Journal Applied Mechanics and Technical Physics, Vol. 36, No. 4, 1995

DETERMINATION OF THE DYNAMIC COEFFICIENT OF FRICTION OF SANDY GROUND ON A RIGID WALL

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UDC 534.222.2+624.131

To predict the motion of free-flowing bulk materials over a rigid base (screes, avalanches), the effect of explosive shock loads on underground constructions, pipelines, and wells, and the body deceleration upon impact on ground, one needs to know the dynamic friction coefficient, which differs significantly from that found under static and quasistatic conditions. It should be noted that determining the static friction coefficient has also not received too much attention. For instance, data on the static coefficient of friction of dry sandy ground on a smooth metal wall are presented only in [1–3].

Below we describe a method for the experimental determination of the dynamic coefficient k_f of the friction of sandy ground on a rigid wall, which does not require a direct measurement of the ground pressure on the wall, and we present some measurement results: values of k_f for the motion of sandy ground with an initial density of 1.66 g/cm and humidity of 4–5 % in a smooth tube of D16T alloy in the range of stresses 0.1–25 MPa and mass velocities 0.9–40 m/sec. The procedure for determining sand stresses and mass velocities behind a shock wave front in experiments of this kind was set forth in [4].

The experimental setup is shown in Fig. 1. Thick-walled tube sections *3* (inside diameter 26 mm, length from 8 to 30 cm) and *5* were mounted one inside the other with a small gap on a massive steel slab *7* and filled up with sand *4*. The sand loading was induced by blasting of an explosive disk (*1*) 5 mm thick initiated at the center. A steel disk striker (*2*) 5 mm thick was placed between the explosive and the sand. The normal stress in the wave σ_r reflected from the steel slab was measured by a piezoelectric pressure gage *6* [5] embedded in the slab flush with its surface. A relatively thin sand layer in tube *5* is used to cushion the explosive effect on the steel slab via the wall of tube *3*. To decrease the friction, a polyethylene spacer 0.05 mm thick was placed between the tube wall and the sand in the second set of experiments. The measurement results are presented in Fig. 2. Points *1* are the data obtained without the polyethylene spacer; *2*, with the spacer; x is the distance from the disk striker to the lower end of tube *3*. The normal stress pulse in the reflected wave

$$i_r = \int_0^\infty \sigma_r(t)\,dt$$

was determined by numerical integration of stress records.

As a first approximation (if the viscous dissipation during wave processes in the ground and losses due to radial deformation of the metal tube are neglected), the total momentum of the sand may be thought of as changing only because of the Coulomb friction on the tube wall:

$$Ri(x) + \int_0^\infty \int_0^x 2k_f\sigma_2(x,t)\,dx\,dt = Ri(0).$$

Russian Research Institute of Experimental Physics, Arzamas-16 607200. Translated from Prikladnaya Mekhanika i Tekhnicheskaya Fizika, Vol. 36, No. 4, pp. 185–187, July–August, 1995. Original article submitted February 25, 1994; revision submitted August 4, 1994.

 0021-8944/95/3604-0640$12.50

TABLE 1

Stress type	Wall material	k_f	Source
Dynamic	D16T	0.31	Present paper
»	D16T with a poly-ethylene spacer	0.17	» »
Static	Stainless steel	0.38	[1]
»	Aluminum alloy	0.47	[1]
»	Steel	0.22	[2]
»	»	0.28	[3]

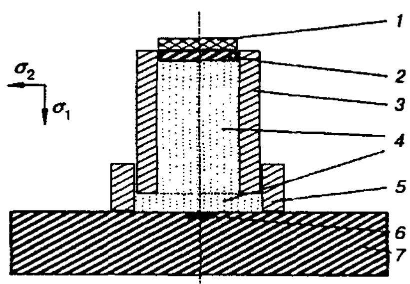

Fig. 1

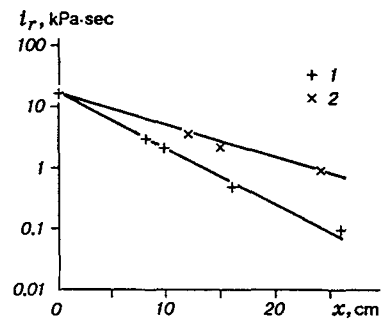

Fig. 2

Here $i(x)$ is the specific momentum of the sand at a distance x from the disk striker:

$$i(x) = \int_0^\infty \sigma_1(x,t)\,dt;$$

R is the tube radius; σ_1 and σ_2 are the axial and radial sand stresses.

