EXPERIMENTAL APPROACH ON MEASUREMENT OF IMPULSIVE FLUID FORCE USING DEBRIS FLOW MODEL

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ABSTRACT

This paper presents an experimental approach on measurement of impulsive fluid force using several materials of debris flow model. First, the hydrodynamic test for only water was performed by using water in stead of debris flow in order to confirm the measurement accuracy of impulsive fluid force as a preliminary test. Second, three kinds of debris flow model, i.e., sediment with water, gravel with sediment including water and beads with water were used as the quasi-debris flow by using channel test with a sharp slope. Third, the pumice stone produced at the Sakurajima volcanic mountain was used as the quasi-debris flow by flowing it naturally. This final test resulted in showing the impulsive load –time relation by presenting the surge in front wave.

Key words: debris flow model, impulsive loading, pumice stone, fluid force, hydrodynamic test

INTRODUCTION

Fig.1: Debris flow disaster

Recently many sediment disasters of Sabo dam as shown in Fig. 1 have occurred at the mountainous area in Japan by local downpour based on the global warming (Sabo Technical Center, 2005). These disasters may be caused by the impulsive loading of debris flow in the steep slope. In the current design of Sabo dam, the impulsive loading of debris flow is divided into two categories, i.e., the one is the impact load due to a huge rock based on the impact theory of

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solid body and the other is the fluid force due to the dynamic fluid theory (Mizuyama,1979). However, the latter is acted on the Sabo dam as a static load based on the dynamic water pressure theory. On the other hand, the dynamic response analysis for the single degree of freedom system structure tells us that the dynamic deformation becomes two times larger than the static one, if the fluid force acts on the structure impulsively (Ishikawa, et al. 2005). This means that the structural response will be changed by the action of static or dynamic loading. To this end, many studies have been made on the fluid force of debris flow based on the dynamic fluid theory (Hirao, et al.1970, Daido,1988, Miyamoto and Daido,1983, Mizuyama, et al. 1985, Miyoshi and Suzuki,1990, Horii, et al. 2002).

However, the measurement device with high frequency is required in order to measure the impulsive loading of fluid force accurately. Further, it should be considered for the occurrence device for the debris flow, the measurement of flow velocity and discharge. It should be also properly selected for the materials of debris flow model.

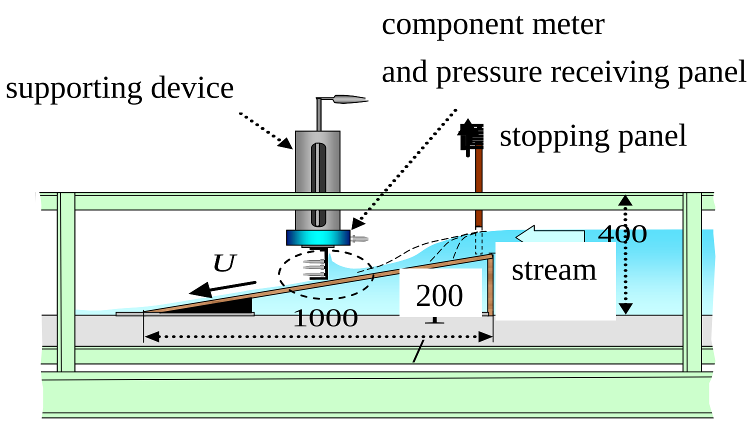
In this study, the hydrodynamic test was first carried out in order to confirm the accuracy of measurement of impulsive loading of fluid force by using only water as a preliminary test (Ishikawa, et al. 2006). Herein, both the force component meter and the pressure sensor were used to measure the fluid force simultaneously. Second, the hydrodynamic channel test with a steep slope was performed to examine the fluid force-time relations of sediment with water, gravel with sediments including water and beads with water. Third, the channel test was also executed for the measurement of the fluid force-time relation by using the pumice stone produced in the Sakurajima volcanic mountain. Finally, the current design load of fluid force is compared with the peak load and the stabilized load after the peak load obtained by the test results using the different materials of debris flow model.

