

The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering

Increase Spillway Capacity using Labyrinth Weir

Mamok Suprpto^{a*}

^a*Civil Engineering, Sebelas Maret University, Jl. Ir. Sutami No. 36, Surakarta, Indonesia*

Abstract

Uncertainty in the change of seasons, high-intensity rainfall, floods and droughts in many areas which previously never experienced such disaster, are natural phenomena as a result of climate change. Impact of these phenomena on the reservoir is that water surface rises faster. This situation may endanger the dam. The concept of labyrinth sharp crest spillway (LSCS) has been used in the study to increase capacity without lowering spillway crest. Existing spillway is considered as the Ogee type. Six kinds of LSCS have been used in the research. The experiments were performed in the laboratory by using an open flume. Ogee prototype was made of wood and LSCS was made of acrylic. During the experiment, water was flowed into the flume with varying discharge. At any change of water thickness above spillway, the water discharge was measured. Observation has been done both on the Ogee and LSCS. The experimental results showed that the ability of LSCS in flowing water is greater than Ogee. Water flowed through the LSCS, particularly trapezoid type-1, about 170% more than that of Ogee. Thus, LSCS is considered to be valuable as an alternative spillway in case of dam safety.

© 2013 The Authors. Published by Elsevier Ltd. Open access under [CC BY-NC-ND license](https://creativecommons.org/licenses/by-nc-nd/4.0/).

Selection and peer-review under responsibility of Department of Civil Engineering, Sebelas Maret University

Keywords: spillway capacity; labyrinth weir.

1. Introduction

In the last few decades, the presence of water in nature has been changed. This change is suspected due to the impact of climate change (Sulistyowati 2006; Dunne et al 2008). Climate change is influenced by human activity. These changes increase the variability of climate on long period (Trenberth et al 1995). Implications of climate change have resulted in instability of the atmosphere in the lower layers, especially near

* Corresponding author. Tel.: +62-815-672-3477.

E-mail address: mamok_suprpto@yahoo.com

the surface of the earth (UNDP-Indonesia 2007). Global warming causes climate change, which in turn, increases the frequency and intensity of extreme weather events. This condition triggers significant changes in physical systems and biologics such as, changes in rainfall patterns. Several observations and studies conducted in Australia showed that climate change has changed the pattern of rainfall and resulting in flooding (Deborah Abbs 2011).

Flooding occurred in several regions in Indonesia and the surface water of reservoir was increased faster. Collapse of the Situ Gintung dam is due to an increase in the volume of the reservoir water (Triwidodo 2009). In March of 2010, there has been an increase of the reservoir water of Jatiluhur dam as indicated by an increase of water level to +108.87 meter, beyond the limit of normal point of +107.00 meter (Ismoko Widjaya 2010). This situation is alarming for many risks that may arise.

The flow of water entering the reservoir is uncertain. This is corresponding with the intensity of rainfall. If the rainfall intensity increased significantly, the reservoir water will rise quickly. This condition can cause overtopping and further endanger the dam. A survey conducted by the Corps of Engineers U.S. Army (USACE), which includes more than 80.000 dams, showed that approximately 36% of the existing dam is included in the category of unsafe due to various reasons. However, about 80% of insecurity is due to inadequate spillway. To increase the spillway capacity is often by additional construction of spillway. However, these efforts are often obstructed due to field conditions that do not support such option. In many cases, modification to the existing spillway may be a better alternative. This alternative was chosen because it can utilize the existing spillway and does not reduce volume capacity (Hay and Taylor 1970; Lux 1984; Tullis e al1995)

Increase of the reservoir water level is quite worrying and interested to be examined. Increased spillway capacity without reducing the reservoir volume is an alternative that is selected in this study. Experiment has been observed on Hydro Laboratory, Faculty of Engineering of Sebelas Maret University. The experiments were conducted by comparing the flow of water through Ogee and labyrinth sharp crest spillway (LSCS). The prototype of Ogee spillway was made of wood and LSCS was made of acrylic.

2. Materials And Methods

2.1 Ogee Spillway

In general, dams are equipped with spillway in order to avoid overtopping. Most of dams are using Ogee spillway. Illustration of Ogee spillway is shown in Figure-1.

