Comparison of lateral spillway and morning glory spillway performance in flood control

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Abstract: With the emergence of climate change and the increasing human intervention in the global climate, floods have affected different parts of the world. In practice, floods are the most terrible natural disaster in the world, both in terms of casualties and financial losses. To reduce the adverse effects of this phenomenon, it is necessary to use structural and non-structural methods of flood risk management. One of the structural methods of flood control is to allocate a certain part of reservoir dams to flood control. In order to safely exit the flood from the dam reservoir, the spillway structure should be used. One of the important issues in

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designing a spillway structure is reducing its construction costs. In order to safely exit the flood with a specified return period from the dam reservoir, as the length of the spillway decreases, the height of the water blade on the spillway increases. In other words, decreasing the spillway length increases the height of the dam and its construction and design costs. In this study, the design and comparison of the performance of two glory spillways and lateral spillways have been considered. The results showed that for a given length for the drain edge of both types of spillways, the height of the water blade on the glory spillway is always higher than the lateral spillway.

Keywords: flood risk management, lateral spillway, glory spillway, spillway design

1. INTRODUCTION

The phenomenon of climate change in many parts of the world is manifested in the form of a sharp decrease in precipitation and in some other regions in the form of destructive and threatening floods [MOUSA 2018].

Such climate change, along with population growth, will pose serious challenges to water, food, and environmental security worldwide [PAHL-WOSTL 2019]. Obviously, without a thorough and expert study of the destructive effects of this phenomenon, irreparable consequences will occur [PIELKE, DOWNTON 2000].

Flood is, in fact, an increase in the height of the river water and the channel and the water coming out of it and occupying part of the plains along the river [ALEXANDER *et al*. 2018]. It can cause damage to buildings and public facilities by flooding the area and cause human and livestock losses [MARVI 2020]. Flood occurs when the soil and plants cannot absorb rainfall, and as a result, the river's natural channel does not have the traction of the runoff [MKILIMA 2018].

Structural and non-structural methods are used for flood protection [CHAN *et al*. 2019]. Structural methods of flood management are a subset of flood management that includes the structure's role and operation [YE *et al*. 2020]. Many of these methods have a history of several thousand years. Structural methods of flood control include reservoir dams, flood dams, delay tanks, route improvement, and flood diversion [ANGELAKIS *et al*. 2020]. The advantage of a reservoir dam is the storage of a large volume of the flood and its gradual discharge, but their construction cost is higher [ALLAWI *et al*. 2018]. But delayed dams have a quick effect on flood control.

Building dams can prevent flood damage; therefore, sufficient studies should be done in this field, and proper planning should prevent the loss of life and property. In addition to the loss of life, the destruction of residential houses, as well as the antiquities of cities, are among the damages caused by severe floods [BALASBANEH *et al*. 2019]. Reconstruction and repair of cities after the flood require a very high cost (many of them are irreparable) that is not comparable to the budget needed to build the dams. Therefore, it is better to avoid spending a lot of money on reconstruction by spending money on the construction of principled dams. In fact, the cost of building dams is an investment in this area.

Reservoir dams are often multi-purpose and are used for purposes such as irrigation, drinking water supply, electricity generation, flood control, and recreational purposes [MEIßNER *et al*. 2018]. The purpose of a flood control tank is to store part of the flood flow in order to reduce its maximum discharge. If river floods have seasonal characteristics, the efficiency of multi-purpose tanks to reduce flood peaks is significantly increased. Ideally, the reservoir is located just above the protected area, and its operation is done in order to reduce the maximum flood to the downstream safe passage capacity. The stored flood is released gradually depending on the time of its occurrence, or if the end of the flood season is near, it will be saved for irrigation and electricity generation. If there is a middle area after the dam and the protected area, the purpose of flood management of the reservoir will be to minimise flooding in the protected area that. In this case, floods at the dam site will not necessarily be minimal. If river floods have seasonal characteristics, the efficiency of multi-purpose tanks to reduce flood peaks is significantly increased.

