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Modeling using the LIRA 9.6 software package of contact interaction of the retaining wall with the base

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The article analyzes the research of scientists who studied the work of retaining walls under different soil conditions, and their contact interaction with the base. Examples of recent designs of retaining walls and their use are given. It is stated that the goal is to study the stress-strain state of a retaining wall with a structural surface, considering its contact interaction with the ground mass. The main stages and features of mathematical modeling of the retaining walls and soil foundation interaction in the conditions of a flat problem with the help of LIRA 9.6 software have been described. As a result, the nature of the retaining wall work has been analyzed under various conditions of interaction with the base and with different parameters of the retaining wall rigidity. The relationship between the retaining wall rigidity and the resulting equivalent stresses in the soil foundation under various conditions of interaction has been established. It has been concluded that on the contact surface of the retaining wall with a structural surface, the effect of stresses redistribution is achieved and the carrying capacity of the foundation soil is increased due to the formation of elastic cores and unloading arches.

Keywords: finite element method, retaining wall with a structural surface, modeling, stress-strain state.

Моделювання з допомогою програмного комплексу LIRA 9.6 контактної взаємодії підпірної стіни з основою

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В статті проаналізовано дослідження вчених, які вивчали роботу підпірних стін при різних ґрунтових умовах та їх контактної взаємодії з основою. Наведено приклади останніх розробок конструкцій підпірних стін та область їх використання. Мета таких досліджень полягає у вивченні напружено-деформаційного стану підпірної стіни зі структурною поверхнею з урахуванням її контактної взаємодії з ґрунтовим масивом. Описано основні етапи й особливості математичного моделювання взаємодії підпірної стіни й ґрунтової основи в умовах плоскої задачі з допомогою програмного комплексу LIRA 9.6. У результаті було проведено аналіз характеру роботи підпірної стіни при різних умовах взаємодії з основою та при різних параметрах жорсткості конструкції підпірної стіни. Виявлено залежність між жорсткістю конструкції підпірної стіни й еквівалентними напруженнями в ґрунтовій основі, які виникають при різноманітних умовах взаємодії. На підставі проведених досліджень встановлено, що на контактній поверхні підпірної стіни зі структурною поверхнею досягається ефект перерозподілу напружень та підвищується несуча здатність ґрунту основи за рахунок сумісної роботи конструкцій підпірної стіни й основи, що деформується.

Ключові слова: метод скінчених елементів, підпірна стіна зі структурною поверхнею, моделювання, напружено-деформаційних стан

Introduction

The pursuit of urban areas rational use leads to the development and search for new types of structures that are more economical and less labor-intensive. A number of requirements are imposed on the arrangement of retaining walls, most of which are based on a study of the geotechnical conditions of a territory that requires engineering protection. These structures in operating conditions are in a complex stress state, characterized by a large amount of capital costs, complexity and heterogeneity of interaction between the retaining wall design and the ground.

Special attention is paid to the methods of calculation and design of these structures in complex engineering and geological conditions. Modern methods of calculation enable to calculate the load on the wall and to simulate the stress-strain state of the soil with the help of software systems.

Methods and programs for calculating retaining walls were developed on the basis of recent advances in the field of structural mechanics, the theory of calculating reinforced concrete structures, soil mechanics, and the theory of elasticity, computational mathematics and practice. The calculation of retaining walls with design features, considering their joint work with the ground in areas with complex engineering and geological conditions, is the basis for further analytical and practical research.

Review of research sources and publications

Complex geotechnical conditions are geological environments that include specific soils, hazardous natural or man-made processes, geomorphological conditions, geological and hydrogeological factors of interaction with buildings and structures, belong to the II and III categories of engineering and geological conditions. Many scientists have devoted their work to the question of determining the lateral pressure of the soil on the retaining walls, considering their joint work with the soil mass.

So, V.F. Rauk [1, 2] investigated the nature and magnitude of the lateral pressure on the vertical face of the retaining wall, considering its deformations and displacement, using the model of a linearly deformable quarter-plane, but he did not consider the joint work of the vertical wall and foundation as a single system interacting with the ground. E.I. Chernysheva [3] investigated the question of the influence of the vertical wall flexibility on the value of the lateral pressure of the soil.

