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Experimental Investigation of the Effect of Flip Bucket Splitters on Plunge Pool Geometry

Flip buckets are common hydraulic structures aiming at deflecting high velocity flows to a free jet trajectory. Systematic experimental tests have been performed to assess the influence on energy dissipation and the plunge pool geometry of varied repartitions of splitters along the flip bucket width. In particular, it is shown that some configurations can create more erosion than a continuous channel without flip bucket.

1 Introduction

In dams engineering, flip buckets, or ski jumps, are common hydraulic structures aiming at deflecting the high velocity flow from a steep and smooth spillway to a free jet trajectory. Air resistance and air entrainment together with pool diffusion and impact provide flow energy dissipation [1].

In general, flip buckets are designed with horizontal rectangular cross-sections. Theoretical analysis, experimental studies and practical experiences have helped in setting up the vast amount of existing guidelines to calculate the bucket profile, elevations, radius and exit angle. Special bucket shapes are sometimes designed, as laterally inclined or slanting ones, to modify the jet trajectory and its compactness [2], [3]. Splitters can also be placed on the flip bucket to divide the jet and thus to improve the energy dissipation, in order to limit the downstream scouring [2], [4]. However, such non-standard geometries need usually to be designed and validated by experimental modelling and scale models studies.

In order to help in the design of flip buckets with splitters, the experimental studies depicted in this paper aimed at assessing the influence on the plunge pool geometry of the splitters repartition along the flip bucket width.

Systematic experimental tests have been performed on a simplified spillway channel with 10 varied geometries of splitters, whose profile and elevation were kept constant. The geometric configurations varied only by the number of splitters, their width and their repartition on the flip bucket.

The efficiency of the splitters configurations is assessed by an analysis of the geometric characteristics of the stabilized downstream plunge pool, resulting from different steady discharges injected upstream of the channel.

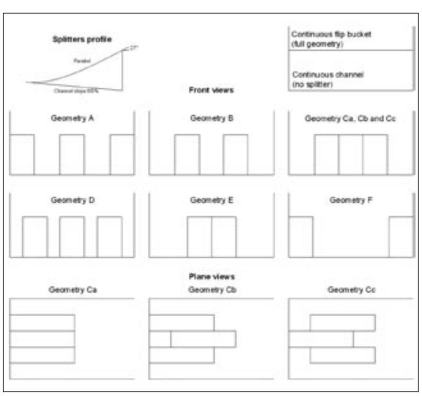

Bild 1: Geometry of the splitters configurations

2 Experimental set up

The experimental installation consists of a 8.6 % slope rectangular smooth channel, 38.4 cm wide and 2.52 m long, located downstream of two 17.1 cm wide and 9.6 cm high Creager weirs on both sides of a 4.2 cm wide pier. Water is injected in an upstream tank and flows over the weirs to produce specific discharges in the channel ranging from 0.052 $m^3/(s \cdot m)$ to 0.156 $m^3/(s \cdot m)$. These values are typical of real smooth spillways ones using a scale factor between 1:60 and 1:100.

14 to 20 mm size gravels with a density of 2,400 kg/m^3 (apparent 1,800 kg/m^3) lie in a downstream 2.4 m wide and 3.5 to 4.3 m long basin, on a depth of approximately 50 cm. The distance between the channel toe and the gravel bed is 6.5 cm. A solid wall 53.5 cm high, working as a thick free weir, contains the gravels downstream of the model and controls the water level in the basin.

Three 12.5 cm high, 7.5 cm wide and 30 cm long splitters with a parabolic profile and a 27° exit angle have been used to model 8 configurations of splitters at the downstream extremity of the channel (**Figure 1**). Tests have also been carried out without splitters and with a continuous flip bucket of same profile as the splitters.

A test consists in injecting the upstream tank with a steady discharge for a period of two hours, which has been found to be enough to reach stable plunge pool geometry. The gravel bar downstream of the plunge pool is removed every 20 min for the first 60 min of the test. Thus, the tests have been carried out at constant water levels for each discharge.

Before and after each test, the plunge pool topography has been measured with a laser distance meter placed on a motorized frame moving automatically in a horizontal plane with a 3 cm step. The covered area is 2.20 m wide and to 3.69 m long and counts for 9,000 elevation measurement points. The laser precision is ± 3 mm. The comparison and analysis of both three dimensional numerical topographies provide most of the characteristics of the plunge pool geometry and location.

3 Results

The results of the 15 erosion tests performed in the scope of this study are summarized in **Table 1**.

