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Risk Management and Control of Water Conservancy and Hydropower Engineering Construction Projects

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Abstract: *Against the backdrop of the current energy structure transformation and infrastructure improvement, water conservancy and hydropower projects face diversified risk challenges due to their large investment scale, long construction period, and complex technical environment. This article aims to systematically analyze the risk factors of water conservancy and hydropower construction projects throughout their entire lifecycle, including decision-making, design, construction, and operation. A scientific risk assessment model has been constructed by identifying multidimensional risks such as geological uncertainty, technical implementation difficulty, environmental impact assessment, and financial control. Research has found that establishing a dynamic risk monitoring and early warning mechanism, as well as a multi-party collaborative control system, is the key to ensuring engineering quality, safety, and efficiency. The risk response strategies proposed in this article can not only effectively reduce the incidence of accidents, but also provide theoretical support and practical reference for the refined management of similar large-scale water conservancy hub projects.*

Keywords: *water conservancy and hydropower engineering; Risk identification; Risk assessment model; Dynamic warning mechanism*

1. Introduction

As the core of national economic infrastructure construction, water conservancy and hydropower projects face extremely high uncertainty due to their large investment scale, long construction period, and complex technical environment. Effective risk management is not only the red line to ensure engineering quality and safety, but also the legal cornerstone to lock in investment benefits and prevent social risks. This article focuses on the dynamic management of quality and progress during the construction phase, as well as the risk avoidance system for change claims in contract performance, from a full lifecycle perspective in the context of the current energy transition and large-scale hub construction. By introducing digital monitoring, earned value auditing, and risk sharing mechanisms, the aim is to build a scientific and systematic risk control network, providing theoretical support and practical reference for improving the level of refined management of water conservancy projects.

2. Risk identification and classification of water conservancy and hydropower engineering construction projects

Due to its large-scale construction and complex geological environment, water conservancy and hydropower projects face extremely high uncertainty. Risk identification, as the primary aspect of management, aims to comprehensively identify negative factors that may affect project progress, quality, and safety. In terms of natural environment, the sudden changes in hydrology and meteorology, as well as the complexity of geological structures, are the main original sources of risk. For example, the stability of underground rock masses and excessive floods in river flow can pose a threat to the safety of the main structure[1]. In addition, the risks of technical implementation mainly lie in the control of difficult construction processes. Due to the high density of large mechanical equipment, any operational errors may trigger a chain reaction. By systematically classifying these risk factors, clear goal orientation can be provided for subsequent refined control, ensuring that the project can still maintain stable operation in complex and changing external environments.

3. Construction of risk assessment model during engineering construction process

The core of risk management is to quantify the risk level using scientific evaluation models after

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completing preliminary risk identification. Water conservancy engineering construction should combine qualitative and quantitative analysis methods, with a focus on assessing the probability of risk occurrence and potential destructive energy[2]. By introducing methods such as fuzzy comprehensive evaluation or analytic hierarchy process, abstract environmental impacts, financial fluctuations, and technological risks can be transformed into quantifiable evaluation indicators, thereby determining management priorities at different stages[3]. In practical operation, the evaluation model needs to be dynamically adjusted based on real-time data feedback from the engineering site, especially in cost control and investment management. The impact range of price changes on total costs should be calculated through the model to provide scientific basis for the setting of emergency reserves. This data-driven evaluation model not only improves the accuracy of risk prediction, but also lays a solid foundation for developing differentiated risk response strategies.

4. Dynamic management measures for quality, safety, and progress during the construction phase of water conservancy and hydropower projects

