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Engineering Practice

Exploration and practice of intelligent engineering in Dadu River hydropower construction

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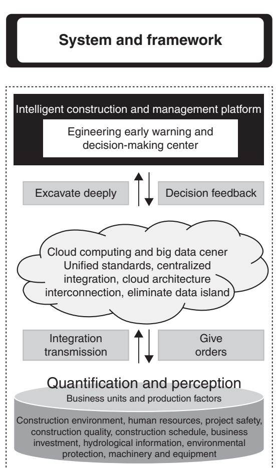
Abstract

In view of the difficulties in promoting intelligent management in the field of engineering construction, based on the concept of intelligent enterprise and the actual situation of hydropower project-construction management, this paper puts forward the basic concept, main features and general idea of intelligent engineering. Based on a review of the exploration, pilot construction and comprehensive practice of intelligent engineering in the hydropower construction of Dadu River, the practical results of the intelligent engineering of Dagangshan, Houziyan, Shaping-II and Shuangjiangkou hydropower stations are summarized. The technical system and management model of engineering an early-warning decision centre, intelligent dam project, intelligent underground project, intelligent electromechanical project, intelligent security control, intelligent service guarantee, intelligent environmental and water protection, and intelligent resource control in Shuangjiangkou hydropower station are introduced. It is proposed that intelligent engineering is a high integration of information technology, industrial technology and management technology. And it is pointed out that intelligent engineering will lead in the new development of water conservancy and the hydropower industry, and even the engineering-construction field, throughout the world.

Graphical Abstract



The traditional hydropower project construction management has the following problems: data fragmentation, complex management, slow risk feedback, high work intensity.
In view of the main challenges, this paper applies emerging cutting-edge technologies to build clod computing and big data center and intelligent construction and management platform based on quantitative perception of various factors. The goals of full life cycle management, all-directional risk prediciton and total factor intelligent control can be achieved.

Keywords: intelligent engineering; Dadu River; hydropower construction; practice

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Introduction

In recent years, a large number of technologies such as cloud computing, big data, the Internet, mobile terminals and artificial intelligence have emerged. All sectors of society are trying to adapt to the changes in social structure and the economic model brought about by new technologies and are actively exploring and practising. Concepts such as smarter planes, smart cities, intelligent factories and intelligent manufacturing have been put forward and put into practice. Under the tide of intelligence, China's traditional industries and traditional enterprises are quietly facing major changes. In order to avoid the traditional enterprises being subverted in this round of technological revolution and industrial revolution, Yangju Tu and his fellows proposed the intelligent-enterprise theory according to the characteristics of enterprise management to guide the intelligent management of enterprises [1]. According to the characteristics of hydropower enterprises, the construction method of four business units including an intelligent power plant, intelligent maintenance, intelligent scheduling and intelligent engineering is proposed under the framework of the intelligent-enterprise system [2–7]. As an important business unit of an intelligent enterprise, intelligent engineering has been tried a lot in the construction and management of the hydropower project in Dadu River basin and played an important role [8]. This paper systematically expounds the construction background, implementation content, general idea and practical results of the intelligent engineering in Dadu River basin.

1 The background of intelligent engineering

The Dadu River basin is rich in water and energy resources, ranking fifth among the 13 hydropower bases in China. With a total installed capacity of ~27.08 million kW and an average annual generating capacity of ~116 billion kWh, it takes up 24% of the total hydropower resources in Sichuan province. The Dadu River basin is an important part of the flood-control system of the Yangtze River basin and it is also the first national comprehensive management pilot. The construction of the Dadu River basin hydropower project faces the following technical and management challenges, both of which generate intelligent-engineering solutions.

1.1 Technological challenges require intelligent technological breakthroughs

(i) The working location is remote. Most of the hydropower projects in the Dadu River basin are located in mountain and valley areas that lack access for transportation. The project is located in the transitional belt between the Qinghai–Tibet plateau and the Sichuan basin, and the natural ecological environment is fragile. The project is distributed on the river reach of 850 km of the Dadu River trunk stream, covering 14 counties (districts), 2 cities and 3 states in Sichuan province.

(ii) Geological conditions are complex. The thickness of riverbed overburden in the Dadu River basin is generally 50~120 m and there are 2212 explored geological hazards in multiple terraces. Several seismic faults cross the Dadu River basin and the nearest distance to the dam site is only 4 km. The maximum designed seismic acceleration at the dam site of Dagangshan is 0.557 cm/s^2, which ranks as the first in the world.

(iii) Hydrological information and weather are unpredictable. The Dadu River covers an area of 77 400 km^2, with an annual run-off of 47 billion m^3. The topography and geomorphology of the basin are extremely complex, affected alternately by several typical weather systems, such as the Pacific subtropical high, the Qinghai–Tibet high, the Siberian high and the south-west warm and humid air flow. It has become one of the most difficult regions in the world.

(iv) The types of dams and reservoirs are various. The dams of the Dadu River basin cascade hydropower stations cover dam types such as core-wall rock-fill dams, concrete-face rock-fill dams, arch dams, gravity dams and gate dams. Among them, the Shuangjiangkou core-wall rock-fill dam, with a height of 312 m, is the highest dam in the world. Reservoir types include multi-year regulation, annual regulation, seasonal regulation, weekly regulation, daily regulation and run-off regulation. Pubugou is the largest reservoir, with a capacity of 5.4 billion m^3, and the total capacity of the basin is >15 billion m^3, which is 1000 times as much as West Lake.

The above technical challenges are very difficult for the 'five controls' of safety, quality, schedule, environmental protection and investment in the construction of the Dadu River basin hydropower project. It is urgent to adopt advanced intelligent technology to solve the problem.

1.2 Management challenges require intelligent management innovation

The construction management of a hydropower project is characterized by numerous participants, complex management objects, complex interest relations, large workloads of coordination and multiple contents of management and control. Therefore, the construction-management units of hydropower projects mostly adopt the traditional management mode of stratified management, multispecialty and administration-oriented. Under this traditional management mode, the following problems exist in engineering-construction management:

(i) The problem of data fragmentation and data islands. Due to the inevitable impact of management and human factors, there are many data fragmentations and information islands in engineering-construction management. The data of all parties involved in the construction and professional sections cannot be integrated and the big data of project-construction management cannot be formed.

