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Congo (Kingdom) ZONGOII Hydropower Project First Valve Room Stability Technical Report

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Abstract: ZONGOII hydropower station is a diversion-type power station constructed in Congo (Kinshasa), which uses Chinese funds and Chinese standards. However, during the implementation of the project, Gangfang Electric Power Company referred to the design form of the completed hydropower station and instructed me Fang added a first valve chamber at the end of the flat section of the pressure pipeline after the surge well, so that the technicians of the rigid side can use the familiar maintenance practices to perform maintenance and maintenance of the power plant units and butterfly valves. The purpose of this paper is to demonstrate the stability analysis of the additional valve room project based on the requirements of Chinese standards and the needs of rigid owners.

Keywords: ZONGOII hydropower station; valve room engineering; stability analysis

1. Project Overview

The ZONGOⅡ hydropower project is located in the Congo province under the DRC. The project area is between 4°46′16〃to 4°46′46〃south latitude and 14°52′02〃to 14°53′40〃east longitude, with an elevation of 200m to 500m. The Inquisi River is a tributary of the left bank of the Congo River. It originates in northern Angola and flows from south to north into the Congo.

The main task of ZONGO II hydropower station is to generate electricity. The project is mainly composed of three parts:the first barrage, water diversion power generation system and shore-type ground powerhouse. The project takes advantage of the natural fall of the channel of about 5km in the lower reaches of the Inki West River, and excavates a tunnel to concentrate water from the head to generate electricity. The power station is equipped with 3 mixed-flow hydro-generator units, with a single unit capacity of 50MW and a total installed capacity of 150MW.

The first valve chamber is connected from the surge shaft through the upper pressure flat hole and the steel bifurcated pipe. The length of the pressure flat hole is about 275m; the type of the steel bifurcated pipe is an asymmetric Y-shaped bifurcated structure with a section length of 26m and a bifurcation angle of 45. °, the center elevation is 301.700m; there is a platform at the valve room, the platform elevation is 297.800m, the valve room is followed by a high slope, the natural slope of the slope is gradually up and down, and the back slope is provided with a four-story track. The valve chamber is followed by a pressure inclined well section and a lower flat hole section.

2. Engineering Geology

2.1 Terrain and landform

There are 5 levels of excavation behind the valve chamber, and a 4-level horse way and valve chamber platform are set up. The excavation elevation of the first-grade slope is 297.6 to 339.0m, the slope ratio is 1:5, and the horse road and drainage ditch are set. The width of the road is 5m, and the slope is sprayed with concrete protection. The excavation elevation of the second-grade slope is 339. to 329.0m., slope ratio 1:1.2, set up a horse road and drainage ditch, the width of the horse road is 3m, the slope is protected by sprayed concrete; the excavation elevation of the third grade slope is 329.0m to 319.0m, slope ratio 1:1.2, a horse path and drainage ditch, horse road the width is 3m, and the slope is protected by sprayed concrete; the excavation elevation of the fourth-grade slope is 319.0 to 309.0m, the slope ratio is 1:1.2, and the road and drainage ditch are set. The width of the road is 3m, and the slope is protected by sprayed concrete; the fifth-grade slope The excavation elevation is 309.0m to 297.6m, the slope ratio is 1:1.0, and a drainage ditch is set up to reach the valve room platform.

2.2 Formation lithology

The lithology of the slope behind the maintenance valve room is divided into three parts, the order from top to bottom is : ① Quaternary brand new slope residual (Q4dl + el) sandy clay, brown-red, slightly wet, hard plastic. The bottom 30-50cm is gravelly soil, variegated, dry to slightly wet and slightly dense. The gravel content is about 70%, and the composition is mainly sandstone, with a particle size of 0.5 to 6 cm, and a subangular shape. ② Upper Proterozoic (Pt3a) fully weathered feldspar quartz sandstone, purple-red, medium-fine-grained structure, sandy. Distributed between the first-level and fourth-level carriageways, with an elevation of 347m to 308m; ③ Upper Proterozoic (Pt3a) strongly weathered feldspar quartz sandstone, purple-red, medium-fine-grained structure, thick layered, rock mass integrity poor, scattered structure. It is distributed in the four-level pavement, the valve room platform and the exit of upper-flat hole.

The lithology of the overhaul valve room and the foundation of the town pier is the Upper Proterozoic (Pt3a) feldspar quartz sandstone, with a purple-red, medium-fine-grained structure, and most of them are fully weathered, and some are strongly weathered.

