It was shown that, in the presence of a rigidly secured vertical shaft, the bearing capacity of the base of a foundation located axisymmetrically in its vicinity is reduced in comparison with an intact mass, which must be taken into account in determining the safe load on the base.

At present, in industrial and civil construction the underground space is being used more and more widely. In connection with this, questions related to the mutual influence of the mouths of vertical shafts and nearby foundations of structures above the mine, or dense development, for example, in the historical centers of large cities, are very important.

We will consider an imponderable elastic half-space with a vertical, rigidly secured shaft axisymmetrically loaded with a ring foundation. In the literature [1-4], only the problem of a foundation adjacent to a shaft is considered. Diagrams of stresses and displacements are described [1-3]; the amounts of stresses and displacements at certain points of a half-space with and without a shaft are compared; and data are obtained on the increase in stresses due to the presence of the shaft [4]. However, the stability of the half-space was not evaluated according to the dimensions of conditional zones of inelastic deformations (a method used in mining [5], as well as in soil mechanics [6]).

On the basis of solution of the more general problem of elasticity theory about a circular load with width b, the inner boundary of which can be displaced from the outline of a shaft with radius \( r_0 \) by the amount \( a \) [7], and with the use of asymptotic improvement of the convergence of improper integrals [8] entering into the solution in [7], the AXISYM program was written in FORTRAN to determine the boundaries of conditional zones of inelastic deformations. This program computes components of the stress tensor at points of a uniform rectangular grid. The grid interval horizontally and vertically is set arbitrarily, and the grid consists of 1200 points. The program takes up 286 Kbytes of RAM; the computation time on an ES-1033 computer is 30 min. A permanent file is created on a magnetic disk for storage of computed values of stress components at the grid points, which makes it possible to check the strength of the mass by substituting arbitrary values of cohesion \( c \) and the angle of internal friction \( \varphi \). The stability of the mass was checked in the plane \( rz \); in this case, the Coulomb-Mohr condition has the following form:

\[
(\sigma_x - \sigma_z)^2 + 4\tau_x^2 \leq (\sigma_x + \sigma_z + 2c \, \text{ctg} \, \varphi)^2 \sin^2 \varphi.
\] (1)

The mass is considered as imponderable.

The nature of development of conditional zones of inelastic deformations of the mass was studied on the example of a foundation with width \( b = r_0 \) adjacent to a shaft (\( a = 0 \)) or set apart from it by the distance \( a = r_0 \). Poisson's ratio of the mass \( \nu \) was taken as equal to 0.35, which is typical of most soils. The value of \( \varphi \) was varied from 8 to 35°. Since the load \( q \) is taken as unitary in the AXISYM program, cohesion \( c \) was varied from 0 to 1.

Calculations showed that even with \( c/q = 1 \) the Coulomb-Mohr condition of strength is not fulfilled at the edge of the foundation. As the ratio \( c/q \) decreases, the conditional zone of inelastic deformations grows, encompassing the outline of the shaft as it does so. With small values of \( \varphi \), a change in the ratio \( c/q \) shows up more strongly in the depth of the zone than with \( \varphi \geq 35° \). Under the action of a load \( q \) comparable with cohesion \( c \), the dimensions of the inelastic region depend little on \( \varphi \). When \( c \to 0 \), with a rise in the mass's angle \( \varphi \) the dimensions of the inelastic region decrease. Near the outer edge of the foundation, the zone of inelastic deformations emerges to the surface. With all values of \( c \) and \( q \), an elastic core is pre-
TABLE 1

<table>
<thead>
<tr>
<th>θ</th>
<th>1°</th>
<th>10°</th>
<th>20°</th>
<th>30°</th>
<th>40°</th>
<th>45°</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>0.3185</td>
<td>0.2398</td>
<td>0.1767</td>
<td>0.1258</td>
<td>0.0852</td>
<td>0.0683</td>
</tr>
</tbody>
</table>

Fig. 1. Conditional zones of inelastic deformations under a foundation adjacent to a shaft (a) and set apart from it (b). The hatching indicates the elastic region with c = 0.

preserved under the foot of the foundation, and the unloaded surface a between the shaft and the foundation remains elastic (Fig. 1).

In soil mechanics [6], N. P. Puzyrevskii's and N. N. Maslov's well known formulas determine the values of marginal safe $P_{sf}$ and critical $P_{cz}$ loads on the base of a foundation. For an imponderable mass ($\gamma = 0$), the two formulas coincide, and the loads are determined as

$$P_{sf} = P_{cz} = \frac{\frac{\pi c}{2} \cot \theta}{\cot \theta + \frac{\pi}{2}} = M_c c,$$

(2)

where $M_c$ is a tabular coefficient [6].

Numerical verification of the applicability of formula (2) for an imponderable mass showed that for values of $\varphi \leq 30^\circ$ the formula corresponds to the critical load according to N. N. Maslov, with the appearance of a zone of plastic deformations under the edge of a foundation with with $b$, the depth of which is $z_p = b \tan(\varphi + 5^\circ)$; and with $\varphi > 30^\circ$, to the safe load according to N. P. Puzyrevskii (an inelastic region does not occur). For the safe load, an increase in it by 3-5% leads to the appearance of plastic deformations with depth $z_p$, and an analogous decrease in the critical load, to the disappearance of the plastic zone. Taking into account these features, a coordinated change in the values of c, q, and $\theta$ does not alter the pattern of inelastic deformations in an imponderable mass.

The elastic half-space is not so sensitive to small changes in the load. The stability of the mass in the vicinity of the shaft can be evaluated by loading the imponderable half-space with a safe load $q = P_{sf} = M_c c$, with verification of the observance of the Coulomb–Mohr condition of strength (1) in the plane rz.

We considered loading of the mass with a foundation with width $b$ from 0.1 to $5r_0$ and displacement of it from the outline of the shaft $a$ from 0 to $4r_0$. Poisson’s ratio $\nu = 0.35$, and the angle $\varphi$ was varied from 1 to $45^\circ$. Cohesion $c$ was assigned in fractions of the load $q = 1$ ($c = 1/M_c$) and took the values shown in Table 1.