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EXPERIMENTAL-STATISTICAL MODELING OF THE WORK STONE PILLS DAMAGED IN THE OPERATION PROCESS

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Abstract. During the experimental and statistical research, the experiment was planned for the three most important factors influencing the residual load-bearing capacity of damaged stone columns rectangular cross section, namely, the depth of damage, the angle of the front damage on one of the main sections of soy and eccentricity.

Numerical modeling of work of the eccentrically compressed rectangular cross section damaged during the operation of stone pillars was carried out in the LIRA-SAPR software package in a non-linear environment.

The results of experimental statistical modeling made it possible to determine the influence on the throughput of each selected factors, as well as the mutual influence of the factors.

Based on the obtained values of the destructive force for 15 column marks, in accordance with the experimental design, a three-factor experimental-statistical model of the second order was constructed. This model is adequate to the experimental error of 0.45, with 7 statistically significant factors.

According to the estimates of the experimental statistical model and single-factor local fields, the depth of damage in the cross section of the column has the greatest impact on the bearing capacity.

The analysis of the presented diagram of the joint effect of the variables factors shows, that the maximum destructive loading of the Ru withstands columns with no damping depth (a = 0 mm) and the angle of inclination of the front of the damage and relative eccentricity are approximately at the main levels (x_1=x_3 ≈ 0).

Keywords: experimental-statistical modeling, stone pillar, damage, bearing capacity.

ЕКСПЕРИМЕНТАЛЬНО-СТАТИСТИЧНЕ МОДЕЛЮВАННЯ РОБОТИ КАМ'ЯНИХ СТОВПІВ, ПОШКОДЖЕНИХ В ПРОЦЕСІ ЕКСПЛУАТАЦІЇ

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Анотація. Отримано експериментально-статистичну модель для опису впливу різних видів пошкоджень на залишкову несучу здатність пошкоджених у процесі експлуатації кам'яних стовпів. Вибрані найбільш розповсюджені та кількісно значимі фактори, також встановлено вплив як одного з видів пошкодження, так і у взаємодії кількох таких факторів як, глибина пошкодження, кут нахилу фронту пошкодження по одній з головних осей перетинів і ексцентриситет.

За оцінками експериментально-статистичної моделі і однофакторних локальних полів, найбільший вплив на несучу здатність надає глибина пошкодження в перетині стовпа, а максимальне навантаження витримують стовпи з кутом нахилу фронту пошкодження 18-22,5° та з відносним ексцентриситетом близько 1/8 прикладеного навантаження.

Ключові слова: експериментально-статистичне моделювання, кам'яні стовпи, пошкодження, несуча здатність.

ЭКСПЕРИМЕНТАЛЬНО-СТАТИСТИЧЕСКОЕ МОДЕЛИРОВАНИЕ РАБОТЫ КАМЕННЫХ СТОЛБОВ, ПОВРЕЖДЕННЫХ В ПРОЦЕССЕ ЭКСПЛУАТАЦИИ

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Аннотация. Смоделирована экспериментально-статистическая модель для описания влияния различных видов повреждений на остаточную несущую способность поврежденных в процессе эксплуатации каменных столбов. Выбраны наиболее распространенные и количественно значимые факторы, также установлено влияние как одного из видов повреждения, так и во взаимодействии нескольких таких факторов как, глубина повреждения, угол наклона фронта повреждения по одной из главных осей сечений и эксцентриситет.

По оценкам экспериментально-статистической модели и однофакторных локальных полей, наибольшее влияние на несущую способность оказывает глубина повреждения в сечении столба, а максимальная нагрузка выдерживают столбы с углом наклона фронта повреждения 18-22,5° и с относительным эксцентриситетом около 1/8 приложенной нагрузки.

Ключевые слова: экспериментально-статистическое моделирование, каменные столбы, повреждение, несущая способность.

Formulation of issue. Modern aggressive environment and other destructive factors impair seriously the physical and mechanical properties of masonry structures of historic buildings. This suggests that the stone buildings and structures that belong to the architectural heritage today are in dire need of protection and timely restoration.

For further reconstruction or re-equipment of existing objects for the purpose of their further exploitation, in turn it requires the availability of a universal method for assessing the actual state [1] and the analysis of factors affecting the residual bearing capacity of damaged stone pillars, both individually and in interaction with each other.

Analysis of the recent researches and publications. The study of damaged during operation non-central pressed damaged pillars of works devoted a lot of domestic and foreign scientists [2-5]. Most of the works devoted to the consideration of such issues as determining the carrying capacity and strength elements [4], the influence of various factors such as an eccentricity. In фrticles by Klymenko I.V. [3-5] it is emphasized that the current definition and forecasting of technical condition of building structures and buildings carried out intuitively and requires more detailed study. The current DBN V.2.6-162: 2010 requires the calculation of damaged stone elements, taking into account not the linearity of deformation.