I.Ya .Luchkovsky [4], using the method of superposition, gives a solution to determine the lateral pressure of the soil on the retaining walls from narrow loads and concentrated force. He draws attention to the attenuation with the depth of the lateral pressure of the soil from the load. However, these authors in determining the lateral pressure did not consider the joint work of the vertical wall and the foundation as a single system that interacts with the ground.

I.A. Simvulidi [5] calculates a flexible retaining wall considering the interaction of all its elements with the ground, but introduces a linearly deformable half-plane as a model of the ground, both filling and base, which is not entirely correct. In addition, this method does not enable to consider the influence of the load on the stress-strain state (SSS) of the system.

A significant amount of research is devoted to the number of works on the dynamics of these structures, especially considering the elastoplastic properties of their materials, is significantly less [8, 9]. Usually, dynamic calculations are performed if the structure is subject to pulsed, vibratory or moving loads [10].

Definition of unsolved aspects of the problem

When building retaining walls in difficult geotechnical conditions, it is necessary to achieve: an increase in the stability and strength of the retaining walls; cost reduction of used building materials; reducing the volume of earthworks; reduction of non-uniformity of deformations; reduced construction time; improvement of the conditions for filling and compacting the backfill; increase of operational reliability, quality of performance of work and increase in service life of retaining walls. Thus, to assess the SSS retaining walls of the corner profile, it is necessary to consider the joint operation of the entire wall with the ground and the use of more reasonable soil models in the area of its vertical and horizontal elements.

Problem statement

The aim of the research is to study the stress-strain state of a retaining wall with a structural surface (RWSS), considering its contact interaction with the ground mass.

Basic material and results

The current regulatory documents recommend that when calculating retaining walls to perform calculations to determine the stability of the position of walls against shear, tipping, turning, to determine the local strength of the base and its bearing capacity, the strength of structural elements and joints should be ensured. It should be made calculations for base deformations. In difficult engineering and geological conditions, which are characterized by vertical and horizontal displacements of the base, which causes complex deformations in the construction of retaining walls. In such conditions it is impossible to implement the existing calculation methods [11, 12]. Earlier experiments on physical modeling [13–15] show areas of formation of elastic and plastic zones in the contact interaction of the RWSS and the deformable base.

It is known that even at low loads the soil goes into an elastoplastic state; therefore, this factor must be taken into account in the calculations. The theory of plastic flow with hardening is used, since deformation theories are not applicable under complex loading [16]. In this formulation, the problem considered here is studied for the first time. The calculation of retaining walls with a structural surface with regard to its joint work with the ground is not considered.

A promising area of research for the «retaining wall – ground» system is the use of mathematical modeling methods based on numerical analysis methods.

The most common today the finite element method (FEM) is, which forms the basis of modern software systems for calculating building structures, buildings and structures. FEM is most suitable for problems with a developed non-uniformity of strength characteristics. Compared with the classical variation methods, the FEM is more flexible in setting geometric parameters and boundary conditions, visual and universal for a wide range of tasks. At the same time, it is possible to choose different soil models for solving the set task. Regulatory documents currently in force in Ukraine [17–19] recommend performing calculations using software systems in which the FEM is implemented.

Digital and finite element models of the usual retaining wall and RWSS are presented in fig. 1 and 2. The retaining wall rests directly on the soil, represented by loam, and loam is also taken as the filling soil.

The calculation of the stability and strength of the retaining wall was performed by the FEM method using the LIRA 9.6 software package. Characteristics of the soil are given in table.1.

