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Rapid Investigation Methods of Soil Properties and Interpretation of their Results for Bridge Foundations Design

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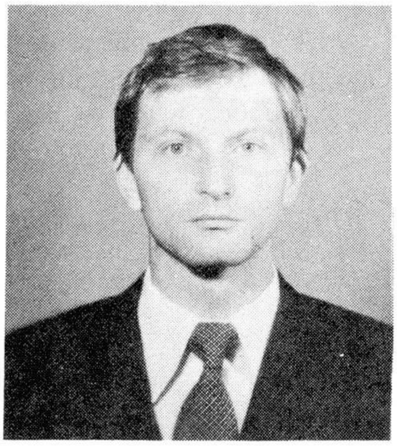

Yuriy Vynnykov, born 1963, got his civil engineering education in Poltava STU. Author of more than 100 scientific works, including books, normative documents and more than 30 inventions. Specialist in research, designing, construction and reconstruction of basements and foundations constructed without earth excavation, including piled foundations for bridges, mathematical simulation of behaviour of such foundations, anisotropic soil properties.

SUMMARY

For solution of geotechnical problems while designing and reconstruction bridge foundations it is reasonable to use rapid methods of field and laboratory investigations of soil properties: penetration, static probing, rotary shear, etc. Static soil penetration with widened tip comparing with traditional method of static penetration with the same rod and tip diameter that allows to use static effort more effectively due to elimination the friction from rod surface and the use of large size tips allows to increase accuracy of determination of poor bearing soils values. The depth of such penetration exceeds 20 m. For determination of soil characteristics in each point of soil massif according to the data of rapid methods of soil investigation the equations of interconnection between their physical and mechanical properties. It allows to set soil characteristics in each element of calculated field of bridge foundation basement with numerical simulation or analytical methods of their calculation quickly and objectively. Numerical simulation of stress-strain state of bridge foundation bedding is carried out with the use of programme of elastoplastic calculation of geotechnic structures based on the method of initial stress in combination with the method of ultimate elements.

1 INTRODUCTION

Main points in process of foundation designing are engineering geological survey, preparation of soil thickness parameters and evaluation of stressed-deformation condition (SDC) of basements and foundations. Speedy methods of soil properties investigation were tested for that purpose, results of which were interpreted for evaluation of SDC basements, foundations and pile bearing capacity with help of interconnection equations between physical and mechanical soil properties.

2 RAPID INVESTIGATION METHODS OF SOIL PROPERTIES

2.1 Static soil penetration with widened tip

Static soil penetration with widened tip (fig.1,a) with 30^0 angle at the top and the diameter exceeding rod diameter 1.6 times and more comparing with traditional method of static penetration with the same rod and tip diameter allows to use static effort more effectively due to elimination of friction from the rod surface (because conditions for pressing soil into formed cavities between the well and stem walls appear), and the use of large size tips allows to increase accuracy of determination of poor bearing soils values for which this only method is very often available. The depth of such penetration exceeds 20 m. For creation of conditions for friction of soil layer by layer during penetration the authors have investigated and patented several modifications of widened tip, namely: tip like a cone with cylindrical steps{1} (fig.1,b); tip like a cone with cylindrical steps which are connected telescopically{2} (fig.1,c); tip with spiral groove beyond the cone surface {3} (fig.1,d). The size of the tip can be changed in the process of penetration {4} (fig.1,e). It makes it possible to determine precisely soil strength characteristics which lay along the whole depth of penetration despite the difference of this characteristics. For combination penetration processes and selection of soil samples the tip {5} (fig.1,f) that has telescopic cylinders with lugs has been worked out.

