Properties of the Water Mass Gushing out from Water-tank After Sudden Break Down of the Sidewall.

By Yutaka MIZOGUCHI

(Received Jan. 24. 1952.)

Abstract: The water mass which gushes out from water tank by inst ntaneous breaking of the side wall was experimentally investigated. The phenomena are distinctly different from those which occur by the opening of the sluice gate. The instantaneous initial velocity of the flood, its damping, the maximum height and the effect of the obstacles in the way are treated.

1. Introduction:

When a dam filled with water is demolished or when the high flood falls on the seawall, the motion of the water mass does not obey the ordinary hydrodynamical laws, and the destructive power also can not be estimated. It is sure that the phenomena are quite distinctly different from those occurring from the openning of the sluice gate. It is rather difficult to reproduce such phenomena in the laboratory. However the similar phenomena can be yielded when the side wall of water tank is quite broken to pieces suddenly, provided that the scale is small. From the investigation of the phenomena on a small scale, the exact estimation on the larger scale can not be obtained, since the law of similaritude is unknown. But if the characteristic properties of those phenomena on the small scale are manifested, it may be expected that the law which rules the phenomena on the small scale remains to hold qualitatively even on the larger scale. In section 2 of this paper the apparatus which yields the similar phenomena on small scale is explained. In section 3, the general properties of the water mass gushing out from the water tank are photographed and discussed. The characteristic property of the water mass is the steep front in the course of progression. In section 4, the velocities of the progression of the front on the way under various conditions and its damping are measured. In section, 5, some obstacles are laid in the way of the progression, and their influences are investigated in detail. Conclusions are drawn in section 6.

2. Apparatus:

The apparatus for the experiment consists of a tank and a channel on small scale. If the entire diaphragm between the tank and the channel can be taken away at a moment, the phenomena in which we are interested can be realized. If any arrangement like sluice gate is used, the jet from the slit will increase gradually in the course of opening with the width of slit. Therefore it does not meet our desires. For the purpose there may be no other way than breaking the diaphragm suddenly. Of course it is desirable to use the comparatively large diaphragm which can be broken to small pieces uniformly and instantaneously. But it is difficult to break it in such way. That is the reason why apparatus on a small scale is used in this experiment. There are two ways to increase the stress against the diaphragm, the one is to increase the pressure in tank and the other is to exhaust the air of the channel. It is preferable to use the latter method, because of facility of preparation. As the diaphragm, thin glass plates are used. The surface is previously marked with thousands of traces of flaws so that the plate may break to small pieces as uniformly and instantaneously as possible.

Indeed the diaphragm breaks to pieces when the pressure difference attains to only a few milimeter, so that the effect of the low pressure in the channel scarcely affects the phenomena. The apparatus is shown in Fig. 1.

The tank is made from iron plate.
The channel is made from thick glass plate framed with iron beam, and the terminal part is provided with a hinge which enables it open from inside at the slightest shock, on arrival of the water front. The camera used is Movicon, Zeis Ikon, 16mm, and the film used is Kodak Super *X*. For time record, a stop-watch revolves each three second is photographed at the same time with the phenomena. The water is illuminated from above and photographs are taken from the side.

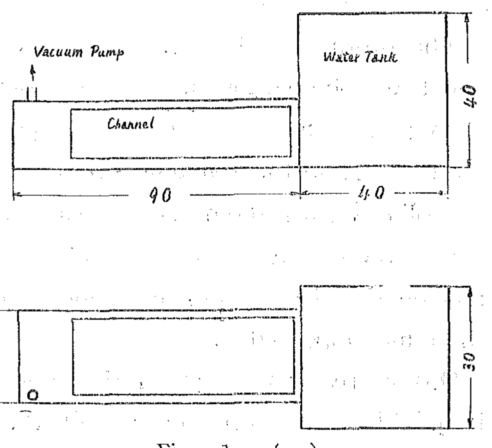


Fig. 1 (cm)

3. General features of the movement of water mass.

i) In the case where there are no obstacles in the way. The water mass gushing out from the tank released by the instantaneous breaking of the diaphragm is photographed as shown in Figs. 2, 3, and 4. The form of the front of the dashing water in the channel is quite distinctly different from the form which appears in the ordinary jet or stream. Judging from the form of the water mass, some conclusion can be deduced, though the actual passage of water particles can not be traced from the photographs. When the diaphragm is broken to pieces, the water mass gushes out from the tank and falls on the floor of the channel, leaps up as if it were reflected, and thereupon another water mass is piled up. The front of the water mass dashes forward as if a rolling sphere were in progression, as shown in Fig. 2 In the course of that progression, the curvature of the front form is considerably large, while the part in contact with the floor of the channel is rather retarded.

The phenomena exhibit three stages; the first stage is that of relaxation of tension abruptly changing the conditions, the second is that of a sort of jet, and the third stage will be considered to be similar to turbulent motion of water. In the first stage the water particles may looked upon as an aggregation of some mass points. Indeed the general features are similar to those of sand under the same conditions. The motion of sand under same conditions is photographed and shown in Fig. 3. In both Figs. 4 and 5 two advancing waves are recognized. The forms which appear in the 4th, 5th, 6th frames in Fig. 4 and in the 4th, 5th, frames in Fig. 5 are compared to the first flood wave. The forms which appear in the 9th, 10th, 11th, 12th, 13th, and 14th frames of Fig. 4 and in the 9th, 10th, 11th, 12th, and 13th, frames of Fig. 5 are comparable to the second flood wave.

ii) In the case where there are some obstacles in the way.

The profiles of the water mass in collision with some obstacles fixed in the channel are photographed. At the moment when the water mass dashes forward and collides with the obstacle, some part of the water mass is pushed backward by reflection and the remaining part climbs up the obstacle. The successive water mass collides with them and streams forward over the obstacle. Photographs to illustrate these movements are shown in Figs. 6 and 7. The obstacles are fixed vertically on the floor of channel; one is a thin plate and the other is a thick plate with round upper edge.

Differently to the case of the sudden complete breaking of the diaphragm if it is quickly drawn up, the jet will advance on the floor of the channel, and collide with the obstacle. The water climbs up straight along the surface of the obstacle. It springs up so high that the most part of the energy may be wasted. Such phenomenon is photographed and shown in Figs. 8, 9, and 10. The difference between the two cases where the diaphragm is suddenly broken to pieces and where it is drawn up is most clearly recognized in the earlier stage.

As remarked already, the water mass collides with the obstacle as if the particles were an aggregation of mass point. As shown in Fig. 11, the motion of sand under the same condition as in the former case is very like to that of the water obtained in the former case.

4. Effect of the roughness and inclination of the floor of channel.

In order to investigate the effect of the roughness of the floor of the channel, three kinds of floor are used; 1) smooth floor, 2) the floor paved with fine sand paper

