Earth-Rock Balance Study for the Construction of Jinyun Pumped-Storage Power Station

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Abstract. In order to further explore the study of earth-rock balance planning of pumped storage power station, it provides a reference for the selection of conversion coefficient of fill material and utilization coefficient of excavation material in subsequent pumped storage engineering construction. Taking Zhejiang Jinyun pumped-storage Power Station as an example, this paper summarizes the amount of earth-rock, selects reasonable conversion coefficient of fill material and utilization coefficient of excavation material with reference to industry norms and relevant engineering experience, carries out earth-rock balance planning, studies and analyzes the timing sequence and sensitivity of earth-rock balance planning. Based on the construction plan and earthwork balance calculation results, the utilization coefficient is generally appropriate, the conversion factors for stone utilization and waste slag meet the requirements of the specifications, overall, the calculation results are generally reliable and the deviation is controllable.

Keywords: pumped-storage Power Station; earth-rock balance; planning

1 Introduction

In recent years, the development and construction of pumped storage power stations have been vigorously promoted, injecting new vitality into the development of the hydropower industry. However, pumped storage power stations differ greatly from conventional hydropower in many aspects such as the layout of reservoirs, the setting of water transmission systems, the design of pressure pipelines, construction planning, and the balance of soil and rock, which requires high attention from relevant design and construction personnel, with soil and rock balance being the most critical. "Large excavation and filling" is a significant feature of pumped storage power station construction. Lean earthwork balance planning can save construction costs, improve resource utilization, reduce environmental impact, and improve construction efficiency[1-5]. This article takes the Jinyun Pumped Storage Power Station in Zhejiang Province as an example to conduct earthwork balance planning, and studies and analyzes the timing and sensitivity of earthwork balance planning.

Y. Zhang et al. (eds.), *Proceedings of the 2024 10th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2024)*, Advances in Engineering Research 259,
https://doi.org/10.2991/978-94-6463-658-1_40

2 Project Overview

The Jinyun Pumped Storage Power Station is located in Jinyun County, Lishui City, Zhejiang Province. The upper reservoir is located at the source of Fangxi River in Caotou Village, Dayang Town, Jinyun County. The lower reservoir dam is located on the main stream of Fangxi River, about 1.9km upstream of Fangxi Township. The installed capacity of the power station is a pure pumped storage power station with daily regulation, mainly responsible for peak shaving, valley filling, frequency regulation, phase modulation, and emergency backup tasks of the Zhejiang power grid. The power station is a first-class (1) type project, with its main buildings classified as Grade 1 buildings and secondary buildings classified as Grade 3 buildings. The normal storage level of the reservoir on the power station is 926.00m, the dead water level is 899.00m, and the effective storage capacity is 8.65 million m3; The normal storage level of the reservoir is 325.00m, the dead water level is 298.00m, and the effective storage capacity is 8.23 million m^3.

3 Quantity of Earth-Rock

The engineering quantity calculation of the upper and lower water reservoirs, water conveyance systems, and factory building systems in this project adopts a combination of three-dimensional design modeling calculation and sectional two-dimensional section calculation method. According to calculations, the excavation, filling, and concrete work quantities for the hub project of this project are shown in Table 1.

Table 1. Summary of Main Quantities of Hub Projects

Project	Unit	Upper reservoir	Water conveyance system	Plant power generation system	Lower reservoir	Traffic engineering	Temporary facilities	Total
Earth excavation	10^4m^3	30.22	13.51	10.91	27.48	20.75	1.38	104.26
Rock excavation	10^4m^3	39.39	44.33	29.27	68.83	46.66	1.40	229.89
Rock excavation of cave	10^4m^3	0.07	64.40	78.87	0.11	18.39	22.89	184.72
Upstream rockfill	10^4m^3	41.18	/	/	78.72	/	/	119.90
Downstream rockfill	10^4m^3	25.94	/	/	66.01	/	/	91.95
Cushion zone fill	10^4m^3	3.33	/	/	4.83	4.60	/	12.76
Transition zone fill	10^4m^3	3.94	/	/	7.25	/	0.12	11.31
Masonry fill	10^4m^3	0.99	/	0.12	1.05	0.79	/	2.94