In the entire lifecycle of water conservancy and hydropower engineering construction, the construction phase is not only a critical period for the formation of physical entities, but also a fluctuating period for the concentrated outbreak of various potential risk factors. For the in-depth management of quality risks, it is necessary to establish a deep control system based on "all elements, all processes, and all parties involved". Water conservancy projects often involve high dams, large reservoirs, deeply buried and ultra long tunnels, and extremely complex geological reinforcement processes. Any minor technical defects or process deviations may transform into irreversible structural safety hazards. Therefore, the core of management should shift from traditional post inspection to a highly integrated approach of pre control and in-process monitoring[4]. In practical operation, it is necessary to strictly implement the three inspection system and the supervision site system, and develop detailed technical risk response plans for key processes such as temperature control and crack prevention of large volume concrete, foundation curtain grouting, and high slope support. For example, in order to address the temperature stress risk in concrete construction, high-precision monitoring sensors should be embedded in the dam body to capture real-time cement hydration heat data, and an automated cooling water circulation system should be used for precise cooling. Numerical simulation technology should be used to evaluate the risk level of cracks in real time. At the same time, the management of construction technology risks should be further extended to the field of digital modeling. Through real-time fitting of geological radar scanning data and drilling information, the support parameters and excavation steps in the construction organization design can be dynamically corrected to eliminate potential stability risks before the physical structure is formed. The construction unit should also strengthen the full process traceability and control of raw material entry, strictly prohibit unqualified aggregates and additives from entering the work surface, and ensure that the main body of the project has extremely high intrinsic safety and durability within decades or even hundreds of years of operation through the dual efforts of technical means and institutional constraints. This refined quality pre control mode can significantly reduce the additional investment and safety risks caused by quality rework in the later stage, and is the cornerstone of achieving engineering excellence rate[5].

On this basis, strengthening multi-party collaborative management and information control at the construction site is the key to resolving cross operation risks in complex environments. Water conservancy and hydropower projects usually involve multiple disciplines in parallel, such as civil engineering, mechanical and electrical installation, and metal structures. The construction logic is highly coupled, which can easily lead to management vacuum or command conflicts. By establishing an integrated management command center and utilizing BIM (Building Information Modeling) technology for high-precision simulation layout of the construction site, it is possible to intuitively identify spatiotemporal conflicts between various work surfaces, thereby optimizing the construction diversion plan and equipment parking layout. In this digital collaborative environment, the management should also introduce a 4D schedule simulation and collision detection mechanism to match and analyze the demand curve of construction resources with the spatial carrying capacity of the site, ensuring that the scheduling logic of mechanical equipment meets the safety distance requirements. The management team should regularly organize a multi-party consultation system to conduct in-depth verification of technical disclosure for closely connected processes such as excavation blasting and monitoring observation, anti-seepage wall construction, and foundation reinforcement. In the collaborative process, it is necessary to establish a cross disciplinary risk information sharing mechanism to ensure that technical indicator changes caused by design changes can be instantly

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transmitted to the end construction team, preventing ineffective construction or rework due to information lag[6]. By combining this strengthened communication mechanism with digital deduction, it is possible to effectively compensate for the fragmented shortcomings of traditional experience management, achieve cross domain optimization of production factors, and provide stable order guarantees for large-scale and high-intensity engineering construction.

In addition, establishing a material supply and emergency support system based on dynamic changes in the construction environment is an important prerequisite for maintaining construction continuity. Water conservancy projects are usually located in remote areas with limited transportation conditions. The logistics supply of bulk building materials and key mechanical and electrical equipment is highly susceptible to geological disasters or extreme weather conditions, which can trigger the risk of supply chain disruption. To this end, the management department should utilize integrated management theory to construct a lean material reserve model, scientifically set safety stock based on the dynamic peak of construction intensity, and establish alternative transportation plans linked to multi-dimensional geographic information systems. When facing sudden construction risks or technological changes, the material support system needs to have the ability to respond quickly. By establishing a deep collaboration mechanism with core suppliers, it ensures the priority allocation of strategic materials such as high-grade cement and special steel. This forward-looking guarantee logic not only alleviates the progress crisis caused by resource shortages during the construction phase, but also reduces the indirect losses caused by work stoppages and material shortages from an economic perspective, providing solid material support for the smooth progress of the project.