(ii) The problem of stratified management and a poor management-operation mechanism. Due to the stratified management and multispecialty, the management rules are relatively macro, the process control is not sophisticated and the business-quantification foundation is weak. As a result, the project-management-operation mechanism is not smooth and the work efficiency is not high.

(iii) Risk feedback is slow and accurate decision-making is difficult. Due to the lack of timely collection of on-site real data and the absence of a platform for overall planning and risk control, it is difficult to form an intelligent and coordinated risk-analysis and decision-support system, resulting in the inability to conduct scientific response and processing.

(iv) High work intensity, with much repeat work. As most hydropower projects are located in deep mountains and valleys, the geographical location is remote and a large number of first-line workers engaged in construction management are far from their families and cities for a long time. The work intensity is very high, repeat work is frequent and work and life are difficult to balance.

As a result of the above management challenges, especially with the rapid economic and social development, employees' demands for individualization and diversification are increasing and their expectations for improving working and living conditions are getting higher and higher. This requires us to carry out management innovation through intelligent-engineering construction to achieve more detailed, scientific, flexible and human management.

2 Basic connotations and general thinking of intelligent engineering

As an intelligent solution to the above technical and management challenges, intelligent engineering has the following basic concepts and main features.

2.1 Basic concepts

Based on the description of the definition of 'intelligent enterprise' and features of intelligent engineering, the concept of intelligent engineering can be described as: intelligent engineering sets life-cycle management, all-round risk prediction and all-factor intelligent control as the construction targets; integrates information technology and engineering management, while constructing an engineering-data centre, engineering-control platform and decision-making command platform. A flexible organization form and new project-management mode, which achieves data-driven automatic perception, automatic anticipation and independent decision-making, can be realized.

2.2 Main features

Intelligent engineering is the product of the deep integration of information technology, industrial technology and management technology. It is an important business unit of the intelligent enterprise of Dadu River Company. Such features determine that it is significantly different from other intelligent-construction, digital and intelligent applications; the following four features are summed up:

(i) Risk-control features: paying more attention to risk prevention and control. Intelligent engineering always focuses on risk control and realizes the automation of risk identification and intelligent risk management through the construction of automatic identification and intelligent control systems.

(ii) Human features: paying more attention to the human factor. In addition to realizing the connection of every object, intelligent engineering also requires that information interchange, human–computer interaction, knowledge sharing and value creation should be achieved.

(iii) Management-transformation features: paying more attention to management transformation. In addition to managing the flattening of the business hierarchy, streamlining organizational structuring, and optimizing the management mechanism and scientific division of labour, intelligent engineering requires the integration of information technology, industrial technology and management technology.

(iv) Comprehensive system features: paying more attention to comprehensively promoting. Intelligent engineering is a comprehensive and systematic network of digital and intelligence, in accordance with comprehensive innovation in the planning and construction processes, total information awareness, total digitalization, full connection and all-round intelligence can be achieved.

2.3 General idea

In terms of these main challenges, through business quantification, integration and centralization, a unified platform and intelligent collaboration, a big perception network can be built, big transmission efficiency can be improved, a big storage platform can be built, big computing capacity can be improved and big analysis can be formed, building a cloud computing and big-data centre and intelligent construction and management platform based on the quantitative perception of various elements. Through the integration of technological innovation and management innovation, the goal of full-life-cycle management, all-around risk prediction and all-factor intelligence regulation is truly realized. The general idea of intelligent-engineering construction is shown in Fig. 1.

3 Exploration process of Dadu River intelligent engineering

The exploration and practice of intelligent engineering in the hydropower construction of Dadu River has gone through three stages:

(i) The early exploration stage: from 2011 to 2014. During this period, based on the informatization and digitalization of project management, Guodian Dadu River Company implemented the construction of the 'digital Dagangshan' system in Dagangshan hydropower station. The construction of the 'intelligent Houziyan' system was carried out at the Houziyan hydropower station, which was a preliminary exploration of the implementation of intelligent engineering in the hydropower development of the Dadu River.

(ii) Pilot construction stage: from 2014 to 2016. During this period, based on the earlier exploration results, the concept of intelligent engineering was formally proposed and the pilot construction of Shaping-II hydropower station was carried out. By summarizing the experience of engineering construction and power-station operation and systematically thinking, the interconnection between intelligent engineering and an intelligent power plant can be realized. With the Internet, big data and a virtual model as the innovation driving forces, Guodian Dadu River Company applied big-data-analysis technology to break down the professional barrier between the project and the power plant, and accumulated some experience in the construction of intelligent engineering.

(iii) Comprehensive practice stage: from 2016 to present. The preliminary exploration and pilot construction focus more on the progress and quality of the 'five controls' and the 'five controls' involved in the construction have not been fully implemented. In 2016, Guodian Dadu River Company initiated the comprehensive practice of intelligent engineering in Shuangjiangkou hydropower station, which is the world's highest dam. The management and control of intelligent engineering go deep into all aspects and links of the 'five controls' of the construction management of Shuangjiangkou project and set up the corresponding management mode, marking that the construction of Dadu River hydropower engineering has entered a new stage of intelligent management.

4 The practical results of the intelligent project of Dadu River

4.1 The exploration stage featured by digital construction

4.1.1 Dagangshan hydropower station

The installed capacity of Dagangshan hydropower station is 2.6 million kW, the project consists of a 210-m-high concrete-arch dam, a water-diversion power-generation system on the left bank, a deep discharge tunnel and spillway on the left bank. The 'digital Dagangshan' system integrates the comprehensive management of