Rock ballast fill	10^4m^3	1.34	0.09	/	2.36	15.22	2.29	21.30
Clay fill	10^4m^3	/	/	/	/	/	1.07	1.07
Saprolite fill	10^4m^3	/	/	/	1.22	/	/	1.22
Earth fill	10^4m^3	0.81	/	/	/	11.26	/	12.06
Concrete	10^4m^3	1.96	27.42	14.32	4.23	17.72	3.60	69.25
Shotcrete	10^4m^3	0.88	3.66	3.23	0.35	1.02	1.06	10.19

4 Earth-Rock Balance

4.1 Selection of Coefficient

4.1.1 Selection of Fill Coefficient.

In the calculation process of earthwork balance in this project, the conversion coefficients of various materials are mainly selected based on the natural bulk density of stone materials and the design indicators of various filling materials.

Table 2. Main Design Indicators for Dam Materials in Each Zone of Upper and Lower Reservoir Dams

	Special cushion zone	Cushion zone	Transition zone	Upstream rockfill zone	Downstream rockfall zone
Dry density (g/cm^3)	≥2.22	≥2.22	≥2.19	≥2.16	≥2.13
Void ration(%)	18	18	19	20	21
Maximum particle size(cm)	4	10	30	80	80
Layer thickness(cm)	20	40	40	80	80

The design indicators of filling materials for the upper and lower reservoirs of Jinyun Power Station are shown in Table 2.

The natural bulk density of stone is selected based on the average value of the rock physical and mechanical test results in each excavation area. Referring to industry standards such as the < Code for Construction Planning of Hydropower Projects> (NB/T 10491-2021) and the < Manual for Construction Organization Design of Water Resources and Hydroelectric Engineering> , as well as relevant engineering experience[6-7], the conversion coefficients for earthwork filling, concrete and natural earthwork selected for the balance analysis of Jinyun Power Station are shown in Table 3.

Table 3. Conversion Coefficient

Before conversion	After conversion	Capacity after conversion
1m^3 natural earth	Excavation volume	1.20
1m^3 natural earth	Filling volume	0.80
1m^3 natural rock	Excavation volume	1.40
1m^3 natural rock	Upstream rockfill	1.20
1m^3 natural rock	Downstream rockfill	1.22
1m^3 natural rock	Transition zone fill	1.19
1m^3 natural rock	Cushion zone fill	1.07
1m^3 natural rock	Rrock ballast fill	1.25
1m^3 natural rock	Masonry fill	1.30
1m^3 Concrete	Natural rock	1.10

4.1.2 Selection of Utilization Coefficient.

The selection principle of the utilization coefficient of earth rock excavation materials in this project is based on the design earth rock demand of the project hub and some temporary buildings, based on the exploration data such as the earth rock ratio of open excavation materials exposed in the geology, the classification of surrounding rock of underground caverns, and referring to the empirical coefficient of earth rock utilization of other projects[8-10], the balance of earth rock excavation materials for the project is carried out, and the mining range and mining output of the quarry are planned, so as to achieve the balance of earth rock for the project. The utilization coefficient of excavated materials in the main parts of this project is shown in Table 4.

Table 4. The Utilization Coefficient of Excavated Materials

Project		The Utilization Coefficient		
		Earth excavation	Rock excavation	Rock excavation of cave
Connection route between upper and lower		55%	48%	85%
Reconstruction route		77%	57%	85%
Upper reservoir	Inlet/Outlet		80%	85%
	Stone material factory		90%	
Water transport	2#Construction adit			75%
	1#、3#、4#、5#、6#Construction adit			85%
	Water conveyance system			85%
Underground powerhouse	Ventilation and safety tunnel	80%	50%	85%
	Access tunnel for entering the powerhouse	80%	50%	80%
	Underground powerhouse system			90%
	Outgoing line tunnel and Switching station		75%	85%
Lower reservoir	Spillway		75%	
	Inlet/Outlet		75%	85%
	Stone material factory		90%	

