Flow Discharge through Rockfill Embankment Measured in Laboratory Water Flume

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ABSTRACT: Discharge and free surface of flow through rockfill embankment were measured in a laboratory water flume to investigate a flow transmissibility of the rockfill. River gravel sieved into 25 to 50 mm and 50 to 75 mm in diameter were used to construct the rockfill embankments in the water flume. Six rockfill embankments were constructed by changing rock particle size, slopes and length of the embankment, and tested with rising upstream water level. A width and a height of the rockfill embankment were 50 cm and about 50 cm, respectively. The discharge of flow through the rockfill embankment was summarized and tabulated with the upstream water level. The free surface of flow within the rockfill embankment was observed and drawn in a figure. Some typical examples of the stage-discharge rating curve were given to show a non-linear increase of the flow discharge with rise of upstream water level.

Results of the laboratory water flume test given in this report may be applied to find out parameters which control the non-linear behavior of flow through rockfill. Once such the flow parameters are determined, the flow transmissibility of the rockfill structure consisting of river gravel up to about 100 mm in diameter can be predicted accurately without any consideration of a scale effect of void structure and rock particle size on the flow.

Key words: Rockfill, Rockfill embankment, Laboratory water flume, Flow discharge, Hydraulic mean radius of voids

INTRODUCTION

Rock material has been advantageously employed in hydraulic structures such as throughflow dam, cofferdam, gabion weir and drain work. Because a flow discharge through the rockfill structure is quite a large amount of water, an accurate estimation of flow transmissibility of the rockfill is required to design and construct the rockfill structure safely.

The first author has investigated hydraulics of flow through the rockfill embankment based on a laboratory one-dimensional permeability test and a laboratory water flume test, in both of which river gravel sieved into 5 to 25 mm in diameter was used[1,2]. In this report, flow discharge as well as free surface of flow through the rockfill embankment constructed in the laboratory water flume using river gravel 25 to 75 mm in diameter is measured and summarized. Although the water flume tests were conducted in the laboratory, it's should be noted that the result reported here can be easily applied to a practical problem to investigate the flow transmissibility of the rockfill structure because the river gravel 25 to 75 mm is usually employed in the construction works. In the following a procedure of the laboratory water flume test is briefly outlined. Then the flow discharge through the rockfill embankment and the free surface of

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flow within the embankment are reported. Finally some possible application of the result is commented.

WATER FLUME TEST AND ROCK MATERIAL

The rockfill embankments were constructed and tested in the laboratory water flume 50 cm wide and 60 cm deep of the Hydraulic Experiment Station of Faculty of Agriculture, Niigata University, Niigata. River gravel was placed into the water flume in layers and compacted lightly by a steel rod to construct the rockfill embankment as shown in **Figure 1**. Mass and volume of the rockfill embankment were measured during and after construction, respectively, to calculate its porosity. A void ratio e of the rockfill embankment was calculated by using the porosity and a specific gravity of river gravel, G. The upstream water level, h_u, was raised successively in five steps. After a steady state of flow was attained at each step, a bulk discharge of flow through the rockfill embankment was measured by using a sharp-crested weir installed at the upstream portion of the water flume. The flow discharge per unit width of the water flume q was calculated by dividing the measured bulk discharge of flow by the width of the water flume. The downstream water level, h_d, was measured, but no regulation was given on h_d in the water flume test. Water temperatures of flow, T, were measured at beginning and completion of the test, and averaged. Height of a free surface of the flow within the rockfill embankment and a exit point of flow appearing on the downstream slope of the rockfill embankment, y_{ex}, were observed through a glass wall of the water flume. Angles of the upstream slope, θ_u, and the downstream slope, θ_d, and a base length, L, of the rockfill embankment were also observed through the glass wall of the water flume.

Being washed and air-dried, the river gravel was sieved into two classes of rock particle size, D5 and D6. Their representative diameter, rock particle shape and physical properties of rock particle in each class of size are given in **Table 1**. The representative diameter of rock particle, d, is defined as an arithmetic mean of rock particle size sieved. The rock particles were classified according to a ZINGG diagram[3] into four shapes of blade, disk, spheroid and rod based on the measurements of three orthogonal lengths of fifty rock particles selected from the rock particle class. Their frequencies are given in the rows (4)-(7) of **Table 1**. Mean shape coefficient of rock particles in each class of size, r, in the row (8) is calculated as a mean of r_e weighted by the frequencies in the rows (4)-(7), in which r_e is the shape coefficient for each shape of rock particles measured by SABIN and HANSEN[4].

