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APPLICATION OF MODERN SOFTWARE COMPLEXES FOR MODELING THE WORK OF DAMAGED STONE STRUCTURES

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Abstract. The article focuses on the estimation problem of the residual rolling capacity and the reliability of the stone structures elements of the buildings and structures in the historical part of the cities, which are approaching the normative term of service. To prevent the destruction of existing buildings and structures and to optimize solutions related to the reinforcement and reconstruction of damaged structures, information on their residual capacity is required. The paper proposes a method for assessing residual carrying capacity in the software complex. The analysis by applying the proposed algorithm (non-destructive method) allows a real prognosis, the difference between the calculation results and the experimental research of the stone structures being 5%.

Keywords: *reliability, reconstruction of stone structures, residual capacity, software modeling.*

Introduction

Stone materials from ancient times, as well as the wooden materials, form the basis of construction, so the existing monuments of history and architecture, in the vast majority of them, were made of solid red brick on limestone and complex solutions.

It is known that a large part of them is located in large cities. These are historical centers of not only Ukrainian, but also European cities and separate houses and churches.

Modern aggressive ecology, as well as other destructive factors, worsen seriously the physical and mechanical properties of brickwork of structures of historic buildings. This suggests that brick buildings and architectural heritage buildings today are in dire need of their protection and timely restoration.

Figure 1. Diocletian Palace, listed on the UNESCO list, Croatia.

Attempts to restore architectural monuments have been already known in antiquity, but until the XVIII-XIX centuries they usually were reduced to simple repair or to restore an object with actual changes in the current history of history. As an independent discipline, the restoration of monuments originates in the middle of the XIX century. in the framework of the

Christian worldview, in which "time is evaluated as a directed process with beginning and end, past and future. Therefore, the possibility of irreversible loss of those values that form the fundamentals of culture, and hence the requirements for their unconditional preservation "[1, p. 32]. By this time, mostly engaged in repair, adjustment, and it was this value that was put into the very term "restoration".

1. The purpose of the research

Nowadays for further reconstruction or re-equipment of existing facilities for the purpose of their further exploitation, in turn, requires the availability of a universal method for assessing the actual state of the structural elements of such buildings and structures.

2. Relevance of work

The problem of estimating the residual bearing capacity and reliability of stone structures elements has also recently intensively increased due to the fact that the age of a significant part of buildings and structures in the historical part of European cities and in Ukraine, which were built 50 and more years ago, are approaching normative term of service.

In order to prevent the destruction of existing buildings and structures, as well as to optimize solutions related to the reinforcement and reconstruction of damaged structures, it is necessary to have information about their level of residual bearing capacity.

3. Normative documents

Existing Ukrainian norms - DBN B. 2. 6 - 162: 2010 and European standards regulates the calculation of such elements, taking into account the nonlinearity of deformation.

The science of the strength and methods of calculating stone structures is based on extensive experimental and theoretical studies, was created for the first time in the USSR in 1932-39. Its founder was L. I. Onishchik [1]. Noncentral compression in the stone structures are the most common type of stress state. All walls and pillars of buildings, bridges, constructions, etc. Are prone to off-center compression. In this regard, the study of the centrifugal compression of the masonry was given much attention in the studies [7-15].

However, the complexity of the phenomenon, which had to meet during the solution of the problem, was so great that, to date, there is no strictly developed theory of off-center compression masonry, and the practical solution to the problem was reduced to the development of empirical calculation formulas [16, 22, 25]. The features of the masonry work from different types of stone and mortar, as well as factors influencing its strength, were studied.

It is established that in a stone masonry, consisting of separate layers alternating between stone and a solution, during the transfer of effort across the intersection there is a complex stressed state and separate stones (bricks) work not only on compression but also on the bend, on the stretching, cut and local compression. The reason for this is the inequality of the stone bed, the uneven thickness and density of the horizontal joints of the masonry, which depends on the