4.2 Earth-Rock Utilization Planning

According to the characteristics of the hub layout and overall construction layout of this project, the utilization of earthwork is planned and balanced according to the upper and lower storage areas, as well as the progress and strength of the project. The useful materials for stone excavation during the preparation period of the project, except for filling, cushion layer materials, and concrete aggregates, are stored in the 1 # slag yard of the highway, the transfer material yard of the lower warehouse, and the 2 # slag yard of the lower warehouse for use in the main project.

4.2.1 Earth-Rock Utilization Planning of the Construction Period. The construction projects during the preparation period of this project include the connection road between the upper and lower warehouses, the reconstruction road of the lower warehouse, the road to the inlet/outlet of the lower warehouse, the road on the right bank of the lower warehouse, the entrance traffic tunnel, the ventilation and safety tunnel, and the intersection section of related tunnels, the 2 # construction support tunnel, the diversion and discharge tunnel of the lower warehouse, the inlet/outlet of the lower warehouse (with an elevation of 330.60m or above), and the slag yard blocking and drainage engineering.

During the preparation period, in addition to meeting the needs of soil and rock mixed filling and artificial aggregate, the remaining usable rock excavation needs to be transferred and provided for the main project utilization. The utilization of soil and rock during the construction period includes the filling of soil and rock mixtures for on-site roads, as well as the use of cushion materials and concrete aggregates for on-site roads, ventilation and safety tunnels, access tunnels, and diversion and discharge tunnels. The backfill material for the on-site roads is a mixture of soil and rock, with low requirements. Highway excavation materials are used; The cushion layer materials and concrete aggregates for the on-site roads, ventilation and safety tunnels, access traffic tunnels, and diversion and release tunnels are mainly excavated from engineering stone tunnels, and the insufficient parts are considered to be excavated from open stone tunnels.

The total amount of earthwork excavation during the construction period is about 1.43 million cubic meters (natural cubic meters), including 300000 cubic meters of earthwork excavation, 610000 cubic meters of open rock excavation, and 530000 cubic meters of rock tunnel excavation; 290000 cubic meters of concrete and cushion materials; The backfilling of road soil and rock is approximately 260000 cubic meters (filling volume).

After balancing, a total of 740000 cubic meters of construction waste (loose cubic meters, the same below) were collected and stored in the 1 # waste disposal site of the lower storage area; The soil and rock mixture required for the road shall be backfilled with self excavated materials. Approximately 80000 cubic meters of excavated materials from the tunnel section of the upper and lower storage areas connecting the highway are centrally stored in the 1 # slag yard of the highway, serving as the source of filling materials for the upper reservoir dam; 80000 cubic meters of excavated stone materials, including the road for the reconstruction of the lower reservoir, the road on the right bank of the lower reservoir, the entrance of the ventilation and safety tunnel, the entrance of the access tunnel, and the inlet/outlet of the lower reservoir, are stored in the 2 # waste disposal site of the lower reservoir as a source of filling materials for the lower reservoir dam; The useful materials for engineering tunnel excavation, except for direct utilization, are stored in the transfer material yard of the lower storage tunnel excavation. Priority is given to the processing of concrete aggregates and cushion materials during the construction period. The remaining 270000 cubic meters is used for the main target concrete aggregates or the filling materials for the lower storage dam.

4.2.2 Earth-Rock Utilization Planning of the Upper Reservoir.
The upper reservoir engineering projects in this project include upper reservoir dam, upper reservoir basin and bank, surrounding reservoir road and quarry, upper reservoir inlet/outlet and gate shaft, water diversion 1 # construction support tunnel, water diversion upper flat tunnel, water diversion upper inclined shaft (concrete pouring), construction diversion, etc.