RESULT OF WATER FLUME TEST

Table 2 shows a summary of the test results. Six rockfill embankments were constructed in the water flume and tested. The first, second and last terms of the test number given in the row (1) of the **Table 2** represent the class of rock particle size given in **Table 1**, the specified upstream and downstream slopes (that is, 11=1V: 1H slopes, 12=1V: 2H slopes, and V=vertical sides), and a specified top width of the rockfill embankment in cm, respectively. After q, the position of the free surface of flow, y_{ex}, and h_d were measured with increasing h_u, the same measurement was repeated. In the following the first series of measurement is denoted by (1) and the second series of measurements by (2) such as D5-12-20(1). Be sure that no measurement of the free surface of flow nor y_{ex} was done in D5-11-20(1) and D5-11-20(2). The hydraulic mean radius of rockfill voids, m, given in the row (2) of the **Table 2** is defined as:

$$m=\frac{ed}{6r} \tag{1}$$

Effects of void structure on the flow hydraulics of the rockfill should be evaluated by taking the size and shape of the rock particles as well as the size and distribution of voids within the rockfill into account. MARTINS[5] shows that all the effects mentioned above can be well described by m.

Some typical examples of a stage-discharge rating curve are shown in **Figure 2**. It is noticed that the

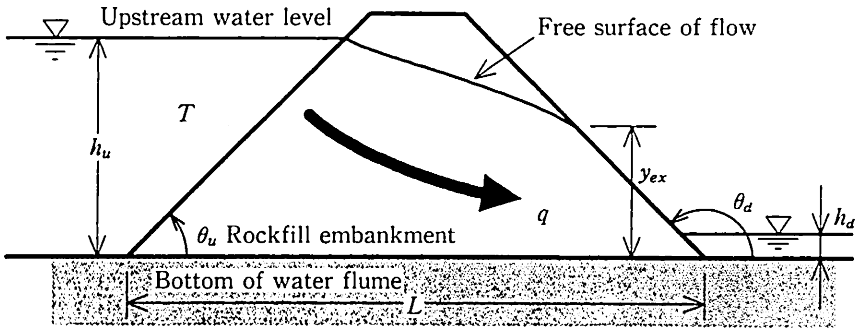

Figure 1 Rockfill embankment constructed in the laboratory water flume.

Table 1 Size, shape and physical properties of the river gravel used in the water flume test.

Class of particle	Particle size, mm	Arithmetic mean of particle size d, mm	Rock particle shape [a]					Specific gravity of dried particle G	Water absorption of particle, %
			Blades	Disks	Spheroids	Rods	Mean shape coefficient r[b]		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
D6	25-50	37.5	0.17	0.40	0.16	0.27	1.9051	2.550	1.2
D5	50-75	62.5	0.18	0.38	0.14	0.30	1.9008	2.601	0.9

a) Numeral in the cells show frequency of rock particle shapes determined by measuring three orthogonal axes of rock particle. Fifty rock particles are selected from each class of rock particle size to determine the frequency of rock particle shapes.
b) r is a mean shape coefficient of rock particles, and is calculated as a mean of r_e weighted by the frequency given in the rows (4)-(7). r_e is the shape coefficient for each shape of rock particles, and is given by SABIN & HANSEN[4].

flow discharge of the rockfill embankment increases exponentially with the upstream water level. The free surfaces of flow within the rockfill embankment observed through the glass wall of the water flume are summarized in **Figure 3**.

DISCUSSION

The discharge and the free surface of flow through the rockfill embankment were measured in the laboratory water flume to investigate the flow transmissibility of the rockfill. The river gravel sieved into 25 to 50 mm and 50 to 75 mm in diameter were used to construct the rockfill embankment in the water flume. Six rockfill embankments were constructed by changing the rock particle size, the slopes and length of the embankment, and tested with rising the upstream water level. The width and the height of the rockfill embankment were 50 cm and about 50 cm, respectively. The discharge of flow through the rockfill embankment was summarized and tabulated with the upstream water level. The free surface of flow within the rockfill embankment observed was drawn in a figure. Some typical examples of the stage-discharge rating curve were given to show the non-linear increase of the flow discharge with rise of upstream water level.

The results of the laboratory water flume test given in the preceding chapter may be applied to find out parameters which control the non-linear behavior of flow through the rockfill. Once such the flow

Table 2 Results of the water flume test of the rockfill embankment.

