Modeling of rocks stress-strain state in the foundations of frame type structures

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One of important problems in the design and construction of bridges, viaducts, tunnels for various purposes is forecasting ecological and geophysical character of the mechanical conditions of the adjacent rock massif in order to determine the stability and durability of bridge type structures. Stress-strain state of soils and frame type structures is determined by geometrical properties with different deformation properties, distribution and characteristics of the peak value of stress in investigated structures. On the stress-strain state of frame basis affect the strength of soil, depth of layering of foundations of bridge structures, processes of soil freezing and melting, the supplies of groundwater level and more.

At present time the situation of bridge structures state predictions based on numerical experiments utilizing the finite element method (FEM) is used [1,2]. In this paper the methodology of mathematical modeling, designed to solve the problem is elaborated. It should match the character of the stressed state of the soil surrounding the object array, the specific of construction and exploitation of buildings. In order to determine the real stress state of the soil the FEM technique is used.

Mathematical model describes the stress-strain state in soil massif under the load of bridge construction. For the calculation the following mathematical relationships are utilized. Approximation of Mohr-Coulomb gives a surface model in three-dimensional case (called Drucker-Prager model [3]).

Force loading is given in the following form in this case:

$$\boldsymbol{F = 3\alpha\sigma_m + \sigma_{eqV} - k,}$$

where $\boldsymbol{\sigma_m}$ is hydrostatic stress given by the formula

$$\boldsymbol{\sigma_m = \frac{\sigma_{kk}}{3},}$$

$$\boldsymbol{\sigma_{kk} = \sigma_x + \sigma_z + \sigma_y,}$$

$\boldsymbol{\sigma_x, \sigma_z, \sigma_y}$ – normal stress components given along Cartesian coordinates;

$\boldsymbol{\sigma_{eqV}}$ – equivalent deviatoric stress:

$$\boldsymbol{\sigma_{eqV} = \sqrt{\frac{s_{ij}s_{ij}}{2}},}$$

$$\boldsymbol{s_{ij}s_{ij} = \left({s^2}_x + {s^2}_y + {s^2}_z\right)/2 + \left({s^2}_{xy} + {s^2}_{yz} + {s^2}_{zx}\right).}$$

The components of deviatoric stress are defined through the components of normal stress $\boldsymbol{\sigma_{ij}}$ in the subsequent way:

$$s_{ij} = \sigma_{ij} - \frac{\delta_{ij}\sigma_{kk}}{3},$$

where $\boldsymbol{\delta_{ij}}$ – Kronecker's symbol; $\boldsymbol{i = 1, 2, 3,\ j = 1, 2, 3}$.

The coefficients in expression for calculating force are as follows:

$$\alpha = \frac{2\sqrt{3}}{3}\frac{\sin\varphi}{(3-\sin\varphi)},\quad k = \frac{2\sqrt{3}}{1}\frac{c\cdot\cos\varphi}{(3-\sin\varphi)},$$

where $\boldsymbol{\varphi}$ – angle specifies the friction, given in degrees; $\boldsymbol{c}$ – cohesion coefficient of the material.

Components of deviatoric stress are defined by the normal stress components in the following way:

$$\begin{aligned} s_x &= \sigma_x - \sigma_m, & s_{xy} &= \sigma_{xy}, \\ s_y &= \sigma_y - \sigma_m, & s_{yz} &= \sigma_{yz}, \\ s_z &= \sigma_z - \sigma_m, & s_{zx} &= \sigma_{zx}. \end{aligned}$$

Material properties of the soil used in the modeling experiment initially are as follows: Young's modulus – E = 10^6 Pa, Poisson ratio ν = 0.3, c = 10^3 Pa, φ = 35 deg. The soil weight per unit volume (specific weight) is γ = 18 10^3 N/m^3, coefficient of cohesion $\boldsymbol{c}$= 10^4 Pa.

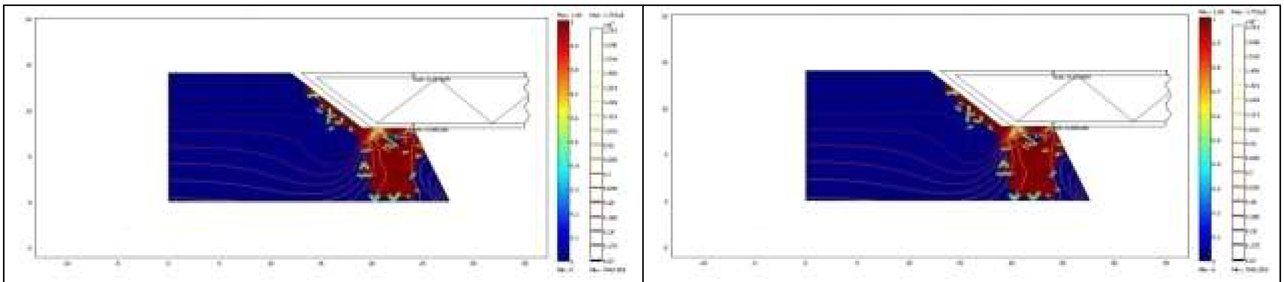
The bridge is considered perfectly elastic, the values of the material properties initially are: E = 25 10^9 Pa, ν = 0.33, γ = 25 10^3 N/m^3.

