), определены зависимости сил резания грунта от величины его пористости и зоны деформации.

Целью исследования является установление силовых зависимостей щелевого резания грунта широким косоугольным ножом *при возможности свободного выхода грунта в боковые технологические прорези*. В рассматриваемой работе, как и в модели, предполагается, что процесс резания грунта – квазистатический. Осуществляется он косоугольным широким плоским ножом с достаточно малым углом резания, как правило, не превышающем 20°. Считаем, что весь объем грунта расходуется на его перемещение вдоль поверхности ножа без образования ядра уплотнения или пластической зоны на лобовой грани.

Отличием настоящей модели является то, что грунт, двигаясь по ножу, может свободно перемещаться в боковые прорези (как минимум равные его высоте), образованные технологической оснасткой предварительно пробуренных скважин, вдоль которых движется нож. То есть, боковые стороны ножа свободны для пропуска избыточного грунта, перемещающегося вдоль его поверхности.

Ключевые слова: щелевое резание, бульдозерный отвал, геостатическое давление, деформация грунта, свободный боковой отток.

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МОДЕЛЬ РЕЗАНИЯ ГРУНТА

Постановка задачи

Рассмотрим схему косоугольного резания грунта широким плоским ножом [1, 3, 5, 9, 16] (Рис.1). Здесь полоса $A^I K AK^I$ – открытая боковая поверхность грунта на передней грани ножа, через которую будет уходить стружка. Отсутствие нароста (ядра уплотнения) и выпирающего вперед за линию BB^I пластической зоны приводит к тому, что стружка будет уходить в прорезь в области треугольника $A^I B^I B$ [2, 11, 12]. Изучим *пирамиду сдвига грунта* $A^I B^I BD^I$ (найдем углы, размеры, давления). Запи-

шем условие, когда $A^I D^I \le A^I C^I$ – то есть ширина ножа b не меньше той граничной величины, при которой весь грунт перед ножом уходит в прорезь, без уплотнения вверх [4, 6, 17]. И в этом случае найдем все составляющие силы, действующие на нож.

Силы, действующие на пирамиду сдвига

Скольжение по поверхности ножа происходит параллельно $D^I A^I // DA$ для стружки. Сдвиг грунта (грунт по грунту) происходит под углом, обозначенным β, к свободной поверхности, то есть $\beta = \angle D^I B^I A^I$ (сдвиг $// B^I D^I // BD$). Высота пирамиды в проекции на плоскость ABC (Рис.2) равна $H_{\text{п}} = DD^{II}$ – высоте стружки [7, 8, 13 – 15]. Вычисляя AB, можно написать

$$H_{\text{п}}\left(\text{tg}\gamma + \text{ctg}\beta\right) = l\cos\delta \qquad (1)$$

Площади граней пирамиды сдвига грунта (см. Рис.1, 2):

$$S_{A^I BB^I} = \frac{1}{2} l \sin\delta l\cos\delta = \frac{l^2}{4}\sin 2\delta \qquad (2)$$

– это основание пирамиды;

$$S_{BAD} = \frac{1}{2} l\cos\delta H_{\text{п}} \qquad (3)$$

– площадь, равная площади боковой грани пирамиды $S_{B^I A^I D^I}$, на которой происходит сдвиг грунта по грунту;

$$S_{BB^I D^I} = \frac{1}{2} l \sin\delta B^I D^I = \\ = \frac{1}{2} l \sin\delta BD = \frac{1}{2} l \sin\delta \frac{H_{\text{п}}}{\sin\beta} \qquad (4)$$

– площадь грани сдвига грунта по грунту.

Аналогично зависимости (19), взятой из [10], находим площадь контакта пирамиды с ножом:

$$S_{A^I BD^I} = \frac{S_{ABD}}{\cos\phi_z} = \\ = \frac{1}{2} l\cos\delta H_{\text{п}} \frac{f}{\cos\delta\cos\gamma} = \frac{1}{2} lf \frac{H_{\text{п}}}{\cos\gamma}\ , \qquad (5)$$

где φ_z – угол нормали (направления составляющей общего давления грунта на нож) с осью OZ; $f = \sqrt{1 - \sin^2\gamma\cos^2\delta}$; γ – угол поворота ножа в плане; δ – угол резания.

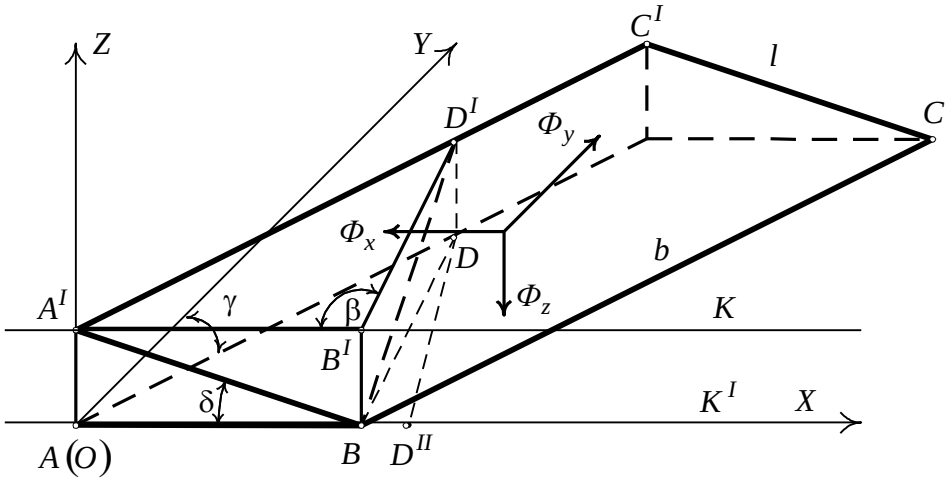

Рис.1. Схема косоугольного резания грунта в глубине массива при открытой боковой поверхности ножа

Fig. 1. Diagram of oblique cutting of soil in the depths of the array with the open side surface of the knife

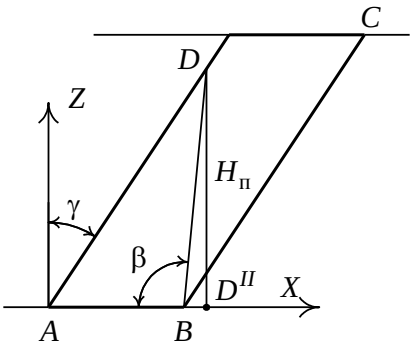

Рис.2. Проекция призмы грунта на плоскость резания
Fig. 2. Soil prism projection to the cutting plane

Давление в точке D^I максимально, обозначим его $\sigma_в$, аналогично верхнему давлению в работе [10]. На свободной поверхности (грани $BB^I A^I$) $\sigma = 0$; считаем, что в пределах пирамиды давление меняется линейно от 0 до $\sigma_в$. При вычислениях сил *F*, действующих на треугольники пирамиды, основываясь на линейности и интегральной формуле Симпсона, считаем, что среднее давление

$$\sigma_{ср} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}; \quad F = \sigma_{ср} S_\Delta, \qquad (6)$$

где $\sigma_1 \ldots \sigma_1$ – давления в вершинах пирамиды.

Находим касательные силы вдоль боковых граней пирамиды сдвига, используя формулы (3 – 5).

Для грани $A^I BD^I$ среднее давление

$$\sigma_{ср} = \frac{0 + 0 + \sigma_в}{3} = \frac{\sigma_в}{3},$$

а касательная сила трения

$$F_1 = \frac{\sigma_в}{3} \operatorname{tg}\mu S_{A'BD'} = \frac{lH_п}{2} \frac{\sigma_в}{3} \operatorname{tg}\mu \frac{f}{\cos\gamma}. \qquad (7)$$

Для грани $BB^I D^I$ тоже $\sigma_{ср} = \frac{\sigma_в}{3}$, а касательная сила по закону Кулона-Мора

$$F_2 = \left(c + \frac{\sigma_в}{3} \operatorname{tg}\Theta\right) S_{BB'D'} = \left(c + \frac{\sigma_в}{3} \operatorname{tg}\Theta\right) \frac{lH_п \sin\delta}{2\sin\beta}. \qquad (8)$$

Для грани $B^I A^I D$ аналогично

$$F_3 = \left(c + \frac{\sigma_в}{3} \operatorname{tg}\Theta\right) \frac{lH_п}{2} \cos\delta. \qquad (9)$$

Учитывая направление сдвигов, описанное в начале статьи, находим суммарную составляющую этих сил Φ_y, перпендикулярную основанию $A^I BB^I$ (вдоль оси *OY*, как в работе [10]):

$$\Phi_y = F_1 \cos\gamma + (F_2 + F_3)\sin\beta = \frac{lH_п}{2}\left[\frac{\sigma_в}{3} f \operatorname{tg}\mu + \left(c + \frac{\sigma_в}{3}\operatorname{tg}\Theta\right) \times (\sin\delta + \cos\delta \sin\beta)\right]. \qquad (10)$$

Находим суммарную составляющую сил давления N_y на боковые грани пирамиды сдвига (тоже вдоль оси *OY*). Для треугольника это будет

$$S_\Delta \sigma_{ср} \cos\varphi_y = S_{пр} \sigma_{ср},$$

где φ_y – угол нормали (составляющей давления) с осью *OY*; $S_{пр}$ – площадь проекции треугольника на плоскость $A^I B^I B$.

Алгебраическая сумма проекций боковых граней пирамиды сдвига (с учетом знаков направляющих косинусов нормалей) дает основание $A^I B^I B$, а $\sigma_{ср} = \frac{\sigma_в}{3}$ для любой боковой грани. Значит

$$N_y = \frac{\sigma_в}{3} S_{A'B'B} = \frac{\sigma_в}{3} \frac{l^2}{4} \sin 2\delta. \qquad (11)$$

Уравнения для геометрических параметров пирамиды сдвига

Из условия равенства $N_y = \Phi_y$ получаем уравнения для высоты призмы $H_{\text{п}}$ и угла сдвига грунта β:

$$\frac{lH_{\text{п}}}{2}\frac{\sigma_{\text{в}}}{3}\left[f\,\text{tg}\mu + \left(\frac{3c}{\sigma_{\text{в}}} + \text{tg}\Theta\right)\left(\sin\delta + \cos\delta\sin\beta\right)\right] = \frac{\sigma_{\text{в}}}{3}\frac{l^2}{4}\sin 2\delta.$$

Деля это равенство на $\frac{lH_{\text{п}}}{2}\frac{\sigma_{\text{в}}}{3}\sin 2\delta$ с учетом зависимости (1) получим уравнение для β:

$$M_1 + C_1\sin\beta = \text{ctg}\beta + \text{tg}\gamma, \quad (12)$$

где

$$M_1 = \frac{3c}{\sigma_{\text{в}}} + \text{tg}\Theta + \frac{f\,\text{tg}\Theta}{\sin\delta};$$

$$C_1 = \text{ctg}\delta\left(\frac{3c}{\sigma_{\text{в}}} + \text{tg}\Theta\right). \quad (13)$$

Найдем оптимальное приближенное решение для уравнения (12). При $\beta = 55°$ равенство (12) превращается в равенство (с точностью до сотых)

$$0{,}82C_1 + M_1 = 0{,}7 + \text{tg}\gamma.$$

При $\gamma \le 35°$ и $55° \le \beta \le 125°$ можно принять $\sin\beta \approx 0{,}9$ (с ошибкой ≤ 10 %), а угол β не может принимать значения $\beta \ge 125° = 90 + \gamma$ (Рис.2).

Итак, запишем условие (12) в виде

$$0{,}82C_1 + M_1 = 0{,}7 + \text{tg}\gamma. \quad (14)$$

Из монотонности по β левой и правой частей равенства (12) следует, что нет корней уравнения (12) $\beta \le 55°$. Из выше сказанного получаем, что

$$\text{ctg}\beta + \text{tg}\gamma = 0{,}9C_1 + M_1, \quad (15)$$

где $\sin\beta \approx 0{,}9$ (с точностью до 10 %).

Тогда высота призмы будет

$$H_{\text{п}} = \frac{l\cos\delta}{0{,}9C_1 + M_1}, \quad (16)$$

где M_1 и C_1 определяются из равенств (13).

Если условие (14) не выполняется, то корень $\beta \le 55°$ и тогда

$$H_{\text{п}} = \frac{l\cos\delta}{\text{ctg}\beta + \text{tg}\gamma} \le \frac{l\cos\delta}{0{,}7 + \text{tg}\gamma}.$$

То есть, высота призмы $H_{\text{п}}$ сравнима по величине с AB и по предположению о сравнительных размерах AB и BC (поскольку ширина ножа гораздо больше его длины) величиной $H_{\text{п}}$ можно пренебречь.

Итак, при условии (14) параметры пирамиды сдвига ищем из равенств (15) и (16), а при нарушении его – пирамидой сдвига пренебрегаем. Отметим, что угол сдвига грунта β можно вычислять и при $\gamma \le 35°$, исключая при этом посторонние корни уравнения (12).

Как сказано вначале, призма не перекрывает в продольном направлении весь нож (то есть $A^I D^I \angle A^I C^I$): $\frac{H_{\text{п}}}{\cos\gamma} \le b$ или, что следует из соотношения (16),

$$l\cos\delta \le b\cos\gamma\left(0{,}9C_1 + M_1\right), \quad (17)$$

где M_1 и C_1 вычисляются по формулам (13).

Определение сил, действующих на нож

Найдем *боковую составляющую* Φ_y суммарной силы резания на передней грани ножа.

В работе [10] эта боковая составляющая для закрытого резания (при отсутствии выхода грунта в боковые прорези) определяется как

$$F_y = lb \sin\delta \sin\gamma \frac{\sigma_в}{2}. \qquad (18)$$

Теперь мы должны вычесть часть F_y вдоль треугольника $A^I BD^I$ (см. Рис.1), соответствующую падению давления $\sigma_{ср}$ от величины $\frac{2\sigma_в}{3}$ до $\frac{\sigma_в}{3}$ на этом треугольнике и добавить появившуюся составляющую силы трения (поскольку теперь присутствует пирамида, смещающаяся в сторону). Эта первая часть равна

$$\Phi_{y_1} = l \frac{H_п}{\cos\gamma} \sin\delta \sin\gamma \frac{\sigma_в}{6}.$$

Здесь вместо значения $b = A^I C^I$ будет $A^I D^I = \frac{H_п}{\cos\gamma}$; появляется $\frac{1}{2}$, так как падение давления происходит на треугольнике.

Вторая часть (по трению) равна

$$\Phi_{y_2} = -\left(\frac{1}{2} l \frac{H_п}{\cos\gamma} f\right)\left(\frac{2\sigma_в}{3}\right) \mathrm{tg}\mu \cos\gamma.$$

В скобках здесь соответственно площадь $A^I BD^I$ и среднее напряжение $\sigma_{ср}$; значение $(-\cos\gamma)$ соответствует направлению силы трения относительно оси *OY*.

В результате имеем

$$\Phi_y = F_y - \Phi_{y_1} + \Phi_{y_2} = \frac{1}{6} l \sigma_в \times \times \left[\sin\delta \sin\gamma \left(3b - \frac{H_п}{\cos\gamma}\right) - 2 f H_п \mathrm{tg}\mu\right]. \qquad (19)$$

Находим *вертикальную составляющую* (направленную вниз) Φ_z:

$$\Phi_z = F_z - \Phi_{z_1} - \Phi_{z_2},$$

где (см. работу [10]):

$$F_z = lb \cos\delta \frac{\sigma_в}{2} T$$

– значение составляющей закрытого резания без пирамиды сдвига (здесь $T = \cos\gamma - f\,\mathrm{tg}\mu\,\mathrm{tg}\delta$).

Аналогично:

$$\Phi_{z_1} = \frac{l H_п}{\cos\gamma} \cos\delta \frac{\sigma_в}{6} \cos\gamma$$

– уменьшение $\sigma_{ср}$ на $A^I BD^I$ без учета трения;

$$\Phi_{z_2} = -\left(\frac{l H_п}{\cos\gamma} \frac{f}{2}\right)\left(\frac{2\sigma_в}{3}\right) \mathrm{tg}\mu \sin\delta$$

– часть составляющей трения в F_z, соответствующая треугольнику $A^I BD^I$, которой теперь (для треугольника $A^I BD^I$) не будет. Составляющая по оси *OZ* для трения при возникшем боковом сдвиге будет равна нулю.

Итак,

$$\Phi_z = \frac{\sigma_в}{6} l \left[\begin{array}{l} \cos\delta\left(3b\cos\gamma - H_п\right) - \\ - f \sin\delta \mathrm{tg}\mu \left(3b - \frac{2H_п}{\cos\gamma}\right) \end{array}\right]. \qquad (20)$$

Находим *горизонтальную составляющую* Φ_x (направлена противоположно оси *OX*), равную силе резания:

$$\Phi_x = F_x - \Phi_{x_1} - \Phi_{x_2} + \Phi_{x_3}, \qquad (21)$$

где $F_x = \frac{\sigma_в}{2} lb\left[f \cos\delta \mathrm{tg}\mu + \sin\delta \cos\gamma\right]$ – такая же составляющая для закрытого резания (см. работу [10]). Аналогично предыдущим рассуждениям:

$$\Phi_{x_1} = \frac{l H_п}{\cos\gamma} \frac{\sigma_в}{6} \sin\delta \cos\gamma$$

– аналог Φ_y, только вдоль горизонтали *OX*;

$$\Phi_{x_2} = \frac{\sigma_в}{3}\frac{lH_п}{\cos\gamma}\,\mathrm{tg}\mu\cos\delta$$

– это сила трения грунта вдоль плоскости $A^I BD^I$, которая есть в составляющей закрытого резания F_x, но отсутствует при открытом резании (свободном выходе грунта в боковые прорези);

$$\Phi_{x_3} = \frac{\sigma_в}{3}\frac{lH_п}{\cos\gamma}\,f\,\mathrm{tg}\mu\sin\gamma$$

– составляющая по оси *OX* силы трения бокового сдвига на $A^I BD^I$, возникшая при открытом резании.

Подставляя все эти слагаемые в равенство (21), получим горизонтальную составляющую (*силу резания грунта*):

$$\Phi_x = \frac{\sigma_в l}{6}\left[\begin{array}{l} H_п\left(2f\,\mathrm{tg}\mu\left(\mathrm{tg}\gamma - \dfrac{\cos\delta}{\cos\gamma}\right) - \sin\delta\right) + \\ +3b\left(\sin\delta\cos\gamma + f\,\mathrm{tg}\mu\cos\delta\right)\end{array}\right], \quad (22)$$

где $f = \sqrt{1-\sin^2\gamma\cos^2\delta}$;

$$H_п = \frac{l\cos\delta}{0{,}9c\,\mathrm{tg}\delta\left[\dfrac{3c}{\sigma_в} + \mathrm{tg}\Theta\right] + \dfrac{3c}{\sigma_в} + \mathrm{tg}\Theta + \dfrac{f\,\mathrm{tg}\mu}{\sin\delta}}$$

– из формул (16) и (13);

$$\sigma_в = \frac{1{,}8\,\mathrm{tg}\delta\,\mathrm{tg}\Theta\left(1+\omega_0\right)\cos\gamma}{aT} + \sqrt{\frac{3{,}2\,\mathrm{tg}\delta\left(1+\omega_0\right)c}{aT}}$$

– из формулы (26) работы [10];

$$T = \cos\gamma - f\,\mathrm{tg}\mu\,\mathrm{tg}\delta\,.$$

ВЫВОДЫ

1. Разработана математическая модель процесса косоугольного резания в глубине массива широким острым ножом при движении грунта по лобовой грани при открытой боковой поверхности (возможности выхода грунта в технологические прорези по сторонам ножа).

2. Модель позволяет определить сопротивление резанию и тяговое усилие на рабочем органе в зависимости от геометрических параметров процесса, угла трения грунта по ножу и прочностных характеристик грунта.

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Crevice cutting soil with free lateral outflow

Mykhailo Sukach

Abstract. Under conditions of cutting the soil in the depths of the array, with limited soil outflow on the sides of the wide knife, the pressure plot on its front face has an approximately triangular shape. At small cutting angles, deformation and extrusion of soil occurs mainly in the crevices of the slit in the vertical direction. Earlier, the author obtained analytical dependencies of the grant pressure on the upper edge of a straight flat knife have been established. With the formation of a slit with a wide sharp knife installed at a certain angle in the plane relative to the direction of its movement (in the absence of lateral outflow), dependences of the

cutting forces of the soil on the magnitude of its porosity and deformation zone were obtained.

The aim of the study is to establish the force dependences of slotted soil cutting with a wide oblique knife with the possibility of free exit of soil into the side technological slots.

In this work, as in the model, it is assumed that the process of cutting the soil is quasistatic. It is carried out by an oblique wide flat knife with a sufficiently small cutting angle, usually not exceeding 20. We assume that the entire volume of soil is spent on its movement along the surface of the knife without forming a compaction core or a plastic zone on the frontal face.

The difference of this model is that the soil, moving along the knife, can freely move into the side slots (at least equal to its height), formed by the technological equipment of pre-drilled wells along which the knife moves. That is, the sides of the knife are free to pass excess soil moving along its surface.

Keywords: slot cutting, dozer blade, geostatic pressure, soil deformation, free lateral outburst.

Control weld geometric parameters when wet underwater welding*

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Abstract. The aquatic environment has a significant impact on the efficiency of heat input to the base metal, significantly reducing the efficiency of the arc. As a result, in wet underwater welding, the penetration of the base metal is reduced compared to welding in the air with the same mode parameters. The purpose of the research was to determine the effectiveness of the influence of the parameters of the process of underwater wet welding with rutile-type flux-cored wire on the geometric parameters of the weld metal – its width and penetration depth of the base metal. In this case, the shape coefficient of the weld was determined - the ratio of width to penetration depth (W/P). It was found that the welding speed, wire feed speed and the amplitude of the welding torch oscillations have a significant impact on the ratio of the width to the penetration depth of the welds. The W/P ratio of welds decreases significantly with increasing welding speed without oscillation of the welding torch. So, when welding with transverse oscillations of the welding torch with an increase in the wire feed speed, it decreased from 7.14 to 3.85. And it linearly increased with increasing amplitude of the torch oscillations. It was found that the oscillation velocity, elongation of the flux-cored wire, and arc voltage have an insignificant effect on the W/P ratio.

Keywords: flux-cored wire, underwater wet welding, width-to – penetration depth ratio.

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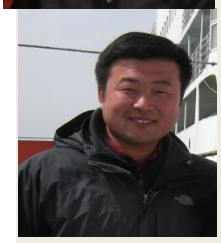

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INTRODUCTION

Underwater welding can be divided into three categories according to the operating environment, namely, wet, dry, and local dry welding [1, 2]. Wet welding is the simplest one in the three methods and has the most widely engineering adaptability [3]. It can work directly in the water without any special drainage facilities. The advantages of wet welding are simple equipment, low cost, flexible operation, and strong adaptability and so on [4, 5]. At present the most commonly used method is underwater shielded metal arc welding (SMAW) [6]. However, it needs divers to dive for welding. The time of each dive welder working in the water is very limited and it decreases with the increase of water depth. In addition, restricted by the length of the electrode, it needs to replace electrode frequently in the welding process, which extends the underwater construction time and leads to low production efficiency. And the quality is also difficult to guarantee [7]. The arc will be unstable when working in the water more than 80 m with solid wire gas shielded welding such as GMAW [8]. The main problems of this method are arc breaking and metal particles splashing [9]. Compared with solid wire, the metal and powder in flux-cored wire can interact more effectively in the heat distribution. And it can improve the arc ionization conditions efficiently and promote the stability of the transition metal thanks to the addition of the solder flux [10]. So the advantages of flux-cored wire are more prominent when used for welding in the deep water [11, 12]. Of course, the welding efficiency of flux-cored wire is significantly improved compared with SMAW. The emergence of flux-cored wire will promote the underwater welding production to the development of high-efficiency, low-cost, high-quality, automation, and intelligence [13].

The basic research of flux-cored wire underwater wet welding involves a large number of objects. There is no special flux-cored wire for underwater wet welding in China. So this paper mainly studied the effects of process parameters on the W/P ratio of rutile type flux-cored wire underwater wet welding with a flux-cored wire manufactured in the Institute of Oceanographic Instrumentation, Shandong Academy of Sciences, Qingdao. Due to the penetration and melting width are important parameters for weld formation, the W/P ratio of welds can reflect to some extent the characteristics of the method and the qualified degree of weld size.

EXPERIMENTAL METHODS AND MATERIALS

The base metal used in this paper is shipbuilding steel plate CCSE40 (σT = 390 МПа) and the size of specimen is 200×100×14 mm. Its chemical composition is given in Table 1.