PRELIMINARY TEST BY WATER

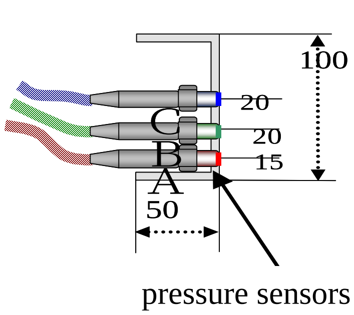
The hydrodynamic channel test was set up to measure the load –time relation at the instant of impact of fluid force by using only water in stead of debris flow model as a preliminary test. Both the force component meter and the pressure sensor were used to measure the fluid force at the same time. The slope of channel can be changed from 1/50 to 1/5 and the channel has the length of 12m, the width of 0.5m and height of 0.4m as shown in Fig.2. The water was flown suddenly by taking off the stopping panel. The pressure receiving panel is composed of the channel made by Aluminum in which the length is 100mm, the width is 100mm and the thickness is 5mm and is set up vertically as shown in Fig 2.

Measurement Items

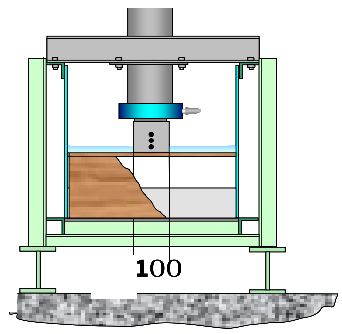
The fluid force is measured by the force component meter (frequency is 700Hz) and the three pressure sensors (frequency is 2.5KHz) as shown in Fig. 3. The flow velocity is



(a) 1/5 slope channel [mm]

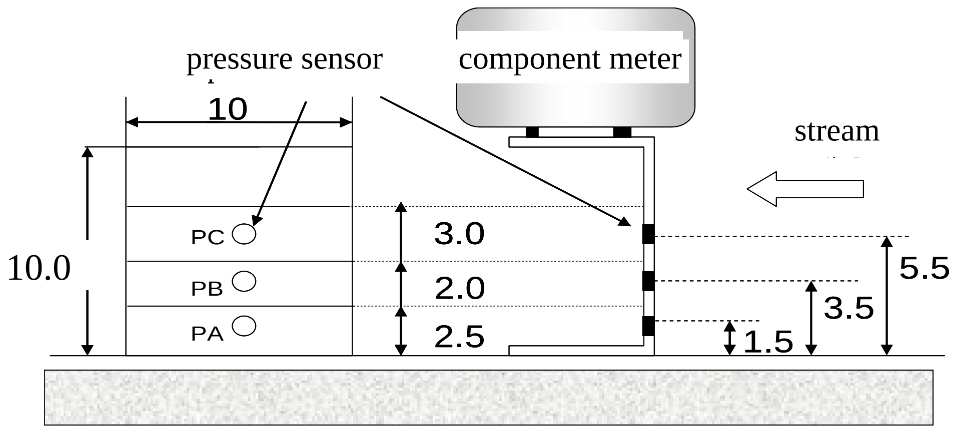


(b) measurement



(c) front plan

Fig.2: Hydrodynamic test [mm]



Sum of pressure sensors: $F_x = 10 \cdot (2.5\,PA + 2.0\,PB + 3.0\,PC)$ [N]

Fig.3: Measurement system [cm]

measured by the Laser-Doppler type meter.

Accuracy of Measurement

Figure 4 (a) shows the fluid force- time relation in case of slope 1/50 and flow velocity of 2.6m/sec.The fluid force measured by the force component meter is almost agreement with the one by the sum of pressure sensors, but is a little different from after 0.55 sec. This may be caused by no existence of pressure sensor at the upper of pressure receiving panel. Figure 4(b) illustrates the local pressure – time relation measured at the points PA, PB, PC which are occurred from the bottom of channel in turn. The rise time (0.01 sec) to the peak pressure measured by the pressure sensors is smaller than the one (0.13 sec) measured by the force component meter in Fig.4 (a). This may be due to the difference between the frequencies of pressure sensor and component meter.

Figure 5 also shows the fluid force- time relation in case of 1/5 and velocity 2.0 m/sec. It is noted that fluid force measured by the force component meter is completely agreement with the one by the sum of pressure sensors. This may be due to the steep slope channel and therefore, the starting times of PA, PB, PC are almost the same. The rise time to the peak load by the pressure sensors is quite quick (0.01 sec) in this case.

