Internal Granular Movement of Sand Treated as Three Dimensional Problems

By

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The experimental investigations of the internal granular movement in sand have been made by a number of investigators since first tried by Forchheimer, 1882, using a box with glass side walls. This may be practically one of the best methods to study the transitional movement of granular masses, from time to time, with the naked eye; but, if one considers the frictional effect between glass and sand as well as the arching effect, one must take another method of investigations to obviate the difficulties.

The effect of the friction between glass and sand mass upon the movement of sand is rather great and therefore for exact measurement, one must observe it at the central part of the apparatus, as many investigators have noticed.

For the mere investigations of the features of the movement of sand, the photo-investigation by using a glass side wall is quite convenient to observe the granular movement, furnishing a similar figure to that in the portion free from the effect of the friction above mentioned. The method of formation of sand blocks at the desired sections, after plain water has been poured through a spray is very practical. It can be applied on the spot to the measurement of the angle of the surface of rupture as well as for the investigations of several kinds of soil phenomena, serving as a visible demonstration for three dimensional problems in space in granular substances. To the slight knowledge of the author, such simple process of observation for inner deformed patterns has never been attempted.

In the following note, there are described the three dimensional representation of the patterns formed by the internal granular movement of dry sand, flowing out from rectangular holes, the deformation of sand bed caused by the load distribution in sand, and also the surface of rupture in different parallel sections.

Experiments and Results.

The granular substances used in the experiments are river sands completely dried and sieved to the size of 0.86 mm dia, mixed, in some measure, with finer grains.

The apparatus of the experiment consists of a rectangular wooden box so constructed without nails as to be able to be taken to pieces as shown in Fig. 1.

For the experiments of the surface of rupture, the apparatus shown in Fig. 15 has been used.

Horizontal layers of black sands were used for observing the deformation of the internal mass.

I. Movement of Dry Sand Flowing out from Rectangular Holes in the Bed Plate.

For the three dimensional investigation of the movement of dry sand flowing out from rectangular holes of similar form, two horizontal rectangular holes were made, measuring 7 cm long and 2 cm wide as seen in Figs. 7 and 8.

Sand is filled loosely in the vessel always in horizontal layers and the different horizontal surfaces are marked by a number of horizontal layers of black sand, making the relative movement of the granular masses easier to observe. In order to study the movement in sand, it was allowed to flow down from the holes, the falling sand grains piling up under the bed plate and the movement was stopped, at a certain instant, the whole space under the bed plate having filled with sand.

Now, in order to investigate the inner feature of the sand mass in several different sections, plain water, whose amount had been estimated as about 40 % to 50 % of the total sand volume, was poured through a spray after a cloth like lawn had been laid upon the surface of the sand and also some amount of sand in order to protect the initial sand surface from the disorder resulting from spraying water. And then many different sections were made, taking off the cloth together with the covering sand, as shown in Figs. 2 to 8. In these figures, the conical surface holes in the sand have been marked with white powder.

The inner sand patterns made by the granular movement have been taken, by many different sections, longitudinally, laterally and horizontally; in the last case there have been made four different horizontal sections; two of which are shown in Figs. 7 and 8. The sectional conditions adopted are described in each figure.

What is new in the experiments is finding out the granular movement of dry sand, as a three dimensional problem, in three different sections intersecting perpendicularly to each other; while the similar patterns observed at the glass side wall, as a two dimensional problem, have been already investigated by Forchheimer and by the present author*.

II. Deformation of Sand Bed Caused by the Load Distribution in Sand as well as Sand Movement by Peg.

In order to investigate the sand movement exerted by a vertical load, the rectangular box shown in Fig. 1 was used.

Sand was filled in the box always in horizontal layers and the different horizontal surfaces were marked as in the foregoing case by a number of horizontal layers of black coloured sand.

* Forchheimer: Über Sanddruck und Bewegungserscheinungen im inneren trockenen Sandes. Z. öst. Ing. u. Arch.-Ver. Bd. 34, 1882. Takabeya: Experimental Investigation on the Internal Granular Movements of Sand, These Memoirs, Vol. 2, No. 6, 1931.

Fig, 9 shows the pattern of sand movement exerted by a vertical load, whose base section was square and Fig. 10 shows the same case, seen at the central point of the square.

Fig. 11 shows the sand movement exerted by a peg of circular cross section, the base being quite rounded off.

These are the experiments made as a three dimensional problem; while in Figs. 12 to 14 are shown the sand movement observed at the glass wall as a two dimensional problem.

Fig. 12 shows the sand movement exerted by a slender peg seen at the glass wall and Figs. 13 and 14 show the movement by tamping and hammering of a peg with regard to the special condition described below the respective figures.

III. Surface of Rupture as a Three Dimensional Problem.

For the purpose of eliminating the effect of friction between side walls and sand as well as the arching effect, use was made of the glass tank, shown in Fig. 15, which has a sliding partition, whose glass side wall may be removed after wetting the inner sand.

Fig. 16 shows the surface of rupture exerted in the glass tank, the sand having been wet and fixed by plain water.

About 50 hours after the sand had been wet the outward frame of the glass tank was taken off to investigate the internal pattern in several section. The sand block, at that time, was cracked by the shock of hammering to remove the metallic frame, along the surface of the rupture and it also slipped down, continuing however to stand upright as shown in Figs. 17 to 19.

This was a very interesting phenomenon obtained by chance, because it shows that the denseness of the portion along the surface of rupture is more loosely adhesive than the other parts, although the appearance is the same as in the other portion of the sand and it is obvious that the shearing resistance of the sand block, in this moment, seems to be minimum in the wet state in question, along the surface of rupture even after stopping the movement.

Figs. 17 to 19 show the surface of rupture in the longitudinal section, distant 8.5 cm, 13.5 cm and 18.5 cm from the glass wall respectively.

Next, as Professor Jenkin has tried, the sand surface was kept always in the same level, filling sand in during the experiment.*

Fig. 20 shows the parallel motion of sand in the case under consideration and the figure taken at the glass wall.

Figs. 21 and 22 are of the longitudinal sections for the surface of rupture, showing the parallel motion, distant 15 cm and 25 cm from the glass wall respectively, eliminating the frictional effect and arching effect.

Figs. 23 and 24 are of the experiments of smaller scale, using the apparatus concerning Fig. 1.

As in Fig. 23, the wet sand block was cut off into four pieces, in order to examine the change of the surface of rupture, as may be seen in Fig. 24. The white powder on the surface is the indicator of the surface depression due to the surface of rupture. The experimental results show the amount of the angle between the surface of rupture and the bed plate as in the following:

Section No. 1 (at wooden side wall):	approx. 70 degrees,
Section No. 2 (10 cm from side wall):	63 degrees,
Section No. 3 (20 cm from side wall):	62 degrees,
Section No. 4 (29 cm from side wall):	63 degrees,

Summary.

The method of spraying the plain water, after the movement of granular dry sand, reveals many patterns with merit for experimental investigation as pointed out briefly below:

(1). Difficult problems of three dimension concerning granular movement of dry sand can be illustrated by the simple method of spraying plain water wetting the entire sand mass, because of the cementing characteristics between sand and water.

* C. F. Jenkin: Predicting the Internal Motion of Sand. Engineering, May 13, 1932.

(2). Plain water percolates and fills up the void of sand and there is no fatal effect therefrom for the observation of the patterns due to the granular movement of sand.

(3). As the blocks once cut off may be replaced in their initial position or form, as stated in Fig. 6, the same specimens are applicable many times to the next experiments anew.

Sapporo, June, 1932.