This method is the most correct, since it corresponds to the real physical model of the masonry work as a non-uniform material.

During recent years, Odessa State Academy of Civil Engineering and Architecture has studied the work of non-centrally compressed and damaged in the process of exploitation of stone structures, allowed to obtain data for further description of their stress-strain state and to develop a method for calculating residual bearing capacity [2].

The purpose and objectives. Experimental-statistical investigations of the deformed state and determination of bearing capacity of non-centrally compressed stone pillars with various damages obtained during the operation, determination of the influence of each selected factors and their mutual influence on the bearing capacity of structures.

The object of researches. The object of the researches was the impact of various types of damage to stone pillars resulting from the operation of the bearing capacity.

General part. The tasks put in practice are reduced to the construction of a mathematical model that describes the whole set of parameters chosen by us and find the numerical values of these parameters. For practical description of the mathematical model of samples properties, methods of experimental-statistical planning were used, which allows taking into account the stochastic nature of the processes taking place in the investigated objects.

Taking into account, that the accepted model of the experiment is manageable, it can be schematically described using a black box model, the internal device of which is unknown, and only its inputs X_i and Y_i outputs are investigated and thus the external environment is stabilized (Fig. 1).

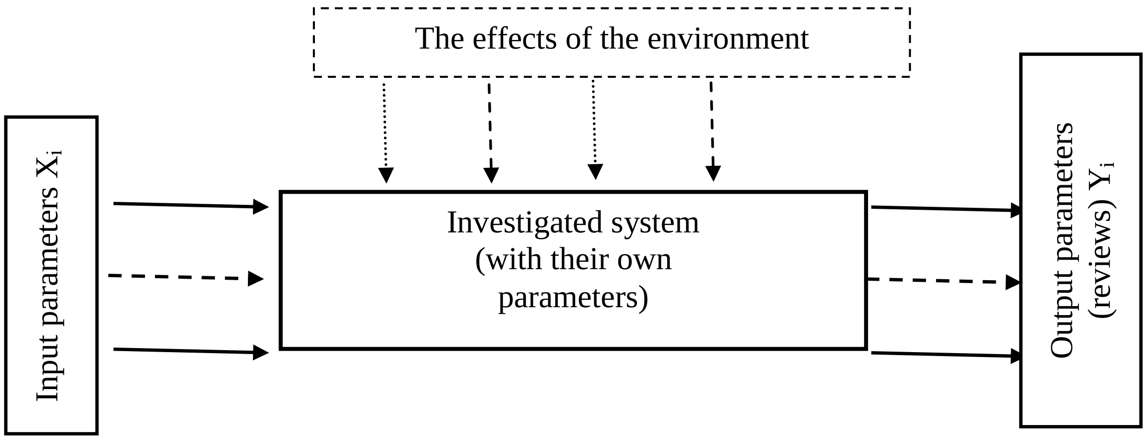

Fig. 1. Statistical model of the experiment

Analysis of scientific and technical literature and preliminary studies allowed to determine the input factors and the boundaries of their scope. The transition to the dimensionless normalized variables $-1 \le x_i \le +1$ is performed according to the following formula: $x_i = (X_i - X_{oi}) / \Delta X_i$ (Table 1).

Table 1 – Variation of input factors

Input factors			The levels of variation			The interval of variation
Code	Value	Meas.unit	«-1»	«0»	«1»	ΔX_i
x_1	The angle of inclination of damage θ	deg.	0	22,5	45	22,5
x_2	The depth of the damage a	mm	0	80	160	80
x_3	The relative eccentricitye_0/h	-	0	1/8	1/4	1/8

The obtained set of the investigated system sates allows us to analyze the dependence of the initial parameter of the samples bearing capacity on the determined factors x_1, x_2 i x_3.

Full factorial design for three factorial experiment has 27 lines – state of the object, which is excessive for the task, therefore, for the practical optimization of the accepted experimental model, a 15-point symmetric plan was adopted. With this approach, as a result of the experiment, we will receive a statistically reliable result with a minimum number of investigated samples.

