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Research Article

Study and Design Analysis of Hazard Removal and Reinforcement Scheme of a Bridge Diversion Sluice

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Most of the existing sluices in China have been in operation for more than 40 years, and the aging problem is becoming increasingly prominent. The selection of reinforcement schemes for sluices in vulnerable conditions is of great significance to the whole project. A reasonable reinforcement scheme can ensure their safe operation and reduce unnecessary resource investment. This study focuses on the diversion gate of a bridge in China that through aging has emerged insufficient capacity of downstream energy dissipation and scour prevention, severe scour of the diversion dike foundation, and insufficient flood control and rescue capacity. Two reinforcement schemes are examined by analyzing the engineering parameters of the bridge diversion sluice and the necessity of engineering construction, namely, raising the flood discharge level and increasing the width of the overflow section. In this study, Super Decisions software was first used to simulate the reinforcement scheme of the bridge diversion sluice, calculate the weight of the factors, and obtain the optimization scheme from the two aforementioned reinforcement schemes, which was based on the analytic network process (ANP), and the related factors affecting the reinforcement scheme of the bridge diversion sluice are determined and evaluated. The relevant calculation and analyses of the optimization scheme are conducted using ANSYS finite-element software. The selection process of reinforcement scheme for such sluices provides a reference for other similar projects.

1. Introduction

During the 1960s and 1970s, many sluices were built in China in a wave of water conservancy construction projects. However, many of these sluices do not meet the current standard requirements owing to technological limitations at the time of construction. In particular, after 20 to 30 years of use, the effects of equipment aging and structure corrosion have resulted in poor flood regulation and have created dangerous conditions by delaying the response time for flood mitigation and rescue and hampering the effective progress of flood control work in the event of a flood disaster [1]. In addition to the aforementioned effects, the main risks of such sluices in China are associated with insufficient flood control standards, damages to the energy dissipation mechanism and antishock features, poor stability of the sluice chamber, failure to meet the requirements of current antiseismic design codes, and other factors [2, 3]. The analysis of sluice risk includes two main research objectives: appraising the safety of sluices in vulnerable conditions and selecting appropriate risk reinforcement measures [4, 5].

To evaluate the hazard removal and reinforcement scheme of sluice is the basis for sluice reinforcement. Till now, there is no scientific, mature, and widely applicable theoretical method to evaluate the safety and reinforcement scheme of sluices that have been in operation for many years. Some scholars have deeply discussed and studied the application technology of safety evaluation, such as dynamic measurement technology of cracks in concrete [6, 7]. Owing to the lack of unified standards, the selection of index evaluation mainly focuses on literature review and subjective judgment of personnel in related fields. Especially for those sluices with different characteristics in different regions, the rationality and applicability of evaluation still need to be further discussed. As many scholars are influenced by subjective factors and ignore the mutual restriction between evaluation factors when comparing design schemes [8–14], it is necessary to find an objective evaluation method suitable for the reinforcement scheme. Selecting the scheme of the hazard removal and reinforcement projects a multiattribute evaluation problem; many factors should be considered, such as the project investment, construction difficulty, scheme reliability, construction period, and scope of environmental influence [15–18]. Meanwhile, in the practical application of constructing the evaluation system of the reinforcement scheme of sluice, the indicators and weights should be adjusted appropriately according to the location of the sluice in vulnerable conditions, the main causes of the occurrence of problem and the characteristics of the project, so as to make the evaluation more accurate and targeted. A reasonable reinforcement scheme can save resource investment and can achieve the effect of safe operation.

At present, scheme evaluation has been widely used in the optimization of water conservancy and hydropower planning scheme. The multiattribute evaluation theory has been applied to the safety evaluation of sluice, but seldom applied to the scheme optimization. Men et al. established a projection model that can be used in multiobjective decision-making based on grey relational projection method, which can be used in the selection of water conservancy project development schemes [19]. Guo proposed the ANP-FCE-integrated comprehensive evaluation method after combining the characteristics of network analysis method and fuzzy comprehensive evaluation method. This method can obtain more objective results in the postevaluation of water conservancy projects [20]. The artificial neural network method has been used by some scholars to study the optimization of hydropower planning scheme [8, 9]. Yabo et al. proposed a decision-making method based on relative entropy ranking, which is an evaluation model that can comprehensively evaluate the differences of all bidding schemes of water conservancy projects and proved to be the most effective compared with other methods [21–23]. To solve the problem of scheme selection, scholars also have put forward many evaluation methods, such as principal component analysis, Monte Carlo simulation comprehensive evaluation method, Entropy-TOPSIS combined method, and so on [24–26].

