The external manifestation of the so-called second (free) form of flow for loose materials in bunkers during discharge is descent of the charge surface parallel to itself, or as it is customary to assume, material movement as a whole column along the wall. It is well known that this form of flow occurs, as a rule, in high silo bins \( H = H/D \geq 3-4; H \) is silo height, \( D \) is diameter).

The second form attracts most attention both from specialists in the field of loose body mechanics, and specialists in the field of design, planning, and operating silo structures. This interest is caused by the fact that with the second form of movement horizontal pressures on the silo walls increase by a factor of 2 to 2.5 compared with static pressures, and according to some data even by a factor of 5-7 \([1]\). Increased pressures develop at a certain characteristic height asymmetric relative to the bunker axis of symmetry and they have a pulsating character \([2, 3]\).

The increase in pressure at the closing surface during discharge, as already noted in \([4]\), is connected with a freely formed change in flow and even with sonic shock waves. A number of researchers are inclined to explain this increase by dynamic phenomena \([5]\) (whence the extensively used term "dynamic" loading). There is no single view on the nature of the rest of these facts.

Standards set in most countries for determining static loads on silo elements recommend the method proposed in 1895 by Janssen \([6]\) in spite of the existence of many other methods. This selection is dictated by the simplicity of relationships obtained in \([6]\), and numerous verifications of calculated results by experiments. This situation is a weighty argument in favor taking the Janssen relationships as a basis for determining dynamic loads (in future we will call them peak or maximum loads). However, the difference in views on the mechanism of load formation, and, as a consequence of this ambiguity in estimates of absolute values of the latter, leads to the fact that the load curves for the same structure calculated by standards of different countries differ markedly. This paradoxical fact is illustrated in Fig. 1, which gives curves for dimensionless horizontal peak pressures in a silo wall according to USSR standards (curve 1), FRG standard DIN No. 1055 (curve 2), RSA CSIR (curve 3), and by the calculation methods adopted in a number of other countries (curve 4) \([7]\). All of this
makes it possible to assume that the question of the stress-strain state of loose materials in silos with the second form of discharge remains open. The most convincing confirmation of this is the quite widespread occurrence of serious accidents in world practice for storing and processing of loose materials [1, 7].

In order to explain the reasons and mechanisms for development of the second form of discharge, and also to attempt to answer the question of stresses existing in this way, it is necessary to consider the loading history for a material in a vessel.

It was shown in [8] that the kinematics of discharge from bunkers are determined by the original quality of the mass or its overall strength. This strength is accumulated from strength as a result of flow, and structural strength. The first depends on the value of angle \( \varphi_\mu \) for contact flow between particles, and the second from the dilation angle \( \nu \). The structural quality of the mass is connected with the method of filling the vessel [8]. Therefore, in the first instance we clarify the question of the structure and original strength of the loose mass formed by a "flow," i.e., a method by which after filling the second form of flow occurs in silos (in fact, usually it is possible to assume the generally acknowledged and reliable method in relation to the form of discharge being considered). This method is used most extensively in practice as a result of using conveyor and pipeline transport. With flow filling the following basic factors operate which contributed to the strength characteristics of the mass: 1) dispersion of the flow and scattering of particles on impact with the surface; 2) dynamic action of the flow; 3) a process of cone formation; 4) segregation; 5) overloading by overlaying material. We characterize briefly each of the factors, and we estimate their contribution to the formation of the structural and strength features of the mass in the case of silo filling by a central flow. 1. Dispersion of the flow and scattering of particles has a marked effect during filling high silos, and it leads to formation, starting from the bottom at a certain height (the higher, the greater the height of the silo and the drop of particles), of a compact and strong stack, close in quality to that formed by "rain" \( (\nu > \nu_{max}) \). 2. Dynamic action of the flow propagates along the structure axis, and it leads to material densification in the center. The area of the effect over the silo height is limited since with a large height of particle drop the flow is dispersed, and with a small height its effect is almost absent. 3. Cone formation is characterized by formation during vessel filling of caps whose particle packing density is greater than the critical value, and which, in view of individual tongues (slides) periodically move from the cone tip toward the walls. Since the thickness of tongues is significant and commensurate with the thickness developed with shifts of slip surfaces, then dispersion in the latter as a result of the dilation effect apparently propagates in the whole thickness of tongues. In view of this, material at the periphery is in a loose condition, and it forms there a mass with low initial strength. Cone formation occurs with quite small material fall heights, i.e., the most marked contribution in strength properties is made at the free surface. The depth at which a region propagates with the least quality structure depends on equipment productivity for filling, and it is independent of silo height. 4. Segregation accompanies cone formation; it is characterized by formation of a relatively compact and strong central core of finer particles, and a region of lower quality packing adjacent to the structure walls representing the coarser fractions. The ratio of sizes for these regions is governed by productivity of the filling equipment. 5. Overloading by overlaying layer initiates sagging of the loose material during filling, rebuilding of its original structure into a more compact form, and it has a weak effect on material at the vessel bottom.

Considering what has been stated, it is possible to confirm that the shear strength of the mass formed by the flow in silos of quite considerable height will decrease from the bottom \( (\psi_{max} (H) \rightarrow \psi_\mu + \nu_{max}) \) to the free surface \( (\psi_{min} (H) \rightarrow \psi_{in} = \psi_\mu + \nu_{min}) \) where \( \psi_{in} \) is internal friction angle and from the center to the silo walls (which develops mainly close to the free surface).

To fill a high vessel by a flow strictly over the center is complicated even in laboratory experiments. Under production conditions this filling is almost impracticable. This leads to the situation that in horizontal cross sections of actual structures there is no symmetry for strength properties of the loose material relative to the vessel axis of symmetry.

Thus, strength of the mass of loose material formed by a flow varies over both the height of the silo and over its perimeter.