In terms of overall management of safety production and construction progress, water conservancy projects face the dual pressure of natural geological uncertainty and extreme meteorological conditions. Security risk control should not be limited to institutional compilation, but should evolve into a dynamic warning platform based on IoT technology and big data analysis. Considering the steep terrain of water conservancy construction sites, the high density of large mechanical equipment, and the presence of a large number of deep foundation pits and underground excavation operations, the management must conduct real-time monitoring of high-risk links such as high-altitude lifting, blasting construction, and diversion operations. When dealing with equipment installation involving cross-border technology introduction or complex patent authorization, it is also necessary to pay attention to the compliance risks of technology patents, establish a sound intellectual property file management system, and prevent on-site work stoppage or legal sanctions risks caused by cross-border technology protection disputes. By combining legal compliance with a dynamic identification system for on-site hazards, and utilizing artificial intelligence algorithms to integrate and analyze unsafe behaviors of construction personnel, stress changes in critical areas, and authorized boundaries of technology patents, the predictability and accuracy of hazard management can be significantly improved. At the same time, schedule management, as another dimension of risk control, is directly related to the flood safety and investment benefits of the project. Water conservancy projects are strongly constrained by hydrological cycles, and construction plans must have extremely high foresight and dynamic adjustment flexibility. The management team should deeply optimize the construction critical path based on network planning technology (CPM) and integrated management theory, and develop detailed resource staggered scheduling strategies and emergency avoidance plans for possible sudden floods or geological disasters. By strengthening the organizational collaboration efficiency among construction, supervision, and construction parties, it is possible to effectively resolve the chain reaction caused by project delays. This dynamic control mode that deeply integrates safety red lines with schedule goals not only greatly improves the scientificity of on-site management, but also provides solid management support for large-scale water conservancy projects to achieve established goals in complex environments.

5. Risk avoidance system for economic contract performance and engineering change claims

Economic contract management, as a legal tool for preventing external risks and locking in the boundaries of rights and interests of all parties in water conservancy and hydropower construction projects, is of great importance throughout project implementation. Due to the typical characteristics of such projects, such as huge investment scale, diverse participating parties, and long construction period, the prevention and control of contract risks must be elevated from simple clause review to systematic strategic prevention. During the contract planning and signing phase, the management should organize technical, economic, and legal experts to conduct multiple rounds of stress testing and vulnerability reinforcement for the risk coverage scope, pricing rules, adjustment formulas, and breach judgment criteria in the contract. In the process of contract performance, a normalized contract performance evaluation and warning mechanism should be established to prevent the spread of performance risks caused by excessive subcontracting or fund misappropriation by real-time tracking of the contractor's personnel availability rate, equipment integrity rate, and fund flow. In response to the unique long-term nature of water conservancy projects, the management should also regularly conduct mid-term evaluations of contract economics, and reserve reasonable flexibility adjustment space for unforeseeable policy changes or geological mutations by introducing flexible clauses in contracts. On this basis, the quantitative standards for risk sharing should be further refined by setting a reasonable threshold for engineering quantity deviation and clarifying the rules for adjusting unit prices beyond the predetermined range, in order to avoid the risk of contract collapse caused by extreme geological deviations[7]. At the same time, the management needs to strengthen the dynamic level of legal tracking, establish a comparison database between contract texts and real-time information on construction sites, and intervene in potential legal violations in advance to ensure the accurate implementation of the escort mechanism. Especially when facing systemic risks such as drastic fluctuations in raw material market prices and policy and regulatory adjustments, a dynamic adjustment mechanism should be scientifically established, and reasonable risk hedging measures should be used to achieve a rebalancing of interests between the employer and the contractor, in order to prevent project stagnation or legal disputes caused by extreme unequal contract terms. In addition, regarding the common service contracts such as supervision, survey, and design in water conservancy projects, the quality lifelong responsibility system and cost control responsibilities of the service provider should be further clarified. By introducing performance incentives and accountability mechanisms, hidden breach risks caused by management deficiencies or information asymmetry can be eliminated, thus building a solid project protection network within the legal framework.

At the same time, building a diversified contract dispute resolution mechanism and a participant credit evaluation system is a key reinforcement for preventing legal risks in contracts. Water conservancy and hydropower projects often involve extremely complex interests. Once a contract dispute occurs, long-term legal litigation often leads to the project being suspended, causing huge economic losses. Therefore, a non adversarial dispute adjudication committee (DAB) system should be established in the contract, inviting industry experts to intervene in immediate conflict resolution, and striving to resolve economic disputes without affecting the progress of the project. Under this negotiation mechanism, the management should also establish a contract risk information database, regularly summarize typical dispute points and convert them into revision basis for contract templates, in order to achieve a shift from a "passive dispute resolution" model to an "active dispute avoidance" model. In addition, in order to enhance the resilience of contract performance, a multi-level risk hedging scheme should be implemented, deeply linking the contract settlement cycle with phased credit evaluation, and significantly improving the sensitivity of default prevention through granular modeling of the performance behavior of participants. The management should use integrated management theory to establish a dynamic credit file, converting indicators such as quality fluctuations, schedule delays, and cooperation deviations during the performance process into quantitative credit points, and using them as a direct basis for subsequent project payment disbursement and payment insurance adjustment[8].