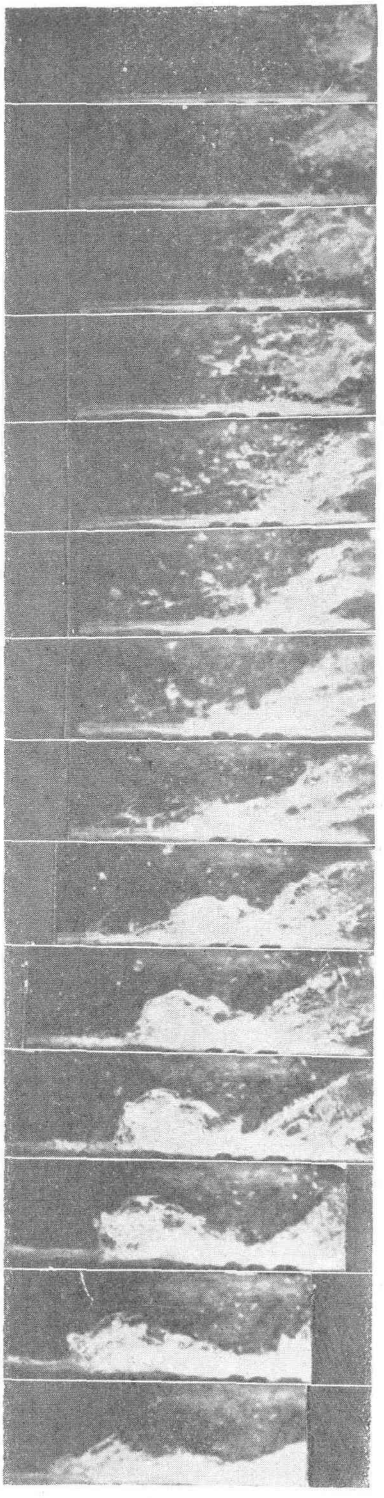


Fig. 2

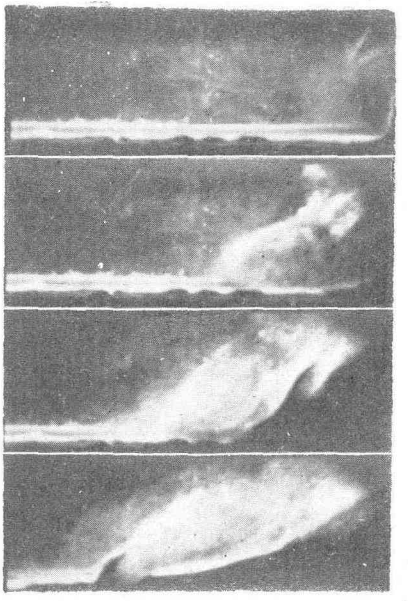


Fig. 3

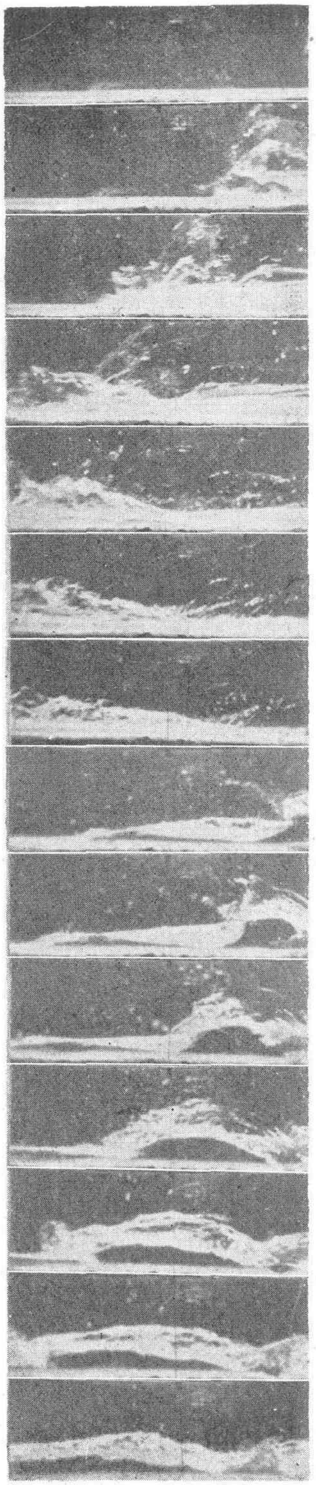


Fig. 4

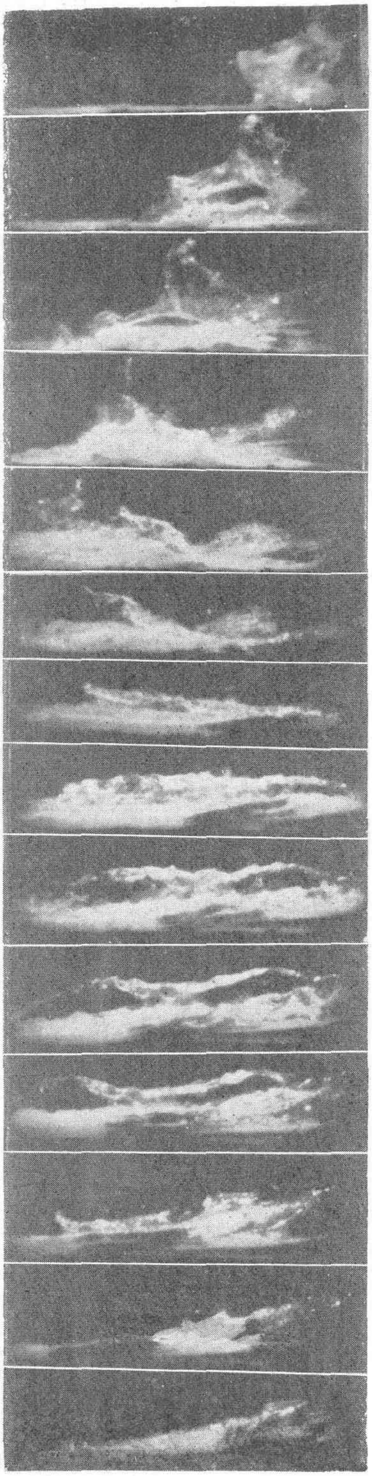


Fig. 5

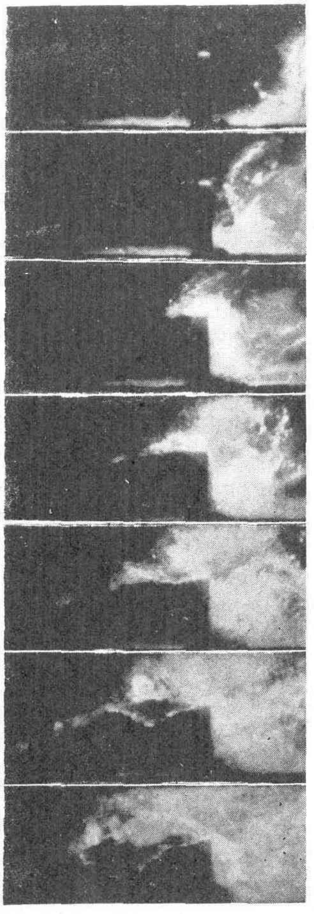


Fig. 6

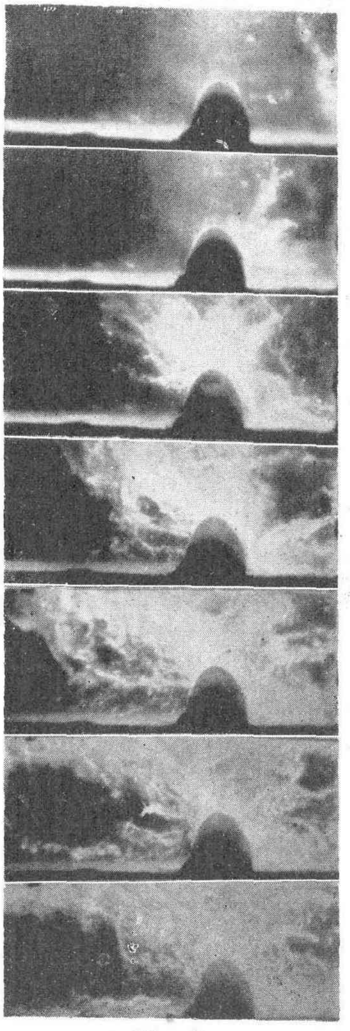


Fig. 7

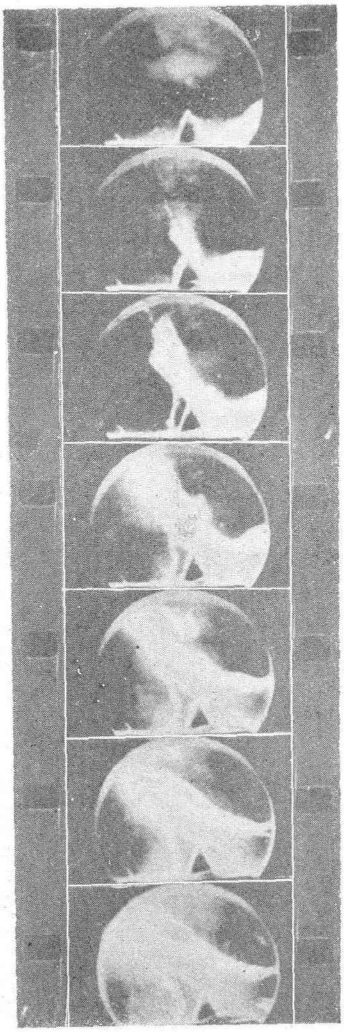


Fig. 8

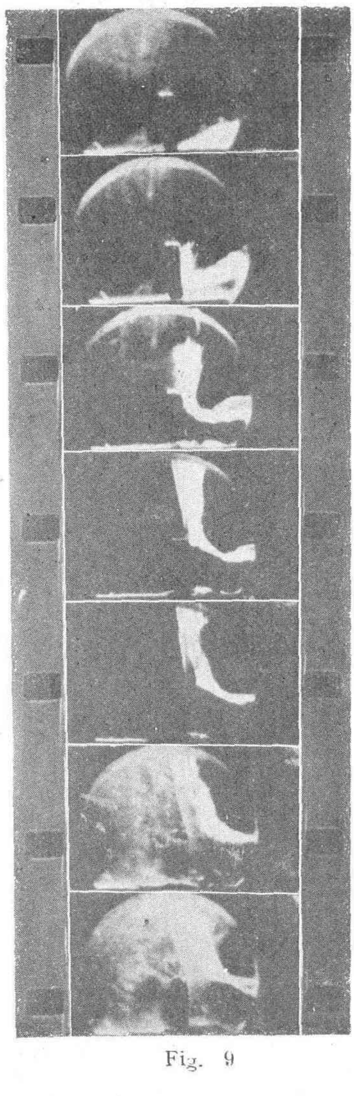


Fig. 9

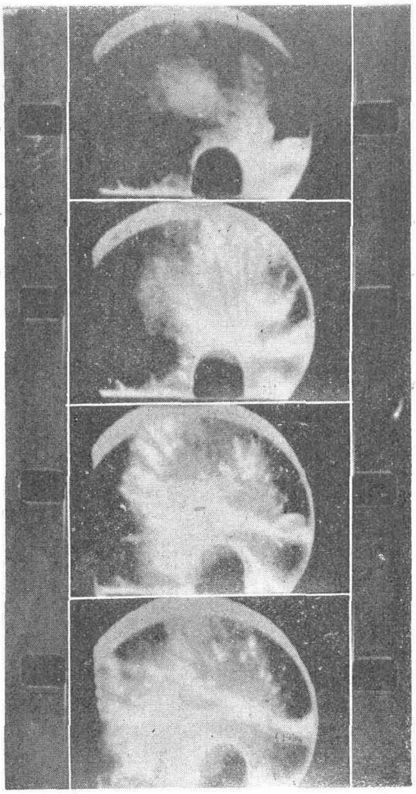


Fig. 10

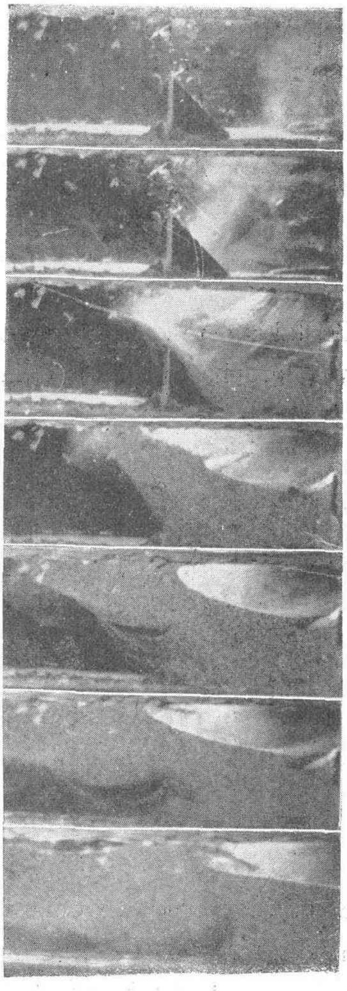


Fig. 11

(No. 400) and 3) the floor paved with rough sand paper (No. 60). In order to investigate the effect of inclination of the channel, the experiment is carried out with three different inclnaitions 1/30, 1/15 and 1/10. By combining each three cases roughness of channel bottom and inclination, there are nine cases. The phenomena in each case are phographed. From the 16mm. film, the profiles of the water