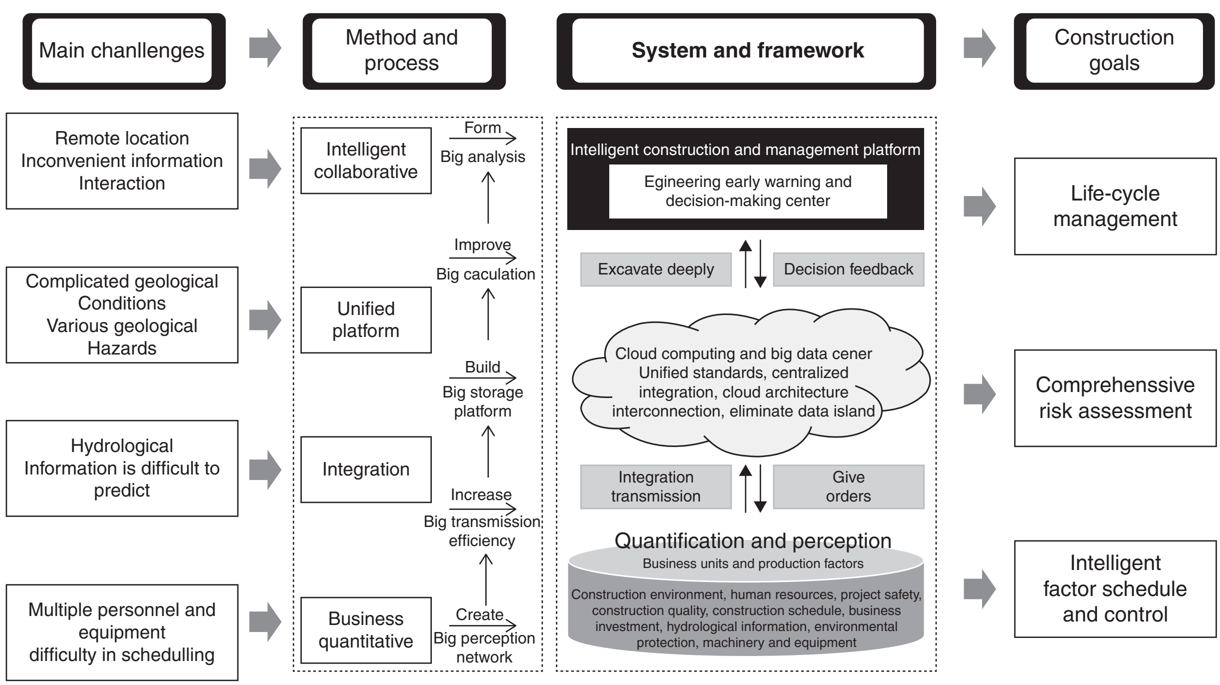

Fig. 1: General idea of intelligent-engineering construction

the concrete-pouring process, temperature-control process, foundation-treatment process, safety monitoring, cable-machine-operation monitoring, mixing-building-operation monitoring and other processes. It deals with the comprehensive issue of safety, quality, progress, measurement and other data of the whole construction process; achieves the management purpose of comprehensive control of the construction process, comprehensive management of the construction quality, and intuitive and effective analysis of the results; and realizes the traceability of the engineering-construction-process control. The specific implementation content of 'digital Dagangshan' includes an engineering information-management system platform, a concrete-production monitoring system, a bucket-positioning system, a cable-machine-operation monitoring system, a dam-construction simulation system, a digital temperature-measuring system, a dam concrete-temperature-control simulation analysis and decision-support system, a dam-foundation grouting-process management system, a safety-monitoring and information-management system, and a digital-surveillance image-information acquisition system.

The successful application of the 'digital Dagangshan' systems has achieved comprehensive temperature control, progress simulation, foundation treatment and safety monitoring in the construction process of the dam, which has played an important role in effective control engineering. First, in terms of safety management, the cable anti-collision system has ensured the safe operation of cable engines >500 000 times, provided warnings >3000 times, realized emergency risk avoidance 5 times and guaranteed continuous safe production for 3409 days without accidents in the Dagangshan project. Second, in terms of quality management, nearly 700 000 cans of concrete-production data and mix-proportion information produced by the concrete system were collected by the mixing-monitoring platform, which provided a guarantee for the quality of the concrete preparation; 2434 thermometers are installed in the dam to reflect changes in the concrete temperature in real time. The temperature-control decision-making system has accumulatively collected >4.5 million pieces of key temperature-control data of the dam concrete and the casting-temperature qualification rate, the highest-temperature qualification rate and the daily cooling rate of the concrete reached >90%, of which the dam-casting-temperature qualification rate increased by 10 percentage points, and there were no harmful cracks in the dam. The installation of 517 crack meters has given timely feedback on the opening of the transverse joints and guided the construction of the field-joint grouting. The grouting monitoring system has collected nearly 100 000 records of grouting, which avoided the control of human factors and ensured the quality of the grouting. The shape-control result of the arch dam is remarkable. The measured data show that the level of monthly passes has improved gradually and the quality has always been maintained. The dam-strength index is higher than the design requirement and the concrete-strength guarantee rate has reached 99%. Third, with the help of the dam-construction-schedule simulation system, the efficiency of the dam-construction-schedule planning has beens improved by >50% and the scientific quality of the planning has greatly improved. Through the combination of the monitoring platform of the mixed building, the cable-machine remote monitoring system and the cable-machine collision-prevention system, the overall construction efficiency of the concrete has improved by 7%, the maximum monthly casting strength is 136 000 m^3 and the casting period has been shortened by 68 days compared with the original plan. Fourth, in terms of investment control, with the use of the digital control system, the concrete-production capacity of the mixing buildings has increased from 4 × 4.5 to 4 × 5 m/h and the concrete volume has transferred from 9 to 9.6 m^3 using a single tank of cable machinery, which has reduced the hoisting and operation times of the cable machinery's hoisting tanks by >22 000 times.

4.1.2 Houziyan hydropower station

The installed capacity of the Houziyan hydropower station is 1.7 million kW and the project consists of a 223-m concrete-face rock-fill dam, flood-discharge and emptying structures on both banks, and an underground water-diversion power system. The construction of the 'intelligent Houziyan' system mainly includes the rolling and compaction control quality monitoring system and the intelligent electromechanical-engineering system for the face rock-fill dam filling. See Figs 2 and 3, respectively.

By monitoring the important technical parameters of the dam filling and compaction, the quality monitoring system of the dam filling and compaction of the Houziyan dam realizes whole-process, all-weather, real-time and online monitoring, and ensures that the project quality is always under control. At the same time, the construction-quality monitoring system, which set 'monitoring–analysis–feedback–treatment' as the core was established, has significantly improved the management level of Houziyan dam construction. Until now, the accumulated settlement of the dam body has been 0.51% of the dam height and the number of cracks in the first-stage concrete panel has been controlled at 1.9 bars/thousand m^2, reaching the international advanced level.