Table 1 – Characteristics of stiffness

Stiffness type	Name	Stiffness parameters
CE 284	Foundation soil, backfill soil	E = 1800 t/m^2 ν = 0,35 H = 100 cm C = 19,51 kPa R_t = 0,15 t / m^2

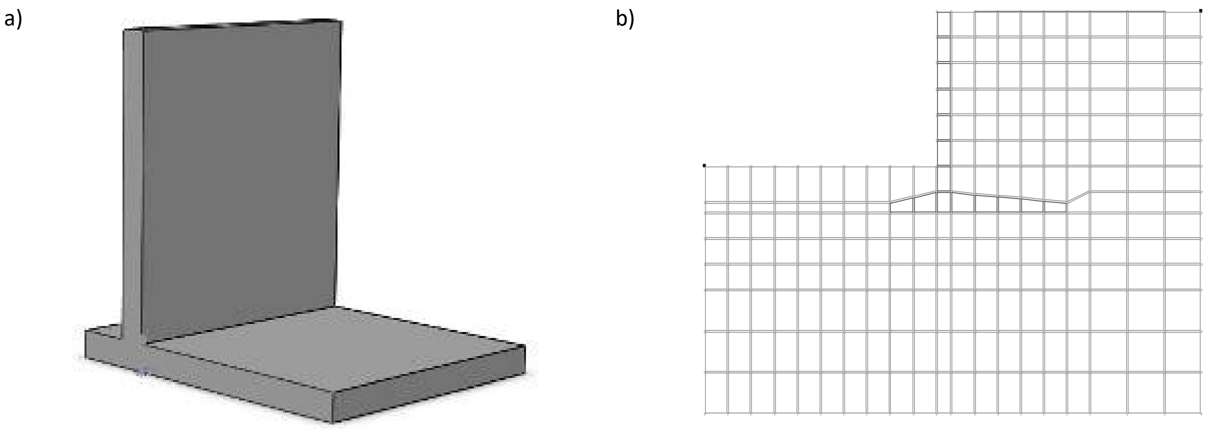


Figure 1 – Models of the usual retaining wall:
a – digital model; b – finite element model