In 1971, Saaty proposed ANP, which is a multiattribute decision theory and applied this method to research of the US Department of Defense [27]. Since then, some scholars used ANP to establish a sustainable building renovation mechanism under the energy performance contracting mode. Through interviews and questionnaires, they obtained key evaluation indicators of the mechanism of continuous building renovation. In their study, the priority of relevant indicators was determined through a panel discussion [7, 28–32]. In separate studies, Guang and Bo analyzed the influence of underground engineering construction on surrounding buildings and the recycling of electronic products using AHP, respectively [33, 34]. In terms of environmental protection, the analytic network process (ANP) method is utilized to derive weights of criteria and subcriteria for practitioners to determine the best construction and demolition waste (CDW) utilization scheme from a comprehensive perspective [35]. There are also some studies on Environmental Assessment focusing on ANP, such as the prioritization of river water quality sampling points, management of socio-ecological wetland systems, Rural Groundwater Demand Management [36–40]. As the ANP evaluation method is relatively objective, the ANP method also is used to determine the index evaluation system of pipeline failure probability. The results show that the evaluation results of this method are consistent with the daily cognition and field detection results [41–44]. In these studies, Super Decisions software was used to calculate the weight, and MATLAB programming was employed to calculate the weight of the corresponding influencing factors, which provided a new method for weight calculation based on ANP [45–47]. However, little research has been conducted on the application of ANP for scheme comparison and the selection of sluice reinforcement.

Structural calculation is an important factor affecting the selection of sluice design scheme, which is always a popular subject in people's research [48, 49]. The traditional method of analyzing the structure of sluice is to calculate the internal force separately from the bottom plate and the sluice pier in the sluice chamber and simplify the sluice pier as cantilever beam by means of material mechanics or structural mechanics [46]. The sluice floor is simplified by strip cutting method, and the internal force calculation of foundation beam is carried out by looking up table method [22, 23, 50, 51]. This method is simple, but it is difficult to reflect the overall role of the structure and is far from the actual situation.

In order to solve the aforementioned problems, the following investigations have been conducted: (1) Employ ANP to compare and select the reinforcement schemes of a sluice in vulnerable condition and use the fuzzy comprehensive evaluation method to consider the selected optimization schemes; (2) adopt the counterforce straight line method or elastic foundation beam method to distribute the unbalanced shear force in proportion to the gate pier and floor, separately; (3) establish an ANSYS finite-element calculation model for the gate chamber structure; (4) finally, considering the gate, pier, and floor as a whole, calculate the displacement and stress of the gate chamber structure.

2. Materials and Methods

2.1. Network Analytic Hierarchy Process. The network analytic hierarchy process (ANP) is a multicriteria decision-making theory used to obtain the relative weights of evaluation indices through personal judgment. The calculation steps of ANP are as follows. (1) The specific situation of the problem is clarified, including the possible results of the control layer and the network layer, and the influencing factors of the decision are analyzed. (2) The control quasi-side cluster (the target of hierarchy) and elements in the cluster are determined. If the model is relatively complex, the clusters and elements can be numbered. (3) The control criterion is connected with its related clusters, and the cluster elements are connected with dependencies within the cluster. (4) The super matrix is established. Numbered elements are first placed to the left of the matrix and are then placed in order at the top of the matrix. The elements are compared pairwise to find the weight, which is entered in the corresponding position of the super matrix. (5) Pairwise comparisons of the elements are made according to their influences on elements in their clusters and in other clusters. (6) Consistency testing is conducted on the judgment matrix. (7) The vector is weighted. (8) Sensitivity analysis is conducted on the final results [52].

2.2. Fuzzy Comprehensive Evaluation Method. Let n factors be related to the object under evaluation, marked as $U = \{u_1 u_2 \ldots u_n\}$, and M represents all possible comments, marked as $V = \{v_1 v_2 \ldots v_m\}$. Then, the steps of the fuzzy comprehensive evaluation method are as follows.

Determine the factor set $U = \{u_1 u_2 \ldots u_n\}$.

Determine the evaluation set $V = \{v_1 v_2 \ldots v_m\}$.

The membership vector is then obtained by single-factor judgment $r_i = \{r_{i1} r_{i2} \ldots r_{im}\}$ and forms the following membership matrix:

$$R_i = \left\{ \begin{array}{cccc} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdot\cdot \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{array} \right\}. \quad (1)$$

Determine the factor centralization weight vector and normalize the evaluation set. Then, determine the comprehensive membership degree $B = A \circ R$, where "$\circ$" represents the synthesis operator.

The evaluation is conducted according to the principle of maximum membership degree.

2.3. Finite-Element Model. The displacement and stress of the sluice chamber were simulated using ANSYS. The calculation model considers the pier and the floor as a whole, neglects the effect of the tooth wall, and puts the floor directly on the foundation. By equivalent simplification, the upper structure of the gate chamber acts on the pier in the form of surface load. The load of the gate chamber is simplified. The upstream water pressure is distributed in the groove of the pier and is applied in the form of surface load. The upstream water weight acts on the upstream floor in the form of surface load. The self-weights of the pier and the bottom plate are automatically calculated by inputting the corresponding density into the program's material definition command. The uplift pressure also acts on the floor in the form of surface load.