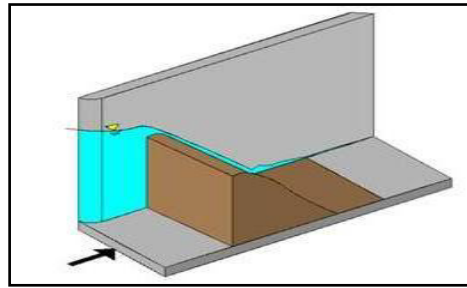


Figure1. Ogee Spillway

2.2. Labyrinth Spillway

Labyrinth weir has a width of water passage greater than Ogee. LSCS can be shaped of series of triangle (saws), series of trapezoid, or series of duck beak. These shapes expected to flow water greater than the Ogee type on the same water thickness above the spillway crest. The advantages of LSCS include:

1. Increase the capacity of the spillway flow. This can prevent abnormal rise of reservoir water level.
2. It can drain a large discharge of water over the spillway with a thinner water layer. This can reduce the rate of increase in the level of water reservoirs.
3. The spillway level is made equal to the level of the previous one, so the reservoir volume did not change.

If the spillway capacity increases, the flood control function would be decreased. However, the increase spillway capacity can reduce the rate of rise of water level, so the dam will be safe from overtopping. Top view and cross sections of LSCS sketches used in the study is shown in Figure 2..

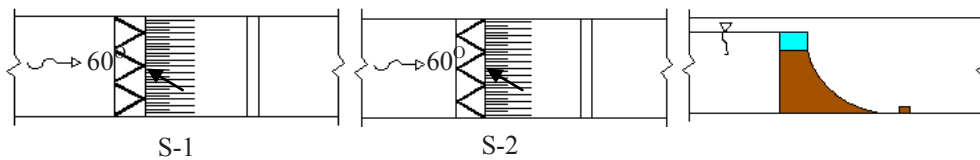


Figure 2a. Saws Type (S)

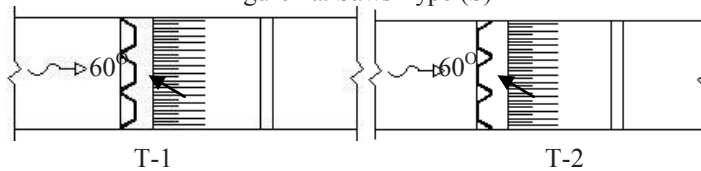


Figure 2b. Trapezoid Type (T)

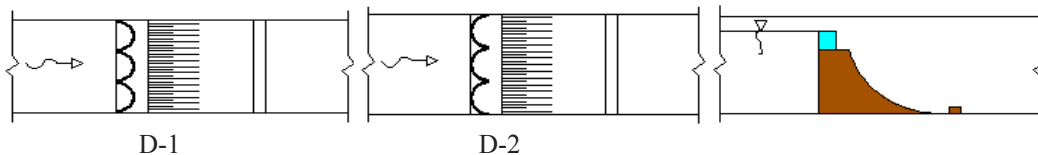


Figure 2c. Duck Beak Type

According (Marcelo, et al, 2009) to estimate the discharge flowing through the spillway can use the classical equations of linear weir crest as follows:

$$Q = \frac{2}{3} C_d \cdot L \cdot h^{1.5} \cdot \sqrt{g} \quad (1)$$

Where: Q=discharge (cm³/dt), Cd= discharge coefficient, g=acceleration of gravity ($\approx 981 \text{ cm/s}^2$), b=width of top point (cm), and h=thickness of water on the tree top (cm).

2.3 Research Tools

Experiments performed at the Laboratory of Hydro, Department of Civil Engineering, Faculty of Engineering, Sebelas Maret University, Surakarta. The main tool used is an open flume made of acrylic with size 30 cm x 30 cm x 180 cm. Sketch of a series of open flume and equipment is shown in Figure 3..

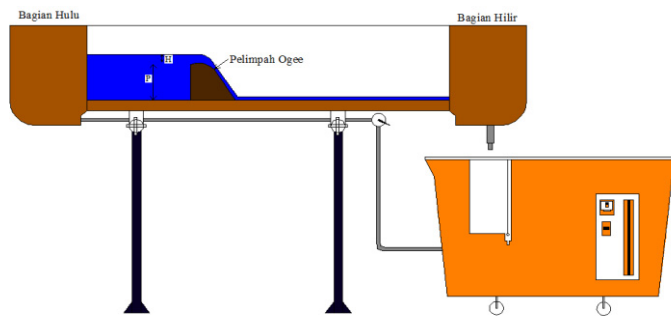


Figure 3. Open Flume

2.4 Research Step

The step of research beginning with the installation of the prototype Ogee type. After observation of the flow for various thicknesses of water on the Ogee is done, then the Ogee consecutive replaced with LSCS.