2.3 Geological structure

The slope behind the maintenance valve room is mainly weathered feldspar quartz sandstone, which is relatively simple in structure, and the layers and structural fissures are not clear and sandy. The rock body at the base of the valve chamber and town pier is feldspar quartz sandstone, most of which are fully weathered, and some are strongly weathered. The rock formations in the valve chamber are: NE10°NW∠14°; three groups of fractures are mainly developed as:①NE35～50°SE∠83°; ②NE15°SE or NW∠14～16°(layer fracture); ③NW340°NE∠68°.

2.4 Hydrogeology

During the excavation process of the back slope of the valve room, the platform of the valve room, the valve room, and the foundation of the town pier, the rock (soil) body was dry and no groundwater was exposed. From the location and elevation of the water outlets of the upper-flat cave and the pressure inclined well, the groundwater level in the valve chamber is lower than the elevation of the valve chamber base. The groundwater level is estimated to be 304m to 280m from upstream to downstream.

The side wall of the valve room is dominated by type Ⅳ rock masses, and there are type Ⅴ rock masses locally. The foundation of the valve chamber and the town pier is a type IV rock mass.

3. Valve Chamber Layout

3.1 Valve room platform layout

The valve room platform is located on the upstream side of the plant, and the platform elevation is 297.800m. The buildings on the valve room platform include steel branch pipe piers, penstocks in the lower bend section of pressure steel pipes, technical water supply tanks, and access roads. The upstream side of the valve chamber is a pressure steel pipe, which is connected to a pressure inclined well. The main part of the valve room and the transformer room of the valve room are designed as a single unit, and the functions are reasonably arranged and compact. The size of the technical water supply tank at the lower right of the valve room platform is 55.6m × 12.1m × 5.1m (length × width × height).

3.2 Interior layout of valve room

The first valve chamber is a single-layer frame structure, with a total length of 46.1m, a width of 11m, and a height of 23.8m. There are three butterfly valves inside, the diameter of the butterfly valve is 4m, and the acting head is 54m. Install a 75 / 20t single-car bridge crane with a span of 9m. The right side is the transformer room for the valve room, the width is the same as the butterfly valve room, and the height is about 7.9m. The upstream side of the valve chamber is rigidly connected to the steel fork pipe, and the downstream side is provided with a telescopic joint and connected to the pressure inclined shaft.

3.3 Overall stability of the valve chamber and foundation stress analysis

According to the layout of the valve room, it is known that a pier is set upstream of the valve room. After calculation, the pier itself meets the stability requirements, so horizontal water pressure is no longer considered in the horizontal direction. Under the condition of not being subject to horizontal water pressure, the valve chamber is only subjected to wind loads in the horizontal direction and the horizontal component force of the butterfly valve is very small, so the calculation does not consider the stability of the valve chamber against overturning.

The calculation of valve chamber stability is based on the requirements of SL266-2001 "Code for Design of Hydropower Plant Workshops", and the whole chamber is used as the calculation object for research.

3.3.1 Stability analysis control standards

3.3.1.1 Anti-sliding and anti-floating stability control standards. The safety coefficient of anti-sliding stability and anti-floating stability of the hydropower station building on the rock foundation shall meet the requirements of the following table.

Table 1. Safety coefficient of anti-sliding and anti-floating stability

Load Combination	Stability Category	
	Anti-Sliding Stability Factor	Anti-Floating Stability Factor
Basic Combination	3.0	1.5
Special Combination	2.5	1.1

3.3.1.2 Normal stress control standards on the ground. When calculating the normal stress on the foundation of a building on a rock foundation using the material mechanics method, the following requirements shall be met: ① The maximum normal stress on the foundation of the building shall not exceed the allowable bearing capacity of the foundation. ② The minimum normal stress (including lifting pressure) on the foundation of the building should meet the conditions: greater than zero.

3.3.2 Basic loads and load combinations

3.3.2.1 Load

The loads mainly include the deadweight of the valve chamber structure, the weight of the permanent equipment, the horizontal thrust of the butterfly valve to the foundation, the pressure of the butterfly valve to the foundation, the tension of the butterfly valve to the foundation, the water pressure at the bottom of the floor, and wind loads.

3.3.2.1.1 The weight of the valve chamber structure A1. The self-weight of the structure of each part of the valve room should be determined according to its geometric size and material weight. The floor structure of the concrete heavy valve room is 24kN/m3; the three-dimensional model of the valve room is shown below:

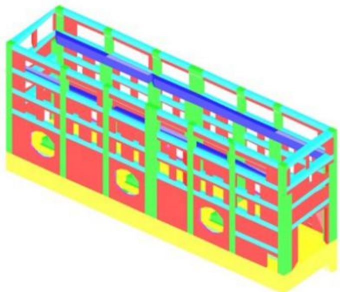

Figure 1. The calculated valve chamber weight is 59712kN

3.3.2.1.2 Permanent equipment weighs A2. Considering the weight of butterfly valves and bridge cranes, the weight of other auxiliary equipment and non-fixed equipment is not considered. The weight of a single bridge machine is 55t, and the butterfly valve is considered as 100t.

