CHANGE IN THE STRENGTH OF PEAT IN AN UNDERGROUND EXPLOSION

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This article reports results of experimental studies of the strength of peat in the underground explosion of a concentrated charge of explosive. It was established that the distribution of strength with distance from the explosion is zonal in character, as it is in water-saturated mineral soils [1]. This means that the peat is weakened in some zones and strengthened in others, relative to its initial state. The explosive cavity is typically adjoined by a weakened zone of peat. This finding is consistent with the data in [2].

Characteristics of Soils and Experimental Conditions

The main factors determining the strength properties of peat are its porosity, moisture content, and degree of decomposition [3]. The parameters of the physical state of the peat (density ρ, the density of the skeleton ρ_0, the gravimetric W_g and volumetric W_V moisture contents, degree of decomposition R, and porosity ε) were determined by taking samples of peat and testing them under laboratory conditions by a standard method [3, 4]. Peat strength (resistance to shear τ) was measured directly in a series of tests in rotational shear conducted by the method in [5] on a model PKZ-1m penetrometer. From ten to fifteen measurements of the peat were made at different points over the area of the peat at the charge depth before the explosion. Table 1 shows the main physicomechanical properties of peat from the test areas, where τ_0 is the weighted arithmetic mean of the peat strengths obtained from the tests, and σ is the standard deviation of this quantity.

We used concentrated charges of ammonite ZhV No. 6. The weight of the charge was 0.15 kg, while its density was 1000 kg/m^3. Three explosions were made in each area. The charge depth was the same in all tests and was 0.7 m. At this depth and with a charge weight of 0.15 kg, the resulting explosion is subsurface in character with regard to the wave and deformation processes it engenders [2, 6].

After the explosion, we subjected the peat to static probing and testing on the penetrometer in three radial directions at different distances from the charge. The peat tested was located at the depth of the charge. Using the results of the static probing (the unit resistance of the peat to probing q) and calibration relations $q = f(\varepsilon)$, we approximately (with an error of ±15-18%) evaluated the change in the porosity of the peat under the influence of the explosion. The relations $q = f(\varepsilon)$ were obtained on a compression-probing instrument (CPI) developed at the L. P. Zagoruiko UkrNIIProekt (State Scientific Research and Planning Institute of the Coal, Ore, Petroleum, and Gas Industries of the Ukrainian SSR). Thanks to the possibility of using soil specimens with a volume of 11,685 cm^3, the CPI makes it possible to perform static probing of the soil during compression tests, i.e., at different values of porosity.

EXPERIMENTAL RESULTS

We will introduce the dimensional distance $R^0 = r/\sqrt[3]{Q}$, m·kg$^{-1/3}$, which is corrected for the mass of the charge (r is the distance from the center of the explosion, m; Q is the mass of the charge, kg). Tests of soil in the ground mass were conducted at distances from 0.75 to 5.0 m·kg$^{-1/3}$.

Figure 1 shows the dependence of the increment $+\Delta\varepsilon$ and decrement $-\Delta\varepsilon$ in peat porosity on R^0. Figure 2, a and b, shows the effect on R^0 of the increment and decrement of shear resistance $+\Delta\tau$, $-\Delta\tau$ and the angle of internal friction $+\Delta\varphi$, $-\Delta\varphi$. The points denote the maximum and minimum values of the measured parameters, i.e., they define their ranges for each specific distance. The dashed curves were drawn from the mean values of the parameters within their respective ranges. Curves 1-3 pertain to test areas 1, 6, and 7 (see Table 1).

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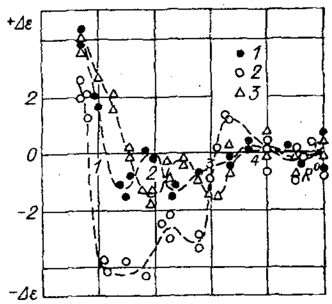