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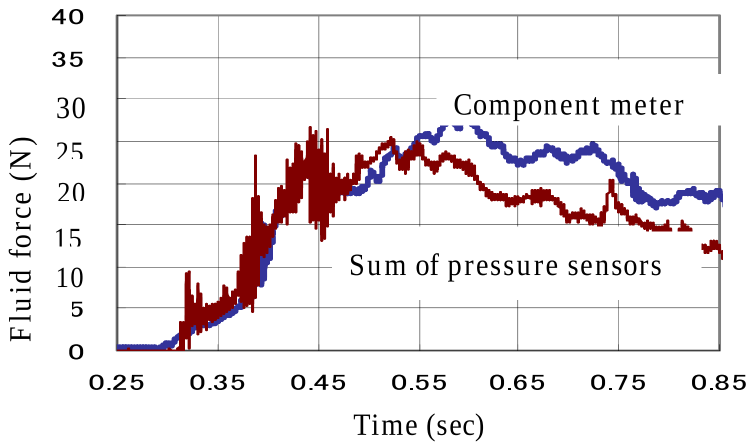
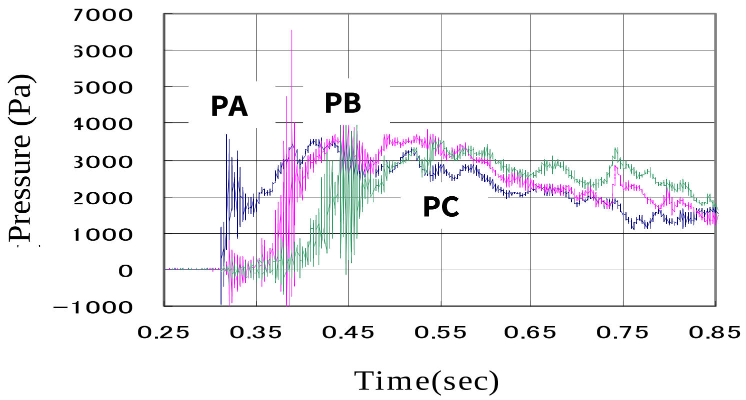


(a) Fluid force-time relation



(b) Pressure-time relation

Fig.4: Fluid force-time relation

(water, channel slope 1/50, flow velocity 2.6m/sec)

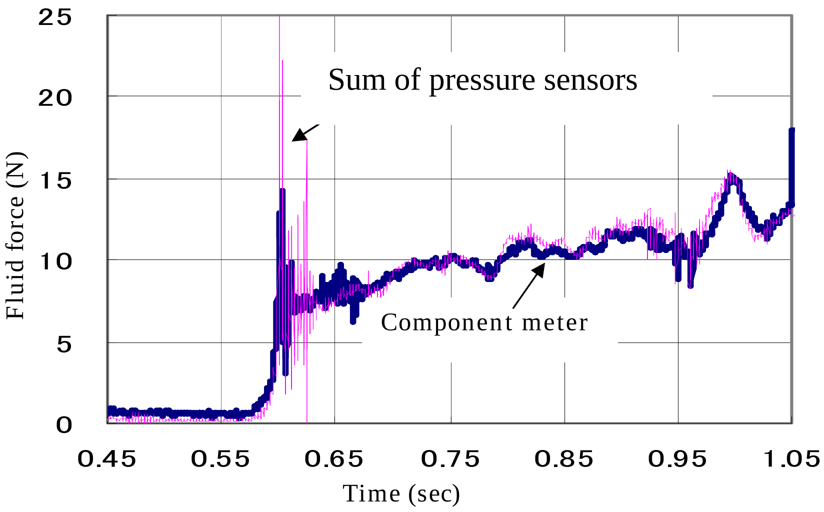


Fig.5: Fluid force-time relation

(water, channel slope 1/5, flow velocity 2.0m/sec)