front are enlarged on a paper and traced as shown in Fig. 12. The velocity of the front of the flash flood is measured, and the variation with respect to time are tabulated in Table 1.

Table 1. (Unit. cm/sec)
The floor condition are denoted by 1. 2. 3.

I Inclination 1/30

1	288	158	140	105
2	300	240	210	180
3	410	360	270	—

II Inclination 1/15

1	415	350	—	—	—
2	400	360	300	280	240
3	390	300	210	180	150

III Inclination 1/10

1	320	250	180
2	360	240	180
3	390	270	150

Be taking time as ordinate and the logarithmus of velocity as abscissa the following graphs Fig. 13 is obtained.

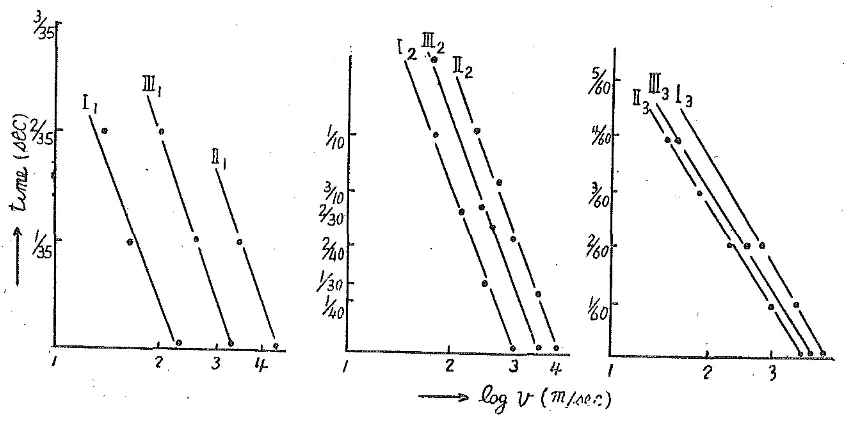


Fig. 13

It can be easily seen that the damping coefficient of velocity is invariable so long as the condition of the floor of channel is the same. The damping coefficient α is 5.9 in case 1, 5.1 in case 2, and 13.6 in case 3. The effect of inclinetion can be scarcely recognized.

