Sand Pressure on a Hole in a Vessel.

By

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The Method of the Experiment.

Apparatus to measure the sand pressure is the same as that by which Mr. K. TAKAHASI[1] carried out his experiment on sand pressure. The apparatus is shown in Fig. 1 and the method of the measurement may be briefly described as follows. The granular material is filled in the cylindrical vessel, whose base has a circular hole cut at the center. The upper end of another cylindrical vessel of smaller diameter than the former one is placed just in contact with the base of the former cylinder. The vessels are placed perpendicularly on one pan of the balance. However, the upper cylinder is independently supported so as to be connected with the system of the balance only by the agency of the granular material filled in the same cylinder. At first a pretty heavy weight is placed on the other pan of the balance. The weight of the balance is gradually decreased as the granules run out and this critical weight of balance is considered as the pressure[2] of grains which acts on the circular hole of the bottom in the vessel.

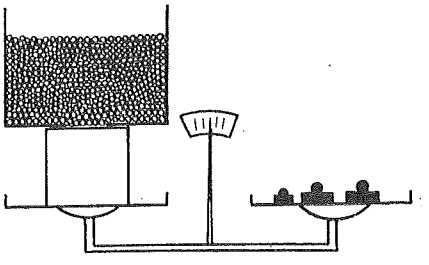

Fig. 1.

Shot of 1.5mm. diameter was generally used as the granular material through the whole experiment. The apparent specific gravity of this material was 6.65.

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(1) TAKAHASI, Experimental Investigation on the Velocity of Efflux of Granular Mass. Sc. Pap. I.P.C.R. No. 540, Vol. 26. 1935. p. 11.

(2) The pressure in this paper means the active pressure in the theory of the earth pressure.

The Experimental Results.

1. Effects on the size and form of the hole.

In cases when various sizes and forms of the hole are used, the pressure exerted on the hole opened at the central part of the bottom of the cylindrical vessel, is measured by means of the balance and the results are tabulated in Table 1. As is evident from this table, the pressure depends upon the length of the hole. The relation between w and L is shown in Fig. 2.

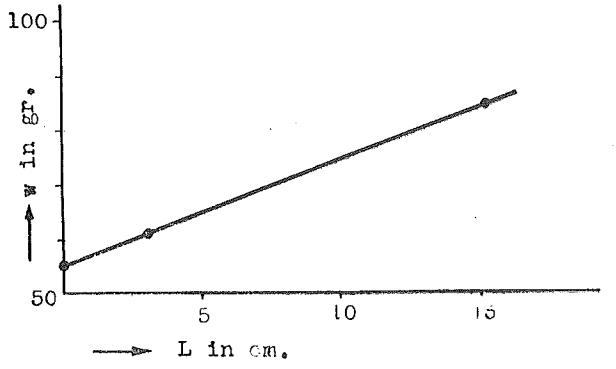


Fig. 2.

As the pressure in the case when the shape of the hole is tapered as shown in No. 1 of Table 1 is exactly placed on the curve $w-L$, the ideal value of w corresponding to the zero length of hole can be easily obtained.

Table 1.

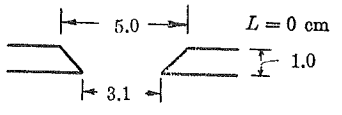
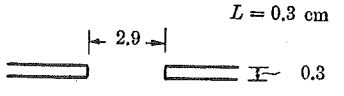
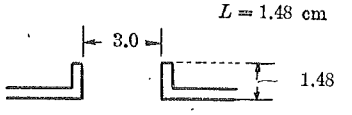
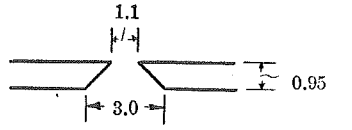
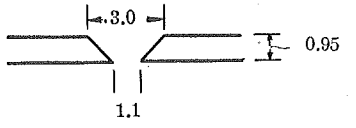
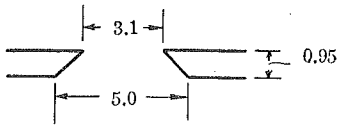
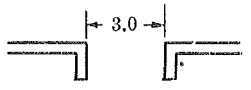
No.	Form of the hole (indicated in cm.)	Total pressure w in gr.	Pressure in the case when the granules filled the hole only (w) in gr.
1		55.8	38.5
2		60.6	—

Table 1—(*Continued*).

