AN INVESTIGATION OF THE COMPRESSIBILITY OF SANDY SOIL UNDER IMPACT-WAVE LOADING

N. N. Gerdyukov, A. G. Ioilev,
A. D. Kovtun, Yu. M. Makarov,
and S. A. Novikov

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The systematic experimental study of the mechanical properties of soft soils under blast loading was begun at the end of the 1950's (see, for example [1-6]). However, in almost all publications the maximum measured pressure did not exceed 75 MPa. The properties of sand under impact-wave loading in the region of large pressures was studied in [2, 4]. Lagunov and Stepanov [2] obtained an impact adiabatic curve for dry sand with an initial density of ρ_{00} = 1.66 g/cm^3 in the 100 MPa-5 GPa pressure range, as well as the dependence of the mass velocity of particles in the discharge wave during the emergence of a plane impact wave (IW) onto an open surface u_1 on the mass velocity in an incident IW u in the 50-800 m/sec range. It proved to be the case that $u_1/u \approx 1.36$. In [4] the impact adiabatic curves of four fractions of dry sand in the pressure range from 1 to 6 GPa and two fractions of water-saturated sand in the range from 2 to 12 GPa were obtained.

Below are presented some results of measurements of the compressibility of broken sandy soil of natural mositure content in transient and reflected IW, generated by the detonation of a flat layer of explosive, in the pressure range from 0.07 to 7.84 GPa.

The investigation of the compressibility of dry, broken sandy soil with ρ_{00} = 1.68 g/cm^3 under impact-wave loading in the pressure region of 0.38-7.84 GPa was carried out with aid of the x-ray diffraction method on an ÉRIDAN-3 apparatus. The maximum particle size of the soil was d = 0.5 mm. An x-ray diffraction pattern made before the experiment was performed is given in Fig. 1a: a cuvette with a steel bottom 6 and organic-glass walls was filled with sandy soil 1 in which strips of copper foil 2 of cross section 0.1 × 5 mm, a flat charge of plastic explosive 3 of thickness 2 mm, separated from the soil by a lavsan film 4 of thickness 0.2 mm, and copper wires 5 of diameter 1 mm were placed. During placement in the cuvette, the soil (with a bulk density of 1.54 g/cm^3) was levelled and tamped to a density of 1.68 g/cm^3. The thickness of the soil layer above the explosive charge and beneath it was ~15 mm. The width of the assemblage in the direction of the x-ray photography was 52 mm, touching every 4 mm the organic-glass side walls of the cuvette. The explosive charge was detonated simultaneously along the entire left end, while the x-ray pictures were taken every 33 and 9 μsec after detonation; the x-ray photograph is shown in Fig. 1b.

The speed of motion of the load along the soil layer is equal to the speed of detonation of the explosive (D_{BB} = 7.85 km/sec), which significantly exceeds the speeds of propagation of the IW and the discharge wave in the soil; therefore, it may be assumed with some precision that the x-ray given in Fig. 1b can serve as a time scan of the motion of the soil that would occur with instantaneous detonation of the entire explosive layer (the ℓ coordinate along the horizontal axis corresponds to the time $t = \ell/D_{BB}$).

For investigation of the compressibility of bulk sandy soil with natural moisture content (about 4%) and density ρ_{00} = 1.54 g/cm^3 under impact-wave loading in the region of lower pressures, piezoelectric pressure sensors (PPS) were used [7, 8]. The maximum size of the soil particles was d = 0.5 mm. A diagram of the design of the experiments is given in Fig. 2. The normal pressure in the soil 2 was measured by pressure sensors 3 placed at distances of x = 10, 20, 30, and 40 mm from the plane of the explosive charge 1 (a square plate 2 mm thick with a side of 25 cm). The normal pressure in the IW reflected from a steel plate 4 of thickness 4 cm was measured by a pressure sensor placed in the plate flush with its surface. From above the explosive charge was covered with a layer of the same soil to a thickness of 5 cm.

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TABLE 1

Soil parameters		Coefficients		Source	Curve number in Figs. 4, 5
ρ_{00}, g/cm³	d, mm	a, km/sec	b		
1,68	⩽0,5	0,406	2.43		
1,66	—	0,5	2,404	[2]	4
1,52	0,85—1.4	0,571	1,61	[4]	5
1,54	0.85—1,4	0.56	1,7	[4]	6
1,49	0,07—0.14	0.504	1.6	[4]	7
1,29	~0,07	0,187	1,86	[4]	8