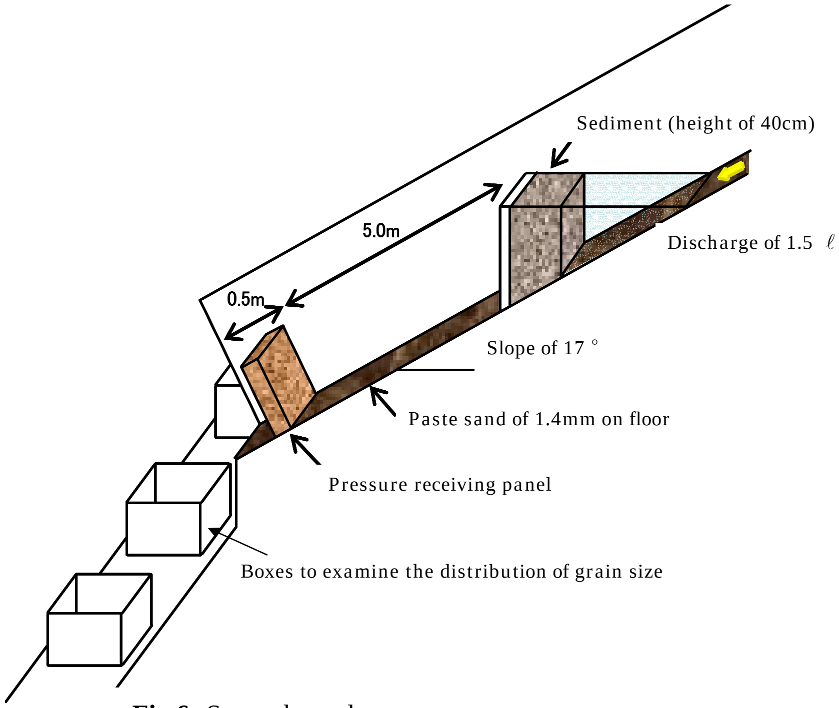


Fig.6: Steep channel test set-up

STEEP CHANNEL TEST OF DEBRIS FLOW MODEL

Figure 6 shows the steep channel test set-up in which the debris flow model (sediment etc.) is flown by taking off the stopping panel after piling up the sediment to the height of 40cm. The channel has the slope of 17 degree, the width of 10cm and the slope length of 5m. The discharge of water is 1.5 ℓ/sec and 4 kinds of debris flow model are used as follows:

①only water, ②sediment with water, ③gravel with sediment including water and ④ beads with water. In order to examine the distribution of grain size in the sediment, the boxes are used at the lower channel end by running them instantly as shown in Fig.6.

Fluid Force-Time Relation

Figures 7,8,9 and 10 show the fluid force-time relations of ①only water, ②sediment with water, ③gravel with sediment including water and ④beads with water, respectively.

Table 1 illustrates the test results.

(1) The fluid force-time relations of ①only water (Fig.7) and ③gravel +sediment +water (Fig.9) show the bilinear shape with steep rise time. On the other hand, the fluid force-time relations of ②sediment + water (Fig.8) and ④beads + water (Fig.10) represent the bilinear type with slow rise time.

(2) It is considered that the latter tendency may be caused by the reason why the consistency is not reached to the equilibrium and the head of flow becomes to the wedge shape.

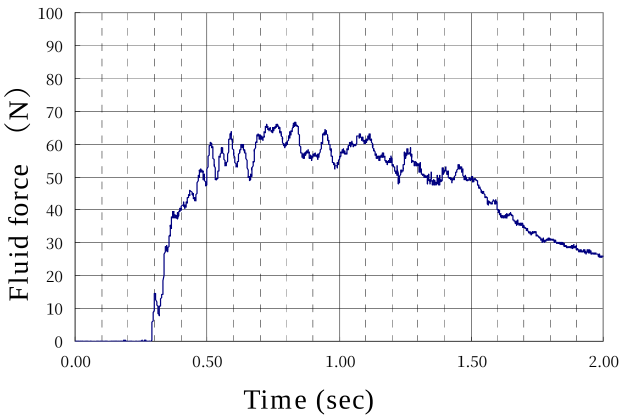


Fig. 7: Fluid force-time relation at sharp channel (only water)

