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ELASTIC-PLASTIC ANALYSIS OF THE BEARING CAPACITY OF ANTI-KARST REINFORCED CONCRETE BEAM FOUNDATION

The paper illustrates the results of engineering calculations and numerical simulation of the "base – foundation – building" system operation for studying the efficiency of the foundation beam application as a constructive measure of anti-karst protection.

***Keywords**: anti-karst foundation, mathematical modeling, elastic-plastic analysis.*

Introduction

Current tendency towards increasing the construction volumes has set a number of requirements to designers as to the rational use of territories including the use of karstland for construction of buildings. At the same time traditional engineering anti-karst structures do not make it possible to take into account special geological conditions arising during karst cavity formation. A new constructive anti-karst protection of a framed industrial building is designed to ensure its normal operation when the base is affected by a karst cavity [2].

Karst processes complicate significantly construction and operation of buildings and structures. Ukrainian and foreign practice of engineering-construction exploration of karst-prone territories shows that safety and efficiency of engineering solutions depends primarily on adequate consideration of special engineering geological conditions (including technogenic ones) of the karst process development and its manifestation in the base of structures.

Mathematical modeling of the foundation structure operation

In designing the structure foundations there is a necessity for experimental substantiation of the foundation design variant, which increases significantly its cost. Under such conditions mathematical modeling of the foundation structure operation under load is rational to be used. In the paper the subsidence process of the foundation beam of a one-storied framed structure under the action of karst is simulated.

In the calculations, performed during simulation of the "base – foundation – building" system functioning process, stress-strain state of the soil in its natural condition without karst processes was taken into account. Calculations for simulation of karst-suffossian processes in the base of the building were also performed. For this formation of karst cavities with a 9m diameter under the central column of the second row of the frame has been simulated.

The simplest methods for simulation of a karst cavity under the foundation bottom are those with the application of elastic-plastic model or a model of variable coefficient of the bed, which makes it possible to take into account the base inhomogeneity and its actual distributive ability. The paper uses scientific-methodological analysis of the method for soil array simulation with the application of an elastic-plastic model for studying the stress-strain state (SSS) of inhomogeneous and anisotropic material environments in order to ensure their stability and strength. To determine SSS of the elements of the "base – foundation – building" system, calculations were performed with the application of PC LIRA that realizes the finite element (FE) method. General view of computer model of the frame is presented in Fig. 1, 2.