3. Results and Discussion

Flow observations of all types for various water thickness above spillway during the study, in cm³/s, presented in Table 1. Comparison of discharge of LSCS with that of the Ogee is presented in Table 2.

Table 1. Discharge of all types (cm³/S)

No	H (Cm)	Q _{Ogee}	Q _{T-1}	Q _{T-2}	Q _{S-1}	Q _{S-2}	Q _{D-1}	Q _{D-2}
1	1.00	90.5	123.9	101.3	70.4	56.4	81.3	69.1
2	1.25	172.3	430.7	400.1	154.9	124.6	216.9	184.3
3	1.50	230.9	632.5	612.7	326.0	298.5	400.5	340.4
4	1.75	299.0	811.7	783.7	512.3	473.5	618.6	525.9
5	2.00	430.1	1084.6	975.2	746.3	722.0	930.2	790.7

Table 2. Comparison of discharge in %

No	H (Cm)	Q _S -1	Q _S -2	Q _D -1	Q _D -2
1	1.00	78	62	90	76
2	1.25	90	72	126	107
3	1.50	141	129	173	147
4	1.75	171	158	207	176
5	2.00	174	168	216	184

Numerical values in Table-1 and Table-2 were presented in graphical form as shown in Figure-4 and Figure-5

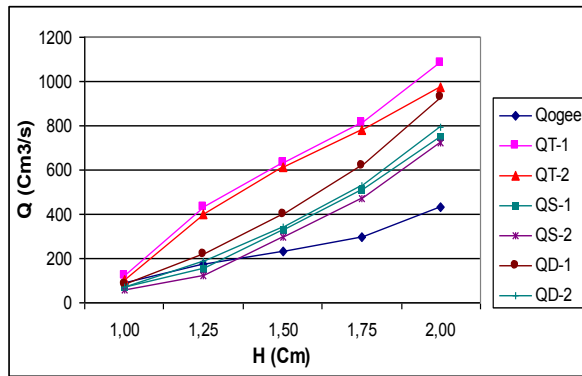


Figure 4. Water Depth vs. Discharge for All Types

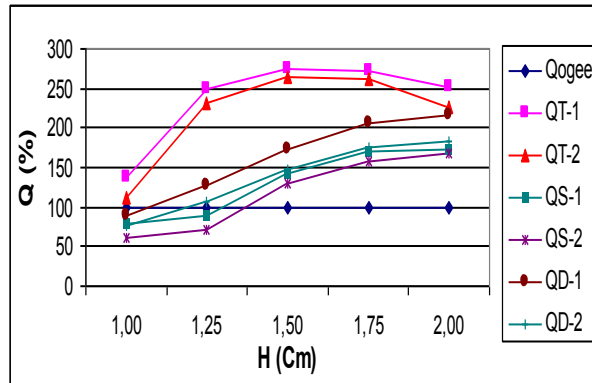


Figure 5. Water Depth vs. % Discharge for All Types

By using Eq. (1) and according to the experiments data, then coefficient of discharge could be calculated. The results for all types are presented in Table 3 and illustrated in Figure 6.

Table 3. Discharge coefficient for all types of spillway

No	H	CD _{Ogee}	Q _T -1	Q _T -2	Q _S -1	Q _S -2	Q _D -1	Q _D -2
1	1.0	0.24	0.20	0.16	0.09	0.08	0.14	0.12
2	1.3	0.33	0.49	0.46	0.15	0.12	0.26	0.22
3	1.5	0.33	0.55	0.53	0.24	0.22	0.37	0.31
4	1.8	0.34	0.56	0.54	0.29	0.27	0.45	0.38
5	2.0	0.40	0.61	0.55	0.35	0.34	0.56	0.47