3. Results and Discussion

3.1. ANP Model in the Super Decisions Interface. As shown in Figure 1, the ANP model for the project study of the bridge diversion junction was established, and the model reflects the relationship between the control and network layers. In the network layer, we divided the research contents into five categories: project cost, scheme reliability, construction period, construction difficulty, and environmental impact. Fifteen evaluation indicators were used, including project number, engineering, geology, engineering, hydrology, land acquisition and immigration, safety, reliability, durability, construction organization and design, political influence, "three wastes" emissions, ecological environment, noise pollution, construction technology, traffic conditions, water and electricity supply, and communication.

3.2. Priority and Comparison of Risk Elimination and Reinforcement Schemes. According to the priority selection of the schemes shown in Figure 2, the weight of Scheme 1 was 0.58674, and the priority of Scheme 2 was 0.41326. Thus, Scheme 1 is more likely to be adopted. After the aforementioned steps were completed, the global weights were generated, and the final weights were obtained, as shown in Figure 2. The scheme was regarded as an optimization scheme, and the evaluation set of its factors is W = {excellent, good, pass, fail}. The bridge sluice risk elimination and reinforcement program evaluation was conducted through a questionnaire survey distributed to seven evaluation experts and three designers. After the completed questionnaires were collected, the evaluation factors were normalized, and the evaluation results were processed. The final results are shown in Table 1.

According to the evaluation results, the corresponding evaluation matrix was constructed as follows:

$$\begin{aligned} A &= \begin{bmatrix} 0.2 & 0.5 & 0.2 & 0.1 \\ 0.3 & 0.3 & 0.4 & 0.0 \\ 0.4 & 0.4 & 0.2 & 0.0 \\ 0.3 & 0.3 & 0.2 & 0.2 \end{bmatrix}, \\ B &= \begin{bmatrix} 0.2 & 0.3 & 0.3 & 0.2 \\ 0.4 & 0.6 & 0.0 & 0.0 \\ 0.3 & 0.4 & 0.2 & 0.1 \end{bmatrix}, \\ C &= \begin{bmatrix} 0.4 & 0.3 & 0.3 & 0.0 \\ 0.6 & 0.4 & 0.0 & 0.0 \\ 0.2 & 0.5 & 0.3 & 0.0 \end{bmatrix}, \\ D &= \begin{bmatrix} 0.4 & 0.4 & 0.1 & 0.1 \\ 0.3 & 0.3 & 0.3 & 0.1 \\ 0.6 & 0.4 & 0.0 & 0.0 \end{bmatrix}, \\ E &= \begin{bmatrix} 0.4 & 0.4 & 0.0 & 0.2 \\ 0.3 & 0.6 & 0.1 & 0.0 \\ 0.4 & 0.3 & 0.2 & 0.1 \end{bmatrix}. \end{aligned} \quad (2)$$

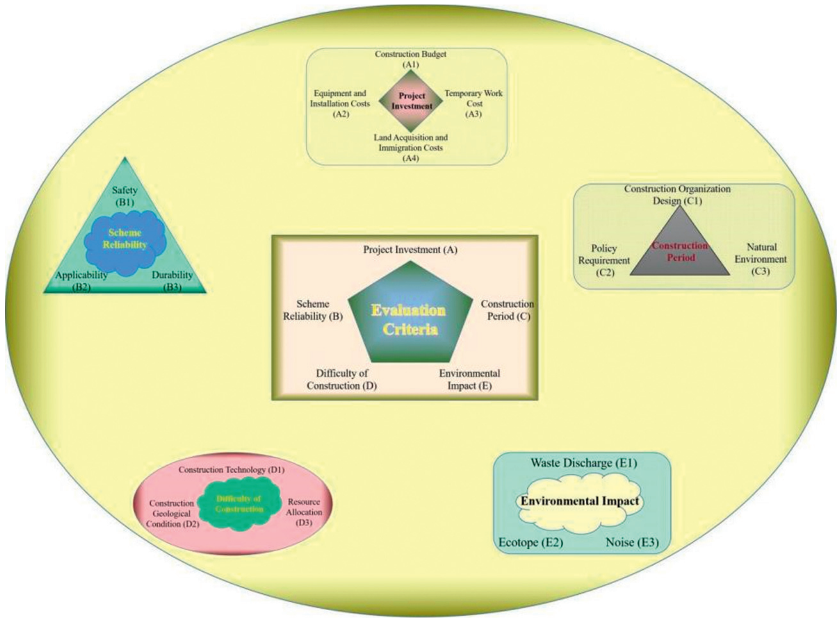

Figure 1: Scheme selection of the analytic network process (ANP) structure.