	Rockfill	Dam/Flow	First series of measurement [a]				Second series of measurement [a]			
Test No.	d, cm e m, cm	L, cm θ_u, deg. θ_d, deg. T_1 [b], ℃ T_2 [b], ℃	h_u cm	h_d cm	q cm³/s/cm	y_{ex} cm	h_u cm	h_d cm	q cm³/s/cm	y_{ex} cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		116.5	12.34	- c)	34.31	-	13.62	-	51.87	-
	6.25	44.0	23.80	-	126.29	-	28.08	-	167.02	-
D5-11-20	0.623	135.2	29.33	-	179.86	-	32.75	-	219.26	-
	0.341	13.0	38.71	-	299.53	-	36.10	-	260.66	-
		14.7	42.60	-	352.81	-	42.50	-	349.17	-
		115.4	15.40	2.57	51.27	5.0	12.57	2.44	34.91	4.8
	3.75	45.0	26.01	4.02	126.94	9.0	22.10	3.67	98.29	7.8
D6-11-20	0.554	134.5	34.07	5.15	195.89	12.9	31.70	4.98	173.38	11.6
	0.182	24.0	41.30	5.75	266.58	17.8	39.33	5.72	243.42	16.6
		24.7	47.90	7.15	347.81	26.3	46.28	2.92	325.12	27.3
		214.6	17.23	3.07	59.99	5.8	15.55	2.70	48.05	5.9
	6.25	26.0	26.80	4.40	131.20	12.1	24.17	3.90	107.25	10.1
D5-12-20	0.602	154.4	33.77	5.38	197.48	18.7	32.10	5.00	179.86	16.3
	0.330	24.5	39.30	6.35	262.49	24.1	37.60	5.87	239.65	23.5
		24.5	44.47	7.30	327.02	29.6	42.50	6.90	299.39	26.5
		214.1	13.77	2.30	27.57	4.3	19.16	2.80	52.65	6.6
	3.75	26.0	21.93	3.20	67.25	7.2	24.10	3.50	77.55	8.6
D6-12-20	0.551	153.7	30.20	4.20	119.87	13.0	35.60	4.80	156.98	17.4
	0.181	24.0	38.70	5.30	188.91	18.0	40.20	5.40	197.26	23.9
		23.7	44.80	3.90	251.20	29.0	46.71	2.60	269.63	30.2
		75.0	14.97	4.80	76.82	5.2	18.63	5.40	108.86	6.5
	6.25	90.0	23.20	6.25	155.35	7.8	26.10	6.75	184.91	9.5
D5-V-70	0.572	90.0	29.80	7.25	227.02	10.7	32.90	7.90	261.31	12.0
	0.314	23.0	35.20	8.30	288.70	13.0	38.13	8.90	322.50	15.1
		22.5	39.60	9.10	339.42	15.7	41.33	9.60	361.36	17.6
		69.7	16.10	4.60	67.25	5.7	15.20	4.45	59.42	5.5
	3.75	90.0	22.70	5.50	121.12	8.2	21.72	5.45	111.78	7.9
D6-V-70	0.537	90.0	30.95	6.72	193.29	11.6	26.38	6.00	151.92	10.1
	0.176	21.1	38.25	7.90	262.23	15.0	34.20	7.30	222.16	13.1
		21.0	43.32	8.80	313.98	18.0	40.70	8.40	286.50	16.5

a) After the first series of measurement given in the rows (4) to (7) was completed, the second series of measurement in the rows (8) to (11) was conducted with increasing the upstream water level.
b) T_1 and T_2 given in the row (3) are water temperature of flow measured during the first and second series of measurement, respectively.
c) No measurement was conducted in the case indicated by a minus sign.

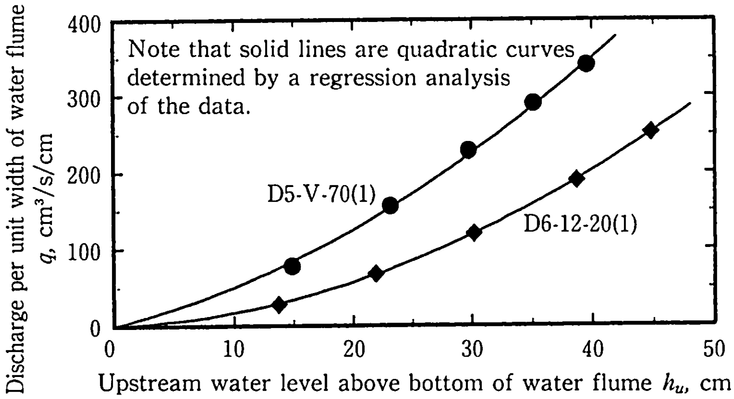

Figure 2 Typical examples of stage-discharge rating curve measured in the water flume tests.

parameters are determined, the flow transmissibility of the rockfill structure consisting of river gravel up to about 100 mm in diameter can be predicted accurately without any consideration of a scale effect of void structure and rock particle size on the flow.

