A THEORETICAL AND EXPERIMENTAL STUDY OF THE MOBILITY OF LOOSE MATERIALS

L. I. Karnaushenko and S. N. Pavlovskii

The effect of external and internal parameters of loose materials on their mobility is investigated. A dimensionless equation describing the mobility of loose materials is obtained and confirmed by experimental data.

A loose material is a discrete statistical system of solid particles in contact with one another in a disperse gas medium with or without liquid. The strength of contacts between the particles is determined by their nature and concentration and external factors [1].

During storage of loose materials the colloid-surface interaction between the particles changes, which results in their consolidation. In this case the strength of the contacts between the particles increases and they lose fluidity and can form a monolith. The strength of loose materials increases due to redistribution of fine particles between large ones, which leads to an increase in the contact area between particles, and due to an increase in the intermolecular attraction forces self-adhesion increases, which results a reduction in the mobility of loose material (consolidation).

Consolidation of finely divided loose materials is a process of change in the physicomechanical and physicochemical properties of the materials with time. The most distinctive property of loose materials determining this process is their fluidity or mobility, which is estimated from the ability of loose materials to transfer stress to the enclosing vertical and horizontal surfaces and depends on internal, external, and design parameters of the storage facilities.

The stressed state of the material \( \sigma_n \), the granulometric composition \( d_i \), and the moisture content \( W \) are internal parameters of loose materials.

The air humidity \( W_1 \), storage time of loose material \( B \), ambient temperature \( t \), and external effects (vibration, shock, etc.) are external parameters.

According to [2] the mobility of loose materials is estimated by the mobility criterion \( m = \frac{\sigma_2}{\sigma_1} \).

The horizontal stress \( \sigma_2 \) arising on the surface of the enclosing walls depends on the vertical stress \( \sigma_1 \), the stress in the dome \( \sigma_0 \), the storage time \( B \) of loose material in a prescribed stressed state, the ambient temperature \( t \), the rate of load application, and deformation characteristics, in particular, the bed coefficient \( e \), which is the ratio of the stress to the absolute deformation of the material:

\[
e = \frac{\sigma_1}{\delta}.
\]

Thus, at a constant ambient temperature \( t = \text{const} \), the pressure on the side walls of the container can be written as

\[
\sigma_2 = f(\sigma_1, \sigma_0, B, V, e).
\] (1)

The apparatus of dimensional analysis can be used as mathematical tools for describing the horizontal transfer of pressure as a function of the aforementioned internal and external parameters of loose materials [3–5].

According to dimensional analysis the obtained data processed in a suitable dimensionless form that describes the mechanism of pressure transfer to the side walls of the container can be extrapolated. The mechanism characterizes changes in the lateral pressure of a loose material as a function of the aforementioned parameters. 

Assuming that in a known range the variables are related by a certain functional relation, we can rewrite Eq. (1) in the following form [3]:

\[ \sigma_2 = [\sigma_1]^{a_1} [\sigma_0]^{r_0} [B]^{r_1} [V]^{r_2} [e]^{r_3}. \]  

(2)

The equation of dimensionsality will be written in the form

\[ \frac{N}{m^2} = \left( \frac{N}{m^2} \right)^{a_1} \left[ \frac{N}{m^3} \right]^z \left[ \frac{m}{\text{sec}} \right]^l \left[ \frac{m}{\text{sec}^2} \right]^b \left[ \frac{N}{m^3} \right]^r. \]  

(3)

A comparison of the exponents of the same units of measurement in the left- and right-hand sides of Eq. (3) gives a system of three equations with five unknown quantities:

\[ 1 = a + z + r, \quad -2 = -2a - 2z + b - 3r, \quad 0 = l - b. \]  

(4)

From the \( \pi \)-theorem it is found that for the number \( N = 6 \) of physical quantities expressed in three basic SI units of measurement the similarity equation should consist of three generalized variables: \( \pi = N - n = 6 - 3 = 3 \). Consequently, system (4) is solved for the three exponents \( a, l, b, \) assuming \( z \) and \( r \) to be prescribed:

\[ a = 1 - z - r, \quad b = l, \quad r = b. \]  

(5)

Substitution of the values of the exponents \( a, l, \) and \( b \) from (5) into Eq. (2) gives

\[ \sigma_2 = [\sigma_1]^{(1-z-r)} [\sigma_0]^{r_0} [B]^{r_1} [V]^{r_2} [e]^{r_3}. \]  

(6)

Having grouped together the quantities with the same exponent, we can express Eq. (6) in the form

\[ \frac{\sigma_2}{\sigma_1} = \left[ \frac{\sigma_0}{\sigma_1} \right]^z \left[ \frac{BV}{\sigma_1} \right]^r. \]  

(7)

where \( \sigma_2/\sigma_1 = m \) is the criterion of material mobility; \( \sigma_0/\sigma_1 = \kappa \) is the criterion of the ability of the loose material to form a dome; \( BV/\sigma_1 = \lambda \) is the criterion of storage time for the loose material in the specified stressed state \( \sigma_1 \).

Substitution of the corresponding criteria into Eq. (7) gives the following dimensionless equation:

\[ m = \kappa^z \lambda^r. \]  

(8)

A method for determining the criteria \( m, \kappa, \) and \( \lambda \) was used for experimental verification of Eq. (8).

A schematic diagram of the device for determining the mobility of materials [6] is shown in Fig. 1a. Rigid housing 1 contains cylinder 2. Upper 4 and lower 5 strain-gauge rings are mounted on three symmetrically located pillars 3. Bottom 6 of the cylinder is screwed into lower ring 5. Loading system 7, containing a rod with piston 8, is located on upper strain-gauge ring 4. The piston is moved by removable handle 9. Rings 4 and 5 serve to measure the vertical force applied to a sample of the test loose material. Sample 10 is located in the cylinder cavity between bottom 6 and piston 8.

On the lower part of the side surface of the cylinder a window was cut out, which is closed with lateral insert 11. During manufacturing the lateral insert is machined together with the cylinder, because of which the cylindrical surface is prevented from being distored. Lateral insert 11 is fastened rigidly to lever 12, which is fixed by special bush 13 with the aid of two axial bearings 14. This suspension system allows the lever to swing with minimum friction losses.