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INFLUENCE OF CONSTRUCTION PERIOD OF BRIDGE ACROSS RESERVOIR ON OPERATION OF ADJACENT POWER STATION

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ABSTRACT

The influence of the construction period of the bridge project across the reservoir on the adjacent power station includes not only the direct impact on the hydropower hub but also the impacts on the reservoir area, flood discharge, power station head, water diversion and sediment prevention, power generation operation, and other factors. In this paper, from the aspects of the power station operation, an evaluation index for the influence of the construction period of a bridge across a reservoir on the adjacent power station is developed, and an evaluation system is constructed. Based on the constructed evaluation system, the influence of the bridge construction period on the adjacent power stations is analyzed. This evaluation system provides a reference for the impact assessment of cross-reservoir bridge engineering on adjacent hydropower stations.

KEYWORDS

Bridge engineering, Construction stage, Environment, Influence, Reservoir

INTRODUCTION

The smooth road is inseparable from the connection of the bridge, and the bridge has become a common and special part of the road building. It is common because crossing rivers and valleys cannot be separated from bridges, every river on the way is crossed by bridges. It is special because the bridge is actually the road in the air. If the road is in the air, the structure and material of the road will become complex and special, and need special scientific support and process production [1][2]. Today, with the rapid development of science and technology, there are talents and universities specializing in the study and study of bridge construction, With the support of advanced technology and a variety of powerful machines, the construction of Bridges under various conditions has become convenient, and ultra-long and ultra-high bridges have become easier and easier [2][3].

Bridges are one type of historically representative engineering structure in the process of human history. The San Francisco Golden Gate Bridge in the United States, the Sydney Harbour Bridge in Australia, London Bridge in the United Kingdom, the Stone Strait Bridge in Japan, the Yangpu Bridge in Shanghai, and the Hangzhou Bay Cross-sea Bridge, the Nanjing Yangtze River Bridge, the Hong Kong Qingma Bridge, and the Hong Kong-Zhuhai-Macao Bridge in China are all valuable works of art and have become regional landmarks and landscape highlights [4][5]. Due to the need for highway construction in various terrains and landforms, including construction in mountainous areas and of reservoir bridges, the construction of some highways has encountered more complex terrain and geological conditions. The main manifestations are as follows: the ground height difference in mountainous areas varies greatly, each span is large, the height of the bridge pier is generally required to be large, and the terrain is steep [6].

For railways that encounter a large number of reservoir dams, the interaction between their construction and the reservoir dams distributed along the line cannot be avoided. It is extremely urgent to find ways to evaluate the impact of the railway bridge construction period on adjacent power stations and to solve the dispute between railway constructors and the owners of hydropower projects along the line. Currently, few studies have been conducted on the impact assessment of cross-reservoir bridge projects on power stations. The Southern Sichuan Railway Company has evaluated the impact of the Fushun Tuojiang River Bridge on the Huangnitan Hydropower Station from the aspects of the power station structure safety, flood discharge, power generation operation, and bank slope [7]. In addition, Huang [8] and Zhang [9] conducted relevant research on the impact of bridge vibration on the surrounding environment and achieved certain results. However, research in this field is still in the supplementary improvement stage, and impact assessments of bridges on reservoir power stations are also very scarce.

Therefore, in this study, a super-large bridge on a railway across a reservoir is taken as an example, and the impacts of bridge construction on all of the aspects of the adjacent power station are determined. Furthermore, the potential impact indicators of the bridge on the power station are determined as much as possible, and an evaluation system is developed to provide a reference for the impact assessment of bridges across reservoirs on adjacent power station projects.

PROJECT PROFILE

The railway is located in Shiyang Town, Tianquan County, Ya'an City, Sichuan Province. It crosses the Xinzhong Hydropower Station via the Xinzhong Power Station Bridge. The bridge obliquely crosses the reservoir area of the Xinzhong Power Station approximately 50 m to the south of the dam, and the bridge axis is 47° obliquely crossing the dam (Figure 1). The bridge is a double-track curved railway. The bridge scheme is a 5-unit 2 × 68 m T-shaped continuous girder bridge. The total length of the bridge is 796.62 m, and the maximum height of the bridge is approximately 33.5 m. The nearest distance between the bridge and the power station is approximately 50 m. Piers 4–12 of the bridge are wading piers. The wading pier 4 is located closest to the power station and is 175 m upstream of the power station water intake.