The results are presented in figures (A-H), which shows the rock massif with given geological and geophysical characteristics and determined stress-strain state of the soil.

Limitations and loading. The lower horizontal boundary is restricted from moving in a horizontal x, and vertical y directions, thus simulating a rigid main bearing rock. The model includes only one half of the bridge due to symmetry. Restrictions apply to the plane of symmetry within a symmetric cut. The left vertical boundary is perfectly smooth and rigid modeling constraints only in the horizontal direction allowing movement in the vertical direction. Densities of soil is introduced as load per unit volume in the negative direction of axis y. Weight per unit volume and strain are modeled in a natural state as the original strain during elastic-plastic analysis in the first stage of the research under load. Initially soil has some natural tension in the natural occurrence, before loading, (shear stresses $\boldsymbol{\sigma_{xy}}$, $\boldsymbol{\sigma_{yz}}$, $\boldsymbol{\sigma_{zx}}$ are put to zero):

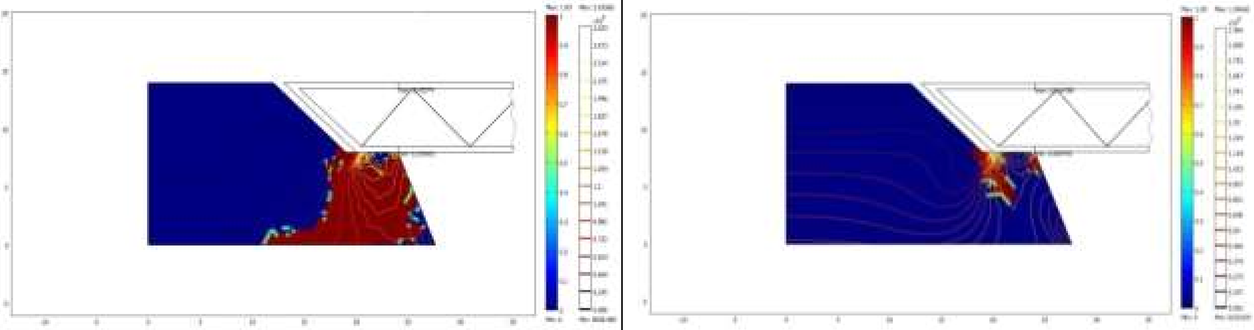
$$\sigma_x = \lambda\cdot\sigma_y,\quad \sigma_y = -\gamma\cdot y,\quad \sigma_x = \lambda\cdot\sigma_y,\quad \lambda = \frac{v}{(1-v)}.$$

With the use of upper described material properties, limitations and loadings the lower presented results are obtained.



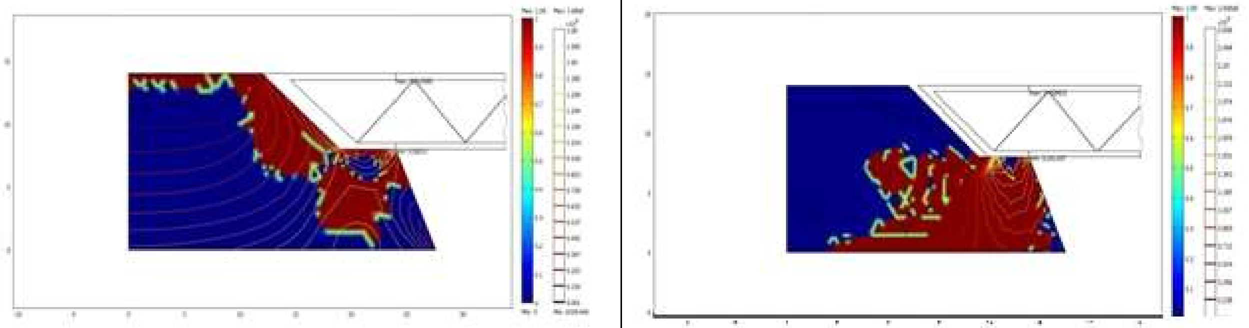
A. Specific weight of the structure and the rock $25*10^3$ N/m3, $18*10^3$N/m^3, soil cohesion $1*10^3$Pa

