Determination of soil lateral pressure loads on a retaining wall taking into consideration its displacements and deformations

Détermination des charges de pression latérale du sol sur un mur de soutènement, prenant en considération son déplacement et sa déformation

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ABSTRACT: Earlier at the 13th International Conference on Soil Mechanics and Foundation Engineering, Delhi, 1994 (10) and at the European Conference on Soil Mechanics and Foundation Engineering, Copenhagen, 1995 (9) as well as in the papers (4,6) the substantiation and main basics of the new kinematic model describing interaction between the components of the system "retaining wall - soil medium" with a consideration of the mixed stressed state of soil medium that acts upon the structure have been reported and published.

This report reviews some methods for practical implementation of the developed model in design and technical operation of the facilities that include retaining walls as well as the results of their application (based on retaining walls of berthing structures).

RESUME: Au début a la 13eme International Conférence de la Sol Mécanique et Foundation Ingenierie, Delhi, 1994(10) et a Europeen Conférence de la Sol Mécanique et Foundation Ingenierie, Copenhagen, 1995(9) aussi en papiers (4,6) la substantiation et la principale base a nouveau kinematic modèle decrire la interaction entre consistantes du systéme " mur conserve - sol milieu" avec de consideration son deplasement et deformation .

1. Algorithm Accounting for Generalized Displacements of Rigid Retaining Walls

The suggested method allows to calculate the "lateral pressure *(E)* versus generalized displacement *(u)*" dependence within theentire range from the soil pressure at rest to the limit (active or passive) state achieved at certain critical value of the generalized displacement. As far as we know, specific parameters of the current strain condition in the course of observations and geodetic measurements, it is possible to evaluate the characteristics of current soil lateral pressure loads acting upon the structure with the aid of the *"E-u"* dependence. Having specified load values, it is easy to correct the calculation of the stress-strain condition of the facility in its relation to a particular practi cal case.

When designing new facilities and in case the generalized displacements of the facility are not known a priori, the following algorithm for a solution of the discussed problem may be recommended:

- based on the operational conditions of the facility that are assigned in the project, the most probable pattern and direction of the generalized displacements are determined;
- the increment of the generalized displacement is preset and the dependence *"E-u"* is calculated and determined (also, graphically);
- the external force T acting on the facility via the contact edge of the retaining wall and transmitted to soil (in case of passive soil pressure) or the resistance to displacement of the facility, Q, caused by the lateral soil pressure (in case of active soil pressure) is determined;
- by plotting the force value T or Q (depending on the direction of possible generalized displacement of the facility) on the pressure axis of the $E = E(u)$ plot, found on the u-axis is the respective value of the generalized displacement whereat the passive pressure withstands the force T or the active pressure does not exceed the force Q; the displacement is evaluated so as to meet the requirements of the operational reliability of the structure.

Some calculation methods applied for the system "structure - soil medium" are expressed as algorithms and are provided with the corresponding calculation programs (5).

The main aim of the developed algorithm is to obtain a nonli-near dependence *"E-u"* between the lateral soil pressure on the structure and the strain state of the structure.

2. Diagrams of Lateral Soil Pressure on Retaining Wall for Arbitrary Current Strain State of Structure

Developed are several methods to plot the diagrams of lateral soil pressure on the contact edge of a rigid retaining wall both for the limit (initial and end) and for the intermediate strain states of the system "structure - soil medium: that are based upon a possibility to define the resultant E of the lateral soil pressure and its limit, E_0, and sublimit, E'', components.

The first method preserves a conventional linearity of the pressure diagrams for both zones of the stress condition of soil and within the limits of the height $h < z \leq H$ for the sublimit zone, however the latter case is considered for several variants of diagrams that reflect actual conditions of interaction of the structure with soil medium including those that result in a partial nonlinearity of the diagram. The second method preserves linearity for the limit stress state zone only (i.e. for the active or passive pressure zone), while for the sublimit stress state zone the diagram is obtained as curvilinear. According to the third method the curvilinear diagram based on a parabolic approximation of soil lateral pressure intensity is plotted along the entire height of the contact edge of the structure.

Taking into consideration a restricted volume of this paper, we describe the last (most general) method only.

As the tests prove (2, 3, 7, 8 and others), the soil lateral pressure diagrams are close to parabolic (convex). In most cases, the centre of pressure (the point where lateral pressure is applied) is located higher than the centre of gravity of conventional rectilinear (Coulomb) diagrams (as the tests prove, at about (0.40-0.45) H distance from the bottom of the wall, where H - wall height; in case there is a surface load, the distance may be still greater - up to (0.45-0.53)H. In particular instances (when the structure has certain deformations) the diagram becomes concave and its centre of gravity is located lower than in the Coulomb diagrams.

