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Hydraulic Model Test on Diversion Structures of Gongguoqiao Hydropower Station during Construction

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Abstract

Based on hydrologic data and diversion structure arrangement of Gongguoqiao hydropower station during construction, the hydraulic model on diversion structures is built according to similarity principle. Then the hydraulic characteristic and its flow model were studied by hydraulic model test. Hydraulic characteristic and flow pattern for the diversion tunnel and dam gap combined discharge were studied subsequently in this paper. The study results show that half pressure flow state is formed in the diversion tunnel when quantity of flow is greater than 3500m^3/s. That submerged flow is formed exactly in the inlet of diversion tunnel when quantity of flow is 5000m^3/s. Three aeration segments are formed in the top of diversion tunnel when quantity of flow is greater than 6580m^3/s. The study results also show non-interpenetrated turbulence is formed intermittently in the right bank of inlet for diversion tunnel when quantity of flow is greater than 7710m^3/s, and the flow over the upstream cofferdam is near the submerged hydraulic jump.

Keywords: Gongguoqiao Hydropower Station; Diversion structures; Hydraulic model test; Hydraulic characteristics; Flow pattern

1. Introduction

Gongguoqiao hydropower station locates in the middle and lower reaches of Lancang River which belongs to Yunlong country in Yunnan Province [1]. The dam site of Gongguoqiao hydropower station is

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158 kilometers east from Dali city, and is 95 kilometers west from Baoshan city. Reservoir of Gongguoqiao hydropower station, whose normal water level is elevation 1307 meters, is a daily regulation reservoir and has the total capacity of 3.16×10^8m^3. Gongguoqiao hydropower station has the capacity of 900MW, and the designed annual generation of this hydropower station is 40.32×10^8 KW·h. The key water control project of this hydropower station is composed of roller compacted concrete gravity (RCC) dam, underground powerhouse and release flood waters structures etc. The maximum height of RCC gravity dam is 105 meters, and its crest length is 365meters. There are one scouroutlet with the size of 5m×7m and five crest overflowiring holes, each hole with the size of 15m×19m, in the dam. The combined dissipator of X-type flaring pier, stepped flow surface at damtoe and bucket basin is used for crest overflowiring outlet [2]. And energy dissipation of ski-jump is used for the scouroutlet. During construction, diversion structures in hydropower station are composed of the soil rock upstream cofferdam with maximum height of 27.6 meters, the soil rock downstream cofferdam with maximum height of 11.7 meters and diversion tunnel with the size of 16.0m×18.0m on the right bank of the dam. The diversion period is 26 months for construction. During dry period, diversion tunnel is used to discharge water separately and cofferdam is used to retain water. The standard of diversion is ten year frequency flood, its diversion flow quantity is 2030m^3/s, and the highest water level is elevation 1260.7 meters for upstream cofferdam. During the flood season, diversion tunnel, upstream cofferdam, downstream cofferdam, dam gap and foundation pit are use to discharge water together. The standard of diversion is twenty year frequency flood, its diversion flow quantity is 7710m^3/s, and the highest water level is elevation 1266.6 meters for upstream cofferdam. Fig.1 shows the topographic mapping and layout of Gongguoqiao hydropower station. Fig.2 shows the relationship between water level and flow velocity in the upstream dam site, in the dam site, in the exit site of diversion tunnel for Gongguoqiao hydropower station.

In order to study flow model, flow erosion to river bed and bank slope, hydraulic characteristic for overflowing in the dam gap, and ensure the safety of the project during construction, hydraulic model test for Gonguoqiao hydropower station was carried out in this paper.