No.	Form of the hole (indicated in cm.)	Total Pressure w in gr.	Pressure in the case when the granules filled the hole only (w) in gr.
3		85.0	60.0
4		28.5	26.0
5		2.3	2.5
6		152.0	100.6
7		81.0	60.0

2. Effect on the length of the hole.

In order to make a more detailed study how the length of the hole may exert influence on the pressure, the following pictured vessel is used. A hollow circular brass cylinder of large diameter has attached to its bottom a small cylinder which can be easily exchanged for other cylinders of the same diameter with the various lengths L.

The pressure in the case when the granules filled the cylinder of small diameter is indicated by (w) and that in the case when the granules filled both the large and small diameter cylinders by w.

The axes of the cylinders have to be kept always perpendicular. The pressures of w and (w) are measured by the former method and the

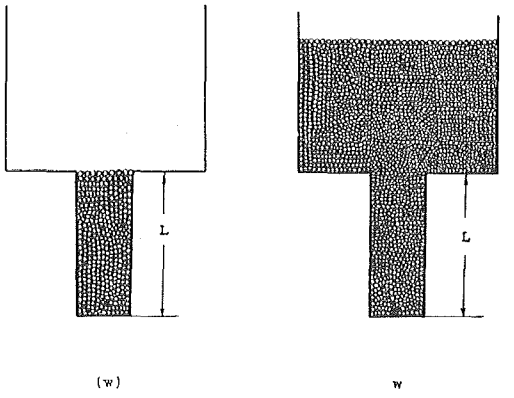


Fig. 3.

results are plotted against L in Fig. 4. Within the range of small value of L, w is directly increased with L which fact is already shown in the preceding paragraph. However w seems to approach the

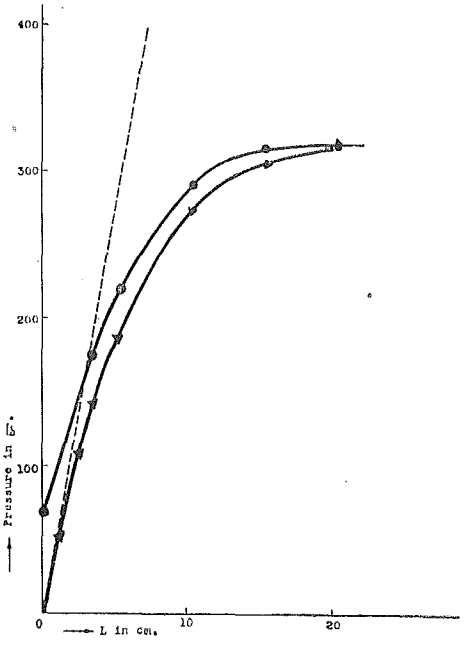


Fig. 4.

saturation value with increase of L. From these curves the plastic part of the granular mass seems to be the black parts as shown in Fig. 5.

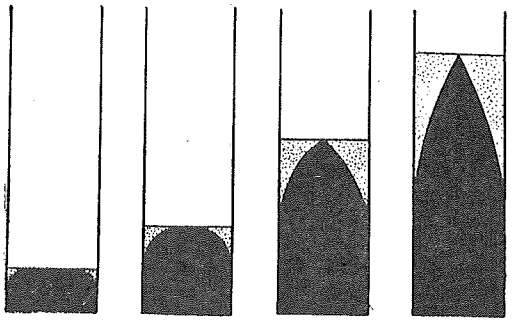


Fig. 5.

Three cases when the granules filled the vessel with tapered hole as shown in Fig. 6, are respectively shown as w, (w) and w'.