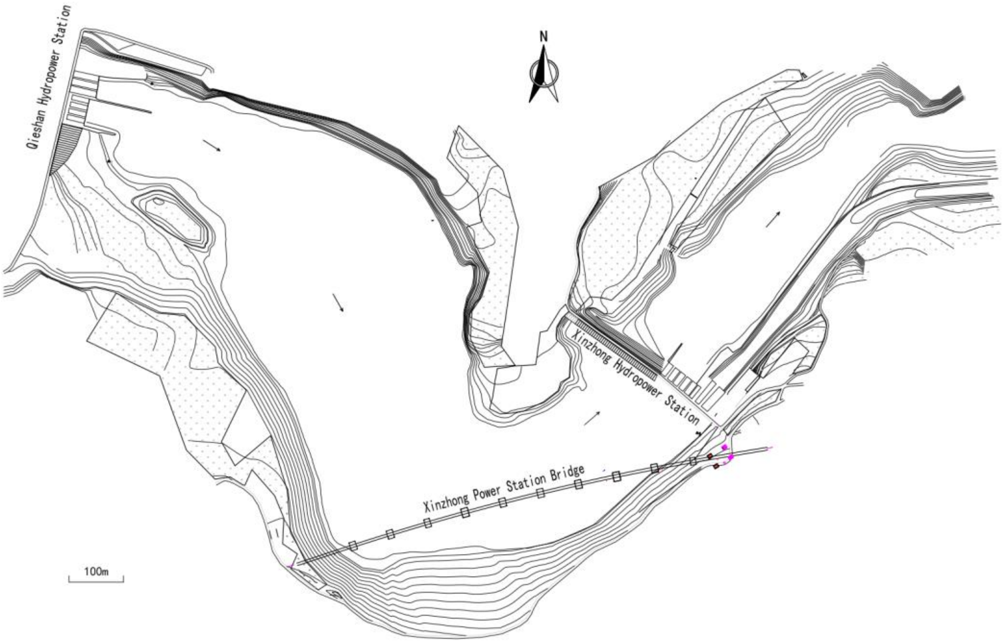


Fig. 1 – Schematic showing the relationship between the location of the Xinzhong railway bridge line and the power station

The Xinzhong Hydropower Station is located on the main stream of the Tianquan River in Tianquan County Town, approximately 11 km from Tianquan County Town (Figure 2). The Xinzhong Hydropower Station is a riverbed power station, and the project consists of a retaining dam, power plant, and tailrace. The installed capacity of the power station is 21 MW (3 × 7 MW), and the designed water head is 13 m. The normal water level of the reservoir is 656.50 m, and the adjustable reservoir capacity is 680,000 m^3. The designed flood standard of the power station is a 50-year flood (flow rate of 3560 m /s), and the check flood standard is a 300-year flood (flow rate of 4620 m^3/s). The reservoir operation mode is as follows: during the flood season (June to October), when the inflow is less than 500 m^3/s, the reservoir is maintained within the normal water level; when the storage flow is greater than 500 m^3/s, the gate is opened and flushing is stopped [10].

The construction and operation of the power station are as follows: the construction of the Xinzhong Hydropower Station began in October 2005 and was completed in December 2010. Through operation, inspection, and rectification over the years, it has been determined that the Xinzhong Hydropower Station hub project is in good health and running normally.

Fig. 2 – Site photos of Xinzhong Hydropower Station

CONSTRUCTION OF IMPACT ASSESSMENT SYSTEM

The impacts of similar cross-reservoir bridges such as the Xinzhong Railway Bridge on the power station are not limited to the impact on the hub project itself. Under the long-term operation of the reservoir, the impact also includes many problems such as erosion and deposition in the reservoir area, flood discharge, power station head, water diversion and sediment prevention, and power generation operation [11]. In this study, a total of nine impact assessment indices were selected from the three aspects of the reservoir impact, the power station hub impact, and the power generation operation impact in the impact assessment of the Xinzhong Railway Bridge on the adjacent Xinzhong Hydropower Station to construct an assessment system for the impact assessment of the power station. The construction of the impact assessment system is illustrated in Figure 3.