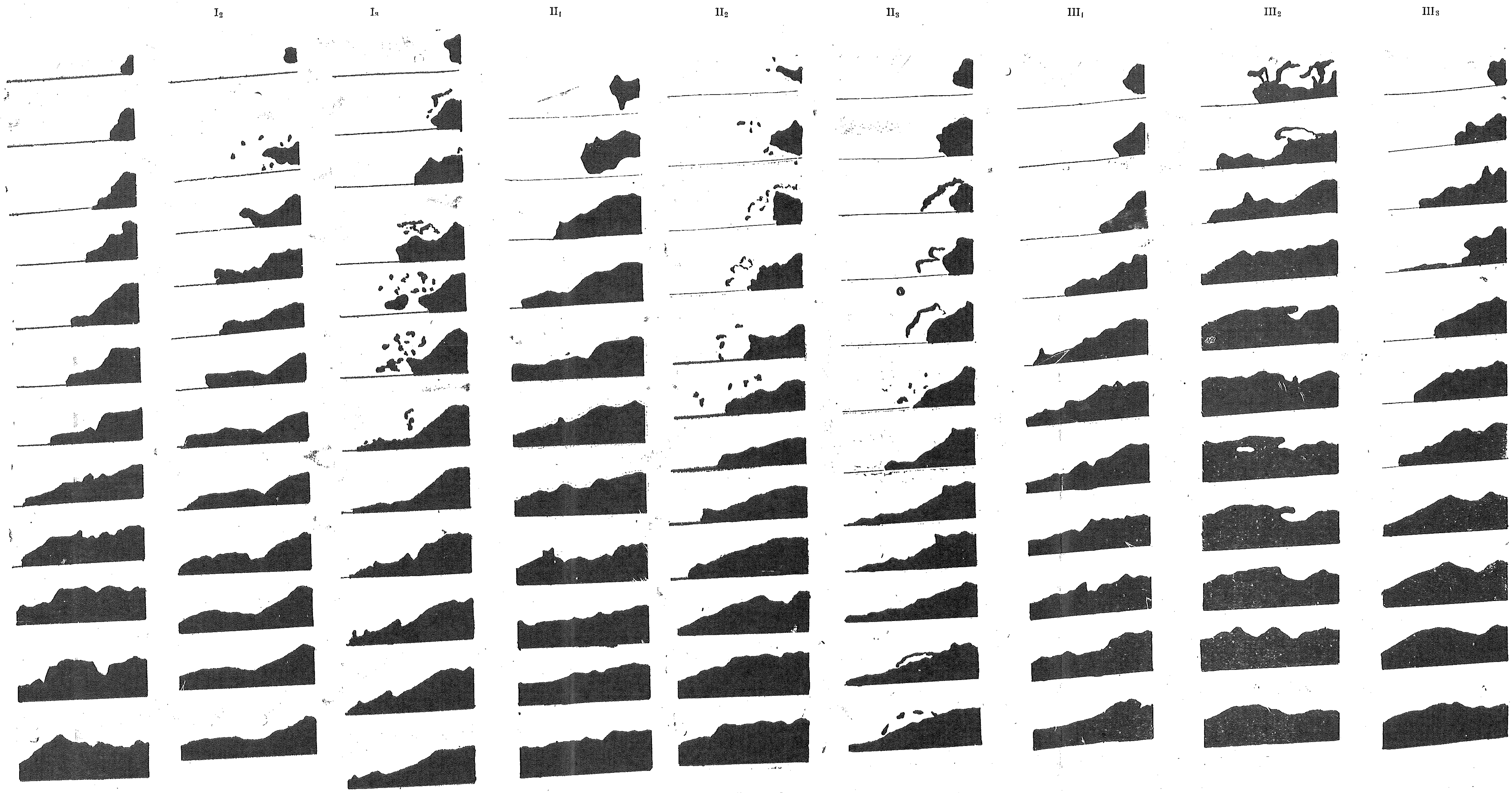


Fig. 12

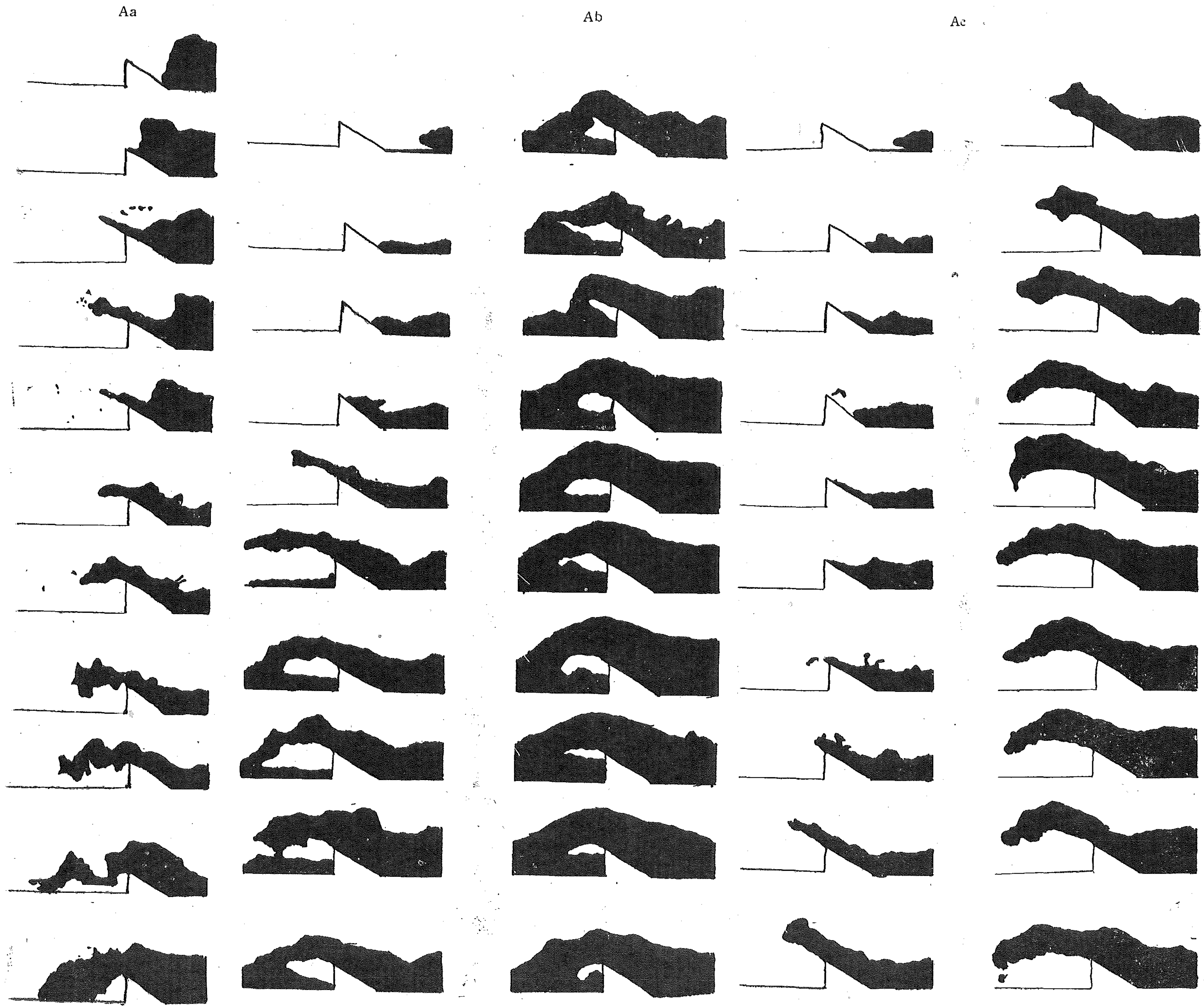


Fig. 14 (A)

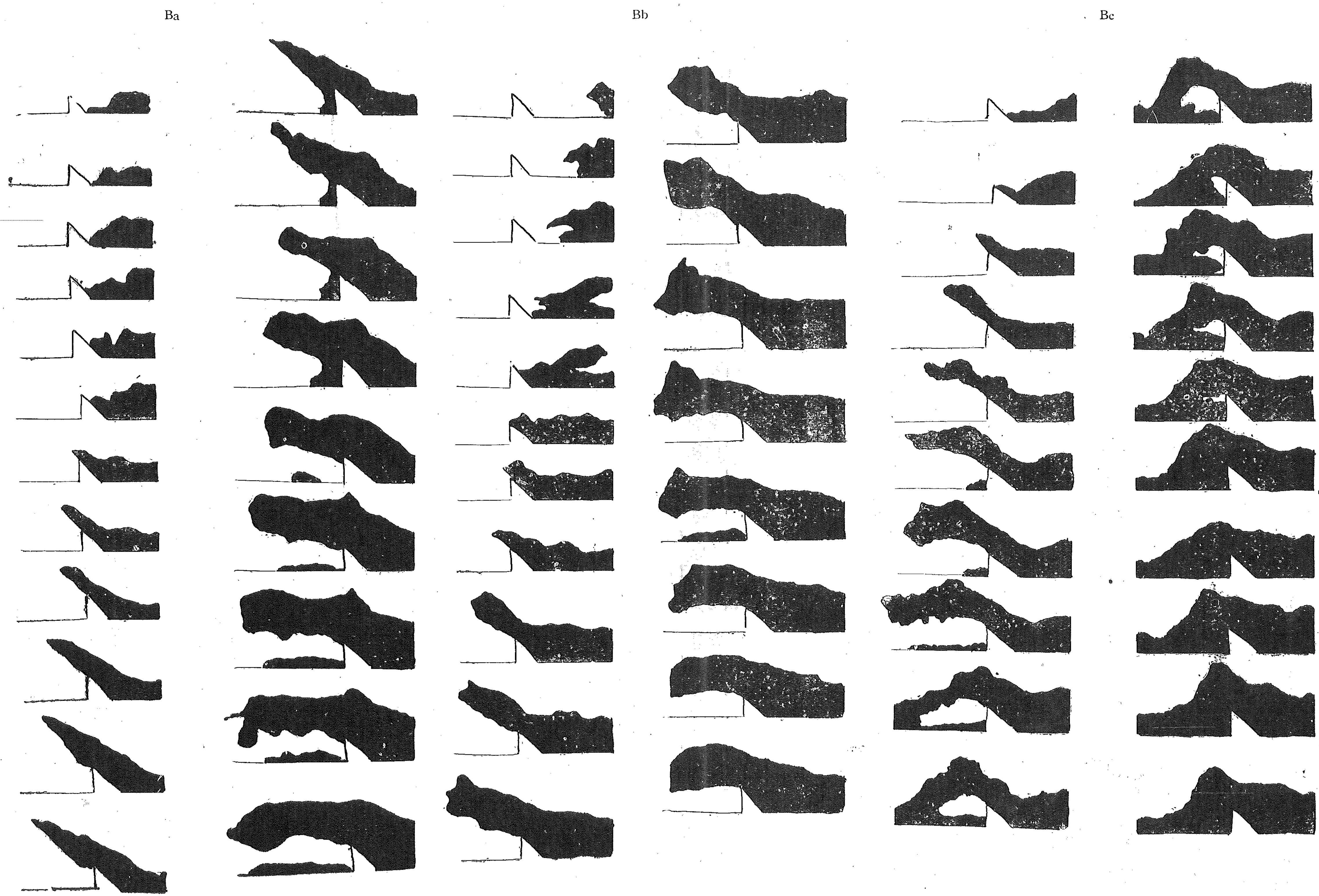


Fig. 14 (B)