Icon	Name	Normalized by Cluster	Limiting
No Icon	Scheme 1	0.5867	0.165253
No Icon	Scheme 2	0.4133	0.116393
No Icon	Construction Budget (A1)	0.5067	0.031969
No Icon	Equipment and Installation Costs (A2)	0.3114	0.019645
No Icon	Temporary Work Cost (A3)	0.1179	0.007435
No Icon	Land Acquisition and Immigration Costs (A4)	0.0640	0.004038

Name	Ideals	Normals	Raw
Scheme 1	1.000000	0.586739	0.165253
Scheme 2	0.704335	0.413261	0.116393

Figure 2: Priority and results of scheme comparison.

Table 1: Weights of scheme evaluation factors.

Evaluation criteria	Normalized by cluster	Factors	Normalized by cluster
Project investment (A)	0.3625	Construction budget (A1)	0.5067
		Equipment and installation costs (A2)	0.3114
		Temporary work cost (A3)	0.1179
		Land acquisition and immigration costs (A4)	0.0640
Scheme reliability (B)	0.2779	Safety (B1)	0.4416
		Applicability (B2)	0.3972
		Durability (B3)	0.1612
Construction period (C)	0.1082	Construction organization design (C1)	0.2707
		Policy requirement (C2)	0.6087
		Natural environment (C3)	0.1205
Difficulty of construction (D)	0.1909	Construction technology (D1)	0.0891
		Construction geological condition (D2)	0.2462
		Resource allocation (D3)	0.6646
Environmental impact (E)	0.0605	Waste discharge (E1)	0.5912
		Ecotope (E2)	0.2748
		Noise (E3)	0.1340

The weighted average M[·,⊕] was selected for fuzzy comprehensive calculation, and the obtained evaluation vectors are S_A, S_B, S_C, S_D, and S_E, respectively.

$$
\begin{aligned}
S_A &= \begin{bmatrix} 0.5067 & 0.3114 & 0.1179 & 0.0640 \end{bmatrix} \cdot \begin{bmatrix} 0.2 & 0.5 & 0.2 & 0.1 \\ 0.3 & 0.3 & 0.4 & 0.0 \\ 0.4 & 0.4 & 0.2 & 0.0 \\ 0.3 & 0.3 & 0.2 & 0.2 \end{bmatrix} \\
&= \begin{bmatrix} 0.2611 & 0.4131 & 0.2623 & 0.0635 \end{bmatrix}, \\
S_B &= \begin{bmatrix} 0.4416 & 0.3972 & 0.1612 \end{bmatrix} \cdot \begin{bmatrix} 0.2 & 0.3 & 0.3 & 0.2 \\ 0.4 & 0.6 & 0.0 & 0.0 \\ 0.3 & 0.4 & 0.2 & 0.1 \end{bmatrix} \\
&= \begin{bmatrix} 0.2956 & 0.4353 & 0.1647 & 0.1044 \end{bmatrix}, \\
S_C &= \begin{bmatrix} 0.2707 & 0.6087 & 0.1205 \end{bmatrix} \cdot \begin{bmatrix} 0.4 & 0.3 & 0.2 & 0.0 \\ 0.6 & 0.4 & 0.0 & 0.0 \\ 0.2 & 0.5 & 0.3 & 0.0 \end{bmatrix} \\
&= \begin{bmatrix} 0.4976 & 0.3849 & 0.1174 & 0 \end{bmatrix}, \\
S_D &= \begin{bmatrix} 0.0891 & 0.2462 & 0.6646 \end{bmatrix} \cdot \begin{bmatrix} 0.4 & 0.4 & 0.1 & 0.1 \\ 0.3 & 0.3 & 0.3 & 0.1 \\ 0.6 & 0.4 & 0.0 & 0.0 \end{bmatrix} \\
&= \begin{bmatrix} 0.5083 & 0.3753 & 0.0828 & 0.0335 \end{bmatrix}, \\
S_E &= \begin{bmatrix} 0.5912 & 0.2748 & 0.1340 \end{bmatrix} \cdot \begin{bmatrix} 0.4 & 0.4 & 0.0 & 0.2 \\ 0.3 & 0.6 & 0.1 & 0.0 \\ 0.4 & 0.3 & 0.2 & 0.1 \end{bmatrix} \\
&= \begin{bmatrix} 0.37252 & 0.4416 & 0.0543 & 0.1316 \end{bmatrix}, \\
S &= \begin{bmatrix} 0.3625 & 0.2779 & 0.1082 & 0.1909 & 0.0605 \end{bmatrix} \cdot \begin{bmatrix} 0.2611 & 0.4131 & 0.2623 & 0.0635 \\ 0.2956 & 0.4353 & 0.1647 & 0.1044 \\ 0.4976 & 0.3849 & 0.1174 & 0.0000 \\ 0.5083 & 0.3753 & 0.0828 & 0.0335 \\ 0.3725 & 0.4416 & 0.0543 & 0.1316 \end{bmatrix} \\
&= \begin{bmatrix} 0.3502 & 0.4107 & 0.1726 & 0.0664 \end{bmatrix}.
\end{aligned} \tag{3}
$$