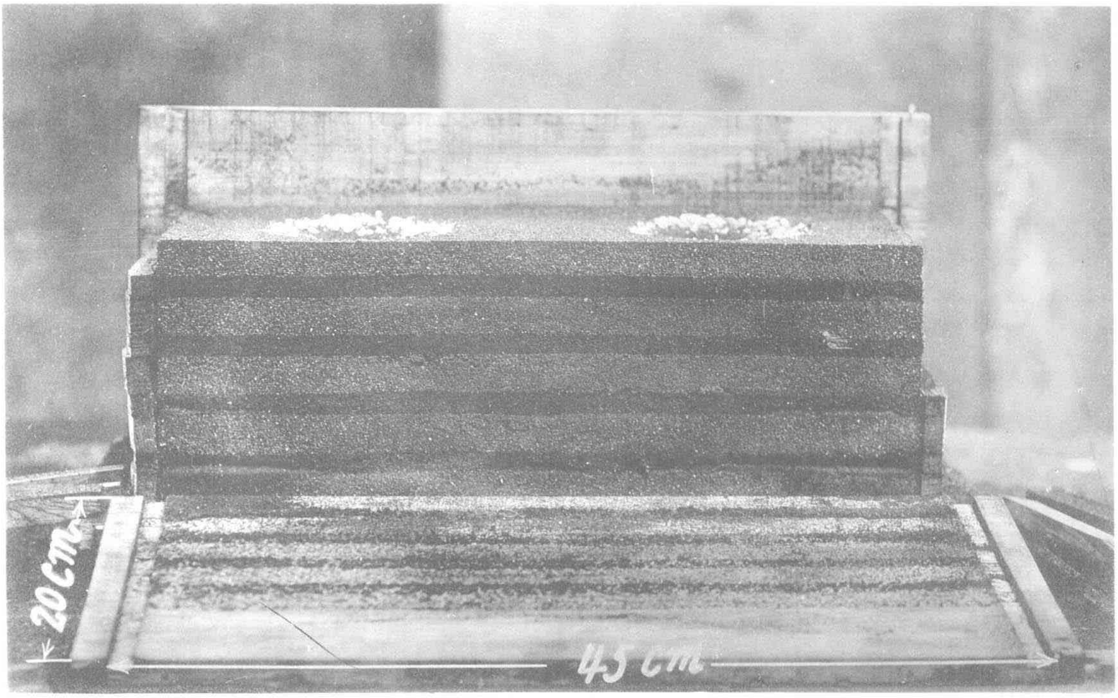

Fig. 1.
The construction of the wooden box adopted. Sand wet with plain water of 40% to 50% of the total volume of sand.

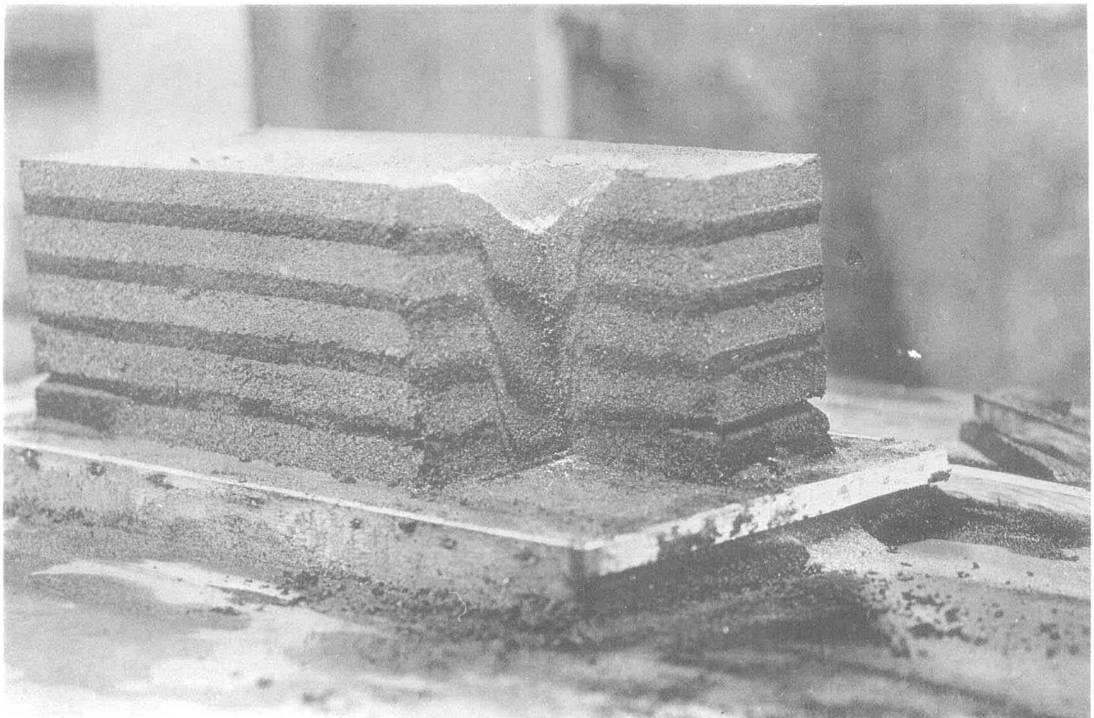

Fig. 2.
Sand over the left hole completely untouched; sand over the right hole cut off approximately quarter.

F. Takabeya: Internal Granular Movement of Sand Treated as Three Dimensional Problems.

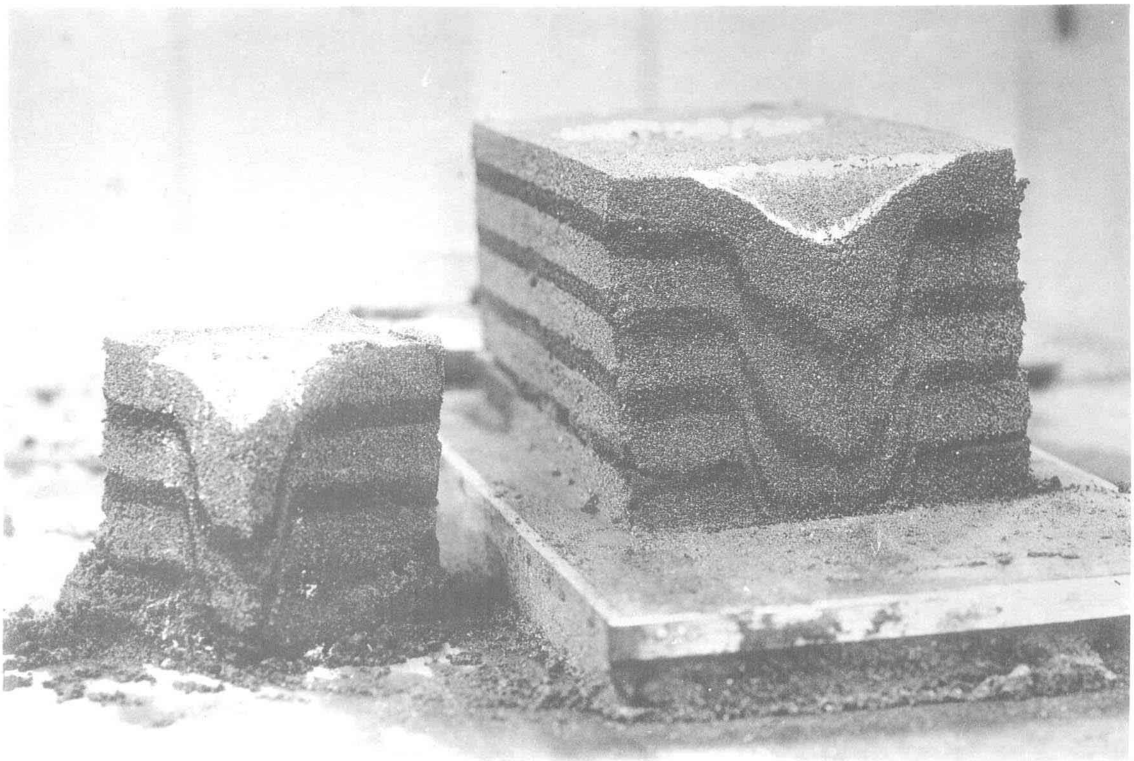

Fig. 3.
Sand over the left hole completely untouched; sand over the right hole cut off approximately half, transversely (right pattern), and quarter volume taken off, seen at the central point (left pattern).