Fig. 1

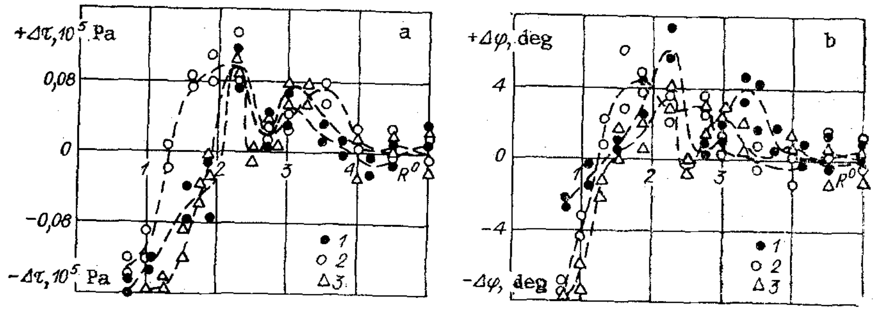

Fig. 2

TABLE 1

Number of area	$\rho\cdot 10^3$, kg/m³	$\rho_0\cdot 10^3$, kg/m³	W_g, %	W_V, %	ε	R, %	$\tau_0\cdot 10^5$, Pa	σ, kPa
1	0,92	0,21	240	64,9	3,4	40—45	0,25	4,13
2	0,97	0,11	590	82,9	7,8	15—20	0,22	5,08
3	0,98	0,07	1000	89,1	12,8	45—50	0,10	4,33
4	1,01	0,073	920	91,1	12,8	25—30	0,20	4,18
5	0,97	0,19	330	74,4	4,1	30—40	0,31	4,95
6	0,98	0,07	1050	89,1	13,0	20—25	0,19	3,47
7	1,05	0,19	620	90,4	4,5	10—15	0,26	3,21

Similar results were obtained for the other areas. It follows from the above relations that, as in waterlogged mineral soil [1, 2], the distribution of residual deformations after an explosion in peat is zonal in character.

Two main zones can be distinguished in regard to the change in the porosity of the peat under the influence of an explosion. A weakened zone (with increased porosity relative to the natural state) is found adjacent to the blast cavity. This weakened zone is followed by a consolidation zone (reduced porosity). The dimensions of the zones and the degree of loosening or consolidation depend more on the moisture content of the peat than on the degree of its decomposition. Thus, for peats with a high moisture content (W_g = 920-1050%), increases in porosity are seen up to R^0 = 1.25 $m\cdot kg^{-1/3}$, while at W_g = 240-330%, porosity increases up to R^0 = 1.35 $m\cdot kg^{-1/3}$. Here, the porosity of the peat increases by a factor of 1.05-1.27 in the first case and 1.47-2.25 in the second case.

In turn, the change in porosity in the peat consolidation zone is of an alternating character (see Fig. 1). A "saddle-shaped" change in porosity in the consolidation zone was noted in all test areas. In soils with W_g = 240-620%, at the minimum points, porosity was 50-73.5% of the initial value. In area 5, we noted a porosity reduction of up to 25% relative to the initial value. The porosity maximum in the consolidation zone for the peats with low and moderate moisture contents ($W_g \leq$ 620%) was 1.1-1.3 times less than the initial porosity.

In areas 3 and 4, porosity decreased by a factor of 1.15-1.58 at the points of minimum porosity. Meanwhile, the porosity at the point of the first minimum was 1.17-1.2 times less than the porosity at the point of the second minimum (points 3 in Fig. 1). At the maximum, porosity was 1.01-1.29 times less than the initial value. As a whole, the zones in which the residual deformations were recorded attained a value of 5.0 $m\cdot kg^{-1/3}$. Regardless of the moisture content, the degree of consolidation of the peat increased with an increase in the degree of its decomposition.

The change in porosity with distance from the explosion is also zonal in character. The alternation of the weakened and strengthened zones is similar to the distribution of the porosity regions. However, in most cases, the sizes of the zones and the position of the extrema points do not coincide with the position of the analogous porosity indices. Here, we should note the decisive effect of the degree of decomposition of the peat R on the change in its strength. The peats characterized by a low or moderate degree of decomposition (R ≤ 30-40%), with a low moisture content, correlate with a closer boundary for the weakened zone (R^0 = 1.15-1.25 $m\cdot kg^{-1/3}$), while high-moisture content, highly decomposed peats (R > 40%) correlate with a farther (R^0 = 2.0-2.1 $m\cdot kg^{-1/3}$) boundary. In this zone, peat strength is 1.15-2.63 times lower than the initial value for little-decomposed peats and 4.0-4.17 times lower than for highly decomposed peats.

The dependence of peat strength on distance from the explosion in the strengthened zone ($R^0 = 1.15\text{-}4.65\ m\cdot kg^{-1/3}$) is of an alternating character: there are two strength maxima and one strength minimum. The strength at the maximum points fluctuates within the range from 130 to 200% of the peat strength in the undeformed state. The minimum strengthening of the peat is 105-116%, i.e., nearly equal to the initial strength. It should be noted that the relative increment in strength $(\tau \pm \Delta\tau)/\tau$ is greater for highly decomposed peats, with a moisture content of 900-1000%, than for little- and moderately decomposed peats.

Discussion of Results

The above experimental results can be explained on the basis of current representations of the nature of peat strength [3] and laws governing the deformation of waterlogged soils by an explosion [1, 2, 7].

