Certain Results Obtained in Cone Penetration of a Sand Base

M.V. Malyshev & A.A. Lavisin
Moscow Civil Engineering Institute
Civil Engineering Institute, Poltava
USSR

Laboratory cone penetration tests were carried out by means of a cone having an apex angle of 30° and a base 40 mm in diameter. The cone was pressed into the sand at rates varying from 0.31 mm/sec to 8.1 mm/sec, i.e.more than 25-fold. Each test was carried out at a constant rate.

For this purpose, a special assembly was designed (Lavisin,1973) having a stoke up to 90cm. The cone was mounted on a rod 16mm in diameter. Thus,the ratio of the cone diameter to the rod diameter was equal to 2.5,whereas the minimum recommended ratio is 1.6. The tests were conducted in a metal tray of sufficient rigidity whose dimensions were 56.6x55.4x x55 cm; the front wall was of glass. The cone was pressed into air-dry quartz sand (SiO_2 content up to 98.7 per cent, unit weight equal to 2.68 cN/cm^3), which had a constant porosity during each test. The porosity varied with each test from e=0.89 (γ=1.42 cN/cm^3) to e=0.56 (γ=1.72 cN/cm^3). According to accepted classification, the sand is considered to be coarse-grained and homogeneous. Its size grading was as follows: fractions with a diameter exceeding 0.5mm-88 per cent; from 0.5 to 0.25mm-11 per cent; and smaller than 0.25mm-1 per cent. The angle of internal friction for this sand was determined in a triaxial apparatus. The obtained results were approximated by the following relationship:

$$\phi=67.084\gamma-67.917=67.917\,\frac{1.647-e}{1+e} \qquad (1)$$

at a correlation factor of 0.98 (γ,cN/cm^3) The same results were obtained during tests carried out at two rates: 0.15mm/ /sec and 3.6 mm/sec. The results of both tests were indentical. A "meshing" of the sand was observed. This corresponds to the initial section of the curve obtained in its linear approximation and characterized by the relationship $c=0.1(\gamma-1)$, where the dimensions of are cN/cm^3; and those of c are N/cm^2. This "meshing" appears to depend on the cone penetration rate. However, because of the relatively small interval of penetration rates under consideration and the smallness of the value c itself, the influence of the rate on c is disregarded.

The main aims of the investigation were: (1) to determine the magnitude of the penetration force P as a function of the rate of cone penetration V, depth of penetration H and unit weight of the soil; and (2) to establish the character of particle displacement in the sand around the penetrating cone by means of photography (for this purpose use was made of a semi-cone that travelled along the glass wall of the testing tray).

To solve the first problem, cone penetration was carried out to a depth of 45 cm, which is equal to 6 times the height of the cone. The penetration rates The tests revealed that the relationship between the penetration force P and the penetration rate V is of a parabolic nature and reacher its. Minimum at the penetration rate v=4.3 mm/sec. The penetration rate that corresponded to the minimum penetrating force did not depend on the density of the soil. Since the influence of the cone penetration rate on the penetration force has not been sufficiently investigated, it is assumed that $P(v)=K(v)Po$, where Po is the penetration force at $V \rightarrow 0$. The value of the dimensionless coefficient was established by means of test data

$$K = 1-0.0165V + 0.0194\,V^2 \qquad (2)$$

where V is in mm/sec.

The tests revealed the presence of a critical depth of cone penetration H_c, corresponding to a maximum penetration force P. Further penetration of the cone took place either at a constant force, or even a certain decrease in the force was absorved. This phenomenon was observed mainly in dense sand. The penetration force Po, corresponding to extremely small penetration rates $V \rightarrow 0$, is related to the angle of internal friction ϕ . The final aim was to establish the magnitude of the angle of internal friction ϕ for the sand by means of penetration tests. This relationship can be found either empirically or theoretically, by making use of the solutions in the theory of limiting equilibrium of loose media.

The proposed theoretical treatment of the problem is based on a solution suggested by V.G.Berezantsev (1955) for certain cases of the axisymmetric problem in the theory of limiting equilibrium of loose media. An approximate design scheme of soil failure is proposed in the following on the basis of Berezantsev's solution and an algorithm has been composed for solving the problem. The results of the obtained numerical solution are presented in the table. It should be noted that the above-mentioned solution of Berezantsev was developed further by Klemiatsionok (1971), who took into account the frictional forces that arise along the cone surface upon its penetration into the soil and established that the angle of friction along the cone surface can be taken from 6° to 10°. V.V.Belenkaya (1972), who also worked on this problem, took into accoun the curvature of the shear diagram for the range of small pressures and showed that this measure has a substantial effect on the results of calculation (naturally, she assumed c'=o). Making use of Berezantsev's basic equations (1958) and the boundary condition at the surface of the cone

$$\psi = \frac{\pi}{2} - \alpha + \frac{1}{2}/\phi_o + \text{arc sin}\,\frac{\sin\phi_o}{\sin\phi}/ \qquad (3)$$

where ψ is the angle between the large radians along the surface of the cone. The depth of cone penetration was conditionally taken into account by means of a surcharge, equal to γH and acting along a horizontal plane, passing through the base of the cone. Angle ϕ_0 is determined by making use of the photographs of particle displacement in the sand. The following relationship is established between ϕ_0 and γ :

$\phi_0 = 22.5\gamma - 23.8$. As a result, the following relationship has been obtained for P_0:

$$P_0 = 2\pi \left[1 + \sin\phi \times \sec\alpha \times \cos\left(\alpha - \phi_0 - \arcsin\frac{\sin\phi_0}{\sin\phi}\right)\right] \times \int_0^a \sigma(r) \cdot r \cdot dr - \pi a^2 c. \qquad (4)$$

where α = angle at base of cone;
$\alpha = 90^\circ - 30^\circ/2 = 75^\circ$
a = the radius of its base
σ = mean stress at a point.