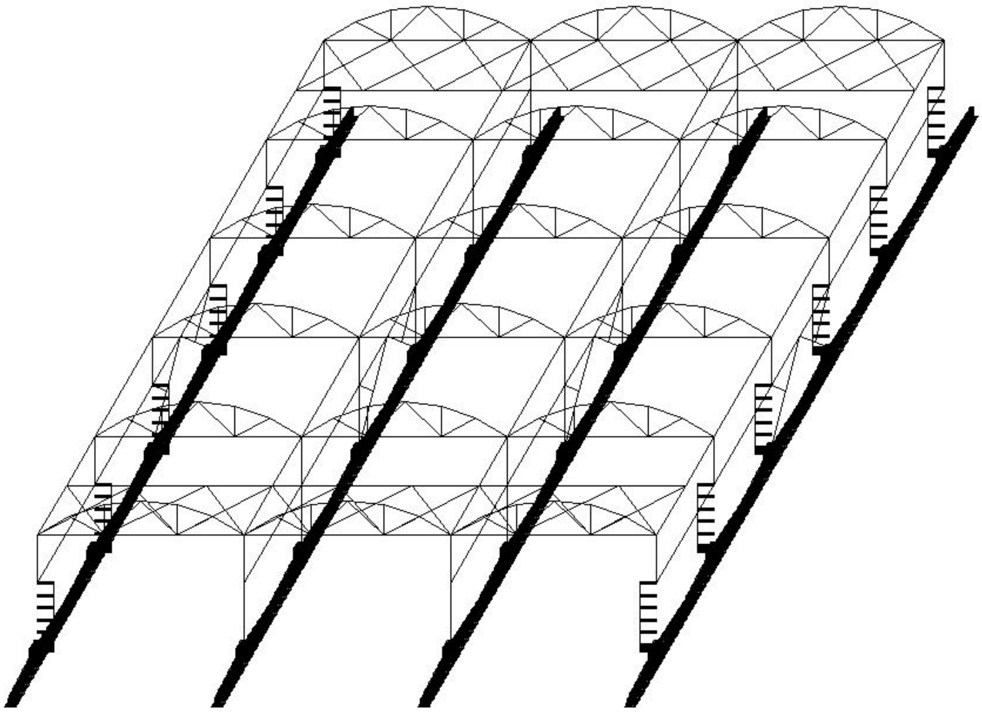

Fig. 1. General view of the computer model of the building frame

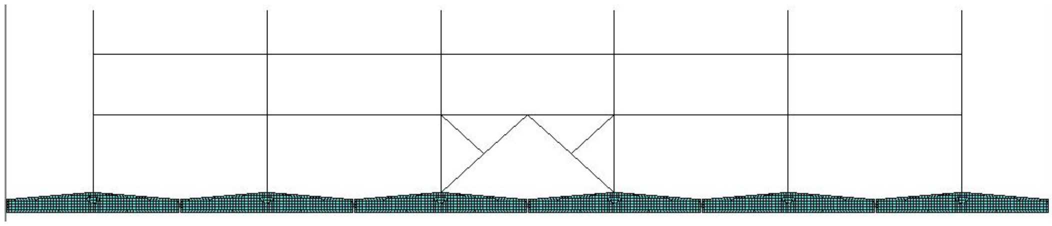

Fig. 2. General sectional view of the computer model of the building frame along digital axes.

For design scheme formation the following FE were used:

– flat FE (a shell with 6 degrees of freedom in the node) with stiffness coefficients in the vertical direction – for simulation of the foundation cushions and the base;

– rod FE (a rod with 6 degrees of freedom in the node) – for simulation of the design elements of the frame;

– 3D FE for simulation of the foundation beams;

Three-dimensional computer model reflects the object design solution and includes plate, rod and 3D elements, basic geometrical and physicomechanical characteristics of which are presented in Table 1.

Table 1.

Stiffness of the elements in the design scheme

№ п.п.	Element	Physical mechanical and geometrical parameters*	Location (purpose) in the design circuit
1	Plate	E=2.3e+006, V=0.2, H=20, Ro=2.4	Foundation cushions
2	Plate	E=2.0 e+007, V=0.35, H=10, Ro=7.8	Plates of beam joints
3	Square tube	Profile «Molodechno» 80×80×3	Horizontal and vertical decorations
4	Bar	E=2.3e+006, Ro=2.5, B=50, H=80	Columns
5	Bar	E=2.3e+006, Ro=2.5, B=15, H=15	Cross-stays of trusses

6	Bar	E=2.3e+006, Ro=2.5, B=25, H=30	Chords
7	I- beam	E=2.3e+006, Ro=2.5, H=140	Crane beam
8	3D FE	E=2.3e+006, V=0.2, Ro=2.5	Foundation beam

Design scheme of the base is a linearly deformed half-space. In PC «LIRA» the design model of the base is represented by stiffness coefficients of the base for flat DE (design elements), located on XOY surface, which simulate the foundation cushions.

Calculation parameters of the foundation base soils are adopted in accordance with engineering-geological conditions of the real construction site located in Kuznetsovsk, Rivne region.

Design scheme of the base is represented by a system of mutually influenced calculation areas of the foundations, which makes it possible to perform calculations of the base for two groups of boundary conditions. Stiffness coefficients of the base in the design schemes are determined from the solution of the contact problem. Calculations were performed by iteration method. At the zero iteration stress-strain state of the structure was determined for equal stiffness coefficients of the bases for all calculation areas of the foundations. Then calculations of subsidence and stiffness coefficients of the base were performed. In the first and further iterations calculations of the structure were sequentially performed taking into account the above-mentioned stiffness coefficients of the bases and coefficients for the next iteration were estimated. The design scheme obtained as a result of solving the contact problem was used for simulation of the karst cavity formation. Failure of the base in the karst cavity area is simulated by elimination of the foundation cushion elements, that get into the cavity region of the calculation diameter, from the design model.

