Journal of Applied Mechanics and Technical Physics, Vol. 40, No. 6, 1999

EFFECT OF ANOMALOUSLY LOW FRICTION IN BLOCK MEDIA

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UDC 550.834 + 622.831

We study mechanical conditions under which the effect of anomalously low friction in block media from various geomaterials, which was revealed by the authors, is realized. It is shown that the maximum transverse (horizontal) displacements of the blocks occur only in the case of canonical coordination of the delay intervals between the vertical and horizontal pulse effects on the block system and the working block, respectively. In the case of static horizontal actions on the working blocks, significant displacements of the latter occur at absolute values of these actions, which are much smaller than the corresponding friction forces.

1. In studying the mechanism of emergence of pendulum-type waves (μ-waves), the authors [1] revealed the effect of friction "disappearance" between the interacting blocks from geomaterials at definite energy levels of the pulse effect on the models of block media. The disappearance of friction is observed in the directions orthogonal to the line of action of the external pulse. In this connection, several problems concerning the mechanical conditions and manifestation of the effect of anomalously low friction in block media arise.

Here we confine our analysis to the following problems:

(1) Finding the link between the transverse displacements of blocks from geomaterials in two-sided hindered conditions when the vertical pulse acts on the block system and the horizontal pulse (or the force) acts on the working block;

(2) the effect of the time interval of delay between the horizontal and vertical pulse effects on the character of transverse displacements of the working blocks.

2. To solve the above problems, a number of experiments were performed by the method of physical modeling. The experiments were carried out on two models. Model No. 1 was a vertical system from six 250 × 125 × 85 mm Plexiglas blocks 3.25 kg each. Model No. 2 was a vertical system from six 250 × 125 × 85-mm blocks from silicate bricks 5.43 kg each. The velocities of longitudinal waves in the Plexiglas and silicate blocks were $V_l = 2814$ and 2662 m/sec, respectively.

Two schemes were used in the experiments.

Scheme No. I. *Study of the transverse pulse response of block* III *under the conditions of statically applied horizontal actions to this block and the vertical pulse action on the surface of block* I (Fig. 1). In this scheme, a node 12 is the node of specification of the static horizontal action. A platform 8 with a dynamometer 9 is fastened rigidly to block IV by means of screws 11. In block III, there is a screw which is connected to the dynamometer by a regulator of action 10. This regulator creates the necessary horizontal action for block III relative to blocks II and IV. Together with block III, a stop 7 on the platform serves to prevent motion of block II. At the point A of block I, at the center a hardened screw, which is the "point" of vertical pulse excitation, is placed. The role of the vertical pulse action is played by a hardened hammer head 2 of weight 82.71 g. To specify different levels of energy action on the block system, the hammer head was dropped from different heights relative to the point A of block I. The fraction of the kinetic energy transmitted from the

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Mining Institute, Siberian Division, Russian Academy of Sciences, Novosibirsk 630090. Translated from Prikladnaya Mekhanika i Tekhnicheskaya Fizika, Vol. 40, No. 6, pp. 133–138, November–December, 1999. Original article submitted April 14, 1998.

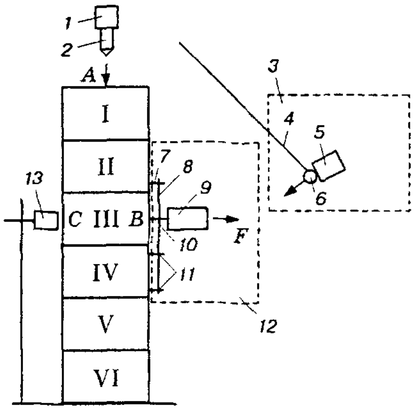
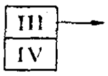
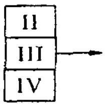
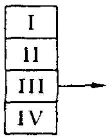
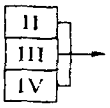
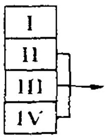


Fig. 1

TABLE 1

Threshold Values of the Static Horizontal Force F^0, N

Material of the model	Scheme of motion for blocks				
	without a platform			with a platform	
					
	1	2	3	4	5
Plexiglas	11.76	22.54	36.26	33.32	64.68
Silicate bricks	36.26	70 56	98.00	94.08	191.10

dropped hammer head to the block system was calculated with allowance for the magnitude of recoil.