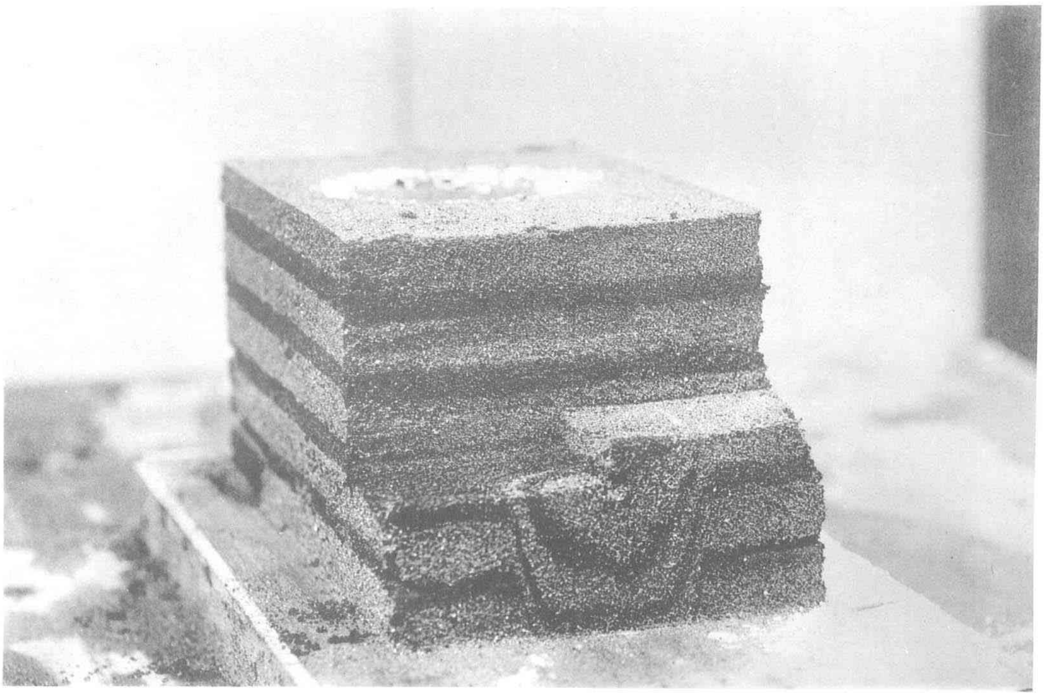

Fig. 4.
The pattern in a stepped section.

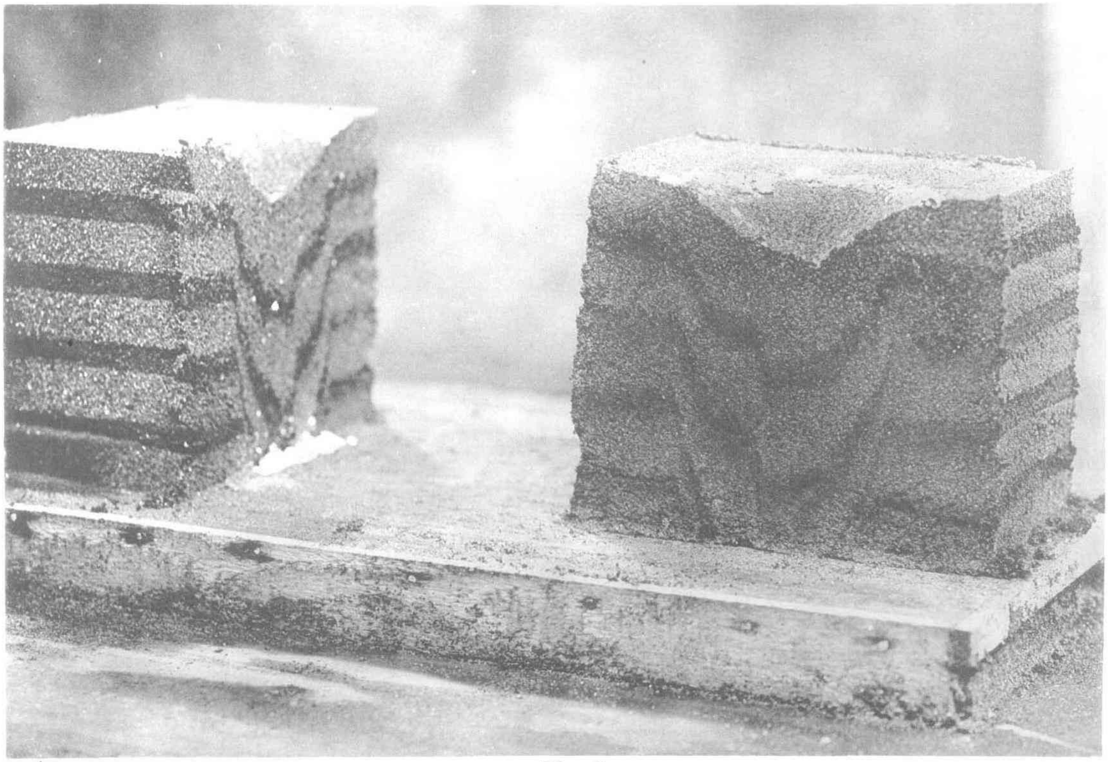

Fig. 5.

Sand over the left hole cut off transversely, showing the position of the hole in the bed plate marked with white powder (left pattern).
Other half block rotated about 90 degrees to show the movement of sand (right pattern).

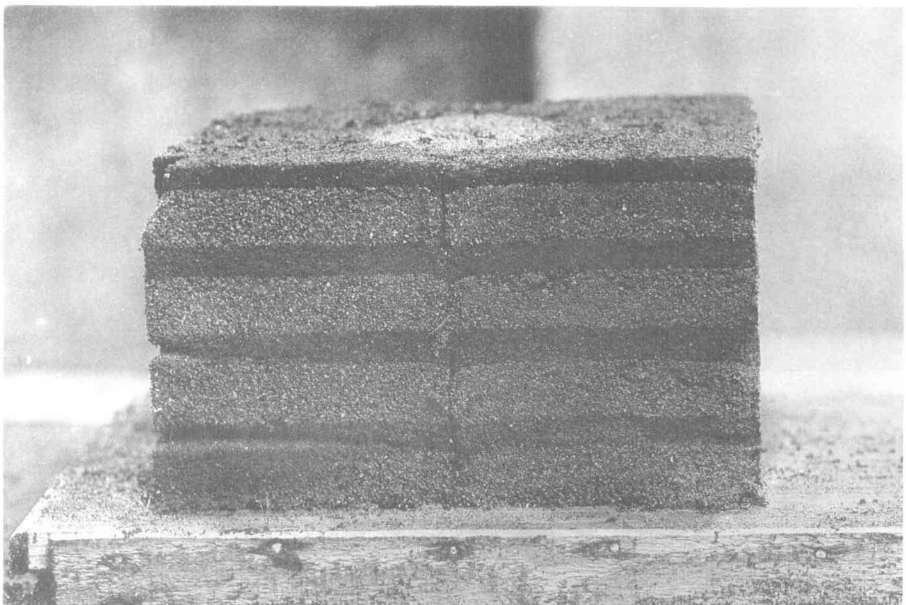

Fig. 6.