The cushion layer materials and concrete aggregates in the upper storage area are supplied by the sand and gravel processing system in the lower storage area, while the filling materials for the dam are provided by the excavation materials from the upper storage engineering and the mining materials from the stone yard. The balance of soil and rock in the upper reservoir area focuses on the matching of the quantity and strength of the fill materials for the upper reservoir dam and the excavation materials for the upper reservoir inlet and outlet, as well as the stone yard.

The total amount of earthwork excavation in the upper reservoir area is about 1.15 million cubic meters (natural cubic meters, the same below), including 370000 cubic meters of earthwork excavation, 730000 cubic meters of open rock excavation, and 50000 cubic meters of rock tunnel excavation; During the preparation period, 60000 cubic meters of transfer materials were used for the project. 140000 cubic meters of concrete and cushion materials; The amount of stone filling for the dam is about 720000 cubic meters (excluding cushion material).

After balancing, the filling material for the upper reservoir dam is about 720000 cubic meters (excluding cushion material and filling party), of which about 410000 cubic meters is upstream rockfill material, about 260000 cubic meters is downstream rockfill material, about 40000 cubic meters is transition material, and about 10000 cubic meters is masonry material. The usable amount of stone materials at the inlet/outlet of the upper reservoir is 260000 cubic meters (natural cubic meters), the usable amount of the upper reservoir stone material yard is 230000 cubic meters (natural cubic meters), and the transfer material during the construction period is 60000 cubic meters (natural cubic meters), which can meet the quantity and quality requirements of the dam's stone filling material; The transition material can be excavated from the upper storage hole to meet the demand. The Upper Reservoir project is not a critical route project. The mining of the Upper Reservoir quarry and the excavation of the inlet/outlet can be carried out based on the strength of the dam filling. The excavated materials can basically meet the requirements of direct dam access, with only a small amount of stone transfer required. The upper reservoir area project generated approximately 750000 cubic meters of waste (loose cubic meters), of which 670000 cubic meters were disposed of in the waste disposal area inside the reservoir, and the remaining 80000 cubic meters were disposed of in the storage capacity formed after the backfilling of Highway 1 # waste disposal area.

4.2.3 Earth-Rock Utilization Planning of the Lower Reservoir.

The reservoir engineering projects under this project include lower reservoir dam, right bank slope spillway, lower reservoir inlet/outlet, lower reservoir basin bank and stone yard, switch station, water diversion system, tailwater system and factory system, construction support tunnel, etc.

The cushion layer material and concrete aggregate in the lower storage area are provided by underground engineering excavation materials, while the dam filling material is provided by the excavation materials from the lower storage area and the quarrying materials from the quarry. The balance of earthwork in the lower storage area is carried out from two aspects: the source of concrete aggregates in the lower storage area, the matching of the quantity and strength of dam stone filling and excavation materials in the lower storage area.

The total amount of earthwork excavation in the lower reservoir area is about 2.6 million cubic meters (natural cubic meters), including 370000 cubic meters of earthwork excavation, 960000 cubic meters of open rock excavation, and 1.27 million cubic meters of rock tunnel excavation; During the preparation period, 250000 cubic meters of transfer materials were used for stone excavation and tunnel excavation. 490000 cubic meters of concrete and cushion materials; The amount of stone filling for the dam is approximately 1.55 million cubic meters (excluding cushion materials).