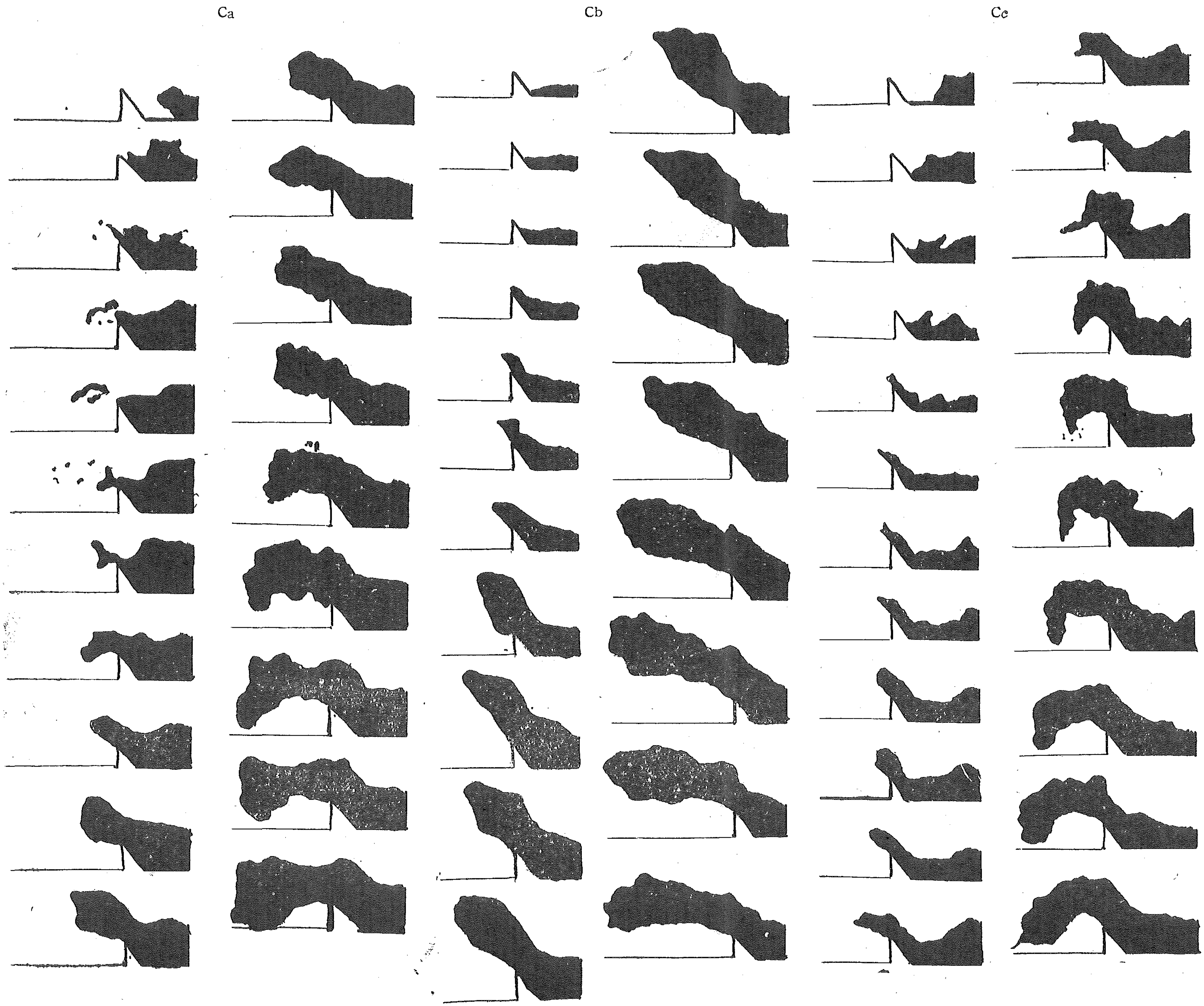


Fig. 14 (C)

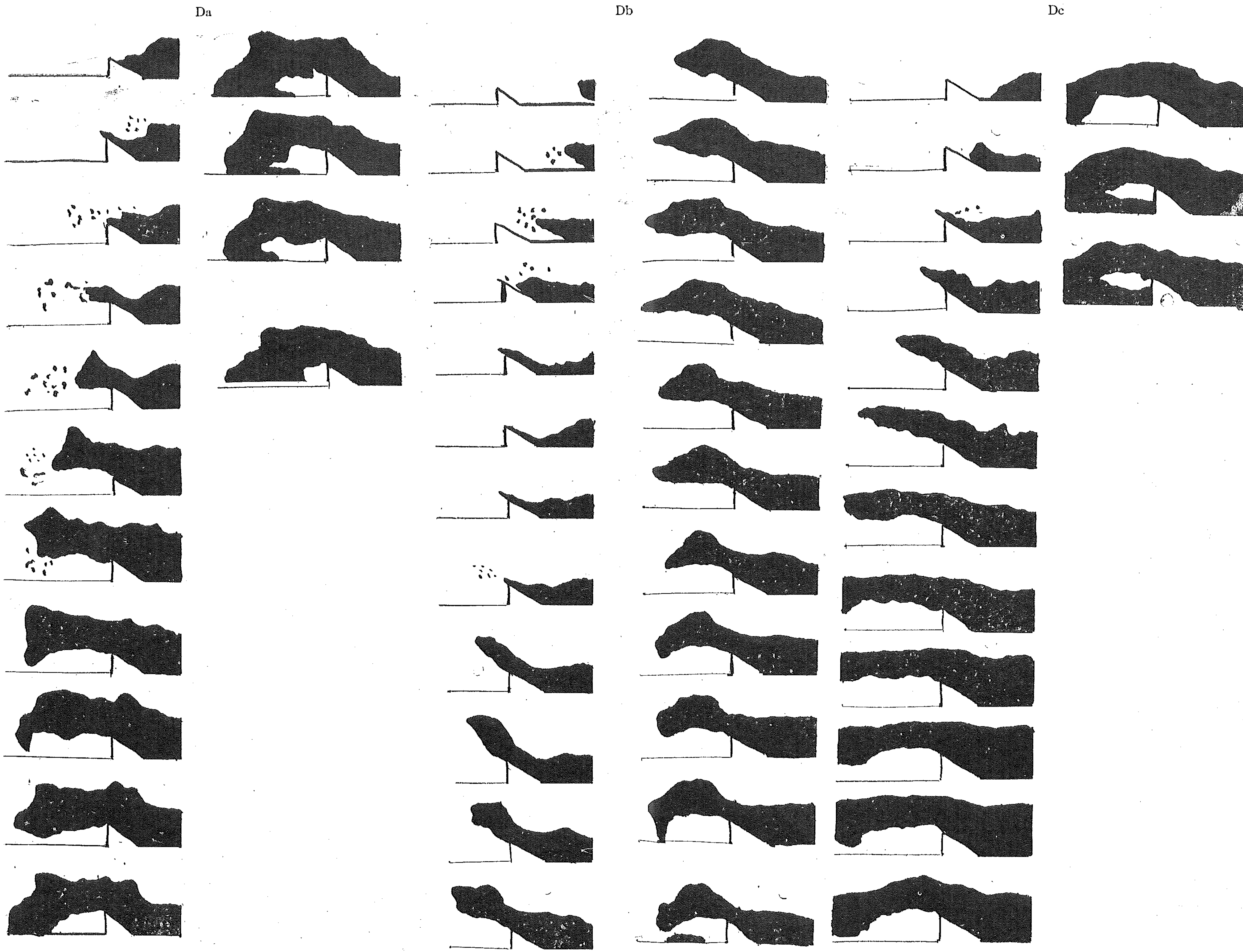


Fig. 14 (D)

The maximum heights of the flood in the nine case were investigated. The time intervals between the moment of gushing out and the moment when the maximum heights are attained, are tabulated in Table 2.