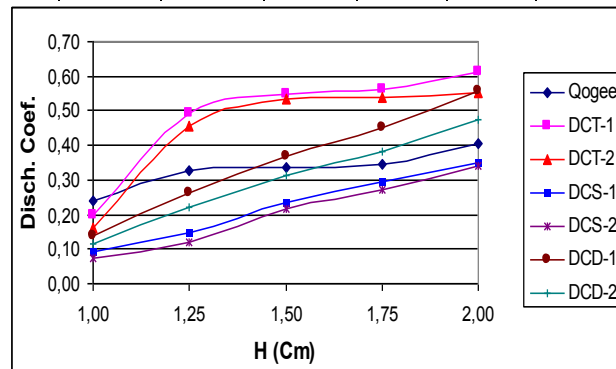


Figure 6. Water Depth vs. Discharge Coefficient for All Types

According to the value in Table 1, it can be seen the differences of discharge for all types of spillway. Minimum discharge of 17.03 cm³/s occurs on Ogee when the water thickness of 0.75 cm and a maximum of 784.31 cm³/s when a thickness of 2.5 cm of water. The range of water thickness is varies from 0.75 cm up to 2.75 cm because the pump capacity available in laboratory is limited.

Among six types of spillway, the smallest increment of discharge at the same water thickness occurs at saws-2 type. It is indicating that saws-2 type not recommended for spillway alternative. Conversely, trapezoid type is the best one, both for type-1or type-2.

The increase in water flow capacity is only a relative value, because at a certain thickness of the discharge water the flow reaches a maximum and will decrease at a certain thickness. This needs to be studied further to find out the other model in order to obtain the best spillway capacity.

4. Conclusion

Based on the analysis conducted in this study, the following conclusions are drawn:

1. It appears that the Ogee type spillway has the smallest capacity, except in the flow thickness of less than 1.50 m. The largest discharge is generated by trapezoid-1 type followed by trapezoid-2 type. Saws type has the smallest capacity among a labyrinth type examined in this study.

2. When the Ogee type spillway is considered as a standard (100%), the largest increase in discharge occur in trapezoid-1 type (max 274% or it is increased by 174%) followed by trapezoidal type-2 (265% or it is increased by 165%), but after the water levels more than 1.5 cm, the percentage decreases. Instead another type of spillway is constantly increasing, although at a thickness of less than 1.5 cm of water, % smaller discharge is resulted by the Ogee type.
3. The coefficient of discharge trapezoid-1 type showed a sharp increase at the beginning of observation until a water thickness of 1.5 cm, and then tend to be flat. In contrast, other types have a tendency spillway discharge coefficient values continue to increase as evidenced by increased thickness of the water in the upstream spillway.

Acknowledgements

Acknowledgements submitted to the Head of Hydro Laboratory, Department of Civil Engineering, Engineering Faculty of Sebelas Maret University that has provided the opportunity for research.

Acknowledgements are also presented to Yuliana Sabilla Widya Iswara, Pertiwi Agusari, and Endah Putri Nurviana who helped this research from start to finish.

References

- Sulistiyowati, 2006, *Dampak Pola Iklim Terhadap Sumberdaya Air Di Indonesia*, Suara Pembaruan, Jakarta.
- Dunne, et al, 2008, *The Impacts of Climate Change on Hydrology in Ireland*, University College, Dublin, Ireland.
- Trenberth, et al, 1995, *The Effects of Climate Change*, Wisconsin University, Madison, U.S.A.
- UNDP-Indonesia, 2007, *Sisi Lain Perubahan Iklim*, Jakarta.
- Deborah Abbs, 2011, *The Effect of Climate Change on the Intensity of Extreme Rainfall Events*, <http://www.bom.gov.au/watl/about-weather-and-climate/risk/>
- Triwidodo, 2009, *Refleksi Bencana di Situ Gantung Bencana di NKRI dan Bencana di dalam Diri*, Semangat Indonesia, Jakarta.
- Ismoko Widjaya, 2010, *Vivanews.com*, 22 Maret 2010
- Hay, N. and Taylor, G., 1970, Performance and Design of Labyrinth Weirs, *Journal of Hydraulic Engineering*, ASCE, 96(11), New York, p.2334-2357.
- Lux, F., 1984, Discharge Characteristics of Labyrinth Weirs, *Proceedings of conference on Water for Resource Development*, Coeur d' Alene, ID, Aug, American Society for Civil Engineers, New York.
- Tullis, J.P., A. Nosratollah and D. Waldron, 1995, Design of Labyrinth Spillways, *Journal of Hydraulic Engineering*, ASCE, 121-3, New York, p.247-255
- Marcelo, et al, 2009, *Hidraulic Capacity Improvement of Existing Spillway Design of Piano Key Weirs*, commission internationale Des Grands Barrages, Brasilia