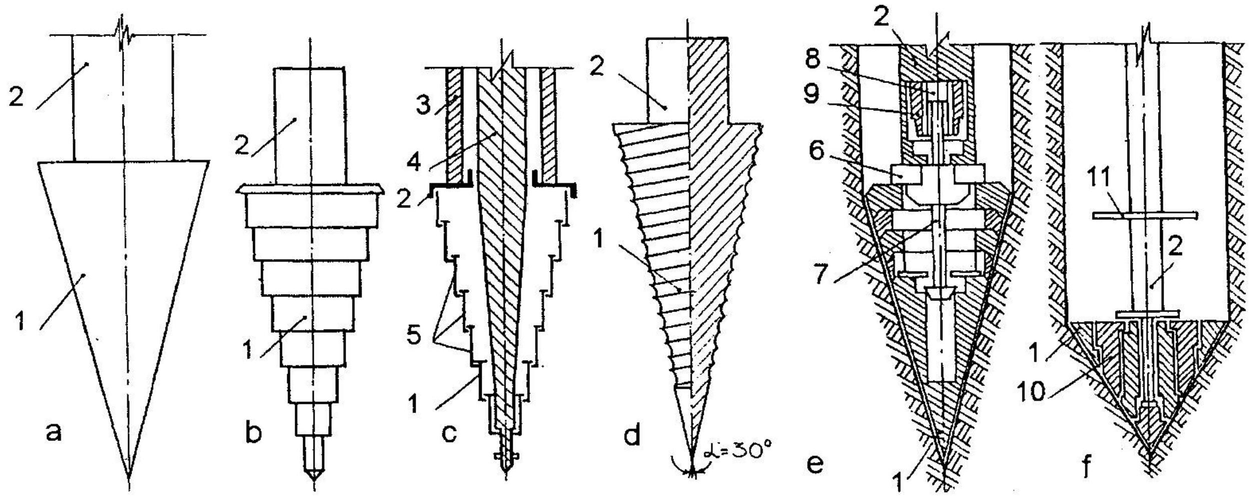

Fig. 1 Typés of the widened tip: 1- cone; 2- tang; 3- bar; 4- stock; 5- cylindrical bucket; 6- figure lug; 7- rod; 8-screw; 9- nut; 10- cylinder; 11- banked-up ring

2.2 Method of penetration

Penetration method is based on slow submersion of tip cone into the depth h that mustn't exceed the cone height. For cohesive soils the investigation penetration characteristic is ratio of penetration effort P to square of cone submersion depth and it is called the unit penetration resistance R, Pa

$$R = P / h^2 . \qquad (1)$$

For non-cohesive soils the so called penetration index U (H/sm^3) is used

$$U = P / h^3 . \qquad (2)$$

Principle of the invariable of test penetration results provides possibility for objective control of precision and truth in definition penetration indices of mechanical soil properties. Results of penetration test present unique indices of resistance to soil shear. According to the results of penetration tests it is determined the angle of internal friction φ and unit cohesion c of non-cohesive soils. For investigation of soils with anisotropic properties it was also worked out a tip shaped like tetrahedron pyramid, opposite facets are symmetrical, side facets are concave and working ones are flat with 90° angles at the top and between working facets angle is 10° {6} (fig.2). Due to such form its interaction with soil occurs only beyond its working facets.

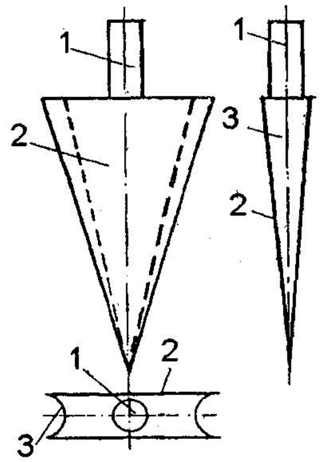

Fig. 2 Tip for penetration of soils with anisotropic properties: 1- tang; 2- working facets; 3- side facets

2.3 Method of rotary shear

Method of rotary shear consists of slow pressing the tip with two perpendicular vanes into soil and measuring the rotary moment at vane turn M_{max}. At laboratories, usually, combination of soil investigation by penetration and rotary shear are used. In a number of cases they help simply and exactly to determine the angle of internal friction φ and unit cohesion c of cohesive soils. The unit resistance to rotary shear τ is determined by ratio

$$\tau = M_{max} / K_{\tau} , \quad (3)$$

where K_{τ} is a constant of vane-shear tip which is received from formula

$$K_{\tau} = 0.5\pi d_{cr}^{2}(d_{cr}/6 + h_{cr}) , \quad (4)$$

where d_{cr} and h_{cr} - diameter and height of the vane. For soft clayey soils and silt where the angle of internal friction is small it is $\tau = c$.

3 INTERPRETATION OF RESULTS OF SOIL RAPID INVESTIGATION METHODS

3.1 Equations of interconnection between physical and mechanical soil properties

Objective characteristics of above given methods are received due to traditional three-term formula of limited basement condition. At the same time, the peculiarities of characteristics for cohesive soils and non-cohesive differ. Theoretical statement is well confirmed by experimental investigations. For determination of soil characteristics in each point of soil massif according to data of rapid methods of soil investigation the equations of interconnection between their physical and mechanical properties are used, for example: humidity W, void ratio e, unit cone resistance R, angle of internal friction φ, unit cohesion c, modulus of deformation E etc. Practically, while determining correlation between physical and mechanical properties in conditions of three - phase state of natural structure soil it is necessary to determine its three indications: free term and two angle coefficients of conditional linear equations. The general correlation equation in this case is:

$$\lg(R/R_0) = W_R(1/e_0) + (\rho_W/\rho_s)(1-M_{kpf})/(1/e_0) - WM_{kpf}(1/e_0) - (\rho_W/\rho_d)(1-M_{kpf})(1/e_0), \quad (5)$$

where R - unit cone resistance, MPa; R_0=1 MPa; $M_{kpf} = 1-(1/e_0)/(1/e)$; $1/e_0$ and $1/e$ -angle coefficients of linear equations for the case of total soil saturation and in condition of constant humidity accordingly; W_R - moisture content in complete saturation with R_0= 1.0 MPa.