Tale 2. (Unit sec.)

	I	II	III
1	0.34	0.37	0.4
2	—	0.32	0.4
3	0.21	0.28	0.3

They are different from each other and no general tendency can be detected. However it is remakable that the maximum height is about 16 cm in all cases. It seems likely that height may depend on the dimension of diaphragm. The diaphragm used in these experimants is 12 cm in height.

5. Collision of flash flood against obstacles in the channel.

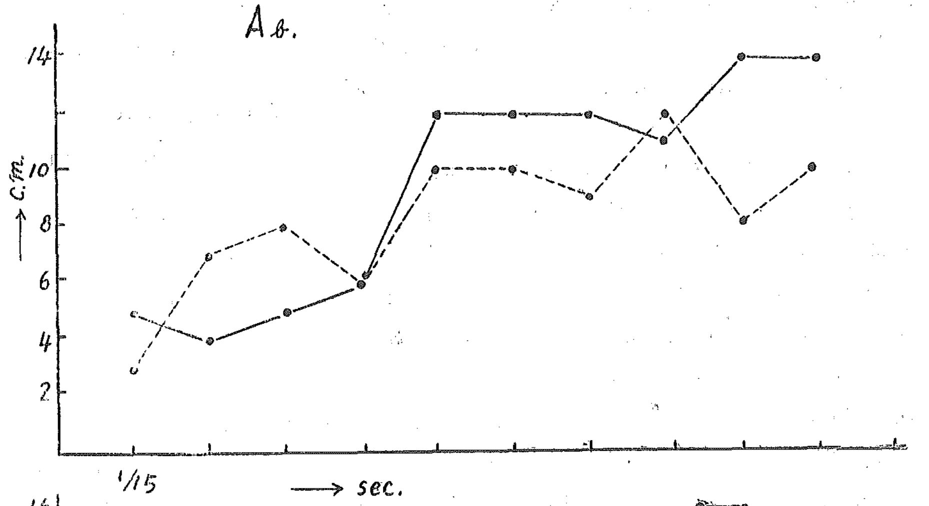
The obstacle used are prisms in form; their surfaces with which the flood collides are inclined at angles of 30°, 45° and 60° with the floor of the channel. The experiments in the cases are designates as A, B and C respectively. When the floor of the channel is paved with sand paper, the experiment is designated as D. The prisms are placed at distances of 20 cm, 30 cm and 40 cm from the orifice of the tank. The experiments in those cases are denoted respectively by a, b, and c. Thus twelve cases are investigated. Fig. 14 exhibits tracings of the form of the water front in these cases.

i) Reflected wave due to the obstacle.

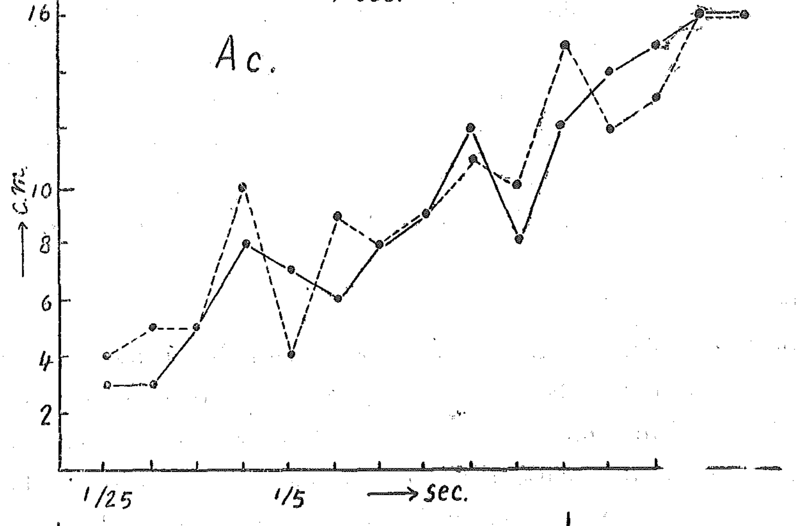
After the front of the miniature flash flood collides with the obstacle, some part of the momentum is reflected. The height is measured at two points, the one is at the lower edge of the prism, and the other is at 10 cm upstream from the former. If the height of the flood is marked as ordinate and time as abscissa, the fluctuation of height with respect to time shows that there are complicated waves. They are shown in Fig. 15, the solid line shows the height at the edge of the prism and the broken line the one at the point 10 cm upstream. It is very interesting that the height at the point 10 cm upstream is at the maximum after about 2/25 sec. from arrival of the flood at the lower edge of the prism, and again maximum after $2/25\times 8$ sec. in case c, $2/25\times 6$ sec. in case b, $2/25\times 2$ in case a. They correspond to the time lags which are necessary for advancing of the water front from the orifice of the tank and returning by reflection to the point in the respective cases. The fluctuation of height can be assumed as propagating wave. The velocity of the propagation is about 75 cm/sec in all cases. There are many other fluctuations in the curves, but data are not enough for the deduction of any conclusions.

ii) The velocity of climbing up the inclined surface of the obstacles.

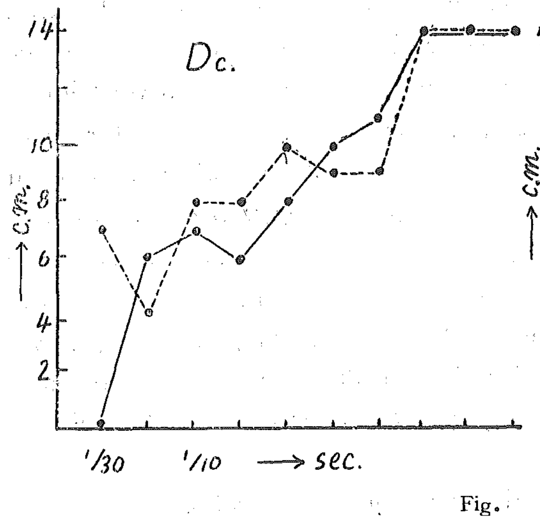
After colliding with the obstacle, the front of the flash flood is seen to be



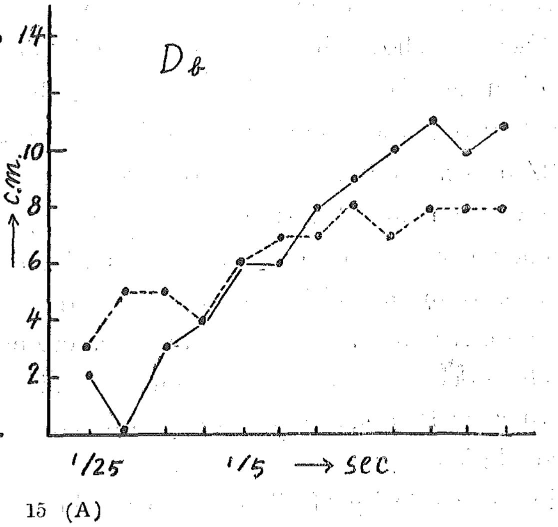
Ab.
14
10
8
6
4
2
→ c.m.
1/15
→ sec.



Ac.
16
10
8
6
4
2
→ c.m.
1/25
1/5
→ sec.



Dc.
14
10
8
6
4
2
→ c.m.
1/30
1/10
→ sec.



Db
14
10
8
6
4
2
→ c.m.
1/25
1/5
→ sec.