The presence of the small weakened zones of peat directly adjacent to the blast cavity (see Fig. 1) can be attributed to the reverse motion of the boundary of the cavity toward the center of the explosion after vanishing of the excess pressure in the gaseous detonation products and to the significant loosening of the peat due to disturbance of its natural structure by the intensive stress wave and the penetration of pores in the soil by gases from the explosion. Thus, it is natural that the strength of the material in the zone adjacent to the blast cavity is lower than the initial strength of the peat. The weakened zone is followed by a zone of reduced porosity (see Fig. 1) with a higher value of the angle of internal friction (see Fig. 2b). However, the overall strength of the peat (resistance to shear τ) still remains lower than the initial value (see Fig. 2a). The increase in the angle of internal friction is explained by the reduced porosity and moisture content of the peat in this zone. It was shown in [2] that compaction of the peat during an explosion is the result of the elimination of the free porosity of the peat and a reduction in its total porosity due to the expulsion of water from pores in the soil under the influence of the dynamic load. In this regard, peat is no different than waterlogged mineral soils [1, 7]. However, the explosion seriously disturbs the natural structure of the peat, which, according to [3], results in a reduction in peat strength by almost 50%. However, internal friction is increased due to the increase in the density of the soil in the zone in question and the reduction in its moisture content, and this increase in internal friction causes the total strength of the peat to decrease by only 25-30%. With a further increase in distance from the explosion, the intensity of the dynamic load decreases, the peat can in large part retain its original structure, and the reduction in porosity and moisture content increases the total strength of the peat.

We established that there is some relative increase in porosity, which reduces the angle of internal friction and accordingly reduces total strength in the zone $1.8 \le R^0 \le 2.5\ m\cdot kg^{-1/3}$ (see Figs. 1 and 2). This finding agrees with the results of the experiments in [1, 2]; it was established that during an explosion in soil, the groundwater moves both away from the explosion and toward it, from deep in the soil mass. This results in the generation of convergent fluid flows in the soil, which in turn cause the formation of a zone with a high moisture content relative to the undeformed state. The presence of such zones was noted in waterlogged organic mineral soils at distances $1.6 \le R^0 \le 2.7\ m\cdot kg^{-1/3}$ from the explosion [2].

The secondary increase in strength is due only to an increase in the density of the peat as a result of elimination of its free porosity. This can be explained by the fact that the strength at the point of the first maximum in peat is always greater than the strength at the point of the second maximum (see Fig. 2a).

Thus, the change in the strength of peat with an underground explosion is ambiguous: the peat is not only weakened, but – in certain zones – is also strengthened relative to the initial strength.

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APPLICATION OF A GENERALIZED FORMULATION OF THE STEFAN PROBLEM TO INVESTIGATION OF RADIATION-CONDUCTIVE HEAT TRANSFER

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Study of the influence of internal thermal radiation on the temperature distribution formation in semitransparent materials by using the classical Stefan model, assuming the presence of a plane interface between the liquid and solid phases, showed that the monotonic nature of the temperature distribution is spoiled ahead of the plane front. This fact was explained in [1, 2] as heating of the solid phase during melting and over cooling of the liquid during solidification caused by heat transfer due to radiation. Overheating and overcooling are metastable states of a substance, but crystal overheating in the domain bounding the liquid phase is not generally realized [3]. Dendritic growth is detected before the crystallization front upon the appearance of an overcooled zone. Moreover, an independent volume generation of crystals is possible [4]. Therefore, instead of overheating and overcooling, a two-phase or transition zone appears in the semitransparent medium, in which partial melting or solidification occurs, caused by solid—phase absorption of thermal radiation or because of radiation cooling. Also confirmed in [5] is the reality of the appearance of a transition zone in a semitransparent medium. The spoilage of the classical Stefan condition and the appearance of a transition zone are also mentioned in [6, 7].

A generalized model, proposed in [5, 7], according to which the material under consideration consists of three sublayers (Fig. 1, zone 1: liquid, 2: solid, 3: two-phase), is used in this paper to investigate the influence of thermal radiation on the phase transformation process in a layer of semitransparent material. The initial layer temperature is below the melting point T_m; then the temperature of the left wall acquires a temperature $T_1 > T_m$ and is later maintained constant. At the initial time, surface melting predominates because of the high temperature gradient. After a certain time, a transition zone appears because of the rapid penetration of the thermal radiation into the solid phase. It is considered that the thermophysical and optical properties are constant in all the phases, a unique melting point exists, and a two-phase domain is in thermodynamic equilibrium at this temperature. The density change during melting is assumed insignificant; consequently, convective motion is neglected.

In a generalized formulation the Stefan problem reduces to determining the temperature as a continuous function $\Theta(x, t)$ satisfying the energy equation

$$\frac{\partial u}{\partial t} = \operatorname{div}(k\nabla\Theta) + f(\Theta); \tag{1}$$

$$u(\Theta) = \int_0^{\Theta} c(\xi)\, d\xi - \alpha(\Theta - \Theta_m)\lambda,\quad \alpha = \begin{cases} 0, & \Theta > \Theta_m, \\ [0, 1], & \Theta = \Theta_m, \\ 1, & \Theta < \Theta_m, \end{cases} \tag{2}$$

within the domain $\{0 < x < 1,\ 0 < t < T\}$, where $u(\Theta)$ is the enthalpy undergoing a discontinuity of the first kind and defined ambiguously for $\Theta = \Theta_m$, and λ is the latent heat of melting.

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