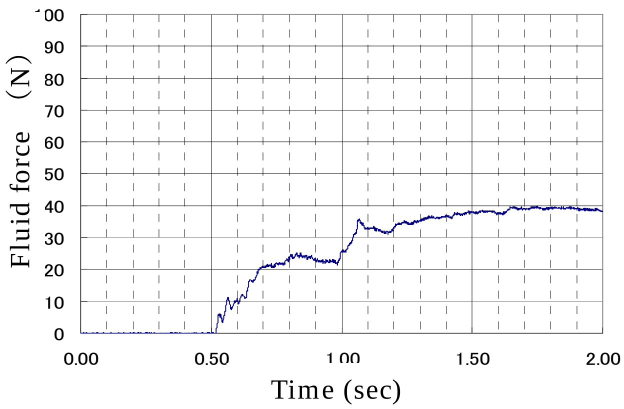


Fig.8: Fluid force-time relation at sharp channel (sediment with water)

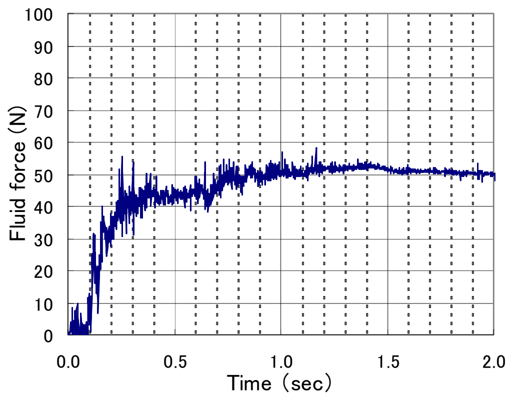


Fig.9: Fluid force-time relation at steep channel (gravel with sediment including water)

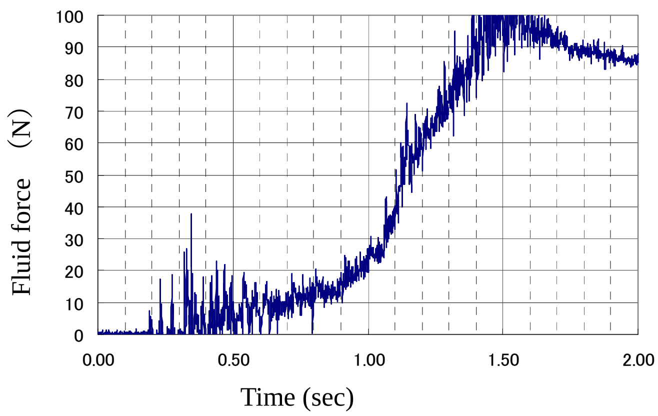


Fig.10: Fluid force-time relation at sharp channel (bead with water)

Tab.1: Test results using water, sediment, gravel and bead

Case	Peak Load F_{max} (N)	Stabilized Load F_0(N)	Ratio F_{max}/F_0	Rise time t_r(s)	Flow Velocity v(m/s)	Flow depth h(cm)	Design load F(N)	Ratio F_{max}/F	Ratio F_9/F
1(water)	60.5	50.0	1.21	0.10	3.42	4.05	47.4	1.27	1.05
2(water)	60.5	51.0	1.11	0.10	3.26	3.93	41.8	1.45	1.22
3(sediment +water)	40.0	40.0	1.00	0.20	3.05	2.34	39.2	1.02	1.02
4(gravel +sediment +water)	50.0	55.0	0.91	0.20	2.38	4.91	46.5	1.08	1.18
5(gravel +sediment +water)	50.5	52.5	0.96	0.15	2.54	4.84	52.2	0.96	1.01
6(gravel +sediment +water)	50.0	51.3	0.97	0.20	1.96	------	-------	--------	-------
7(gravel +sediment +water)	45.0	46.0	0.98	0.20	2.21	--------	---------	---------	---------
8(bead +water)	100.0	90.0	1.11	0.40	2.33	6.98	79.6	1.13	1.13
9(bead +water)	100.0	89.0	1.12	0.50	2.40	6.91	83.6	1.08	1.065

Peak Load and Stabilized Load

The peak load of ④beads +water in Fig.10 is the largest among all cases. Because the impact load of fluid force may be due to the hardness of bead, although the rise time to the peak load is the latest. The stabilized load means when the fluid force becomes constant after the peak load. These loads of materials ①,② and ④ are smaller than the peak load except the material ③. The reason why the stabilized load of material③(cases 4-7 in Tab.1) becomes larger than the peak load may be due to the effect of sedimentation of gravel.