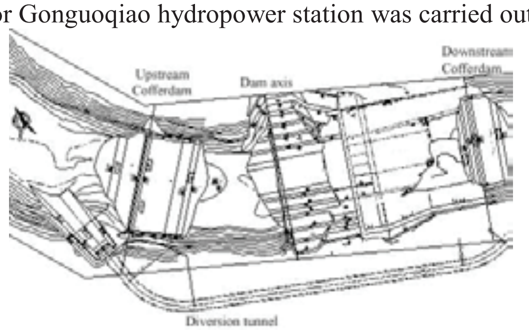

Fig. 1. Layout of Gongguoqiao hydropower station

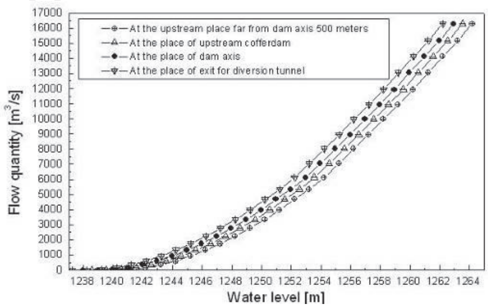

Fig. 2. Relationship between water level and flow velocity

2. Diversion hydraulic model and test conditions

2.1 Hydraulic model

According to the similarity principle, the mechanical similarity conditions between model and prototype [3]-[5], original river and overflow model on diversion structures are built base on the river channel topographic map with the scale of 1:500 in the dam site of Gongguoqiao hydropower station [6]. The model is 1634.4 meters in the length, which is from the position 200 meters above upstream cofferdam axis to the position 500 meters below downstream cofferdam axis. The model is 327 meters in the upstream and 292.2 meters in the downstream. The height of model is 35 meters in the upstream and

20 meters in the downstream. In the model building, elevation is determined according to the normal superelevation and the highest water level in the upstream and downstream. Table 1 shows the hydraulic model scale of diversion structures in Gongguoqiao hydropower station during construction. Fig.3 shows the hydraulic model of diversion structures in Gongguoqiao hydropower station.

Table 1. Hydraulic model scale of diversion structures in Gongguoqiao hydropower station

Scale type	Length scale	Flow velocity scale	Flow quantity scale	Roughness coefficient scale	Time scale
Actual scale	60	7.746	27885	1.979	7.746

(a) Inlet of diversion tunnel (b) Main part of diversion tunnel

(c) Outlet of diversion tunnel (d) Upstream cofferdam (e) Downstream cofferdam

Fig.3. Hydraulic model of diversion structures in Gongguqiao hydropower station

2.2 Test conditions

Diversion hydraulic model test conditions are selected according to the characteristic flow quantity during construction and the hydraulic actual conditions of Gongguoqiao hydropower station. Table 2 is the model test conditions in detail.

In the model test, flow velocity, flood-carrying capacity of diversion tunnel, water level in the upstream and downstream, gap flow model, and hydraulic parameters are determined when the key parts is overflowing in the diversion structures. The scour to the both sides of slope and foundation pit is also observed when the hydraulic model and dam gap is in the different flow quantity.

3. Test results

3.1 Test results of diversion tunnel's hydraulic model experiment

Table 3 shows the test results of flow velocity in the outlet of the diversion tunnel. Table 4 shows flow model when diversion tunnel and cofferdam are discharging water together. Fig.4 and Fig.5 show flow model of diversion tunnel's hydraulic model test for Gongguoqiao hydropower station.

The hydraulic model test results of diversion tunnel shows: (1) in the inlet of diversion tunnel, flow is relatively stable. When the flux rate of discharging water is small, there will be circumferential motion on the left bank of diversion tunnel because of the larger transverse velocity. With the quantity of flow increasing, there will be a greater gradient for water surface line in the left zero to 29 meters of diversion tunnel inlet because of topographic effect. When flow velocity is larger than 7710m^3/s, there will be intermittent turbulence on the right bank zero to 29 meters of diversion tunnel inlet. (2) In the outlet of diversion tunnel, because water level is low in the downstream of river channel and the flux rate over downstream cofferdam is also small, when quantity of flow is between 2500m^3/s and 3810m^3/s, there is wavy hydraulic jump, which is rushed to the left bank of river bank, and formed backflow in the local range 0+445.0 meters～0+629.4 meters below the dam. The test results show that submerged discharge is formed exactly in the inlet of diversion tunnel when quantity of flow is 5000m^3/s and the water level at the downstream river channel is elevation 1253.22 meters. The quantity of flow for cofferdam is larger than that of diversion tunnel when quantity of flow is between 6580m^3/s to 7710m^3/s. Thus, water in the outlet of the tunnel is forced to flow to the right bank of river channel firstly and then to the main river channel. (3) When quantity of flow is between 2500 m^3/s to 4000 m^3/s, hydraulic jump in the diversion tunnel is in the diversion tunnel without lining all the time and the location of the hydraulic jump moves upside with the increasing of flux rate. When quantity of flow is 5490 m^3/s, hydraulic jump in the diversion tunnel moves upside to the position of 309.77 meters. With the increasing of flux rate, the aeration period is formed in the diversion tunnel because of water surface's disturbance. When quantity of flow is 6580 m^3/s, three aeration periods are formed in the top of diversion tunnel because of water surface's disturbance. Furthermore, because of gate slot's mixes gas effects in the inlet of the diversion tunnel, the gas is at equilibrium, and there is mixed gas in the surface all the time.