Multiple investigations showed that while determining correlation between the properties of clayey soils the indicative values of equation (5) are influenced by such properties as plasticity index, mineralogical composition of clayey ingredient, grain size distribution and mineralogy coarse-graded component of soil. The condition for determination of correlation between indices of physical state of soil (W, e) and indices of mechanical properties (R, φ, c, E) is the accumulation of test results for determination of these soil characteristics with relatively constant plasticity index and uniform genetically. Thus, for definite soils we can set a number of dependencies:

$$\lg(R/R_0) = A_R - B_R e - C_R W; \tag{6}$$

$$\lg(E/E_0) = A_E - B_E e - C_E W; \tag{7}$$

$$\lg(c/c_0) = A_c - B_c e - C_c W; \tag{8}$$

$$\lg(tg\varphi/tg\varphi_0) = A_\varphi - B_\varphi e - C_\varphi W; \tag{9}$$

where $R_0; E_0; c_0; tg\varphi_0$ are values that equal the unity in the taken units; A, B, C - coefficients are functions of indicative soil features: $1/e_0$, $1/e$, W_R.

According to these equations we have the following:

$$\lg(E/E_o) = A_E - (B_E/B_R)A_R - W[C_E - (B_E/B_R)C_R] + (B_E/B_R)\lg(R/R_0); \tag{10}$$

$$\lg(c/c_o) = A_c - (B_c/B_R)A_R - W[C_c - (B_c/B_R)C_R] + (B_c/B_R)\lg(R/R_0); \tag{11}$$

$$\lg(tg\varphi/tg\varphi_o) = A_\varphi - (B_\varphi/B_R)A_R - W[C_\varphi - (B_\varphi/B_R)C_R] + (B_\varphi/B_R)\lg(R/R_0). \tag{12}$$

With the help of equations (10-12), having indices of soil natural humidity W and unit cone resistance R in any point of footing it is possible to determine mechanical soil characteristics. Equations (6-12) were determined for soils at several dozens of sites during field and laboratory works. They give opportunity to determine mechanical characteristics of natural structure soil and within the compaction zones while calculating and modeling work of bridge basements and foundations. It allows to set quickly and objectively soil characteristics in each element of calculated field of bridge foundation basement with numerical simulation or analytical methods of their calculation

3.2 Determination of pile bearing capacity due to results of soil static penetration

We should point out that technique of determination of bearing capacity of pile bridge foundations due to results of soil static penetration by widened tip was successfully conducted.

3.2.1 Bearing capacity of driven prismatic piles

Bearing capacity of driven prismatic piles is:

$$F_d = \theta q_S^0 A \lambda_0 + 0.0117 u \sum_{i=1}^{n} q_S^i \lambda_i h_i + 6u \sum_{i=1}^{n} h_i , \tag{13}$$

where θ - coefficient that takes into account deformation character of pile base; $q_S^o; q_S^i$ - resistance to soil cone in the plane of pile edge and of each layer along the whole length of pile, kPa; A - pile cross section area, m^2; $\lambda_0; \lambda_i$ - transition coefficients from q_S to calculated soil resistance; u - perimeter of pile, m; h_i - thickness of bearing layer within depth of pile submersion; n - number of bearing layers of soil along pile length.

In fig.3 there are diagrams of dependence coefficient λ on value q_s and soil type. Diagrams are based on results of parallel test of soil by penetration and static pile tests carried out in the central part of Ukraine.

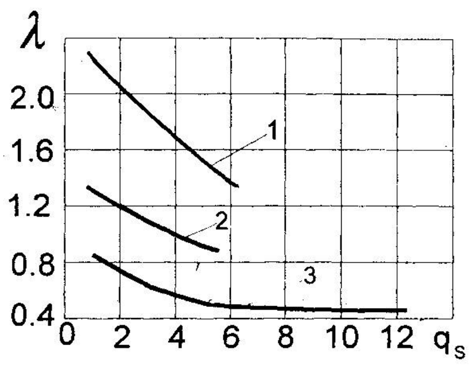

Fig.3 Dependence curves $\lambda = f(q_s)$:
1- loam and clays; 2- loamy sands; 3- sands