Scheme No. II. *Study of the transverse pulse response of block* III (*absolute shifts*) *under the conditions of joint effect of the horizontal pulse action on block* III *and the vertical pulse action on the surface of block* I. In this scheme, the node of horizontal pulse action 3 is employed. The dynamic horizontal excitation of block III is set by a steel ball 6 of weight 226.9 g suspended on the filament of a bracket 4. Changing the angle of deviation of the ball, one can change the energy of pulse horizontal excitation. The same screw as in block I is installed at the point B of block III; this screw is the "point" of horizontal pulse excitation. Electromagnets 1 and 5 keep the hammer head and the steel ball in the initial positions and are controlled by a special scheme of time delay; this scheme sets the time delay δt between the beginning of free fall of the hammer head and the beginning of the motion of the steel ball, i.e., between the vertical and horizontal pulse excitations. The absolute displacements of block III were registered by an optical gauge of displacements 13 described in [2]. The data were processed by a measuring-computational complex presented in [3].

3. At the first stage of experiments, the threshold values of the static horizontal force F^0 for overcoming the quiescent state of block III in model Nos. 1 and 2 under conditions where the vertical pulse excitation of the block systems is absent were measured. The corresponding measurement results are given in Table 1. In schemes 2 and 3, block III (Plexiglas or silicate bricks, respectively) is shifted together with the overlapping block II or blocks II and I; in schemes 4 and 5, block II rests upon the platform fixed to block IV, i.e., block III moves between blocks II and IV. For schemes 1–5 of motion of the silicate and Plexiglas blocks, which are presented in Table 1, the ratios between the force characteristics to overcome friction are 3.08 (1), 3.13 (2),

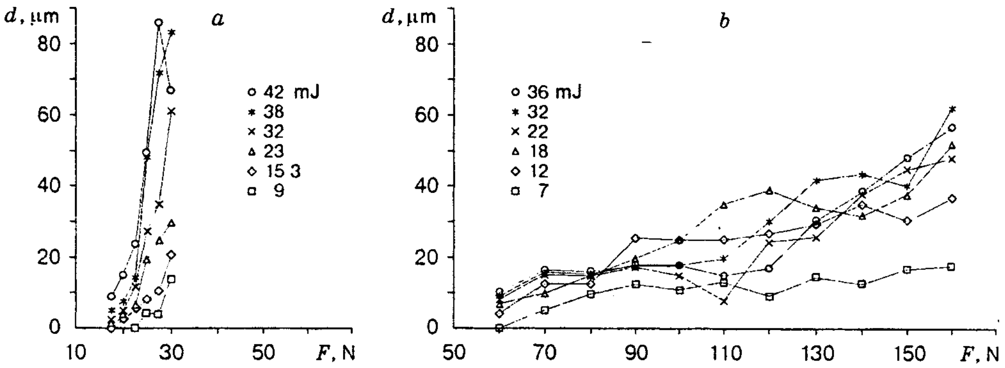


Fig. 2

2.70 (3), 2.82 (4), and 2.95 (5), respectively; the average value is approximately 2.94. In other words, the friction coefficient between the silicate blocks is a factor of three greater than the friction coefficient between the Plexiglas blocks. Here the relative scatter of the data reduced to their average values does not exceed 7%.

At the second stage of experiments, for models 1 (Plexiglas) and 2 (silicate), the shift of block III was registered under the joint action of the static horizontal force F and the vertical pulse excitation with energy W (see the description of scheme No. I in Sec. 2). The measurement results are shown in Fig. 2a and b for model No. 1 from Plexiglas and model No. 2 from silicate blocks.

It follows from Fig. 2a and Table 1 (scheme 5) that the first noticeable displacements of block III are observed during the lateral static action F, which are considerably weaker than F^0. For example, for $W_v \cong 42$ mJ (W_v is the energy of the vertical pulse action), the displacements $d \cong 10$ μm occur already for $F \cong 17.15$ N, whereas $F^0 \cong 64.68$ N. Thus, $F^0/F \cong 3.8$, i.e., the force characteristics gain significantly for the processes of block motion to occur in hindered conditions. For various levels (9–42 mJ) of the vertical pulse actions W_v on the block system, the common properties of the indicated diagrams of transverse displacements d of block III are

1) the almost monotone increase in the shift values of the working block III as the energy of the vertical pulse W_v increases for fixed horizontal action F;

2) the dependence of the magnitude of the shift d of the working block on the lateral (horizontal) action F, which is close to a parabolic dependence.