The volume is the amount of gravel under the initial level moved by the water during the test. The surface is the area covered by the plunge pool. The “max depth” parameter is the maximum depth of the plunge pool under the initial level of gravels. For tests 9 and 10, the erosion reached the concrete slab under the model and the max depth has thus been limited by the boundary conditions. The length (L) and width (l) are those of the plunge pool surface. They helped in defining the plunge pool shape by the calculation of its aspect ratio L/l. “Max scour location” is the distance between the channel extremity and the point of maximum depth in the plunge pool. The “min impact distance” is the minimum value of the distance between the plunge pool and the downstream extremity of the spillway, i. e. the minimum impact distance of the jet which produces significant erosion.

The splitters geometry A has been tested twice with a 0.0156 m²/s discharge to assess the reproducibility of the tests (tests 2 and 2‘). Considering the measurements precision, the gravel size and the method applied to compute the plunge pool geometric characteristics by comparison of the initial and final digital elevation models of the downstream basin, the max depth uncertainty is 10 mm and the volume uncertainty is about 1 % of the surface. Regarding these values, the tests are found reproducible.

Most of the tests have been realized with the highest 0.156 m²/s discharge in order to maximise the downstream erosion. The influence of the discharge has been analyzed with the continuous flip bucket and the splitters geometry Ca (tests 4 and 10 to 14).

Tab. 1: Main features and results of the experimental tests

Configurations		Flow	Plunge pool characteristics							
Test number	Splitters geometry	Specific discharge	Volume	Surface	Max depth	Length	Width	Shape	Max scour location	Min impact distance
		[m²/s]	[m³]	[m²]	[m]	[m]	[m]	[-]	[m]	[m]
1	No		0,277	1,75	0,376	1,90	1,10	oval	1,16	0,25
2	A		0,322	1,94	0,429	1,90	1,25	oval	1,16	0,25
2′			0,336	1,91	0,430	2,00	1,25	oval	1,27	0,25
3	B		0,217	1,53	0,335	1,85	1,15	oval	0,83	0,25
4	Ca		0,129	1,13	0,294	1,15	1,10	round	0,91	0,25
5	Cb	0,156	0,114	1,08	0,285	1,10	1,15	round	0,86	0,20
6	Cc		0,129	1,25	0,301	1,40	1,10	oval/ round	0,80	0,20
7	D		0,158	1,47	0,295	1,90	0,95	oval	0,83	0,25
8	E		0,184	1,31	0,335	1,30	1,15	round	0,89	0,25
9	F		0,391	2,18	0.472 (*)	1,95	1,50	oval	1,37	0,15
10			0,263	1,85	0.445 (*)	1,85	1,30	rect	1,40	0,40
11	Full	0,104	0,145	1,38	0,333	1,50	1,10	rect	1,16	0,25
12		0,052	0,031	0,55	0,163	0,90	0,60	rect	0,74	0,12
13	Ca	0,104	0,064	0,78	0,222	0,95	0,95	2 ovals	0,74	0,20
14		0,052	0,015	0,40	0,107	0,60	0,70	2 ovals	0,52	0,15

(*) Limitation of the plunge pool erosion as its bottom reached the concrete slab under the model

4 Discussion

The results have been analysed in the purpose of finding the optimal configuration to decrease the plunge pool volume and depth while preserving the spillway toe.

For a constant specific discharge, the lower volumes of erosion and the lower plunge pool surfaces are observed in the configurations with a central position of the splitters (geometries B to E). In this framework, configurations with three splitters (geometries Ca to D) are more efficient than those with two ones (geometries B and E), and contiguous splitters (geometries Ca to Cc) are more efficient than separated ones (geometry D). Both configurations with splitters along the channel banks (geometries A and F) induce significantly higher volumes and surfaces of erosion. The configurations without splitter (test 1) and with a continuous flip bucket (test 10) provide similar volume results, twice higher than the ones of configurations 4 to 6.

These results can be explained by the spreading or concentration of the jet, depending on the splitters repartition along the channel width. With extremity splitters, the tendency is to a jet concentration on the axis of the channel while, with central splitters, the tendency is to a jet spreading with an impact area larger than the channel width (**Figure 2**).

Regarding the depth of erosion, the influence of the position of the splitters is similar to the one on the volume: lower depths are observed for central splitters configurations (geometries B to E) and higher ones for configurations involving side splitters (geometries A and F). Splitters on 3/5 of the channel width (geometries Ca to D) induce lower plunge pool depths than splitters on 2/5 of the channel width (geometries B and E). The configuration with a continuous flip bucket (test 10) induces relatively high scour depth.