The Houziyan intelligent mechanical and electrical engineering system enforcement content mainly includes: 3D overall mechanical and electrical engineering, mechanical and electrical equipment, piping system, spatial relations of bridges and structures, the main technical parameters of the main equipment, main power plant and vice power plant, main transformer, equipment 3D layout of each layer of the switch station, main equipment, piping, bridge 3D graph, the power cable, control-cable and communication-cable design, etc. The main achievements after the implementation

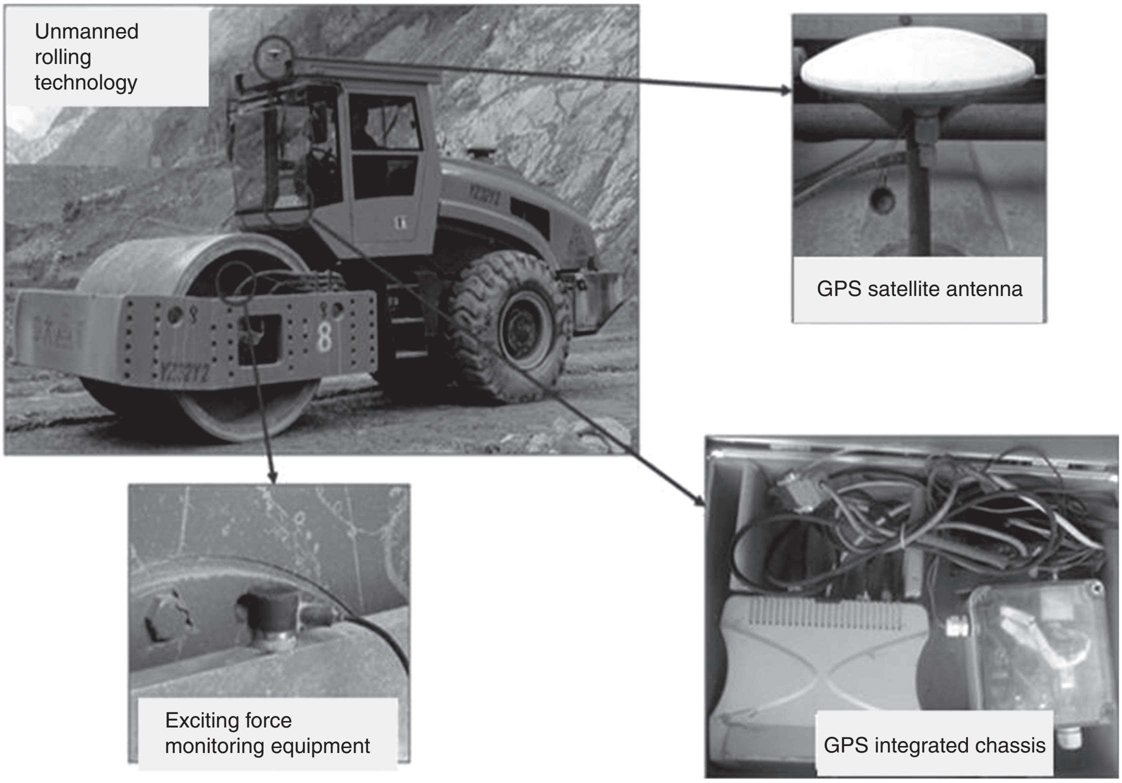

Fig. 2: Dam crushing machine of the Houziyan dam project

Fig. 3: Display chart of the Shaping-II intelligent-engineering-system platform

of the system include the following. First is the realization of the scheme simulation and optimization. On the basis of the 3D refined and multi-professional collaborative design, through model collision detection, errors, omissions and defects of the electromechanical-equipment layout scheme have been reduced from the design source and reworking in the construction process has been reduced. The second is to make technology disclosure more intuitive and effective. By using the visualization features of the 3D model, assistant engineers and technicians can observe the dynamic assembly process of structural equipment from any visual angle and intuitively show the 3D-image appearance and spatial relationship of buildings and electromechanical equipment, improve the efficiency of information communication in design and construction, and avoid information communication and rework caused by technical disclosure based on 2D drawings. Third, it is helpful for the fine control of mounting quality. Based on building information model (BIM) technology and based on the 3D model, it integrates the design data, manufacturer data, construction-process requirements, installation acceptance standards and other information on the electromechanical equipment of the plant, and applies them in the overall handover construction stage to guide the design of the installation scheme, construction organization, material procurement and quality inspection and evaluation. Fourth is the scientific monitoring of the installation progress. Based on the simulation of the electromechanical installation process and the pre-construction process, the optimization of the engineering schemes and the comparison of multiple schemes can be realized to improve the engineering technical indicators and quality, reduce construction conflicts, shorten the installation cycle and provide a reference and basis for the secondary design. Fifth is achieving the accurate procurement of electromechanical materials. The 3D design can accurately count the quantity of materials and materials, and combine that with the construction simulation. The mechanical and electrical equipment list, bidding and procurement situation, equipment information, equipment-installation progress and other information can be related and summarized, so as to scientifically and accurately formulate the mechanical and electrical material-demand plan, so as to guide precise procurement and logistics. Sixth is laying the foundation for intelligent operation and maintenance. The 3D power-station model integrating the design information and construction information is digitally transferred to display the real-time status and defect information of the power station. It can realize visual management of production-management data and real-time monitoring data of five levels of spatial-object attributes, state, overhaul, knowledge and technical standards of a hydropower station unit, public system, functional system, main equipment and main components. The intelligent electromechanical-engineering system integrates power-station design information, equipment-property information, construction progress and quality information, providing interfaces and the basis for power-station operation, maintenance and overhaul.

4.2 The pilot construction featured by intelligent application

The installed capacity of Shaping-II is 348 000 kW and the project is mainly composed of riverbed power-generating plant on the left bank, flood-discharge sluice on the right bank and a gravity dam, and the maximum dam height is 63 m. The construction of the Shaping-II hydropower station mainly includes construction-resource monitoring, concrete-production monitoring and 3D digital plant construction.