After balancing, the amount of stone filling for the dam in the lower reservoir area is about 1.55 million cubic meters (filling volume, excluding cushion material), of which about 530000 cubic meters (natural volume) of stone open excavation materials are used for the spillway, lower reservoir inlet/outlet, and ground switch station, about 490000 cubic meters of underground plant and water conveyance system tunnel excavation materials, and 130000 cubic meters of transfer materials are used for the construction period; The Xiaku stone quarry extracts approximately 130000 cubic meters of useful materials. The concrete (including shotcrete) and cushion material aggregates in the upper and lower storage areas are provided by the artificial sand and gravel processing system in the lower storage area. The total volume of concrete (including shotcrete) is 550000 cubic meters, including 110000 cubic meters in the upper storage area and 440000 cubic meters in the lower storage area; The total amount of cushion material is 80000 cubic meters, including 30000 cubic meters in the upper storage area and 50000 cubic meters in the lower storage area,A total of 680000 cubic meters of natural rock are required. The rolling material sources include 600000 cubic meters (natural cubic meters) of excavated materials from stone tunnels in the lower storage area water conveyance system, underground power plants, 500kV outlet tunnels, and construction support tunnels. During the preparation period, approximately 80000 cubic meters of excavated materials were temporarily stored in the transfer material yard of the lower storage area. In summary, a total of 1.99 million cubic meters (natural cubic meters) of excavated stone materials were used in the lower reservoir area project. In addition to approximately 1.64 million cubic meters of excavated stone materials from the main project of the lower reservoir area, approximately 130000 cubic meters of excavated stone materials were used in the stone quarry within the reservoir area. During the preparation period, 220000 cubic meters of intermediate materials were used in the project. The lower storage area project generated a total of approximately 1.11 million cubic meters of waste (loose cubic meters). In the later stage, the cleaning waste of the storage basin can be disposed of in the 2 # slag yard after the backfilling of useful materials, with approximately 80000 cubic meters. All other waste will be disposed of in the slope behind the lower storage dam.

4.3 Timing Analysis of Earth-Rock Utilization Planning

The filling of the upper reservoir dam mainly utilizes the upper reservoir stone material yard, inlet/outlet, and intermediate materials excavated during the construction period. The excavation time of useful materials is basically the same as the filling time of the dam, and the strength of the materials can be adjusted according to the filling strength of the dam. Therefore, the time can basically meet the requirements of synchronous production and filling. The amount of materials directly used for excavation and filling of the upper reservoir is 510000 cubic meters. During the filling process of the upper reservoir dam, the excavated materials at the inlet/outlet of the upper reservoir cannot fully meet the synchronous filling and rising needs of the upstream and downstream rock materials. Therefore, the insufficient amount of upstream rock materials will be supplemented by the excavated materials from the stone yard in the upper reservoir, and the insufficient amount of downstream rock materials will be supplemented by the intermediate materials excavated from the tunnel excavation during the construction period, By adjusting the strength of the stone quarry and the intermediate materials during the construction period, synchronous production and filling can be basically achieved. The amount of materials needed for excavation needs to be transferred to the upper dam for filling is 80000 cubic meters. Among them, 50000 cubic meters of materials need to be transferred during the construction period of connecting the upper and lower reservoirs to the highway tunnel, and 30000 cubic meters of materials need to be transferred during the excavation of the main project of the upper reservoir. Temporary transfer can be carried out using the waste disposal area inside the reservoir.

The filling of the lower reservoir dam mainly utilizes the lower reservoir spillway, underground power plant, water conveyance system, ground switch station, lower reservoir stone yard, lower reservoir inlet/outlet, and pre construction transfer materials. The excavation time of useful materials is basically the same as the filling time of the dam, and the strength of the materials can be adjusted according to the filling strength of the dam. Therefore, in terms of time, synchronous production and filling can be basically met. Before the filling of the lower reservoir dam begins, a small portion of the underground powerhouse and water conveyance system's stone holes are excavated and directly transported to the lower reservoir's artificial sand and gravel processing system for concrete aggregate production. The remaining useful materials are stored in the transfer material yard I of the lower reservoir as a source of subsequent artificial aggregate materials. After the start of dam filling, on the premise of meeting the demand for artificial aggregates, the excavated materials from the underground power plant and water conveyance system's stone tunnels are given priority as dam building materials. At the same time, the mining intensity of the materials used in the spillway of the lower reservoir and the ground switch station matches the peak filling period of the dam, and can basically be directly used on the dam. The insufficient amount of upstream rockfill material will be supplemented by the downstream rockfill material yard, while the insufficient amount of downstream rockfill material will be supplemented by the transfer material during the construction period (using the stone excavation materials from the 2# waste disposal site and the transfer material yard II area). The amount of excavated materials directly used for dam filling (natural cubic meter, the same below) is 1.15 million cubic meters. The transfer materials for dam filling are basically the transfer materials for the construction period, about 130000 cubic meters. During the dam filling process, the transfer materials can be used for transfer in the 2 # waste disposal site.