Rise Time to the Peak Load

The rise time to the peak load is found as shown in Tab.1 by the fluid force –time relations in Figs.7,8,9 and 10.

The rise times of materials ②,③and ④ are very slow compared with ①only water. This may be the same reason as mentioned in fluid force-time relation (2).

Design Load

The design fluid force load is computed by using Eq.(1) as shown in Table 1.

$$F = \rho A v^2 \qquad (1)$$

where, ρ :density (g/cm^3), $A(= b \times h)$:sectional area of channel (cm^2), b, h :channel width and the average water depth, v :flow velocity (cm/sec).

It should be noted from Tab.1 that the design loads in all cases are almost smaller than the peak loads. This may be the reason why the design loads in all cases are almost the same as the stabilized loads after the peak and the average water depth may be estimated as the smaller than the depth after the sedimentation.

DEBRIS FLOW MODEL TEST USING PUMICE STONE

Outline of Test

The pumice stone produced in the Sakurajima volcanic mountain was used as the debris flow model. The slope of channel is 10 ° and the density of pumice stone is 1.29g/cm^3.

The method of flow is performed in the two ways as follows as shown in Fig.11.

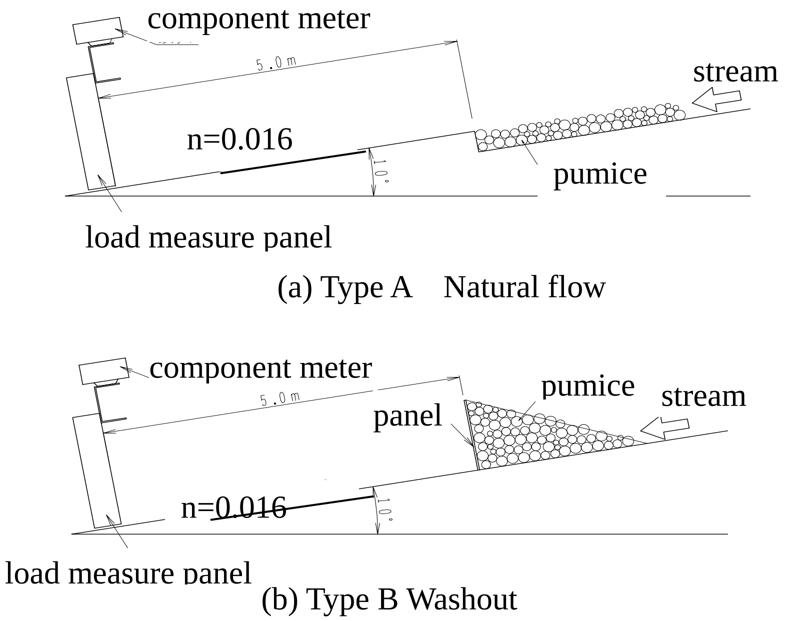


Fig. 11: Model test using pumice

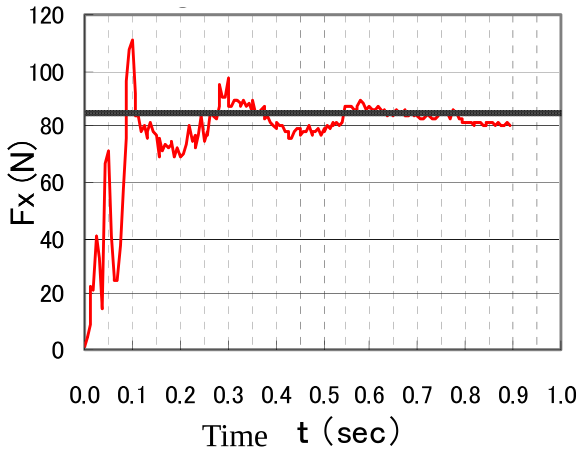


Fig.12: Case 1: Fluid force-time relation (pumice Type B) [Thick line: design load]