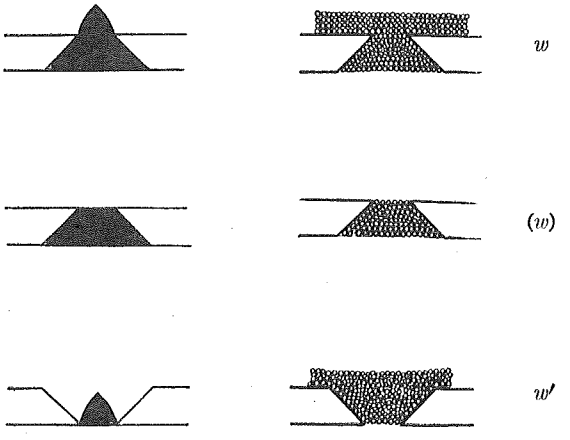


Fig. 6.

Each black part at the left side indicates the plastic part of the granular mass of the right side.

The pressure of w is considered as the sum of the pressures of (w) and w'. Therefore $w = (w) + w'$. Such good examples can be easily reduced from the table above described.

For D(dia. of hole) $= 1.1$ cm.

$$w_4 - (w_4) = 28.5 - 26.0$$
$$= 2.5 \text{ gr.}$$

whereas $w_5 = 2.3$ gr.

therefore

$$w_4 - (w_4) \fallingdotseq w_5$$

For $D = 3.0$ cm.

$$w_6 - (w_6) = 51.4 \text{ gr.}$$

$$w_1 = 55.8 \text{ gr.}$$

$$w_6 - (w_6) \fallingdotseq w_1$$

3. Effect on the wall of the vessel.

The granular material are piled up in a cylinder which is exchanged for other cylinders of various diameters which are in turn put on the plate having a circular hole of 3 cm. diameter, and the pressures are measured by the method above described. This apparatus is shown in Fig. 7.

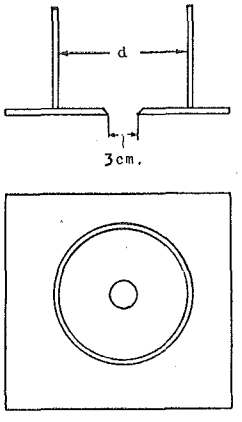


Fig. 7.

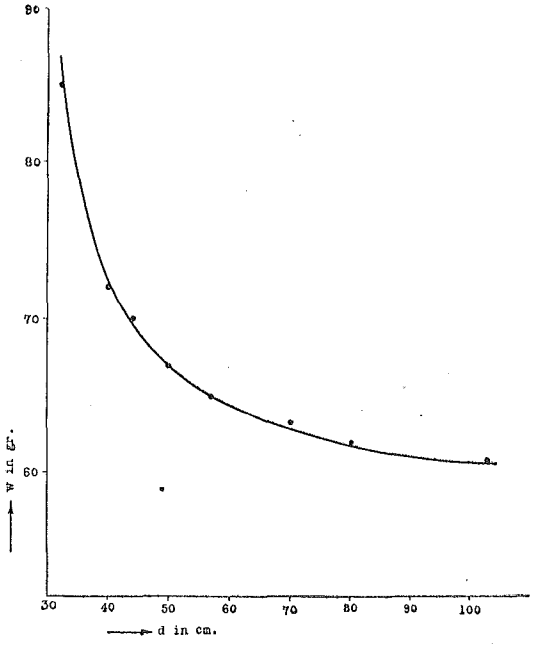


Fig. 8.

The values thus obtained are tabulated in Table 2 and plotted in Fig. 8.

Table 2.

d in cm.	w in gr.	d in cm.	w in gr.
3.0	300	5.7	65
3.2	85	7.0	63.5
4.0	72	8.0	62
4.5	70	10.3	60.6
5.0	67		

From this curve the plastic part of the granular material are supposed and schematically shown in the black part of Fig. 9.

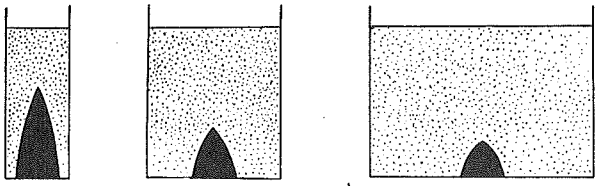


Fig. 9.

From this series of diagrams it is clear that the more close the wall approaches the hole, the higher the plastic part above the hole becomes.

4. Effect on the form of the grain.

Using grains of the various kinds, the variations of the pressure are found and the results are compared with that of shot.