According to the experimental data of [6, 7], when $\sigma_1 < 50$ MPa the coefficient of the lateral pressure $k_{21} = \sigma_2/\sigma_1$ for dry outside sandy ground depends only slightly on σ_1 and the rate of loading (on static trials, $k_{21} = 0.42$, in blast waves, $k_{21} = 0.45$ [6], and on trials on an impact tester, $k_{21} = 0.44$ [7]). Assuming that $k_f = \text{const}$ and $k_{21} = \text{const}$, we obtain

$$\int_0^\infty 2k_f\sigma_2(x,t)\,dt = 2k_f\,k_{21}\,i(x).$$

Then,

$$\frac{di}{dx} = -\frac{2\,k_f\,k_{21}}{R}\,i(x),$$

i.e.,

$$\frac{d(\ln i)}{dx} = -\frac{2\,k_f\,k_{21}}{R} = \text{const}.$$

In the approximation under consideration, assuming the steel slab to be a rigid wall, we have $i(x_t) = i_r$ (x_t is the tube length). The experimental values are approximated well by a function of the form $i(x) = i(0)\exp(-Ax)$; $A = 0.21$ 1/cm without the polyethylene spacer and $A = 0.12$ 1/cm with the spacer (the approximating straight lines are shown in Fig. 2). In this case

$$k_f = \frac{A\,R}{2\,k_{21}}.$$

The values of the dynamic friction coefficients obtained by this means are shown in Table 1. The values of the static coefficient of friction of dry sandy ground on a smooth metal wall, obtained in [1–3], are presented for the sake of comparison. It was noted [2] that the friction coefficient increases as the sliding length increases (for a sliding length of 1 cm k_f increases to 0.3). On the whole, we can conclude from the results of the experiments that the dynamic coefficient of friction of sandy ground on a smooth metal wall differs insignificantly from the static one, while a polyethylene spacer decreases the friction coefficient almost two times.

This work was supported by the Russian Foundation for Fundamental Research (Grant 93-013-16504).

REFERENCES

1. R. G. Murfitt, P. L. Braushby, and A. W. Nienow, "Flow in core flow hoppers," in: *Particle Technology*, Birmingham (1981).
2. A. J. Tejchman, "Tarcie miedzy materialem zianistym a stalowa sciana konstrukcji," *Arch. Hydrotechn.*, **33**, No. 4, 517–525 (1986).
3. V. Ya. Skovronskii, "Study of ground-on-wall friction," in: *Intensification of Exploitation of Navigable and Port Hydraulic Structures and Upgrading of Quality of Works on Navigation Improvement* [in Russian], LIVT, Leningrad (1987).
4. N. N. Gerdyukov, A. G. Ioilev, and S. A. Novikov, "Study of the effect of explosive shock loads on soft ground," *Prikl. Mekh. Tekh. Fiz.*, No. 2, 149–152 (1992).
5. S. I. Bodrenko, N. N. Gerdyukov, Yu. A. Krysanov, and S. A. Novikov, "Application of quartz pressure gauges to investigation of shock wave processes," *Fiz. Goreniya Vzryva*, **33**, No. 3, 146–148 (1981).
6. G. V. Rykov and A. M. Skobeev, *Ground Stress Measurement under Short-Time Loads* [in Russian], Nauka, Moscow (1978).
7. Kh. A. Rakhmatulin, A. Ya. Sagomonyan, and N. A. Alekseev, *Problems of Ground Dynamics* [in Russian], Moscow University Press, Moscow (1964).