The construction-resource monitoring system uses GIS technology, GPS positioning and mobile application (APP) + wireless fidelity (WIFI) technology to realize the whole-process and all-weather online real-time monitoring of the coordinate orientation of vehicles and personnel within the work area. At the same time, track playback is implemented to query the track of people and vehicles at any time. In addition, the personnel- and vehicle-monitoring data were statistically analysed to improve the management level of the construction resources.

The concrete-production monitoring system realizes the quantitative management of traditional concrete preparation, transportation, production and other work tasks based on the on-site real data, and provides data services such as information consulting, real-time monitoring, statistical analysis and early-warning reports for the whole process of concrete preparation, transportation and pouring in the engineering site, so as to improve the efficiency of concrete production and management.

The 3D digital power-plant-construction system includes modules such as 3D progress appearance query, 3D visual construction simulation, warehouse surface statistical analysis and buried-pipe and embedded-parts management, as shown in Fig. 4.

Based on BIM, RIFD and other technologies, the system quantitatively analyses the progress in the construction process and enables statistics for buried-pipe and embedded parts to be analysed; the 3D dynamic visualization simulation and demonstration are provided, and the image of the project is provided at any time, so as to prevent mistakes and leakage in the process of buried pipes and embedded parts, and comprehensively improve the management level of the construction of hydropower engineering.

The pilot exploration of intelligent engineering in Shaping-II has produced huge economic benefits and effectively controlled the safety, quality and progress of the project. The construction and operation of the monitoring unit of concrete production increased the completion rate of the project from ~80% to ~100%, and the waste rate of concrete decreased by ~10%. On 28 August 2016, the development and application project of the management model research and management control platform of the Shaping-II hydropower station passed industrial scientific and technological appraisal, and the above-mentioned three pioneering innovations have reached the international leading level.

4.3 Comprehensive practice featured by intelligent construction and management

Shuangjiangkou hydropower station is a control reservoir project in the upper reaches of the Dadu River, with an

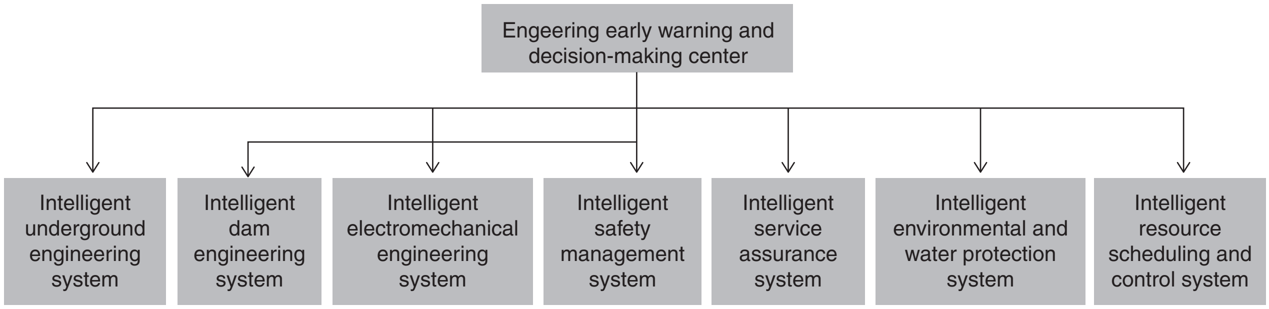

Fig. 4: Diagram of the technical support system of Shuangjiangkou hydropower station

installed capacity of 2 million kW and a maximum dam height of 312 m; it ranks as the highest hydropower project already built or under construction in the world. The intelligent-engineering system at Shuangjiangkou is composed of technical measures and a management mode, which deeply integrates information technology and management technology and becomes a typical case of comprehensive practice.

4.3.1 *Intelligent technical system*

The technical support system of 'one centre and seven systems' (shown in Fig. 4) is constructed in the Shuangjiangkou hydropower station project.

(i) Engineering early-warning and decision-making centre

The decision command centre serves as a 'decision brain' for the Shuangjiangkou intelligent project. It is a platform for the integrated display, comprehensive analysis and decision warning of the system of the Shuangjiangkou project. It integrates all the data of each system, by establishing unified data standards and data relationships, achieving centralized and unified management of data, documents, models and other information. The overall risk control capacity of enterprises is improved using cross-platform model integration, design and construction data standard coordination, 3D visualization and interaction, remote control and other technologies. The knowledge-based cloud platform employs an expert database and control model for engineering control and decision-making for scientific control and early warning of risks, intelligent formulation of effective solutions.

(ii) Intelligent dam-engineering system

The system consists of four modules: intelligent monitoring of the dam-construction progress, intelligent monitoring of quality, intelligent monitoring of grouting and information-integration demonstration. It aims at achieving the goals of full coverage of quality control, dynamic progress management, traceability of the construction process and full control of the grouting process. Intelligent innovative control measures were applied such as fast detection of the moisture content, intelligent discrimination of the infiltration soil material, monitoring the thickness of spread, automatic driving of roller compaction and quality-assessment APP. At present, the intelligent water-blending module is being developed. Establishing the whole-process quality real-time monitoring system, the intelligent control and management level of the construction quality improved. The schematic diagram of the dam body-roller-compaction monitoring module in the intelligent dam-engineering system is shown in Fig. 5.

(iii) Intelligent underground-engineering system

The system is composed of four modules: design management, schedule management, quality management and concrete whole-process control. It aims at realizing the goals of safety real-time monitoring, quality traceability, progress dynamic control and an information visualization integration demonstration of Shuangjiangkou's underground engineering. Utilizing modern advanced information technologies such as the Internet, global positioning technology, building information model technology and mobile Internet technology, it is the first time that WIFI communication and a high-precision positioning (centimetre-level) network covering the underground engineering of a large-scale hydropower station has been realized. Based on indoor high-precision positioning technology, real-time monitoring and warning of the quality of the manual vibration process of mass concrete are realized. The integrated full-information model of underground-engineering design and construction has been created for the first time; it integrates information about the geology, surveying and mapping, design, construction plan, schedule, quality and safety of each construction unit visually. It provides big-data support for the dynamic optimization of underground-engineering design, risk identification of engineering construction and hierarchical warning. The intelligent underground-engineering system is shown in Fig. 6.