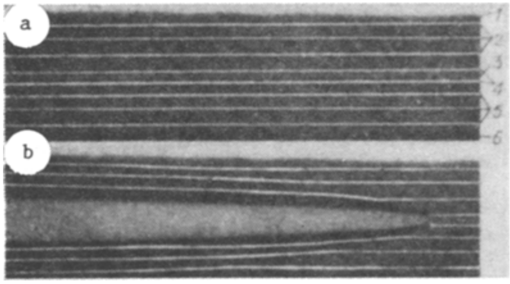

Fig. 1

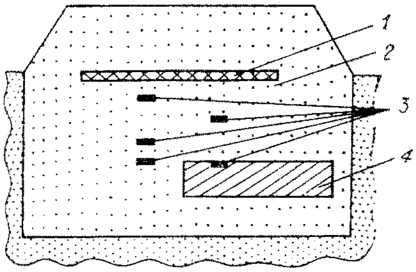

Fig. 2

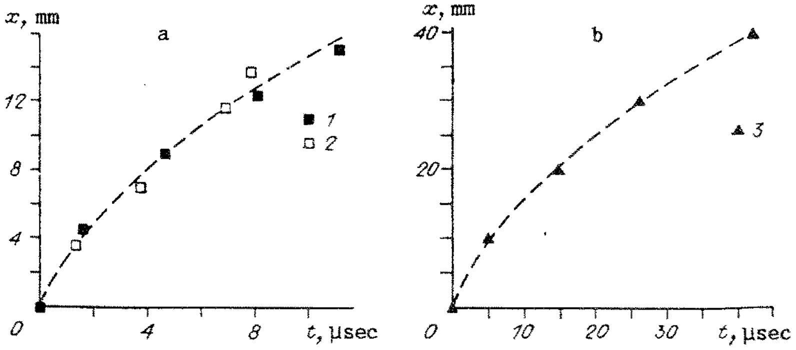

Fig. 3

From the results of the experiments t—x diagrams of the propagation of the IW through the soil were constructed; these are shown in Figs. 3a and 3b (x is the distance from the explosive charge, points 1 and 2 are the results of measurements in the soil above and beneath the explosive charge respectively obtained from processing of the x-rays, 3 is the result of measurements using the sensors, and the dotted line is a polynomial approximation). An averaged dependence of the IW speed D on x is obtained by differentiating the corresponding approximating polynomial. In the experiment with x-ray recording of the deviation of the foil and wires during passage of the IW through the soil, its mass speed u was determined, from the relations at the IW front it is possible to obtain the normal pressure σ_n and the compressibility $\beta = 1 - \rho_{00}/\rho$ in the passing IW (ρ is the density of the compressed material):

$$\sigma_n = \rho_{00}\, u\, D, \; \beta = u/D.$$

In the experiment using the PPS sensors, the compressibility and mass speed were also determined from these relations involving known D and σ_n. From the effect of the IW, the sensors located 10 and 20 mm from the explosive charge were destroyed, and so their readings can be used to judge only the fact of the arrival of the IW.

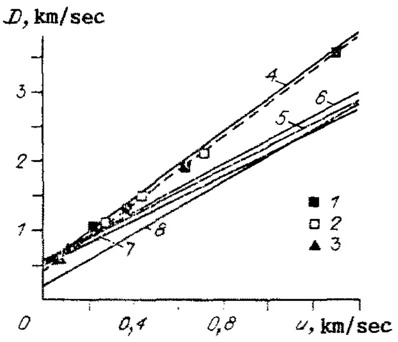

Fig. 4

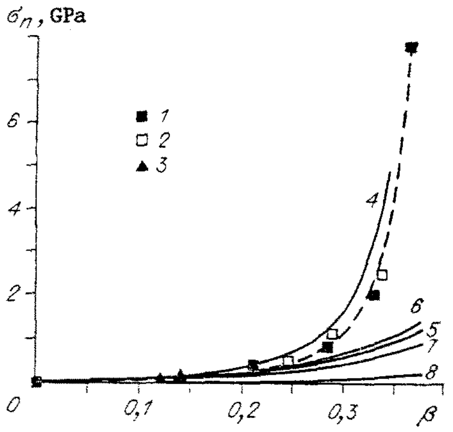

Fig. 5

The D—u diagram for the sandy soil is given in Fig. 4. The experimental points obtained during processing of the x-rays give a completely satisfactory approximation of the dotted line $D = a + bu$, where $a = 0.406$ km/sec and $b = 2.43$ (see Table 1) (1 and 2 are the results of measurements in the soil above and below the explosive charge respectively, found from processing of the x-ray, while 3 is the result of measurements with the aid of the PPS). Table 1 shows the analogous functions obtained in [2, 4] for dry (heated before the experiment) soil, the soil parameters, and the coefficients a and b. We note the close values of a and b for unfractionated sandy soil, found in [2], which differ markedly from the values for the fractionated soil given in [4].

Also obtained in the experiments were: for poured sand with natural moisture content, the value of the reflection coefficient $\sigma_r/\sigma_n = 7.5$ for $\sigma_n = 0.07$ GPa (σ_r is the maximum normal pressure in the reflected wave), and for dry sand, the value of the ratio of the mass velocity as the IW emerges onto the open surface to the mass velocity in the passing IW of $u_1/u = 1, 4$ for $u = 0.22$ km/sec, which agrees with the value of 1.36 cited in [2].

The σ_n—β function obtained for sandy soil in comparison with other authors' data is given in Fig. 5 (the symbols are the same as those used in Fig. 4). The divergence can be explained both by differences in the composition and moisture of the soil being tested, and by differences in the loading conditions.

LITERATURE CITED

1. V. D. Alekseenko, S. S. Grigoryan, A. F. Povgorodov, and G. V. Rykov, "Some experimental investigations of the dynamics of soft soils," DAN SSSR, 113, No. 6 (1960).
2. V. A. Lagunov and V. A. Stepanov, "Measurement of the dynamic compressibility of solid at high pressures," PMTF, No. 1 (1963).
3. G. M. Lyakhov, Fundamentals of the Dynamics of Explosive Waves in Soils and Rocks [in Russian], Nedra, Moscow (1974).
4. M. D. Dianov, N. A. Zlatin, S. M. Mochalov, et al., "Impact compressibility of dry and water-saturated sand," Pis'ma ZhTF, 2, No. 12 (1976).
5. G. V. Rykov and A. M. Skobeev, Measurement of Pressures in Soils during Short-Term Loadings [in Russian], Nauka, Moscow (1978).
6. Soil Behavior under Pulse Loads [in Russian], Naukova Dumka, Kiev (1984).
7. S. I. Bodrenko, N. N. Gerdyukov, Yu. A. Krysanov, and S. A. Novikov, "Use of Quartz pressure sensors in investigations of impact-wave processes," FGV, No. 3 (1981).
8. N. N. Gerdyukov, A. G. Ioilov, and S. A. Novikov, "An investigation of the effect of explosive loads on soft soil," PMTF, No. 2 (1992).