Real-time analysis expert system for concrete dams

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ABSTRACT: This paper presents the general structure of real-time analysis expert system for concrete dam, which consists of inference engine, method base, knowledge base, graph base and project database. The knowledge base and inference knowledge are included from the laws of dam safety, design standards and experts knowledge. The method base is built to implement quantitative analysis with the advanced achievements in dam field. The project is used to store the data on design, construction, operation, monitoring and daily checking. The graph base is composed of all kinds of graphs to support analysis and judgment. With the theory of pattern recognition or fuzzy judgment, this system can analyze and assess dam safety by use of the inference engine and four bases.

1 INSTRUCTION

A large number of dams have been built in China since 1950, which have brought enormous social and economic benefit. However, some dams exist the unsafe factors, such as hydrology, geology, construction quality and aging, etc., which influence the full play of the project benefit, and even threaten the security of downstream people's lives and properties. Meanwhile, the scale of the hydraulic structures is more and more enormous, and the geological condition is more and more complicated. Therefore, their safety should be paid more attentions. In the past, dam safety is monitored with mathematics models which are built by analyzing observation data. Because the work condition of the dam is complicated, it is limitative only adopting above-mentioned methods to monitor dam safety. The final synthesis analyze need be implemented by experienced experts. Especially while presenting the dangerous situation in flood season, the experts need come to the scene to decide emergency measures. In addition, the prototype observations could neither be analyzed in time, the unusual behaviors could nor be analyzed and appraised in time.

The laws of dam safety, design standards and experts knowledge are combined into a knowledge base. The maturity research results in dam field are synthetically applied to set up the multi-functional method base. The database and graph base with fine graphical display function are set up. Quantitative analysis and qualitative analysis are combined together to carry on comprehensive appraisal and aid decision to dam safety.

2 GENERAL NETWORK OF REAL-TIME ANALYSIS EXPERT SYSTEM FOR CONCRETE DAMS

The purpose of this system is as follows. Firstly, the monitoring models and monitoring index are built according to observations of dam safety. The forecasting values and monitoring index are compared with the observations. Dam behavior is analyzed through the regulation of time and space distribution, the data and results of daily inspection. The trend and dangerous status of unsafe factors can be found and predicted. The next step is to analyze physical genesis of unsafe factors and decide corresponding measures. According to the above aim, the total network of real-time analysis expert system for concrete dams (for short RAESCD) can be described as Figure 1 and Figure 2. The figures can reflect real-time analysis and decision process visually. It reaches the real-time analysis and decision mainly by comprehensive calling of knowledge base, database, method base and graph base.

2.1 Professional technique network

(1) According to the data of design, construction and operation, the charts of the project and security overview are shown or typed by the graph base. the

users can understand the project and security state vividly.

(2) Through judging the dam safe status in real time, the system can judge the working state of the dam in time, explain the doubtful point among the operation course, find the unsafe factors, and analyze its genesis and tendency.

(3) According to the judging results, if there are obvious unsafe factors in the dam, then the system implements the control for the operation water level.

2.2 Computer system network

The system consists of one engine and four bases, namely, inference engine, method base, knowledge base, graph base and database.

2.2.1 Comprehensive inference engine

It is mainly made up of judge, physics genesis analysis and decision. The qualitative analysis and qualitative analysis are combined organically in inference course. Dam behavior is judged, unsafe factors are analyzed, and making-decision is proposed by the expert system.

2.2.2 Knowledge base

For the conditions of the dam and characteristics of different dams, through visiting the expert relevant design and operation, and according to the safe regulation of relevant dams and design rules, the system obtains the judgment criterion of dam safety. C language is adopted to carry on organizational management.

2.2.3 Project database

The project database is constructed to store the data on design, operation, construction and observations with ORACLE. The data are input and implemented pretreatment according to the professional way. In addition, the interface is developed to implement the communication between data and solving system.

2.2.4 Method base

Analysis programs are written with C language and FORTRAN language, and made up method base. Meanwhile, the system adopts module mode to assemble, produce and transmit various kinds of programs.

2.2.5 Graph base

All kinds of charts and tables worked out with intellectual CAD or C language can meet the display require of judgment, physical genesis analysis for unsafe factors.