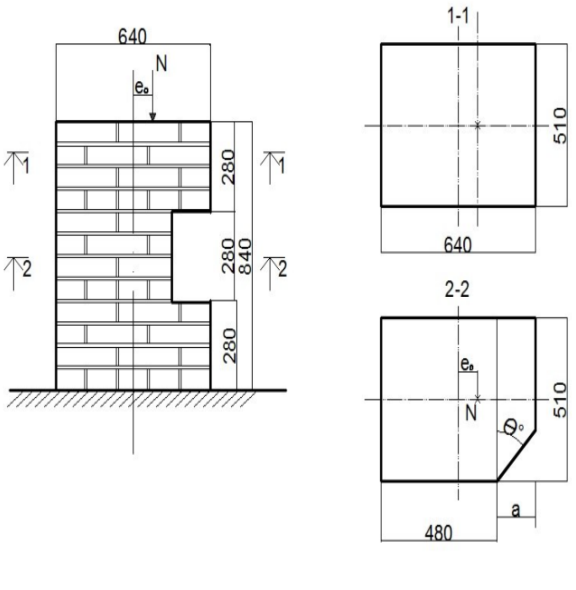

Figure 2. Diagram of simulation of damaged sample-pillar.

thoroughness of the mixing of the solution, the degree of alignment and compression at the laying of the stone, the conditions of hardening, etc. A stone masonry, made by a qualified mason, is stronger (by 20-30%) than that performed by the worker of secondary qualification. Another reason for the complex stressed state of the masonry - various elastic-plastic properties of the solution and stone. For example, the stiffer the solution, the worse the seams come out.On the strength of masonry can provide a great influence and shape of the bricks. If the surface in them is very distorted, the thickness of the seams turns out very uneven, and from this increases the bend of the brick in the masonry. Reducing the strength of masonry for that reason can reach 25%.
Belyov V. V. call a spurious analysis of the causes of defects (Table 1).

Table 1.

Quantitative assessment of the reasons for the refusal of construction sites

Causes of Avarities	Share in total
not uniform rainfall reasons	(65-75%)
overload designs	(10-15%)
temperature deformations	(10-15%)
humid deformations	(5-8%)
special load and action	(2-5%)

To prevent the destruction of structures and accidents it is needed to have information about their level of residual bearing capacity, reliability and residual resource.

The development of new numerical modeling methods allows the study of the residual duration of load bearing capacity by comparing the data obtained both with theoretical and practical studies. Establishing the most efficient and most modern method of assessing the bearing capacity of damaged structures can be done on the basis of their stress-strain analysis.

One of the main methods on the basis of which most of the applications (ANSYS, MatLab, SCAD, LIRA) are written is the finite element method used to calculate linear and nonlinear problems in various branches of science in the technical field.

One of the most popular software complexes used by most of our country's scientists and researchers who are studying and improving building constructions is the PC LIRA software package, which has gained popularity [5, 6, 8, 9]. That is why we decided to use PC LIRA 9.4 development of the Institute of Nuclear Physics, Kyiv. Based on the analysis of scientific and technical literature and preliminary studies [18-21, 23, 24], an experiment was planned on three the most significant factors influencing the residual bearing capacity of damaged stone pillars of a rectangular cross section, namely: depth of damage, angle of inclination of the front of the damage on one of the main axes of the intersections and eccentricity.

Before conducting modeling in the PC LIRA in the laboratory of OSACEA experiments [4] were conducted on the examination of the bearing capacity of damaged stone pillars.

4. Modeling in pc lira

According to the current norms, on the proposal of L. I. Onishchik diagram of "stress-deformation" for the masonry has the following form (Figure 3).

To construct the dependence curve "ε - σ" for this masonry, we use the preconditions for calculating from the textbook Vakhnenko P.F.

$$\varepsilon = \frac{\sigma_1}{E_0 \cdot \left(1 - \frac{\sigma_1}{1.1 \cdot R_u}\right)} \tag{1}$$

where:
E_0 - initial modulus of masonry deformation (modulus of elasticity at stressed, close to zero)
R_u - average compressive strength

The initial modulus E_0 of elasticity can be expressed through the ultimate strength:

$$E_0 = \alpha \cdot R_u \tag{2}$$

where:

α - elastic characteristics of the masonry, which depends on the type of masonry and brand of the solution.