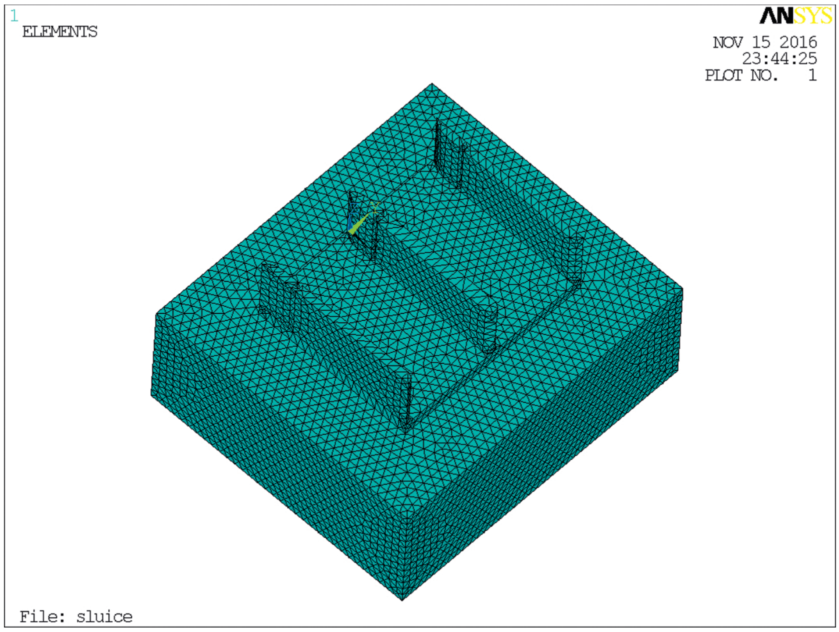

Figure 3: Lock chamber structure mesh graph.

The evaluation results were calculated as follows:

$$S = [\,0.3502 \;\; 0.4107 \;\; 0.1726 \;\; 0.0664\,]. \quad (4)$$

The final score of the optimization scheme of the bridge diversion sluice reinforcement project was $4 \times 0.3502 + 3 \times 0.4107 + 2 \times 0.1726 + 0.0664 \times 1 = 3.0445$. Considering the various factors, the questionnaire respondents generally indicated that the optimization scheme has a good W score.

3.3. Finite-Element Model. The pier and bottom plate used a SOLID65 concrete unit, and the foundation used a SOLID185 solid element. The calculation model consisted of 26,975 nodes and 143,296 entity units. The horizontal and vertical water flow directions were given as the X- and Y-axes, respectively, and the vertical direction was used as the Z-axis. The size of the foundation was based on the base plate: the length of the foundation was the same as the pier's height and twice its depth. As boundary conditions, normal and full constraints were imposed on the four sides of the foundation and on the bottom, respectively. Normal constraints were imposed on both sides of the pier. The mesh division model is shown in Figure 3, and the calculation model is shown in Figure 4.

According to the calculation model, the gate chamber displacements under three working conditions were determined, as shown in Table 2, and the principal stress calculated by ANSYS is shown in Table 3. The displacement and stress of the gate chamber were maximum when the flood level was checked and minimum when the construction was completed. In addition, the stress was concentrated at the bottom of the gate pier near the bottom plate.

4. Discussion

The original design of flood discharge of the hub does not meet the requirements of the current code. The original design of the bridge's water diversion hub adopted a 50-year flood design and a 200-year flood check of 2160 m^3/s and 2900 m^3/s, respectively. The spillway sluice of the diversion project was designed to include 10 holes, each having a width of 10 m. When the upstream water reached its original designed check flow of 2900 m^3/s, the water level before the spillway gate was 1128.6 m. Therefore, the existing spillway sluice does not meet the flood check requirements and must be reformed to increase the flood discharge capacity, which will ensure the safe operation of the diversion hub.

The original design scheme of the downstream anti-scouring sluice adopted the skirt plate surface flow energy dissipation method. At the beginning of the project construction, the elevation of the downstream riverbed was 1123.3 m; currently, the elevation is 1120 m. The energy dissipation function of the skirt plate cannot be exerted owing to riverbed cutting. At present, the floor elevation of the upstream gate chamber is 1123.3 m, and the average elevation of the downstream bed is 1120 m, indicating a drop difference of 3.3 m. The depth of the basin is 0.6 m, and the length is 22 m. According to the calculation, the depth of the existing basin is too shallow to meet the requirements of energy dissipation. The current conditions of the energy dissipation facilities are relatively thin. Once a flood is discharged, it is difficult to ensure the safety of the flood crossing. The energy dissipation scheme of the original design of the sand sluice is the same as that of the flood sluice, and the existing problems are also the same. Past the sand sluice, the existing pool is 25 m long and 1.25 m deep. The elevations of the upper and lower river beds are 1122.8 m and 1120 m, respectively, indicating a drop of