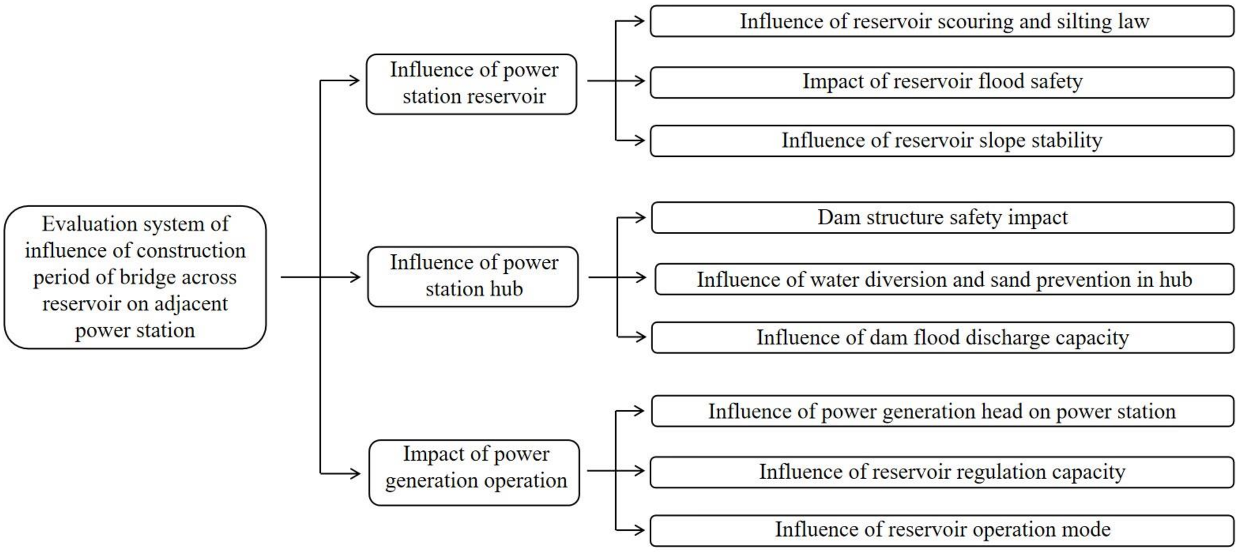


Fig. 3 – The impact assessment system of the construction period of the cross-reservoir bridge on the adjacent power station

RESULTS: IMPACT ASSESSMENT OF XINZHONG POWER STATION

Status evaluation of Xinzhong Power Station

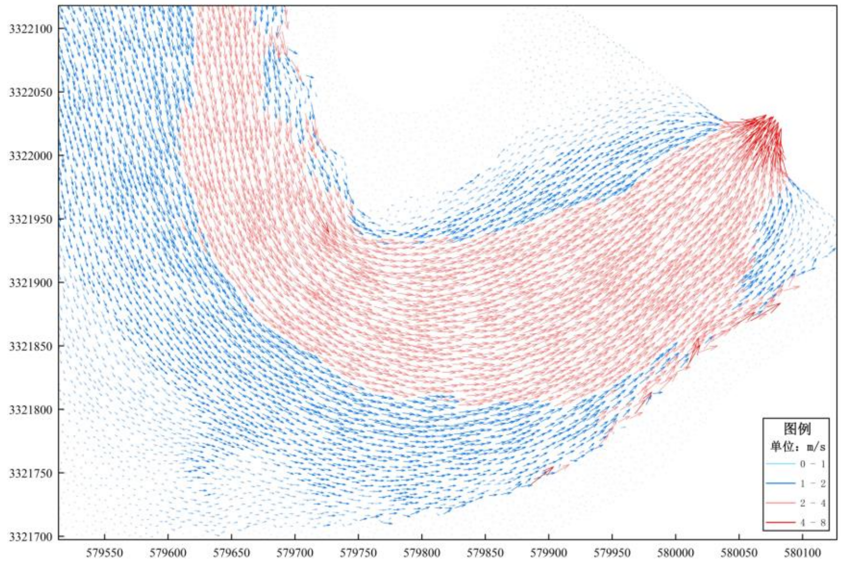
The Xinzhong Power Station was commissioned in 2010. During the first 10 years of reservoir operation, all of the hydraulic structures were in normal operation without major reconstruction or expansion. According to the analysis presented in the External Deformation Monitoring Report of the Xinzhong Power Station, the reservoir and dam of the Xinzhong Power Station have good safety conditions without obvious external deformation.