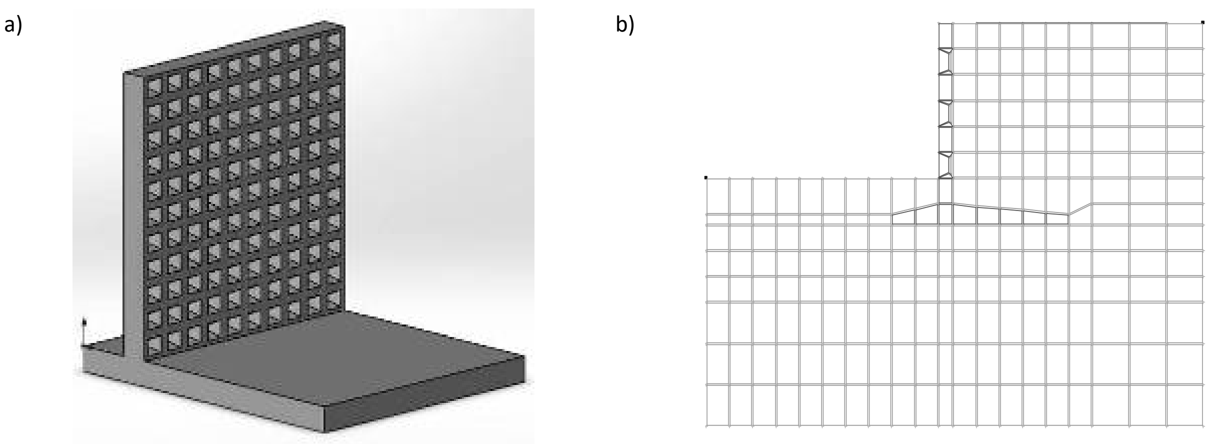
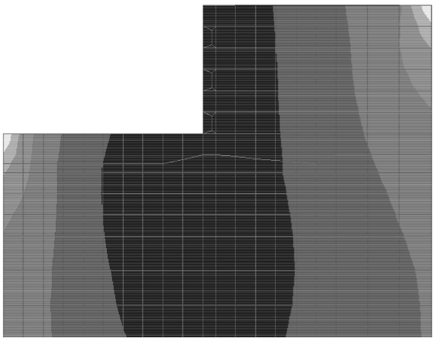
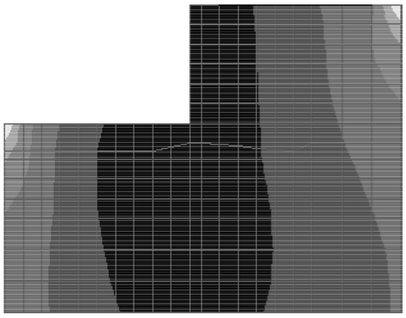
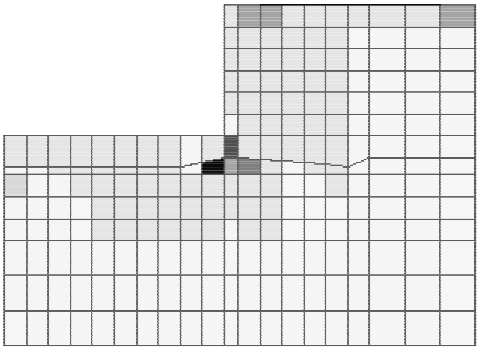
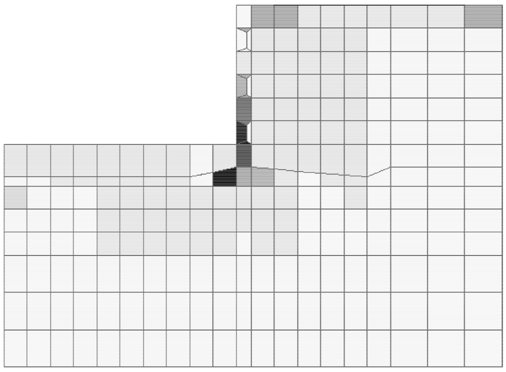
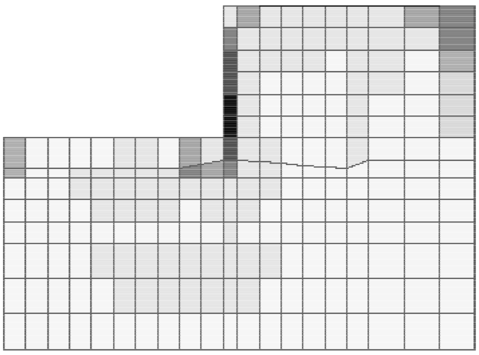
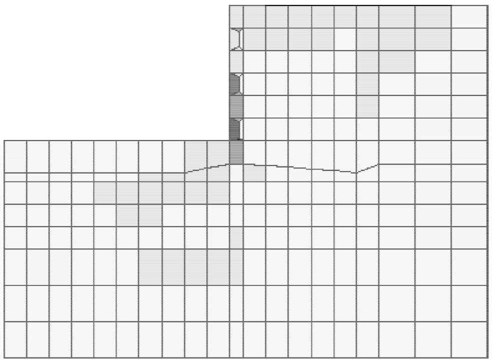
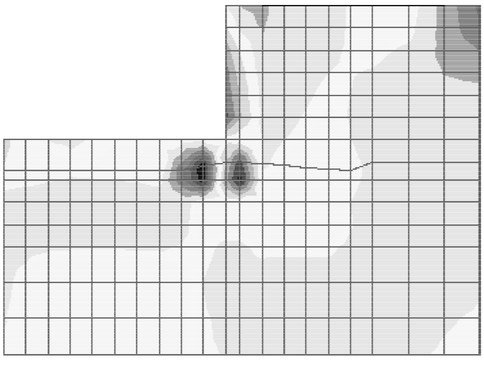
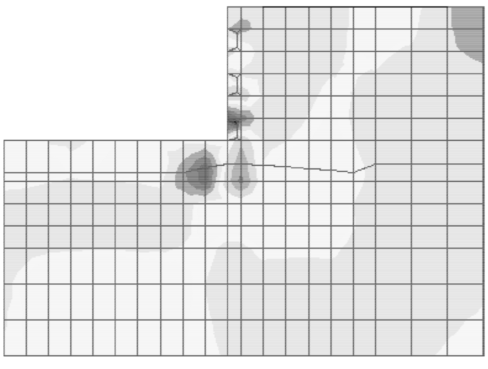