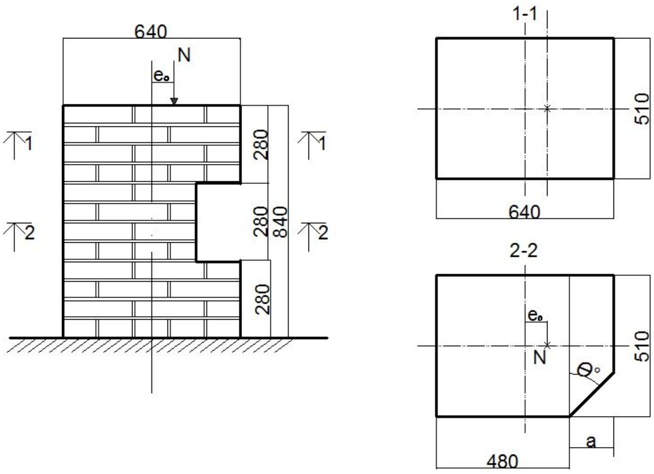

Fig. 2. Scheme for modeling of damaged sample-pillar

The formed matrix of the experiment with Physical variables of variation of the investigated parameters for a three-factor quadratic ES-model has the form (Table 2).

Table 2 – Physical variables of the studied parameters

Experiment No.	The coded values of factors			Actual Values of Variation Factors		
	x_1	x_2	x_3	The angle of inclination of damage θ, deg.	The depth of the damage a, mm	The relative eccentricity e_0/h
1	-1	-1	-1	0	0	0
2	-1	1	-1	0	320	0
3	0	0	-1	22,5	160	0
4	1	-1	-1	45	0	0
5	1	1	-1	45	320	0
6	-1	0	0	0	160	1/8
7	0	-1	0	22,5	0	1/8
8	0	0	0	22,5	160	1/8
9	0	1	0	22,5	320	1/8
10	1	0	0	45	160	1/8
11	-1	-1	1	0	0	1/4
12	-1	1	1	0	320	1/4
13	0	0	1	22,5	160	1/4
14	1	-1	1	45	0	1/4
15	1	1	1	45	320	1/4

Based on the received values of the destructive force ($\mathbf{R}_u$, tf) for the 15 variations of the pillars, according to the experimental plan, a 3-factor experimental-statistical model (ES-model) of the 2nd order (1) was constructed. The ES model is adequate for an experiment with the error $s_e[\ln\{\mathbf{R}_u\}] = 0.45$, with 7 statistically significant coefficients.

$$\begin{aligned}\ln\{\mathbf{R}_u\} = 4.075 &+0.497x_1 - 0.721x_1^2 + 0.634x_1x_2 \pm 0x_1x_3 \\ &-1.008x_2 \pm 0x_2^2 \pm 0x_2x_3 \\ &-0.239x_3 - 0.374x_3^2 \end{aligned} \quad (1)$$

The main general indicators of the model in the coordinates extremes for $\mathbf{R}_u$ include a minimum $\mathbf{R}_{u.min}$ = 1,8 tf (for x_1=–1, x_2=x_3=+1) and maximum $\mathbf{R}_{u.max}$ = 168,7 tf (for x_1=–0.095, x_2=–l, x_3=–0.320) levels; absolute $\Delta\{\mathbf{R}_u\}$ = 166.9 tf and relative $\delta\{\mathbf{R}_u\}$ = 93.7 times.

Estimates of the coefficients of the model and generalizing indicators characterize the individual and combined effects of the inclination angle of the damage front (θ, degrees), the depth of damage (a, mm), and the relative eccentricity (e_0/h) of the cutoff on the level of destructive force. The visualization of this effect is presented on Fig. 3 and 4

According to the estimations of the ES-model and single-factor local fields (Fig. 3), the significant influence on $\mathbf{R}_u$ makes x_2 with the increase of the depth of damage in the section of the column significantly decreases the destructive load, so in the zone of maximum values of 8.5 times.