Generally, the equation describing pressure diagram ordinates versus depth is:

$$s(z) = az^2 + bz + c, \quad (1)$$

where: a, b, c - unknown coefficients;

z - the ordinate plotted vertically down from the point where soil surface crosses the contact edge of the wall ($0 \leq z \leq H$).

To find the unknown coefficients in equation (1),we shall consider the following prerequisities and respective boundary conditions:

1) At any, even very small, displacement of the wall which means the respective displacement of its top end (it is not practically possible to fix it absolutely rigidly in an actually erected structure) the limit stress state appears at the point $z = 0$, i.e.:

$$s(z = 0) = c = ql, \quad (2)$$

where: q - surface load intensity;

l - coefficient of soil lateral pressure (active or passive, depending on the direction of structure displacement).

2) The pressure diagram area is numerically equal to the lateral pressure force related to the unit of the structure length, i.e.:

$$\int_0^H s(z)\,dz = E, \quad (3)$$

The value of E, when the kinematic method is used, may be determined for an intermediate strain state of the structure as the vector sum of the limit and sublimit components of pressure (6). In the extreme particular case when the limit soil pressure is achieved across the entire length of the contact edge, E value is assumed equal to this limit pressure and may be found by means of one of the known methods without resort to plotting conventional rectilinear diagrams.

3) Taking into consideration known experimental data (2, 3, 7 and others) and based upon the developments referred to in (6), we may assume that the pressure centre location is known as well as its ordinate, z_0, in the adopted system of coordinates, then:

$$\int_0^H z\,s(z)\,dz \Big/ \int_0^H s(z)\,dz = Z_0. \quad (4)$$

After integrating expressions (3) and (4) with due account of function (1) and condition (2), we obtain the following system of three equations containing three desired unknown coefficients a, b, c:

$$\left.\begin{aligned} & c = ql \\ & at_1 + bt_2 + ct_3 = E \\ & \frac{at_4 + bt_1 + ct_2}{at_1 + bt_2 + ct_3} = z_0 \end{aligned}\right\} \quad (5)$$

where: $t1 = H^3/3$; $t2 = H^2/2$; $t3 = H$; $t4 = H^4/4$. (6)

Solution of system (5) may be written as:

$$\left.\begin{aligned} & a = (1/H)\,[2A(3v - 2) + B]; \\ & b = -A\,(4v - 3) - B; \\ & c = ql = BH/6. \end{aligned}\right\} \quad (7)$$

where: $A = 6E/H^2$; $B = 6ql/H$; $v = z_0/H$. (8)

The obtained general formulae enable to come to the classic triangular diagram of pressures for the particular case v=2/3, i.e. when force E is applied at a distance of $H/3$ from the bottom of the wall, as in this case, when q = 0, the parameter a is always equal to zero irrespective of the value of E, and equation (1) is simplified to $s(z) = bz$.

The paper reviews peculiar features of the pressure diagram that is described by function (1).

3. Some Results of Comparison Between Experimental and Calculated Data. Verification at Calculation of Actual Structures.

E.V.Tsagareli has performed the experimental study of sea sand soil pressure (φ =37^0; γ = 18 kH/m^3; =0.75) upon the model of a retaining wall having back edge inclined towards the backfill. At various wall heights (from 2 to 4 m) and the back edge inclined to the vertical towards the backfill (-5^0; -10^0; -15^0; -20^0), soil pressures have been determined as well as their distribution pat- tern across the wall height. The results of calculation prove good convergence of the values compared: if the model is higher (which makes it closer to real structures), the calculated and experimental pressure values come rather close and have similar distribution pattern within the analysed range of inclination angles of the wall contact edge.

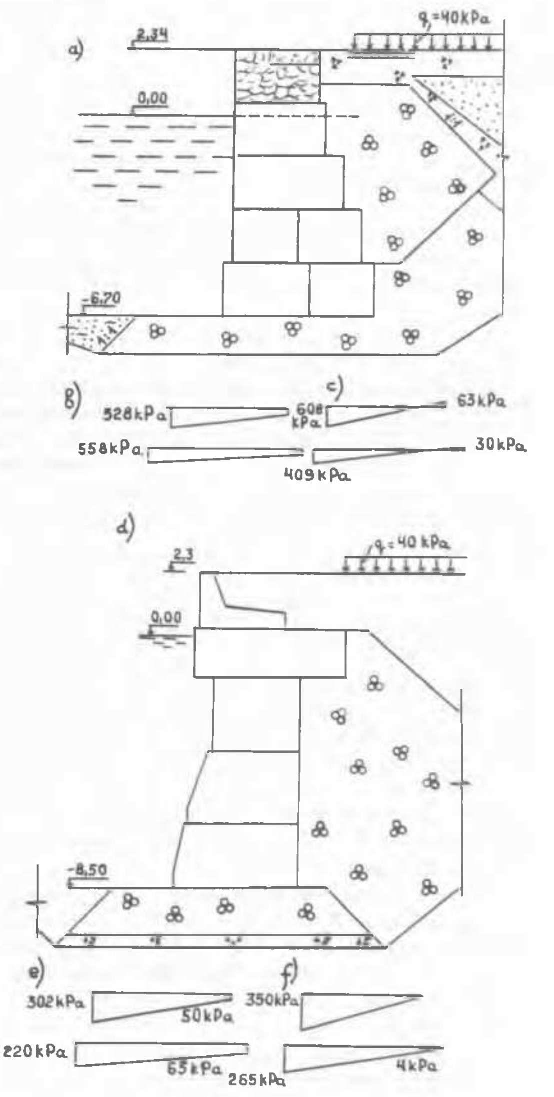
Experimental data of E.V.Tsagareli allows, as well, to compare the diagrams calculated according to the above described method of parabolic approximation (for the retaining wall models of various heights and angle of the contact edge of the structure to the vertical), which evidences that the approximation assumed in the calculation model provides for a good qualitative and quantitative convergence of the diagrams for all reviewed cases-that is advantageous when compared with the conventional Coulomb diagrams also contained therein.