The diameter of flux-cored wire is 1.6 mm. The wire is made with low carbon steel strip of which the size is 8×0.3 mm. The welding type used in this paper is D.C. plate welding. The torch is designed for reciprocating oscillating in the perpendicular direction of the forward

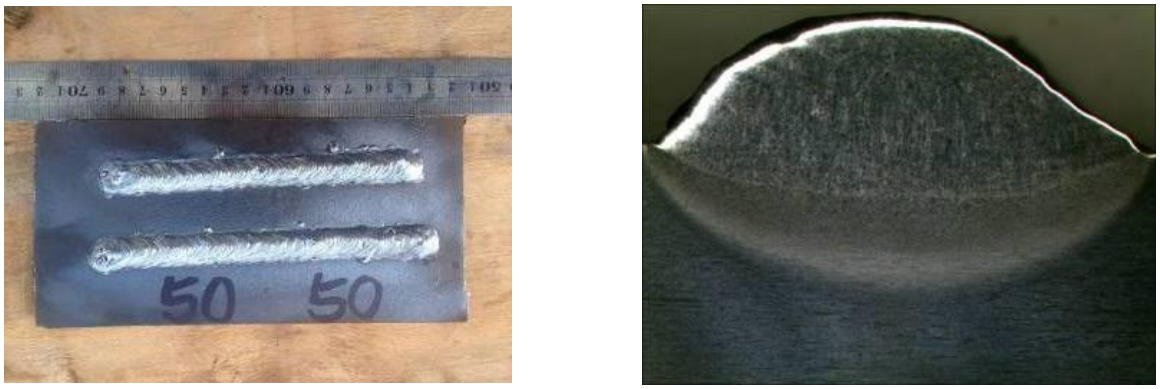
Table 1. Chemical composition of CCSE40 steel plate (wt.%)

C	Mn	Si	S	P	Mo	Ni	Cr	V
≤0.18	1.2	≤0.5	≤0.035	≤0.035	≤0.08	≤0.4	≤0.20	0.06

direction. There is no dwell time on both sides of the torch oscillating. The amplitude and speed of oscillating can be changed individually. The test is carried out in a glass tank, of which the size is 900×450×400 mm. And the tank is filled with fresh water, the depth of which is 0.3 m. The temperature of water used in this paper is 20℃ and the main equipment's are showed in Fig.1. It needs to remove the rust on the specimen with the method of mechanical grinding before welding. Vernier caliper is used to measure the penetration and width of welds to research the effect of different parameters on the W/P ratio after cutting the specimens transversely.

a *b*

Fig.1. Welding equipment: *a* – welding tank and control system, *b* – power source



a *b*

Fig.2. Formation and macro morphology of welds appear quite visible:

RESULT AND DISCUSSION

Formation and macro morphology of welds

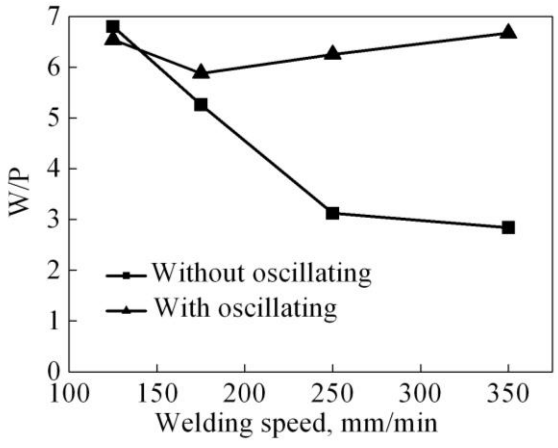
Fig.2*a* shows the formation of weld that welded with the homemade flux-cored wire. As seen in the figure, it exhibits an excellent appearance on the specimen. There are no obvious defects on the surface of welds, except a little spatter. Fig.2*b* shows the macro morphology of cross section surface on the weld. As shown in the figure, there is no slag or crack in the weld. The welding material combines closely with the base metal and the boundaries of each area.

The effect of welding speed on the W/P ratio of welds

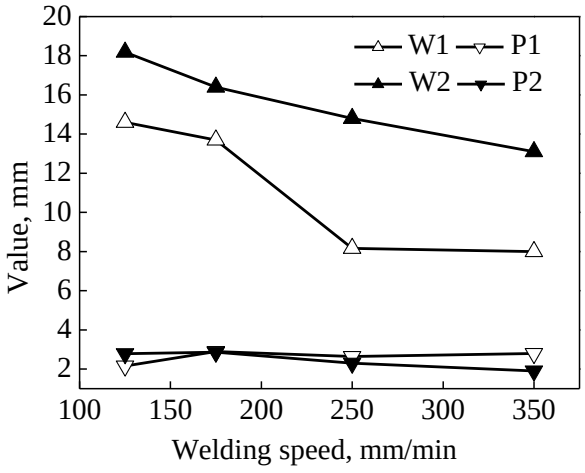
In this paper, W1 and P1 stands for the width and penetration depth of welds that welded without torch oscillating, meanwhile, W2 and P2 stands for the width and penetration depth of welds that welded with torch oscillating.

The effect of welding speed on the W/P ratio of welds is showed in Fig.3*a*. And the experimental result is obtained with welding voltage of 31 V, wire feeding speed of 3.3 m/min, wire extension of 20 mm and without torch oscillating. As showed in Fig.3*a*, the W/P ratio of welds decreases with the increasing of welding speed. The W/P ratio of weld increases significantly with the increasing of welding speed when the welding speed increases from 125 mm/min to 250 mm/min. It also decreases with the increase of the welding speed when the welding speed increases from 250 mm/min to 350 mm/min, but the trend of decreasing slows down apparently. This is because the width of welds decreases rapidly with the increase of welding speed, while the penetration depth of welds maintains within a small range of fluctuation. This trend is showed clearly in Fig.3*b*.

Another line in Fig.3*a* shows the effect of welding speed on the W/P ratio of welds when the oscillating amplitude is 5 mm and the oscillating speed is 1000 mm/min. It changes within a small range when the welding speed increases from 125 mm/min to 350 mm/min. The trend is not as obvious as that without the torch oscillating. It can accelerate the heat dissipating to the water when the torch oscillates actively, resulting in reducing the heat input to the base material. So the W/P ratio of welds is larger than that when the torch does not oscillate.

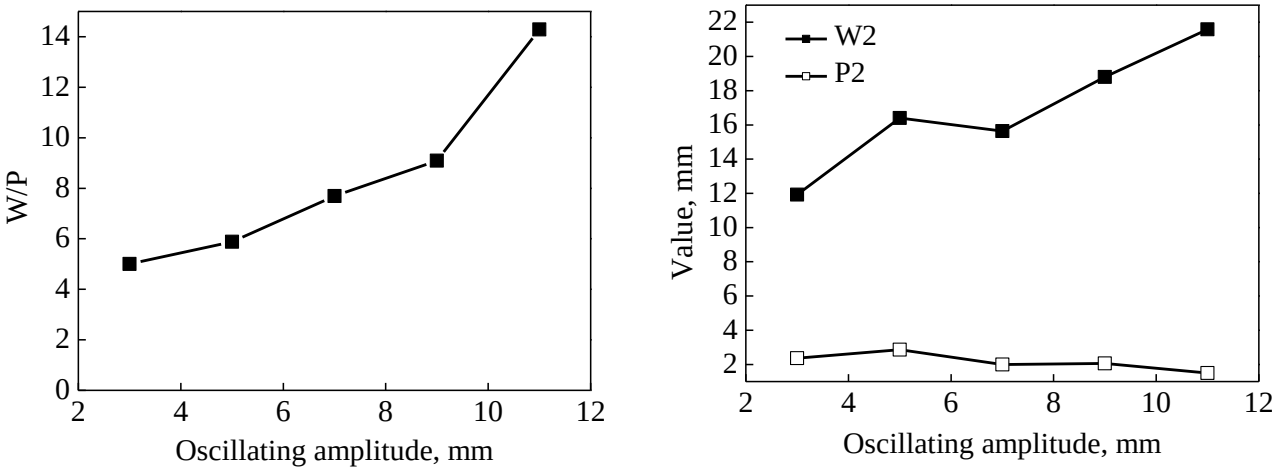


a



b

Fig.3. Effect of welding speed on W/P ratio: *a* – D/W ratio of welds, *b* – penetration depth and width of welds



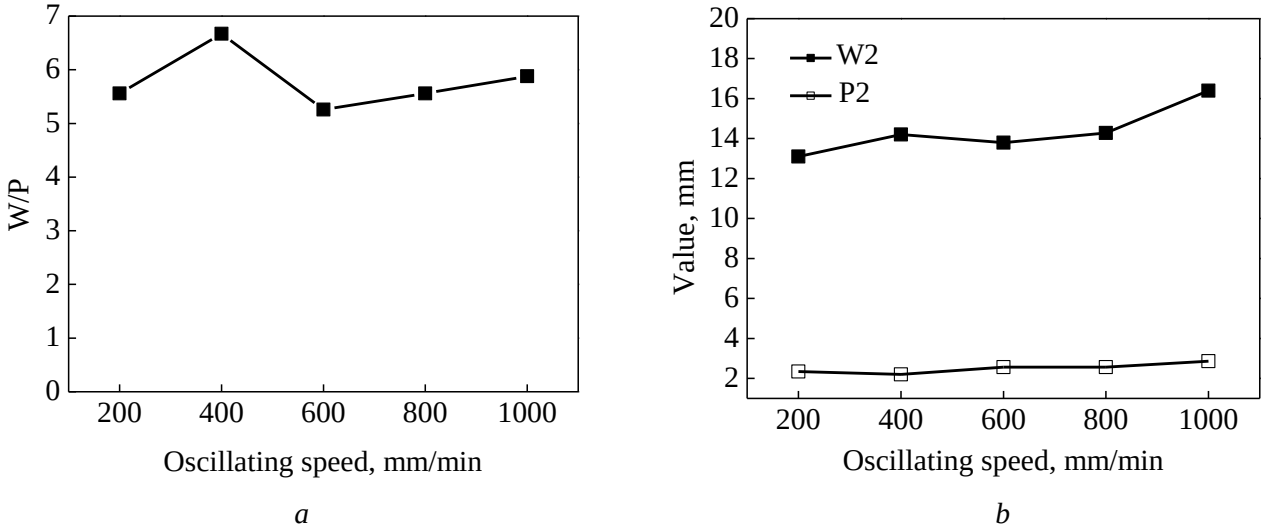
a *b*

Fig.4. Effect of torch oscillating amplitude on W/P ratio: *a*– W/P ratio of welds; *b* – Penetration depth and width of welds

The effect of torch oscillating amplitude on the W/P ratio of welds

The effect of torch oscillating amplitude on the penetration depth-to-width ratio of welds is showed in Fig.4*a*. The experimental conditions of this part are as follows. The welding voltage is 31V, the wire feeding speed is 3.3 m/min, the wire extension is 20mm, the welding speed is 175 mm/min and the torch oscillating speed is 1000 mm/min. It can be seen from Fig.4*a* that the W/P ratio of welds increases linearly with the increase of torch oscillating amplitude. It is obvious that the width of welds would increase with the increase of torch oscillating amplitude, just as shown in Fig.4*b*. In the case of other parameters remains unchanged and the heat input remains all the same, the depth of penetration would not change apparently, however, the width of welds would increase, which could cause the increase of W/P ratio of welds.

The effect of torch oscillating speed on the W/P ratio of welds



a *b*

Fig.5. Effect of torch oscillating speed on W/P ratio: *a* – W/P ratio of welds; *b* – penetration depth and width of welds

The effect of torch oscillating speed on the W/P ratio of welds is showed in Fig.5*a*. The experimental conditions of this part are as follows. The welding voltage is 31 V, the wire feeding speed is 3.3 m/min, the wire extension is 20 mm, the welding speed is 175 mm/min and the torch oscillating amplitude is 5 mm. As can be seen from the figure, there is no clear trend for the W/P ratio in pace with the increase of the torch oscillating speed. The W/P ratio is maintained within a small range (5.26 – 6.67) of fluctuation. In other words, the effect of the torch oscillating speed to W/P is not obvious and the changing of the torch oscillating speed could not cause bad weld formation. Fig.5*b* shows that the depth and width of welds also maintains within a small range.

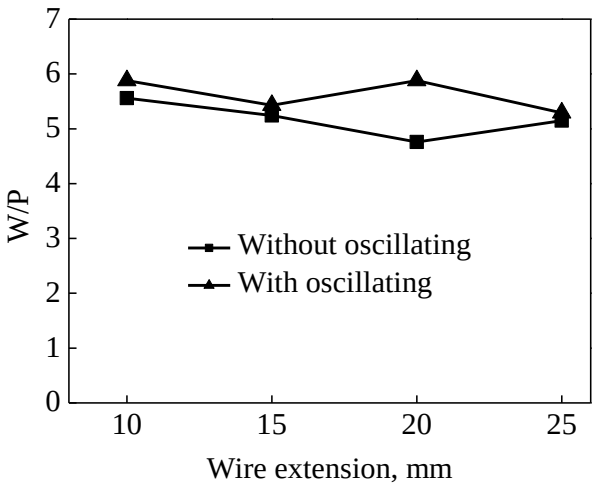
Effect of wire extension on the W/P ratio of welds

The effect of wire extension on the W/P ratio of welds without torch oscillating is conditions of this part are as follows. The welding voltage is 31 V, the wire feeding speed is 3.3 m/min and the welding speed is 175 mm/min. As can be seen from the figure, the W/P ratio first decreases with the increase of wire extension (from 10 mm to 20 mm) and then increases showed in Fig.6*a*. And the experimental with the increase of wire extension (from 20 mm to 25 mm). But the variation range of the W/P ratio is not great. Namely, the minimum value is 4,76, and the maximum value is only 5,56. The penetration depth and the width of welds change in a small range with the increase of wire extension, just as been showed in Fig.6*b*.

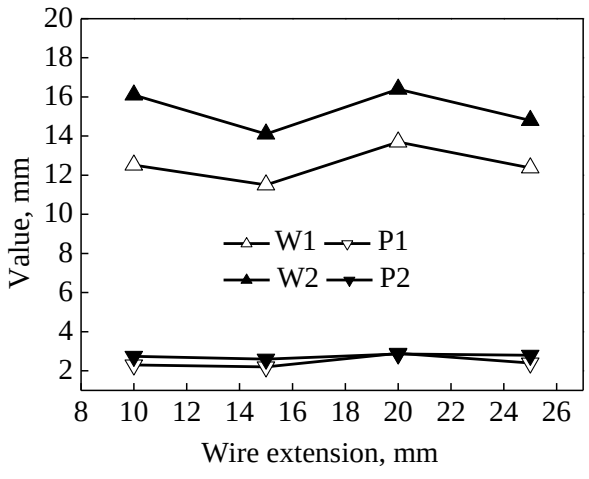
The effect of wire extension on the W/P ratio of welds with torch oscillating is showed in Fig.6*a*. All the other parameters of this part are the same as above except the followings. The torch oscillating amplitude is 5 mm and its oscillating speed is 1000 mm/min. As been showed in Fig.6*a*, the W/P ratio of welds changes in a small range (from 5,26 to 5,88) with the increase of wire extension. Thus, regardless of whether the welding torch oscillates, the effect of wire extension on the penetration depth-to-width ratio of welds is not significant.

Effect of welding voltage on the W/P ratio of welds

The effect of welding voltage on the W/P ratio of welds without torch oscillating is

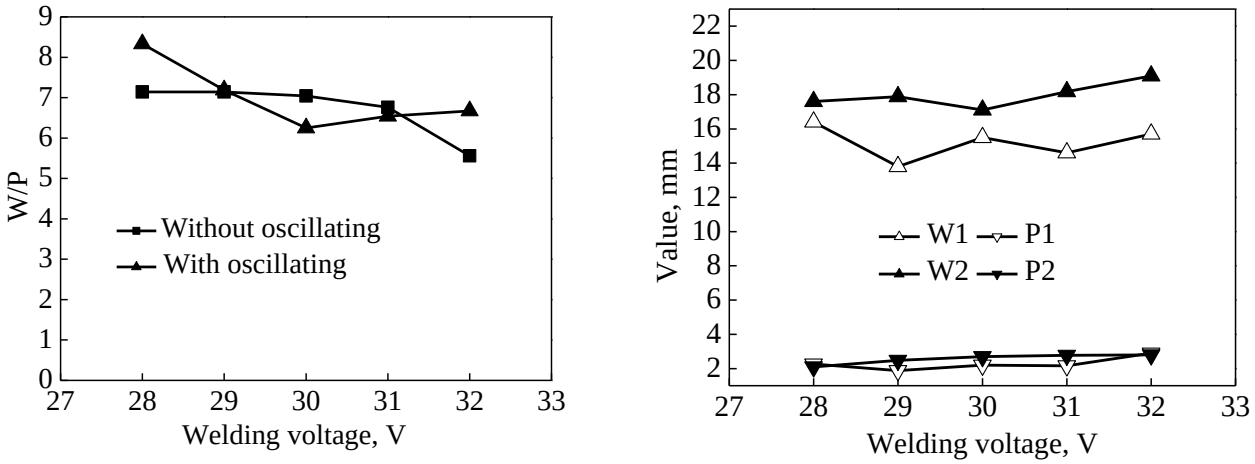


a



b

Fig.6. Effect of wire extension on W/P ratio: *a* – W/P ratio of welds; *b* – depth and width of welds



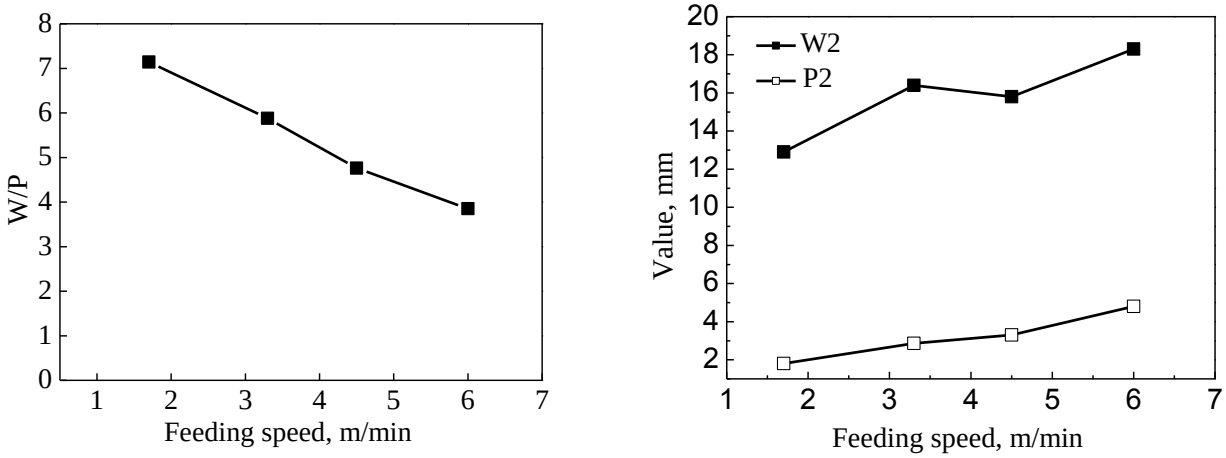
a *b*

Fig.7. Effect of welding voltage on W/P ratio: *a* – W/P ratio of welds; *b* – Penetration depth and width of welds

showed in Fig.7*a*. The parameters of this part are as follows. The wire feeding speed is 3.3 m/min and the welding speed is 175 mm/min. As can be seen from Fig.7*a*, the W/P ratio of welds decreases smoothly with the increase of welding voltage and its changing range is not large, only from 5,56 to 7,14. This is because the penetration depth and width of welds changed smoothly with the increase of welding voltage, just as been showed in Fig.7*b*.

The effect of welding voltage on the W/P ratio of welds with torch oscillating is also showed in Fig.7*a*. All the other parameters of this part are the same as above except the followings. The torch oscillating amplitude is 5 mm and its oscillating speed is 1000 mm/min. It is showed in Fig.7*a* that the W/P ratio of

welds first decreases and then increases with the increase of welding voltage. However, the changing range of the W/P ratio of welds is not large. Namely, the minimum value is 6,25 and the maximum is just 8,33. In a word, no matter whether the welding torch oscillate, the effect of welding voltage on the penetra-



a *b*

Fig.8. Effect of wire feeding speed on W/P ratio: *a* – W/P ratio of welds; *b* – Penetration depth and width of welds

tion depth-to-width ratio of welds is not great. The W/P ratio of welds is not sensitive to the change of welding voltage within the scope of this paper.

The effect of wire feeding speed on the W/P ratio of welds

The effect of wire feeding speed on the W/P ratio of welds is showed in Fig.8*a*. The parameters of this part are as follows. The welding voltage is 31 V, the wire extension is 20 mm, the welding speed is 175 mm/min, the torch oscillating amplitude is 5 mm and its oscillating speed is 1000 mm/min. As seen from Fig.8*a*, the W/P ratio of welds decreases (from 3,85 to 7,14) with the increase of wire feeding speed.

The reasons for this phenomenon are as follows. In the flux-cored wire welding, increasing the wire feeding speed will cause increasing the welding current. In the case of other conditions remain unchanged, the increasing of welding current means that the increasing of heat input to the base metal, which will lead to the increasing of penetration depth and width of welds, Fig.8*b*. Therefore, the W/P ratio of welds decreases with the increase of wire feeding speed. It is obviously showed in Fig.8*a*. But if increase the wire feeding speed continually, the welding process would not be stable and a bad formation of welds can be got. So the W/P ratio of welds is not showed in this paper when the wire feeding speed increased greater than 6m/min.

CONCLUSIONS

1. Under the condition that without welding torch oscillating, the W/P ratio of welds increases significantly with the increase of welding speed. And it increases (from 3,85 to 7,14) with the increase of wire feeding speed.

2. The W/P ratio of welds changes within a small range in pace with the increase of welding speed while the welding torch oscillating. It increases linearly with the increase of torch oscillating amplitude. But the effect of torch oscillating speed to the W/P ratio of welds is not obvious and the changing of the torch oscillating speed would not cause bad weld formation.

3. Regardless of whether the welding torch oscillating, the effect of wire extension on the W/P ratio of welds is not significant. And the W/P ratio of welds is not sensitive to the changing of welding voltage within the scope of this paper.

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Контроль геометрических параметров сварного шва при мокрой подводной сварке

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Аннотация. Водная среда оказывает значительное влияние на эффективность тепловложения в основной металл, значительно снижая коэффициент полезного действия дуги. В результате, при подводной мокрой сварке проплавление основного металла уменьшается по сравнению со сваркой на воздухе при одинаковых параметрах режима. Целью проведенных исследований было определить эффективность влияния параметров процесса подводной мокрой сварки порошковой проволокой рутилового типа на геометрические параметры металла шва – его ширину и глубину проплавления основного металла. При этом определяли коэффициент формы шва – отношение ширины к глубине проплавления (W/P). Установлено, что скорость сварки, скорость подачи проволоки и амплитуда колебаний сварочной горелки оказывают существенное влияние на отношение ширины к глубине проплавления сварных швов. Отношение W/P сварных швов значительно уменьшается с увеличением скорости сварки без колебаний сварочной горелки. Так, при сварке с поперечными колебаниями сварочной горелки с увеличением скорости подачи проволоки оно уменьшилось с 7,14 до 3,85. И оно линейно возрастало с увеличением амплитуды колебаний горелки. Установлено, что скорость колебаний, удлинение вылета порошковой проволоки и напряжение дуги оказывают несущественное влияние на отношение W/P.

Ключевые слова: порошковая проволока, подводная мокрая сварка, отношение ширины к глубине проплавленияения.

Underwater radio device

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Abstract. Creation of a radio communication device for underwater objects for the exchange of voice messages and for the transmission of digital data. The relevance of this problem is determined by the fact that the currently existing samples of equipment for underwater radio communications are excessively powerful, dimensional and with low bandwidth. An analysis of developments in this area showed that underwater radio communications can be organized on longitudinal electromagnetic waves or by using only the magnetic component of the electromagnetic wave.

The principle of operation of the device is based on the use of only the magnetic component of the electromagnetic wave. It is known that an electromagnetic wave consists of two components: electrical and magnetic. Water is an electrically conductive medium where the skin effect acts, according to which the deeper, the weaker the signal. But this is for the electrical component. Water has weak magnetic properties, so water is not a hindrance to the magnetic component of an electromagnetic wave.

Such a device, depending on its power, can be used both for individual communication of swimmers, and for the organization of radio communication between beacons and even for communication with submarines. It is possible to isolate the magnetic component of an electromagnetic wave according to two principles: to strengthen the magnetic component or to weaken the electrical component.

The separation of the magnetic component of the electromagnetic wave is carried out in the so-called magnetic antennas, which can be built in the form of coils with a ferrite core, can be of a frame type of a certain size or in the form of a coil in a screen made of non-magnetic metal.

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When upgrading conventional radio communication devices to the underwater version of their use, only the antenna-feeder path is subject to change, while other components of the communication channel remain unchanged. Application of such principles of radio communication organization will allow building submarine communication systems for an almost unlimited distance.

Keywords: radio communication, antenna, electromagnetic wave, electromagnetic field, magnetic component, electromotive force, submarine.

INTRODUCTION

It is known that the water of the oceans and seas has conductivity and significantly absorbs radio waves. In this environment, the radio wave almost attenuates in the thickness of the skin layer. In addition, the absorption coefficient increases with increasing frequency.

Therefore, long and ultra-long waves are commonly used to organize underwater radio communication, and optical [1] and acoustic [21, 22] waves can also be used. Specific features of the aquatic environment for the propagation of electromagnetic waves [3] are bias currents are much smaller compared to conduction currents, at the skin-layer distance the resistive and inductive properties of the medium are comparable, and capacitive are not affected, there is no wave zone: at any distance from the radiation source the pointing point is much less than Joule losses, impossible formation of narrow radiation patterns, etc. Therefore, to organize long-distance communication requires powerful equipment with antennas [6], the length of which is several kilometers, and this connection is quite slow, the bandwidth of such a communication channel reaches hundreds of bits per second. Obviously, other principles, one of which is suggested in this article, need to be used to organize a high-speed communication channel and over long distances underwater.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The history of communication with submarines [1] defines the basic principles that have guided the last 100 years. Long and ultra-long waves for long-distance communication (kilometers) are commonly used for underwater radio communication, and optical and acoustic waves can be used for short-distance communication (meters). According to the results of research of underground and underwater radio communication [3], the peculiarities of the aquatic environment for the propagation of the electromagnetic wave are clarified and it is determined that it is not effective to use Hertz radio waves in the aquatic environment. The article [4] discusses the issue of still insufficiently studied radiation of a rotating magnet, which can penetrate through the aqueous medium. Article [6] states that the existing system of communication with submarines involves high-power equipment, which also has large dimensions for almost submarines. Such equipment may not be used for individual communication of scuba divers. In [9] the connection between the longitudinal electromagnetic wave and the known system of Maxwell's equations is proved, where the vector of the longitudinal wave component of the electric field strength is found as an exact solution of Maxwell's standard equation with a specific case of gradient type of electric current and charge density. That is, it is possible to use longitudinal electromagnetic waves for underwater radio communication, which propagate under water almost without restrictions.

