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Non-Linear Calculation for Bases and Foundations

Calculs Non-Linéaires par Semelles et Fondations

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Synopsis The results of calculation for soil bases and foundation plates taking into account non-linear deformations in reinforced concrete and soil are outlined.

In the present paper, the results of theoretical investigations of the behaviour and strength of soil bases obtained by applying the model of the deformation theory (Krizhanovsky, 1977) and the model of the elasto-plasticity theory (Bugrov, 1974) are given. To describe the deformations of the reinforced concrete, the model (Karpenko, 1976) is used. The following equations of the deformation theory of plasticity are assumed:

$$\varepsilon_i = \varepsilon_i(\sigma_i, \sigma_0, \mu_\sigma); \quad \varepsilon_0 = \varepsilon_0(\sigma_i, \sigma_0, \mu_\sigma); \quad \mu_\varepsilon = \mu_\sigma \quad (1)$$

where ε_i is a shear strain intensity, ε_0 is a volumetric strain, σ_i is a shear stress intensity, σ_0 is a mean stress, $\mu_\sigma, \mu_\varepsilon$ are Nadai-Lode's parameters for strains and stresses. The type of function (1) is obtained by testing soil samples in the triaxial apparatus. Eqs. (1) are used to calculate soil bases. The behaviour of a reinforced concrete plate element subjected to bending is determined by the rigidity parameters depending on the moments (Karpenko, 1976) acting upon the element.

$$\kappa_i = D_{ij} M_j; \quad D_{ij} = D_{ij}(M_{ij}, \alpha) \quad (2)$$

where κ_i are curvatures and a torsion, M_j are bending and torque moments, D_{ij} are the rigidity parameters of a plate element, α is an angle indicating the direction of cracks, $i = 1, 2, 3, j = 1, 2, 3$. The idea of the behaviour of reinforced concrete elements in bending is given by the curve of dependence of the beam rigidity (D) on the bending moment (M). It is shown in Fig.1.

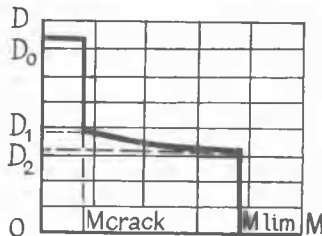


Fig.1 D - M Dependence of a R.C. Beam

We believe that the bearing capacity of a foundation - base system is determined by the found-

ation strength. The bearing capacity is considered to be exhausted if the plastic lines in a foundation form closed zones and the further increase of a load is possible only at the expense of an increase of reactions of a soil base. Eqs. (1) and (2) are used to get a solution and compile a computer programme to calculate ring and circular foundation plates and their bases. The slip of soil along the lower surface of a foundation occurring in the points where shear stresses reach limit values is accounted. The equations relating the displacements and deformations in a soil base are assumed to be geometrically non-linear. With this programme the designs of the foundations for a number of actual structures have been done, the foundation to the chimney stack 420m high being one of them. The latter is used to study the effect of the superstructure and non-linear deformations in the reinforced concrete (a linearly elastic layer is assumed for a base) on the distribution of bending moments in it. (Solomin, Shmatkov, 1979), Fig.2.

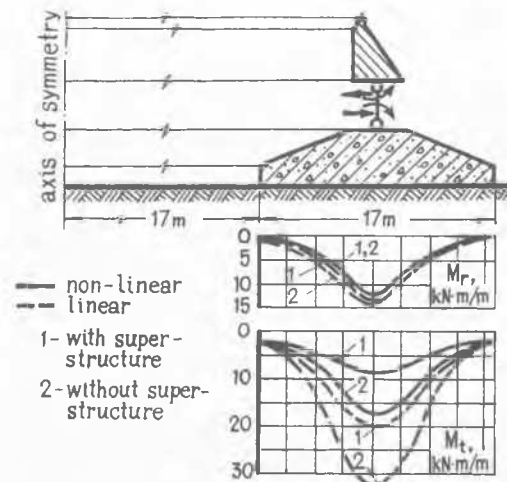


Fig. 2 Bending Moments in the Foundation Plate of the Chimney Stack

With another programme (Solomin, Visokovsky) a number of plates of more complicated forms has been calculated. In Fig.3, the results of calculation for a rectangular foundation plate to a frame type structure are shown. Loads for all columns are the same (2450 kN) and chosen so that the width of cracks in the plate is not greater than 0.4 mm. The analysis of the results shown in Figs.2-3, as well as of those of a number of similar problems allows to make the following conclusions:

The differences between the data of linear and non-linear calculations are great. In zones with cracks the rigidity decreases considerably. The redistribution of moments is the most significant. The results of determining moments in the linear and non-linear approaches may be several times as different. The rapid growth and concentration of curvatures within rather small zones of a foundation take place. The foundation falls into individual blocks, each with the rigidity equal to the initial one. The areas with cracks are boundaries between these blocks. The redistribution of stresses and strains is defined, in the main, by the value and type of a load, the initial rigidity of a foundation - base system, the reinforcing, the model of a soil base, the type of a superstructure.

In determining the value of a destroying load, both physical and geometrical non-linearities of deformations in a base should be taken into account. The shear stresses on the foundation lower surface are also of importance.

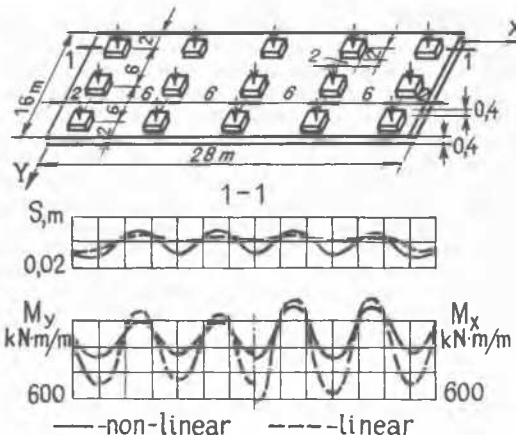


Fig.3 Settlements and Bending Moments in the Foundation Plate

Another way to investigate the behaviour of a soil base is the assuming of the base to be an elasto-plastic medium with strictly outlined zones (Bugrov, Ivanov, Zarkhi). The set of the problem using the associated and non-associated laws of a flow is considered in the paper (Bugrov, 1974). The solution has been obtained and the programme compiled, this allows to calculate the stressed-strained state of a base subjected to the action of a flexible loading and a rigid strip, do detail comparisons of the calculated and test "load-settlement" curves, the displacements of points in the base, the stress-strain distribution, the development of soil compaction and loosening zones. This comparing shows the applicability of the associated law to the description of delatancy for dense soils and the soils of a medium density. In practice, a wide range of problems for different schemes of bases and their loadings was considered (Bugrov, 1974).

In particular, the calculations revealed the considerable effect of the internal friction angle of soil on both the settlements of elasto-plastic bases and the character of "load-settlement" curves. Fig.4 shows the curves $q-S$ for a homogeneous base, the soil of which takes different values of φ and C parameters of Coulumb's condition at equal values of the deformation modulus $E=30000$ kPa, Poisson's ratio - 0.3, the delatancy coefficient - 0.3, the unit weight - 20 kN/m^3 , the lateral pressure coefficient = 1.

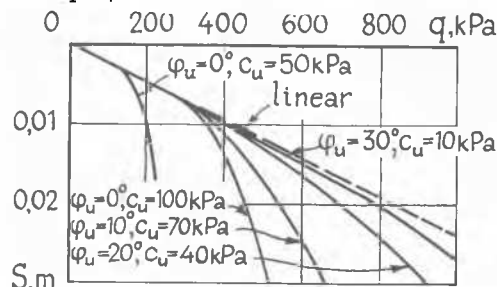


Fig.4 Settlements in the Middle of the Strip

The results have been obtained for the layer 10m thick loaded evenly along the strip 10m wide. The figure shows that for soils having a sufficient friction, the curves $q-S$ in a wide range of loads remain almost linear. Plastic zones appearing in a base result in a redistribution of contact stresses along the lower surface of a foundation, this results in the decrease of bending moments in the foundation if compared with the data of the linear solution for the problem. So, when the distributed loads $q = 170 \text{ kPa}$ are applied to the foundation strip $2a = 10 \text{ m}$, the bending moments in the middle of the strip, in case of cohesive soil base, ($\varphi=0$, $c=50 \text{ kPa}$) are respectively equal to $0.036 q a^2$ and $0.088 q a^2$. The load q increasing, the difference between the values of bending moments becomes still greater.

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