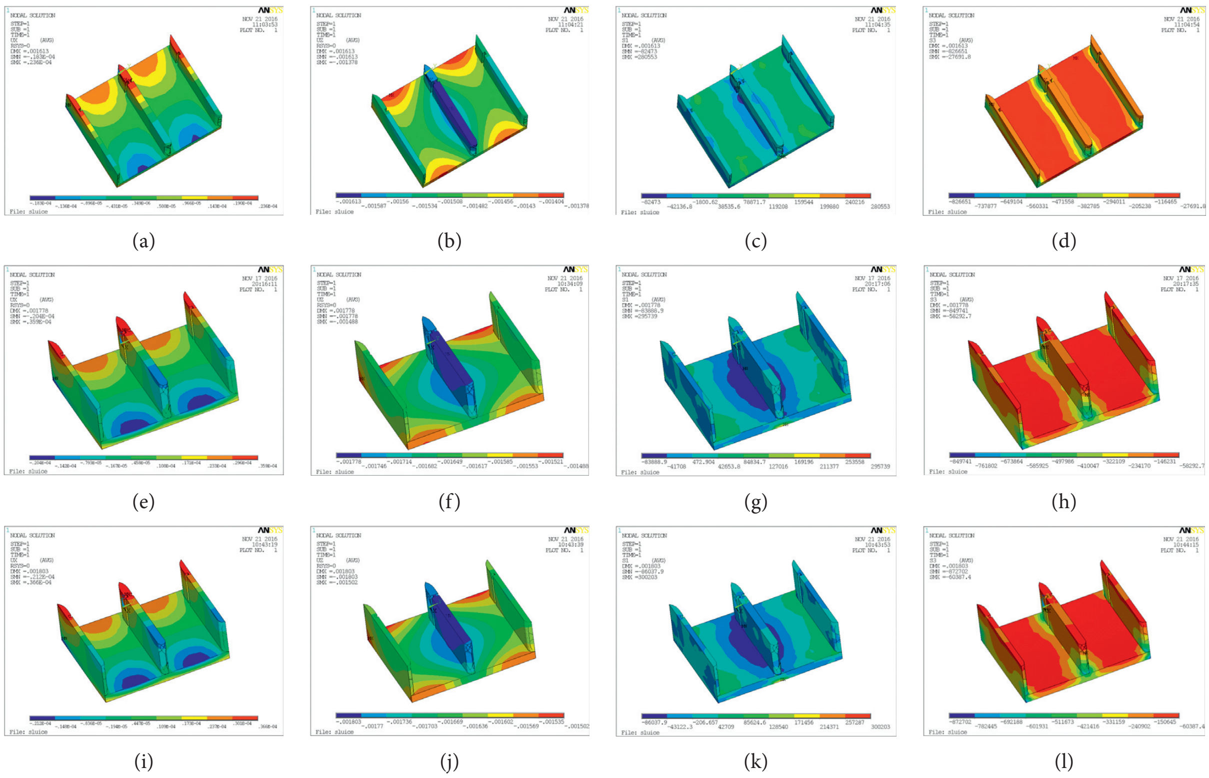

Figure 4: Nephograms of (a) lock chamber horizontal displacement, (b) vertical displacement, (c) first principal stress, and (d) and third principal stress in the first case; (e) lock chamber horizontal displacement, (f) vertical displacement, (g) first principal stress, and (h) third principal stress in the second case; and (i) lock chamber horizontal displacement, (j) vertical displacement, (k) first principal stress, and (l) third principal stress in the third case.

2.8 m. By calculation, the length of the downstream basin should be 29.8 m, and the depth should be 1.96 m. Similar to the conditions of the spillway sluice, those of the energy dissipation facilities are also relatively thin, and it is difficult to ensure safe flood crossing in this area when a flood is discharged.

The top elevation of the upstream diversion dike is 113 m, which is the same as that of the gate pier top; the top width is 3 m; and the burial depth of the foundation is 1.0 m. The upstream diversion dike has the following problems.

The embankment lacks a high top. To reduce the ice discharge pressure of the hydropower station downstream of the bridge in winter, an ice storage warehouse with a designed capacity of $2.6 \times 106\,m^3$ was established by the bridge diversion project using the upstream diversion dike and a class-I terrace of a dry river. This reduced the flood peak appropriately during the summer flood season. However, the super elevation of the diversion dike top does not meet the requirements of the current code.

The concrete plate is severely damaged by the effects of aging. The upstream diversion embankment is a sand and gravel dam with 15 cm thick concrete slabs. After a few years of use, the actions of wind, rain, and waves have severely eroded the concrete slab, resulting in its collapse, and pockmarks have developed on the surface. In addition, weed growth between the joints is widespread. All of these factors threaten public safety when the diversion dike is used.

