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Discharge Structure, Flood Discharge Sluice Gate and Floating Debris Sluice Design for the Mekin Hydropower Project

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ABSTRACT

This work shows the results obtained from the design of the discharge structure, the flood discharge sluice gate and floating debris sluice for the mekin hydropower project. To begin, the basic design data which includes the type and grade of discharge structure, the flood standard, the characteristic water level and the discharge rate are determined. The work continues with the presentation of the exact location, and the structural composition. The hydraulic calculations which are the flow rate calculation and the energy dissipation calculation are also presented.

INTRODUCTION

The Mekin hydroelectric dam situated in the south region of Cameroon located after the confluence of the rivers Dja, lobo and Sabe, is constructed to produce 15MW. The retaining structure is constituted by the main and the auxiliary dam and also includes a discharge structure, a flood discharge sluice gate and a floating debris sluice.

The majority of dam safety deficiencies identified in the world in recent years consist of inadequate spillway capacity for passage of new design floods up to the probable maximum flood (PMF) [1]. The passage of large floods through undersized spillways can result in overtopping failure of the dam, with potential loss of life and significant downstream damages. Hydrologic studies and assessments of both the threat to life and potential economic losses are used to establish the design flood. Safe passage of the design flood may require increased spillway capacity, increased reservoir storage, overtopping protection or some combination of these approaches [3].

Increased spillway capacity is achieved by increasing the spillway crest length, the discharge coefficient or the operating head. The operating head for a given spillway can be increased by lowering the spillway crest and installing gates, or by raising the dam crest to permit higher reservoir levels. A modest increase in the discharge coefficient can generally be realized by refinements to the spillway crest shape and by channel improvements. A more common modification, however, is enlargement of the existing spillway or construction of a new spillway to increase the total spillway crest length [2,5].

The type of the spillway selected for design is primarily dependent upon site conditions and release requirements. The dam abutments may be suitable for enlargement of the existing spillway or construction of a new spillway. An existing saddle or depression along the reservoir rim leading to a natural waterway may be an ideal site for a new auxiliary-type spillway [4]. The dam may be considered to provide a foundation for a new spillway or for overtopping protection. Gated spillway may be considered where their operation can be ensured through onsite attendance and proper maintenance, although uncontrolled crests are often seen as being more economical and reliable. Energy dissipation of spillway releases entering the downstream waterway may be provided by a roller buckets or hydraulic-jump structure, or by a plunge pool bellow an elevated flip structure. For lower heads, the energy dissipation may be provided within the chute itself by the use of concrete baffle blocks or concrete steps [6].

The design of these structural elements presents a major challenge for African engineers and experts notably due to lack of documentation and sometimes experience.

This work seeks to propose a simplified methodology base on international standards and a case study. It presents concrete results which are being implemented on the construction site of the dam.

In this work, the basic design data necessary for the studies are presented. In this light, the type and grade of discharge structure, the flood standard, the characteristic water level and the discharge rate are determined. The discussion of the discharge structures follows with the specification of its location, and arrangement of structures. Finally the hydraulic calculations which are the flow rate calculation and the energy dissipation calculation are discussed in detail.

Basic Design Information

Type and Grade of Discharge Structure

Flood discharge sluice gate and floating debris sluice:	Grade 2
Discharge type:	Bottom hole
Energy dissipation type:	Energy dissipation by base flow

Flood Standard, Characteristic Water Level and Discharge Rate

According to flood control principle, open type overfall dam is first used for flood discharge, when the water level is over 612.50 m; the flood discharge sluicing gate is used for joint discharge.

The design flood level of the reservoir is 613.45 m, corresponding discharge rate is 796.40 m^3/s, and check flood level is 613.80 m, corresponding discharge rate is 901.10 m^3/s.

Table 1: Characteristic water level of reservoir and characteristic discharge rate of flood discharge sluice gate and floating debris sluice

Operation state	Flood standard (year)	Upstream water level (m)	Downstream water level (m)	Discharge rate (m^3/s)
Check flood level	2000	613.80	609.45	361.80
Design flood level	100	613.45	608.20	318.05
Normal high water level	-	612.00	603.35	-

Arrangement of Structure

The flood discharge sluice gate and floating debris sluice are situated on the bottomland on the right side of Dja River. It is coaxial with the main dam. It is connected to the power station on the right side and the overfall dam at the left side. The total length of the flood discharge sluicing gate is 24.00 m. See table 2 for parameters of control points.

