INVESTIGATION OF THE INTERACTION OF WAVE IN SOIL WITH THE OBSTRUCTION FROM THE RECORDS OF STRESSES AND STRAINS

G. M. Lyakhov, V. A. Plaksii,
and K. S. Sultanov

UDC 662.215.2

The stresses and the particle velocities in the soil, the loading at the obstacle, and its displacement were investigated earlier in experimental investigations of the interaction of explosion waves with obstacles [1-4]. Below we present the results of experimental investigation involving simultaneous measurement of stresses and strains of soil during the passage of incident and reflected waves and also of the loading at the obstacle. This permitted us to refine the characteristic features of the primary and secondary compression of the soil and to verify the applicability of the model of an elastoplastic medium [4].

The experiments were carried out in forest soil of disarranged structure placed in a pit 2 m deep, 1 m wide, and 1 m long. The walls of the pit were coated with sheets of roofing iron for decreasing friction of the soil during the displacement and for ensuring homogeneous motion. A concrete slab was placed in the pit along its entire transverse cross section. In the first variant the thickness of the slab was 0.05 m, while in the second variant the thickness was 0.5 m; the mass per unit area was 120 kg/m^2 and 1200 kg/m^2, respectively. The slab with 0.05 m thickness was placed at a depth of 0.3 m, while the slab with 0.5 m thickness was placed at a depth of 0.6 m.

The sensors for measuring the stresses and strains were placed in the soil above the slab and on its surface. The stress was measured by a high-frequency tensometric sensor; the strains of the soil were measured by sensors utilizing simultaneous records of the displacements of the two thin aluminum disks parallel to the plane of the charge and separated by 0.05 m from each other. The space between the disks was filled with the soil except for a thin tube connecting the disks in which the mechanism permitting the recording of the displacement was placed. The resistance of this mechanism to compression was negligibly small compared to the resistance of the soil. The readings of the sensors were recorded on loop oscillographs. In order to ensure identical conditions the pit was cleaned of soil before each experiment and then filled again. The sensors were also installed at that time.

The wave was produced during the explosion of a plane high-explosive charge at the surface of the soil covering the entire transverse cross section of the pit. The charge consisted of filaments of detonating fuse placed parallel to each other and interconnected at the edges. Charges with mass per unit area $C = 0.3$ kg/m^2 were used. The top of the charge was covered by soil of thickness 0.4 m (ground surface).

The granulometric weight of the soil was $\gamma_0 = (1.37 - 1.43) \cdot 10^3\ kg/m^3$; the water content, was $W = 9.8$-16.2%. The granulometric composition is given in Table 1.

Let us discuss the results of the experiments. The incident wave retains a discontinuity at the front at the distance of $r \leq 0.1$ m from the charge which corresponds to a maximum stress $\sigma_{max} \sim 5.0 \cdot 10^5\ N/m^2$. At distances up to 0.3 m the curves contain a segment where the stress increases almost with a jump. With increasing distance from the wave the discontinuity gets eroded and a continuous compression wave approaches the slab. Due to its relatively small mass the slab with thickness of 0.05 m is rapidly set into motion together

---

Moscow, Kiev. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 166-169, May-June, 1976. Original article submitted June 5, 1975.

TABLE 1

Particle diameter, mm	0,25—0,05	0,05—0,01	0.01—0.005	0.005—0
Compsoition, %	9.6	73.6	6.8	10.0

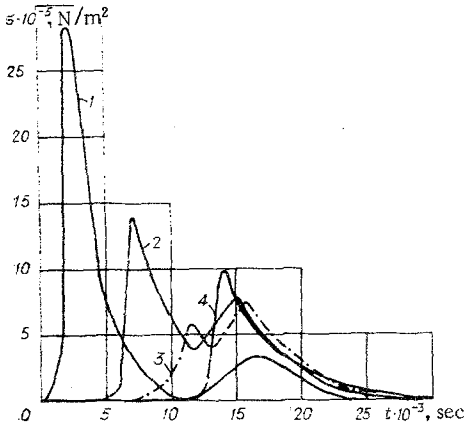

Fig. 1

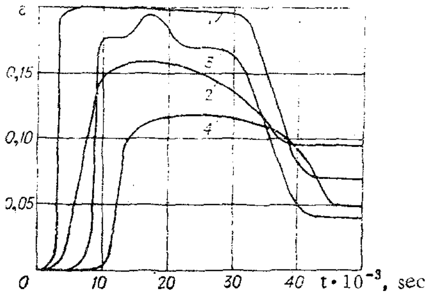

Fig. 2

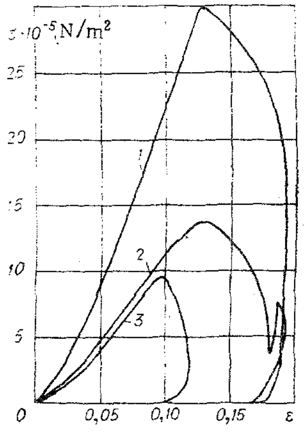

Fig. 3

with the soil, and therefore the effect of reflection is insignificant; the maximum stress at the upper surface of the slab is larger by 5-10%, and at the lower surface, smaller by 5-10%, than the maximum stress at the depth in the incident wave. The sensors placed in the soil above the slab practically did not show any record of the reflected wave.