Reservoir impact

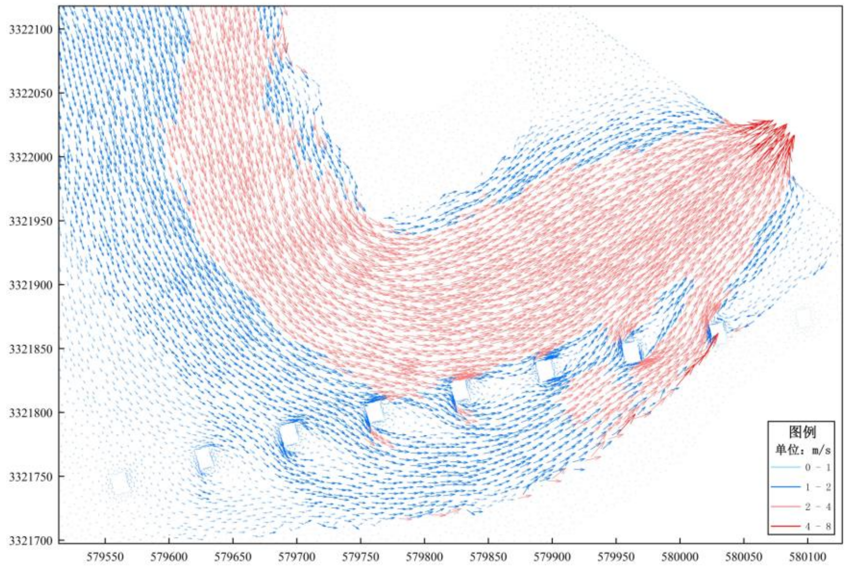
The influence of the bridge construction on the reservoir area of the power station was mainly caused by the construction of the wading bridge pier, including the change in the flow field in the reservoir area caused by the cofferdam of the wading bridge pier, the rise of the water level, and the disturbance of the riverbed by construction. In this study, the influence of the Xinzhong Railway Bridge on the Xinzhong Power Station reservoir area was evaluated. Using the Mike21FM two-dimensional hydraulic calculation software, the hydraulic calculations were performed for the cofferdam of the wading pier during the construction period, and the influence of the bridge on the reservoir area during the construction period was evaluated based on the changes in the flow field, water level, and sediment deposition [12].

Change in the reservoir flow field

There are nine wading piers on the Xinzhong Railway Bridge. The flow field analysis was performed as follows: the flow velocity in the main flow area of the bridge section was between 2.00 and 3.20 m/s, and the main flow in the river section was located on the right side of the center of the riverbed under natural conditions. Due to the large size of the steel cofferdam during the construction period (maximum size of 11.1 × 14.9 m), the influence of the bridge pier cofferdam on the flow field in the river section during the construction period was obvious. Under the action of the bridge pier cofferdam, the water flow was pushed to the central part of the area. The main stream of the river was completely located in the middle of the riverbed, and the flow velocity in the middle of the riverbed area was significantly increased compared with the current situation.