The strength of a masonry, studied in this work is theoretically determined by the formula of L.I. Onishchik:

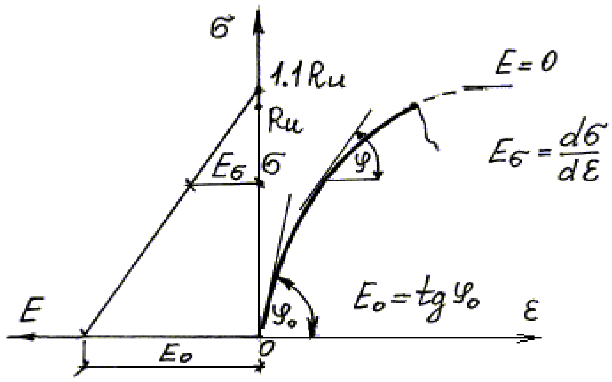

Figure 3. The deformation pattern of the masonry.

$$R_u = AR_1\left(1 - \frac{a}{b + {R_2}/{2R_1}}\right) \tag{3}$$

where:

R_1 - the compressive strength of the stone;

R_2 - strength of the solution (cubic strength);

A — coefficient that characterizes the maximum possible strength of the masonry and is determined by the formula:

$$A = \frac{100 + R_1}{100m + nR_1} \tag{4}$$

γ — coefficient that is used in determining the strength of masonry on different solutions of low grades (M25 and below)

In this case, the brand M25: = 11.1 MPa; = 5.52 MPa; a = 0.2;
b = 0.3; m = 1.25; n = 3 (Table 2 [75]); A = 0.46; γ = 1 substituting in the formula (3)

$$R_u = 0{,}46 \cdot 11{,}1 \cdot \left(1 - \frac{0{,}2}{0{,}3 + {5{,}52}/{2 \cdot 11{,}1}}\right) \cdot 1 = 3{,}24\ \text{МПа} \tag{5}$$

$$E_0 = \alpha \cdot R_u = 1200 \cdot 3{,}24 = 3800\text{Мпа} \tag{6}$$

To solve the problem, it is necessary to construct a graph of the dependence of "ε - σ" by substituting the coordinates into formula 3 (Tab. 2). Using the Microsoft Excel software program, the resulting characteristic points are presented as a graph.

Table 2.

The dependence of "ε - σ" by substituting the coordinates into formula 3

R_u	E_0	σ	ε
3,24	3800	0	0
		0.5	0.000153
		1	0.000366
		1.5	0.000682
		2	0.001201
		2.5	0.00221
		3	0.005019
		3.24	0.009486

The resulting calculation results are presented in Figure 4

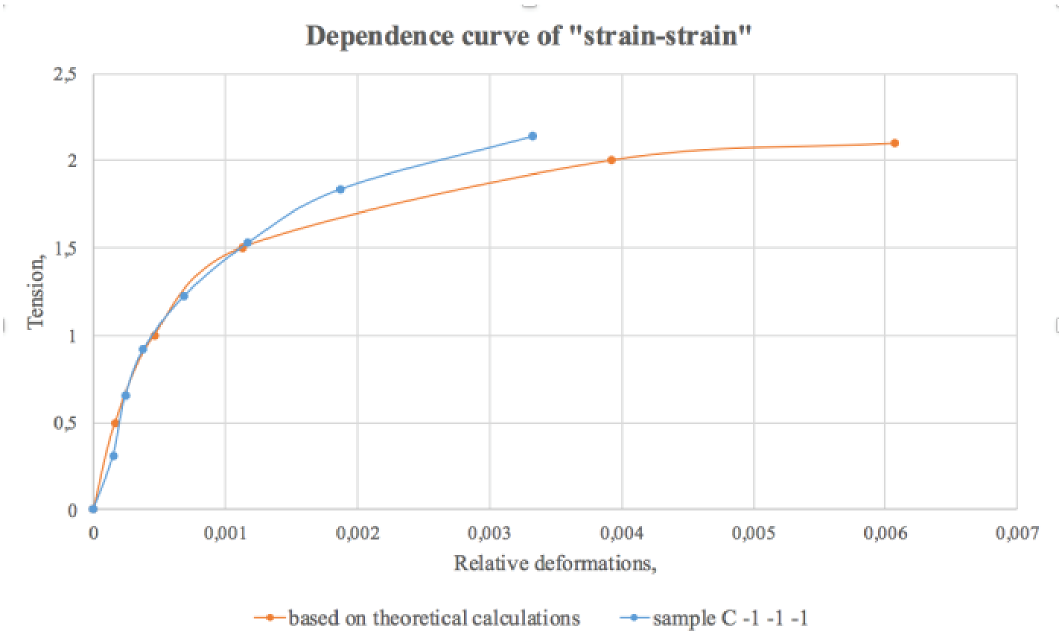

Figure 4. Graph of tension and deformation.