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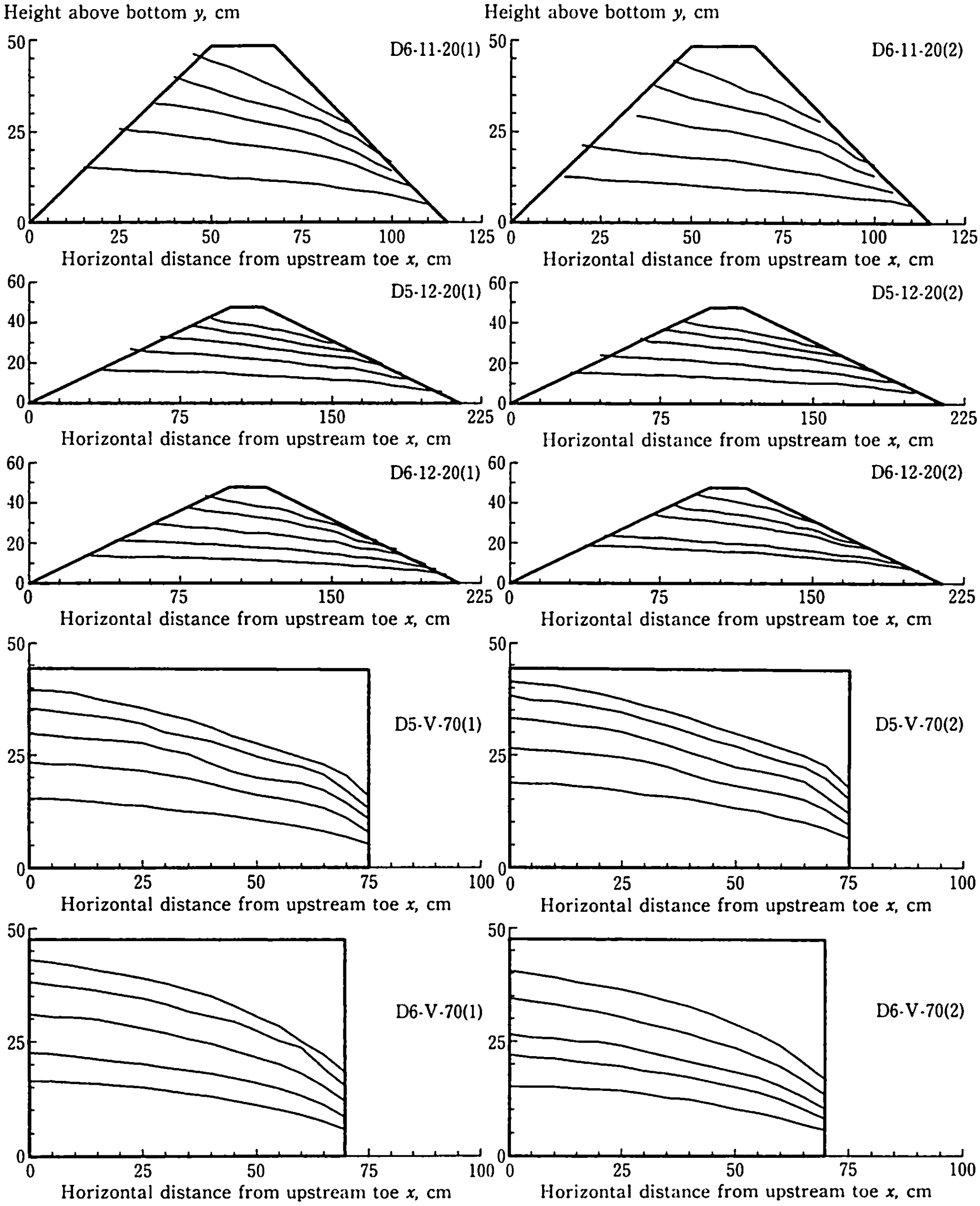

Figure 3 Free surfaces of flow through the rockfill embankment observed in the water flume test. No observation was conducted in D5-11-20. (1) and (2) attached to the test number represent the first and the second series of measurement, respectively.

室内水路実験で測定されたロックフィル堤体の通水流量

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摘　　要

ロックフィルの通水特性を調べるために、室内水路を用いて、ロックフィル堤体を通る流れの量と自由水面を測定した。25～50mm と50～75mm にふるい分けた河川礫を用いた。ロック材粒子の大きさ、堤体の斜面こう配および長さを変えて6個のロックフィル堤体を作製し、上流側水位を上げながら測定を行なった。ロックフィル堤体の幅および高さは、それぞれ、50cm および約50cm であった。ロックフィル堤体の通過流量は、上流側水位に対応させて一覧表にまとめた。観察によって求めた堤体内の自由水面は、図で表した。水位流量曲線の代表的な測定例により、ロックフィル堤体の通過流量が、上流側水位とともに非線形的に増大することを示した。

本報告で示した測定結果は、ロックフィルを通る流れの非線形な挙動を支配するパラメータを探るために用いることができる。いったん、このような流れのパラメータが決まれば、流れに及ぼす間隙構造や粒子径の寸法効果を考慮せずに、最大約100mm までの直径の河川礫で築造されるロックフィル構造物の通水特性を、精度よく予測することが可能となる。

キーワード：ロックフィル、ロックフィル堤体、室内水路、流量、間隙の水理学的平均径

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