A Distorted Model of a Hydraulic Structure Including Steep Open Channels with Bends

（屈曲のある急勾配開水路を含む水理構造物の歪模型）

Key words: Distorted hydraulic model, Rainwater harvesting system, Similitude

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1. INTRODUCTION

Some arid regions with annual precipitation below 100 mm are also prone to floods due to heavy rainfall events occurring several times in a year. Runoff from such a rainfall event is mostly ephemeral and thus difficult to utilize as water resources. Abdulla *et al.*[1] evaluated the potential for potable water savings by using rainwater in residential sectors. A novel type of rainwater harvesting system is being developed to collect flushes into a reservoir, so that the stored water is readily available for agricultural purposes. This study focuses on the hydraulic structure to divert currents in a dry river to the reservoir, and an experimental approach is taken to reproduce flows in the structure.

2. OUTLINE OF HYDRAULIC STRUCTURE

The prototype of the hydraulic structure was constructed in the agricultural research station of Mutah University at Ghor Al Mazrah in Jordan. The construction site was well considered in order to effectively collect the flushes. As shown in **Fig. 1**, the hydraulic structure consists of a gutter set across the bed of the dry river flowing between steep cliffs and a conveyance channel with bends to guide the collected water to the reservoir.

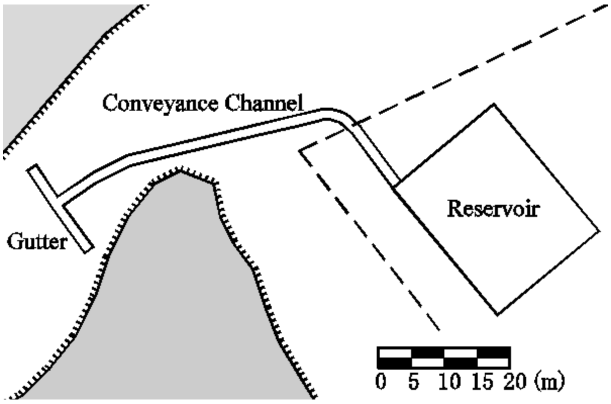

Fig. 1 Construction site

3. DESIGN OF DISTORTED MODEL

The hydraulic model tests were conducted in the hydraulic experimental station of Kyoto University at Maizuru in Japan. A distorted model for the hydraulic structure was constructed, according to the similitude deduced directly from the 2-D shallow water equations (2-D SWEs) governing dominantly horizontal flows. The horizontal scale of the model was decided as $1/8$, allowing for the land and labor available at the experimental station. The channel bed was paved with concrete, while the sidewalls were made of bricks. Although concrete blocks were used for the sidewalls in the prototype, the roughness determining the friction slope was assumed to be identical between the model and the prototype. These result in the ratios of physical quantities satisfying the similitude as shown in **Table 1**, where L =horizontal length, n =Manning's roughness coefficient, H =vertical length, V =velocity, Q =discharge, t =time, respectively, and the subscript r represents the ratio.

Table 1 Ratios of physical quantities

L_r	$1/8$
$n_r = L_r^{-1/2} H_r^{2/3}$	1
H_r	$1/8^{3/4}$
$V_r = H_r^{1/2}$	$1/8^{3/8}$
$Q_r = L_r H_r^{3/2}$	$1/8^{17/8}$
$t_r = L_r H_r^{-1/2}$	$1/8^{5/8}$

4. CONSTRUCTION OF THE DISTORTED MODEL

Construction works in the hydraulic experimental station were performed during the period from July to September 2014. A reservoir made of piled sand bags was created at the upstream end of the model, instead of the catchment basin of the prototype. As the basement of the distorted model, recycled concrete of 0-40 mm was embanked and well compacted until the designed ground surface elevations were achieved along the shape of the structure. Then, bricks were aligned and fixed with mortar to make the sidewalls of the gutter and the conveyance channel. Finally concrete was filled in the channel bed and finished with trowel.

5. HYDRAULIC MODEL TESTS

Hydraulic model tests were conducted in September 2014. The upstream reservoir was initially filled with water which was pumped up from a freshwater reservoir and the sea. There were three different pumps available, whose nominal discharges and types were 80 L/min submersible, 290 L/min submersible, and 540 L/min engine, respectively. The overflowing water was led from the gutter to the conveyance channel, realizing a steady state within few minutes for each fixed discharge. Measurements were conducted for the seven different discharges as the all possible combinations of the three pumps: 80 L/min, 290 L/min, 370 L/min, 540 L/min, 620 L/min, 830 L/min, and 910 L/min. The measurement points include P0 at the center of the gutter and S1-S5 along the conveyance channel, as shown in **Fig. 2**, where L, C and R represent the left side, the center, and the right side, respectively. Water depths were measured by a point gauge at 16 points, which were P0 and S1L/C/R-S5 L/C/R. The travelling time of tracer dye from S2 to S4 was measured for larger discharges (540 L/min, 620 L/min, 830 L/min, and 910 L/min).