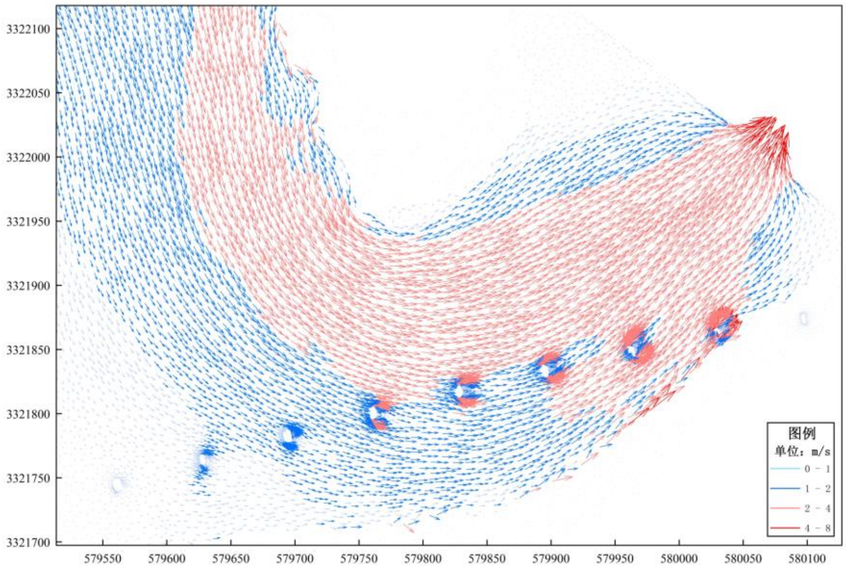


(a) Current flow field



(b) Flow field during construction

Fig. 4 – Comparison of the flow fields in the reservoir area during and after bridge construction (designed flood flow conditions)



(c) Operating flow field

Fig. 4 – Comparison of the flow fields in the reservoir area during and after bridge construction (designed flood flow conditions)

Effect of reservoir erosion

The river section of the bridge is a typical river bend section. The sediment transport forms a bent circulation phenomenon. The right concave bank is dominated by erosion, and the left convex bank is dominated by deposition. During the bridge construction period, when the inflow was less than the boundary flow of 500 m3/s, due to the operation of the water level in front of the power station dam at a higher normal storage level, the flow velocity in the reservoir area was small, and the sediment carrying capacity of the water flow was weak. Under these conditions, the change in the flow velocity caused by the construction of the pier was also very small. Therefore, when the inflow was small, the pier construction had little effect on the riverbed siltation. When the inflow was greater than the demarcation flow of 500 m3/s, the water level of the power station was a lower open water level, and the flow velocity of the river section increased and returned to the natural river state. Under the action of the bridge pier steel cofferdam, the sediment, which was originally moving with the main stream of the river on the right side, was pulled to the riverbed area on the left by the flow, resulting in the change in the local riverbed deposition pattern. However, because the construction period was only 32 months, the influence of the change in the riverbed sedimentation on the long-term operation of the power station was controllable.

Impact of reservoir flood safety

The steel cofferdam of the bridge pier is located in the main stream area of the river, occupying the flood area of the river, and it has a certain water-blocking effect, resulting in a certain rise in the water level of the reservoir area. The results of the hydraulic calculation revealed that under the condition of a 50-year flood flow in the design standard, the maximum water level of the river section would rise by 0.64 m. However, there would be no important flood control object or flood control sensitive point in the Xinzhong reservoir area, and the rise in the water level would have little effect on the flood control in the reservoir area.

Effect of bank slope stability

The reservoir area of the Xinzhong Power Station mainly exposes the Oligocene Lushan Formation (E3l), which is composed of silty mudstone interbedded with thin argillaceous siltstone and a small amount of sandstone. The bank slopes on both sides are composed of bedrock, and there is no unfavorable fracture combination. Although a small amount of collapse occurs under the action of dynamic water processes, it has little effect on the whole bank, and the bank slopes on both sides are stable.

The pier is located near the right bank slope. During the foundation excavation stage of the construction, the excavation was controlled, the support was well done, blasting was strictly prohibited to prevent instability of the bank slope, and slope observation and early warning were also well done. If the bank slope collapses or loses stability, it should be repaired before the flood season.

The river section of the bridge is a typical curved river section. During the flood season, the main stream of the river is located on the right side of the river. The right bank of the river section belongs to the top scour part of the river. Under the action of the steel cofferdam of the bridge pier, the main stream area was shifted from the right side of the river to the center of the riverbed. Therefore, the pier steel cofferdam of the bridge construction reduced the risk of water erosion of the right bank.

Influence of power station hub

The influence of the construction of this new railway bridge in China on the power station hub was a direct dominant influence, which was mainly manifested as direct damage to the power station dam by the bridge construction and a negative effect on the safety of the engineering structure. The bridge construction resulted in water diversion and sediment problems caused by the power station shutdown, and the influence of the bridge construction on the dam discharge capacity caused dam flood control safety problems.