THE AIM OF THE STUDY

The urgency of this problem is determined by the fact that the current models of underwater radio equipment are excessively powerful, large and with low bandwidth. The results of the analysis are: alternative types of underwater radio communication are longitudinal electromagnetic waves and radio communication using the magnetic component of the electromagnetic wave. The purpose of the study, which is conducted in this article, is to determine the design features of equipment for the organization of radio communication using the magnetic component of the electromagnetic wave. The tasks that will be solved: to determine the principles of separation of the magnetic component from the electromagnetic wave and to determine the features of the construction of the communication channel for underwater radio devices.

RESULTS OF THE RESEARCH

Of course, the electromagnetic wave consists of two components: electric and magnetic. Water is a conducive medium where the skin effect acts, which is deeper, the weaker. But this is for the electrical component. For the magnetic component, water is not an obstacle. It is possible to distinguish the magnetic component of an electromagnetic wave according to two principles:

- amplify the magnetic component (the so-called magnetic antenna);
- weaken the electrical component (so-called HZ-antenna).

The type of antennas that respond to the magnetic component of the electromagnetic field (EMF) has been widely used in any industry due to its small size and transceiver properties. The main advantage of magnetic antennas – immunity to electrical interference [11]. The latter fact allows them to be used in any city where there is a high concentration of electrical signals [12, 13]. Their design is often really very simple. The magnetic antenna is made in the form of a closed coil, frame or coil (Fig.1). The simplest magnetic antenna consists of: a core; inductor; coil frame. A frame is provided on the core, and an inductor is wound on the frame. The core of such an antenna is made of magnetic material. Most often made of ferrite, which has good magnetic properties. The core can be made of a longitudinal piece of ferromagnetic, but it is more effective to give this material the shape of a frame. In such a design, the magnetic field will also create an electromotive force (EMF), but variable.

The antenna will turn into an inductor, which converts the energy of the EMF into electrical energy (this is the main task of the antenna). The magnitude of the induced EMF in the frame depends on the position of the structure relative to the plane of the field. The

Fig.1. The magnetic antenna

Fig.2. Frame antenna

EMF is maximum if the plane of the turns of the structure is directed to the transmitting station. If you rotate the antenna around the vertical axis (top view), then for one revolution it will have two highs and two lows (zero values) EMF.

EMF in it is given in accordance with the law of electromagnetic induction of M. Faraday [18]:

$$\varepsilon\lambda = -N\frac{\partial\Phi}{\partial t},$$

where N - the number of turns,

Φ – the magnetic flux that permeates the turns and is equal, in turn,

$$\Phi = \mu\mu_0 HS,$$

where H – the magnetic field strength of the wave;

S – cross-sectional area of the coil, frame or coil;

μ – current (effective) magnetic permeability of the core. For ferrite antennas μ is determined by the size and magnetic permeability of the core. Its approximate values for widespread ferrite rods are in the range from 160 (ferrite 1000HH) to 130 (ferrite 400HH);

μ_0 – magnetic permeability of vacuum ($\mu_0 = 4\pi \cdot 10^{-7}$ H/m).

Just like an electric, a magnetic antenna is characterized by an active height. Given the relationship between E and H, we can deduce [19]:

$$h_d = \frac{2\pi\mu SN}{\lambda}.$$

Now the EMF developed by the antenna is determined by the formula:

$$\varepsilon = \mathrm{E} \cdot h_d.$$

Magnetic antennas also include frame-type antennas. In addition to the Hertz electric dipole, there is a Hertz magnetic dipole, sometimes called a "frame antenna". The basis of the design of such antennas is a loop of cable

connected to a capacitor of variable capacity [20]. The perimeter of the loop is usually in the range from to and has the shape of a circle. A circle-shaped antenna is considered a classic loop antenna. Such an antenna can work with many frequency bands, including with shortwave (HF) – band.

This range is interesting because the waves of this range are still propagating in the water. The larger the area of the loop (better if it is round), the greater the signal coverage. Also in the circuit sometimes include a matching transformer. But a frame antenna with a frame perimeter less than 0.1 wavelength is called a "magnetic loop". To further reduce its sensitivity to the electrical component and make a minimum of the pattern deeper and sharper, the frame itself is also shielded (Fig.2).

The pattern of such an antenna will have the shape of infinity or figure eight (Fig.3).

Radio communication on the so-called EH-antennas [2] is a new unknown direction. This radio communication was born by the efforts of radio amateurs relatively recently (decades ago), but it seems promising, in particular, because this radio communication can work underwater. The prospect of research (both theoretical and experimental) work in this area is quite broad, as the principle of operation and theoretical foundations of communication on EH-antennas have not yet been established [8]. The reason is that EH-antennas operate on a new, virtually unknown electromagnetic principle, using a previously unknown type of electromagnetic radiation [15 – 16]. The design of EH-antennas consists of two cylinders

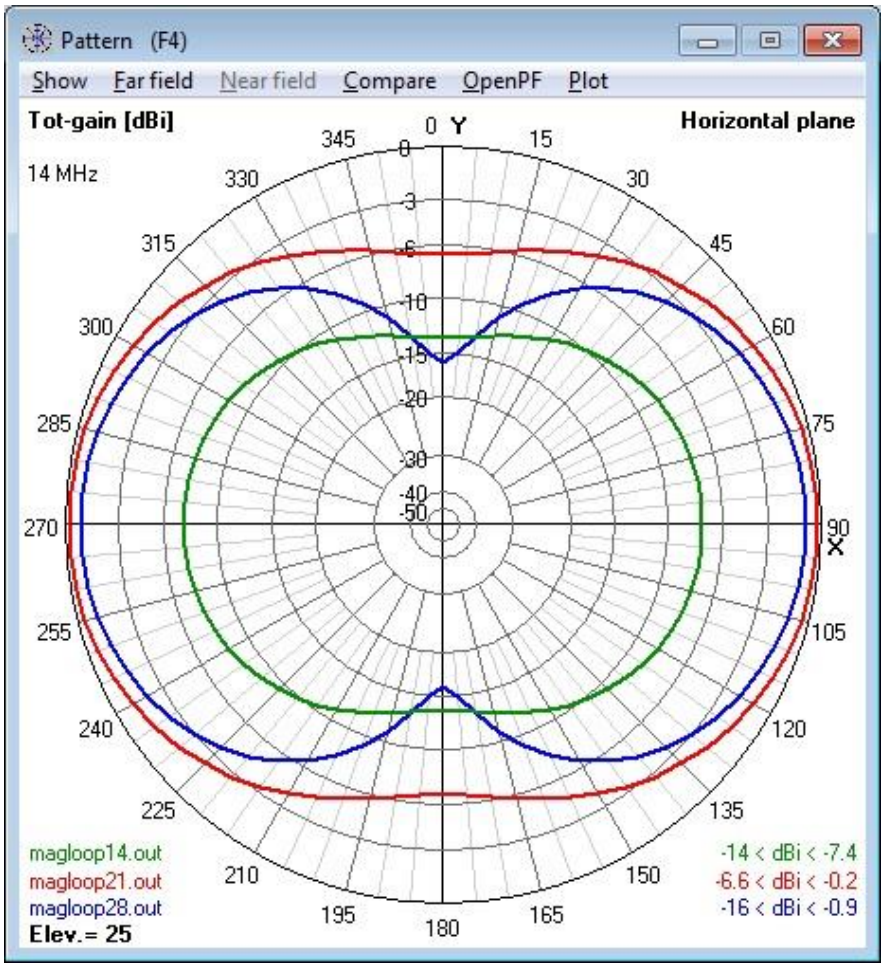

Fig.3. Azimuth Radiation Patterns for Magnetic Loop Antenna modeled for 14, 21 and 28 MHz at 5 feet above Average Ground [14]. As the radiation frequency increases, the antenna efficiency (Fig.4) and the gain (Fig.5) increase, but, unfortunately, the resistance of the aqueous medium increases

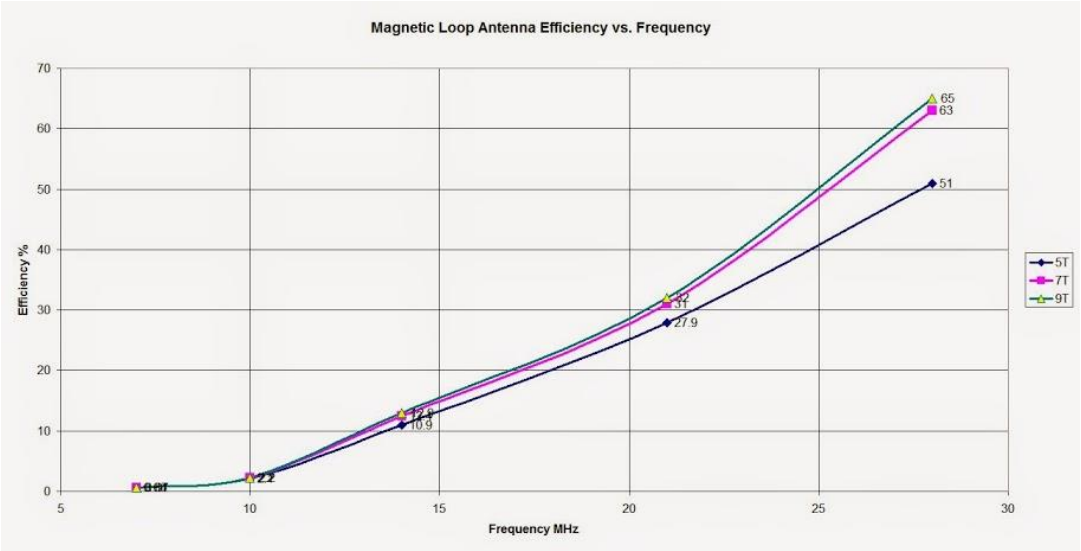

Fig4. Plot of calculated Magnetic Loop Antenna Free Space Efficiency vs. Frequency

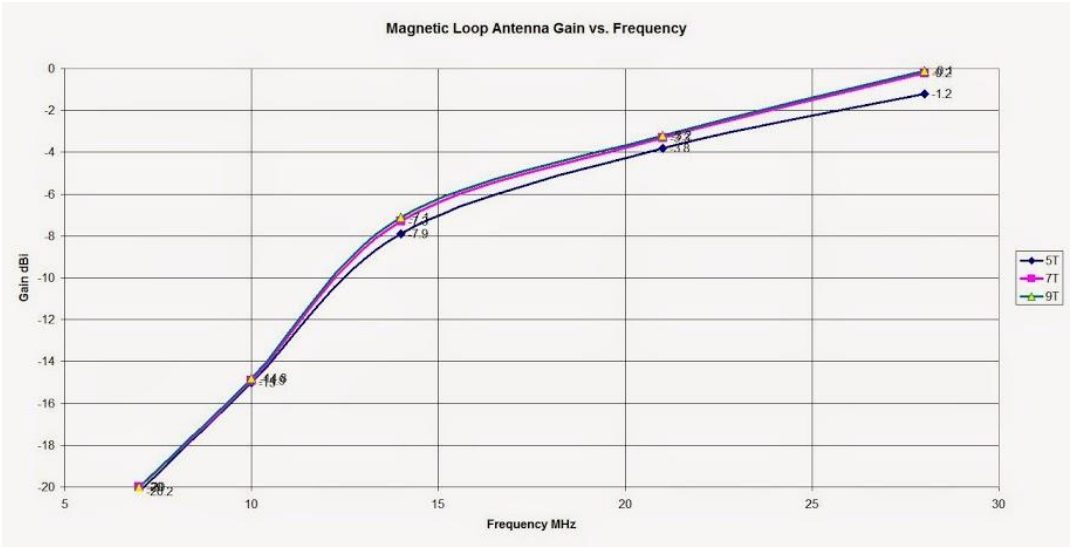

Fig.5. Plot of calculatated Magnetic Loop Antenna Free Space Gain vs. Frequenc

made of non-magnetic material and is made in such a way that the electric charges in its cylinder have a dominant rotational (spin) motion. High voltage is created by a resonant tuning coil, which ends with cylinders (Fig.6). This creates an intense field E between the cylinders. And this, in turn, creates a very large voltage between the ends of each cylinder, which creates a linear movement of charge on the surface of the cylinders, as in a conventional antenna. These streams allow the EH-antenna to generate the same type of radiation as any conventional Hertz antenna, even though the antenna is very small compared to the wavelength (less than 2% of the wavelength) [17].

The differential voltage across each cylinder creates a large current and, as a result, a magnetic field. The differential voltage on each cylinder is high, the resistance of the cylinders is low, and therefore the current is large and creates a large magnetic field, despite the small size of the antenna. The ratio of the amplitude between the fields E and H is set automatically, forming a very high resistance to radiation. Here is the fundamental difference

between EH-antennas and all conventional antennas. Thus, conventional antennas operate on the translational motion of electric charges, and the EH-antenna is assumed to operate on the rotational (spin) motion of electric charges. In the radio communication line, the EH-antenna works much better with the EH-antenna than with the usual one.

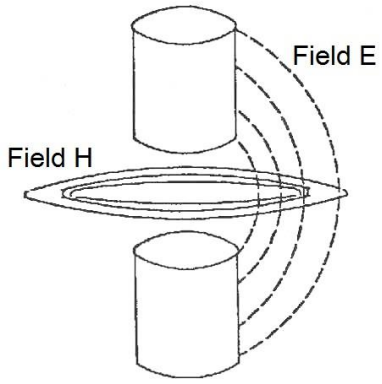

Fig.6. EH-frame antenna

In the study [2] it was determined that the motion of dynamic electrons can have two components – translational and rotational. If so, the resulting electromagnetic field from the motion of these dynamic electrons consists of two complex components, i.e. two separate and distinct electromagnetic fields. The properties of these two electromagnetic fields are very different from each other. In ordinary Hertz antennas there is a translational motion of electrons that form a known electromagnetic field. The peculiarity of En-antennas is that in the cylinders there is also a translational (linear) motion of electrons, but the rotational motions of electrons are dominant.

This situation is created by magnetic fluxes in the tuning coils of the EH-antennas. The magnetic field from the tuning coil penetrates through the cylinders in antiphase to the field caused by currents in the antenna from the phasing coil. Six equations are the result of the application of Maxwell's main two equations, which determine electric and magnetic fields, and supplemented with the assumption of rotation, their application in three dimensions, in comparison with the rectilinear motion of electrons used by Maxwell:

$$\dot{H}_x = \frac{\gamma'\lambda_x}{\pi}\cdot\dot{H}_0\cdot\sin\frac{\pi x}{\lambda_x}\cdot\exp\left(i\omega t-\gamma' z\right);$$

$$\dot{H}_y = 0;$$

$$\dot{H}_z = \dot{H}_0\cdot\cos\frac{\pi x}{\lambda_x}\cdot\exp\left(i\omega t-\gamma' z\right);$$

$$\dot{E}_x = 0;$$

$$\dot{E}_y = -\frac{i\omega\mu\mu_0\lambda_x}{\pi}\cdot\dot{H}_0\cdot\sin\frac{\pi x}{\lambda_x}\cdot\exp\left(i\omega t-\gamma' z\right);$$

$$\dot{E}_z = 0,$$

From these equations we see that even in the simplest wave representation there are two orthogonal magnetic vectors, one of which describes Hertz waves and the other the others. In the general case, it can be represented as

$$\gamma = \alpha + i\beta,$$

where α characterizes the wave attenuation along the Oz axis and can be is called the damping coefficient;

β characterizes the phase change along axis Oz and can be called the phase coefficient. From the relation

$$\left(\frac{m\pi}{\lambda_x}\right)^2+\left(\frac{n\pi}{\lambda_y}\right)^2=\omega^2\mu\mu_0\varepsilon\varepsilon_0+(\gamma')^2$$

we obtain for the region λ_x, λ_y:

$$(\gamma')^2=\left(\frac{m\pi}{\lambda_x}\right)^2+\left(\frac{n\pi}{\lambda_y}\right)^2-\omega^2\mu\mu_0\varepsilon\varepsilon_0. \quad (1)$$

For

$$\left(\frac{m\pi}{\lambda_x}\right)^2+\left(\frac{n\pi}{\lambda_y}\right)^2>\omega^2\mu\mu_0\varepsilon\varepsilon_0$$

we obtain $(\gamma')^2>0$ and γ' – is a real number, i.e. $\gamma'=\alpha$ and $\beta=0$. This case corresponds to a damped wave.

For

$$\left(\frac{\mu\pi}{\lambda_\xi}\right)^2+\left(\frac{\nu\pi}{\lambda_\psi}\right)^2<\omega^2\mu\mu_0\varepsilon\varepsilon_0$$

we obtain $(\gamma')^2<0$ and γ' – is a imaginary number, i.e. $\gamma'=i\beta$ and $\alpha=0$. In this case, we obtain a wave propagating along the axis

Oz without attenuation. Wherein in the region λ_x, λ_y, created by the electron (mass-charge) corresponds to the critical frequency, determined from the condition $\gamma'=0$ expression:

$$\omega_0=\frac{\pi}{\sqrt{\mu\mu_0\varepsilon\varepsilon_0}}\cdot\sqrt{\left(\frac{m}{\lambda_x}\right)^2+\left(\frac{n}{\lambda_y}\right)^2}.$$

At frequencies below ω_0 the waves are damped. At frequencies above ω_0 the waves are undamped.

The distance over which an electromagnetic wave propagates during one period of its change, as you know, is called the wavelength

$$\lambda=vT,$$

Where

$$v=\frac{1}{\sqrt{\mu\mu_0\varepsilon\varepsilon_0}},\ T=\frac{2\pi}{\omega}.$$

Therefore, the critical frequency ω_0 corresponds to the critical wavelength λ_0 in space:

$$\lambda_0=\frac{2\pi}{\omega_0\sqrt{\mu\mu_0\varepsilon\varepsilon_0}}=\frac{2}{\sqrt{\left(\frac{m}{\lambda_x}\right)^2+\left(\frac{n}{\lambda_y}\right)^2}}.$$

The quantities ω_0 and λ_0 are interrelated with the numbers m and n, which determine the nature of the wave. In our case $\lambda_x>\lambda_y$, therefore the smallest critical frequency is obtained for $m=1$ and $n=0$. It turns out to be equal to:

$$\omega_0=\frac{1}{\sqrt{\mu\mu_0\varepsilon\varepsilon_0}}\cdot\frac{\pi}{\lambda_x}$$

and, therefore, the longest critical wavelength is $\lambda_0=2\lambda_x$. Since for $\omega>\omega_0$ we have $\gamma'=i\beta$ and

$$e^{i\omega t-\gamma' z}=e^{i\omega t-\beta z}$$

to obtain expressions for real instantaneous values of $\dot{H}_x$, $\dot{H}_y$, $\dot{H}_z$, $\dot{E}_x$ and $\dot{E}_y$ it is necessary in expressions for their complexes, replace the factor $e^{i\omega t-\gamma' z}$ with $\sin(\omega t-\beta z)$.

The quantity

$$\frac{\omega}{\beta}=v'$$

is the phase velocity of the wave.

The wavelength Λ along the Oz axis is obtained from the relation

$$\beta\Lambda=2\pi.$$

Replacing in the relation (1) $(\gamma')^2$ by $\omega^2\mu\mu_0\varepsilon\varepsilon_0$ through $\left(\frac{2\pi}{\lambda}\right)^2$ we find:

$$\beta^2=\left(\frac{2\pi}{\lambda}\right)^2-\left(\frac{m\pi}{\lambda_x}\right)^2-\left(\frac{n\pi}{\lambda_y}\right)^2.$$

Then we have

$$\frac{2}{\Lambda}=\sqrt{\left(\frac{2}{\lambda}\right)^2-\left(\frac{m}{\lambda_x}\right)^2-\left(\frac{n}{\lambda_y}\right)^2}$$

or

$$\frac{1}{\Lambda}=\sqrt{\left(\frac{1}{\lambda}\right)^2-\left(\frac{1}{\lambda_0}\right)^2}$$

This shows that the wavelength Λ along the Oz axis is greater than the wavelength λ in the Oxy plane at the same frequency. This difference is the greater, the more λ approaches the critical wavelength λ_0, and for $\lambda = \lambda_0$ we get $\Lambda = \infty$. Phase velocity can be represented as:

$$v' = \frac{\omega}{\beta} = \frac{\omega}{2\pi} \cdot \Lambda = \sqrt{\frac{1}{\mu\mu_0\varepsilon\varepsilon_0}} \cdot \frac{\Lambda}{\lambda} = v \cdot \frac{\Lambda}{\lambda}.$$

Therefore, the phase velocity v' of the electromagnetic waves along the Oz axis is greater than the speed of electromagnetic waves in the Oxy plane. This, of course, does not mean that the electromagnetic field changes with a speed of 10 greater than v, since v' is the speed with which the steady-state phase distribution along the Oz axis changes. In the physical sense this means, that for any violation of the existing mass distribution of the charge the coefficients m and n change, which change the phase distribution along the Oz axis with a speed v'. In other words, with this speed, the coefficients m and n change, which determine the frequency filling of the mass-charge wave, i.e. spectrum, which can also be represented by the trigonometric Fourier series whose member numbers correspond to the coefficients m and n.

In this case, along the Oz axis there is a non-zero component of only the magnetic field strength. In this connection, it is of interest that

$$\nabla B = 0$$

always (the absence of magnetic charges, and the lines of the magnetic field are closed) and magnetic induction is a complex quantity. The magnetic component along the Oz axis of the critical electron wave (mass charge) is closed at infinity. According to this magnetic wave, the electron (mass-charge) considered in a particular place can be controlled instantly everywhere in the Universe. He constitutes with her one whole, infinitely closed space, where any changes in the phase distribution of his waves are realized instantly in the entire Universe.

The considered properties of the electron component $\dot{H}_z$ (mass-charge) fully correspond to the same component of our Earth (mass-charge). It is tempting to influence information on a component $\dot{H}_z$ near the Earth. This is the instant passage of information on the universe! Of course, the usual techniques used in conventional radio communications are not applicable here.

The obtained complex expressions of the instantaneous values of the components of the strengths of the magnetic and electric fields $\dot{H}_x$, $\dot{H}_y$, $\dot{H}_z$, $\dot{E}_x$, $\dot{E}_y$ and $\dot{E}_z$ electron (mass-charge) are fully applicable to electrons in the shell of an atom. It also follows from the foregoing that the orbit of an electron (mass charge) in an atom is an epicycloid, and not a distorted circle-ellipse. These complex expressions already in finished form are a kind of periodic wave function of the electron shell of the hydrogen atom H_1. The region λ_x, λ_y determines the external dimensions of the hydrogen atom H_1. The periodic wave function for electrons in an atom may turn out to be more convenient than transformations of the Schrödinger equation, from which the probability of an electron being at a given point in time at a given point in the orbit is obtained.

EH-antennas are already sufficiently tested in the world and are produced almost industrially [7]. The design of the antenna for this principle is almost patented [10].

A special case of EH-antennas are the so-called HZ-antennas. The device of the HZ-antenna is quite simple (Fig.7). The antenna consists of two coils arranged coaxially at

Fig.7. HZ-antenna [7]

some distance from each other. The coils are included so that their magnetic fields are directed opposite to each other, in other words, there is an anti-phase inclusion of these inductors. To increase the sensitivity, the capacitor is included, which together with the inductors forms a circuit.

This circuit is tuned to the frequency of the received signal. The coils are placed in a copper cylinder or in a copper screen. The magnetic fields of the frame are directed in opposite directions. The field in the far radiation zone, when the distance from the antenna significantly exceeds the diameter of the loop antennas and the distance between them, can be defined as the sum of the fields from each of the loop antennas. This type of antenna is called Hz antennas and belongs to the class of EH-antennas. Particular attention is drawn to the fact of shielding the antenna. For conventional antennas, such a screen does not allow the antenna to receive a signal from the surrounding space or emit it into space. However, in this case, as studies have shown, the screen not only does not suppress, but also improves the performance of the antenna. Between the same coils, included in antiphase, there is a space of some thickness in which the electric and magnetic fields are zero. The wires that are connected to the coil are also placed in the screen and there is no radiation from them.

Another feature of the HZ-antenna, which was predicted by theory and confirmed in practice, is the high penetrating power of the vector [2]. The field emitted by the HZ-antenna can penetrate water. This was experimentally established when a small transmitter and an EH antenna enclosed in a plastic sealed housing were placed under water. Both conventional antenna and EH-antenna were used as receiving antennas. Only the EH-antenna was able to receive a signal from a transmitter located under water.

DISCUSSION OF THE RESULTS OF THE STUDY

Thus, there is a theoretical possibility of organizing underwater radio communication on the principle of using only one component of the electromagnetic wave (magnetic). The use of such radio communication will allow to build communication systems for almost unlimited distance. Issues of energy supply of such systems are subject to further study.

In 2018, a message appeared on the Internet [5] that the Russian Federation has developed technology for the transmission of information and voice data in sea and fresh water, as well as across the border of the environment (water-air). The device provides uninterrupted communication between underwater and surface subscribers. The solution is based on the magnetic component. According to Fig.8, this is a frame magnetic antenna of the HF band, which is described above.