Both blocks in Fig. 5 replaced in the initial position, in order to make anew the horizontal sections shown in Figs. 7 and 8.

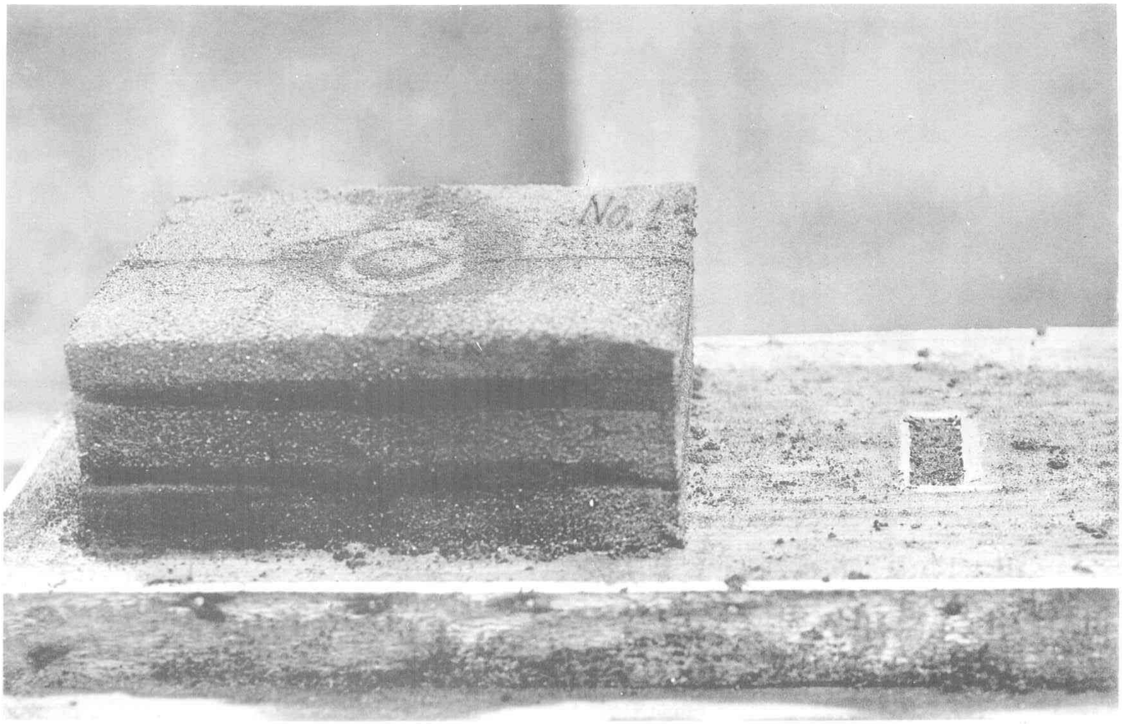

Fig. 7.
The horizontal section No. 1 and the right hole in the bed plate filled with sand.

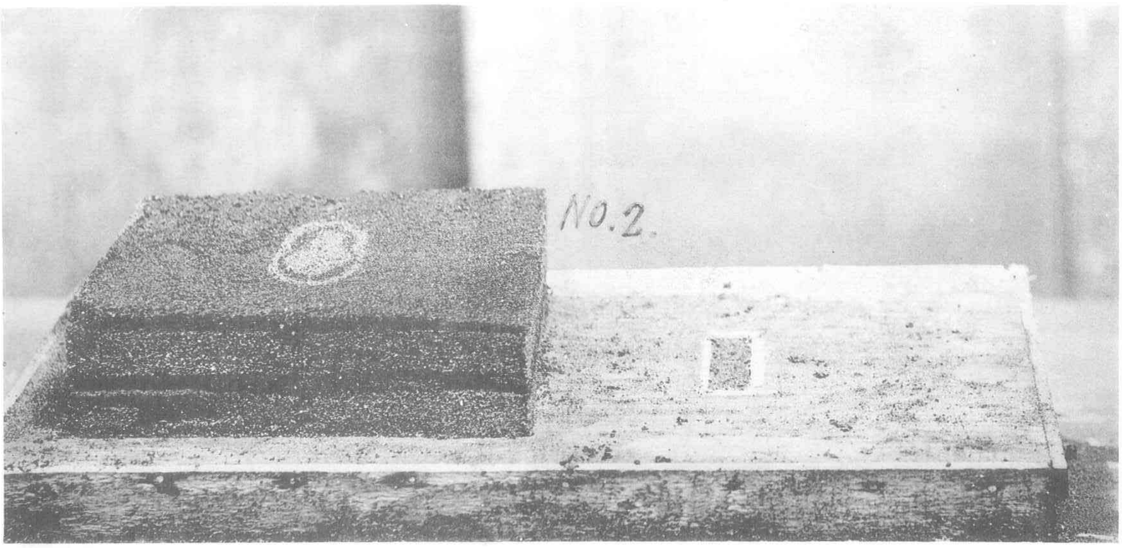

Fig. 8.
Horizontal section No. 2.

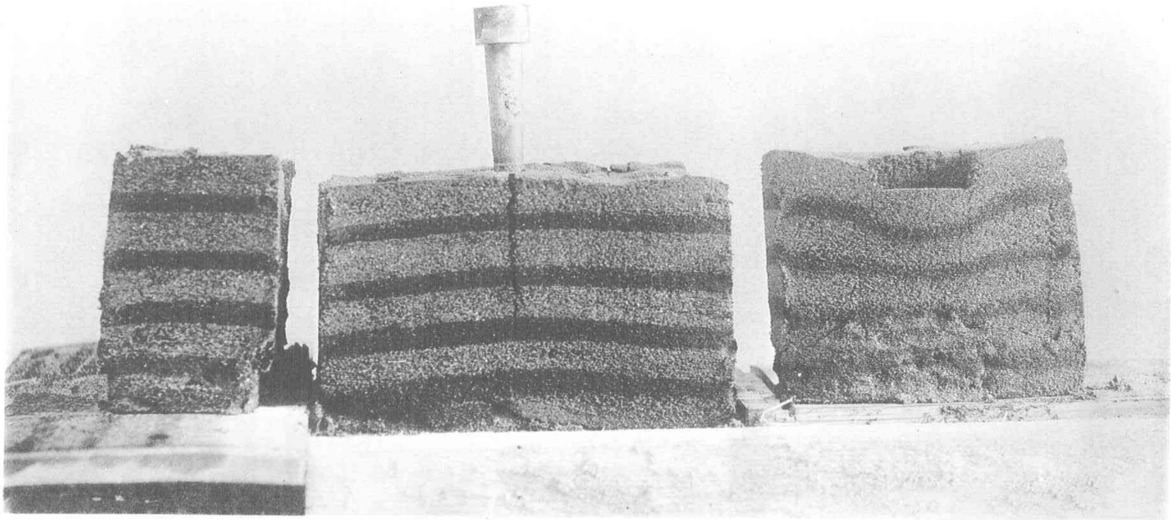

Fig. 9.