Influence of dam structure

The retaining dam, flood discharge sluice, power plant, and other buildings are the most important facilities of the dam. The bridge needs to be carefully evaluated before construction, and protection should be strengthened during construction. The construction of the Xinzhong Railway Bridge included trestle construction, bored pile construction, cofferdam construction, bridge structure construction, and other procedures. There were no violent construction activities such as blasting in these construction procedures, and there were small vibrations during the bored pile steel casing and pier cofferdam insertion processes. However, the riverbed overburden medium between the bridge and the power station had an obvious buffering effect on the construction vibrations. Under the condition of a reasonable construction scheme and other control measures, the influence of the vibrations on the dam could be effectively controlled. Therefore, during the bridge construction period, the direct safety threat to the structure of the retaining dam, flood discharge sluice, power plant, and other buildings of the Xinzhong Power Station was low.

Influence of water diversion and sand prevention in hub

The Xinzhong Power Plant is located on the right side of the riverbed. The bridge construction period had little effect on the change in the flow field near the sand trap of the plant, and the effect of the sand trap in front of the plant was not significantly changed by the bridge construction.

The foundation construction directly disturbed the sediment of the riverbed cover, which caused an increase in the suspended sediment content of the water flow for a short period, increasing the sediment amount passing the power station and threatening the operation safety of the generator set. To ensure the safe operation of the power station unit, when the bridge construction had a great influence on the riverbed disturbance, the power station needed to be shut down in time to avoid the sand peak.

Influence of dam flood discharge capacity

The flood discharge capacity of the hydropower station is mainly controlled by the orifice size of the flood discharge facility and the downstream water level flow relationship. The Xinzhong Railway Bridge is located upstream of the Xinzhong Hydropower Station. The bridge does not affect the orifice size of the flood discharge facilities or the relationship between the downstream water level and flow. Therefore, the construction period of the Xinzhong Railway Bridge did not affect the flood discharge capacity of the Xinzhong Hydropower Station and did not affect the flood control safety of the hub.

Influence of power station operation

Compared with the direct impact of the bridge on the power station hub, the impact of the bridge on the power generation operation of the power station was more indirect and implicit. For example, the backwater caused by the bridge construction led to a decrease in the water head or a decrease in the regulating reservoir capacity and forced the management to change the reservoir operation mode, resulting in the hidden loss of power generation by the hydropower station.

Impact of power generation head

The power generation head of the power station is mainly controlled by the tailwater level flow relationship of the power station when the water level in front of the dam is constant. The bridge project was generally located downstream of the power station and could raise the tailwater level and reduce the power generation loss of the power station. In this case study, the Xinzhong Power Station Bridge is located upstream of the Xinzhong Power Station. The bridge does not affect the downstream water level flow relationship and does not affect the power generation head of the Xinzhong Power Station.

Adjusting the storage impact

The normal reservoir level of the Xinzhong Hydropower Station is 656.50 m, the regulating reservoir capacity is 680,000 m^3, and the total reservoir capacity is 1.47 million m^3. The total steel cofferdam volume during the construction period of the wading bridge was approximately 75,000 m^3, accounting for approximately 0.5% of the total reservoir capacity of the reservoir, so it had little effect on the regulating reservoir capacity of the reservoir.

Influence of reservoir operation mode

The reservoir operation mode is mainly related to the reservoir scouring, silting rule, regulating storage capacity, tail water level, and flow. If the above indices change significantly, the operation mode of the reservoir needs to be adjusted. According to the analysis, the construction period of the Xinzhong Railway Bridge did not cause significant changes in these indicators and did not cause adjustment of the operation mode of the power station reservoir.

Construction of evaluation system of Xinzhong power station

According to various influencing factors, the evaluation index system includes 3 first-level indicators and 10 second-level indicators. According to the characteristics of Xinzhong Power Station, the weight of each index is set. For different environmental characteristics, the choice of index weight can also be different. The evaluation index system is shown in Table 1.