In order to test and develop the theory, it is necessary to conduct further theoretical and experimental research in the following areas: it is necessary to make sure that we are not dealing with an instantaneous, but with a wave process; it is necessary to determine the speed of propagation of the emitted wave. This speed can differ significantly from the speed of light in vacuum and does not depend on μ and ε, but on other parameters of the medium. This is qualitatively evidenced by experiments on the good passage of a new type of waves through water and reinforced concrete buildings in comparison with electromagnetic waves; it is necessary to study the polarization of these waves. Personal experience (especially the pattern) identifies the moments that indicate the longitudinal nature of these waves; it is also necessary to study the phenomena of reflection from different media, interference of these waves and diffraction.

CONCLUSIONS

Thus, the following conclusions are possible from the above:

- underwater radio communication can be organized on the principle of separation of the magnetic component of the electromagnetic wave;
- the release of the magnetic component of the electromagnetic wave is carried out in the so-called magnetic antennas;

Fig.8. Mobile radio complex of wireless underwater communication IVA S/W

- the magnetic antenna can be built frame, for example [5], or according to the patent [10];

- for the organization of underwater communication, only the antenna-feeder path is subject to change, and other components of the communication channel remain unchanged.

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Устройство подводной радиосвязи

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Аннотация. Создание устройства радиосвязи для подводных объектов для обмена голосовыми сообщениями и для передачи цифровых данных. Актуальность этой проблемы определена тем, что существующие на сегодня образцы оборудования подводного радиосвязи является чрезмерно мощными, габаритными и с низкою пропускной способностью. Анализ разработок в этой области показал, что подводную радиосвязь можно организовать на продольных электромагнитных волнах или с помощью использования только магнитной составляющей электромагнитной волны.

Принцип работы устройства основан на использовании только магнитной составляющей электромагнитной волны. Известно, что электромагнитная волна состоит из двух составляющих: электрической и магнитной. Вода - это электропроводящая среда, где действует скин-эффект, по которому чем глубже, тем сигнал слабее. Но это для электрической составляющей. Вода имеет слабые магнитные свойства, поэтому для магнитной составляющей электромагнитной волны вода - не помеха.

Такое устройство в зависимости от его мощности может быть использовано как для индивидуальной связи пловцов, так и для организации радиосвязи между радиобуями и даже для связи с подводными лодками. Выделить магнитную составляющую электромагнитной волны возможно за двумя принципами: усилить магнитную составляющую или ослабить электрическую составляющую.

Выделение магнитной составляющей электромагнитной волны осуществляется в так называемых магнитных антеннах, которые могут быть построены в виде катушек с ферритовым сердечником, могут быть рамочного типа определенного размера или в виде катушки в экране из немагнитного металла.

При модернизации устройств обычной радиосвязи в подводный вариант их использования изменениям подлежит только антенно-фидерный тракт, а другие составляющие канала связи остаются без изменений. Применение таких принципов организации радиосвязи позволит строить системы подводной связи для практически неограниченного расстояния.

Ключевые слова: радиосвязь, антенна, электромагнитная волна, электромагнитное поле, магнитная составляющая, электродвижущая сила, подводная лодка.

Basic provisions for the analytical calculation of vertical cylindrical containers

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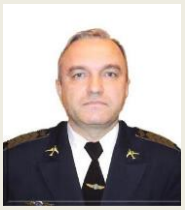
Abstract. The basic provisions for the analytical calculation of vertical cylindrical capacities are provided in this article. The submitted data is the result of a global study accomplished by the authors in recent years. The simplified procedure of mathematical calculations, which is used in the formulation of these dependencies, can characterize the outlined aspects in line with the engineering method and be recommended for practical application. In the given research the problem of the influence of profiling of the wall of the vessel on the radial movements of the case under the action of axially asymmetric and asymmetric loading is analyzed. The basic calculation formulas are given for determination of internal forces (ring normal stresses, running bending moments and running transverse forces) and displacements of the no-gauge storage capacity under load, which is described by the exponential law characteristic of the pressure of the loose material. A brief description of the influence of vertical ribs on the rigidity characteristics of silo tanks, as well as the expressions for estimating longitudinal forces in the ribs at a certain altitude level is given. Particular attention is given to the calculation of cylindrical capacities under conditions of asymmetrical radial loading.

In this case, the problem is considered for two variants of the simplified procedure, in accordance with the instantaneous theory and a more precise analytical solution in applying the equilibrium equations of the moment theory, which allows taking into account the effect of internal bending moments in the sections. In both cases, the simplification of the computational procedure is accomplished by decomposing an asymmetric load into a finite trigonometric series and conducting a calculation for each component separately. The internal forces arising in the edges of the conical roofs from the action of the most probable loads own weight, weight of technological equipment, wind pressure and snow load are also calculated. In this case, only the simplest construction of the roof was considered, characteristic of small diameter containers, which consist exclusively of the main radial edges. The article provides the formulas for finding the internal forces in this element and the maximum compressive force and maximum bending moment in a dangerous section.

Keywords: cylindrical shell, displacements, corrugated wall, exponential law, deflection functions, stress state, vertical stiffeners, axisymmetric load, radial deflection.



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INTRODUCTION

Our country is one of the key players in the sector of production and export of grain crops. In this process, the most important technological operation is the processing and storage of grain, requiring the availability of appropriate complexes, which should provide the necessary conditions for the quality maintenance of seeds. The advantage in this segment is given to industrial metal capacities of different structural form (Fig.1). The basic requirements for this type of structures are based on general technical characteristics of strength, rigidity and stability, as well as economic feasibility.

Fig. 1. General view of the vertical steel cylindrical containers of "Lubnymash" (https://lubnymash.com/)

Modern steel containers for storage of grain crops have taken leading positions in the elevator market. Despite a rather long period of production and operation of buildings of this type, the calculation of their supporting structural elements and a comprehensive study of their general characteristics have not received sufficient development till now.

MATERIALS AND METHODS

The analysis of the stress-strain state of steel in cylindrical silos tanks is a complex engineering task that requires significant scientific effort and knowledge; it is based on the use of special software groups and complicated mathematical apparatus for computing [1 – 5]. The purpose of the calculation is the unambiguous definition of the stress-strain state of the container from the action of the most probable loads the vertical and horizontal pressures of the loose material, which causes the axially symmetric loading and the pressure of the wind pressure, which applies asymmetric loads [6, 7] .This is the most accurate method for determining the full range of internal efforts and displacements is the finite element method, which is recommended for use in practical calculations. However, there is often a need for an analytical calculation, which allows not only to quickly evaluate some project decisions, but also to formulate conditions for related tasks, weakly dependent on inaccuracies of formulas. For example, we can give the task of calculating the minimum weight or maximum reliability. In addition, the results obtained are a guide for the designer, which will allow to avoid technical errors or possible inaccuracies in the construction of FEM computer model in the future.

RESULTS AND DISCUSSION

Steel vertical cylindrical container is a rotation shell, which is supported by vertical ribs of stiffness. The thickness of the plates, from which the body of the container is tiled, varies in height, and the texture of the plates can be both smooth and wavy.

A comparative analysis of the resistance to deformation of profiled sheets [8 – 10] showed that with increasing thickness of the sheets, their rigidity characteristics deteriorate. With the classic bend of thin plates that work as membranes, the use of profiled sheets is more effective. However, with axially symmetric loading of the cylindrical shell of rotation with evenly distributed loads, which causes both tensile strength and compression forces, sheet profiling does not affect the radial displacement of the construction.

With asymmetric loading, sheet profiling reduces radial movements of the shell. This phenomenon is most pronounced for thin sheets with more "frequent" wave steps.

Determination of internal forces and displacements of a cylindrical thin-walled shell at various boundary conditions is given in many scientific and reference sources, but the practical analytical calculation is complicated by the search for a solution in loaded state, which is described by the exponential law, characteristic for the pressure of the loose material.

Dependences for internal forces and displacements for small-diameter capacities that do not have edges under load adopted by the Jansen-Kenen formula are expressed in terms of equation

$$w(x) = w_0 \alpha e^{x s_w} \left\{1 - e^{-k_w x} \times \right. \\ \left. \times \left[\sin(k_w x) + \cos(k_w x)\right], \right. \quad (1)$$

where $w(x)$ is the function of moving of the shell; w_0 is the entered designation for this expression; k_w is the ratio that can be defined by the formula

$$k_w^4 = E t_{ef,r} \Big/ \left(D_w^2 D_r\right), \quad (2)$$

where $t_{ef,r} = t_w \ell_{w,1} / \ell_w$ is the thickness of the sheets (the rigidity of which is equivalent to the rigidity of the corrugated profile by thickness t_{ef}); $\ell_{w,1}$ is the length of the scanning of the corrugation in the waveform of the corrugated sheet of the shell ℓ_w; E is the module of elasticity of the material; D_r is the cylindrical rigidity of the shell on the bend in the circular direction; D_w is the diameter of the shell.

Assessment of internal forces (circular normal stresses σ_h, geared bending moments $M_x(x)$ and running transverse forces $Q_x(x)$) Can be made by classical ratios [11 – 14]

$$\sigma_h(x) = 2w(x)\frac{E}{D_w}, \quad (3)$$

$$M_x(x) = -D_r \frac{d^2 w(x)}{dx^2}, \quad (4)$$

$$Q_x(x) = \frac{dM_x(x)}{dx} = -D_r \frac{d^3 w(x)}{dx^3}. \quad (5)$$

The impact of vertical ribs on the rigidity characteristics of silo storage for grain depends on many factors [15 – 18].

With asymmetric loading and a small number of vertical edges, the value of the deflections is much smaller than that of non-rebound containers. In profiled shells it is more pronounced than flat ones (Fig. 2).

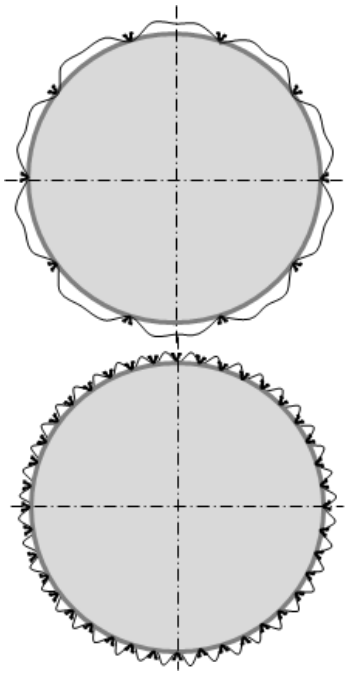

Fig. 2. Character of deformation of capacities from profiled sheets with different degrees of vertical stiff ribs and axisymmetric loading

Under the influence of an asymmetric load, the efficiency of vertical edges increases, especially with a sufficiently large number of them.

To evaluate the longitudinal force N_p in each edge at the level z from the top of a cylindrical container, with axial-symmetric loading we can use the expression

$$N_{p,z} = \frac{\pi D_w^2}{4 n_p}\left[g_m + S_m + \gamma_g H_w \psi_{y,1}(y)\right], \\ \psi_{y,1} = y\left(1 - \left(1 - e^{-\Delta_y}\right)\Big/\Delta_y\right), \quad (6)$$

where g_m is the proper weight of the roof; n_p is the number of vertical edges; S_m is the snow load; $\Delta_y = 4\Delta_w \lambda_0 f_g y$ is the dimensionless parameter determined by dimensionless height $y = z/H_w$, which has an area of values $0 \le y \le 1$.

If you analyze the value of the ratio of lateral pressure λ_0 and the ratio of friction f_g, then you can see that the values $\lambda_0 f_g$ are in a fairly narrow range from 0,18 ... to 0,19. Accordingly, it allows to adopt a unified value $\lambda_0 f_g \approx 0,2$ and essentially simplify the expression $\Delta_y \approx 0,8\Delta_w y$.

Vertical pressure $p_{f,z}$ on the wall of the tank at the level y from friction material

$$\begin{aligned} p_{f,z} &= 0,2\gamma_g D_w \psi_{y,2}(y) = \\ &= 0,2\gamma_g H_w \left[y - \psi_{y,1}(y) \right], \\ \psi_{y,2}(y) &= 1,25\left(1 - e^{-\Delta_y}\right). \end{aligned} \qquad (7)$$

The value of the functions $\psi_{y,1}(y)$ and $\psi_{y,2}(y)$ for capacities of different elongation were calculated in [19].

Procedure for estimating the bending moment M_p in the vertical edges of the stiffness of the silo tank can be performed using conditional eccentricity $e_{p,ef}$ which determines the position of the center of gravity of the reduced cross section of the vertical rigidity edge

$$\begin{aligned} e_{p,ef} &= h_p k_y / (1 + \alpha_{wp}), \\ \alpha_{wp} &= A_p n_p / (\pi D_w t_w), \end{aligned} \qquad (8)$$

where $\alpha_{wp} = A_p n_p / (\pi D_w t_w)$ is the ratio of the cross-sectional areas of all vertical stiffening ribs and the wall of the vessel.

Calculation of cylindrical capacitances under conditions of asymmetric radial loading, as in the case of axisymmetric loading, can be carried out in a simplified procedure, in accordance with the no-moment theory. A more precise analytical solution can be obtained in the case of equilibrium equations of moment theory, which allows taking into account the effect of internal bending moments in cross-sections. The task of calculating cylindrical capacitance in both cases is reduced to the expansion of an asymmetric load into a finite trigonometric series and the calculation for each component separately. For wind load W_k this will be a cosine-series of aerodynamic ratios $C_{aer}(\varphi)$

$$\begin{aligned} C_{aer}(\varphi) = a_0 + a_1 \cos(\varphi) + a_2 \cos(2\varphi) + \dots \\ \dots + a_k \cos(k\varphi) + \dots + a_m \cos(m\varphi), \end{aligned} \qquad (9)$$

where A_k is the amplitude value k component; φ is the angle of attack that takes into account the direction of the wind; a_k is the ratio of expansion.

In accordance with the momentary theory, the full efforts of the wind load will manifest themselves, depending on the number of m members in the trigonometric series

$$\begin{aligned} S_k(x,\varphi) &= kA_k x \sin(k\varphi), \\ N_{p,k}(x,\varphi) &= k^2 A_k x^2 \cos(k\varphi) / D_w, \\ N_{h,k}(\varphi) &= A_k D_w \cos(k\varphi) / 2. \end{aligned} \qquad (10)$$

And the displacement of the capacity from the load W_k is determined on condition

$$\begin{aligned} \frac{\partial u(x,\varphi)}{\partial x} &= \frac{k^2 x^2}{E t_w} \frac{1}{D_w (1 + \alpha_{wp})} A_k \cos(k\varphi), \\ \frac{\partial v(x,\varphi)}{\partial \varphi} &+ w(x,\varphi) = 0, \\ \frac{2}{D_w} \frac{\partial u(x,\varphi)}{\partial \varphi} &+ \frac{\partial v(x,\varphi)}{\partial x} = 0. \end{aligned} \qquad (11)$$

where u, v and w is the longitudinal, circular and radial movement of the body.

For maximum displacement values (at $\varphi = 0$) we can use the formulas

$$\begin{aligned} u_{\max} = 0,5 G_H \xi_p / \Delta_w, \quad w_{\Sigma,\max} = 0,75 G_H \xi_w, \\ \xi_w = \sum_{k=0}^{m} k^4 a_k. \end{aligned} \qquad (12)$$

where $G_H = 2w_p H_w^2 \Delta_w^2 \Big/ \left[3(1+\alpha_{wp})Et_w\right]$ is the conditional deflection; w_p is the estimated value of the wind load.

Applying the moment theory, it is necessary to outline the basic variables of the method, which will include normal tensions $\sigma_{p,k}$ in the section of the capacity, tangent $\tau_{p,k}$ in the longitudinal and three basic displacements, longitudinal u_k, radial w_k and the ring v_k. Lowering complex calculations, studied in detail in [20], we note the expressions for loads in cross-sections $\sigma_{p,k}(y,\varphi)$ and $\tau_{p,k}(y,\varphi)$

$$\begin{aligned}
\sigma_{p,k}(y,\varphi) &= \frac{E}{\Delta_w^2}\Lambda_w \frac{\psi_{\sigma,k}(y)}{k^2(k^2-1)^2}\lambda_{\eta,k}^2 a_k \cos(k\varphi)\\
\tau_{p,k}(y,\varphi) &= \frac{E}{\Delta_w^3}\Lambda_w \frac{\psi_{\tau,k}(y)}{k^3(k^2-1)^2}\lambda_{\eta,k}^3 a_k \sin(k\varphi)\\
\psi_{m,k}(y) &= M_{1,k}\,\mathrm{chs}(y\lambda_{\eta,k}) + \cos(y\lambda_{\eta,k})\times\\
&\times\left[M_{2,k}\exp(-y\lambda_{\eta,k}) + M_{3,k}\exp(y\lambda_{\eta,k})\right],
\end{aligned} \qquad (13)$$

where $M_{1,k}$, $M_{2,k}$ і $M_{3,k}$ is the dimensionless capacitance reaction function; $\xi_{k,0}$ is the proportionality factor, which has the dimension of the function $\xi_k(y)$ and takes into account the nature of harmonious loading W_k; $\lambda_{\eta,k}$ is the response factor.

And also radial $w_k(y,\varphi)$, ring $v_k(y,\varphi)$ and longitudinal $u_k(y,\varphi)$ moving

$$\begin{aligned}
w_k(y,\varphi) &= 2D_w\Lambda_w \frac{[1-\psi_{m,k}(y)]}{(k^2-1)^2}a_k\cos(k\varphi),\\
v_k(y,\varphi) &= 2D_w\Lambda_w \frac{[1-\psi_{m,k}(y)]}{k(k^2-1)^2}a_k\sin(k\varphi),\\
u_k(y,\varphi) &= \frac{D_w}{\Delta_w}\Lambda_w \frac{\psi_{u,k}(y)}{k^2(k^2-1)^2}\lambda_{\mu,k}a_k\cos(k\varphi)
\end{aligned} \qquad (14)$$

where Λ_w is the ratio of capacity compliance.

Functions $\psi_{u,k}(y)$, $\psi_{\sigma,k}(y)$ and $\psi_{\tau,k}(y)$ are similar in their mathematical nature to $\psi_{m,k}(y)$. Their formula representation depends on the variation of the boundary conditions of fixing each edge (Fig.3).

The total state is defined as the sum of stress-strain states influence, and it depends on the number of ratios of the layout laid down in the calculation

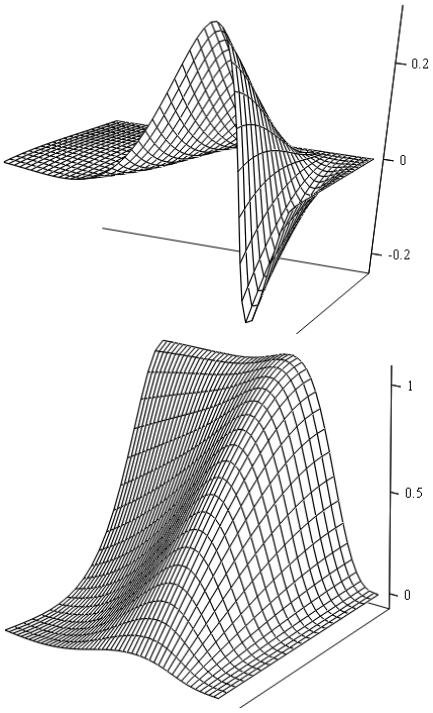

Fig. 3. Isometric representation of functions $\psi_{m,k}(y)$ and $\psi_{u,k}(y)$ for capacities with free end (top) and absolutely rigid ring (below)

$$R_D(y,\varphi) = \sum_{k=0}^{m} a_k R_k(y,\varphi) \qquad (15)$$

where R is the generalized reaction parameter $R = \sigma_p \vee \tau \vee w \vee v \vee u$.

One of the essential steps in the calculation of vertical cylindrical tanks is the study of internal forces that arise in the edges of the conical roofs by the action of the most probable loads – own gravity, weight of process equipment, wind pressure and snow load (Fig. 4).

The construction of a conical roof of a cylindrical storage tank consists of rectilinear edges installed radially and connected by a series of rings that form a compatible spatial system. With relatively small diameters of capacities, radial ribs are made from beams, while large ones are in the form of trusses. In the case when the main radial edge is made in the

form of trusses, the forces in its rods are calculated on the basis of beam effort. According to the principle of operation, radial edges can be divided into main and secondary. The main ribs, on one end, rely on the wall of the tank, reinforced by an elastic lining, and the other on the central rigid ring. Secondary ribs are placed between the main ones and are supported by one or both ends on the ring edges, hinged to the main radial beams.

Fig. 4. Conical roofing of MSVU silo with a diameter of 33m "Lubnymash"

The simplest construction of the roof consists of only the main radial edges. A similar roof is characteristic for capacities of small diameter (approximately up to 7000 mm) Internal forces in the main ribs can be calculated by the formulas.

$$N_{q,F}(y) = -\sin\beta\left[\frac{H_A}{\mathrm{tg}\beta} + F_m + q_A \ell_M y \times \left(\Delta q + 0{,}5y(1-\Delta q)\right) + \Delta N\right], \quad (16)$$

$$Q_{q,F}(y) = q_A \ell_M \cos\beta\left[y\Delta q - \frac{1}{3}\left(\frac{1}{2} + \Delta q\right) + \frac{y^2}{2}(1-\Delta q) + \Delta Q\right], \quad (17)$$

$$M_{q,F}(y) = 0{,}17 q_A \ell_M^2 y \cos\beta(1-y) \times [1 + y(1-\Delta q) + 2\Delta q] + \Delta M\ . \quad (18)$$

where y is the coordinate; g_m is the actual weight of the roof structures, F_m is the force, from the weight of the thermopadders, T_m is the reference pressure on the central ring of rigidity from the superstructure gallery, S_m is the snow load; W_m is the wind load; n_M is the number of main beams; β is the angle of the slope of the roof to the horizon; Δ_D is the ratio of the diameter of the central rigidity ring d_0 to the diameter of the tank D_w; ℓ_M is the length of the main radial beams; EA, EJ is the longitudinal and flexural stiffness respectively; $\Delta N, \Delta Q, \Delta M$ is the arithmetical supplements of internal forces when placing a thermopaddings in the flight of a beam

The maximum compressive force acts on the left beam support, and the maximum bending moment in the section located at a distance $y_{M,\max}$ from the right support.

$$N_M = 6F_m + q\ \ell_M(1+2\Delta q)/(6\sin\beta),$$
$$M_{q,\max} = \frac{q_A \ell_M^2 \cos\beta}{18}\left(\frac{2f_M^3 - 3f_M^2 + 1}{f_M^2 - \Delta q}\right), \quad (19)$$
$$f_M = \sqrt{\left(1 + \Delta q + \Delta q^2\right)/3 - \Delta f}\ .$$

In the circular ribs there are only longitudinal compressive forces that can be estimated by the formula

$$N_p = (N_b - N_t) n_M / (2\pi). \quad (20)$$

where N_b and N_t are the longitudinal forces in the main radial edge below and above the annular rib of rigidity.

CONCLUSIONS

1. In the article the basic provisions of the analytical calculation of vertical cylindrical capacities were provided.

2. The issues of influence of profiling of the walls of the container on the radial movements of the case under the action of axially symmetric and asymmetric loading were analyzed.

3. The basic calculation formulas for the determination of internal forces and displacements of the ribless capacities under load, were described by the exponential law, characteristic for the pressure of the loose material.

4. The brief description of the influence of vertical ribs on the rigidity characteristics of silos capacities was given..

5. The calculation of cylindrical capacities in conditions of asymmetrical radial loading was solved in accordance with the instantaneous theory and has a more precise analytical solution in applying the equations of moment theory.

6. The formulas for finding internal forces in the edges of the conical roofs were indicated.

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К расчету оптимального уровня надежности из экономических соображений

Александр Лапенко, Наталия Махинько

Аннотация Приведены основные положения аналитического расчета вертикальных цилиндрических емкостей. Представленные сведения являются результатом глобального исследования, выполненного авторами в последние годы. Упрощенная процедура математических выкладок, которая применяется при формулировании указанных зависимостей, может

характеризовать указанные аспекты в русле инженерной методики и быть применена для практических рекомендаций. В представленном исследовании анализируется влияние профилирования листов стенки емкости на радиальные перемещения корпуса при воздействии осесимметричного и асимметричного загрузки. Приводятся основные расчетные формулы для определения внутренних усилий (кольцевых нормальных напряжений, погонных изгибающих моментов и погонных поперечных сил) и перемещений безреберной емкости хранения. Предоставлена краткая характеристика влияния вертикальных ребер на жесткостных характеристики силосных емкостей, а также выражения для оценки продольных усилий в ребрах на определенном высотном уровне.

Особое внимание уделено расчету цилиндрических емкостей в условиях несимметричного радиального загрузки. При этом задача рассмотрена по упрощенной процедуре, согласно безмоментной теории и получено более точное аналитическое решение при применении уравнений равновесия моментной теории, которая позволяет учесть действие внутренних изгибающих моментов в сечениях. В обоих случаях выполнено упрощения вычислительной процедуры путем разложения асимметричной нагрузки в конечный тригонометрический ряд и проведении расчета для каждой составляющей в отдельности. Выполнены также исследования внутренних усилий, возникающих в ребрах конусных кровель от действия наиболее вероятных нагрузок. При этом была рассмотрена лишь простейшая конструкция кровли, характерная для емкостей малого диаметра, которая состоит исключительно из главных радиальных ребер. Указанные формулы для нахождения внутренних усилий в данном элементе, максимальная сжимающая сила и максимальный изгибающий момент в опасном сечении.

Ключевые слова: цилиндрическая оболочка, перемещения, гофрированная стенка, функции прогиба, напряженное состояние, вертикальные ребра жесткости, асимметричная нагрузка, радиальное отклонение.