(iv) Intelligent electromechanical-engineering system

The system is composed of modules of equipment life-cycle management, equipment acceptance standard management, installation and construction simulation and schedule management, equipment comprehensive information management and buried-pipe and embedded-parts visualization. It aims at realizing the

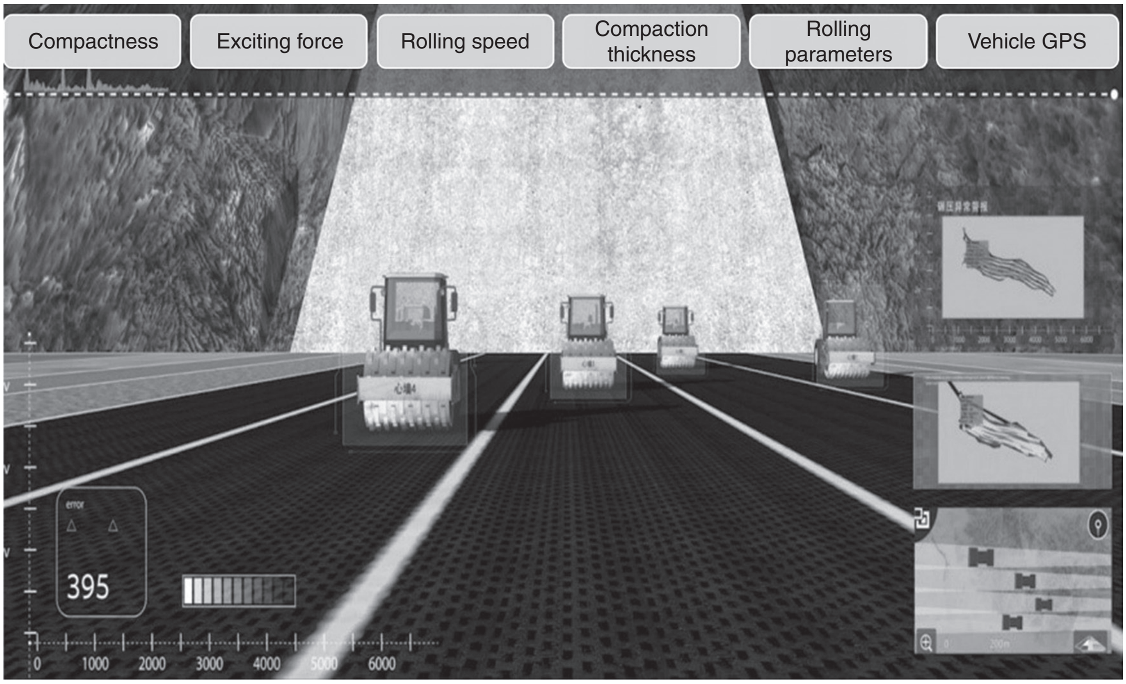

Fig. 5: Schematic diagram of the roller-compaction monitoring of the Shuangjiangkou intelligent dam project

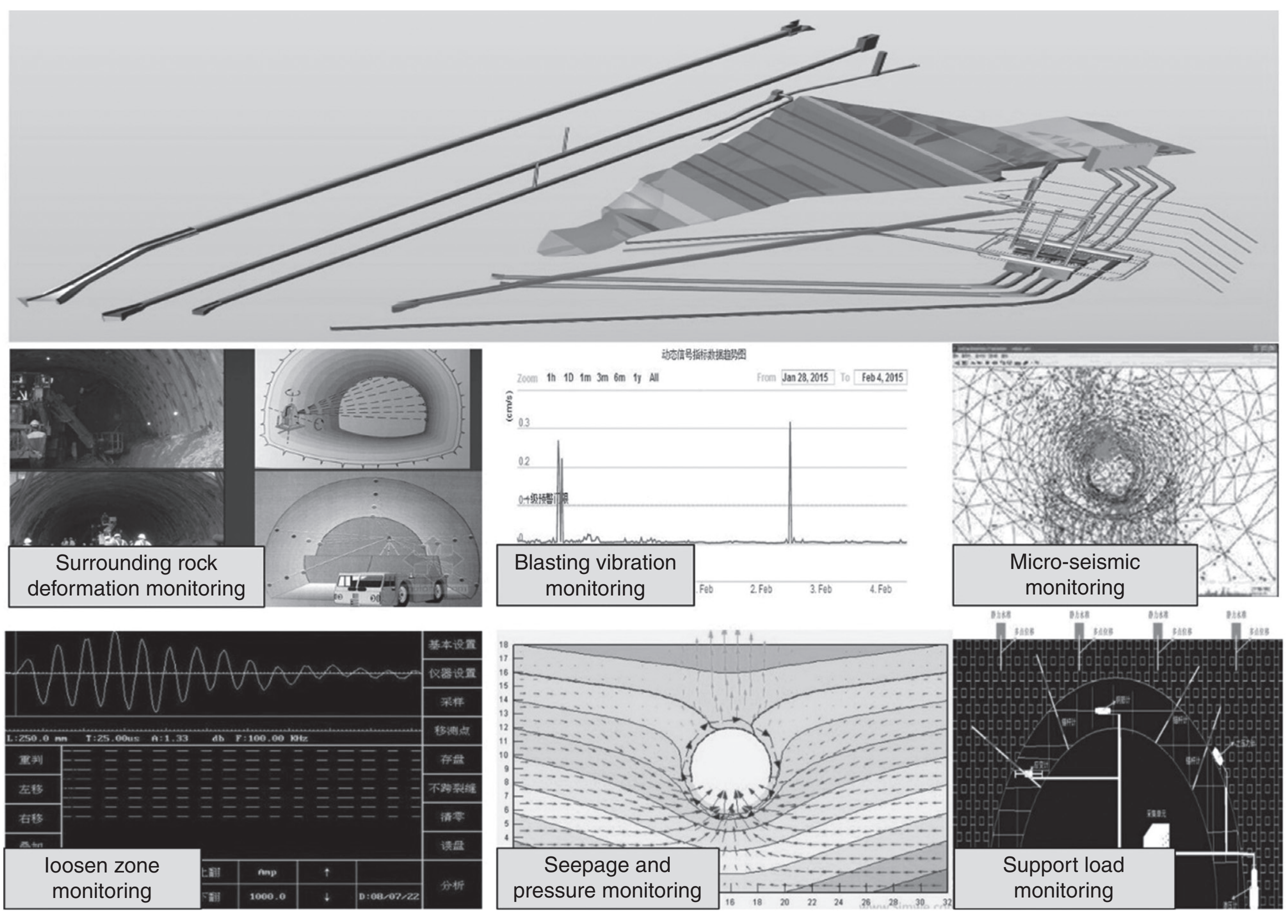

Fig. 6: Display diagram of the intelligent underground-engineering system of Shuangjiangkou hydropower station.