Table 2: Parameters of control points of sluice

Position	Stake No.	Coordinate x	y
Left side of gate	Main Sta0+135.000	360372.6560	46923.6480
Right side of gate	Main Sta0+159.000	360393.0720	46911.0305

The flood discharging sluicing gate is of reinforced concrete structure, the total width is 24.00 m, the longitudinal length is 12.00 it has two 6.00 m X6.00 m (HxW) flood discharge sluicing bottom holes and one 6.00 m X6.00 m (HxW) floating debris sluicing upper outlet. Each hole is equipped with corresponding working gate and bulkhead gate, and 0.75 m-thick parapet is provided above each bottom gate to retain water.

The gate chamber is divided into three spans, each span is 8.00 m, each side piers are 1.00 m thick and each middle piers are 2.00 m thick, the elevation of the top of gate chamber baseboard is 598.00 m, the baseboard is 2.00 m thick, a 1.00 m-thick cut-off wall is provided at upstream and downstream of the baseboard respectively, 13.00 m reinforced concrete anti-washing apron is provided downstream, which is 0.30 m thick. The elevation of the bottom hole top (elevation of parapet bottom) is 604.00 m, and the elevation of the upper outlet bottom is 607.80, the elevation of the gate chamber roof is the same as that of the main dam crest, which is 615.20 m the working gate and the bulkhead gate are opened and closed whit the two-way gate lifting device, which is commonly for the bulkhead of the power station and the trash rack. Bulkhead gate storeroom is arranged on the right side of the power station.

Hydraulic calculation

Flow Rate Calculation

The flood discharge sluicing gate is also used as stream guidance structure during the construction period of the overfall dam. The scale is limited by flood stream by flood stream guidance during the construction period.

During construction dry season, Dja first order bottomland (604.00 m) must not be submerged by flood. The flood in flood season is restricted near the first order bottomland. Therefore the gate opening top elevation is 604.00 m.

The gate opening overflow capacity is calculated with the following formula [7,9]:

$$Q = \sigma \varepsilon m B \sqrt{2g H_0^{3/2}} \qquad Eq1$$

$$\varepsilon = \frac{\varepsilon_z (N-1) + \varepsilon_b}{N} \qquad Eq2$$

$$\varepsilon_z = 1 - 0.171\left(1 - \frac{b_0}{b_0 + d_z}\right)\sqrt[4]{\frac{b_0}{b_0 + d_z}} \qquad Eq3$$

$$\varepsilon_b = 1 - 0.171\left(1 - \frac{b_0}{b_0 + \frac{d_z}{2} + b_b}\right)\sqrt[4]{\frac{b_0}{b_0 + \frac{d_z}{2} + b_b}} \qquad Eq4$$

$$\sigma = 2.31\frac{h_s}{H_0}\left(1 - \frac{h_s}{H_0}\right)^{0.4} \qquad Eq5$$

Where:

$Q - Flow\ rate, m^3/s$;
$B - Total\ net\ width\ of\ gate\ opening, m$;
$H_0 - Weir\ head\ included\ with\ velocity\ head, m$;
$g - Gravity\ acceleration, m/s^2$;
$m - Flow\ rate\ coefficient\ of\ weir\ flow, 0.385$;
$\varepsilon - Side\ contraction\ coefficient\ of\ weir\ flow$;
$b_0 - Net\ width\ of\ gate\ opening, m$;
$N - Number\ of\ gate\ openings$;
$\varepsilon_z - Side\ contraction\ coefficient\ of\ middle\ gate\ opening$;
$d_z - Thickness\ of\ middle\ gate\ pier, m$;
$\varepsilon_b - Side\ contraction\ coefficient\ of\ side\ gate\ opening$;
$\varepsilon_z - Distance\ from\ side\ gate\ pier\ downstream\ edge\ to\ water\ edge\ of\ upstream\ riverway, m$;
$\sigma - Submerge\ coefficient$;
$b_b - Downstream\ water\ depth\ from\ weir\ crest, m$;

See table 3 for calculated discharge capacity curve of the flood discharge sluicing gate.