The majority of the aggregate materials for the concrete and cushion layer materials in this project are sourced from underground engineering tunnel excavation materials, and there is a tunnel excavation material transfer yard near the sand and gravel processing system in the lower reservoir, which can meet the temporary storage of tunnel excavation materials (with a capacity of about 520000 cubic meters and a maximum storage capacity of about 500000 cubic meters, including about 90000 cubic meters of intermediate materials for the construction period for the lower reservoir dam). Therefore, the misalignment of concrete aggregates and tunnel excavation materials in the production schedule can be solved, The direct utilization of aggregate sources is about 320000 cubic meters, and about 450000 cubic meters need to be transferred through a transfer yard.

In summary, the filling and aggregate production of this project are carried out in accordance with the principle of synchronizing as much as possible and matching with the progress, and temporary storage space is provided for any mismatched phenomena that occur during the construction process, which solves the contradiction in timing and meets the needs of engineering construction.

5 Conclusions

Based on the construction plan and earthwork balance calculation results, the possible deviations and countermeasures for earthwork balance in this project during the construction process are analyzed as follows:

(1) Storage capacity of the material yard. The total reserves of the useful layer in the quarry on the west bank of the upper reservoir are about 2.7375 million cubic meters, and the total reserves of the useful layer in the quarry on the right bank of the lower reservoir are about 572300 cubic meters. The reserves meet the 1.25 times of the reserve factor required by the planned mining output in the Code for Construction Planning of Hydropower Projects (NB/T 10491-2021).

(2) Designed mining output. If the design mining output of the upper and lower reservoir quarries fails to meet the dam filling volume during the construction, the upper reservoir can continue to excavate the quarry in the reservoir or mine the spare quarry,

and the lower reservoir can mine the spare quarry to meet the needs of engineering filling materials.

(3) Concrete aggregates. The concrete aggregates used in this project are excavated materials from underground engineering, which can fully meet the needs of concrete aggregates. During the implementation process, the excavated materials from the tunnel should be prioritized for use as concrete aggregates; When excavation materials cannot meet the needs of concrete aggregates during the construction process, a slight increase in excavation materials from the material yard can be used to supplement the situation.

(4) Spoil storage. If the amount of abandoned slag increases during the implementation process, the upstream reservoir area can start the pressure slope behind the dam; The capacity of the slag yard in the lower storage area is relatively large, with surplus reserve capacity, so there will be no situation where waste slag is stored without a place.

(5) Calculation results. The overall utilization rate of earthwork and stone excavation in this project is about 65%. Without considering the quarry, the utilization rate of other earthwork excavation materials is about 60%, and the overall utilization rate of earthwork excavation is about 83%. The utilization coefficient is generally appropriate; The conversion factors for stone utilization and waste slag meet the requirements of the specifications. Therefore, overall, the calculation results are generally reliable and the deviation is controllable.

In this paper, by selecting reasonable conversion coefficient of fill material and utilization coefficient of excavation material, the soil and rock balance planning of pumped storage power station is carried out, and the timing and sensitivity of the planning are studied and analyzed. However, the construction period of pumped storage power station is long and the geological conditions are complex, so the earth-rock balance planning should be a dynamic adjustment process, and the dynamic change of earth-rock balance is not considered enough in this paper. The research of dynamic planning will be the key breakthrough direction of the soil and rock balance research of pumped storage power station in the future.

Acknowledgments

Headquarters science and technology Project of State Grid Corporation of China<Research on Dynamic Multi-dimensional Perception and Prediction Warning Technology for Hydraulic Structure in Construction Period of Pumped Storage Power Station>(Project Code：5108-202218280A-2-301-XG)

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