The curves $\sigma(t)$ obtained in the experiments with the slab of mass 1200 kg/m^2 are shown in Fig. 1 on a single scale [1-3) recorded at depths of 0.2, 0.4, and 0.5 m, respectively; 4) at the upper surface of the slab (0.6 m)]. In the case of the slab with mass 1200 kg/m^2, two maxima of the stress are observed above the slab; these are produced by the incident and the reflected waves. At a depth of 0.5 m the stress in the reflected wave is larger, while at the depths of 0.2 and 0.4 m the stress in the reflected wave is smaller, than in the incident wave. The time of growth of the stress in the incident wave increases with the distance (the erosion of the wave continues). The velocity of propagation of the stress maximum in the incident wave is 50-70 m/sec, while in the reflected wave it is 250-300 m/sec, i.e., larger by a factor of 4-6. The significant increase of the velocity of the maximum in the reflected wave compared to that in the incident wave was observed in sandy soils also. The velocities were 50-60 and 800-1000 m/sec, respectively [3].

The curves of $\varepsilon(t)$ are shown in Fig. 2 [1 and 2 correspond to the readings of the strain sensors placed at the upper and lower surfaces of the slab with mass 120 kg/m^2 (depth 0.3 m)]. The maximum strain of the soil under the slab was approximately 20% smaller than that above the slab and the growth to the maximum occurs after a longer time interval. Above the slab the secondary growth of the strain was not observed.

Curves 3 and 4 correspond to the experiments with the slab of mass 1200 kg/m^2 for the depth of the sensors equal to 0.4 and 0.6 m (at the slab). A secondary increase of strain caused by the reflected wave is observed above the slab for this value of the mass. At the surface of the slab the increase of the strain occurs more slowly than at the depth of 0.4 m.

The diagrams of $\sigma(\varepsilon)$ are constructed from the graphs $\sigma(t)$ and $\varepsilon(t)$ (Fig. 3, where curve 1 corresponds to a depth of 0.3 m and experiments without the slabs; curves 2 and 3 correspond to experiments with the slab with mass 1200 kg/m^2 at depths of 0.4 and 0.6 m, respectively). Curves 1 and 2 (before the arrival of the reflected wave) are different, since due to the erosion of the wave the time of increase of the stress to the maximum increases with the depth; i.e., the strain rate ε decreases. Curves 1 and 2 contain segments with different strain rates. In curve 1, the stress increases from $15 \cdot 10^5$ to $25 \cdot 10^5$ N/m^2 almost with a jump and we can assume that $\varepsilon \sim \infty$. In curve 2, close to the initial point $\varepsilon \sim 2$ sec^{-1}, which is close to the static diagram. On decreasing the stress, the increase of strain continues for some time. The secondary loading (curve 2) does not proceed along the line parallel to the diagram of primary dynamic compression ($\varepsilon \rightarrow \infty$); it has a significantly larger slope to the strain axis. In the first approximation we can assume that the secondary loading corresponds to the load line of the medium realized after attaining the maximum strain. The diagram $\sigma(\varepsilon)$ during unloading contains a segment which practically coincides with the $O\varepsilon$ axis. The residual strains after the primary and repeated loadings differ significantly.

The results presented above show that during short-lived wave processes the bulk viscosity of the soil can manifest itself: the curves of $\sigma(\varepsilon)$ depend substantially on the strain rate and after the removal of the loading the residual strains are retained, which indicates the presence of plastic properties. The diagrams of dynamic and static compression are convex with respect to the strain axis. In the first approximation, the secondary loading proceeds along the load line. These properties correspond to the model of viscoplastic medium [4].

LITERATURE CITED

1. G. M. Lyakhov and R. I. Dubova, "Waves in soil during underground explosion and their interaction with obstacles," in: Proceedings of Fifth Session of Educational Soviet on National Economic Use of Explosions [in Russian], Frunze, Ilim (1965).
2. G. M. Lyakhov and N. I. Polyakova, Waves in Dense Medium and Loading at Structures [in Russian], Nedra, Moscow (1967).
3. Z. V. Narozhnaya, "Experimental determination of the rate of unloading in soil during dynamic processes," Fiz. Goreniya Vzryva, No. 1 (1965).
4. G. M. Lyakhov, Fundamentals of the Dynamics of Explosion Waves in Soil and Rocks [in Russian], Nedra, Moscow (1974).