M.N. Vargin conducted experiments with a displacing retaining wall (2) wherein he determined active lateral pressure of dry fine Luberetsky sand (γ =15.5 kH/m^3, φ =33^0) on a rigid model with he vertical contact edge of 1.9m high and with and without a continuous evenly distributed load of q=13.5 kPa intensity on the daily surface of fill. This paper contains, also, the experimental diagrams of active pressure of dry and suspended in water sand on the retaining wall model, the tests were aimed to determine not only force parameters of the lateral pressure but also the point where the pressure resultant was applied. The latter condition made it possible to apply the parabolic approximation method for calculating active pressure diagrams. Comparison of the experimental and calculated data proves that both for the dry soil and for the soil suspended in water (this is important for port structure operation) parabolic approximation, according to the above described method, leads to a satisfactory convergence with the test results. This conclusion is true irrespective of availability or absence of the surface load.

As the number of studies dealing with the dependence of passive pressure upon the kind and value of soil displacement is limited, it is interesting to consider the data obtained by A.K.Bugrov (1) both for the wall (5m high) that is displaced translationally and for the wall that is turned around its lower end. The analysis of the results of these studies indicates that for both kinds of displacement the calculated values of the passive pressure agree well with A.K.Bugrov data.

A change in the system kinematics influences the diagrams of active pressure. Experimental data (tests made by R.V.Lubenov and P.I.Yakovlev /8/) and the calculated diagrams for the translational displacements of the wall combined with a turn around the top axis proves that the displacements of the wall obtained during tests and calculated numerically lead to similar changes in measured and calculated diagrams.

Considering efficiency of kinematic calculation methods applied to retaining walls of the reviewed type which is revealed by comparison of the experimental and calculated data, said methods and means have been used when analysing stress strain



condition of the gravity type berthing structures located in a number of Black Sea ports and shiprepair yards. For example, curvilinear (parabolic) diagrams of active soil pressure have been plotted for the berths in Kerch Port and Tuapse Ship-repairing Yard of two rather widely spread construction types. In the first case, a trapezoidal section concrete blockwork and cyclopean concrete superstructure (Fig.a), and in the second case the blockwork with the top cantilever block (Fig.d) designed by Soyuzmorniiproekt have been used. Shown in Figures, for the purpose of comparison, are the diagrams of contact pressures in stone bedding and in the foundation soil determined both by the conventional linear active pressure diagrams (Fig.b,e) and by the parabolic diagrams (Fig.c,f). Both cases are characteristic of a considerably more unfavourable distribution of contact pressures in case parabolic diagrams are used which is caused, evidently, by a higher location of the point where the resultant of the active pressure is applied. The latter consideration has resulted, in particular, in an increase of the maximum compressing pressures by 10-15 per sent as well as in appearance of negative pressures near the rear edge of the wall or in a transformation of the trapezoidal diagram to the triangular one.

SUMMARY

When appraising the above comparison of calculated and expe- rimental data obtained for various test conditions and by a number

of researches who studied the models of rigid retaining walls, both stationary and experiencing different generalized displace-ments, the following conclusion may be made. The applied kinematic model describing interaction of the elements in "port hydrotechnical structure - soil medium" system allows of calculating the dependence of "lateral pressure - generalized displacement" type within the entire possible range of displacements and deformations for the considered structures that are alike by quality and close by quantity to the test data. The test- based diagrams of active and passive soil pressure acting on the contact edge of the structure make it possible to reflect, with a sufficient accuracy, the actual distribution pattern of the lateral pressure intensity and to take into consideration the realized kinematic factors.

The calculation model described in this paper for the actual structures allowed to explain the phenomena observed in situ and to develop recommendations (both as to changing the load pattern of the berths and as to their desirable reinforcement and reconstruction) on their further optimum and reliable operation.

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