These flow control structures (reservoir dams) are designed to protect areas with floods with a certain return period [AHMAD, SIMONOVIC 2000]. By studying past floods and using statistical science, engineers estimate the probability of floods with different dimensions [MASINA *et al*. 2015]. The level of safety provided by dams is determined based on economic considerations, the inclinations of the respective communities, environmental impacts, and other factors. Engineers can design structures to ensure a high level of safety [TITOVA *et al*. 2017]. Communities usually choose a lower level of safety. This is due to the considerable initial cost. To pass excess water from upstream to downstream of dams, a structure called a spillway is used. Dam spillway is one of the key members of the dam, and the failure of many dams has been attributed to the inadequacy of their spillway. Dam safety is directly and closely related to spillway capacity adequacy. Most of the dam failure occurs due to the passage of water over their canopy. The safe operation of spillways under abnormal conditions is an important factor in the safety of dams. According to reports published by the International Conference on Large Dams (ICOLD), about 0.33 dam failures stem from spillway inadequacy. As a result, due to the sensitivity of the operation, the spillway must be selected as a strong, reliable, and high-efficiency structure that can be ready for operation at any time. In general,

Commented [A5]: Kindly add reference's citation and include it into references' list flood selection is the basis of reservoir dam spillway design, and their design criteria are one of the most important issues in dam construction and play a major role in reducing the risk of flooding of cities or lands upstream of reservoir dams. In short, dam spillways can be classified according to these cases: 1) to have or not to have a valve, 2) build it inside the dam or outside it. Spillways that are usually made outside the dam body are: 1) anterior spillway (straight), 2) lateral spillway, 3) glory spillway, 4) siphon spillway, 5) stair spillway.

One of the main components of the glory spillway and the lateral spillway is the edge of the overflow. By increasing the length of the edge of the overflows, flood control is easier and more floods can be controlled. However, it should be noted that this increase in length can increase the cost of spillway construction. On the other hand, for a given flood, the smaller length of the overflow edge, the height of the water blade increases on the edge of the overflow drain. This increase will be accompanied by an increase in the volume of control of the dam and an increase in the construction costs of the dam. Therefore, the main purpose of this study is to compare the performance of two glory spillways and lateral spillways for different overflow edge lengths. In addition, the performance of these spillways underflows with different return periods will be examined. The results of this study can help reservoir dam designers in selecting the appropriate spillway.

2. MATERIALS AND METHODS

2.1. STUDY AREA AND DATA

This study compares the design of the Bili-Bili dam spillway (located in Indonesia) is considered for different lengths of the overflow. The normal level of the dam is 1315 m. According to studies, the maximum flood discharge with a return period of 10,000 years, 1000 years, and is 2500, 1300, and 700 $m^3 \cdot s^{-1}$, respectively.

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2.2. GLORY SPILLWAY

The glory spillway was introduced in 1930 and proved to be economical, provided that the diversion tunnel can be used as the horizontal channel of this spillway [ALFATLAWI, ALSHAIKHLI 2015]. For narrow sections and rocky riverbeds, tunnels are usually used to divert river water. After the construction of the dam, the water diversion tunnel will be completely closed or connects to the spillway to transmit floods. In the glory spillway, the continuation of the inlet crown profile may be circular or part of a circle.

The structure of this dam spillway consists of three main parts, which are: 1) reservoir, 2) a vertical duct with a 90-degree elbow, and 3) an almost horizontal tunnel. To have atmospheric pressure along the entire length of the spillway, in order to prevent cavitation damage, the air is supplied through the aeration duct at the conversion point between the vertical duct and the horizontal tunnel. It is also necessary to have a non-submersible (free) flow in the spillway to be safe during floods. There is free surface flow in all parts of the spillway from the reservoir to the energy dissipating structure. Therefore, the hydraulic capacity of the vertical duct and the horizontal tunnel is more than the capacity of the catchment structure.

Glory spillway is commonly used for dams with low to medium design discharges (with a maximum value of about 1000 $m^3 \cdot s^{-1}$) [SHIRALI *et al*. 2017]. Use this spillway is recommended in a situation where the probability of an earthquake is low. The horizontal spillway can be connected to an existing diversion duct, or the amount of floating material is not significant, there is also no space to build a direct spillway and geological conditions are suitable in terms of structural leakage. A short diversion can be provided [KAMANBEDAST *et al*. 2014]. Such a structure is prone to creating rotational currents at its inlet, which should be prevented by choosing a suitable position for the horizontal duct, in accordance with the topography of the reservoir and the axis of the dam. Because of its resemblance to a glory flower, which is in the shape of a cup, this type of spillway is also called a glory spillway. Photo. 1 shows the various components of a glory spillway as a flood pass.