3.2.2 Bearing capacity of cast-in-situ piles in punched hole (CPPH)
For determination of bearing capacity of CPPH according to results of static soil penetration the calculation scheme was accepted according to which soil resistance along the side surface of the shaft is taken into account only at a point h from its top till the point of intersection of shaft with surface of conditional cone having the forming line tangential to the edge of widening at angle $\varphi / 4$ to pile axis, where φ is average arithmetical value of internal soil friction angle laying within limits of the given cone. We offer to determine bearing capacity of CPPH on the base of static penetration by formula

$$F_d = \theta q_s^0 A_{cr} \lambda_0 + 0.0117u\sum_{i=1}^{n} \theta_{si} q_s^i \lambda_i h_i + 6u\sum_{i=1}^{n} \theta_{si} h_i \ , \qquad (14)$$

where

$$\theta = 1005/(4213 + q_s^o) \ , \qquad (15)$$

$$\theta_{si} = 4328/(3850 + q_s^i) \ , \qquad (16)$$

$q_s^o ; q_s^i$ - resistance of soil to cone on the level of bottom of widening and for each layer within point h, kPa, correspondingly; $\lambda_0 ; \lambda_i$ - transition coefficients for each soil layer on level of widening and within limits of h; u is perimeter cross section of shaft, m; h_i - strength of each soil layer within point h, m.
3.2.3 Bearing capacity of tapered piles
Bearing capacity of tapered piles equals

$$F_d = kmq_s A \ , \qquad (17)$$

where k is coefficient of soil uniformity; m - scale coefficient m=0.5; q_s - average value of soil resistance under the tip; A - area of cross section of tapered pile on top section, m^2.

4 NUMERICAL SIMULATION OF STRESSED-DEFORMATION CONDITION OF BRIDGE FOUNDDATION BASEMENTS

Numerical simulation of stress-strain state of bridge foundation bedding is carried out with use of the programme of elastoplastic calculation of geotechnic structures based on method of initial stress in combination with method of ultimate elements and theoretic - mathematical description of soil as continuous isotropic media modeled in accordance with theory of plastic flow.

4.1 Hypotheses in statement of elastoplastic task
In statement of elastoplastic task such hypotheses are used: 1)evidence of non-linearness includes plastic deformation of form change in complicated stressed state and free deformation in tension; 2)in complicated stressed state (compression with shear) general deformations include linear and

plastic parts, plastic components of deformation appear after reach of strength limit according Mises-Shleikher-Botkin:

$$\alpha I_1 + I_2^{0.5} - K = 0 \ , \qquad (18)$$

where $I_1(I_2)$ is first (second) invariant of stress gauge (deviator); α and K - characteristics of soil strength in space stressed state; 3)vectors of main plastic deformations (and their velocities) and main stresses in complicated stressed state are taken as co-axial; 4)at the stage of plastic deformation was taken into account dilatancy was taken into account with correlation between speed of volume change and form change, which is expressed as the constant (non-associated law) in space stressed state:

$$\Lambda = I'_1 / 6I'_2 \ , \qquad (19)$$

where I'_1, I'_2 are speeds of main stresses.

4.2 Calculated sphere of foundations and piles

Calculated sphere of axis symmetric task is cylinder, it is based on revolution of rectangular calculated zone around symmetry axis (fig.4). Symmetry axis coincides with foundation axis. In calculations the continual space elements of triangular section which simulate foundation material and soil of bedding are used. Properties of bedding are defined by real soil characteristics: unit weight γ, modulus of deformation E, coefficient of side pressure ν, angle of internal friction φ, unit cohesion c, parameter dilatancy. Physical and mechanical soil characteristics within calculated zone are determined according to the results of penetration and revolving shear and with help of equation of interconnection (10-12).

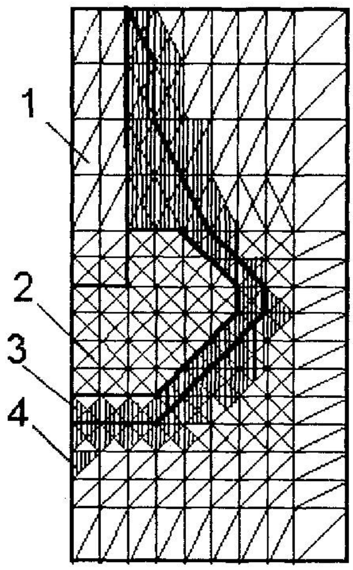

Fig.4 This is an example of the calculated sphere of cast-in-situ piles in punched hole during of numerical modeling its work: 1- shaft; 2- hard widening; 3- compaction zone; 4- zones of plastic deformations

5 SUMMARY

Investigations of soil properties by static probing with the widened tip, penetration, rotary shear with following interpretation of results for designing and bridge foundations considerably allow to speed up process of designing with great extent of reliability.

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