Calculation of the base stiffness coefficients have been performed for main combination of the loads and for combination of the loads when a karst cavity is formed. For simulation of the karst cavity under the column additional iterations were performed until balanced state of the "base – foundation" system was achieved on the foundation areas near the karst cavity. Calculated values of the foundation base stiffness coefficients are in the range from 2450 to 4400 t/m^3, provided that there are no karst cavities (Fig. 3), and in the range of 2300 – 4400 t/m^3 if a cavity with a 9 m diameter is simulated (Fig. 4).

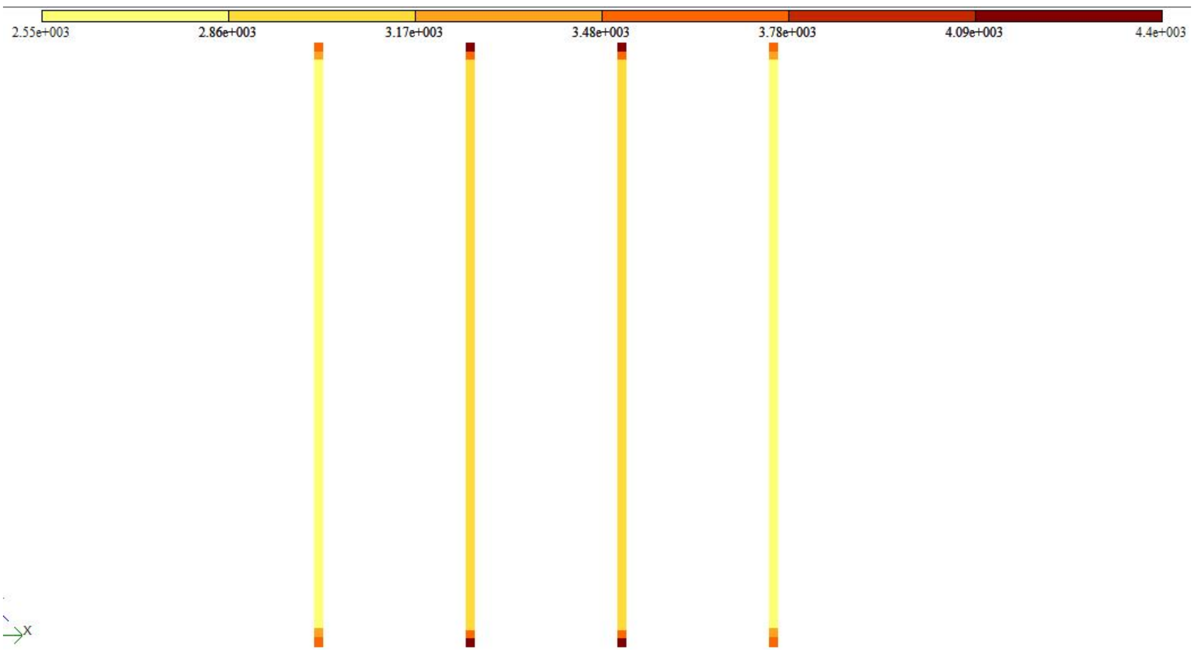

Fig. 3. Mosaics of distribution of the calculated base stiffness coefficient values under normal operating conditions