The production of the splash phenomenon, as a way of dissipating the energy of a gravitational wave

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Abstract. Investigations are aimed at revealing the conditions for the generation of a Splash wave phenomenon by a submerged breakwater, as having a particularly effective form of wave energy dissipation. On the basis of a wide range of well-known theoretical studies of wave transformation over bottom inhomogeneities, the expediency of laboratory experiments on physical models is shown as a method that allows taking into account the peculiarities of the influence of targeted turbolization of the water flow. Numerous experiments on physical models have shown the possibility of the occurrence of such a phenomenon over a system of bottom inhomogeneities and the rationality of further scientific search. However, the effect is achieved when certain parameters of many independent variables (significant and represented in a wide range of factors) are combined. This circumstance makes a positive solution of the problem rare in nature.

In view of the multifactority of the hydrodynamic process under investigation, an analysis of the theoretical premises was carried out, which allowed us to concentrate on a new variant of the solution of the problem posed – a single breakwater with a special crest design. The version of a "box" type breakwater was taken.as a basis But part of the wave energy quenched in it is directed to quenching another part of the energy of the wave flow passing over the top of the breakwater. The task was to find the location, shape and size of the opening in the top. Two versions were investigated: in the form of a perforation and in the form of a slit located along the breakwater. The last version showed its superiority and this result allowed to proceed to the solution of the next problem, the search for the most effective of the of the breakwater cavity cross-section.shape. The obvious direction of the search was the effect of a curvilinear wave-breaking wall of the embankment. Instead of the vertical face under the "visor" (that is, under the horizontal plane of the top surface) previously accepted in the studies, two schemes for calculating the surface curves, differing from each other in radius and length, are studied. The size of the slit in the "visor" varied. The conditions and prospects for the development of Recommendations for the design of the submerged breakwater of this type are described.

The urgency of the solution of the problem lies in the broad perspective of the use of submerged breakwaters in recreational zones.

Keywords: recreational zone, breakwater, wave transformation, energy dissipation, physical modeling, hydrodynamic bench.

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INTRODUCTION

Among the structures of coastal hydraulic engineering, submerged submerged breakwater is of particular importance as an object of environmental nature. If the full-profile breakwater is designed to completely Among the structures of coastal hydraulic engineering

submerged breakwater is of particular importance as an object of environmental nature. The full-profile breakwater is designed to completely dampen the wave, for example, allowing ships to be directly at the pier, but the submerged breakwater is used mainly to protect the beach from erosion. Namely, the beach of recreational areas, where it allows to provide water exchange in the closed water area [1 – 3]. This obvious requirement was underestimated until recently, which led to serious sanitary and epidemic problems [4]. An example of this is the existing system of coast protection of famous resort areas, where quarantine measures are systemic in nature.the wave, for example, allowing ships to be directly at the pier, the flooded breakwater is used mainly to protect the beach from erosion. It is the beach of recreational areas, where it allows to provide water exchange in the closed water area. This obvious requirement was underestimated until recently, which led to serious sanitary and epidemic problems. An example of this is the existing system of coast protection of famous resort areas, where quarantine measures are systemic in nature.

There are many types of designs of submerged breakwaters, both in the form of projects and built, and even more developments in the form of inventions, information about which abounds in the Internet. The matter boils down to the choice of compatibility of performance and cost of construction [5 – 7].

The experimental studies previously conducted in the laboratory Of the Institute of hydromechanics of NAS of Ukraine were aimed at identifying the possibility of certain designs of submerged breakwater to give the structure the function of not only passive but also active wave annihilation. That is, by means of a certain design solution, to turbolize the wave flow over the structure. Mainly, combinations of free-standing breakwaters with a large variation of the parameters of the structural elements and the planned location relative to each other were studied. Special attention was paid to the systems of two and three breakwaters. The search for the compatibility of the studied parameters led to the possibility of production of the Splash phenomenon in the interference of the incoming and reflected waves.

The functional dependence of the degree of wave annihilation on the parameters of local conditions, the dimensions of structures and their location at this stage of research was presented in a simplified form:

$$K_{tr} = f(d, i, h_w, \lambda_r, Z, L), \qquad (1)$$

where: K_{tr} is wave transformation coefficient, d is water depth at the breakwater (Const), i is slope of the bottom surface of the water area (Const), h_w is wave height ("before", "above" or "behind" the breakwater), λ_r is relative wavelength (steep – 10 and somewhat gentle – 15), Z is deepening of the top of the breakwater (in 3 values for each option), L is distance between the individual breakwaters in the system (in 3 values).

Considering the theoretical assumptions, the solution of the problem can be based on the known provisions [8]. Thus, wave annihilation and wave reflection are studied by the extremal values of the wave surface shape on the approaches to the structure, directly at the structure and behind the structure. The shape of the traveling wave can be described by the following relation:

$$\xi = -a\cos(kx-\omega t) - \frac{ka^2}{2}\cos\left[2(kx-\omega t)\right] - \\ -\frac{3k^2a^3}{8}\cos\left[3(kx-\omega t)\right], \qquad (2)$$

where: a is wave amplitude, g is acceleration of gravity, ω is wave circular frequency, k is wave number, λ is wave length, d is water depth at the structure, χ and z are point coordinates, t is time coordinate, ξ is profile shape.

Numerical evaluation of the importance of the members of the right part of the present relation shows that the refinements made to the first member by the second one do not exceed 5%, and by the third one do not exceed 1%. This allows us to exclude them from consideration as not essential for engineering

practice. Using the theory of plane potential waves of finite amplitude at finite depth, we have a relation for the potential velocities of the initial wave:

$$\phi = \frac{agch\left[k\left(d-z\right)\right]}{\omega chkd}\sin\left(kx-\omega t\right) \qquad (3)$$

Interaction with the structure modifies the waveform and its velocity potential. The ratio of the amplitudes of the original and reflected waves has a physical meaning of the reflection coefficient "Ko". Due to the configuration of its profile, the structure can reflect waves partially to a certain extent. The magnitude of the initial wave amplitude is denoted by "ą", directly at the structure by "ą1", behind the first obstacle (breakwater) by "ą2".

The velocity potential of such a wave is equal to:

$$\phi_1 = \frac{agch\left[k\left(d-z\right)\right]}{\omega chkd}\times$$
$$\times\left[\sin\left(kx-\omega t\right)+K_0\sin\left(kx+\omega t\right)\right] \qquad (4)$$

The structure of an incomplete profile passes part of the wave energy through itself, due to which a residual wave with an amplitude of ą2 is formed behind the structure. In this case, the velocity potential is equal to:

$$\phi_2 = \frac{a_2 gch\left[k\left(d-z\right)\right]}{\omega chkd}\sin\left(kx-\omega t\right) \qquad (5)$$

The ratio ą2/ą characterizes the permeability, and 1-ą2/ą is called the annihilation coefficient Ka.

Further consideration of the process should be conducted according to the scheme, which shows that the residual wave with amplitude a_2 is the initial wave for the second underwater obstacle and repeats the effect of the first obstacle.

The velocity potential of the interfered wave between the obstacles will take the form:

$$\phi_3 = \frac{a_2 gch\left[k\left(d-z\right)\right]}{\omega chkd}\left[\sin\left(kx-\omega t\right)+\frac{a_3}{a_2}\sin\left(kx+\omega t\right)\right] \qquad (6)$$

Using the energy approach to the consideration of the process of interaction of waves with the studied system of structures, we state that a part of the wave energy is reflected (E_O), a part is extinguished due to friction and is spent on turbulence (E_T), but a part passes behind the structure (Eost). The balance equation is as follows:

$$E = E_o + E_T + E_{ocm} \qquad (7)$$

The energy of the components of the equation is proportional to the corresponding amplitudes:

$$E = 0.5\rho g\lambda a^2, \quad E_0 = 0.5\rho g\lambda a_1^2, \quad E = 0.5\rho g\lambda a_2^2 \qquad (8)$$

This is how the proportion of wave energy extinguished by the structure is quantified.

The idea of spectral representation of a complex excited surface is known, which was first expressed by Peterson [9] and found its expression in the works of Longue-Higgins [10]. Phillips [11] showed that in the high-frequency range of the wind wave spectrum there is an equilibrium region where the spectrum does not depend on wave-forming factors and is determined by physical parameters regulating the continuity of the wave surface. Such simplification would help to solve the problem, but there are many assumptions. The specificity of this work and the lack of necessary technical capabilities determined a simplified approach to the development of research methods.

The study of the wave surface transformation process was carried out under the influence of bottom inhomogeneities in the form of cylinders lying on the bottom of the reservoir. This was in line with the question of the use of mobile structures, which in practice are soft synthetic shells. The designs of such structures are developed at the level of inventions [12, 13]. Numerous series of experiments

in the wave basin and tank showed the exceptional complexity of the studied hydrodynamic processes. The pattern of interference between the shells is complex, since the wave with energy losses (and a decrease in amplitude correspondingly) is repeatedly reflected from the next and previous shell. As it is predetermined by the theory, at distance between shells multiple to a half of wavelength the resonance of oscillations, and at non-multiple distances the crush is observed. The phenomenon of crush does not allow us to obtain a numerical solution of the problem.

With a certain combination of parameters of independent variables, that is: the depth of water before the first submerged breakwater; the height of the initial incoming wave and its relative length; the size and ratio of the diameters of the shells, that is, the depth of the top of the breakwaters, as well as their mutual distance from each other, the Splash effect was obtained – the phenomenon of high dissipation of wave energy.

However, in practice, a small probability of a certain combination of wave parameters and multicomponent structure is obvious [14].

The aim of this work was to find a design of a single submerged breakwater that has the ability to generate a Splash effect, which in practice is more likely in a wider range of wave parameters than for a system of submerged breakwaters [15].

The solution of the problem was carried out on the basis of the design of a single breakwater with a top resembling a box-type breakwater [16]. On an intuitive level, it is quite natural to solve the problem by means of a "visor" on the top of the breakwater, which would dissect the wave flow at the top of the breakwater. In this case, the crest of the wave will pass over the breakwater, and the trough of the wave will be under the "visor", where the pressure will increase and the flow as a whole can be turbolized.

The design of the upper part of the breakwater was presented in different versions. So, the box-type chamber can vary in size, shape of the back wall, and the upper plane with a "visor" can have different lengths and perforations. It was adopted a gravitational type base of the breakwater with parameters in some accordance with the current norms [17]. Thus, a clear feature is the strtucture crowning the top of the breakwater. In Fig.1 the initial version (Scheme No.3) and the version having the desired properties (Scheme No.2) are presented.

In contrast to the previous stage of research, the efficiency of the structure depends mainly on the depth of the top of the breakwater, and practically – on the water level in the reservoir.

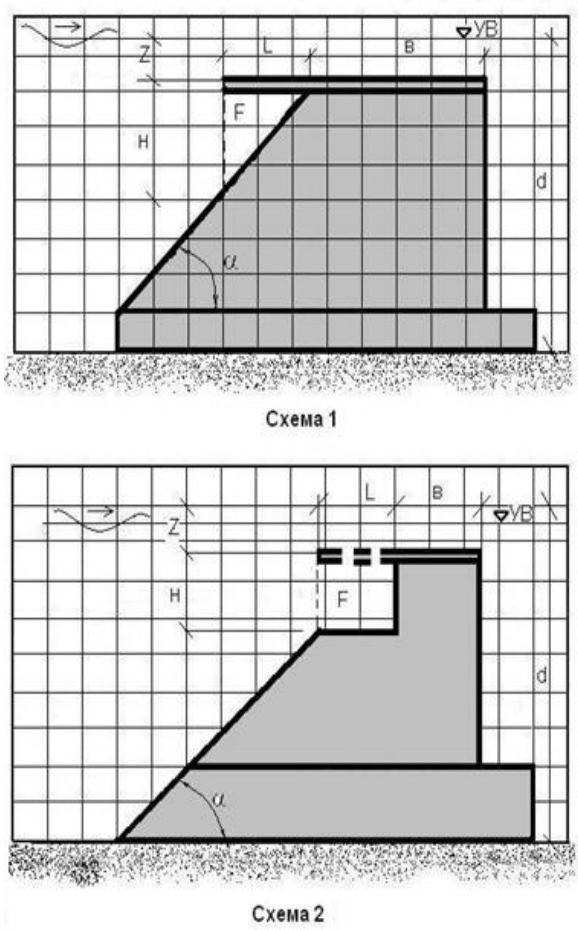

Fig. 1. The original and the desired version of the construction of the top of the submerged breakwater with a perforated visor

It should be assumed that the sea level may change due to wave positive or negative surge as well as a very real increase in the level of the world ocean. The latter circumstance is particularly important for the designs of traditional monolithic structures. The mode of the

wave flow is less significant and this may be considered as an advantage of the considered design [18].

Since the studies were exploratory in nature, the basic law of modeling was the inverse relationship between the wave period and the square root of the scale of modeling [19, 20]. Thus, the wave produced on the hydrodynamic stand in 0.8 s, 1.0 s and 1.2 s corresponded in nature to the storm wave and two values of slightly more gentle waves (λo = 10 and 15). The studies were carried out in a hydrodynamic tank equipped with a shield-type waveproductor and a wave suppressor in the form of a gentle slope. Video recording and capacitive sensors with the output of information to the PC [21] were used as sensors.

In Fig.2, a photo of a Splash above the top of a single breakwater is presented, which is achieved through a successful choice of shape and location of the perforation.

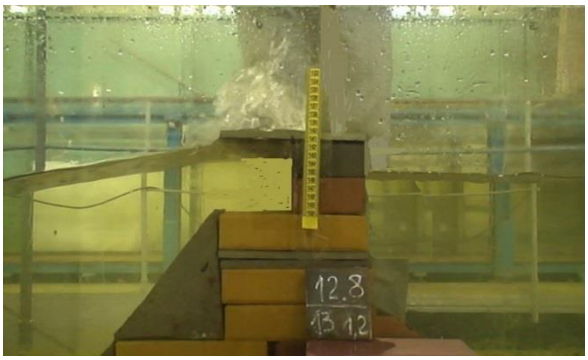

Fig. 2. Splash effect over the top of a single submerged breakwater with perforated visor

Comparing the waveforms recorded in the ports in front of the breakwater and behind the breakwater, we clearly have the fact of significant damping of the incoming wave, where the transformation coefficient reaches 0,8. As shown by a series of experiments, in the framework of the studied parameters of the wave and the structure, the studied design with a perforated visor is the most effective one.

The search for the design of the top for the Splash effect was based on versions of perforation of the upper plane of the top of the breakwater in combination with a certain water level and wave parameters. Special attention was paid to the cavity under the visor. The name of the breakwater type "box" suggests the shape of a rectangular parallelepiped. However, the principle of design of the breakwater wall should be considered in the present design.

The main feature of the study is the testing of models with a curved wall. Two versions are accepted for the test: with a radius of 3.8 $h_в$ (Fig.3) and 4.9 $h_в$ (Fig.4). At the same time, the version of perforation in the top in the form of a transverse slit was studied.

Fig. 3. A version of the design of the submerged breakwater with a steeply curved back wall of chamber that blocks the wave

Fig. 4. A version of the design of the submerged breakwater with a gently curved rear wall of the chamber that blocks the wave

Fig.5. Splash of the significant magnitude over the submerged breakwater with a steeply curved wall

Fig.6. Splash of the less significant magnitude over the submerged breakwater with a gently curved wall

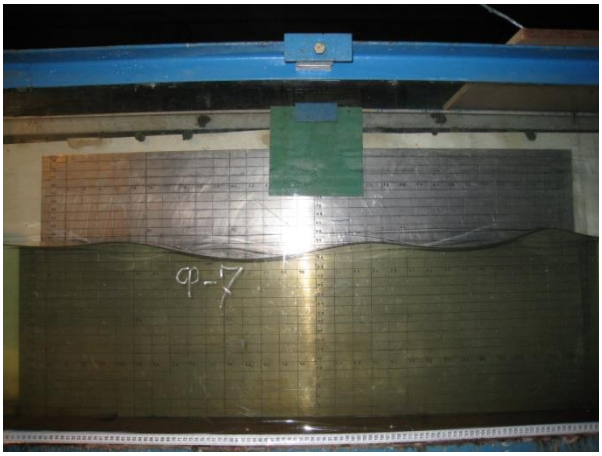

Fig. 7. An example of fixing the height of the wave by the method of photography

According to the results of the experiments, the steep curvature of the wall and the small size of the slit were found to be more effective. (Figs.5 and 6).

Fixing the height of the transformed wave by the method of photography (as an example) is shown in Fig.7.

The numerical value of the damping energy of the incoming wave, as well as its transformed height, can be accurately determined through a large series of time-consuming experiments with proper technical support of the instrumentation, which will allow to develop Recommendations for design and implementation in practice [22, 23].

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RESULT OF WORK

It is confirmed that in conditions were complex hydrodynamic processes cannot be subject to accurate theoretical assessment, a physical simulation allows us to assess the performance of the studied design of the submerged breakwater.

It is shown that it is possible to effectively turbolize the wave flow over the top of the breakwater in the form of a Splash phenomenon, which corresponds to a high dissipation of wave energy.

A single submerged breakwater with a perforated visor, unlike a system of submerged breakwaters, is able to work effectively in a wider range of wave flow parameters.

To develop Recommendations for the design and use of the studied structure of the submerged breakwater, it is necessary to conduct a series of experiments with additional proper equipment of the hydrostand and the use of more modern instrumentation.

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Продуцирование явления всплеска, как способ диссипации энергии гравитационной волны

Yevhen Horbatenko

Abstract. Исследования имеют своей целью выявить условия генерации подводным волноломом явления Всплеска, как обладающего особо эффективной формой диссипации энергии волны. На базе широкого круга известных теоретических исследований трансформации волны над донными неоднородностями показана целесообразность проведения лабораторных опытов на физических моделях, как метода, позволяющего учесть особенности влияния целенаправленной турболезации волнового потока. Многочисленные опыты на физических моделях показали возможность возникновения такого явления над системой донных неоднородностей и рациональность дальнейшего научного поиска. Однако эффект достигается при сочетании определённых параметров многих независимых переменных (значимых и представленных в широком спектре факторов). Это обстоятельство делает положительное решение задачи редким в натуре.

В виду многофакторности исследуемого гидродинамического процесса проведён анализ теоретических предпосылок, что позволило сосредоточиться на новом варианте решения поставленной задачи – одиночном волноломе с особой конструкцией гребня. За основу был взят вариант волнолома «ящечного» типа. Но погашаемая в нём часть энергии волны направлена на гашение другой части энергии волнового потока, проходящего над гребнем волнолома.

Задача состояла в поиске места расположения, формы и размера проёма на поверхности гребня. Исследовано два варианта: в виде перфорации и в виде щели, расположенной вдоль волнолома. Последний вариант показал своё превосходство и этот результат позволил перейти к решению очередной задачи – поиску наиболее эффективной формы поперечного сечения плоскости волнолома. Очевидным направлением поиска представился эффект криволинейной волноотбойной стенки набережной. Вместо ранее принятой в исследованиях вертикальной грани под «козырьком» (то есть под горизонтальной плоскостью поверхности гребня) исследовано две схемы расчёта кривых поверхности, отличающиеся друг от друга радиусом и протяжённостью.

При этом варьировался размер щели в козырьке. В статье изложены условия и перспектива разработки Рекомендаций по проектированию подводного волнолома рассматриваемого типа. Актуальность решения вопроса состоит в широкой перспективе использования подводных волноломов в рекреационных зонах.

Ключевые слова: рекреационная зона, волнолом, трансформация волны, диссипация энергии, физическое моделирование, гидродинамический стенд.

The use of geographical and informational systems the provision state and public interests in the implementation of urban development

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Abstract. The article summarizes that the main problem of forming a modern urban development documentation system consists in direct tendencies of functional-spatial and planning regulation of urban layouts, in the development of the territory with the help of special tools, territorial indicators, and urban planning regulations. Whereas the updated documents should meet new conditions of spatial development of the territory – regulation of socio-economic processes and the architectural-planning organization of urban planning systems with the help of urban development, including legal regulation of relations between subjects of urban development.

The purpose of the article is to analyse the condition and prospects of using geographical and informational systems in urban planning. A number of scientific methods have been used to achieve this purpose, in particular: analysis, synthesis, generalization, summaries, etc.

Urban development informational content expansion is a trend that characterizes each stage of its development. Under modern socio-economic conditions, the tendency has become a consistency, which, in combination with the managing (regulating) aspect of the modern content of urban development and the improvement of legal relations of subjects of urban development determines the essence of the current stage of urban development.

At present, informational systems are more actively used in Ukrainian urban development rather than in urban development data banks. It has been summarized that due to informational systems, specialists have the opportunity to see, assess, take into account modern processes of the territory development and create the basis for its sustainable spatial development. Informational technologies have become an integral part of urban development and have contributed a new organizing and optimizing start, having increased its overall efficiency. A special place in urban development is given to geographical and informational systems (GIS). Their main functions are to create an urban development informational environment, to store territorial cartographical (spatial) information.

It has been generalizes that the use of GIS in urban development involves their specific complex structural application. The information structure of any GIS urban profile is formed on the basis of informational and technological blocks, thematic and informational layers of graphic (cartographical) information, banks and databases.

Keywords: urban development, systems of urban development documentation, informational systems, geographical and informational systems.

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INTRODUCTION

Ukrainian cities and their surroundings developed as new poles of growth and development, forming labour resources, expanding the physical and technological infrastructure, creating a stable and reliable mechanism of land-use regulation, providing a range of proper support services, offering financial incentives and building the capacity of institutions. Cities, especially the largest ones, have formed everything that development cannot do without. Today, in our country, the goals of economic growth increasingly dominate the political agenda, but for successful development, economic growth should proceed in the context of social justice and environmental sustainability.

These problems are associated with many shortcomings in planning system operation. In view of this, the issues that should be addressed to make the spatial development and operation of social and engineering infrastructure systems environmentally sustainable, affordable in economic relations and socially fair, have been highlighted. This builds the dialectic of what the normative goals of Ukrainian urban policy should look like. They require deliberate choice, built on a thorough study of the facts and governed by agreed principles and standards.

Today, the urban development system and set of its principles are set out in a revolutionary document that defines the urban development policy concept at the beginning of the 21st century – 2019–2030 Concept of public administration in urban development. This document is the doctrine and long-term basis of the strategy and tactics of urban development and serves as the fundamental document for improving the urban development of the territory not only for the transition period, but for the entire foreseeable future of the 21st century. While the formation of a system for serving state and public interests in the implementation of urban development and the regulation of such activities as far as architectural and planning organization of urban planning systems is concerned is considered as the internationalization of the ideas of sustainable spatial development of the territory in the contemporary urban planning policy of Ukraine.

PURPOSE AND METHODS

The purpose of the article is to analyse the status and prospects of the use of geographical and informational systems in urban planning. To achieve the purpose, a number of methods of scientific knowledge were applied, in particular: analysis, synthesis, generalization, summarization, etc.

RESULTS AND EXPLANATIONS

The urban planning systems regulation provides for the proper effect from the controllability of the processes of use and development of the territory, which is adequate to the conditions of the existing real estate, land and investments markets. However, an increase in the number of urban development entities, a large-scale expansion of their activity, and a change in legal priorities in their relations greatly complicate serving the state and public interests in the implementation of urban development. Having established the basic principles of the architectural and planning organization of urban development systems, urban science is unable to investigate the managerial relationships between the economic and business activities of urban development entities and the structure of urban development systems, to determine their exact dynamics and development processes without information support. Such difficulties indicate the need to improve and expand the information aspect of the sustainable spatial development of the territory, which will meet state and public interests during the implementation of urban development. Thus, the requirements of contemporary urban planning science and practice, the existing theoretical developments makes it possible to actualize the scientific problem of information support for urban development regulation.

Information support for urban development is actively used in all its existing directions – urban (territorial) planning, levelling and building in the territory, architectural and con-

struction design, creation of urban planning data banks. Its essence lies in working-out and applying urban development informational systems. Up to the present moment, there are legal and technological prerequisites for the implementation of specialized informational systems in order to solve the problems of urban development regulation regarding the architectural and planning organization of urban planning systems (regulation of urban development systems) and serving state and public interests in the implementation of urban development. The variety of managerial tasks within the indicated systems activity puts forward specific requirements for such informational systems.

Managerial informational systems should open up new opportunities in serving state and public interests in the implementation of urban development through the use of system analysis and management methods and modern computer technology. Thus, the most important substantive component of the proposed scientific concept is the substantiation of the possibility of practical use of informational systems adapted to modern state mechanisms for regulating socio-economic systems, which researchers now call “system regulators” to provide for state and public interests in urban development.

The above-mentioned system regulators organize the interaction of urban development entities in a spatial environment and reflect the system of urban development tools, focusing on mutual taking into account and coordinated realization of public interests and economic and business interests of urban development entities that carry out urban development and spatial development of the territory.

The expansion of urban planning regulation procedures and the introduction of informational systems in urban planning activities makes it possible to formulate a theoretical concept for research of serving state and public interests in urban development in the form of an informational and technological system for urban planning systems regulation, harmonizing the efforts of state and municipal government authorities and urban development entities into a single whole towards the implementation of design solutions of urban (territorial) planning documentation.

There are relatively few modern scientific and theoretical developments dedicated to the features and systematization of purposes, the content of developmental tasks and informational content of urban planning documentation in the Ukrainian urban planning practice. However, the breadth of comprehension, definitions, terms and methods of urban (territorial) planning and design vision allows to interpret the term "urban planning documentation" in terms of different contents and forms of graphic expression, which is reflected in the current tendencies in the formation of a system of urban planning documents.

Urban planning documentation is a key link in the formalization of urban planning design decisions in the public administration system. The system of urban planning documents is established by the urban planning legislation of Ukraine. As a rule, urban planning documents are spelled out in the legislation, up to the level of the master plan of the city, providing the government and local authorities at lower levels with the opportunity to choose and combine several different types of urban planning project documents. The search for a new mode of action for urban development subjects in the context of socio-economic transformation in our country makes it necessary to clarify the meaning and significance of urban planning documents, to provide urban planning activities with the necessary documents, to create informational and legal conditions for independent but controlled development of urban planning systems, which will make it possible to balance the problem of serving state and public interests in the implementation of urban development.