Table 2. Diversion hydraulic model test conditions for Gongguoqiao hydropower station during construction

Testing project	Working conditions	Quantity of flow Q/[m^3/s]	Location of dam gap	Testing project	Working conditions	Quantity of flow Q/[m^3/s]	Location of dam gap
Project 1	D11	3000	1256m 5#～7# dam block on the left bank Gap width: 67.0m	Project 4	D41	3000	1253m 14#～15# dam block on the right bank Gap width: 48.0m
	D12	3850			D42	3850	
	D13	5000			D43	5000	
	D14	6580			D34	6580	
	D15	7710			D35	7710	
Project 2	D21	3000	1253m 5#～7# dam block on the left bank Gap width: 67.0m	Project 5	D51	3000	1256m 13#～15# dam block on the right bank Gap width: 65.0m
	D22	3850			D52	3850	
	D23	5000			D53	5000	
	D24	6580			D54	6580	
	D25	7710			D55	7710	
Project 3	D31	3000	1256m 2#～7# dam block on the left bank Gap width: 100.0m	Project 6	D61	3000	1256m 8#～12# dam block on the middle bank Gap width: 95.0m
	D32	3850			D62	3850	
	D33	5000			D63	5000	
	D34	6580			D64	6580	
	D35	7710			D65	7710	

Table 3. Test results of flow velocity in the outlet of the diversion tunnel

Exit site	Quantity of flow /[m³/s]	Flow velocity /[m/s]			Quantity of flow /[m³/s]	Flow velocity /[m/s]			Quantity of flow /[m³/s]	Flow velocity /[m/s]		
		left	middle	right		left	middle	right		left	middle	right
surface	3000	10.46	10.61	11.62	3850	11.31	11.46	12.08	5000	12.47	13.01	13.94
central		9.76	9.68	10.84		10.38	10.22	10.69		10.92	10.92	13.01
bottom		9.45	9.76	10.92		9.60	10.38	10.46		11.15	11.31	12.47
surface	6580	12.01	13.56	14.48	7710	11.62	13.87	13.79	—	—	—	—
central		11.23	11.08	11.93		11.77	11.23	12.24		—	—	—
bottom		11.31	12.08	12.78		11.23	11.62	12.63		—	—	—

Table 4. Flow models when diversion tunnel and cofferdam are discharging water together

Quantity of flow /[m³/s]	Quantity of flow at diversion tunnel/[m³/s]	Quantity of flow over cofferdam/[m³/s]	Diversion ratio of diversion tunnel /[%]	Flow velocity on the left bank of diversion tunnel outlet /[m/s]	Flow model on the left bank of diversion tunnel outlet
3000	2503.87	358.72	87.47%	1.01	backflow
3810	2832.72	930.43	75.28%	4.42	backflow
5000	3159.36	2682.30	54.08%	0.93	mainstream is in the river
6580	3199.68	3702.40	46.36%	0.39	mainstream is in the right bank
7710	3297.60	4666.15	41.41%	1.24	mainstream is in the right bank

(a) Inlet of diversion tunnel (b) Main part of diversion tunnel (c) Outlet of diversion tunnel

Fig.4 Flow model of diversion tunnel's hydraulic model test for Gongguoqiao hydropower station ($Q=3850m^3/s$)

(a) Inlet of diversion tunnel (b) Main part of diversion tunnel (c) Outlet of diversion tunnel

Fig.5 Flow model of diversion tunnel's hydraulic model test for Gongguoqiao hydropower station ($Q=7710m^3/s$)

3.2 Test results of cofferdam's hydraulic model experiment

When test is in the different quantity of flow, measured results of flow velocity and water level at upstream and downstream cofferdam are showed in Table 5 for Gongguoqiao hydropower station. Table 6 shows flow velocity of hydraulic jump at upstream and downstream cofferdam. Fig.6 shows flow model of cofferdam's hydraulic model test for Gongguoqiao hydropower station.