Sand movement exerted by a vertical load, whose base section was square (right pattern).

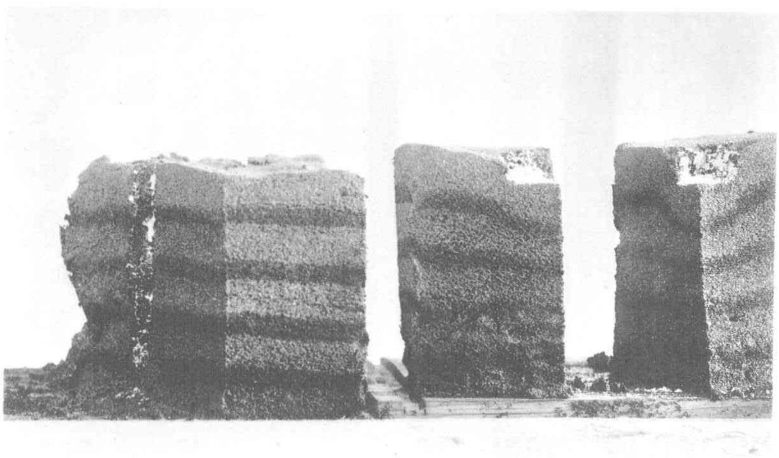

Fig. 10.

Sand movement exerted by a vertical load of square section seen at the central point of the square (right pattern). Do. by a peg (left pattern).

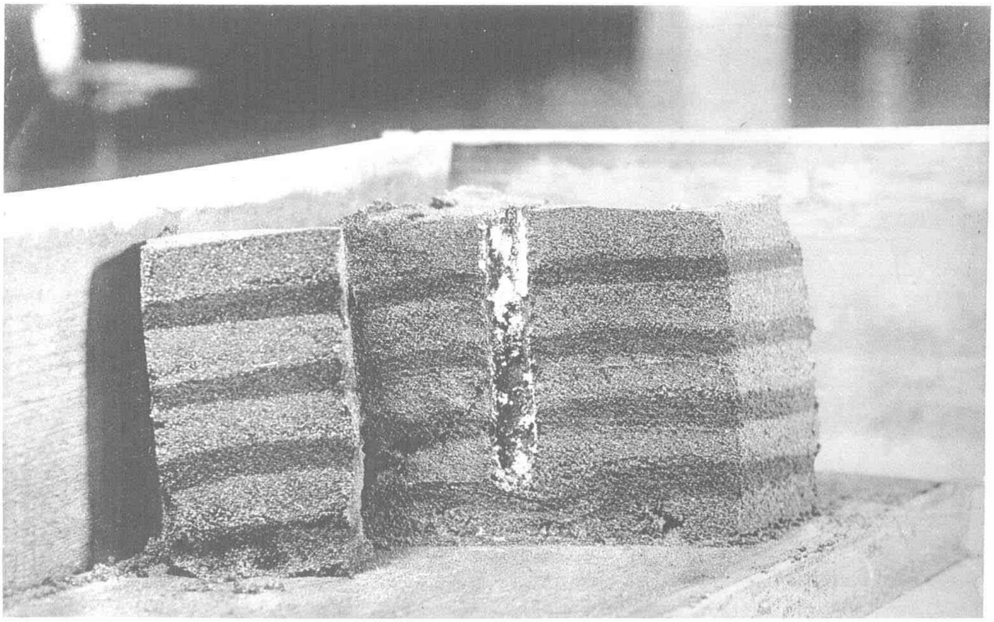

Fig. 11.

Sand movement exerted by a peg of circular cross section, the base being quite rounded off.

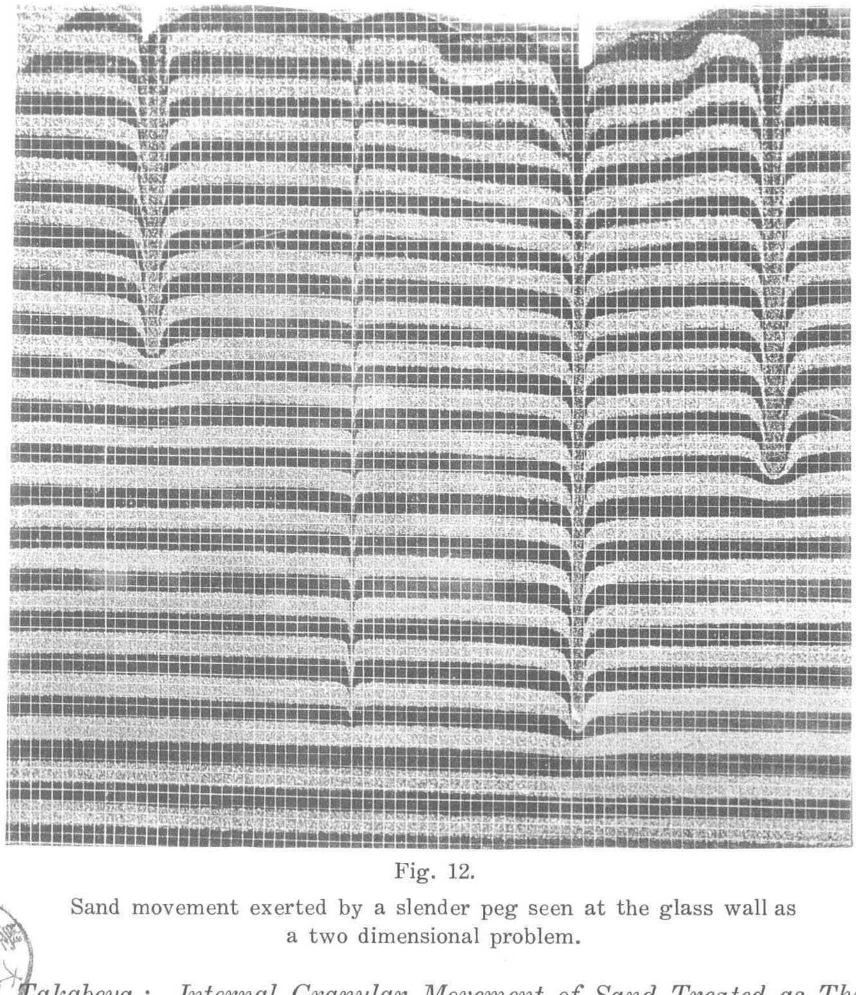

Fig. 12.

Sand movement exerted by a slender peg seen at the glass wall as a two dimensional problem.

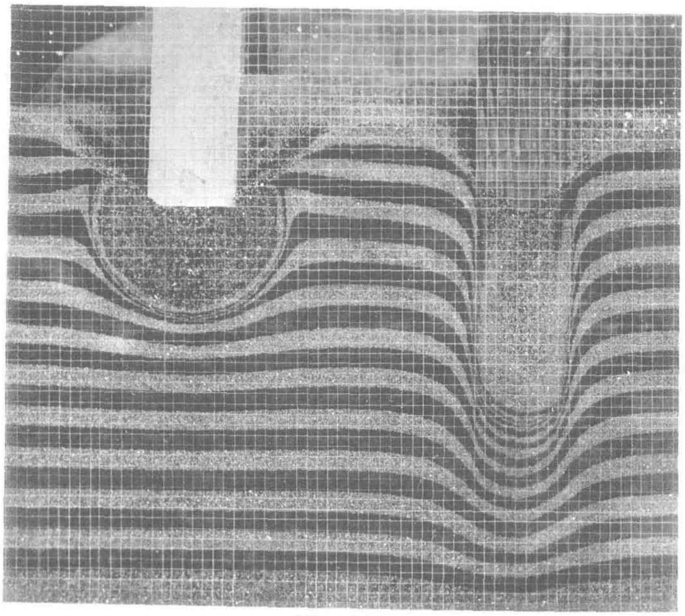

Fig. 13.