The main problem of the formation of a modern urban development documentation system is the immediate tendency of the functional-spatial and planning regulation of urban planning systems, in the development of the territory with the help of special tools, territorial indicators, and urban planning regulation standards. The updated documents, in our opinion, should meet the new conditions for the spatial development of the territory – regu-

lation of socio-economic processes and the architectural and planning organization of urban planning systems with the help of urban development, including legal regulation of relations between subjects of urban development.

Therefore, the methodology of building a modern IT environment for urban development, informational systems and banks of urban development profile data (databases) is gaining importance. The effectiveness of the latter is proved by international experience, although in Ukraine they are not widely used [1]. At present, in the Ukrainian urban planning activities, informational systems are used more actively, unlike urban planning databanks [2].

Due to informational systems, specialists have the opportunity to see, assess, take into account the modern processes of development of the territory and create the basis for its sustainable spatial development. Information technology has become an integral part of urban development, being its new organizing and optimizing element that increases its overall effectiveness [3]. A special place in urban development is given to geographical and informational technologies (GIS) (Fig.1).

Their main functions are to create an urban development informational environment, to store territorial cartographical (spatial) information [4].

With GIS, it is possible not only to localize the spatial position of urban buildings with maximum coordinate accuracy, but also to "attach" them to information (to generate spatial data), conduct natural and landscape zoning on a geographical basis that is updated (adjusted) to the current time, and connect heterogeneous information [5].

The events of the last decade and the analysis of foreign experience of urban development suggest that the use of GIS urban development is a method of constructing the urban development informational environment [6, 7, 8]. The outlined method reflects the directions of sustainable spatial development of the territory, as well as the problems and imbalances in its organization, the socio-economic and spatial effectiveness of the regulated territorial indicators of changes in urban planning systems condition, the direction of information

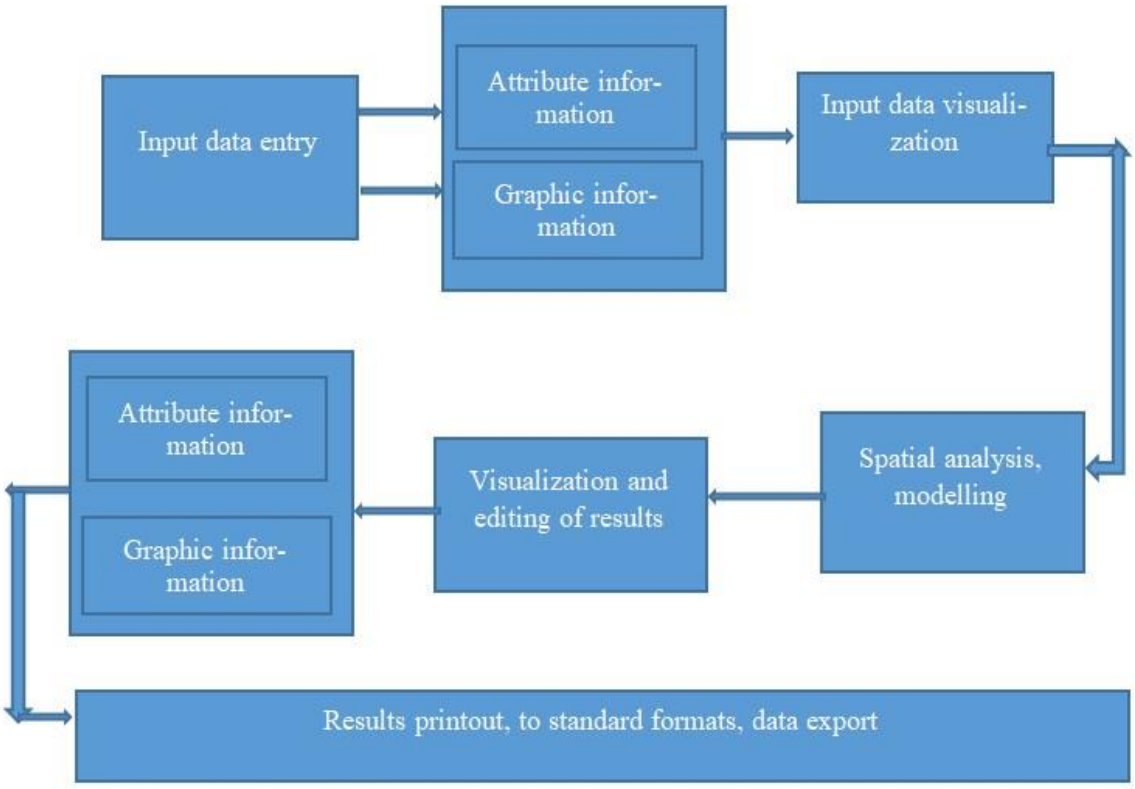

Fig. 1. Generalized scheme of GIS functioning

flows in accordance with the tasks of managing urban development activities [9, 10]. However, the use of this method provides a balance of state and public interests in the implementation of urban development.

The essence of the method is to improve the structure and quality of the input data for the purposes of the architectural organization of urban planning systems, the development of project documentation, decision-making on real estate management and informing the population, as well as the convenience of conducting the territory analysis [11].

The use of GITs in urban development involves their specific complex structural application. The informational structure of any urban planning profile GIT is formed on the basis of informational and technological blocks, thematic layers and informational layers of graphic (cartographic) information, data banks and databases. [12].

In modern practice, the most important are such technologies in urban development activities, the types of which can be defined as multifunctional territorial urban planning GISs (territorial GIS and urban planning GIS) and local territorial urban planning GIS. They differ in the quality and thematic focus of the graphic (cartographic) layers of information attached to them and independent data banks and databases [13].

In territorial GISs, which use results is evaluated by real socio-economic and territorial and spatial characteristics and indicators as objective data for making managerial and urban planning decisions, The following IT blocks are distinguished:

- geographical [11];
- administrative and territorial objects [14];
- spatial planning scheme [15];
- natural and ecological [16];
- engineering and infrastructural [17];
- law documents [18];
- the results of monitoring the implementation of documentation of urban (territorial) planning [14].

In large territorial GIS, these blocks form a fixed core. The IT blocks describe and characterize the main indicators and characteristics of the structural and infrastructural organization of the territory [19]. The content of thematic layers is coordinated not only with the peculiarities of building the structure of the territory [10], but also the complex tasks of managing its development [20].

CONCLUSIONS AND RECOMMENDATIONS

The problem of information support is one of the most important in urban development [3]. In the process of preparing and executing urban development projects, the decision maker has to deal with huge arrays of cartographic material, statistical, economical and other indicators. The tasks of creating an optimal model and urban planning project have been stretched for years: the cost of the mistake was very high. Significant cost of time, money, resources limited the number of alternatives, caused some superficiality of decisions and lack of calculations of project details. Geological and informational system is the contemporary computer technology making it possible to combine a model image of the territory (electronic display of maps, diagrams, aerial and orbital surveys) with table datatype (a variety of statistics, lists, economic indicators, etc.). A geographical and informational system also refers to a spatial data management system and attributes associated with them. More specifically, it is a computer system enabling the use, storing, editing, analysing and displaying of geographical data. Geographical and informational technologies (GIT) are the technological basis for creating geographical and informational systems to make them realize their functional capabilities. In the field of urban development, new GITs that provide promptness, completeness and reliability of information both about the existing condition of the urban environment within a particular urban area and about proposed measures for its change during development and reconstruction are of the greatest interest. The main purpose of the use of geographical and informational systems is to provide state authorities and local self-government with relevant, reliable and extensive information for comprehensive operational research, assessment and justification

of managerial decisions aimed at creating a high-quality environment and life of the population in the city, protecting the environment and its sustainable development. The solution to these problems is based on the analysis of various multidimensional information and mathematical methods of modelling and forecasting the scenario of the city development.

The use of outlined technologies in the process of serving state and public interests will allow to achieve a number of constructive decisions in urban planning activities, including:

1. When planning and developing the urban territory, public interests will be taken into account by identifying the needs of the territorial community in existing and promising areas necessary for the placement and safe operation of housing and utilities infrastructure, of social, engineering and transport infrastructure, and solving other tasks to ensure sustainable urban development.

2. Individuals and legal entities will be provided with equal opportunities to acquire ownership or use of land for urban development on the basis of the comprehensive implementation of competitive principles, and the receipt of appropriate land at public auctions and tenders.

3. Land plots for urban planning needs will be provided in accordance with the General Plan of the city and other officially published urban planning documentation, which, in cases expressly provided for by the legislation of Ukraine or the decisions of local authorities, passed a public hearing or a survey among members of the territorial community of a city, region, micro district, district or other territorial unit.

4. Before making official decisions on the implementation of urban development, the executive body of the city council (city state administration) should:

- inform members of the Kyiv City Territorial Community residing in the territory of the urban development project on the planned urban development measures through the mass media or otherwise.

- formally inform deputies of city council about preparation and consideration of draft decisions on implementation of urban development in their constituencies.

- provide an opportunity for discussion of urban development projects in local self-government bodies, etc.

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Применение геоинформационных систем при обеспечении государственных и общественных интересов при осуществлении градостроительной деятельности

Евгений Клюшниченко, Ирина Савчук

Аннотация. В статье резюмировано, что основная проблема формирования современной системы документации градостроительной деятельности заключается в непосредственной тенденций функционально-пространственного и планировочного регулирования градостроительных систем, в освоении территории с помощью специальных инструментов, территориальных показателей, нормативов градостроительного регулирования. Тогда как обновленные же документы должны удовлетворять новые условия пространственного развития территории – регулирование с помощью градостроительной деятельности социально-экономических процессов и архитектурно-планировочной организации градостроительных систем, включая нормативно-правовое регулирование отношений субъектов градостроительной деятельности.

Целью исследования является анализ состояния и перспектив использования геоинформационных систем в градостроительстве. Для достижения цели применен ряд методов научного познания, в частности: анализ, синтез, обобщение, резюмирование и тому подобное. Расширение информационного содержания градостроительной деятельности является тенденцией, которая характеризует каждый этап ее развития. В современных социально-экономических условиях тенденция превратилась в закономерность, которая в совокупности с управляющим (регулирующим) аспектом современного содержания градостроительной деятельности и совершенствованием правовых отношений субъектов градостроительной деятельности определяет сущность текущего этапа градостроительства.

На современном этапе отечественной градостоительной деятельности информационные системы используются более активно в отличие от градостроительных банков данных. Резюмировано, что благодаря информационным системам специалисты имеют возможность увидеть, оценить, учесть современные процессы освоения территории и создать основу для ее устойчивого пространственного развития. Информационные технологии стали неотъемлемой частью градостроительной деятельности, внесли

в нее новое организующее и оптимизирующее начало, повысив в целом ее эффективность. Особое место в градостроительной деятельности отводится геоинформационным системам (ГИС). Их основные функции заключаются в создании информационной среды градостроительной деятельности, хранении территориальной картографической (пространственной) информации.

Сделан вывод о том, что использование ГИС в градостроительной деятельности предполагает их специфическое комплексное структурное применения. Информационная структура любой ГИС градостроительного профиля формируется на основе информационно-технологических блоков, тематических слоев и информационных слоев графической (картографической) информации, банков и баз данных.

Ключевые слова: градостроительство, системы документации градостроительной деятельности, информационные системы, геоинформационные системы.

University as the Core of the Functional Planning Organization of an Innovative City

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Abstract. The rapid spread of IT technologies at the current stage of human new economic development, the formation of smart and innovative cities demonstrates extraordinary growth of the science and education significance. As a result, universities, research centres and high-tech industries are more and more often beginning to be the core of the contemporary city spatial organization.

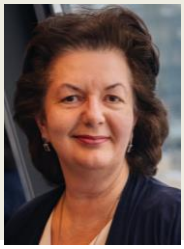
The article deals with the stages of universities historical development as society scientific thought and technological knowledge concentration – *ancient* (formation and development of philosophical thought), *medieval* (creation of universities and formation of scientific branches – the humanities or trivium development, and the exact sciences or quadrivium), *modern* (spread of exact sciences as a basis for technical and technological innovations and industrial production development).

Above mentioned universities' spatial development models are being characterized as an integral part of the city functional-planning organization, the predominant function of which is the educational or scientific-technological function. They are - *monocentric* (the university is the dominant integral planning element in the structure of the city); *polycentric* (formation of a group of universities as independent planning entities on the ground of a single historically formed university) and *dispersed* (spatial development of a mono- or polycentric model with the creation of separately located structural elements of the university, mainly in the peripheral city zone).

The actual quantitative indicators of the most typical foreign and domestic university cities, in particular, the share of teachers and students number in the total University City population are giv en below. The functions of the university at the contemporary stage of the development of society are described – they are educational, research, educative, commercial and communicative ones.

The article presents the tendencies in the formation of the modern city functional planning organization. The examples of innovative cities spatial organization are – the city of Masdar (UAE) and UNIT-City (Ukraine). Recommendations on the eventual transformation of existing domestic cities according to the innovative University City model are given below.

Keywords: university, University City, innovative city, spatial functional planning organization; university functions.



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INTRODUCTION

The end of the 20th – beginning of the 21st century is marked by the human entry into a new civilizational development stage, which was called *neo-economy* (new economy). A.L. Gregorian defines the "new economy" as the first stage of a new "post-industrial" system [1, 2]. The new technological round has created a modern idea of the comprehensive development of free areas and reconstruction of

existing areas as a new smart or innovative urban space type [3].

The growing significance of science and technology for the development of society during the fourth scientific and technological revolution requires the formation of a modern type of a person with well-grown potential, able to implement and maintain highly intelligent contemporary technologies [4]. But the new type person requires a new innovation space, which must meet the challenges of time [5, 6].

City as a spatial form of concentration of people, material infrastructure and technology at each historical stage of human development consolidates the idea of the human environment, development and self-identification [4, 7]. The post-industrial period created the latest forms of urban space, such as: ecopolises and arcopolises [7], hydropolises (underwater cities) [8], smart cities [3], vertical cities etc. But even well-known cities have undergone significant changes over the centuries under the influence of innovative ideas about the latest urban environment. Such cities, first of all, include university cities, the importance of which in the period of initial formation (The Middle Ages) and in the contemporary post-industrial stage is extremely important [9, 10].

Innovative university cities require a radical change in the usual city functional and planning organization spatial model. To meet the challenges of society, the formation of a highly educated modern person, it is the university with its research centers and experimental laboratories network that acquires a new meaningful existence and becomes the core of the spatial organization of the innovative city. The creation of new innovative university cities and the reconstruction of existing ones is becoming a priority.

Unfortunately, the national regulatory framework for urban planning does not meet such requirements. According to article 4.10 DBN B.2.2-12:2019 “Creation of new settlements can be provided in connection with the need to locate new large industrial enterprises, need of mineral resources production, as well as due to population resettlement from existing or potential zones of catastrophes and environmental disasters, historical and cultural factors" [11]. Awareness of the need to revise the main tasks of national urban planning should ensure the creation of preconditions for the formation of the modern world man.

AIM AND RESEARCH METHODS

The purpose of the study is to identify transformation patterns of the contemporary city functional planning organization, the core of which is the university as the basis of innovative development of society.

Based on the historical comparative research method, the transformation tendencies of the university spatial organization as an urban environment formation structural core are revealed. The graph-analytical method application allowed establishing the transformation regularities of the industrial city functional planning organization into a post-industrial innovative university city.

RESULTS AND EXPLANATIONS

University (from the Latin *universitas* – "a whole", *universitas magistrorum et scholarium* – community, association of teachers and scholars [12]) – an autonomous higher education institution type, which was formed in Europe during The Middle Ages. Let's focus on some aspects of the formation and development of universities and university cities.

1) Formation of the university as a basis for the city development.

There are three basic periods of growing of knowledge and science significance for society as a whole and for person in particular.

The first period – ***ancient*** (Ancient Greece, Ancient Rome) – covers the period of the 6th century – 2nd century B.C., it includes several stages marked by the world-famous scientific schools formation [13]:

- *Ionian* stage. The Greek science origin period (natural philosophers – Thales of Miletus, Pythagoras, Heraclitus of Ephesus, Anaximander, Hippodamus of Miletus, etc.);
- *Athenian* stage. Covers 5-4 centuries

B.C. and associated with the names of Aristotle, Socrates, Plato, Hippocrates of Chios;

- *Alexandrian (Hellenistic)* stage of ancient science development – 3-2 centuries B.C. Its representatives are Apollonius of Perga, Archimedes, and Aristarchus of Samos.

The ancient period science is characterized by the extraordinary role of the individual, surrounded by students and followers, who formed scientific schools. But such schools were based on a philosophical understanding of a surrounding world and the laws of its development; in fact, they did not require the developed infrastructure formation [13].

The next stage – **the medieval** – 12-16 centuries – is characterized by the antiquity cultural heritage revival (Renaissance). The growing desire in the cities to get education leads to the first educational institutions emergence - *episcopal, monastic, parish and cathedral schools*. Monasteries played the role of education and science knowledge centers, as they accumulated numerous manuscripts, which mostly were copied by monks [14, 15].

The division of all "seven liberal arts" knowledge branches into two parts is introduced in training: trivium (three ways of knowledge – grammar, rhetoric and dialectics); quadrivium (four ways of knowledge – geometry, arithmetic, astronomy and music) [14].

It is on the basis of monasteries and churches that universities are gradually starting to establish. The first universities appeared in the 12th century in Bologna (Italy) and in Paris (France). Later on, they also appeared in other countries: Oxford, Cambridge – in England, Salamanca – in Spain, Prague – in the Czech Republic, Krakow – in Poland and more. At the end of the 15th century there were 79 universities in Europe.

The Medieval University is no longer just a group of pupils, students, gathered around the spiritual and scientific leader of antiquity. The university must have the minimal necessary infrastructure to perform educational function - church, library, mess hall and gardens [16]. The lack of any component did not give the right to be called "university" or "college". It remained just a "school".

Gradually, the university, using modern terminology, begins to play the city forming role, implementing three basic functions: work or employment places concentration – the library, the church; everyday life – mess hall, cells; recreation - monastic and then university gardens.

The third stage – **modern** – conditioned the spread of scientific and technological progress in industry and production (the so-called STR – scientific and technological revolution). Even the names of the most famous universities, founded during this period, proved the unity of science and technology – Lviv Polytechnic National University (1816), Harvard University (1836), Massachusetts Institute of Technology (1861), I. Sikorsky Kyiv Polytechnic Institute "Kyiv Polytechnic" (1898), Imperial College, London (1907), Max Planck Institutes (1914), this list includes 83 universities and institutes of chemical-physical-technological and biological-medical orientation.

The science and technology development contributed to the formation and development of production and industry, capitalist relations formation and led to evolving numerous industrial type urban settlements. The university material and technical infrastructure is significantly developing, supplemented by research centres, experimental laboratories and even research facilities [17].

2) University as a component of the city spatial organization

The University City at the initial stage of its evolving performed mainly the concentration of scientific thought and dissemination of educational knowledge functions. City territory functional and planning organization represented a concentrated placement of all university functional components within the monastery walls, which, as a rule, played the role of city borders, protecting it from possible invasions. The medieval University City population consisted mainly of students and teachers. For example, in the 12th century in the "happy city" of Paris the students outnumbered the local population [18].

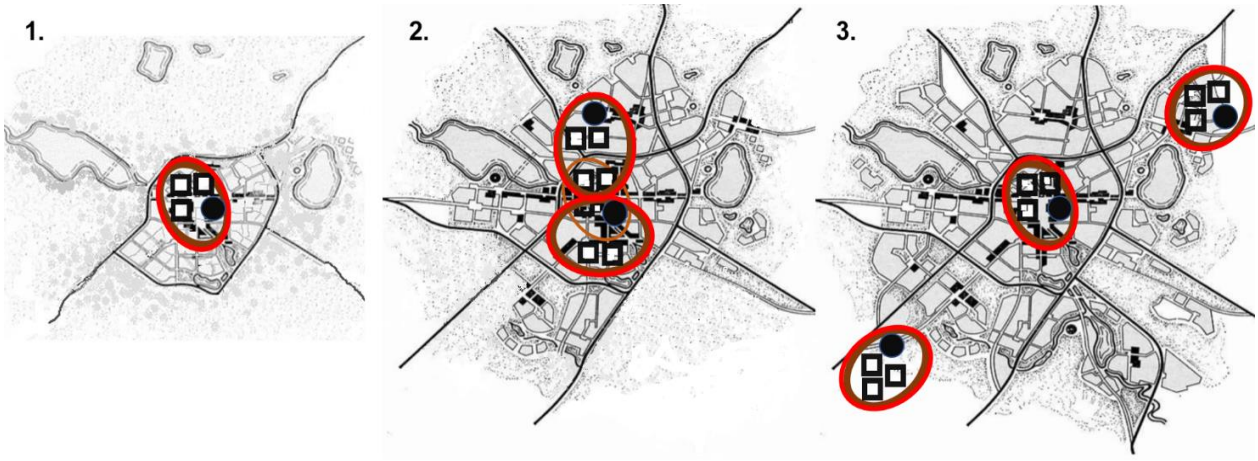

Fig.1. Models of spatial development of the university complex:
1) monocentric; 2) polycentric; 3) dispersed

The primary spatial model of such a city was *monocentric*, where university was the dominant integral planning element of the urban structure (see Fig.1, Scheme 1). In the following stages, the evolution of the monocentric model of the university complex location in the city planning structure could evolve in several ways.

1) Development of a *monocentric* model. The dominance of the university complex monocentric location with the subsequent territorial expansion of university separate structural units in the spatial structure of the city. Examples of such monocentric university cities, both at the primary and modern stages are – Cambridge, Oxford and St. Andrews.

2) The evolution of the monocentric model into a modern *polycentric* one is typical for universities, which during their history split into two or more units. For example, the first medical university in France (Montpelier), founded in 1289 by Pope Nicholas IV, is now divided into three autonomous universities. The University of Bordeaux (France), founded in 1441, in 1968 was divided into four independent universities.

After division, these re-created universities are further developed as independent integral planning entities with their own infrastructure (see Fig.1, Scheme 2).

The third model – *dispersed* – can become an evolutionary continuation of both the monocentric and polycentric models of the university spatial organization. This model is characterized by the creation of new separately standing university structural elements mainly in the peripheral zone of the city (see Fig.1, Scheme 3). Such a model at the present stage is the most common due to the lack of large free areas around the historical city centre, where the primary core of the university is usually located. For example, in Kyiv, this is Taras Shevchenko National University of Kyiv, founded in 1833, separate faculties of which (Faculty of Geography, Faculty of Computer Science and Cybernetics, Faculty of Sociology and Faculty of Mechanics and Mathematics, etc.) are located at a considerable distance from the initial core - the Red Building. The models of the university cities spatial organization are most clearly revealed for cities that have preserved their scientific and educational function as dominant in the overall balance of economic activity.

As already mentioned, a characteristic feature of university cities is a high-students and teachers rate towards the total population of the city. Let's look at this aspect on the example of the most typical university cities (see Table 1).

Depending on the population rate, university cities can be small, medium and big [11]. The bigger is the city (in terms of population), the greater is the city functions diversity [19, 20]. Therefore, cities with a population over 500 thousand people are multifunctional, even despite the big number of educational institutions of higher and secondary level.

Table 1. Comparative characteristics of the oldest European and innovative university cities (examples)

No	City			University			% від населення
	State, city	Year of establish-ment	Population, (thousand people)	University nam	Year of estab-lishment	Population, thousand (Residents +students)	
1	2	3	4	5	6	7	8
The oldest European university cities (examples)							
1.	United Kingdom, England, Oxford	8th century	154,6	University of Oxford	1117	26,1 (22,0+4,1)	**16,9%**
2.	United Kingdom, England, Cambridge	1th century	124,8	University of Cambridge	1209	34,8 (11,5+23,3)	**28,0%**
3.	United Kingdom, Scotland, St Andrews	9th century	16,8	University of St Andrews	1412	11,7 (2,7+8,98)	**69,5%**
4.	Italy, Bologna	534 B.C.	392,7	University of Bologna.	1088	89,5 (2,9+86,6)	**22,8%**
5.	Italy, Padua	12th century B.C.	214,1	University of Padua	1222	61,5 (2,2+59,3)	**29,1**
6.	Germany, Heidelberg	1196	160,4	Heidelberg University	1386	38,1 (8,4+29,7)	**23,7**
7.	France, Montpellier	10th century	285,1	University of Montpellier	1289	44,6 (1,9+42,7)	**23,4%**
8.	Netherlands, Leiden	13th century	124,9	Leiden University	1575	37,6 (8,1+29,5)	**30,1%**
9.	Spain, Salamanca	12th century B.C.	144,0	University of Salamanca	1254	33,8 (3,6+30,2)	**23,5 %**
10.	Hungary, Pecs	2nd century B.C.	143,3	University of Pecs	1367	21,9 (1,9+20,0)	**15,3 %**
11.	Sweden, Uppsala		168,1	Uppsala University	1477	49,7 (7,1+42,6)	**29,5 %**
12.	Ukraine, Kyiv	7th century	15,0	Kyiv-Mohyla Academy	1615	1,1 (Year of 1700)	**7,3%**
Contemporary innovative university cities (examples)							
13.	United Arab Emir-ates, Masdar	2006	40,0 (exp.)	Masdar Institute of Science and Technology	2017	5,5 (0,5+5,0)	**13,8 %**
14.	Russia, Innopolis	2014	155,0 (exp.) 4,0 (2020)	Innopolis University	2015	25,0 (exp.) 700 (2019)	**16,1%**
15.	Ukraine, Innovation park UNIT.City (Kyiv)	2017	14,0 (exp.)	UNIT Factory	2017	3000 (exp.) 900 (2019)	**21,4%**

For university cities, the teachers and students share ranges from 15% (Pecs, Hungary; Oxford, United Kingdom) to almost 70% (St Andrews, Scotland, United Kingdom). To compare, in Kyiv, the Kyiv-Mohyla Academy, the first officially recognized East Slavic world higher education institution, founded in 1615, there were around 1,100 students and teachers (in 1700) – 7% of the Kyiv population then. [21]. The average rate value of teachers and students makes 21.7% of the total city population (see Table 1).