The integral in equation (4) was computed point by point, and approximately by the area of a trapezoid, where values of σ at the base and the apex of the cone serve as its ordinates. The simplified computation by means of a trapezoid is justified by the fact that in the limiting state a redistribution of stresses occurs- a "saturation" of the stress diagram up to a trapezoid (Berezantsev, 1958).

The calculation results revealed the following: (1) it can be assumed that during the process of cone penetration the diagram of stresses along the cone surface passes over with the depth from an "integral" $P_{\int}$ to a trapezoidal $P_{\triangle}$ " It may be that the critical peenetration depth of the cone is characterized by a complete transition of the stress diagram into a trapezoid; (2) for a denser sand, the "saturation" of the stress diagram occurs at lesser depths than for looser sand. Results of calculations and test data are given in Table , where P_t- are test data; $P_{\int}$ -results of calculations by means of an "integral" diagram. $P_{\triangle}$ -results of calculations by means of a trapezoidal diagram.

Tests by means of photography (see Fig.) showed that:
(1) The zone of soil deformation (at a constant unit weight before the given test for the same depth, does not depend on the rate of cone penetration, but a change occurs in the angles at which the soil particle displacement paths approach the cone and go out into the soil mass.
(2) The visible zone of soil defomation increases with the penetration depth. The development of a larger zone of deformation to the sides is characteristic for a denser sand.
(3) In the case of a loose sand, the displacement paths have a larger radius of curvature.
(4) With an increase in sand density at V=const, the zone of soil deformation is increased together with the angle of approach of the displacement paths to the cone. The zone of deforming soil above. the base of the cone also increases.
(5) The angle of path approach in all cases decreases toward the apex of the cone.

The lines seen in the photographs were treated as envelopes of the displacement paths of particles (Malyshev, 1971).

REFERENCES

BELENKAYA, V. V. (1972). "An Experimental Verification of the Nonlinear Theory of Strength for a Sand Base Under a Circular Plate", Journal "Bases, Foundations and Soil Mechanics", No.1, Moscow.
BEREZANTSEV, V. G. (1955) "Limiting Equilibrium of a Cohesive Media Under Spherical and Conic Plates" Journal "Izvestia (News) of the USSR Academy of Sciences",

TEST DATA AND COMPUTED VALUES OF THE FORCES OF PENETRATION, N

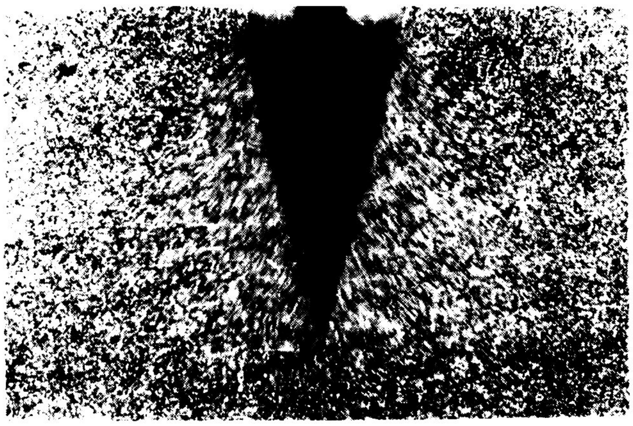
cN/cm^3	P, N	H, cm 5	10	15	20	25	30	35
1.42	P_t	-	40	65	94	116	131	155
	$P_{\int}$	10	32	48	64	76	92	107
	$P_{\triangle}$	11	46	60	73	126	142	159
1.50	P_t	42	68	126	186	236	175	302
	$P_{\int}$	18	62	93	123	150	180	210
	$P_{\triangle}$	22	84	112	141	237	270	305
1.60	P_t	48	125	296	526	743	923	1017
	$P_{\int}$	44	156	23I	309	387	464	542
	$P_{\triangle}$	76	374	5I6	615	719	826	934
1.69	P_t	52	168	438	933	I34I	1666	-
	$P_{\int}$	94	336	510	684	858	1060	1264
	$P_{\triangle}$	115	689	913	11 2	3 I	1665	1874

BEREZANTSEV,V.G., JAROSHENKO,V.A.et al. (1958). "Investigation of the Strength of Sand Bases", Proceedings of TsNIIS, issue 28, Transzheldorizdat,Moscow.

BEREZANTSEV V.G., SIDOROV N.N. et al. (1971). "Features of Soil Strength Investigations by Means of Penetration", Proceedings of the III All-Union Conference on Foundation Engineering, Kiev.

LAVISIN A.A. (1973) "Features of the Deformation of a Sand Base Depending on Its Density and on the Rate of Cone Penetration", Journal "Isvestia Vizov", Siberian Branch of the USSR Academy of Sciences, No.6, Novosibirsk.

MALYSHEV,M.V.(1971) "On Slip Lines and Displacement Paths of Particles in a Loose Media", Journal "Bases,Foundations and Soil Mechanics", No.6, Moscow.



Photofixation test results. Diameter of cone 6.0 cm. Unit weight 1.42 cN/cm^3. Maximum penetration depth 22.5 cm. Rate of penetration V = 0.62 cm/sec.