Table 5. Measured results for flow velocity and water level at the cofferdam of Gongguoqiao hydropower station.

Characteristic section	location	Quantity of flow (Q=3850m^3/s)					Quantity of flow (Q=7710m^3/s)				
		flow velocity (m/s)			water level（m）		flow velocity (m/s)			water level（m）	
		left	middle	right	left bank	right bank	left	middle	right	left bank	right bank
Upstream cofferdam	surface	1.95	2.01	2.07	1264.36	—	3.18	5.19	4.80	1268.59	—
Platform 1250m at upstream cofferdam	surface	1.78	0.31	1.32	1258.56	1258.62	0.23	2.09	1.94	1267.62	1267.98
	bottom	0.46	0.23	0.23			0.23	2.09	1.24		
Downstream cofferdam	surface	1.95	2.47	1.96	1253.69	—	4.49	6.51	5.03	1257.99	—
Platform 1243m at downstream cofferdam	surface	2.56	0.23	2.01	1251.66	1251.12	0.77	0.54	4.65	1255.62	1256.22
	bottom	0.39	0.31	1.86			0.39	3.64	4.57		

Table 6. Flow velocity of hydraulic jump at upstream and downstream cofferdam

Quantity of flow /[m^3/s]			3000	3850	5000	6580	7710
Flow velocity /[m/s]	Hydraulic jump at upstream cofferdam	Jump in the head	—	2.89	9.50	7.93	5.09
		Jump in the end	0.36	1.06	2.17	1.98	1.99
	Hydraulic jump at downstream cofferdam	Jump in the head	—	3.59	7.52	7.10	8.34
		Jump in the end	—	1.49	2.30	2.40	3.08

(a)Upstream cofferdam (Q=3850m^3/s) (b) Upstream cofferdam (Q=7710m^3/s) (c) Downstream cofferdam (Q=3850m^3/s) (d) Downstream cofferdam (Q=7710m^3/s)

Fig.6 Flow model of cofferdam's hydraulic model test for Gongguoqiao hydropower station

The hydraulic model test results of cofferdam shows: (1) Temporary dam section water retaining and gap flood waters releasing make the water level of between upstream cofferdam and the foundation pit rise. Water surface is jointed together between hydraulic jump in the upstream cofferdam and the foundation pit. Flow velocity is uniform, the max flow velocity of hydraulic jump is 12.239m/s in the head, and 4.648m/s in the end. Flow velocity is between 1.34 m/s and 4.31m/s and it is smooth in the top of upstream cofferdam. When the max flux rate is $7710m^3/s$, the flow over the upstream cofferdam is near the submerged hydraulic jump. (2) The flow over the downstream cofferdam is smooth. Because the water level is high behind the downstream cofferdam, the link of flow behind the downstream cofferdam and in the river channel is well. Water surface is gentle and hydraulic jump is not obvious. The flow velocity of hydraulic jump behind downstream cofferdam is between 0.55 m/s and 3.49 m/s, the max flow velocity is not happened with the max flow quantity at the same time.

4. Conclusions

(1) In the inlet of diversion tunnel, the water flow is stable. When the quantity of discharging water is small, transverse flow velocity is large. There will be circumferential motion on the left bank of diversion tunnel. With the quantity of flow increasing, there will be a greater gradient for water surface line in the left zero to 29 meters of diversion tunnel inlet because of topographic effect. When flow velocity is larger than $7710m^3/s$, there will be intermittent turbulence on the right bank of diversion tunnel inlet.

(2) In the outlet of diversion tunnel, because water level is low in the downstream of river channel and the flux rate over downstream cofferdam is also small, when quantity of flow is between $2500m^3/s$ and $3810m^3/s$, there is wavy hydraulic jump, which is rushed to the left bank of river bank.

(3) Temporary dam section water retaining and gap flood waters releasing make the water level of between upstream cofferdam and the foundation pit rise. Water surface is jointed together between hydraulic jump in the upstream cofferdam and the foundation pit.

(4) The flow over the downstream cofferdam is smooth. Because the water level is high behind the downstream cofferdam, the link of flow behind the downstream cofferdam and in the river channel is well. Water surface is gentle and hydraulic jump is not obvious. The flow velocity at the top of downstream cofferdam is between 1.23 m/s and 5.29 m/s when quantity of flow is between $3000m^3/s$ and $7710\ m^3/s$.

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