The quantitative parameters, given in Table 1, were obtained from the websites of those cities and universities. These data are not completely accurate, but it should be noted that these figures do not take into account the additional number of support staff and employees of other related departments and facilities involved in university functioning. University plays a powerful city-forming object role, which ensures the whole city existence, creating employment places for numerous service facilities (trade and entertainment facilities, cafes, restaurants, hotels, health care facilities, etc.). University financing is a separate issue. On the one hand, there are budget subsidies for the educational institution's operation. On the other hand, paid educational services, research results commercial effect, numerous start-up companies, as well as the operation of numerous service facilities contribute to local and state budget revenues.

3) Functional planning model of the innovative city territory

Functional planning organization of the city at each historical development stage has its own features [7, 20]. The idea of living environment comfort was incarnated in various models of the ideal city – "The Sun City", "The Star City" (rational representation of the city organization as a fortress or shopping center); the "Utopia" city (personification of the society social justice idea); Howard's "Garden City" (the desire to get closer to the natural environment); "Sustainable City" (attempts to solve the problems of economy, society and nature balanced development); "Smart City" (IT-technologies maximal implementation in everyday life) and finally "Innovative City" (city of science) [20].

The planning organization of cities formed during the period of industrial development is based on the Athens Charter principles [22], they are characterized by the predominating monofunctional territory zoning (residential, industrial and recreational zones), having a well-defined spatial organization. The city central and peripheral parts mainly consist of residential and recreational zone elements with the public service centre forming.

The city peripheral zone consists of the territories of industrial objects, communal warehousing, engineering, transport facilities. A typical model of the industrial city functional planning organization (on the example of the city of Vyshneve, Kyiv region) is shown in Fig.2, Scheme 1.

The innovative city of the modern period is formed on fundamentally different principles. The central and peripheral areas consist of research facilities, innovation centres, higher education institutions, primarily universities and business centres. The middle zone is formed by residential small and medium storey building blocks with the approach to the peripheral recreational zone. The model of functional planning organization of the innovative city is shown in Fig.2, Scheme 2, 3.

The world experience of creating the newest innovative cities with the university, as a core, is actively developing. One of the most vivid examples of an innovative city in the world is the city of Masdar (UAE). It is also called the "City of the Future" or Eco city. It is the first city in the world to be supplied exclusively with solar energy and other renewable energy sources [23]. A sustainable ecological environment with minimal carbon dioxide emissions into the atmosphere, as well as a system of municipal activity complete waste recycling is created in Masdar City [24].

The functional planning organization of this city, where the university with its numerous innovative research centres is in the middle, is presented in Fig.2, Scheme 3. Masdar City construction began in 2006 in the United Arab Emirates on an area of 600 hectares. It is de-

signed for 50 thousand permanent residents, and as many people as planned will come to work. The project contains the most revolutionary cities organization ideas. Masdar City main idea is "green" technology. Public transportation is located exclusively underground, gasoline engine cars are prohibited. Instead, automatic individual electric transport is provided.

Geothermal and solar energy (solar panels, mirror devices that concentrate sunlight etc.), as well as waste recycling energy, provide the city's energy independence.

Masdar City architecture was designed by prominent architect Norman Foster and it was adapted to the UAE climate.

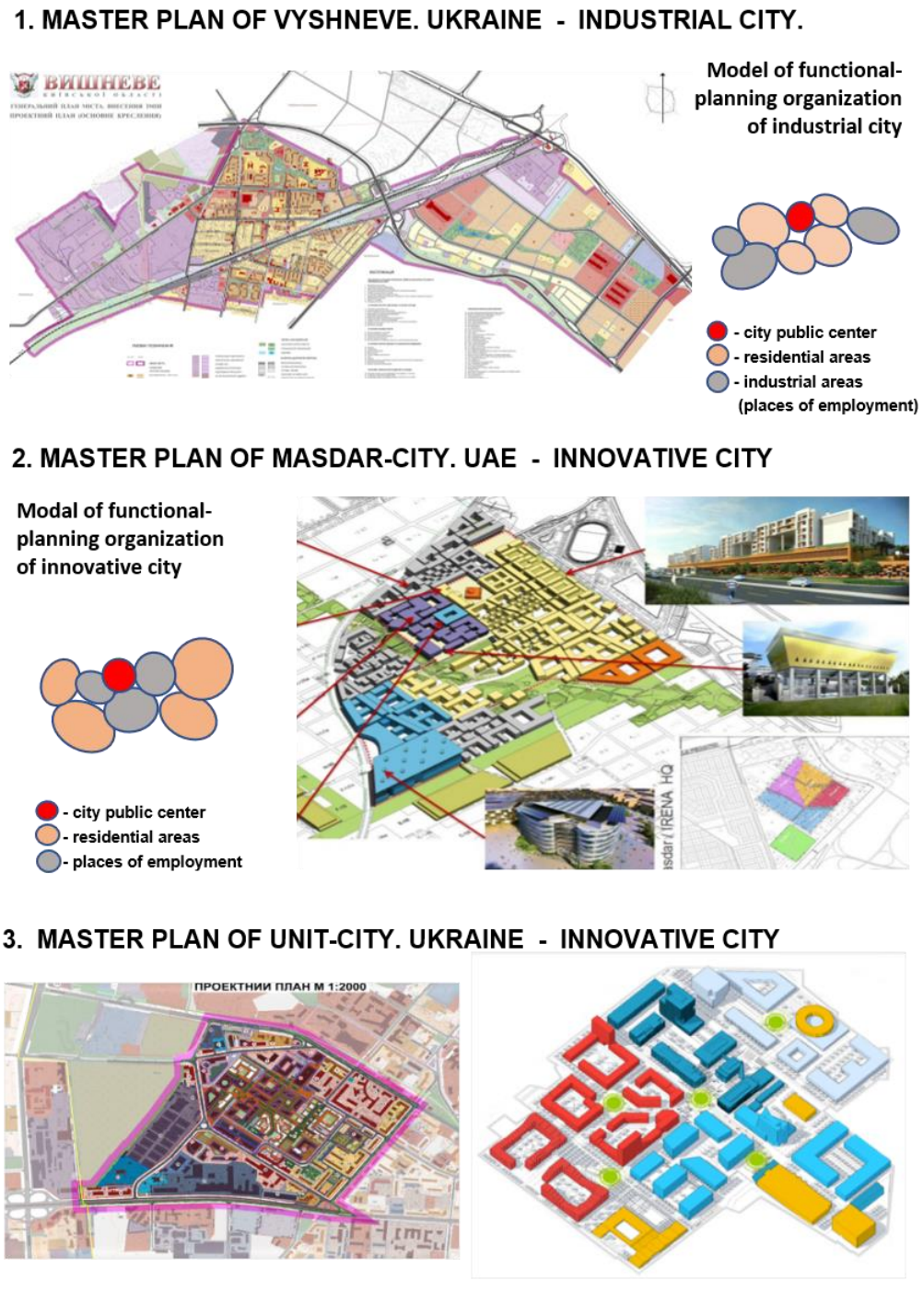

Fig.2. Models of the city territory functional planning organization: Industrial city. Vysneve; 2) Innovative city. Masdar; 3) Innovative city. UNIT.City

The Innovative City Project has aroused great interest in the world; it has attracted as partners many large corporations that consider Masdar City an experimental and advertising platform. A specialized science campus has already been opened, a solar power plant has been built, well-known companies' and educational institutions' laboratories will soon be opened, including the Masdar Institute of Science and Technology, affiliated with the Massachusetts University of Technology. The expected number of students is 5.0 thousand.

In Ukraine, the experience of new university cities creation is only shaping. The first is ***UNIT.City*** in Kyiv. UNIT.City is an example of a multifunctional innovation city with a developed infrastructure. It is being built on the territory of a former industrial enterprise Kyiv Motorcycle Plant/

The site area is 25 hectares, located in the central part of the capital of Ukraine. The land is privately owned, the project is completely commercial.

UNIT.City is positioned as a city within a city, designed for the development of Ukraine's creative economy: conducting innovative business and supporting start-ups, high technologies training, conferences and research, as well as for living, recreation, sports, cultural entertainment [25].

The project provides the creation of up to 15 thousand jobs, construction up to 200 thousand square meters of housing with infrastructure, cultural and educational facilities. Promising number of inhabitants – 14.0 thousand people. The total complex area should be almost 500 thousand square meters, although it may be adjusted depending on demand.

The project is funded privately. It is assumed that the investment amount by 2025 will be $700-800 thousand. The partners are the Kyiv-Mohyla Business School and a number of organizations involved in the high technology's development in Ukraine.

The UNIT.City opened in 2017 and is under development now. UNIT.Factory was the first facility to open, which uses an innovative Peer-to-Peer (P2P) training method. It is based on collective learning, which helps to reveal the students' creative abilities while working on projects. The system is based on gamification. The program aims to form high quality software development skills. UNIT.Factory prepares students to work in the most demanding advanced IT companies [26]. Currently almost 800 students study here. In the future the number of UNIT.Factory students will reach 3.0 thousand, of the expected number of 14.0 thousand residents; it will be 21%, which corresponds to the average value rate for university cities.

There are business campuses, Chasopys.UNIT coworking, laboratories, conference halls, recreation areas and sports complex. Newly built UNIT.City facilities are immediately rented out and put into operation.

The UNIT.City is known as a convenient venue for various events. A hundred resident companies, mostly small, already work here. The authors of the project have ambitious plans to make UNIT. City one of the biggest innovations centres in Central and Eastern Europe.

CONCLUSIONS AND RECOMMENDATIONS

Throughout the human history, the new knowledge – from extracting fire ability to nanotechnology and genetic engineering - played an important driving force in the creative habits of individuals and the formation of a comfortable environment for their existence. The material personification of human strives to education and science can be the university as the core of the city spatial planning organization formation.

The university city, known since the Middle Ages, now is acquiring extremely important features not only as a place of education, but also as a basis for building of the new third millennium man. Active implementation of advanced IT-technologies in all activity areas, production and even everyday life requires a high level of education for everyone.

The university as the core of the city plan functional planning organization determines the evolution of the city spatial development. Typical models of such development are – monocentric, polycentric and dispersed.

The activities of the modern university have become more diverse than the primary universities. They are:

- training of future specialists in various fields of activity,
- science and technology development on the basis of research and experimental laboratories and centres, training of scientists;
- commercial educational services to all people, regardless of age and education level;
- creation of public spaces and communication platforms not only for students, but also for all city residents;
- participation in the world globalization process through the introduction of the teachers' and students' educational mobility.

Except for these basic functions, the university creates numerous (up to 20-25%) employment places. Taking into account the university related areas of activity (cultural and entertainment services, health care, sports and travelling), the number of employees reaches 70-80% of the working force.

Despite the existence of powerful higher educational institutions in Ukraine with a long history, the classical European type of university cities is not determinative. However, the country has a unique opportunity to create new university cities on the principles of contemporary innovative cities. In particular, this approach can be used to address the problem of rebuilding or reconstructing cities destroyed during the war in the east of the country. To ensure the possibility of implementing such an approach, it is necessary to significantly change the legislative and regulatory framework for urban planning in terms of basic approaches to the formation of functional and spatial organization of the territory of both new and reconstructed cities.

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Университет как ядро функционально-планировочной организации инновационного города

Алла Плешкановская

Аннотация. Скачкообразное распространение IT-технологий на современном этапе неоекономического развития человечества, формирования разумных и инновационных городов демонстрирует чрезвычайный рост значимости науки и образования. Как следствие, ядром пространственной организации современного города все чаще начинают выступать университеты, научно-исследовательские центры и высокотехнологичные производства.

В статье рассмотрены этапы исторического развития университетов как фокусов концентрации научной мысли и технологических знаний общества – *античный* (формирование и развитие философской мысли), *средневековый* (становления университетов и формирования научных направлений – гуманитарного или тривиум, и точного или квадриум), *новейший* (распространение точных наук как базиса технико-технологических новаций и развития промышленного производства).

Охарактеризованы модели пространственного развития университетов как неотъемлемой составляющей функционально-планировочной организации города, преобладающей функцией которого выступает образовательная или научно-технологическая функция. Это – *моноцентрическая* (университет доминирует как целостный планировочный элемент в структуре города); *полицентрическая* (формирование группы университетов как самостоятельных планировочных образований на базе единого исторически сложившегося университета) и *рассредоточенная* (пространственное развитие моно- или полицентрической модели с сформированием отдельно расположенных структурных элементов университета, преимущественно в периферийной зоне города).

Приведены актуальные количественные показатели отдельных, наиболее характерных, зарубежных и отечественных городов-университетов, в частности, доля численности профессорско-преподавательского состава и студентов университета в общем количестве населения университетского города.

Охарактеризованы функции университета на современном этапе развития общества – образовательная, научно-исследовательская, просветительская, коммерческая, коммуникационная.

В статье изложены тенденции трансформации функционально-планировочной организации современного города. Охарактеризованы примеры пространственной организации инновационных городов на примере города Масдар (ОАЭ) и UNIT-City (Украина). Даны рекомендации по возможной трансформации существующих отечественных городов по модели инновационного города-университета.

Ключевые слова: университет, университетский город, инновационный город, пространственная организация, функционально-планировочная организация, функции университета.

The problem of determining traffic and pedestrians delay in the city road-street network unregulated intersection area

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Abstract. The motorization level increase in the city of Kyiv, taking place since the late 1990s up to 2008, caused the increase of the traffic flows intensity in the city and overwork of the city road-street network (RSN). The city streets and roads intersections became the places of traffic and pedestrian flows network concentration. In the City of Kyiv over a half of all intersections of streets and roads are unregulated. Therefore, in the aforementioned conditions (continued motorization level increase, limited number of parking spaces, public transport lanes allocation), as well as increasing demand for individual vehicles (Segway, gyro scooters, bicycles), the problem of unregulated crossings operation assessment is relevant. Proper traffic organization, taking into account all traffic participants, is the factor of the whole system efficient operation.

While analyzing the regulatory framework of Ukraine for the design and operation of urban transport infrastructure, there are several problem areas: the lack of sufficient description of the requirements for the unregulated crossings design; the absence of a comprehensive assessment of the intersection including all traffic participants (cars, pedestrians, cyclists and public transportation); the absence of regulatory transportation capacity.

The article proposes to introduce the common structure of indicators of unregulated intersection work efficiency of traffic network. Such indicators have been used for more than 50 years by American, European and other countries' designers to solve urgent urban construction and transport problems. This direction uses the level of service (LOS) Concept that aims to maximize the comfort of the transportation infrastructure elements – roadway, sidewalk, pedestrian crossing etc. The main indicators in this concept are the traffic and pedestrians delay control in the unregulated intersection area; this article deals with the method of its determination. Thus the method of full-scale traffic and pedestrians delay measurements is provided. Multimodal intersection level of service (MMLOS) is determined using the automotive and pedestrian components.

Keywords: road-street network (RSN), unregulated intersection, level of service, pedestrian crossing delay, traffic delay.

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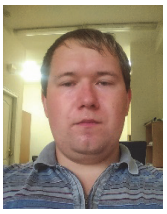

Oleksiy Dvorko
postgraduate

OBJECT AND SUBJECT OF RESEARCH

The object of the research is a simple (unregulated) intersection on the city road network. The subject of the research is the principles and methods of functional-planning

solutions of simple (unregulated) intersections in the city road-street network.

The *unregulated intersection* of the city streets and roads is any RSN crossing or adjacent, which does not have traffic lights.

The *simple intersection* of city streets and roads is referred to as RSN crossing or adjacent, which do not have straight structures and elements (islets, road marking, etc.) that organize traffic.

PROBLEM FORMULATION

The purpose of this study is to develop and reason the methodology for evaluating the operation of unregulated intersection on the city's road-street network.

It requires the research and development of a scientific base for complex solutions of unregulated crossings when choosing them depending on the urban conditions. For this purpose it is necessary to collect and structure the road network output data – traffic intensity, flow composition, intersection geometry etc. The main objective of the study is to establish the boundaries of the effective functioning of unregulated crossings, depending on the urban planning conditions using the specified evaluation criteria – traffic delays, queuing length and lines capacity levels.

STUDIES AND PUBLICATIONS ANALYSIS

The theme of increasing the unregulated crossings efficiency in the city has been traced back to the 1960s. In Western Europe, the USA and the former USSR, cross-sectional studies have been conducted, based on which two approaches can be outlined:

- an approach based on Probability Theory, whose founder is E.M. Lobanov [1, 2]. Also in this direction worked such scholars as Buga P.G., Shelkov Yu. D. [3], Romanov A.G. [4], (USSR); B. Grinschilds [5], T. Metson [6], (USA); as well as contemporary scholars Chikalin Y.M. [7, 8], Simul M.G. [9] (Russian Federation), O.O. Lobashov [10], Gorbachov P.F. [11], Shirin V.V. [12] (Ukraine);

- an approach based on queuing theory with the introduction of a level of service (LOS) criterion. This trend has developed primarily in the USA and the Western Europe. The scholars D. Drew [13], I.E. Baervald, A.V. Trofimov [14], A.Y. Mikhailov [15, 16], Kyte, M., Z. Tian, Z. Mir, Z. Hameedmansoor, W. Kittelson, M.Vandehey, B.Robinson, W. Brilon, L. Bondzio, N.Wu [17] worked in this area.

THE CITY ROAD-STREET NETWORK UNREGULANED INTERSECTION INDICATORS STRUCTURE

Prior to choosing the basic unregulated intersection model, it is necessary to classify the object of study according to the set of criteria characterizing the intersection operation conditions. The RSN unregulated crossings operation conditions in Kyiv can be divided into planning and transport ones, which in turn are divided into the following subtypes:

Planning conditions include the city functional-planning area and the intersection geometry.

Transport conditions – the category of intersecting streets; transport flows priority; transport flow composition.

Based on the current State Building Standards [18, 19] there are no clear criteria for the unregulated intersections operation in the city [32]. In the previous DBN B.2.3-5:2001 edition [18] the following transport conditions restrictions (the traffic and pedestrians intensity) were specified in the area of unregulated intersection as 700 units per hour of total transport flow and 150 persons per hour for one pedestrian crossing in the intersection zone. There was also a restriction on the category of streets – an unregulated traffic and pedestrian traffic scheme was allowed on city streets and local roads (residential streets). There were no planning restrictions regarding the intersection geometry. There is no regulation on the use of unregulated crossings at the level of the City Master Plan [20, 33].

The intersection was designed in accordance with the city roads and streets design rules. In contemporary urban conditions, the

traffic intensity and its individual types (bicycle, gyro, Segway) increase, pedestrian mobility augment and growing demand for such services of the current standards are not sufficient for a comprehensive urban development assessment of the unregulated crossroads design solution.

Several parameters have been used to evaluate the work of the city RSN unregulated intersection. These parameters are described the US Highway Capacity Manual [21, 22] and its German analogue [23]. These include delay level d, delay of pedestrians d_p, 95th grade queue length Q_{95}, emissions level M, intersection safety G, and road transport costs D.

Table 1. The unregulated crossroads operation indicators interrelation

RSN Element	LOS Criteria	Different Assessments Availability		
		Air quality	Noise level	Transport costs
Unregulated crossing	Operation delay	Yes	No	Yes
	Queue length	Yes	Yes	Yes
	Line capacity factor	Yes	No	Yes

For an unregulated intersection, the main efficiency indicator is *traffic delay* and *pedestrians delay* at the junction. These two parameters determine the Level of Service (LOS). The LOS Concept is used from Queuing Theory [14]. In the number of publications the LOS Indicator is defined as "quality characteristics that reflect such aggregate factors as speed, travel time, free makeover, driving safety and convenience" [14, 15].

METHODS OF DETERMINING TRANSPORT TRAFFIC DELAY: THEORY AND PRACTICE

The methodology for determining the traffic delay according to HCM-2010 [22] is a 13-step algorithm. The HCM use boundary conditions for the unregulated intersections are the absence of influence of closely spaced crossings, except for those unregulated intersections that are located 0,467 km (0,25 miles) from the regulated intersection. The necessary model preconditions are:

1. The number of lanes and their width at each intersection approach;
2. Traffic flow percentage rate;
3. Intensity of traffic of input and output traffic flows and intensity of pedestrians crossings at each unregulated crossroads during rush hour;
4. Geometric characteristics of intersection:
   4.1. Channelization form of traffic flows;
   4.2. The presence of the left turn line or the cumulative line, marked or having islets;
   4.3. Intersection zone surface curves;
   4.4. Subordinate street approaches;
   4.5. Presence of road traffic lights;
   4.6. Rate of drivers yielding pedestrian movement and pedestrian “jam traffic”;
   4.7. The analyzed period length (15 min per rush hour).

Hereford, all movement directions in the unregulated intersection area can be divided into the ranks in relation to the right turn traffic (for X-shaped crossings) (Fig.1):

Rank 1(i): 2 (2-1), 3 (2-3), 5 (1-2), 6 (1-4), 15 (3-3 ped.), 16 (4-4 ped.)

Rank 2(j): 1 (2-4), 4 (1-3), 4U (1-1), 1U (2-2), 9 (3-1), 12 (4-2), 13 (2-2 ped.), 14 (1-1 ped.)

Rank 3(k): 8 (3-4), 11 (4-3)

Rank 4(l): 7 (3-2), 10 (4-1)

For T-sections, these categories are divided as follows (Fig.2):

Rank 1(i): 2 (2-1), 3 (2-3), 5 (1-2), 15 (3-3 ped.)

Rank 2(j): 4 (1-3), 4U (1-1), 1U (2-2), 9 (3-1), 13 (2-2 ped.), 14 (1-1 ped.)

Rank 3(k): 7 (3-2)

There are 13 HCM-2010 steps [22]:

Step 1. Determine movement priorities

Step 2. Determine flow intensity rates.

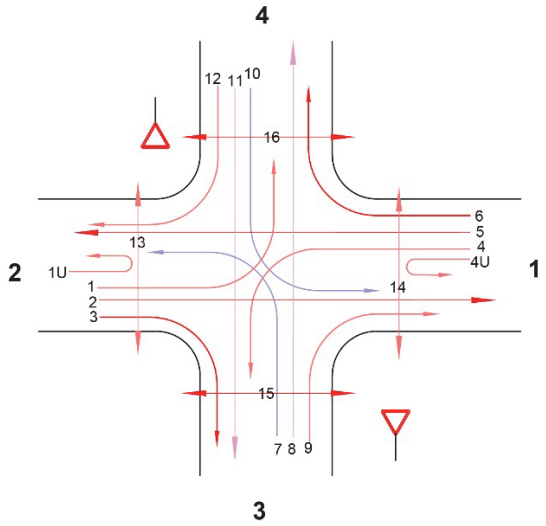

Fig.1. Priority of pedestrian and transportation flows at the unregulated T-shaped crossing

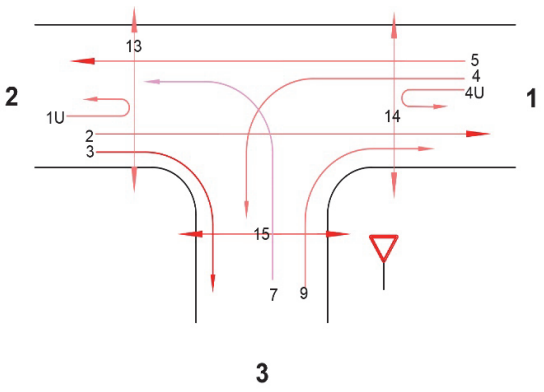

Fig.2. Priority of pedestrian and transportation flows at the unregulated X-shaped crossings

Step 3. Determine conflicting flow rates.

Step 4. Determine critical movement intervals and casual intervals

Step 5. Potential capacity calculation.

5a) Potential capacity accounting neighboring regulated crossings.

5b) Potential capacity under road traffic lights.

Step 6. Determine Rank 1 movement capacity.

Step 7. Determine Rank 2 movement capacity.

Step 8. Determine Rank 3 movement capacity.

8a) One direction highway crossing.

8b) One direction highway crossing.

Step 9. Determine Rank 4 movement capacity.

Step 10. Determine common lane (right turn and turns).

Step 11. Determine movement directions delay.

Step 12. Determine intersection approach delay.

Step 13. Determine 95th grade queue lengths.

For the model verification let us use the calculation of indicators at the intersection of Vishniakivska street and L. Rudenko street in Darnytskyi district (Kyiv) (Fig.3, 4). Open air examinations were conducted on June 25, 2019 (6:15-6:40 pm).

Initial data were collected in terms of traffic and pedestrian traffic intensity by the method [24] developed by the KNUCA MB Department. According to this method, the values of the traffic intensity are reduced to the average daily using the coefficients of non-uniformity [25]. Some parameters of the traffic flow, such as composition and time intensity, can be determined by [10, 26 – 27]. The transition from daily average to hourly intensity can be made by the formula:

$$N_{hrs} = 0,08\overline{N_{day.}}, \qquad (1)$$

where N_{hrs} – hour traffic intensity, veh/h;
N_{day} – average daily traffic intensity, veh/day.

The theoretical calculation of intersection operation according to [22] is performed in MS Excel. The whole algorithm of the problem is not specified in detail, but in Tables 2 and 3 were given the results of calculating delays of all movements d, s/veh. Under traffic delays we understand a traffic speed decrease compare to normative one, permitted by the Traffic Rules of Ukraine [28].