In addition, strengthening the control of financial risk infiltration and financial warning throughout the entire process of contract performance is an important barrier to ensure the economic security of the project. Considering the huge flow of funds and complex payment nodes in water conservancy projects, the management should establish a financial collaborative monitoring model based on contract payment ledgers to finely match project advance payments, progress payments, and reserve funds. By introducing a third-party auditing agency to conduct regular fund flow penetration checks, it is possible to effectively identify whether the contracting unit has signs of using project funds for illegal financing or other purposes, thereby avoiding the risk of contract breach caused by a broken funding chain. At the same time, for cross-border procurement or large-scale mechanical and electrical equipment leasing contracts, special attention should be paid to exchange rate fluctuations and tax compliance risks, and a foreign exchange risk hedging mechanism and tax dispute prevention plan should be established. By embedding financial risk warning logic into contract dynamic execution evaluation, it is possible to achieve a deep transformation from single physical progress control to asset value security control, providing a rigorous institutional guarantee for the closed-loop operation of funds in large-scale water conservancy projects.

Establishing a refined disposal system with rigorous procedures, sufficient support, and multi-party collaborative participation is of utmost importance in avoiding economic losses in response to frequent engineering changes and claims risks in water conservancy projects. Due to the influence of many concealed works and complex hydrogeological conditions on water conservancy projects, it is very

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common to find discrepancies between the actual situation and the survey and design during the construction process, as well as adjustments to the engineering quantity caused by design optimization or national standard updates. In response to such changes, it is necessary to implement a closed-loop processing flow of "instant discovery, instant recording, and instant approval", and introduce a change risk pre evaluation system on this basis. The economic feasibility of design scheme changes should be deeply verified using shadow price or opportunity cost models to reduce non mandatory engineering changes from the source. At the same time, utilizing digital tools such as BIM to conduct dynamic simulation rehearsals after changes, analyzing the deep impact of scheme adjustments on water flow patterns, structural stress, and construction diversion, ensuring that every increase in expenditure can bring definite engineering gains. In addition, a post evaluation mechanism for change claims should be established to restore costs and trace benefits of changes that have occurred, analyze the subjective and objective causes of changes, and strategically avoid them in subsequent construction organizations. In terms of evidence preservation, the management team should use high-definition surveying and digital monitoring methods to fully archive the original terrain and landforms before and after changes in three dimensions, ensuring that every increase or decrease in costs is supported by irrefutable physical data. The project management shall require the construction unit, supervision unit, and contractor to conduct on-site joint inspection, data collection, and image data verification as soon as changes occur, to ensure the authenticity and compliance of each change cost.

When handling claims, the management should strengthen the application of integrated management theory, introduce digital audit tools to cross verify the integrity of claim data, and identify possible false or missed reporting logic. The project management team should Deeply analyze the comprehensive impact of claim events on overall investment, critical paths, and subsequent construction organization, and achieve precise pre control of investment expenditures by establishing a dynamic claim ledger. At the same time, a sound multi-level audit and internal monitoring mechanism should be established to severely crack down on behaviors that seek improper benefits through unbalanced quotations, false reporting of engineering quantities, and concealed engineering fraud. This management model, which combines rigorous audit logic, scientific pricing system, and strategic communication, can not only effectively curb the risk of exceeding the budget, but also create a healthy, fair, and transparent construction market environment, significantly improving the investment control and comprehensive management efficiency of water conservancy and hydropower projects.

6. Conclusion

In summary, risk management in water conservancy and hydropower engineering construction projects is a continuous, complex, and systematic project, and its success or failure directly affects the quality and efficiency of national economic infrastructure construction. By deeply identifying natural, technological, and management risks throughout the entire lifecycle, and relying on scientific evaluation models and dynamic control systems, uncertainties in the implementation process of engineering can be effectively resolved. In practice, strengthening refined pre control during the construction phase, strict contract performance, and change claim management are the core means to avoid quality accidents and cost control. In the future, we should continue to deepen the concept of integrated management and use digital monitoring and information platforms to improve the accuracy of risk prediction.

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