Sand movement exerted by tamping a peg of flat base and rectangular section seen at the glass wall (left pattern). Do. by hammering the same peg (right pattern).

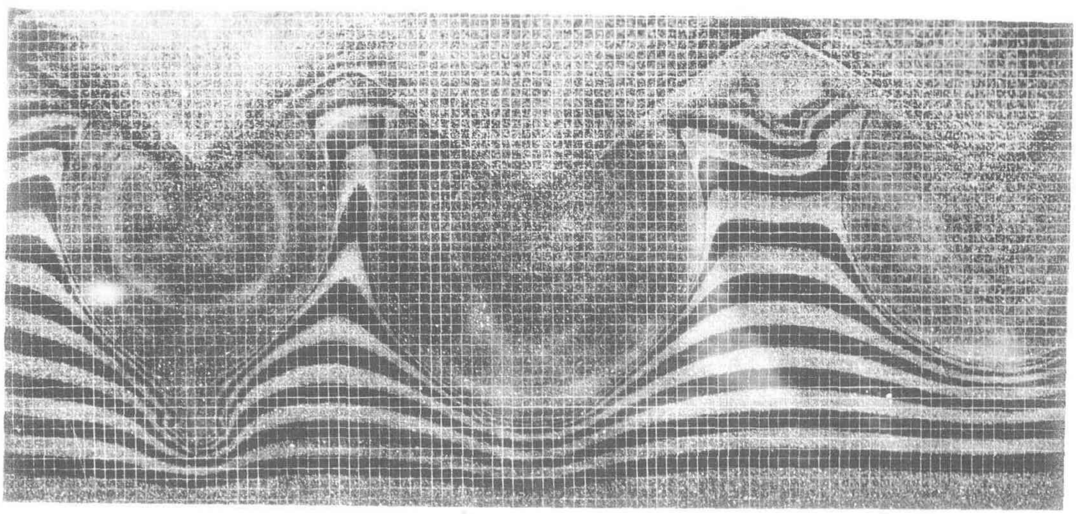

Fig. 14.

Sand movement exerted by tamping a peg, with special regard to inserting some amount of sand.

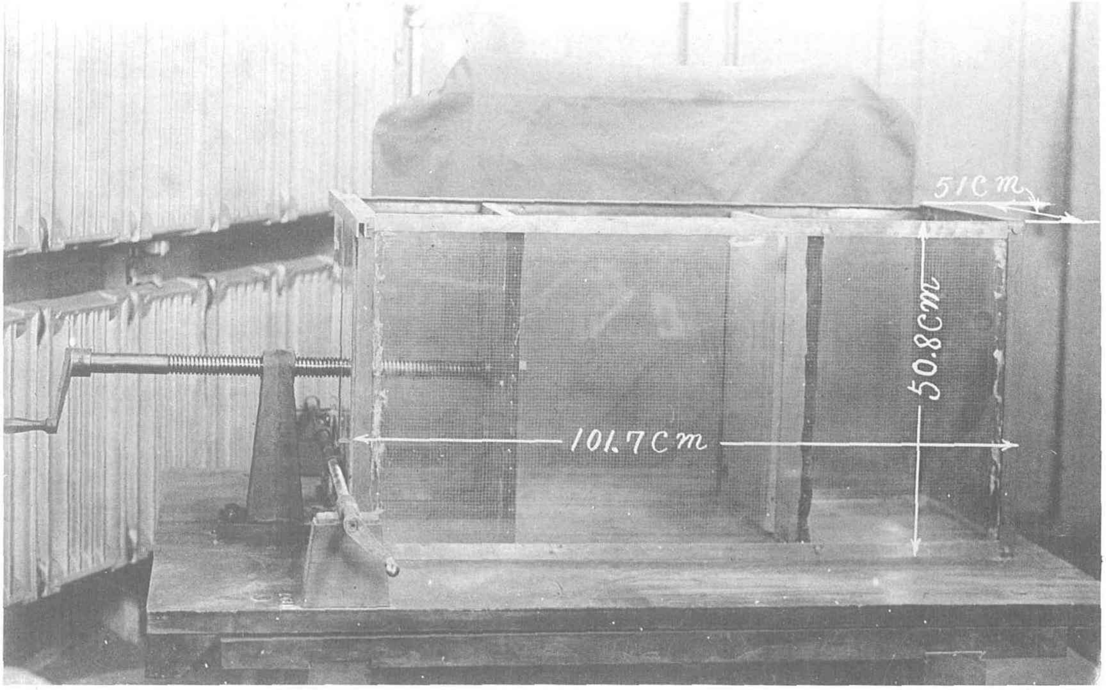

Fig. 15.

Glass tank with sliding partition, whose glass wall may be removed after wetting the inner sand.

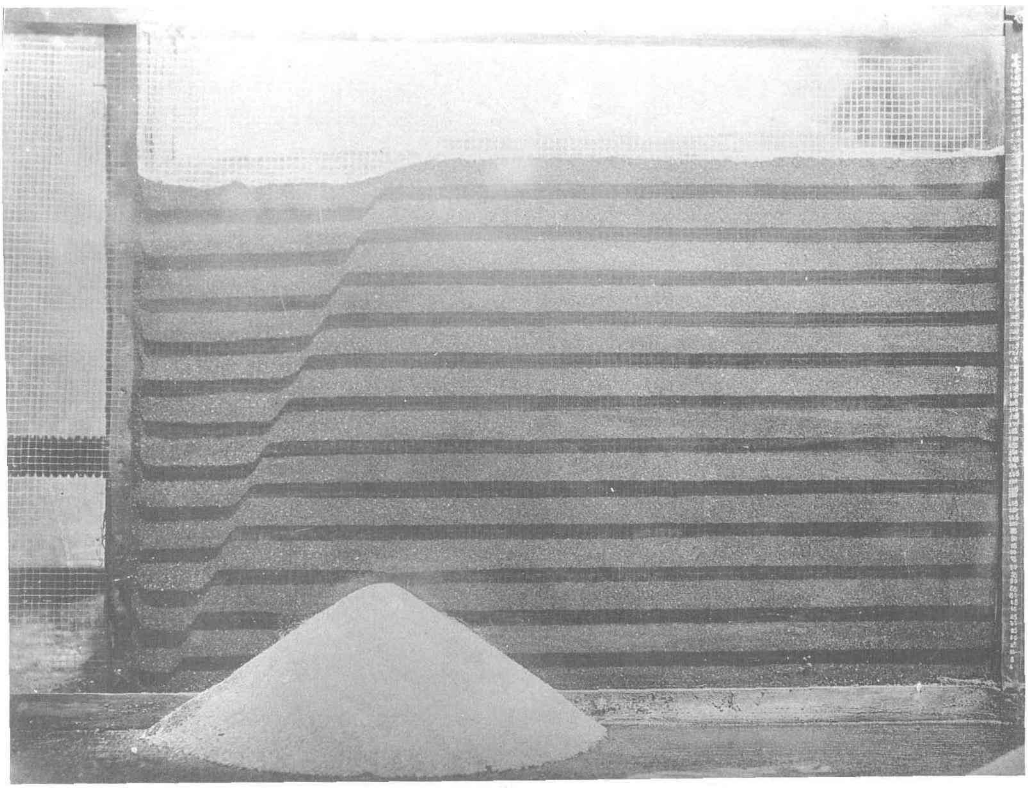

Fig. 16.