Fig. 15 (A)

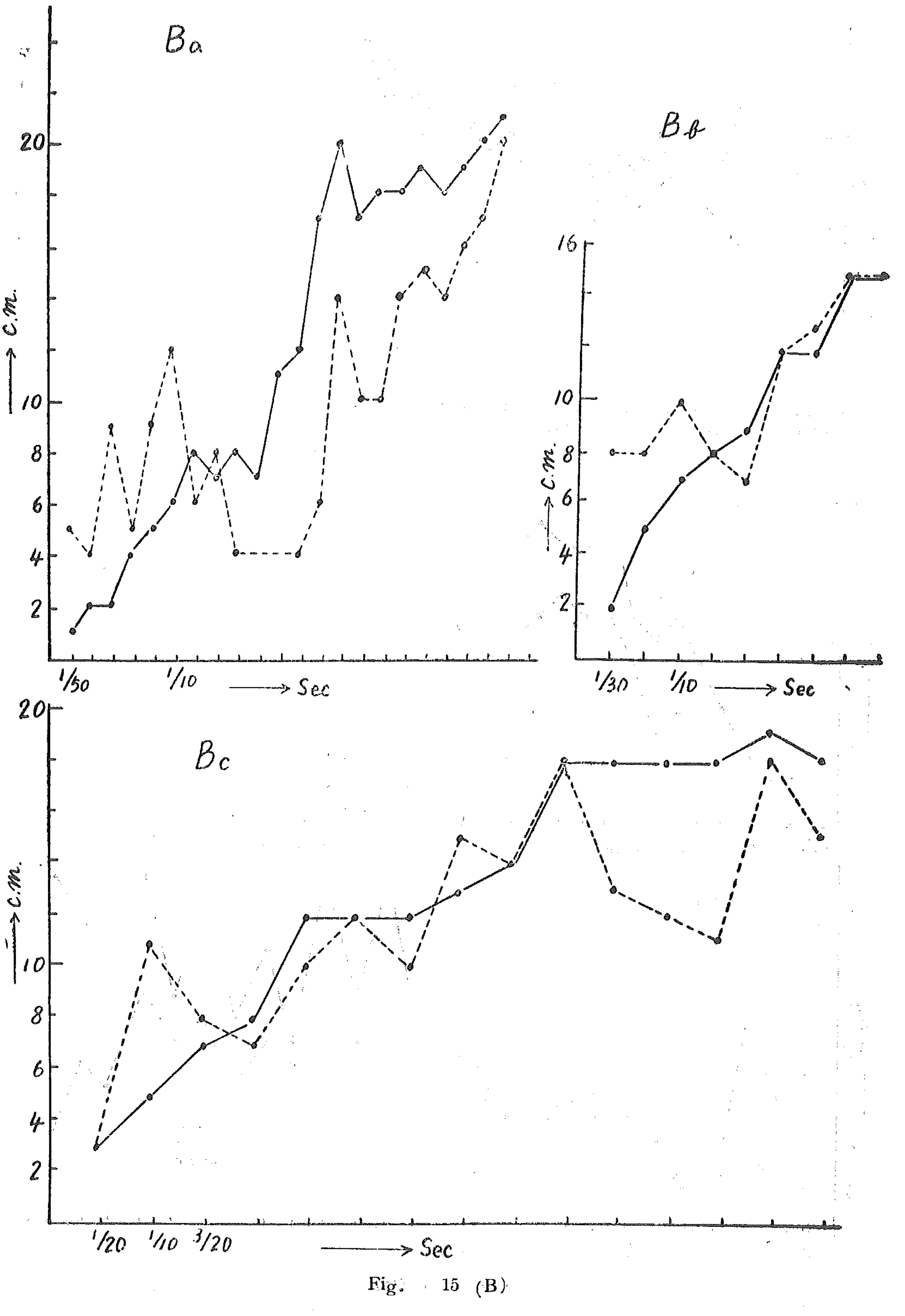

Ba
20
10
8
6
4
2
→ c.m.
1/50
1/10
→ Sec
Bb
16
10
8
6
4
2
→ c.m.
1/30
1/10
→ Sec
Bc
20
10
8
6
4
2
→ c.m.
1/20
1/10
3/20
→ Sec

Fig. 15 (B)

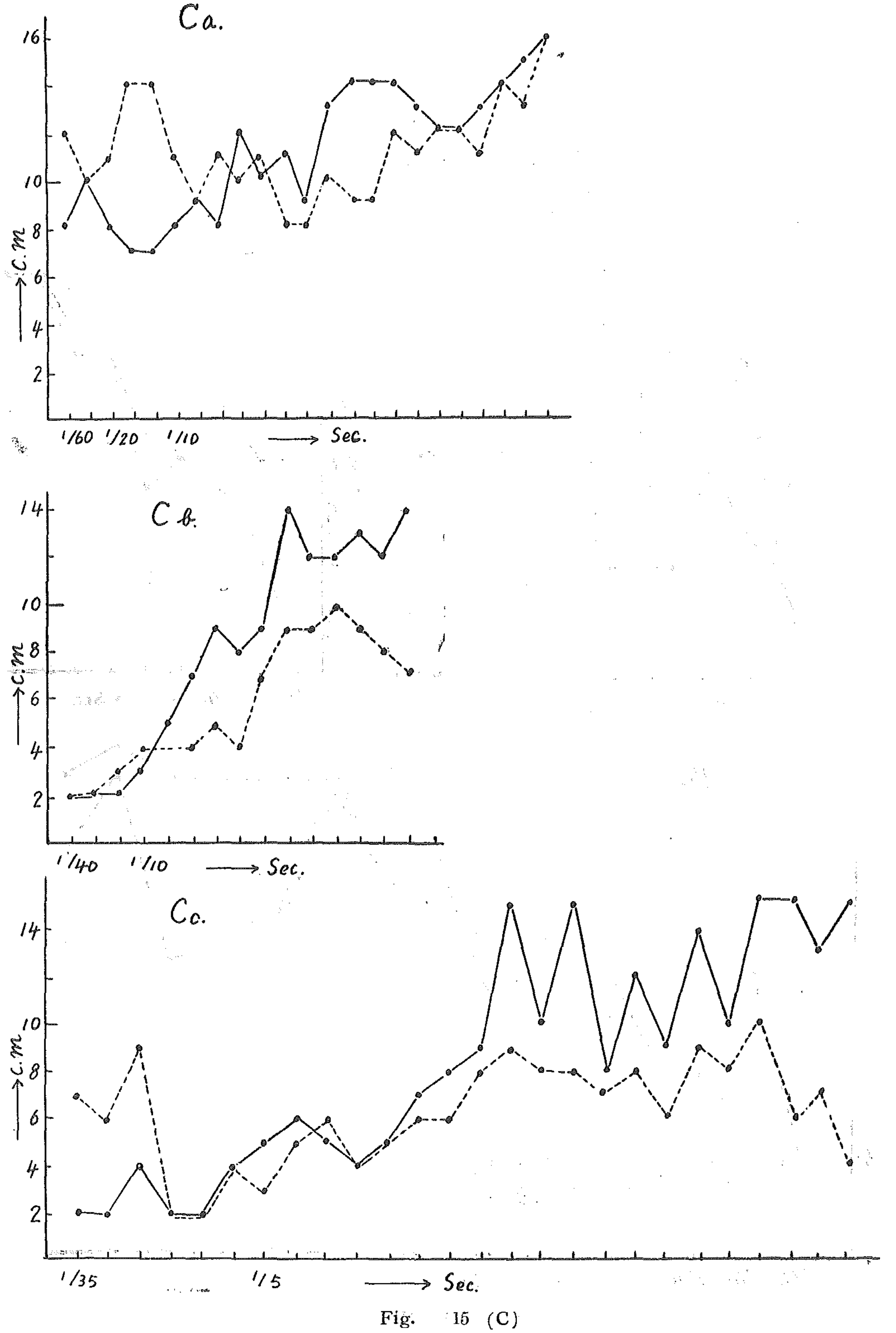

Ca.
16
10
8
6
4
2
→ c.m
1/60 1/20 1/10 → Sec.
Cb.
14
10
8
6
4
2
→ c.m
1/40 1/10 → Sec.
Cc.
14
10
8
6
4
2
→ c.m
1/35 1/5 → Sec.