Photo 1. The various components of a glory spillway as a flood pass (phot.: *X. Photo's Author*)

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The relations used to route the flood with a certain return period from the glory spillway are as follows:

$$Q_a = 0.552 \cdot C_{0a} \cdot L_a \cdot H_{0a}^{\frac{3}{2}} \quad (1)$$

$$L_a = 2\pi R_s \quad (2)$$

where: C_{0a} = spillway discharge coefficient when flowing maximum through the overflow edge of the spillway, L_a = overflow edge length, $H0_a$ = the height of the water blade on the edge of the overflow drain, Q_a = maximum discharge overflow edge, R_s = glory spillway radius.

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As you can see in Equation (1), C_{0a} is required to calculate the maximum discharge rate. Figure 1 shows the diagrams needed to determine the value of C_{0a}.

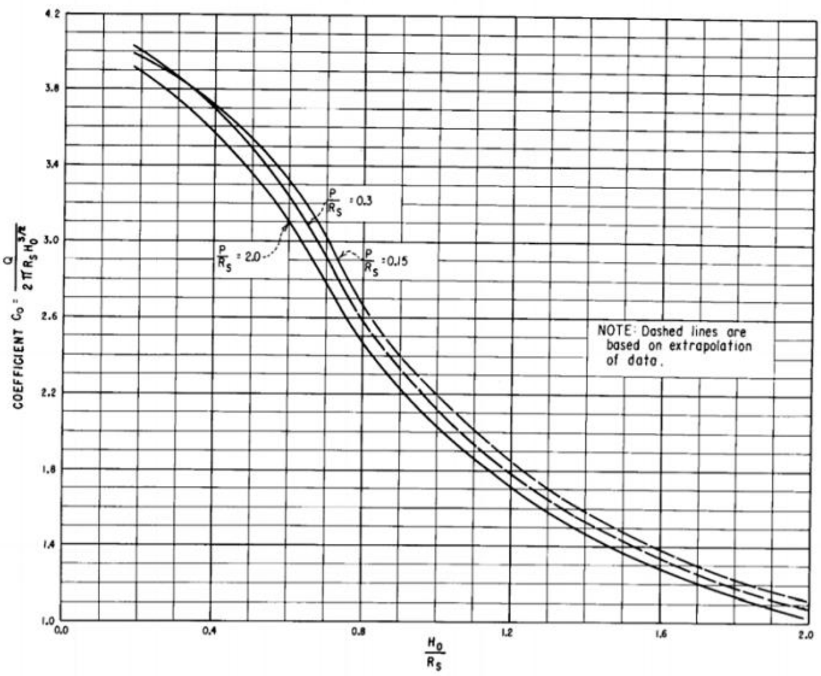

Fig. 1. Relationship of circular crest coefficient c_{0a} to H_{0a}/R_s for different approach depths; Q = discharge, R_s = glory spillway radius, H_0 = the height of the water blade on the edge of the overflow drain, P = the height of the upstream outcrop; source: own elaboration???

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2.3. LATERAL SPILLWAY

The lateral spillway is a common structure used to spillway a stream [MONAZAMI 2016]. The axis of the lateral channel consists of a direct spillway and a duct whose axis is parallel to the crown of the spillway, while the downstream channel axis is a standard spillway perpendicular to the spillway crown. The lateral spillway is made separately from the dam structure, and the discharge passing through it is passed through the downstream valley to the downstream. In contrast, a direct spillway is usually installed in the dam structure. The lateral spillway was successfully used in the Hoover Dam in the United States in the late 1930s. Using this spillway is convenient in areas where direct spillway is not practical, such as earthen dams, or when another position next to the dam makes better and easier communication with the relaxation area. If the length of the spillway canopy perpendicular to the river axis does not correspond to flood transmission, a lateral spillway may be used. The specific discharge of this spillway with a crown length of more than 100 m is usually limited to 10 $m^3 \cdot s^{-1}$.

The lateral dam spillway may join the downstream river through a water transfer tunnel or rapid water. So far, many lateral spillways have been made in the world. It should be noted that this type of spillway is suitable for low and medium discharges. Also, this type of spillway is used in areas where the valley is narrow, and there is no suitable width to build a direct spillway. Problems such as forces due to water impact to the bed and as a result there is a lot of scours in arched dams and topographic conditions are suitable for the lateral spillway. It is not possible to build a spillway on the dam body, like an earthen dam. Also, lateral spillways are usually not made with valves, and when adjusting the tank alignment, a cylindrical valve is often the best choice. The cross-sectional area of the lateral canals is considered rectangular or trapezoidal to reduce the cost of drilling in large dams [TULTS 1956]. Photo 2 shows the different components of a lateral spillway.