The surface of rupture exerted in the glass tank, sand having been wet and fixed by plain water. White cone shows the colour of dry sand piled, for the sake of contrast to the wet sand, showing the angle of repose for the sand used.

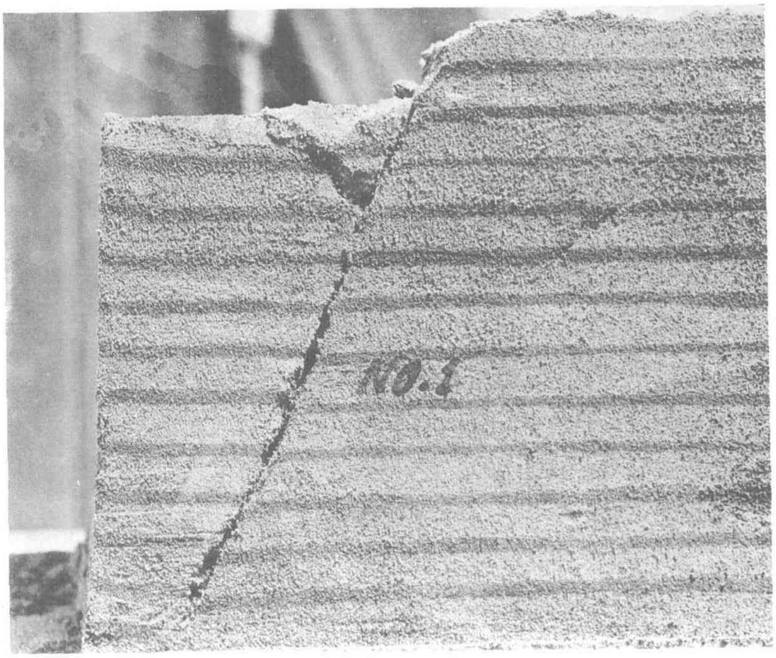

Fig. 17.

The surface of rupture No. 1 in the longitudinal section, distant about 8.5 cm from the glass wall.

Fig. 18.

The surface of rupture No. 2 in the longitudinal section, distant about 13.5 cm from the glass wall.

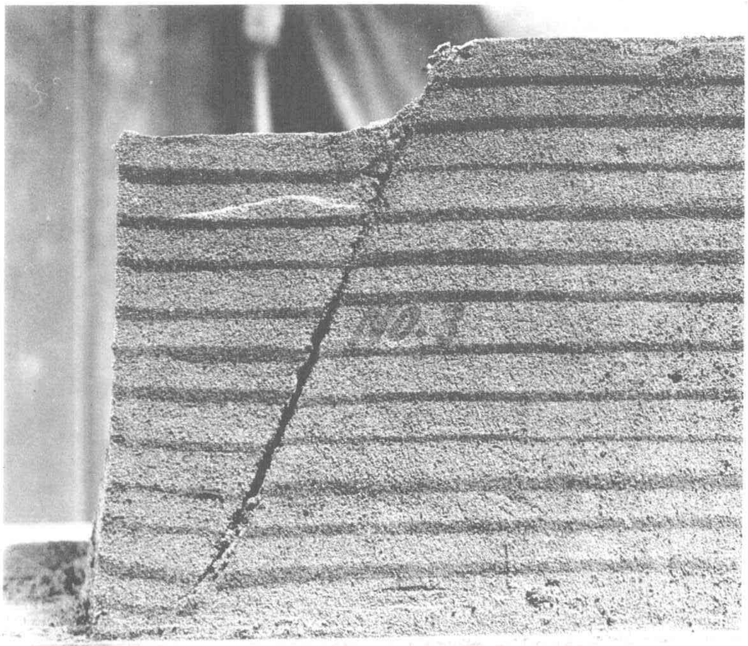

Fig. 19.
The surface of rupture No. 3 in the longitudinal section, distant about 18.5 cm from the glass wall.

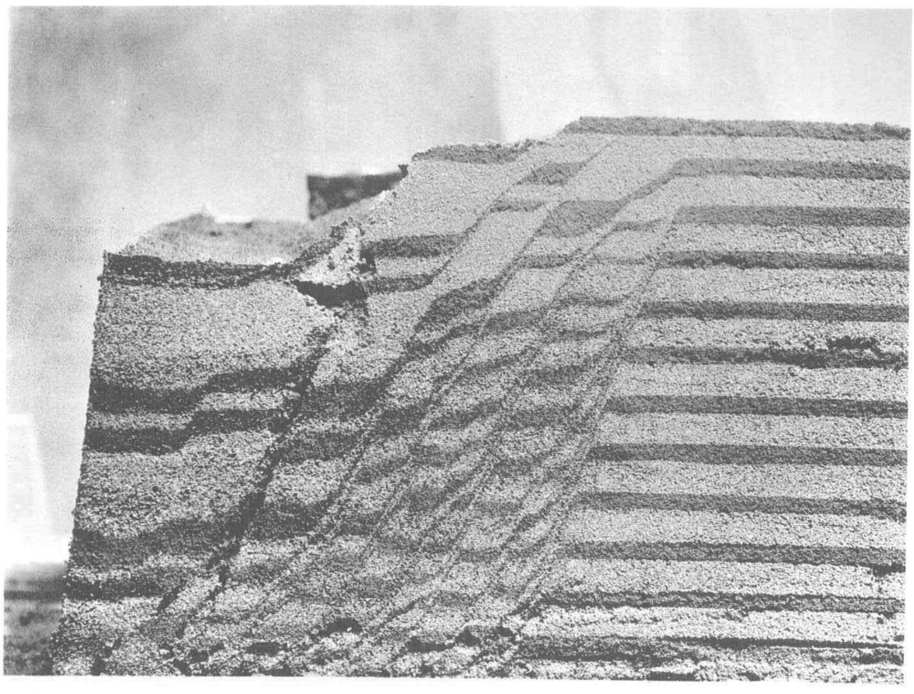

Fig. 20.
The parallel motion of sand, when the sand surface was kept always at the same level, filling sand in during the experiment. This figure has been taken at the glass wall.