Fig. 15 (C)

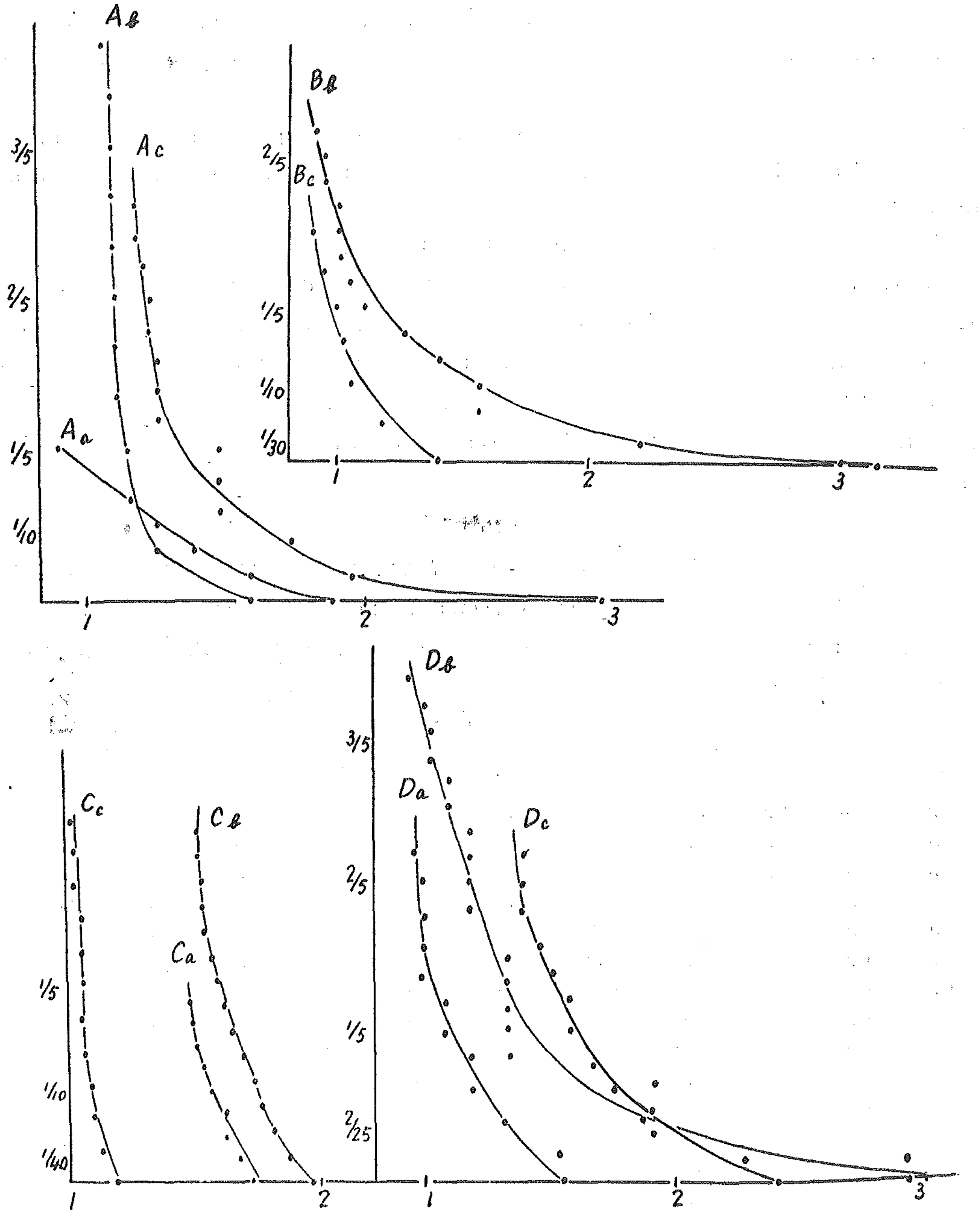

Ab
Ac
Aa
3/5
2/5
1/5
1/10
1
2
3
Bb
Bc
2/5
1/5
1/10
1/30
1
2
3
Cc
Cb
Ca
1/5
1/10
1/40
1
2
Db
Da
Dc
3/5
2/5
1/5
2/25
1
2
3

Fig. 16

partly reflected and partly climbing up the inclined surface. The most part of the flash flood water is piled up on the retarded front and leaps over the upper edge of the obstacles. Only a few photographs are available for measuring the velocity of this climbing up, for the surface of the obstacle is too small in comparison with the velocity. The obtained results are shown in Table 3.

Table 3. (cm/sec.)

Aa	Ba	Bb	Bc	Cc
348	55.7	135	180	105
—	125.0	180	240	181

From Table 3 it is seen that the velocity is small at first but increasing afterward.

iii) The velocity of leaping over the obstacles.

As shown in Fig. 15 the flash flood leaps over the upper edge of the obstacle with considerable velocity. The profile is like a parabola. The front of the flash flood moves as if the water mass were an aggregation of mass points. As in the case of a projectile, the initial velocity can be calculated from the range and the height at the apex of the profile. The result is shown in Fig. 16. If the velocity u is represented by the formula

$$u = (u_0 - u_1)\, e^{-\alpha t} + u_1$$

where u_0 is the initial velocity and u_1 the terminal velocity and α is the damping coefficient. The damping coefficient α seems to be independent of the angle of the obstacle and the distance from the orifice of the tank. As for the initial velocity, it is the largest in case b except Ab.

Table 4 (m/sec.)

Aa	Ab	Ac	Bb	Bc	Ca	Cb	Cc	Da	Db	Dc
1.93	1.54	2.93	3.14	1.40	1.73	1.96	1.20	1.54	2.93	2.41
1.54	1.17	1.93	2.20	1.48	1.67	1.87	1.13	1.54	2.93	2.18
1.32	1.07	1.70	1.56	1.04	1.61	1.79	1.10	1.32	1.93	1.87
1.17	1.07	1.42	1.56	1.02	1.61	1.76	1.10	1.17	1.93	1.75
1.07	1.07	1.42	1.40	0.99	1.56	1.73	1.06	1.17	1.32	1.66
0.92	0.99	1.42	1.28	0.94	1.53	1.67	1.06	1.07	1.32	1.58
0.78	0.99	1.17	1.10	0.90	1.51	1.64	1.06	1.07	1.32	1.58
—	0.99	1.17	1.04	—	1.49	1.61	1.06	0.99	1.32	1.51
—	0.99	1.17	1.04	—	1.47	1.58	1.06	0.99	1.32	1.45
—	0.99	1.17	0.99	—	1.45	1.56	1.03	0.99	1.32	1.39
—	0.99	1.17	0.99	—	—	1.53	1.03	0.99	1.17	1.39
—	0.92	1.12	0.99	—	—	1.53	1.03	0.92	1.17	1.39
—	—	1.07	0.94	—	—	1.53	1.03	—	1.17	—
—	—	1.07	0.94	—	—	1.51	1.01	—	1.17	—
—	—	0.99	0.90	—	—	1.51	—	—	1.07	—
—	—	0.99	—	—	—	—	—	—	1.07	—
—	—	—	—	—	—	—	—	—	0.99	—
—	—	—	—	—	—	—	—	—	0.99	—
—	—	—	—	—	—	—	—	—	0.92	—

The height of the flood at the moment of leaping over the upper edege is measured. The data is compared with the curves in Fig. 16 and it can be concluded that α is the larger, the smaller the rate of increasing of the height.

Table 5

	Ab	Ac	Bb	Bc	Ca	Cb	Da	Db	Dc
α	11.25	120	11.5	10.4	7.2	6.4	3.75	4.5	8.25
u_0 (cm/sec)	154	270	270	140	171	196	154	310	241
u_1 (cm/sec)	90	90	90	90	143	150	90	90	131

Now the height and the velocity are measured. The momentum can be known. Hence the normal pressure on the inclined surface can be calculated. The maximum amount will be estimated approximately. It is about 0.1 atmospheric pressure. The pressure on the obstacle will be measured directly soon after.

iv) The highest point after leaping over the obstacles.

The maximum height of the flood is measured in each case, and the distance from the orifice and the time after the front of the flash flood leaped over the obstacle are measured at the same time. They are shown in Table 6.

Table 6

	Ab	Ac	Ba	Bb	Bc	Ca	Cb	Cc	Da	Db
Time	0.6	0.24	0.3	0.23	0.35	0.32	0.25	0.43	0.2	0.15
Height	24	23	26	29	25	21	28	22	20	19
Distance	10.15	15.20	10.20	30.00	15.25	15.22	20.25	10.15	20.30	20.00

As discussed already, after the water mass gushes out from the tank, some parts of the water mass fall on the floor and reflect and dash forward with the remaining part. Therefore the velocity in the case where the obstacle is placed at a distance of 30 cm from the orifice is most vigorous.

6. Conclusion.

Through this experiment, the phonomena are seen to be quite distinctly different from those occurring in case of jet or stream. They resemble the motion of mass points rather than those which occur with water in the state of stream.

The experiments will be continued and a supplementary report will be published shortly.

The author expresses his sincere thanks to Prof. Y. Ikeda for his kind oversight of the studies and also to Mr. R. G. Hager of C. I. E. and Mr. Isamu, Kanai who gave facilities for this experiment. This study was helped by a research grant from the Ministry of Education.