Photo 2. The different components of a lateral spillway (phot.: *X. Photo's Author*)

The relationships used to route floods with a definite return period from the glory spillway are as follows:

$$Q_d = 0.552 \cdot C_{0d} \cdot L_d \cdot H_{0d}^{\frac{3}{2}} \quad (3)$$

where: C_{0d} = spillway discharge coefficient when flowing maximum through the overflow edge of the spillway, L_d = overflow edge length, H_{0d} = the height of the water blade on the edge of the overflow drain, Q_d = is maximum discharge overflow edge of the lateral spillway.

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Exactly according to the argument presented in the previous section, in order to calculate the maximum discharge through the lateral spillway, the value of C_{0d} is required.

Figure 2 shows the diagrams needed to calculate C_{0d}.

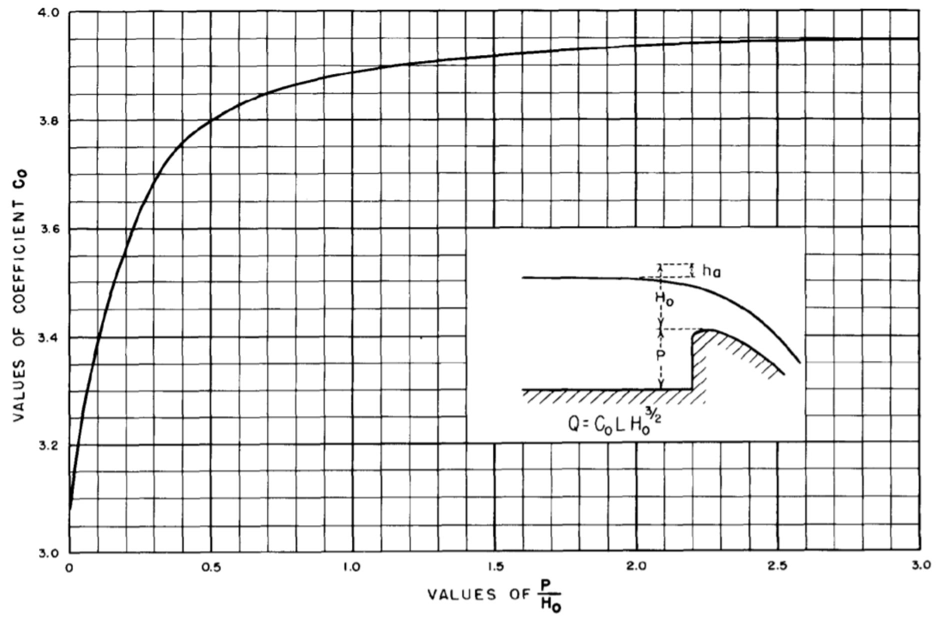

Fig. 2. Discharge coefficients for vertical-faced ogee crest; source: own elaboration??

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3. RESULTS AND DISCUSSION

The purpose of this section is to evaluate and compare the performance of lateral and glory spillways for the length of specific overflow edges during floods with different return periods. As previously mentioned, according to studies, the maximum flood discharge with a return period of 10,000 years, 1000 years, and 100 years are 2500, 1300, and 700 $m^3 \cdot s^{-1}$, respectively. Also, the height of the upstream outcrop of both spillways is 4 m. Given the available information, Equations (1)–(3) have been calculated as Tables 1–3 to determine the outflow from the lateral spillway and the glory spillway for the length of the different overflow edges.

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Table 1. Results of 10,000-year-old flood routing for a lateral spillway and a glory spillway

Lateral spillway			Glory spillway			
L_d (m)	H_{0d} (m)	Q_d ($m^3 \cdot s^{-1}$)	L_a (m)	R_s (m)	H_{0a} (m)	Q_a ($m^3 \cdot s^{-1}$)
50	8.31	2500	50	7.96	16.84	2500
60	7.31	2500	60	9.55	13.34	2500

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70	6.57	2500	70	11.15	7.92	2500
80	6.00	2500	80	12.74	6.46	2500

Source: own study.