Analysis of field surveys is carried out according to the method described in [29].

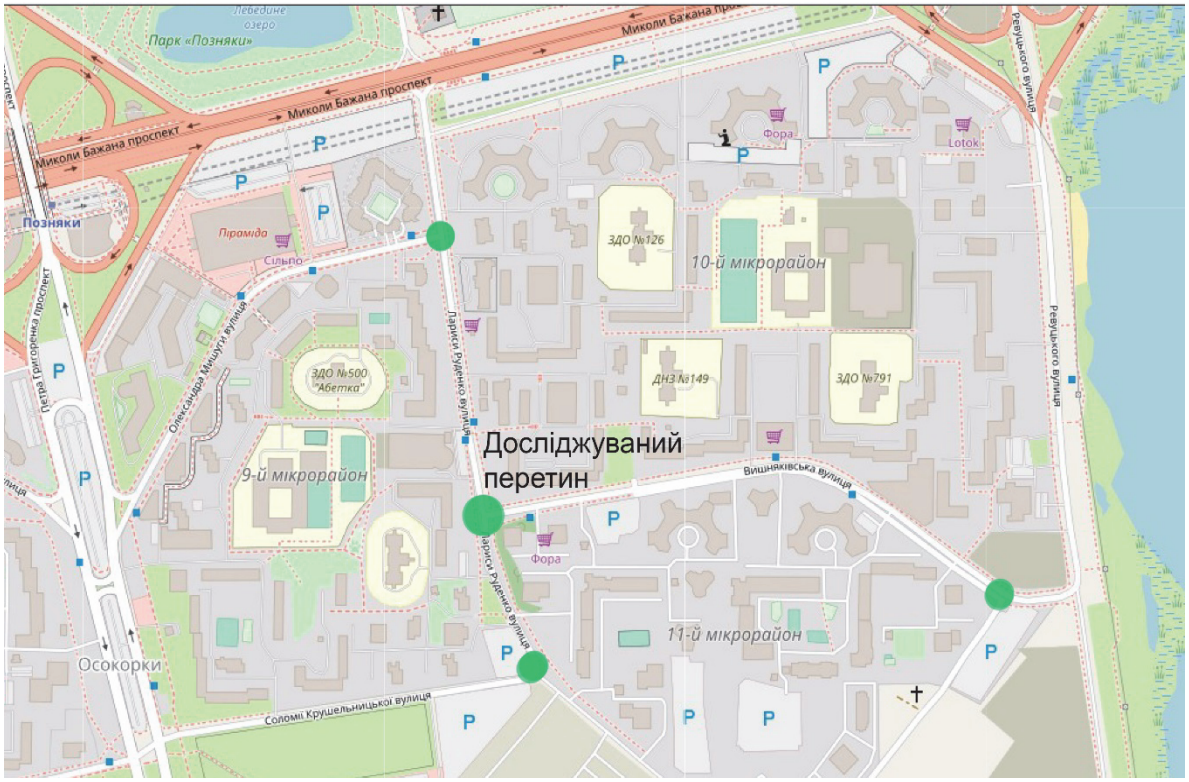

Fig.3. Intersection location in the road-street network

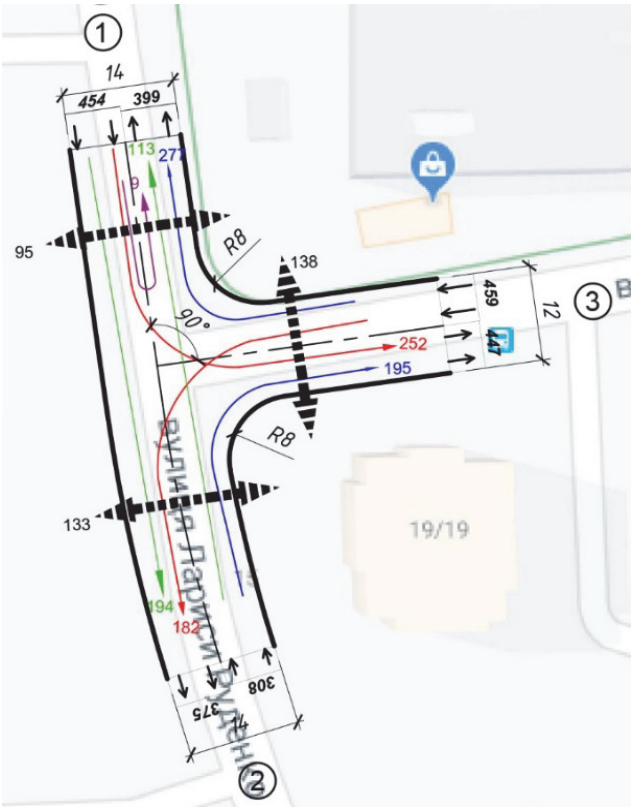

Fig.4. Intersection scheme

In order to show the traffic situation, a 15 min video recording (five 3-min videos) was made (Fig.5). The manual data processing protocol is presented in Table 4.

The whole video is split into 1 min segments. The periods of detailed fixation of the vehicle number make 15 seconds. Each 15-second segment shows the number of cars waiting in a queue $n_{i.ч}$ and every 1 min video shows the number of cars that stopped $n_{зуп.}$, or drove nonstop $n_{б.зуп}$.

The processing of the delay determination results includes the following steps:

The HCM-2010 traffic delay [22] is determined by equation:

$$d = \frac{3600}{P_i} + 900T \times$$

$$\times \left[\frac{N_i}{P_i} - 1 + \sqrt{\left(\frac{N_i}{P_i} - 1\right)^2 + \frac{\frac{3600 N_i}{P_i^2}}{450T}} \right] + 5 \quad (2)$$

де d – average traffic delay, s/veh;
N_i – movement intensity, veh/h;
P_i – movement capacity, veh/h;
T – observation time (T = 0,25 for 15-min period).

Table 2. Determination of traffic delay and level of service directions, Rank 2-4

Movement	T	v_x, veh/h	$c_{m,x}$, veh/h	d, s/veh	LOS
1	-	-	-	-	-
4	0,25	252	1122	9,13	A
4U	-	-	-	-	-
1U	-	-	-	-	-
9	0,25	277	638	14,89	B
12	0,25	-	-	-	-
7	0,25	182	173	135,99	F
8	-	-	-	-	-
11	-	-	-	-	-
7	-	-	-	-	-
10	-	-	-	-	-

Table 3. Determination of traffic delay and level of service directions, Rank 1

Movement	N, lane	$d_{M,LT}$, s/veh	$v_{i,1}$, veh/h	$v_{i,2}$, veh/h	$s_{i,1}$, veh/h	$s_{i,2}$, veh/h	$p_{0,j}$	$p_{*0,j}$	d, s/veh	LOS
2	2	0	113	0	2000	2000	0	-0,0600	0,00	A
3	2	0	113	0	2000	2000	0	-0,0600	0,00	A
5	2	9,13	194	0	2000	2000	0,7758	0,7517	1,13	A

Fig.5. Video fixation of the traffic situation at the intersection of Vishniakivska str. and L. Rudenko str. (25.06.2019, 18:15:17)

Table 4. Traffic delay determination of direction 4 (1-3) by the method of field studies

Time		$n_{i.ч.}$, veh in period I, s				Movement, veh	
Hour	Minute	0 - 15	15 - 30	30 - 45	45 - 60	$n_{зуп.}$	$n_{б.зуп.}$
18	15	0	2	1	1	0	5
18	16	1	0	1	1	0	3
18	17	1	0	1	0	0	2
18	20	0	2	0	1	2	1
18	21	1	0	1	2	3	2
18	22	1	0	0	0	0	1
18	26	1	2	1	1	1	4
18	27	1	0	1	1	0	3
18	28	0	0	0	0	0	0
18	32	1	2	0	1	0	4
18	33	0	1	0	1	1	1
18	34	1	0	0	0	0	1
18	38	0	1	1	1	0	3
18	39	1	0	1	1	2	1
18	40	1	1	0	0	0	2
Σ		10	11	8	11	9	33

Movement capacity is determined by equation:

$$P_i = k_\Sigma N_{гол} \frac{e^{-\frac{N_{гол} t_c}{3600}}}{1 - e^{-\frac{N_{гол} t_f}{3600}}} \qquad (3)$$

де P_i – potential movement capacity of i line, veh/h;

$N_{гол}$ – highway movement intensity, veh/h;

t_c, – critical movement interval, s;

t_f, – movement interval i, s;

k_Σ – adjustment factor for steps 5 – 8 [22].

1. Determination of total delays in one direction:

$$AT = \sum_{i}^{i=15} n_{i.ч.} I \qquad (4)$$

where AT – total delays in the traffic direction, veh·s;

$n_{i.ч}$ – the total number of cars in a queue, veh;

I – fixation interval (I=15 s).

2. One car stop average delay

$$t_{зуп.} = \frac{AT}{\sum n_{зуп}} \qquad (5)$$

where $\Sigma n_{зуп.}$ – the total number of cars that stopped at the intersection during the observation period

3. Nominal delay of each car passing through the intersection is given by the formula:

$$t_{ум.} = \frac{AT}{n_{зуп.} + n_{б.з.}} \qquad (6)$$

where $n_{б.зуп}$ – the total number of cars passing non-stop through the intersection.

Calculate the appropriate parameters for direction 4:

1. $AT = (10 + 11 + 8 + 11) \cdot 15 = 600$ авт · с
2. $t_{зуп.} = \frac{600}{9} = 66,7$ с ;
3. $t_{ум.} = \frac{600}{9 + 33} = 14,3$ с

We do the same calculations for directions **7** (3-2) and 9 (3-1). The results of theoretical and practical calculations are summarized in Table 5 to compare.

Table 5. Delay level comparison results

Directions	Traffic delay for [3,4]	Practical calculation according to [14]	Error, %
4 (1-3)	9,13	14,3	+36,0
7 (3-2)	135,99	24,6	-81,9
9 (3-1)	14,89	15	+0,73

As we can see, in two cases the results of theoretical calculations and experimental data differ significantly (over 10% error). There are several factors that can affect this:

- Data collection accuracy;
- Data analysis accuracy;
- Data collection quality;
- The need for calculation methods adjustment.

METHODS OF DETERMINING PEDESTRIANS CROSSING DELAY ON UNREGULANED INTERSECTION: THEORY AND PRACTICE

The pedestrian crossing delay method according to HCM-2010 is a 6-step algorithm that allows us to determine the level of service on an unregulated pedestrian crossing.

Step 1. Determine two-way crossings.

Step 2. Determine critical intervals.

Step 3. Probability of delayed pedestrian crossings.

Step 4. Calculate average waiting interval delay.

Step 5. Estimate delay reduction due to yielding vehicles.

Step 6. Calculate average pedestrian delay and determine LOS (pLOS).

The pLOS Assessment Model, which was first tested in HCM 5th edition [22], offers three versions of unregulated pedestrian crossing:

A. Unmarked crosswalk, no median safety islet;

B. Unmarked crosswalk, median safety islet;

C. Marked crosswalk with visible equipment and median safety islet.

HCM recommends the following data to determine pLOS:

- Number of lanes on a major street;
- Traffic intensity on a major street, veh/h;
- Crosswalk length without median islet (option A), m;
- Crosswalk length with median islet (option B and C), m;
- Pedestrian crossing speed, m/s;
- No pedestrian “jam traffic”.

As an example, let us take the calculation of indicators at the intersection of Vishniakivska street and L. Rudenko street (see Fig.4), Tables 6 – 8. On-site examinations were conducted on June 25, 2019, 6:15-6:40 pm.

Table 6. Traffic delay and pLOS, crosswalk 1-1

	d_{gd}		$d_{gd,\Sigma}$	pLOS
Scen. A	13,15		13,15	E
Scen. B	1,01	1,17	2,18	B
Scen. C	1,01	1,17	2,18	B

Table 7. Traffic delay and pLOS, crosswalk 2-2

	d_{gd}		$d_{gd,\Sigma}$	pLOS
Scen. A	13,27		13,27	D
Scen. B	0,96	1,20	2,16	A
Scen. C	0,96	1,20	2,16	A

Since HCM-2010 has no procedure for determining the unregulated pedestrian crossing capacity, it is necessary to further distinguish two approaches in the crossing determination – namely the determination of the traffic lane capacity in the area of the unregulated crossing and the capacity of the pedestrian lane across the traffic lane.

In general, within the framework of urban transportation planning, the general tasks of pedestrian crossing design are to calculate their capacity and to select the location in the street.

In the former USSR, pedestrian crossing subject was studied by such scholars as Buga P.G, Shelkov Y.D., Lobanov E.M., Romanov A.G., as well as contemporary Russian researchers Chikalin E.M., Simul M.G. etc. In 1977, an act was adopted [30] that addressed issues related to improving the pedestrian crossing arrangement. The one lane pedestrian crossing capacity is determined by the formula:

$$N_{n.1} = \frac{e^{-\left(1{,}5+\frac{\Delta t_{zp} M}{3600}\right).}}{1-e^{-\frac{\delta t M}{3600}}} \qquad (6)$$

where M – major street total traffic intensity, veh/h;

$\lambda = M/3600$ – M traffic intensity mathematical expectancy, veh/s;

Δt_{zp} – critical interval in major street, s;

δt – traffic interval in subordinate street, s

The crosswalk capacity is determined by the formula:

$$N_n = \frac{b_n}{b_{n.1} N_{n.1} K_p} \qquad (7)$$

where b_n – crosswalk width, m;

$b_{n.1}$ – crosswalk lane width, m (0,75 – 1,0 m);

K_p – adjustment factor of traffic road lights.

Scholars Bug PG, Shelkov Y.D. offered a formula for estimating traffic delays in a pedestrian crossing area [7, 8]:

$$d_{ped} = 0{,}00147 \frac{N_n N_{mp}}{v^2} \qquad (8)$$

where N_p та N_{mp} – respectively the intensity of pedestrian (ped/h) and automobile traffic (veh /h); v – speed of movement, km/h.

In Ukraine, the issues of pedestrian crossing in the area of unregulated intersection are regulated by a number of DBN and DSTU, among them [18, 19] and the new DBN [31].

Table 8. Calculation of pedestrian crossing delay (1-1) by the method of field studies

Time		$ni_{.ч.}$, ped in period I, s				Movement, ped	
Hour	Minute	0 - 15	15 - 30	30 - 45	0 - 15	$n_{зуп.}$	$n_{б.зуп.}$
18	15	0	0	0	0	0	1
18	16	0	2	0	0	2	0
18	17	0	1	0	0	1	2
18	20	0	0	1	0	1	1
18	21	0	0	0	0	0	2
18	22	0	0	0	0	0	4
18	26	1	0	0	0	1	0
18	27	0	0	0	0	0	0
18	28	0	0	0	0	0	0
18	32	0	0	0	1	1	3
18	33	0	2	0	0	2	3
18	34	0	0	0	0	0	0
18	38	0	0	0	0	0	2
18	39	0	0	0	0	0	2
18	40	0	0	0	0	0	5
Σ		1	5	1	1	8	25

As we can see (Table 9), the results of theoretical calculations and experimental data differ significantly in the two cases (over 10% error). There are several factors that can affect this:

- Data collection accuracy;
- Data analysis accuracy;
- Data collection quality;
- The need for calculation methods adjustment.

Table 9. Calculation of crossing delay

Dir.	Crossing delay for [22]	Practical calculation according to [29]	Error, %
1-1	13,15	3,63	-72.2
2-2	13,27	8,95	-33.5

CONCLUSION

Nowadays the problem of providing capacity of both the RSN as a whole and its separate nodes – streets and their crossroads – is urgent for the city of Kyiv. Therefore, first, unregulated crossroads make up about 70% of the total number of RSN nodes in Kyiv, as the study of their work and determining the criteria for their effective functioning is an important part of the complex task of improving the whole RSN efficiency.

Second, in the current regulatory framework of Ukraine for the RSN design and operation there is no method of applying RSN design solutions of unregulated intersections. There is no assessment of its impact on the entire network operation, nor even individual criteria for such assessment.

Third, in the Ukrainian regulatory framework there is no assessment of individual transport, pedestrians, cyclists and public transportation for their mutual (comprehensive) impact on the intersection operation.

Based on the analysis of foreign literature and the regulatory framework, three indicators of the city RSN unregulated intersection operation were identified – traffic delay, queue length and load factor in the movement directions. Traffic delay is used in the United States and Germany as a key indicator of the efficiency of unregulated crossings.

However, when determining the movement delays by the "manual" method, there is a certain problem of inconsistency between the theoretical data (according to calculations [22]) and the data determined by the method [29].

Based on this, we can make some recommendations:

- Further scientific and theoretical research with the introduction of correction factors of reduction in formulas (2-3) is needed;
- Computer video processing method application to show the road situation in order to determine the traffic and pedestrians delays.

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Проблематика определения задержки движения транспорта и пешеходов в зоне нерегулируемого пересечения на городской улично-дорожной сети

Николай Осетрин, Алексей Дворко

Аннотация. Рост уровня автомобилизации в городе Киеве, которое состоялось с конца 1990-х гг. до 2008 года, способствовало увеличению интенсивности транспортных потоков в городе и перегрузке городской улично-дорожной сети (УДС). Местом концентрации транспортных и пешеходных потоков на сети является пересечения городских улиц и дорог. На УДС города Киева больше половины всех пересечений улиц и дорог приходится на нерегулируемые. Поэтому, в вышеупомянутых условиях (продолжающегося роста уровня автомобилизации, недостаточном количестве парковочных мест, решений по виделения полос для движения общественного транспорта), а также рост спроса на индивидуальные транспортные средства (сегвей, гироскутер, велосипед) вопросы оценки работы нерегулируемых пересечений является актуальным. Правильная организация дорожного движения с учетом всех участников движения является фактором эффективной работы всей системы.

Анализируя нормативную базу Украины по проектированию и эксплуатации объектов городской транспортной инфраструктуры можно выделить несколько проблемных направлений: отсутствие достаточного описания требований проектирования нерегулируемых пересечений; отсутствие комплексной оценки работы пересечения с учетом всех участников дорожного движения (автомобили, пешеходы, велосипедисты и общественный транспорт); отсутствие нормативных транспортных нагрузок. Основными показателями в этой концепции является задержка движения транспорта и пешеходов в зоне нерегулируемого пересечения, методика определения которых рассмотрена в данной статье. Предложена методика натурных измерений задержки движения транспорта и пешеходов.

Ключевые слова: улично-дорожная сеть, нерегулируемое пересечение, уровень обслуживания, задержка движения транспорта, задержка движения пешеходов.

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Оформлення:

- пишуть прямо – цифри, грецькі букви, кирилицю, тригонометричні функції (tan, sin та ін.), усталені вирази (max, const та ін.), хімічні елементи; курсивом – англійські символи формул, римські цифри, номери експлікації
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- скорочені слова «Табл.» (Table), «Рис.» (Fig.) пишуть з великої букви (в тексті – світло, в назві – н/ж); текст на полі рисунків зводять до мінімуму, пояснення дають в підписах під рисунками
- в якості розділових знаків у списку літератури використовують тільки крапку і кому (стандарт APA); кількість сторінок (діапазон) вказують без їх позначення
- приклади оформлення статей і архів журналу – див. www.uwtech.at.ua, http://library.knuba.edu.ua/node/867

Заява про публікацію
в міжнародному науковому журналі

_____
(назва журналу)

Форма 1

ІНФОРМАЦІЯ ПРО СТАТТЮ

Мова статті	**Автор(и)** (ім'я, прізвище − *мовою статті*) (предметна галузь) / (к-сть стор.)	**Документи (+/−) *** Про статтю (*ф.1*)	Про авторів (*ф.2*)	Дві рецензії (*ф.3*)	Експ. висновок (*ф.4*)	Угода про публ.(*ф.5*)	Завірений переклад	Рекомендація	**Назва статті** / **Рецензенти** (ім'я, прізвище, науковий ступінь, вчене звання − *мовою статті*)	**Замовлення** (к-сть прим.) / Оплата (грн.) Дата / Підпис
		1	2	3	4	5	6	7	*Рец.1*: *Рец.2*:	

* − наявність зазначити позначкою

Форма 2

ДОВІДКА ПРО АВТОРІВ
(*мовою статті*)

Статус			**Контакти**	
h-index (*Scopus*)	Прізвище, ім'я, по батькові науковий ступінь, вчене звання	Місце роботи, посада адреса, поштовий індекс контактний телефон	Фото автора (.jpg, 300 dpi)	Моб. тел. E-mail, ORCID Scopus Author ID Researcher ID

Форма 3

РЕЦЕНЗІЯ

(дві, зовнішні)

Повинна містити:

1) *Назву статті, Ім'я* та *Прізвище автора(ів)*
2) *Оцінку праці* (оригінальність; відповідність назви й тексту статті; методи і мета праці; термінологія; стиль викладення; граматика)
3) Інформацію про *Якість статті* (по суті й перекладу англійською) та відсутність *Плагіату*
4) *Зауваження* й *Корективи* (або вказування на необхідність передачі статті іншому рецензенту)
5) *Рекомендацію* (до опублікування; подальшого опрацювання; повторного рецензування; відмовлення у публікації)
6) Відомості про *рецензента* (ім'я, прізвище, науковий ступінь, вчене звання, місце роботи − мовою статті)
7) *Дату, Підпис* (завірений)

Форма 4

(зразок)

ЗАТВЕРДЖУЮ

(посада, науковий ступінь,
вчене звання)

П.І.Б.

« ___ » _____ 20 ___ р.

ЕКСПЕРТНИЙ ВИСНОВОК № ____

про можливість опублікування матеріалів
у пресі та інших джерелах інформації

Експертна комісія Київського національного університету будівництва і архітектури, розглянувши матеріали рукопису

_____

ім'я, прізвище автора(ів)

_____

назва статті

_____

_____

в обсязі ____ сторінок, зазначає, що в них немає відомостей, які б підлягали забороні до опублікування згідно «Розгорнутого переліку відомостей, що становлять державну таємницю у Міністерстві освіти і науки України – 2001 р.»

Висновок: матеріали рукопису дозволяється опублікувати відкрито

Керівник експертної групи П.І.Б.

Форма 5

УГОДА № _____

про вільне використання авторського права щодо періодичного видання

_____
назва журналу

м. Київ «___»_____ 20 ___ р.

Редакцією журналу *Підводні технології: промислова та цивільна інженерія*, засновником якого є Київський національний університет будівництва і архітектури з юридичною адресою: КНУБА, Повітрофлотський проспект 31, Київ, Україна, 03037, в особі головного редактора д.т.н., професора М.К. Сукача, з однієї сторони (далі – Редакція), та власник(и) майнових авторських прав в особі

_____ _____ _____,
П.І.Б. науковий ступінь, звання (ORCID)

_____ _____ _____,
П.І.Б. науковий ступінь, звання (ORCID)

_____ _____ _____,
П.І.Б. науковий ступінь, звання (ORCID)

з іншої сторони (далі – Автор(и)), які разом іменуються Сторони, керуючись Цивільним кодексом, Законом України «Про авторське право і суміжні права», іншими законодавчими і нормативно-правовими актами України, уклали цю Угоду про наступне.

п.1

1.1. Автор(и) заявляють, що вони є дійсними авторами наукового Твору/Статті під назвою

_____

_____
мовою оригіналу

який є результатом їхньої спільної творчої праці, і що вони мають відносно зазначеного твору виключне авторське право.

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п.2

2.1. Автор(и) надають Редакції вільно і без будь-яких обмежень на територію, час і кількість копій повне авторське право на Твір/Статтю з метою його опублікування у періодичному виданні *Підводні технології: промислова та цивільна інженерія* в друкованому та електронному вигляді з наступними умовами використання:

а) збереження на будь-яких носіях/медіа

б) розмноження Твору/Статті, його частин або фрагментів будь-якими відомими методами, копіювання Твору/Статті або його частин та фрагментів будь-якою технікою, зокрема друкуванням, різографією, магнітним записом та оцифруванням

в) збереження на комп'ютері та розміщення у приватних і громадських комп'ютерних мережах (у тому числі Інтернет) і поширення через мережі

г) розповсюдження оригіналу і/або копій Твору/Статті, окремих його частин або фрагментів, розповсюдження та передача в користування оригіналу або його примірників.

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п.3

3.1. Автор(и) та Редакція згодні на те, що Редакція також матиме право:

а) здійснювати необхідне оформлення Твору/Статті за результатами його редакційної обробки

б) визначати самостійно кількість видань, друк додаткових копій і тираж Твору/Статті, кількість копій окремих видань і додаткових тиражів

в) опублікування Твору/Статті в інших виданнях, пов'язаних з діяльністю Редакції, ніж вказаних у п.2.1.

п.4

4.1. Автор(и) та Редакція спільно засвідчують, що вільне використання авторських прав в межах цієї угоди є безкоштовним.

4.2. Будь-які зміни до цієї Угоди мають бути складені у письмовій формі.

4.3. Питання, не врегульовані положенням цієї Угоди, підлягають правилам Цивільного кодексу та Закону України «Про авторське право і суміжні права».

4.4. Будь-які суперечки, які можуть виникнути під час виконання та протягом терміну дії цієї Угоди вирішуватимуться в межах територіальної юрисдикції за місцем знаходження Редакції.

Угоду складено у 2 (двох) ідентичних примірниках, по одному зі Сторін.

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Наукове видання

ПІДВОДНІ ТЕХНОЛОГІЇ

ПРОМИСЛОВА ТА ЦИВІЛЬНА ІНЖЕНЕРІЯ

2020 Випуск 10

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- Усі статті одержали позитивну оцінку незалежних рецензентів
- Передрук розміщених у журналі матеріалів дозволяється тільки за письмовою згодою редакції

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