functions and objectives of full-life-cycle management, 3D digital management, progress-risk early-warning management and quality-standardization management in electromechanical engineering. According to the requirements for equipment management during the construction period and the operation and maintenance period, a unified electromechanical-equipment information-management database and a 3D simulation model are established to conduct whole-life-cycle management from the design, procurement, transportation, installation, acceptance and handover of electromechanical equipment. After the completion of the system, it will lay a foundation for the whole-life-cycle management of mechanical and electrical engineering, progress-risk early-warning management, quality-standardization management, as well as create favourable conditions for the subsequent construction of intelligent power plants.

(v) Intelligent safety-management system

The system is composed of modules of the standardized management of safety production, standardized management of civilized construction, classified control of hazard sources, management of geological-disaster prevention and control, management of construction equipment (facilities), safety monitoring and graded warning of key indicators. It aims to realize the automatic identification and perception of danger sources and safety risks, promoting the improvement of intelligent, efficient, visual and integrated levels of safety management. Supported by cutting-edge technologies in the fields of communication, engineering 3D design, the Internet and information integration, the APP system for security management was first developed and used. For the first time, the intelligent safety cap is applied to the construction of hydropower projects, and a real-time dynamic tracking and monitoring system for dangerous sources is established to realize the classification control of dangerous sources. At the same time, the system of weather forecasting for rain and water conditions and the remote monitoring system of ground disasters are utilized. In combination with the unmanned aerial vehicle patrol, the safety state of hidden disaster dangers or vulnerable points is automatically assessed. In addition, it took the lead in realizing the combination of virtual technology, VR equipment and electric machinery in hydropower engineering, and established the first safety-management experience hall of large-scale hydropower engineering to improve the training effect.

(vi) Intelligent service-assurance system

The system is the main carrier of Shuangjiangkou's intelligent project management, data collection and management optimization. The aim is to achieve the standardization of project-management-information collection and processing, standardization of business management and processes, and improvements in project quality, progress, investment, environmental protection and other management and control capabilities. With the application of modern project-management ideas and information technology, the whole-process management information system for hydropower infrastructure projects is built based on project management, with the planning schedule as the main line, with capital control as the core, with owners as the main body, and with the participation of all participating units. A matrix management model centred on engineering management can be formed.

(vii) Intelligent environmental- and water-protection system

The system is the main system for environmental-protection management and control of Shuangjiangkou hydropower station, which is composed of modules such as comprehensive demonstration of environmental information, intelligent management and control platform, monitoring data analysis and environmental-quality-trend warning. The aim is to realize the professionalization and standardization of environmental-protection management in the construction of hydropower projects, improve the site-management efficiency of environmental protection and the ability of intelligent responses and early warning of environmental events. Supported by cutting-edge technologies in the field of the Internet, information integration and unmanned aerial vehicles, it can quickly identify and dispose of environmental-protection unqualified items; fully excavate the environmental data in the control modules of environmental monitoring and intelligent dam projects, intelligent underground projects and intelligent service guarantees; evaluate the effect of environmental-protection measures and the state of engineering environmental quality; and establish an intelligent supervision and early-warning system for the construction of environmental protection in hydropower projects.

(viii) Intelligent resource scheduling and control system

Through the integration of data information of construction-site personnel and mechanical equipment, the human-resources and mechanical-equipment management of engineering construction can be standardized, and the efficient allocation and utilization of construction resources and all-round control can be realized. Collect data related to human resources and mechanical equipment from intelligent dam projects, intelligent underground projects, intelligent electromechanical projects, intelligent security control, intelligent service guarantees, intelligent environmental protection and water protection and other systems, as well as monitor data such as video, identification, operation traces, management behaviours, aerial photography, access control and road gate. Through the establishment of data association and analysis, improve and optimize the control of human resources and mechanical equipment to improve work efficiency.

4.3.2 *Intelligent management mode*

(i) The difficulty of the traditional management mode

Hydropower projects generally have the characteristics of large-scale, high-investment, complex technology, long construction cycles and much management content [1]. Under the current leading system of the project legal