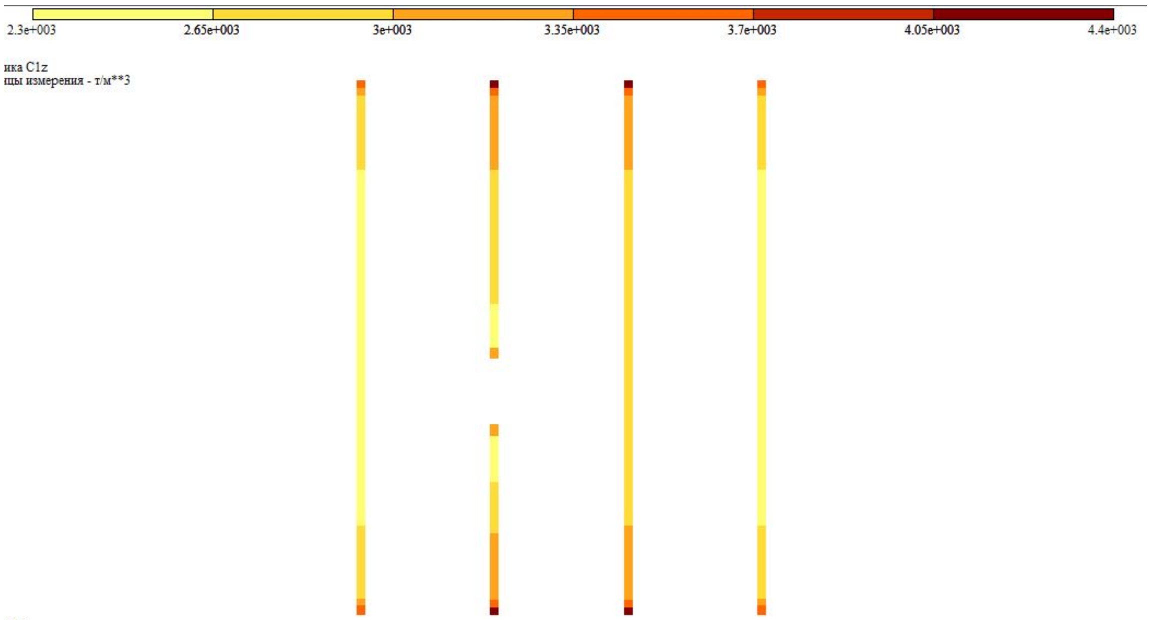

Fig. 4. Mosaics of distribution of the calculated base stiffness coefficients values when a karst cavity with 9m diameter is simulated, t / m³

The calculated resistance of the base soil in natural conditions is 24.5 t / m^2. Maximal value of pressure along the bottom under normal operating conditions of the base reaches 18.3 t / m^2,which does not exceed the calculated resistance of the base soil. In accordance with the performed calculations maximal values of subsidence reach 6.4 mm. Maximal relative difference between the values of subsidence of foundations is 0.0003, which does not exceed $(\Delta s / L)u = 0.002$.

When a karst cavity under the column is simulated, distribution of pressures along the bottom of foundation cushions changes at the distance of about 12 – 13m from the cavity edge. Pressure along the bottom of end cushions of the foundation beam, under which a karst cavity is simulated, increases by 80% and reaches 25 t / m^2 on the average, which exceeds the calculated resistance of the base. The scheme of the pressure value distribution over the foundation cushions before and after the karst cavity formation is presented in Fig. 5.

Conclusions

Maximal value of pressure along the foundation bottom is observed in the end area of a karst cavity and reaches 33.2 t / m^2 (average value along the calculation area of the foundation is 25 t / m^2), which exceeds the calculated resistance of the foundation soil).

Maximal additional values of vertical deformations of the base under the foundation bottom when a karst cavity is formed reach 11.8 mm in the same area where the maximal pressure is observed. Isofields of the total subsidence values are presented in Fig. 6.

Maximal relative difference between the foundation subsidence values is 0.003, which does not exceed $(\Delta s / L)u = 0.002$. Stiffness of the foundation plate is sufficient for ensuring normal operation of the building frame under the influence of karst processes.