3.3.2.1.3 The horizontal thrust of butterfly valve B1. The maximum horizontal thrust of a single butterfly valve is 380kN.

3.3.2.1.4 Butterfly valve pressure B2. The maximum pressure of a single butterfly valve is 4000kN.

3.3.2.1.5 The lifting force B3 of the butterfly valve to the foundation. The maximum lifting force of a single butterfly valve is 1680kN.

3.3.2.1.6 Lifting pressure C1. According to extreme conditions, the bottom surface of the bottom plate is subject to the head of free seepage from the floor of the valve room platform.

3.3.2.1.7 Wind load D1. The standard value of the wind load acting vertically on the building surface should be calculated as follows:

$W_K = \beta_Z \mu_Z \mu_S W_0$

In the formula:

W_K——standard value of wind load (kN / m2);

β_Z——wind vibration coefficient at Z height;

μ_Z——coefficient of variation of wind pressure height;

μ_S——form factor of wind load carrier;

W_0-basic wind pressure (kN / m2)

The basic wind pressure is calculated according to Appendix E of the "Code for Loads of Building Structures", the maximum wind speed is 26.4m / s, and the altitude of the valve chamber is 298 ~ 322m.

Air density can be approximated from the altitude z (m) of the location using the following formula:

$\rho = 0.00125e^{-0.0001z}$ (t / m3)

The basic wind pressure can be calculated as follows:

W0 = 0.5ρV02

The change coefficient of wind pressure height should be 1.80 according to the ground roughness category, the ground roughness category and the height from the ground or sea level; the wind load carrier shape coefficient is taken as 0.8, and the wind vibration coefficient is 1.0.

The calculated basic wind pressure is 0.43kN / m2, the standard value of wind load is 0.62kN / m2, and the maximum horizontal wind load is 680kN.

3.3.2.2 Load combinations

See Table 2 for stability calculation load combinations.

Table 2. Combination table of valve chamber stability calculation load

Working Condition	Load Combination						
	A 1	A 2	B 1	B 2	B 3	C 1	D 1
Valve Closed During Operation	√	√	√	√		√	√
Valve Opens During Operation	√	√	√		√	√	√
Valve Not Installed During Construction	√					√	√

3.3.3 Anti-sliding stability

The anti-sliding stability of buildings adopts the following calculation formula:

$$K' = \frac{f' \sum W + c' A}{\sum P}$$

In the formula:

K'—slip safety stability factor of the building;

ΣW— normal load of all loads on sliding surface, including lift pressure, kN;

ΣP—tangential value of all loads on sliding surface, including lift pressure, kN;

f ’, c’-shear friction coefficient and adhesion (kPa) of sliding surface;

A—Calculation of the area of the section of the building foundation, m2.

3.3.4 Anti-floating stability

According to SL266-2001, Design Specification for Hydropower Plant Buildings, the anti-floating stability of valve chambers uses the following calculation formula:

$$K_f = \frac{\sum W}{U}$$

In the formula:

Kf—floating stability safety factor, under no circumstances should be less than 1.1;

ΣW— normal load of all loads on sliding surface, including lift pressure, kN;

U—the sum of the lifting pressure acting on the foundation of the building, kN.

3.3.5 Normal stress on the foundation

The normal stress on the building foundation is calculated as follows:

$$\sigma_{\substack{max \\ min}} = \frac{\sum W}{A} \pm \frac{\sum M_x y}{J_x} \pm \frac{\sum M_y x}{J_y}$$

In the formula:

$\sigma_{\min}^{\max}$ —Normal stress on the ground, kPa;

∑W—the sum of the normal component forces of all the forces acting on the building in the calculated section, kN;

∑Mx, ΣMy—the sum of the moments of all the forces acting on the building to calculate the centroid axis X, Y of the section, kN • m;

x, y—the distance from the calculated point on the cross section to the centroid axis Y, X, m;

Jx, Jy—Calculate the moments of inertia of the centroid axis X, Y of the section, m^4;

A—Calculate the area of the section under pressure, m^2.

4. Conclusion

According to the above analysis, the anti-sliding, anti-floating, anti-overturning stability and foundation bearing capacity of the additional valve room project of ZONGOII hydropower station meet the specifications and design requirements. From the perspective of stability and functional safety, the valve room project is stable. of. The successful design experience of the ZONGOII hydropower station valve room project has opened up new design concepts and ideas for the subsequent design of valve rooms in similar hydropower projects in Central and West Africa, and will gain a wider scope in the design and implementation of subsequent similar hydropower projects in Africa.

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