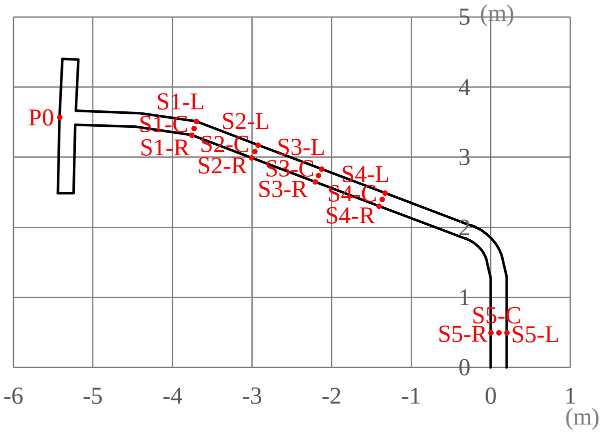

Fig. 2 Measurement points

6. RESULTS

Table 2 shows measured channel bed levels (BL), water depths (WD), and water surface levels (WSL) for the larger discharges (540 L/min, 620 L/min, 830 L/min, and 910 L/min). The cross-sectional average velocities in the reach between S2 and S4 were calculated as shown in **Table 3**, implying that the actual discharges Q_m in the model and the corresponding discharges Q_p in the prototype were as in **Table 4**. The maximum discharge 0.74 m^3/s in the prototype is large enough to reproduce common floods at the site. The values of Manning's roughness coefficient were identified from the measured water depths and the cross-sectional average velocities, as shown in **Table 5**. These results are in good accordance with the literature, which asserts that the value ranges between 0.014 and 0.016 $s{\cdot}m^{-1/3}$ in concrete channels$^{2)}$. Oblique hydraulic jumps occurred along the conveyance channel in the model, exhibiting particular cross-wave pattern in the spillway bend.

Table 2 BL, WD, and WSL in the model (cm)

		910		830		620		540(L/min)	
	BL	**WD**	**WSL**	**WD**	**WSL**	**WD**	**WSL**	**WD**	**WSL**
S2-L	11.79	3.68	15.47	3.11	14.90	2.96	14.75	2.85	14.64
S2-C	11.34	4.45	15.79	4.10	15.44	3.96	15.30	3.78	15.12
S2-R	11.62	4.32	15.94	3.68	15.30	3.28	14.90	1.33	12.95
S3-L	9.49	3.91	13.40	3.27	12.76	2.90	12.39	3.20	12.69
S3-C	9.00	4.36	13.36	4.00	13.00	3.87	12.87	3.47	12.47
S3-R	9.40	4.21	13.61	3.53	12.93	3.30	12.70	3.17	12.57
S4-L	7.19	3.76	10.95	2.91	10.10	2.85	10.04	2.79	9.98
S4-C	6.65	4.25	10.90	3.85	10.50	3.73	10.38	3.43	10.08
S4-R	7.18	3.47	10.65	3.03	10.21	2.75	9.93	2.81	9.99

Table 3 Cross-sectional average velocities

	910	**830**	**620**	**540**(L/min)
V (m/s)	1.083	0.969	0.953	0.949

Table 4 Discharges in the model and the prototype

	910	**830**	**620**	**540**(L/min)
Q_m (L/min)	536	421	392	356
Q_p (m^3/s)	0.74	0.58	0.54	0.49

Table 5 Identified values of Manning's roughness coefficient

	910	**830**	**620**	**540**(L/min)
n ($s{\cdot}m^{-1/3}$)	0.0148	0.0158	0.0156	0.0152

7. CONCLUSION

The constructed distorted model is basically consistent with the prototype in terms of the similitude, having an ability to reproduce flows in common floods at the site with the maximum discharge of 0.74 m^3/s. The identified values of Manning's roughness coefficient in the model were in a reasonable range. Therefore, the results of hydraulic model tests are reliable and also useful for understanding complex hydraulic phenomena in the structure which are not sufficiently reproduced in computational models.

REFERENCES

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