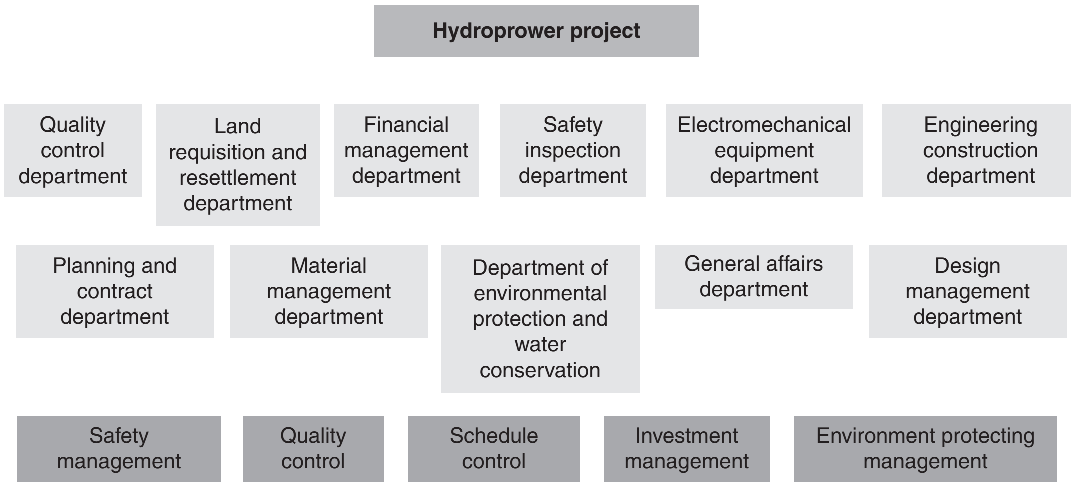

Fig. 7: Typical traditional management mode of a hydropower project

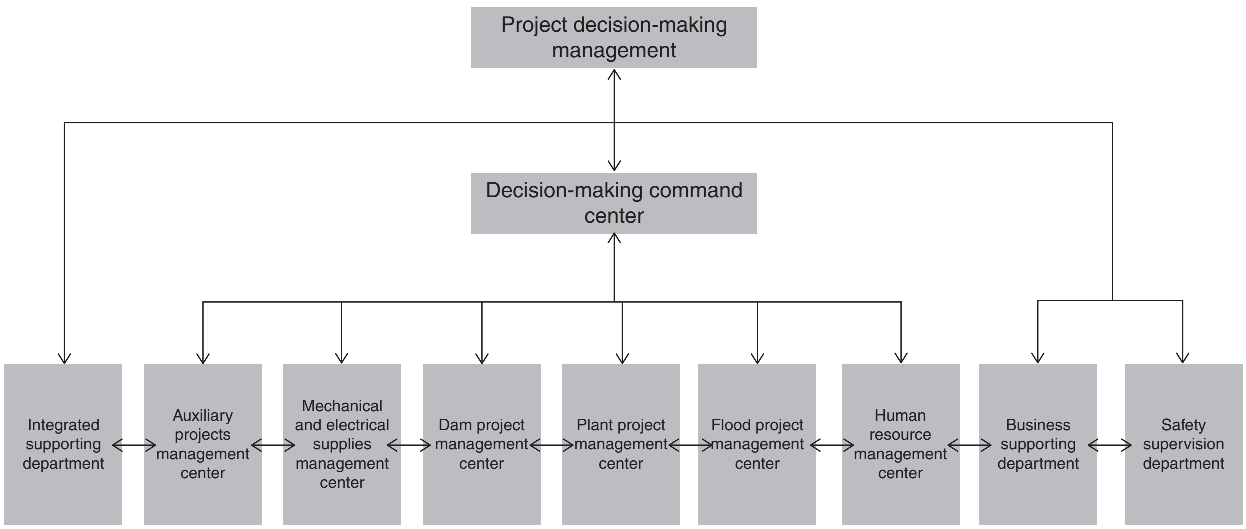

Fig. 8: Management framework of the Shuangjiangkou project

person system, bidding system and supervision system in China, construction management of hydropower projects has the following characteristics: first, there are many participants, involving the government, owners, design, supervision, construction, scientific research and other units; second, the management object is complex, including personnel, machinery, equipment, materials, sites and so on; third, the complexity of the relevant interests and coordination of the workload result in an increase in uncertainty; fourth, the control has many contents and high requirements, covering safety, quality, investment, progress and environmental protection. As a result, the construction-management units of hydropower projects mostly adopt the traditional management mode with multiple levels and specialties (shown in Fig. 7).

(ii) The research emphases of the intelligent management mode

Under the traditional hydropower project-management mode, engineering-construction information and data are affected by human factors and cannot be collected and summarized quickly, accurately and effectively. Therefore, the problem of information and data fragmentation and silencing appears. In addition, massive information and data cannot be updated in a timely manner after the comprehensive promotion of engineering construction, and there is no effective way to realize real-time sharing of information and data, resulting in the 'big data' of engineering-construction management being difficult to form, and the actual situation of engineering construction cannot be reflected in a timely, comprehensive and objective way. At the same time, construction risks can only be controlled within professional departments, the correlation analysis of information and data between different professional departments cannot be effectively played, and the overall risk of project construction cannot be fully predicted, warned and controlled. In addition, the traditional management mode cannot form a shareable knowledge base of experts, which is difficult to be widely used and plays a greater role, and the scientific decision-making ability is weak, so intelligent decision-making cannot be realized. In order to effectively solve the above problems and realize the scientific management of hydropower project construction, hydropower project-construction managers need to make the best use of information, digital, networking and intelligent cutting-edge technologies to create artificial brains, implement intelligent-engineering construction, set up adaptive management modes and innovate project-management modes.

(iii) Organizational structure of intelligent management

In view of the disadvantages of the traditional construction-management mode of hydropower projects mentioned above, a fully data-driven management mode was established in the management process of the Shuangjiangkou project based on the intelligent-enterprise management model—that is, the central management mode of business-implementation decision-making in the centre and coordination and assurance in the department (see Fig. 8). Each centre has a corresponding technical system to support. Each centre is the centre of both management and data. In this mode, the responsibilities of the centre and departments are clearly divided and the management interface is clear.

5 Conclusions

Intelligent dam, intelligent underground engineering, intelligent concrete temperature control, intelligent concrete pouring and other systems and modules of the intelligent project have been successfully implemented in Houziyan, Dagangshan and Shaping-II hydropower stations, which were developed and constructed by Dadu River Company. Intelligent engineering is being fully rolled out in the construction of Shuangjiangkou hydropower station. The system of the engineering early-warning and decision-making centre, the intelligent dam-engineering system, intelligent underground-engineering system, intelligent electromechanical-engineering system, intelligent safety-management system, intelligent service-assurance system, intelligent environmental- and water-protection system, and intelligent resource scheduling and control system have been built and put into trial operation. At the same time, the intelligent-engineering management mode with the 'centre' as the core has been running normally in the management of the hub project of Shuangjiangkou hydropower station. Dadu River Company will fully implement the intelligent-engineering construction and 'centre' management mode in its hydropower projects. Intelligent engineering is not a simple application of information, digital and intelligent technology in project-construction management, but a new management system integrating information technology, industrial technology and management technology, which breaks through the traditional management concept, management means and management mode. With the continuous promotion of the concept of intelligent engineering, engineering-construction management in China and even the world will enter the smart era in an all-round way.

Conflict of Interest

None declared

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