B. Specific weight of the structure and the rock $55*10^3$ N/m^3, $18*10^3$N/m^3, soil cohesion $1*10^3$Pa



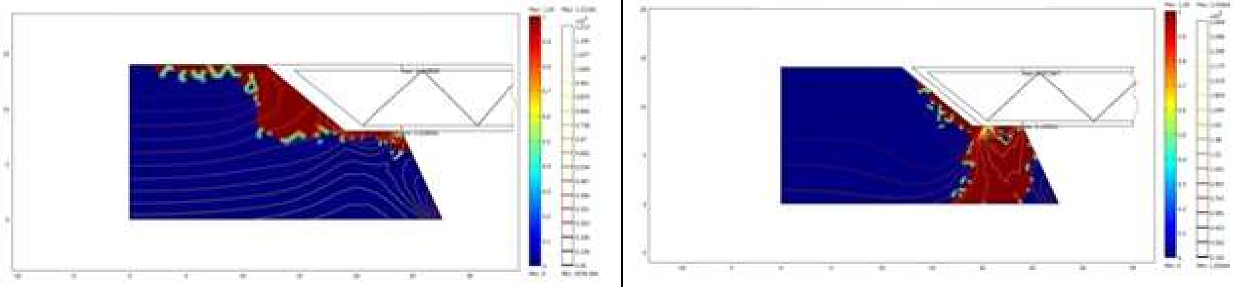
C. Specific weight of the structure and the rock $75*10^3$ N/m^3, $18*10^3$N/m^3, soil cohesion $1*10^3$Pa

D. Specific weight of the structure and the rock $25*10^3$ N/m^3, $18*10^3$N/m^3, soil cohesion $4*10^3$Pa



E. Specific weight of the structure and the rock $75*10^3$ N/m^3, $5*10^3$N/m^3, soil cohesion $1*10^3$Pa

F. Specific weight of the structure and the rock $75*10^3$ N/m^3, $1*10^3$N/m^3, soil cohesion $1*10^3$Pa



G. Rigid contact of construction with the soil. Specific weight of the structure and the rock $25*10^3$ N/m^3, $18*10^3$N/m^3, soil cohesion $1*10^3$Pa

H. Rigid contact of construction with the soil. Specific weight of the structure and the rock $75*10^3$ N/m^3, $18*10^3$N/m^3, soil cohesion $1*10^3$Pa

Figure. Bridge structure with specified geological and geophysical characteristics and determined stress-strain state of the soil basis

Results of modeling experiment are presented in figures (A-H), where the soil with prescribed geological and geophysical characteristics and determined stress-strain state of soil rock are shown.

The consequences of increasing the specific load of the frame structure on the soil are shown in Figures A – C. It is seen the increase of the region of anomalous strain with increasing specific load from 25 N/m^3 to 75 N/m^3. At the same time increase of soil cohesion to 4*10^3 Pa leads to a decrease in strain as it is seen in Figure D. Figures E and F show how decreasing specific load from 5 N/m^3 to 1 N/m^3 indicate strain growing in the rock. In the figures G and H, where the rigid contact of construction with the soil is used, the growing of the strain is similar with the cases A and C, but in this case the subsequent growing of the strain in the rock on the left side of the frame are seen.

Stress as a whole meets the changing strain and therefore it is interesting in terms of soil resistance to stress in terms of the destruction of their structure.

Conclusions. The obtained results of the stress-strain state of soil in the basis of frame structures allow managing of geotechnical processes with the aim to predict and reduce the negative impact of anthropogenic influence on the environment. As it is seen from the carried model studies, it is possible to calculate and find probable critical properties of particular types of frame (bridge) construction on the existing soil type massif with certain geological-geophysical characteristics and predict stress-strain state of it.

References

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Abstract

George Starodub Modeling of rocks stress-strain state in the foundations of frame type structures. – The results obtained for the approximation of Mohr-Coulomb model that gives a surface model in three-dimensional case with aim to estimate the stress-strain state of soil in the basis of frame structures allowing handling the geotechnical processes in order to predict and reduce the negative impact of anthropogenic influence of built-up areas on the environment. As it is seen from the carried model studies, it is possible to evaluate and find probable dangerous influence of particular types of frame constructions on the existing rock foundation massif with certain geological-geophysical characteristics and predict stress-strain state of it.