Table 2: Minimum and maximum vertical displacements of the chamber under various operating conditions (unit: mm).

Vertical displacement	First case	Second case	Third case
Maximum vertical displacement	−1.6	−1.7	−1.8
Minimum vertical displacement	−1.3	−1.4	−1.5

Table 3: First and third principal stresses of the lock chamber under various operating conditions (unit: MPa).

Stress	First case	Second case	Third case
σ_1 maximum stress	0.281	0.296	0.300
σ_1 minimum stress	−0.082	0.084	−0.086
σ_3 maximum stress	−0.827	−0.85	−0.873
σ_3 minimum stress	−0.028	−0.058	−0.060

The width of the top of the diversion dike does not meet the requirements of flood control. The measured width of the top of the upstream and downstream diversion dikes of the bridge is only 2.8 m. Traffic cannot pull over to enable the passage of flood control and emergency rescue vehicles, which will affect the distribution of materials. Therefore, to meet the traffic requirements, it is necessary to widen the dike.

The original elevation of the downstream channel is 1123.00 m, and the original design foundation elevation of the diversion dike is 1119.80 m. Since its initial operation, the downstream channel has been cut continuously by sand mining. The average elevation of the channel has been reduced from its original 1123.0 m to the current 1120.0 m. Accordingly, the burial depth of the downstream diversion dike foundation is insufficient. According to the calculation, the maximum downstream scour depth of the diversion dike is 1.61 m, and the burial depth of the diversion dike foundation is at least 1118.40 m. Therefore, the downstream diversion dike foundation of the existing hub is insufficient and includes major safety hazards.

Throughout the overall layout of the junction, the inlet sluice, sand sluice, and external contact roads are arranged on the right side of the junction, and the flood control key parts such as the flood sluice and the river diversion embankment are on the left side. The upstream and downstream diversion dikes of the spillway sluice need to reserve large amounts of stone and wood annually for flood control. These materials need to be transported to the left bank of the hub through the traffic bridge behind the entrance sluice, the traffic bridge behind the sand sluice, the diversion dike on the left bank of the artificial bend, and the spillway sluice. Past the entrance sluice and the sand sluice, the clear width of the traffic bridge deck is 2.6 m, and the width of the top of the artificial bend diversion dike is 3 m. The width of these roads is too narrow to meet the traffic requirements of large machinery. Moreover, no traffic facility is present past the spillway sluice, and materials are transferred and transported by agricultural tractors traveling on the crane beam of the spillway gate, which poses a large safety risk. This type of bad traffic infrastructure does not meet the transportation requirements of flood control materials, seriously hampers the development of flood control work, and prevents the safe operation of the project.

The concept of raising the flood water level is introduced as follows (Scheme 1). Raising the flood water level will inevitably make the water level rise in front of the spillway gate and at the entrance of the artificial bend simultaneously, which will increase the flow rate and water level of the sand sluice. In the calculation, whether the spillway sluice, artificial bend, and sand sluice can meet the requirements of the new water passing capacity was not considered. First, the elevation of the rushing high water level and the water flow of each sluice need to be calculated, and the additional work to be added in the spillway sluice, artificial bend, and sand sluice under this new working condition can then be rechecked.

The plan of increasing the width of the water cross-section (Scheme 2) is briefly introduced as follows: two types of flood discharge channels are present in the water diversion junction of the bridge: the flood sluice and the artificial bend, which includes the downstream sand sluice and the inlet sluice. Increasing the width of the cross-section can only increase the width of the sluice chamber or the cross-section size of the artificial bend. Considering that increasing the section width of the artificial bend will inevitably change the circulation effect of the artificial bend, which could cause a large amount of sediment to enter the sluice, it is inconvenient to increase the section size of the artificial bend. Therefore, increasing the width of the cross-section can be accomplished only by increasing the width of the sluice opening. The single width of the existing spillway gate chamber is 10 m. To facilitate the mutual deployment of the metal structure equipment and the layout of the traffic and pedestrian bridges at the upper part of the gate chamber, the single width of the increased spillway gate hole is also 10 m. To select the best reinforcement scheme with optimal, economic, reasonable, and comprehensive effects, the measures and capabilities of the two basic schemes used to solve the hidden danger of the water diversion junction of Xi Bridge were compared and selected. After the comprehensive evaluation of the questionnaire answers of the 10 experts, the final determination of selection includes the project investment, building reliability, construction period, construction difficulty, and environmental impact.

The project investment had an important influence on the scheme selection. The influencing factors, including the costs of investment, construction engineering, equipment and installation, temporary engineering, land acquisition and immigration, and construction engineering, are affected mainly by the quantity and costs of the metal structure equipment and mechanical and electrical equipment. Temporary works include construction, diversions, construction, temporary roads, and other projects. In terms of project investment, in addition to the aforementioned costs, there are independent costs, basic reserve costs, and others. However, in the total project investment, these costs account for a small proportion and are thus not considered. Owing to the increase in the number of sluice holes and the width of the sea mantle of the stilling pond, the reconstruction of the diversion dike on the left side of the spillway sluice; and the deepening of the downstream diversion dike foundation at other parts of the junction, the project amount in Scheme 2 is larger than that in Scheme 1. By calculation, the total investment of Scheme 1 is 4003.27 million yuan, and that of Scheme 2 is 5537.22 million yuan.