Figure 2 – RWSS models:
a – digital model; b – finite element model

Table 2 – Comparison of retaining walls

Plain corner retaining wall	Retaining wall with structural surface
1	2
Isopole displacement, mm	
	
Voltage mosaic Nx, kPa	
	
Voltage mosaic Nz, kPa	
	
Isopole voltage Tzx, kPa	
	

RWSS has vertical and horizontal elements on the surface, which are located on the contact side, supporting parts and voids in the form of truncated pyramids of the same size and directed by a smaller base into the vertical and base elements [20].

The monolithic angular retaining wall consists of a base plate, which has voids and supporting parts, which are located on the sole and on the back side of the vertical element. The soil is directed into voids, which have the shape of truncated pyramids. Under the sole of the base plate and on the back of the vertical element are two sheets of elastically flexible material. With the development of a deforming load in time, that is, with the vertical and horizontal displacements of the ground in relation to the monolithic wall of the corner type, after its installation, the soil gradually penetrates into the voids. Premature filling of voids is prevented by sheets of elastically compliant material.

The modeling of the operation of the RWSS and non-uniformly deformable base was carried out in the Lyra 9.6 software package under the conditions of a flat problem. It enabled to perform numerical modeling, calculation and design of such structures, considering the real soil conditions.

The modeling process was carried out in three stages: the creation of the calculated finite element model of the structure; creation of a calculated finite element model of a soil massif; contact surface modeling "buried construction - soil massif".

To create a computational finite element model that considers the joint operation of structures with a ground massif, finite elements were used: KE 284 – a physically nonlinear universal rectangular for a planar problem (soil); CE 10 – universal spatial rod; CE 21 – rectangular CE for a planar problem (beam-wall); CE 22 – triangular EC for a plane problem (beam-wall); CE 30 is a quadrilateral EC for a plane problem (beam-wall) [21].

The finite element model (QE model) has deformation boundary conditions, namely, the movement of the upper nodes of the model extreme points, is limited. The model height is taken from considerations of the wall joint work and the surrounding massif, which is composed of loams.

CE-models are provided with deformation characteristics - elastic modulus E and Poisson's ratio ν, R0 is the specific weight of the material. After specifying the CE-model stiffness, the load values in the load cases should be specified.

Analyzing the horizontal movements of retaining walls, it can be concluded that there is an insignificant difference in the values for both structures, with the same soil conditions and loading.

At the same time, the obtained values of Nx = 0.78 kPa, Nz = 1.57 kPa, Txz = 4.70 kPa show a decrease in contact stresses, whereas for a typical retaining wall they were Nx = 1.96 kPa, Nz = 4.9 kPa, Txz = 11.76 kPa.

SSS of finite element models of retaining walls are presented in Table 2.

In this study, the LIRA 9.6 finite element software package was used to simulate the retaining wall, which is a finite element software method and has been at a continuous improvement stage for many years.

The backfill of the ground and ground of the base was modeled using the Coulomb – Mohr model, which is an elastic-plastic model capable of considering the expansion of the ground. Considering the fact that the retaining wall is much more rigid than the foundation and backfill primer, all elements of the retaining wall were adopted as an elastic material.

Conclusions

The calculation results have confirmed the experimental studies carried out earlier. Mathematical modeling enabled to demonstrate the voltage reduction on the contact surface. Phased filling of voids leads to a uniform distribution of deformations, which in the long term increases the structure life, thereby providing an economic effect. The peculiarity of the design of the RWSS, when the soil interacts with the structural surface, increases the base bearing capacity due to the construction joint work of the retaining wall and the deformable base.

As a result of this work, scientific results have been obtained:

– the features of the base and structure SSS in the flat base conditions – retaining wall system have been identified and analyzed using the model in the LIRA 9.6 software package;

– the influence of the structural surface use of the RWSS on the soil foundation SSS during their contact interaction has been investigated;

– it has been recorded that the main stresses in a number of sections in the RWSS models are less than the stresses in the ordinary wall models by 15-18%.

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