The method of evaluation of residual bearing capacity in the software complex, non-destructive method is proposed hereafter. At the first stage, we create points on coordinates, which later connect and set the boundary conditions to nodes in five degrees of freedom. At the second stage, we set the stiffness of the elements. Using the "Hardness → Hardness Elements" menu, we call the "Elemental Hardness" dialog. In this window, click on the "Add" button to display the list. Choose the third dialog "Plastic, Volume, Numerical", the type of section - "Volume Limit Elements", and then put a tick on the account of nonlinearity and press "parameters of the material", choose the "law of nonlinear deformation", in our case, it is 14 (piecewise -linear law of deformation), and then we introduce data on the characteristics of the material from the received graph of the dependence of "stress-deformation" (Figure 4)

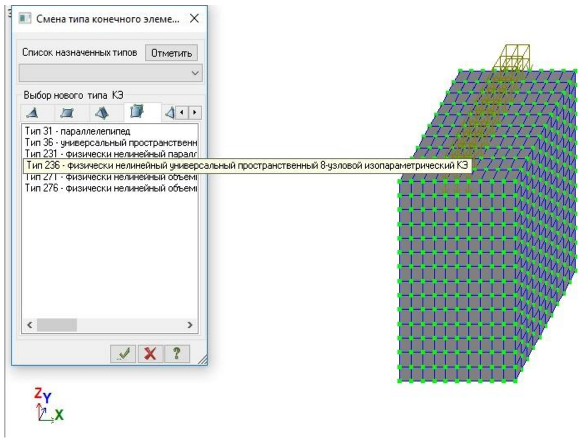

Figure 5. Selecting the type of the final element.

The pillar was divided into finite elements in the form of rectangular parallelepipeds with a face dimension of 1 to 2 cm, as well as octal and six-node endpoints in the form of triangular and quadrangular prisms in places where this required the geometry of the sample for modeling the slope of the shelves and the front of the damage.

The laying was given by physically nonlinear spatial eight-node and six-node isoparametric KEs of type 236 - "physically nonlinear universal spatial 8-node isoperimetric Limit Elements" (Figure 5) and a metal plate for the transfer of load 234, taking into account geometric and physical nonlinearity.

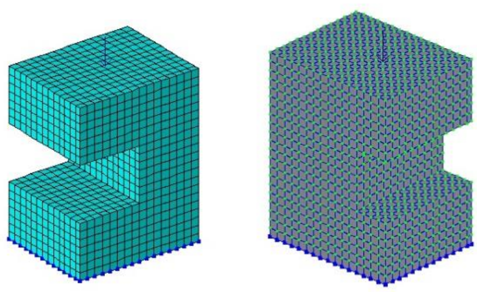

Figure 6. Finite Element Model of a Damaged Column.

The resulting model is close to a full-scale experiment (Figures 7, 8). We perform the calculation of the model, and the results are obtained in tabular form.

Figure 7. Isolation of normal voltages in t/m^2.

Figures 7, 8 show that in the case of small areas of damage, the protective layer of concrete is less, compressing stresses are approximately the same throughout the section under consideration. In the case when the rebars of concrete exposed the reinforcing bars, a redistribution of compressive stresses on the reinforcement is observed, which provides additional strength of the damaged columns during compression.

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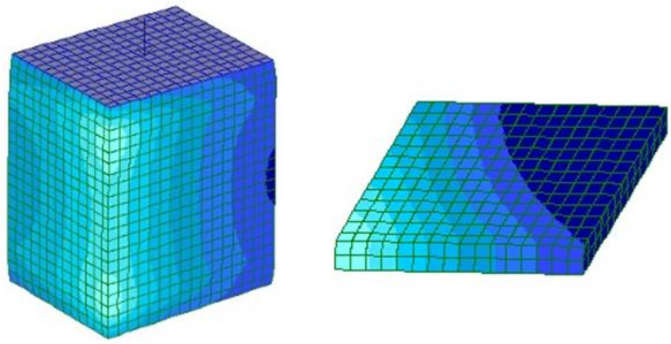

Figure 8. Isolation stresses in the C -1-1-1 column.

In all the specimens examined, the neutral line in the damaged section is beyond its limits and has the form close to the straight line. It is parallel to the damage front in the case of its parallelism of one of the main axes of the section. In the case of "skew" damage, the turn of the neutral line occurs relative to the main axes of the section and the front of the damage.

Conclusion

The analysis of the above method of calculating the damaged stone pillar allows us to conclude that this method completely takes into account the actual work of the material. The difference between the calculation results and the experimental research of stone structures is within 5%.

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