One can see from a comparison between Fig. 2b and the data of Table 1 (scheme 5) that the main features of the displacement characteristics of the working silicate block are similar to those considered above for the Plexiglas block. The effect of greater roughness of the silicate surfaces compared to the Plexiglas surfaces is manifested in the quasimonotonic structure of the diagrams of displacements of the working block. Taking into account the almost double difference in F^0/F for the silicate and Plexiglas blocks, one can conclude that the average-amplitude characteristics of the roughness of the corresponding surfaces can differ by a factor of approximately 2. This is supported by the results obtained at the third stage of experiments at which the deformations of blocks III at the point C (see Fig. 1) were registered for model Nos. 1 and 2 under the conditions of action of only the vertical pulse excitation of the block systems. The measurement results are given in Fig. 3a and c (model No. 1 from Plexiglas) and Fig. 3b and d (model No. 2 from silicate blocks).

It follows from Fig. 3 that the amplitudes of displacement of the silicate and Plexiglas blocks in the direction transverse to the pulse effects differ by a factor of approximately 2 for $t \geqslant 75$ msec.

4. At the final stage of experiments, the displacements of block III were measured according to scheme II described in Sec. 2 (see Fig. 1) with the use of the node of horizontal pulse action. In this case, the

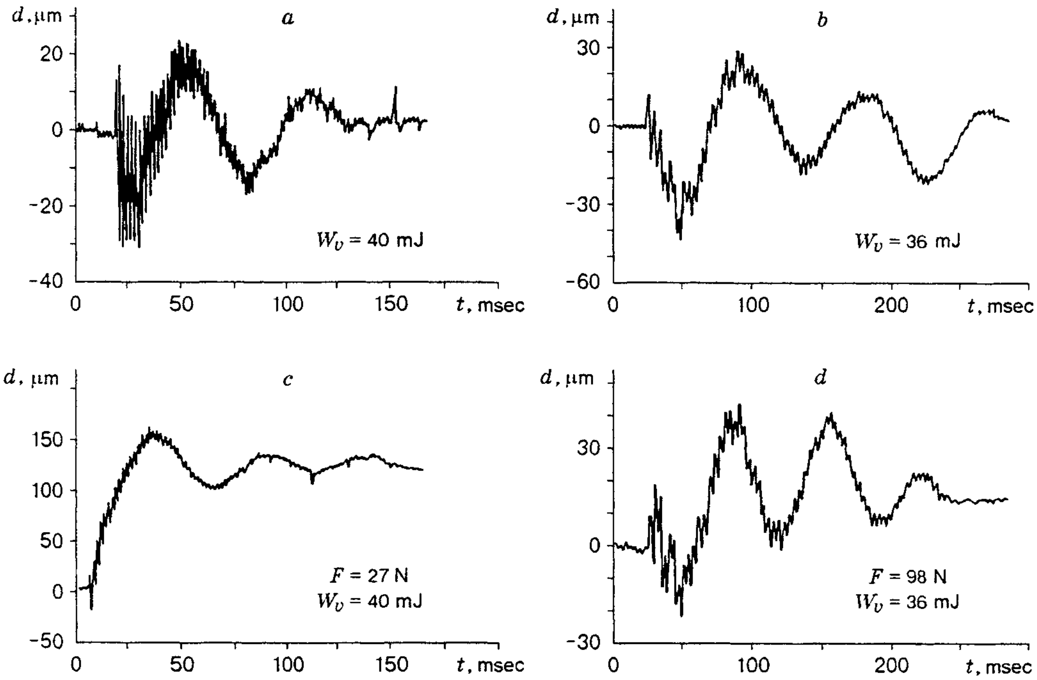


Fig. 3

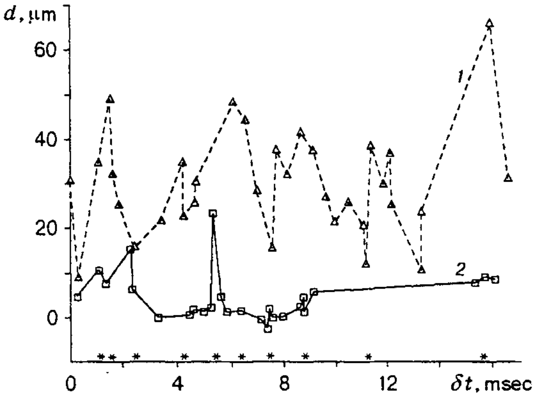


Fig. 4

experiments were carried out only on model No. 2 from silicate blocks under the joint action of different (in energy) vertical and horizontal pulse excitations (curve 1 in Fig. 4 refers to $W_v = 73$ mJ and $W_h = 106$ mJ, and curve 2 to $W_v = 37$ mJ and $W_h = 24$ mJ). An analysis of the diagrams in Fig. 4 shows a very important feature, namely, the canonical [1] character of coordination of the significant local maxima of the transverse displacements of the working block III in the modulus $\sqrt{2}$ in the scale of the relative time delay of the vertical and horizontal pulse actions. Here, if one uses 5.4 msec as the duration of the basic action (the distinct maximum for $d = 23$ μm corresponds to this value on curve 2 in Fig. 4), the canonical values of the series (in milliseconds) $\delta t_0 = 5.4$, $\delta t_1^- = (1/\sqrt{2})\delta t_0 \cong 3.8$, $\delta t_2^- = (1/2)\delta t_0 \cong 2.7$, $\delta t_3^- = (1/(2\sqrt{2}))\delta t_0 \cong 1.9$, $\delta t_4^- = (1/4)\delta t_0 \cong 1.4$, $\delta t_6^- = (1/8)\delta t_0 \cong 0.7$, $\delta t_1^+ = \sqrt{2}\delta t_0 \cong 7.6$, $\delta t_2^+ = 2\delta t_0 \cong 10.8$, and $\delta t_3^+ = 2\sqrt{2}\delta t_0 \cong 15.3$ coincide with the significant local maxima of the parameter d as the function δt (asterisks above the δt axis in Fig. 4) with an accuracy not worse than 5%. For the cases considered, the energy characteristics of the pulse actions differ greatly. The latter circumstance indicates that the dependence between δt and d is of fundamental character; this is important for specifying the optimum modes of action on the block system for effectively utilizing the phenomenon of anomalously low friction for various technological purposes. The interesting fact following from analysis