Table 3: Stream guidance and discharge capacity curve of the flood discharge sluicing gate

Reservoir water level (m)	600.00	600.50	601.00	601.5	602.00	602.50
Discharge rate (m³/s)	0.00	10.85	30.70	56.40	86.85	121.35
Reservoir water level (m)	603.00	603.50	604.00	604.50	604.80(P=5%)	605.00
Discharge rate (m³/s)	159.50	172.70	242.00	292.30	301.00	333.80

Through calculation, the three gate openings, each opening is 6.00 m wide, can meet the standard requirement for stream guidance of 20-year flood.

The flood discharge sluicing gate is only opened when the overfall dam cannot meet flood discharge requirement. Therefore, the overflow capacity of discharge through gate opening is calculated according to the flow rate of the opening.

The discharge capacity of gate opening is calculated according with this formula [8,9]:

$$Q = \sigma' \mu h_s B \sqrt{2gH_0} \qquad Eq6$$

$$\mu = \varphi \varepsilon' \sqrt{1 - \frac{\varepsilon' h_e}{H}} \qquad Eq7$$

$$\varepsilon = \frac{1}{1 + \sqrt{\lambda\left[1 - \left(\frac{h_e}{H}\right)^2\right]}} \qquad Eq8$$

$$\lambda = \frac{0.4}{2.718^{lg\frac{r}{h_e}}} \qquad Eq9$$

Where:

Q – Flow rate, m^3/s ;
h_e – Height of gate opening, m ;
μ – Coefficient of opening flow rate ;
φ – Coefficient of opening flow velocity ;
ε – Vertical contraction coefficient of sluice flow ;
λ – Calculation coefficient ;
r – Parapet bottom circle arc radius ;
H_0 – *Acting head at opening center in case of free discharge, water level difference between upstream and downstream in case of submergence discharge, m;*
g – Gravity acceleration

Table 4: Flood discharge and drainage capacity curve of flood discharge sluicing gate (single opening)

Reservoir water level (m)	612.00	612.50	613.00	613.45	613.50	613.80	614.00
Flood discharge	255.30	260.90	266.40	271.25	271.75	274.95	277.05
Floating debris	78.25	92.60	107.80	122.05	123.70	133.60	140.30

Energy dissipation calculation

Hydraulic jump parameters are calculated with the following equation [9]:

$$h_c^3 - T_0 h_c^2 + \frac{\alpha q^2}{2g\varphi^2} = 0 \qquad Eq10$$

$$h_c'' = \frac{h_c}{2}\left(\sqrt{1 - \frac{8\alpha q^2}{g h_c^3}} - 1\right)\left(\frac{b_1}{b_2}\right)^{0.25} \qquad Eq11$$

Where:

h_c – Contracted depth, m ;
h_c'' – After jump depth, m ;
α – Kinetic energy correction coefficient of water flow, 1.0 ;
q – Total potential energy from top surface of stilling pool floor, m;
φ – Coefficient of opening flow velocity ;
T_0 – Coefficient of flow velocity, 0.95 ;
b_1 – Head end width of stilling pool, m ;
b_2 – Tail end width of stilling pool, m.

See table 5 for results of energy dissipation calculation.

Table 5: Results of energy dissipation calculation

Operation state	Reservoir water level (m)	Unit discharge (m^3/s.m)	Downstream water level (m)	Water depth at necked-down section (m)	After jump water depth (m)	Downstream water depth (m)	Type of hydraulic jump
Design water level	613.45	45.20	608.20	1.620	7.605	8.20	Submergence hydraulic jump
Check water level	613.80	45.85	609.45	1.625	7.725	9.45	Submergence hydraulic jump

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Through calculation, the flood discharge sluicing gate experiences submergence outflow when flood is discharged. Viewing that it is base rock excavated face behind the gate, which has a certain anti-scour capacity, only built 13.00 m reinforced concrete anti-washing apron.

CONCLUSION

The objective of this work was to design discharge structure, flood discharge sluice gate and floating debris sluice design for the Mekin hydropower project.

The simplified methodology used in the design of these elements was based on international standards. Concrete results were obtained which are being implemented on the construction site of the dam.

Detailed studies of the basic design data and the arrangement of structures enabled us determining the location and the structural composition of the discharge structure, flood discharge sluice gate and floating debris sluice design for the Mekin hydropower project.

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