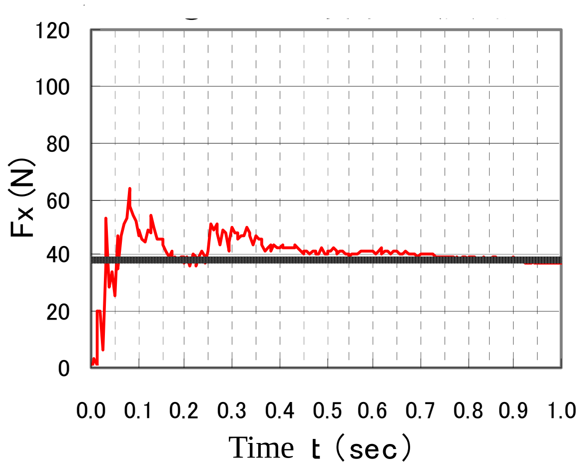


Fig.13: Case2: Fluid force-time relation (pumice, Type A) [Thick line: design load]

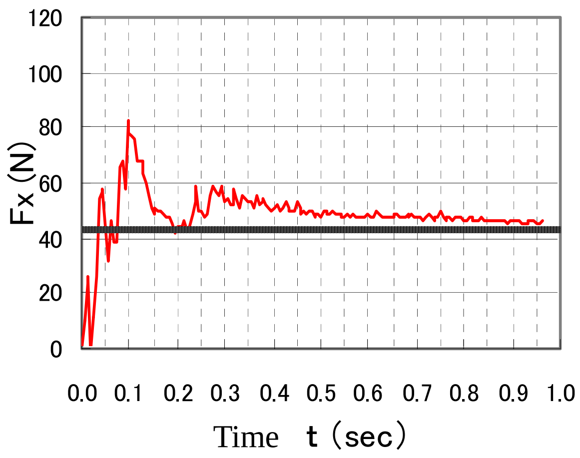


Fig.14: Case 3: Fluid force-time relation (pumice ,Type A) [Thick line: design load]

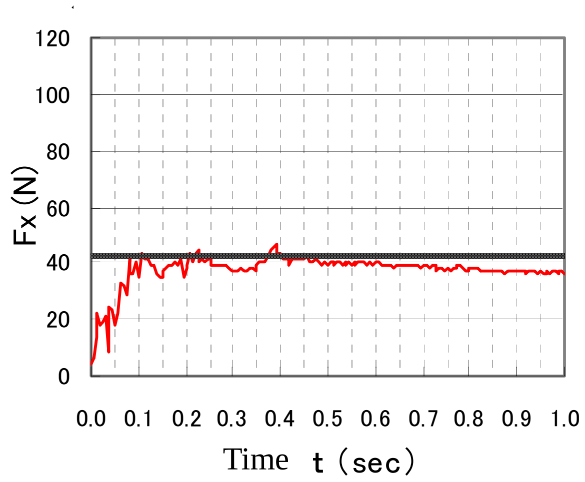


Fig.15: Case 5: Fluid force-time relation (pumice, Type C) [Thick line: design load]

Furthermore, it is added to change the channel slope 17 ° (Type C).

(1) Type A (Natural flow, channel slope with 10 °): The pumice stones are flown naturally without using the stopping plate.

(2) Type B (Washout, channel slope with 10 °): The pumice stones are flown by taking off the stopping plate after sedimentation.

(3) Type C (Natural flow, channel slope with 17 °): The pumice stones are flown naturally as the same manner as Type A by only changing the channel slope with 17 ° .

The flow velocities in all cases are about 1.6-1.7m/sec.

Fluid Force-Time Relations

Figures 12, 13, 14 and 15 show the fluid force-time relations in cases 1,2,3 and 5 in Tab. 2 , respectively.

(1) It is found that the fluid force-time relations in all cases show the bilinear behavior with

very steep slope rather than the cases of water in Fig.7 and gravel +sediment +water in Fig.9.

(2) This tendency may be due to the reason why the head flow of pumice forms the surge shape by coming up to the surface at the front of pumice stones.