of the diagram for $W_v = 37$ mJ and $W_h = 24$ mJ (curve 2 in Fig. 4) is noteworthy. For 7.0 msec $< \delta t <$ 7.3 msec, one can observe a response inverse to the expected response of the block, i.e., in the indicated interval of delay between the actions of the vertical and horizontal pulses, the working block begins to move in the direction opposite to the vector of action of the horizontal pulse, which seems paradoxical at first sight. This phenomenon is unlikely to be explained beyond the framework of the concepts of the role of rough surfaces of the blocks of geomaterials and the resonance mechanism of appearance of anomalously low friction between them.

Using the dependence in Fig. 4, one can calculate the average values of the transverse displacements of the working block for the case of interaction between the horizontal and vertical pulse actions. It is easy to show that the work at average values of d_m irrespective of the parameter δt can result in ambiguous conclusions on the character of the correlation between the real displacements d of blocks and the energy levels of the pulse action. A different situation arises when one considers the same correlation but from the viewpoint of the significant local maxima of the parameter d which are canonically coordinated relative to δt. The averaging of the latter gives a monotonically increasing dependence of d on the energy parameters; this is easy to show by means of the data in Fig. 4.

Thus, under the conditions of joint action of the vertical (in the block system) and horizontal (in the working block) pulse excitations the effect of anomalously low friction is observed if the relation between the delay intervals between them, which is canonical relative to the modulus $(\sqrt{2})^i$, is satisfied:

$$\delta t_i = (\sqrt{2})^i \delta t_0, \qquad i = 0, \pm 1, \pm 2, \ldots, \qquad \delta t_0 = 2\chi\Delta/V_l, \qquad \chi = (\sqrt{2})^9 \cong 22.63.$$

Here Δ is the characteristic linear dimension of the working blocks and V_l is the velocity of longitudinal waves in the geomaterials of the blocks Δ. This conclusion follows from [1] and a comparison of the main carrier harmonics in the high- (285.2 Hz) and low-frequency (13.7 Hz) regions of the spectrum of the diagrams of transverse displacements of the silicate blocks with the base frequency $f_0 = V_l/(2\Delta)$.

The effect shown in the present paper is of primary importance for studying of the mechanism of earthquakes, rock impacts, and other dynamic forms of manifestation of rock pressure; it can be widely used in technical applications to solve problems connected with weakening of the friction between interacting bodies.

This work was supported by the Russian Foundation for Fundamental Research (Grant No. 99-05-64637).

REFERENCES

1. M. V. Kurlenya, V. N. Oparin, and V. I. Vostrikov, "Pendulum-type waves, Part 2. Basic results of physical modeling," *Fiz.-Tekh. Probl. Razrab. Polezn. Iskop.*, No. 4, 3–39 (1966).
2. M. V. Kurlenya, V. N. Oparin, and V. I. Vostrikov, "Effect of anomalously low friction in block media," *Fiz.-Tekh. Probl. Razrab. Polezn. Iskop.*, No. 1, 3–16 (1966).
3. M. V. Kurlenya, V. N. Oparin, and V. I. Vostrikov, "Pendulum-type waves, Part 1. The state of the art of the problem and a measuring-computational complex," *Fiz.-Tekh. Probl. Razrab. Polezn. Iskop.*, No. 3, 3–8 (1966).