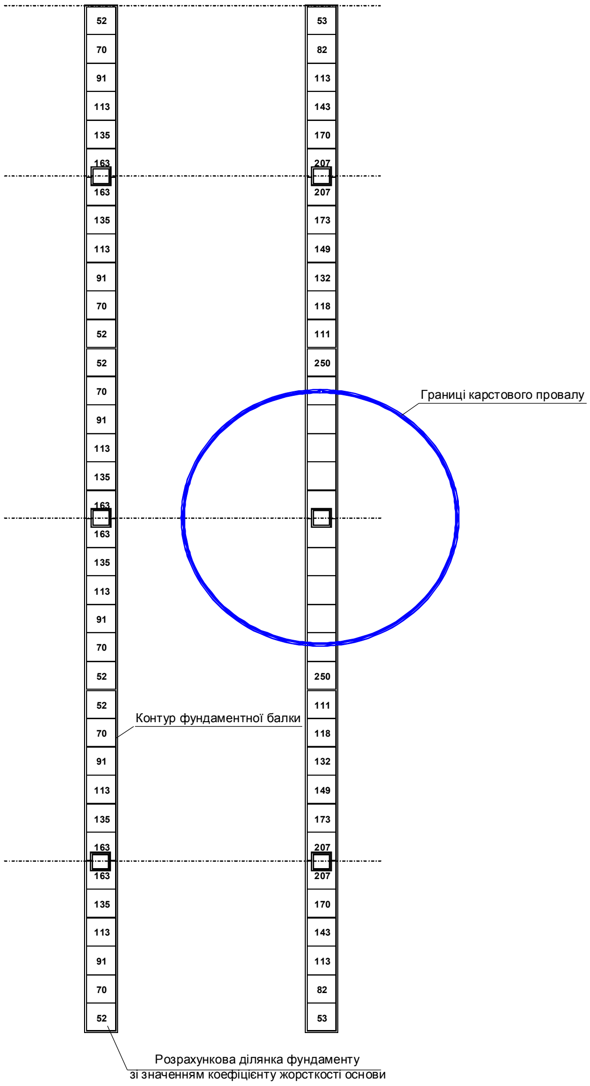

Fig. 5. The scheme of distribution of pressure values over the foundation bottom under normative loads for foundation areas without karst cavities (on the left) and when a karst cavity is simulated (on the right), t / m^3

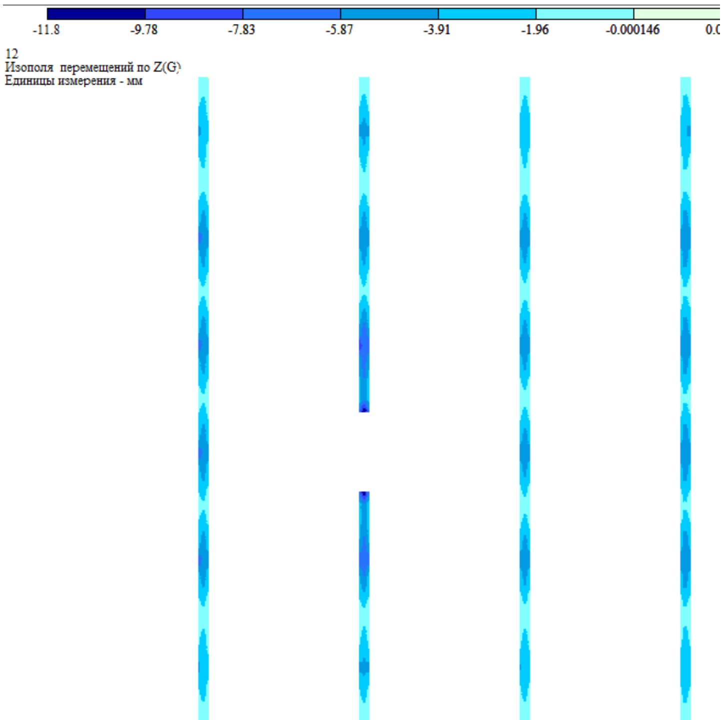

Fig. 6. Isofields of distribution of the base subsidence values under normative loads when a karst cavity is formed (calculation performed in accordance with 2-nd GBS)

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