The data thus obtained are summarized with ones taken from Takahasi's paper[1] in the following table.

Materials	D (dia. of hole) in cm.	W_c in gr.	ρ gr./cm.^{3}	V in cc.	$V^{\frac{1}{3}}$
Lycopodium	3.0	3.0	0.346	8.7	2.05
Shot	3.1	55.8	6.65	8.4	2.02
Shot	1.1	2.5	6.65	0.38	0.725
*Iron Sand	4.0	—	2.74	21.9	2.8
*Iron Sand	1.88	—	2.74	2.37	1.33
*River Sand	1.99	—	1.41	2.48	1.36
Soda Laim	3.0	2.8	0.725	3.9	1.26
Small nails	3.0	4.0	1.9	2.1	1.22
Hydroquinon	3.0	2.0	0.526	3.8	1.56

* denotes Takahasi's data.

The volume of the plastic part in the sand mass is obtained from w divided by ρ. If the plastic part for the various diameters of the hole is similar in various cases, the relation between D and $v^{\frac{1}{3}}$ will be shown by a straight line through the origin. From the data in the above table, the linear relation between D and $v^{\frac{1}{3}}$ is shown in the straight line of Fig. 10 except when the form of the grain is very needlelike. Therefore, the form of the grain can be qualitatively defined by the deviation from this straight line in Fig. 10.

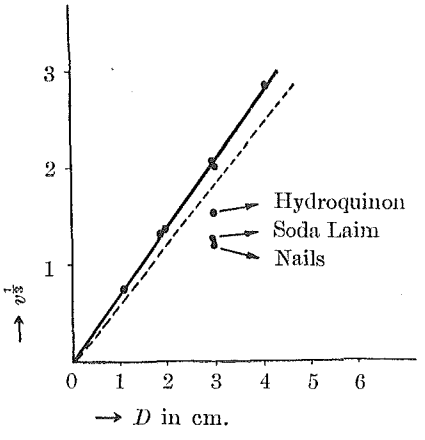


Fig. 10.

The dotted line in Fig. 10 shows the volume of the cone whose base coincides with the diameter of the hole and whose height is equal to the diameter of the hole. Therefore, the volume of the plastic part differs from the cone of the same base.

5. The variation by the water content.

The variation of the pressure is much affected by the water content in the sand mass. By the same method above described this variation was measured by Mr. M. Aramata who used quartz sand as the granular mass in his experiment. The total pressure is plotted

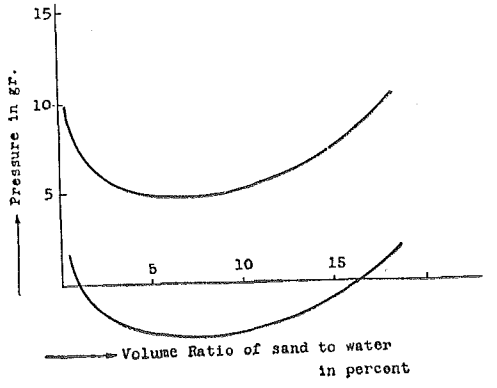


Fig. 11.

against the percentage of the water content in the sand mass and the result is shown in the lower curve of Fig. 11. As is evident from

this curve, the pressure takes negative sign within some range of the water content.

This is expected from the assumption of the existence of the adhesion of contact surfaces between sand mass and vessel under the hole. As the measured pressure of the sand mass in this state is considered to be equal to the sum of the real pressure and the adhesion, the real pressure must be obtained by subtracting adhesion from the measured pressure. If the adhesion is nearly constant in this experiment, the real pressure will be bodily changed with the percentage of the water content as shown in the upper curve of Fig. 11.

Summary.

The pressure exerted on the hole of the vessel has been quantitatively confirmed to be remarkably affected by the following conditions or states.

1. The size and form of the hole.
2. The length of the hole.
3. The distance to the hole from the wall of the vessel.
4. The form of the grains which are filled into the vessel.
5. The water content of the sand mass.

In conclusion, the writer wishes to express his cordial thanks to Professor Y. IKEDA for his valuable suggestion and continuous encouragement.

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