(3) It is interested to note that the rise times in all cases are very quick rather than the cases of sediment + water, gravel + sediment +water and bead + water. This may be caused by the surge shape in which the front wave of pumice is flown as stepwise.

The Peak Load and Stabilized Load

Table 2 shows the peak load and the stabilized load after the peak in all cases of pumice stones.

(1) The ratios of peak load and stabilized load $(F_{\max}/F_0)$ are almost 1.7-1.9 and this tendency means the impulsive loading, because of forming the surge shape due to the effect of rising up to the surface of pumice stones.

(2) However, the ratio $(F_{\max}/F_0)$ was 1.2 in case 5 of type C. This may be the reason that the velocity of front wave increases and as such, the front pumice did not rise up to the surface and did not represent the surge shape.

Rise Time to the Peak Load

Table 2 shows the rise time to the peak load in all cases using pumice stone.

(1) The rise times of cases 1-4 are all less than 0.1 sec except case 5. This is regarded as the impulsive loading –time relation, and the structural dynamic response will become two times larger than the static loading, if this impulsive loading acts on the structure (Ishikawa, N. et al. 2005).

(2) Therefore, the rise time is important factor for the judgment of impulsive loading or not, although this value is actually compared with the natural frequency of the structure.

Design Load

The thick line in Figs.12-15 and Table 2 show the design fluid force load which is computed by using the average water depth, the average velocity and the density of pumice stones ($\rho = (1.29 \times 0.44 + (1.00 \times (1-0.44)) = 1.13 g/cm^3$)), because the transportation consistency of pumice stones is measured as 0.44.

(1) The ratios of stabilized load and design load (F_0/F) in all cases become almost 1.0. This fact indicates that the design load coincides with the stabilized load.

(2) The ratios of peak load and design load ($F_{\max}/F$) of cases 2,3,4 are about 1.7-1.8 and as such, the impulsive loading is 1.7-1.8 times larger than the design load. This means that the impulsive load acts on the Sabo dam large rather than the design load.

Tab.2: Test results using pumice

Case (Type)	Peak load F_{max}(N)	Stabilized load F_0(N)	Ratio F_{max}/F_0	Rise time t_r(sec)	Flow velocity v(m/sec)	Flow depth h(cm)	Design load F(N)	Ratio F_{max}/F	Ratio F_0/F
1 (B)	112.2	80	1.4	0.098	2.54	11.6	84.6	1.3	0.95
2 (A)	63.9	38	1.7	0.078	1.60	13.4	38.8	1.7	0.98
3 (A)	82.7	47	1.8	0.092	1.84	12.9	49.4	1.7	0.95
4 (A)	89.2	48	1.9	0.070	1.84	13.0	49.7	1.8	0.97
5 (C)	45.4	38	1.2	0.112	1.71	13.0	43.0	1.2	0.88

Sedimentation Profile

Figure 16 shows the sedimentation profile before the impact to the panel in Cases 1,2,3 and 5. It is noted that the front waves in Cases 2 and 3 resulted in showing the surge shape, but the front waves in Cases 1 and 5 illustrated the wedge shape.

(a) Case 1（Type B）

(b) Case 2 (Type A)

(c) Case 3 (Type A)

(d) Case 5 (Type C)

Fig.16: Sedimentation profile of pumice before impact to pannel

CONCLUSIONS

The following conclusions are drawn from this study.

(1) It is confirmed that the fluid force measured by the force component meter is almost

good agreement with the sum of pressure sensors.   Therefore, the force component meter can measure the fluid force of debris flow models, i.e., water, sediment +water, gravel +sediment +water, bead +water and pumice +water.

(2) It is found that it is difficult to get the impulsive loading in cases of sediment +water, gravel + sediment +water, even if the channel slope becomes steep.

(3) It is interested to note that the front wave of debris flow model using pumice stone resulted in showing the surge shape and as such, the ratio of the peak load and the stabilized load became quite large (1.7-1.8). This phenomenon is called as the impulsive fluid force.

(4) The rise time in fluid force-time relation using pumice stone became faster than other debris flow model materials. This may be due to the effect of forming the surge shape.

(5)These phenomena will be simulated by using the particle method which may be used for the Sabo dam design in the near future.

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