The classification of the splitters geometries is different regarding the distance between the beginning of the eroded area and the channel extremity or the location of the maximum erosion depth. The continuous flip bucket (test 10) is far more efficient than all the other geometries to move the plunge pool away from the spillway toe. In general, the splitters configurations inducing the lower volumes of erosion show a plunge pool bottom closer to the spillway toe. Geometries Cb, Cc and F produce erosion very close to the channel extremity and are thus the less efficient.

The analysis of the shape of the plunge pool, together with the location of the maximum scour depth, help in defining the effect of the flip bucket geometry on the jet. In oval plunge pools, with a length significantly higher than the width, erosion occurs along a preferential direction aligned on the channel axis. The jet keeps a preferential action in the channel direction. The oval shape is observed for the configu-

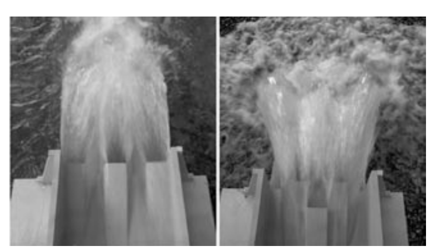

Bild 2: Jet concentration and spreading depending on the splitters repartition of geometry A (left) and Cb (right), specific discharge of 0.156 m²/s

rations with disjointed splitters (geometries A, B, D and F) or without flip bucket.

On the contrary, for round plunge pools, with a length roughly equal to the width, the splitters spread the jet and erosion occurs in all the directions around the impact point. The round shape is observed for the configurations with splitters in central and contiguous position (geometries Ca to Cc and E).

With the full flip bucket, the rectangular plunge pool shape is more circular than oval. The good deviation of the jet provides an impact direction rather vertical and thus erosion upstream and downstream of the impact point, on the whole jet width.

The geometry Ca and the full flip bucket have been tested with two smaller discharges. The results of these tests indicate that the amplitude of the geometric parameters of the plunge pool varies in accordance with the specific discharge in the channel. For smaller discharges, the plunge pool volume, surface and depth decrease, as well as the distance between the eroded area and the spillway toe. The relative efficiency of both tested geometries of the splitters remains also similar for the three discharges.

The analysis of the shape of the plunge pools confirms the lateral spreading of the jet with the use of central contiguous splitters, as two erosion areas are visible from side to side of the channel axis (2 ovals shape – Tests 13 and 14). For the full flip bucket, the shape of the plunge pool is identical whatever the discharge.

5 Conclusions

On the basis of the results of scale model experimental tests, the effect of splitters at the downstream extremity of a spillway channel has been analysed regarding the plunge pool geometry and location for varied specific discharges.

All the tested splitters geometries decrease the minimum impact distance from the spillway toe in comparison with the results of a full flip bucket. However, it is possible to decrease the volume and depth of the plunge pool by replacing the full flip bucket with splitters of same profile, without decreasing prohibitively the minimum impact distance of the jet from the spillway toe.

At constant proportion of the channel width occupied by splitters, it appears to be more favourable to group the splitters on the channel axis in order to decrease the plunge pool volume and depth. Splitters along the channel banks increase the plunge pool volume and depth in comparison with the full flip bucket or a channel without splitters.

These results could be directly transposed to prototype design, despite air entrainment effects are not correctly scaled on the physical model. Indeed, air entrainment should have little influence on the jet concentration or spreading by the splitters, which is the main effect at the basis of the results variation in the tests depicted in this paper.

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Experimentelle Untersuchung der Auswirkungen der Ski-Sprung-Teiler auf die Tosbecken-Geometrie

Ski-Sprünge sind übliche Strukturen in Wasserbau, entworfen um Wasser in eine Freiwurfflugbahn mit hoher Geschwindigkeit zu lenken. Die Splitter sind manchmal auf des Ski-Sprünge installiert um die Energiedissipation zu verbessern und damit des Gefahr des Erosion zu reduzieren. In systematischer Weise wurden experimentelle Untersuchungen durchgeführt, um den Einfluss der Strömungsteiler auf die Geometrie des Tosbeckens zu analysieren. Aufgrund der Tosbecken-Geometrie wurde eine Klassifizierung von verschiedenen Konfigurationen von Strömungsteilern durchgeführt und Empfehlungen für eine effiziente Gestaltung erarbeitet. Insbesondere wird gezeigt, dass bestimmte Strömungsteiler-Geometrien erheblich mehr Erosion produzieren als ein Ski-Sprung ohne Teiler.

Hinweis für die Autoren:

Die Übersetzung ins Russische wird

verlagsseitig vorgenommen!

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