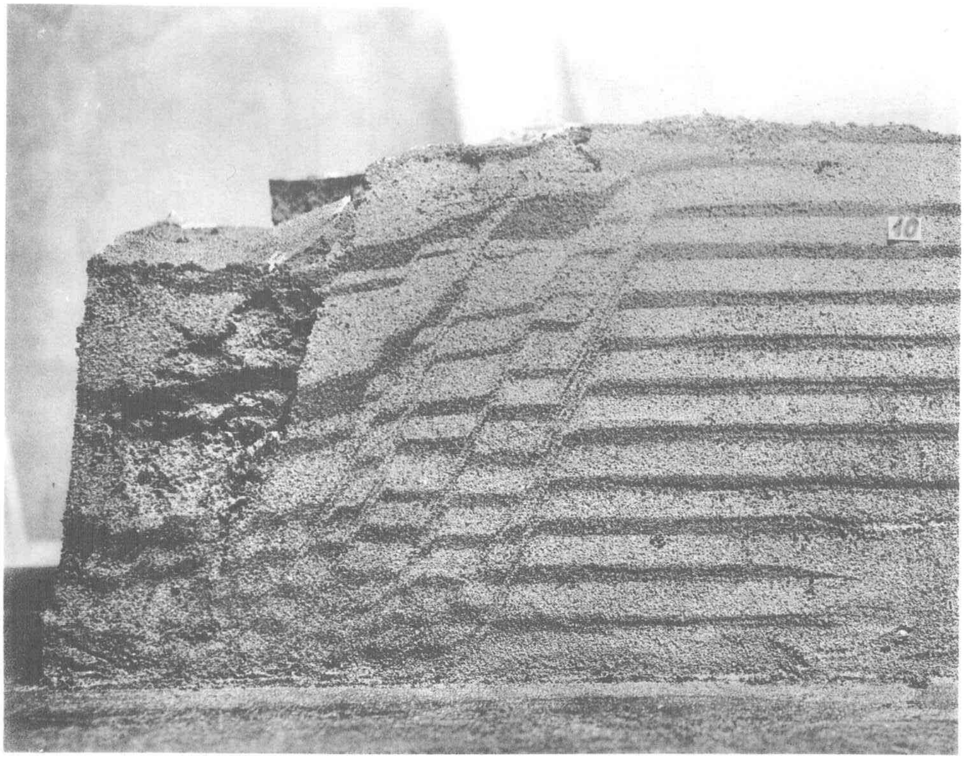

Fig. 21.
The surface of rupture in the longitudinal section, distant about 10 cm from the glass wall.

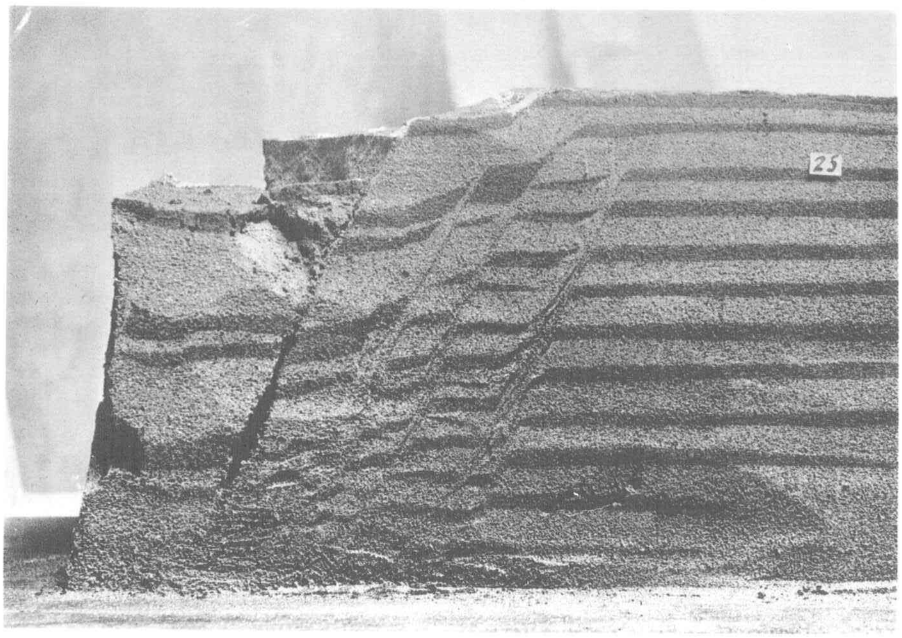

Fig. 22.
The surface of rupture in the longitudinal section, distant about 25 cm from the glass wall.

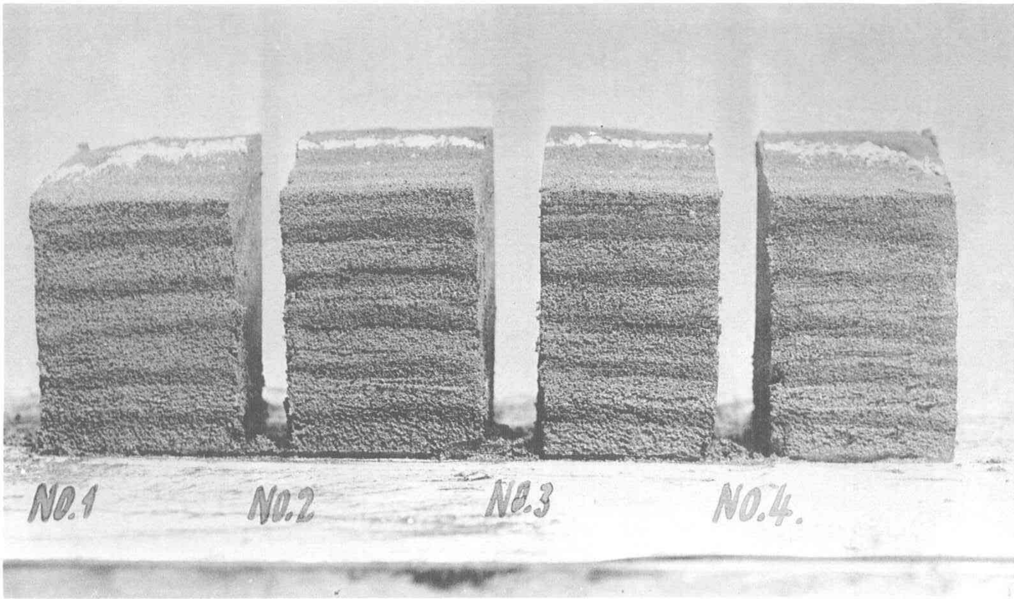

Fig. 23.

Wet sand block cut off into four pieces, marking with white powder the surface depression due to the surface of rupture.

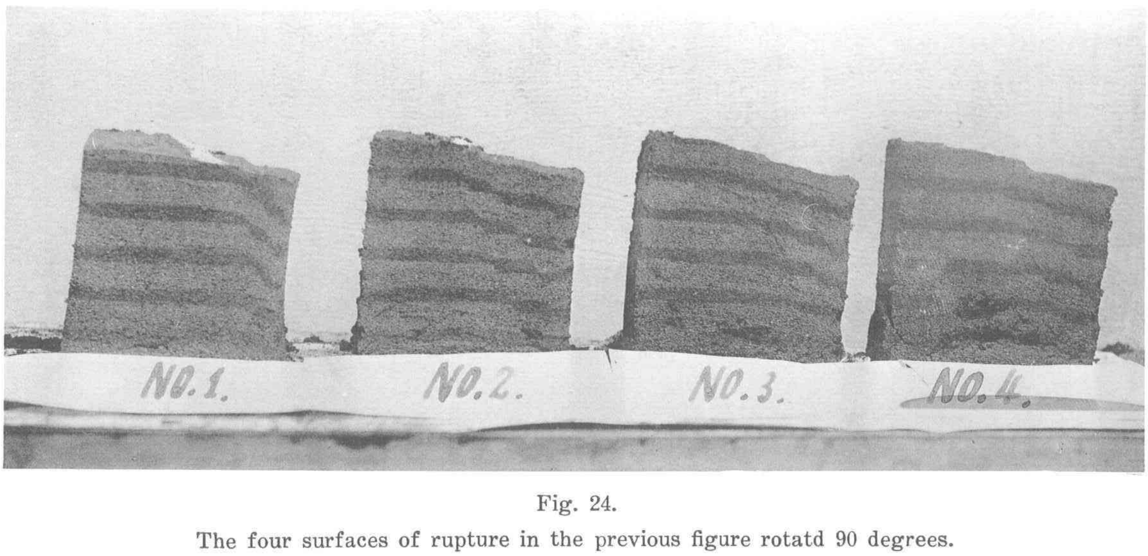

Fig. 24.

The four surfaces of rupture in the previous figure rotatd 90 degrees.