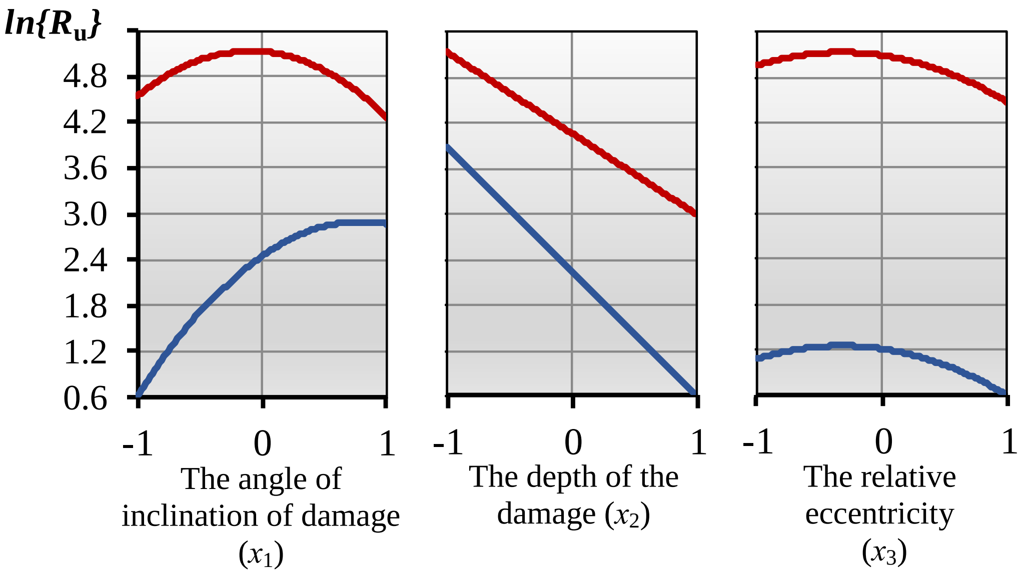

Fig. 3. Single-factor dependence of influence variation of input factors on destructive load

Due to the fact that the maximum boundary force of $\mathbf{R}_{u.max}$ is achieved on products without depth of damage (x_2=–1), the subsequent analysis of the other two factors x_1 and x_3 influence is logically conducive to two factor models (2):

$$\mathbf{ln\{R}_u\mathbf{\}} = 5.083 - 0.137x_1 - 0.721x_1^2 \pm 0x_1x_3 - 0.239x_3 - 0.374x_3^2 \quad (2)$$

From the analysis of the model it follows: the limiting load of sample pillars depends on the magnitude of inclination angle of the damage front x_1, and on the relative eccentricity x_3. So, with an increase in the eccentricity e_0/h (assuming x_1=–1) of the applied load, $\mathbf{R}_u$ it first grows by about 18% for x_3=–0.40, and then decreases by about 47% for x_3=+1. Influence of inclination angle of the damage front (provided x_3=–1) on the external load is slightly larger. With the change of X_1 from 0 to 22.5° $\mathbf{R}_u$ increases by 79%, and with further change of X_1 from 22.5° to 45°, the destructive load decreases more than 2 times (from 140.9 to 59.7 tf).

The analysis of the presented diagram (Fig. 4) constructed on the two-factor model (2) shows that the pillars can withstand the maximum load in $\mathbf{R}_u$=167.1 tf, but only if the inclination angle of the damage front (X_1) is about 18-22.5°, and the relative eccentricity (X_3) will be about 1/8 of the applied load.

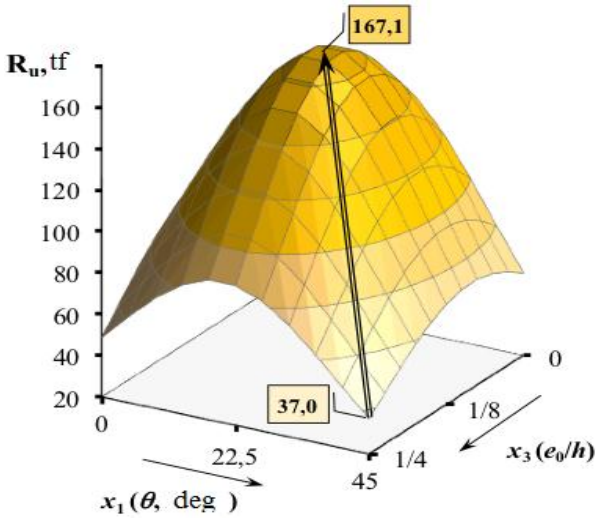

Fig. 4. Influence x_1 and x_3 on the destructive loading of the pillars in the absence of damage to the columns $x_2 = -1$

Conclusions and perspectives of further research:

1. The results of experimental-statistical simulation allowed to determine the effect on the bearing capacity of each of the selected factors, as well as the mutual influence of factors.

2. Based on the received values of the destructive force for the 15 variations of the pillars, in accordance with the experimental plan, a 3-factor experimental-statistical model of the 2nd order was constructed. This model of experiment is adequate with an error of 1.57 tf, with 7 statistically significant coefficients.

3. According to estimates of the experimental-statistical model and single-factor local fields, the depth of damage at the intersection of the column most strongly affects the bearing capacity.

4. From the analysis of the presented diagram of the joint effect of the variables, it is evident that the maximum destructive loading of the $\mathbf{R_u}$ holds the columns with no damping depth (a = 0 mm) and the inclination angle of the damage front and the relative eccentricity are approximately at the main levels ($x_1 = x_3 \approx 0$).

5. In the further research it is necessary to develop, based on the basic preconditions of the existing norms, the method of calculating the residual strength of damaged stone pillars with various injuries.

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