Table 2. Results of 1000-year-old flood routing for a lateral spillway and a glory spillway

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Lateral spillway			**Glory spillway**			
L_d(m)	H_{0d}(m)	Q_d ($^{m^s}/_s$)	L_a(m)	R_s(m)	H_{0a}(m)	Q_a ($^{m^s}/_s$)
50	5.30	1300	50	7.96	7.45	1300
60	4.69	1300	60	9.55	5.11	1300
70	4.22	1300	70	11.15	4.36	1300
80	3.85	1300	80	12.74	3.88	1300

Table 1. Results of different year-old flood routing for a lateral spillway and a glory spillway

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Lateral spillway		**Glory spillway**		
10,000-year-old flood routing, Q_d = 2500 $m^3 \cdot s^{-1}$				
L_d (m)	H_{0d} (m)	L_a (m)	R_s (m)	H_{0a} (m)
50	8.31	50	7.96	16.84
60	7.31	60	9.55	13.34
70	6.57	70	11.15	7.92
80	6.00	80	12.74	6.46
1000-year-old flood routing, Q_d = 1300 $m^3 \cdot s^{-1}$				
50	5.30	50	7.96	7.45
60	4.69	60	9.55	5.11
70	4.22	70	11.15	4.36
80	3.85	80	12.74	3.88
100-year flood routing, Q_d = 700 $m^3 \cdot s^{-1}$				
50	3.48	50	7.96	3.68
60	3.08	60	9.55	3.14
70	2.77	70	11.15	2.77
80	2.54	80	12.74	2.52

Source: own study.

As you can see in Tables 1–3, for both glory spillway and lateral spillway, as the return flood design period increases, the height of the water blade on the overflow edge of the spillway also increases. It also seems that for both types of spillways, the slope of water blade height changes increases with increasing design flood return period (Fig. 3). According to Figure 3,

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which shows a better representation of the values in Tables 1 to 3, the height of the water blade on the edge of the glory spillway is always higher than the lateral spillway. However, it seems that with increasing design discharge (increasing flood return period), the performance of both glory and lateral spillways becomes closer to each other [FATTOR, BACCHIEGA 2009].

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Table 3. Results of 100-year flood routing for a glory spillway and a lateral spillway

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lateral spillway			glory spillway			
L_d(m)	H_{0d}(m)	Q_d ($^{m^s}/_s$)	L_a(m)	R_s(m)	H_{0a}(m)	Q_a ($^{m^s}/_s$)
50	3.48	700	50	7.96	3.68	700
60	3.08	700	60	9.55	3.14	700
70	2.77	700	70	11.15	2.77	700
80	2.54	700	80	12.74	2.52	700

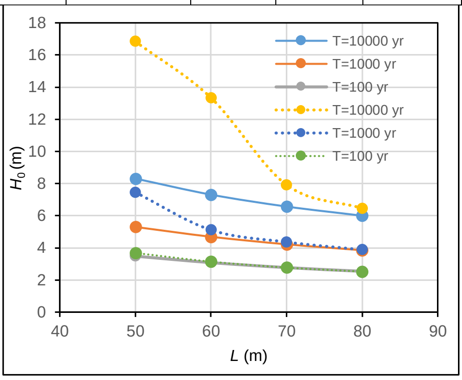

Fig. 3. Design results for lateral spillway (solid lines) and glory spillway (dotted lines); source: own study

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4. CONCLUSIONS

Floods are one of the most important and destructive natural phenomena and hazards in the world, which is the most destructive one among all accidents and natural disasters. Therefore, flood management is one of the most important measures in any region. Flood protection measures are divided into two categories: structural and non-structural. One of the methods of flood management and control structures is the use of reservoir dams (flood storage in the reservoir and reduction of flood peak). In order to prevent the destruction of the dam against floods, a spillway drainage structure is always needed. Glory spillway and lateral spillway are two different types of spillways used in reservoir dams. The purpose of this study is to compare the performance of these two spillways. The results showed that for a given length for the overflow edge of both types of spillways, the height of the water blade on the glory spillway is always higher than the lateral spillway. Also, the slope of water blade height changes increases with increasing flood return period. This means that when designing spillways for longer return periods, the cost of constructing a regular dam with an increasing slope can increase. This study's results can help designers analyse the performance of two types of lateral spillway and glory spillway.

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