The establishment of the evaluation index system is the basis for the decision-making evaluation of the scheme for reinforcing and safety. If the construction is not appropriate, the index weight and the final evaluation result of the scheme will not be reasonable and credible [11, 12]. When selecting the influencing factors and constructing the comprehensive evaluation index system, this study considers three aspects: safety, applicability, and durability. During the comparison and selection of the project scheme, the design of the scheme should first ensure the safety of the project after completion. Accordingly, we should also ensure that the project is applicable to flood control, irrigation, and water diversion. At the same time, the durability principle should be guaranteed after the reinforcement of the diversion junction is completed. To solve the problem of insufficient flood discharge capacity of the bridge diversion sluice, the method adopted in the first plan is to artificially raise the flood level before the sluice to 0.53 m, and the second plan is to add a flood sluice with two holes having a net width of 10 m. Comparatively speaking, the flood control pressure of Scheme 1 is large, whereas that of Scheme 2 is reduced. After opening the sluice chamber section, however, the riverbed in front of the sluice will widen, and the siltation in front of the sluice will be more severe than that currently occurring.

The construction period is also an import in the scheme selection, particularly for water conservancy projects that often need to consider the dry period of construction. The construction organization design is based on the engineering geology, hub layout, and building characteristics. These combined with the raw building materials, construction machinery, resource allocation, and other factors determine the corresponding construction method, construction process, and other factors in the construction scheme design, which will directly affect the length of the construction period. In addition, the weather and other natural environment conditions as well as the relevant policies of government departments will also affect the construction period.

The factors influencing the degree of construction difficulty are the construction technology level, construction geological conditions, and resource allocation conditions. The main functions of the bridge diversion canal head hub are irrigation and power generation. The environmental impact assessment is based on the principles of industrial policy; ecological protection, in which the ecological environment will incur no major damage; rational allocation and utilization of water resources; and standard discharge.

These factors need to comply with the functional environmental requirements. The construction site of the project is concentrated, and the influence of mechanical noise is high.

Based on the analyses of the scientific, systematic, representative, flexible, and maneuverable principles of the scheme comparison and the selection of bridge diversion sluices, the factors affecting the scheme comparison and selection were determined, and the correlation between the factors was made. The model calculation, which employed system dynamics (SD) software showed that Scheme 1 is more acceptable than Scheme 2 and can be used as the optimization scheme. Finally, a fuzzy comprehensive evaluation of Scheme 1 was conducted, and the questionnaire survey results were considered. We concluded that the scheme has a good W score. Compared with other evaluation methods of sluice reinforcement scheme, ANP considers the relationship between evaluation indexes, which is ignored in other studies.

5. Conclusion

In this study, the ANP is used to construct the scheme comparison model of the diversion sluice reinforcement project of the bridge. The conclusions that can be drawn are as follows: First of all, by conducting a questionnaire survey, the important factors and their effects on the selection of a scheme for reinforcement of the bridge diversion sluice are determined. The weights of the factors affecting the scheme comparison were calculated by Super Decisions software. It is found that the weight of raising the flood discharge level as Scheme 1 was 0.58674, and the priority of Scheme 2 was 0.41326. Thus, Scheme 1 is more likely to be adopted as an optimization scheme. Second, it is more practical to consider the pier and the bottom plate as a whole, which is easily achieved using ANSYS to model the hydraulic calculation of the hub, the floodgate, and the diversion dike. It can be found from the simulation results that the displacement and stress of the gate chamber are the maximum when the flood level is checked, and the displacement and stress are the minimum when the construction is completed, and there will be stress concentration at the bottom of the gate pier near the bottom plate. Finally, this study not only respects subjective information such as the value orientation, work experience, and knowledge ability of decision makers and experts but also includes objective law information and actual data in engineering practice. The engineering practice shows that it will not lead to the situation that the evaluation results are contrary to the reality and overcomes the singleness and one-sidedness. It is a more applicable comprehensive evaluation method. This research can serve as a reference in the study of bridge diversion sluice reinforcement schemes.

There are still some deficiencies of this study. Although the benefit is apparent as the hot-spots can be easily detected, encompassing the detailed information of the evaluation system of process consumes a large amount of time to collect data and design the ANP model. In addition to this, only the sluice reinforcement scheme is studied, rather than all hydraulic engineering. To further discuss the problem of the selection of reinforcement schemes for water conservancy projects, this study can be extended to include reservoirs and channels in addition to sluices.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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