Fig. 1 - Xinzhong power station evaluating indicator system table

First-level indicators		First-level indicators	
Name of indicator	Weight	Name of indicator	Weight
Reservoir impact	0.4	Change in the reservoir flow field Effect of reservoir erosion Impact of reservoir flood safety Effect of bank slope stability	0.25 0.25 0.25 0.25
Influence of power station hub	0.3	Influence of dam structure Influence of water diversion and sand prevention in hub Influence of dam flood discharge capacity	0.30 0.30 0.40
Influence of power station operation	0.3	Impact of power generation head Adjusting the storage impact Influence of reservoir operation mode	0.30 0.30 0.40

The calculation formula of the influence index of the power station is as follows:

$$RHI = \sum_{i=1}^{n}(ZB_{nw} \times ZB_{nr}) \tag{1}$$

In Formula (1): RHI is the comprehensive score; ZB_{nw} is the weight of the nth index in the index layer; ZB_{nr} is the score of the nth index of the index layer.

The power station impact assessment level is divided into three levels according to the evaluation index score from high to low, namely level I (safe), level II (relatively safe), and level III (unsafe). The scoring range and evaluation grade of the impact index of the power station are shown in Table 2.

Tab. 2 - Power station impact index classification standard table

Assignment range	Evaluation grade
[85.00，100]	Grade I
[60.00，85.00)	Grade II
[0，60.00)	Grade III

Loss evaluation

The loss estimation of the impact of railway bridges on power stations mainly includes the inundation loss of the reservoir area, the structural loss of the power station hub, and the power loss. The inundation loss of the reservoir area is the compensation cost of the new inundated object caused by the bridge construction. The structural loss of the power station hub is that when the bridge construction causes structural damage to the power station hub, it is necessary to evaluate the degree of structural damage and to calculate the compensation cost according to the amount of reconstruction or repair work. The electric quantity loss is calculated according to the electric quantity loss caused by the decrease in the water head of the power station, the shutdown of the station to avoid the sand peak during the construction period, and the change in the reservoir operation mode.

According to the above analysis, the Xinzhong Railway Bridge had no compensation for new submerged objects in the reservoir area, no compensation for structural losses to the power station hubs, and no compensation for power losses caused by a decrease in the power station head and changes in the reservoir operation mode. However, there was compensation for power losses caused by the disturbance of the riverbed during bridge construction, which required shutting down the power station to avoid the sand peak. However, the influence of the sediment on the operation of the unit was more complex. Whether it was necessary to stop the machine to avoid sediment depended on the sediment content, grain type, the effect of the unit itself on the sediment adaptability, the bridge construction period, and other factors. Therefore, it is necessary to strengthen the sediment monitoring of the intake of the power station during the bridge construction period, to dynamically adjust the operation period of the unit according to the situation, and to carry out statistical analysis of the power generation loss according to the actual power station shutdown days after the construction is completed.

Problems that may be encountered during construction

There are relatively few regulations for mountainous areas and reservoir areas, and the corresponding schemes should be adopted in combination with different landforms. Many research aspects need to be refined and improved.

(1) The transportation of bridge materials in mountainous areas has always been a difficult problem in the construction process. Due to the poor linear shape of the access channel, it is difficult for large vehicles to enter and exit, and thus, the transportation of beams and plates or large materials becomes a technical problem.

(2) There are many factors affecting the type of bridge constructed in mountainous areas and reservoirs, so it is necessary to monitor the mid- and long-term stress and deformation of the bridge in the later operation process to study the wind load, temperature, concrete shrinkage and creep, and the influence of materials on the durability of the structure.

CONCLUSIONS

In this paper, the impact assessment system of the railway bridge across the reservoir on the adjacent power station is constructed, the impact assessment factors are constructed, and the analytical weight value of each factor is determined. Taking the construction of railway bridge for Xinzhong Hydropower Station as an example, the impact of the bridge on the construction period and the whole life of the bridge is evaluated systematically. According to the calculation, the evaluation value of the railway bridge to the power station is 86, and the evaluation impact is small.

The construction of the evaluation system can provide a powerful negotiation basis for resolving the disputes between the railway construction side and the hydropower project owners along the line, and help to quickly resolve the differences between the parties and promote the project process.

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