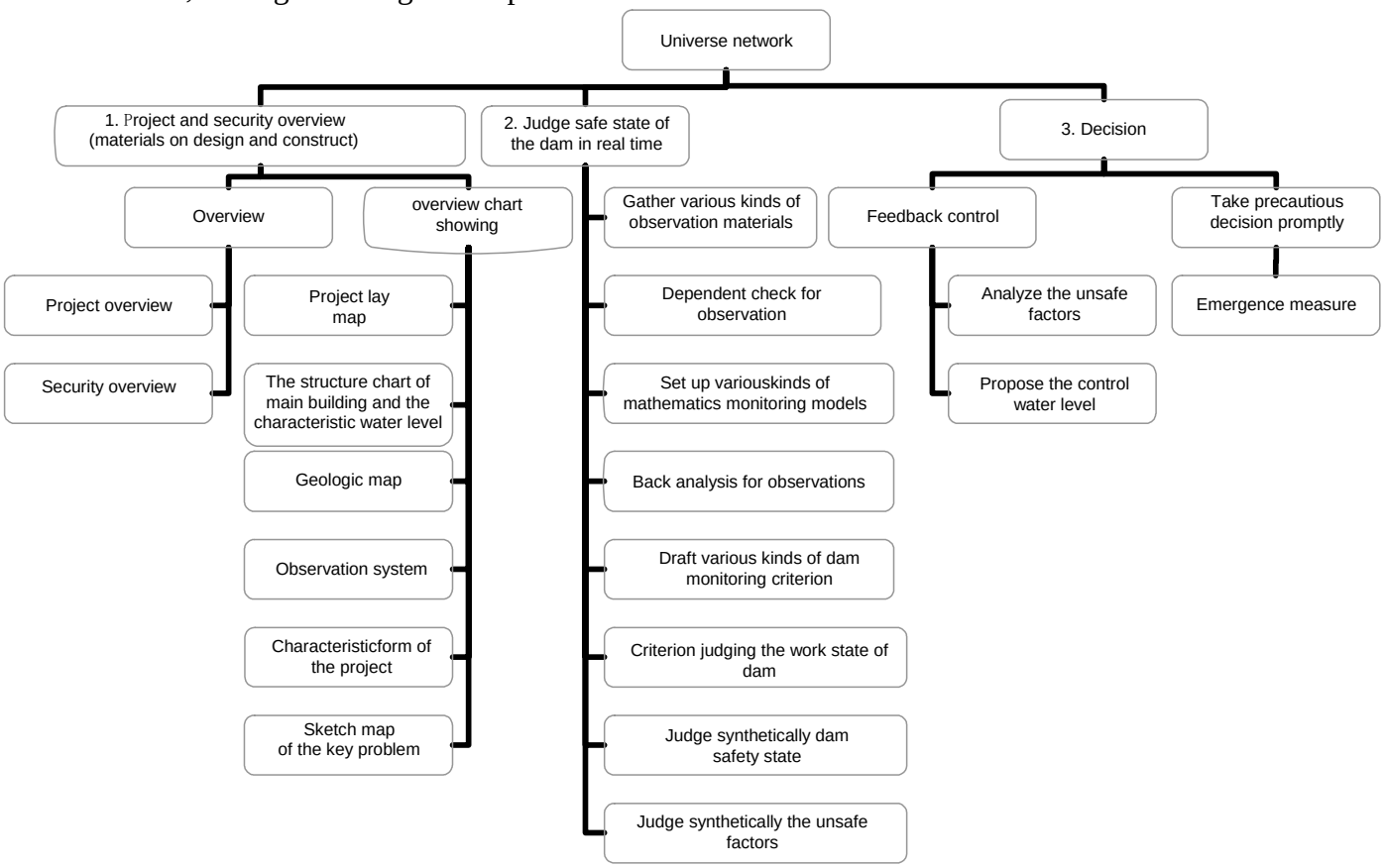

Figure 1. General network of professional technique.

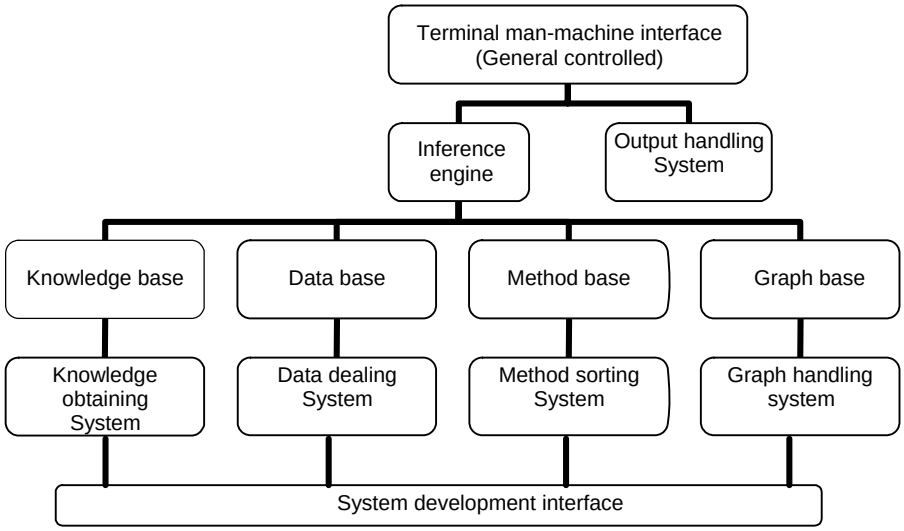

Figure 2. General network of computer system.

3 REAL-TIME ANALYSIS EXPERT SYSTEM FOR LONGYANGXIA DAM

3.1 Overview and doubtful points of Longyangxia dam

3.1.1 Project overview

Longyangxia dam lies in the master stream of the Yellow River. The above drainage area of dam is 131420 km^2. This project started building in 1980, store water in October, 1986.

3.1.2 Doubtful points during dam operation

The geological condition of Longyangxia dam is complicated. Since 1986, the observations indicate that the dam has the following doubtful points.

(1) The radial displacement above EL 2497m of No.9 dam monolith had mutation about 5.8mm to 7.0mm towards upstream during in June, 1989. It was the first 'doubtful point of deformation'.

(2) The deformation of the dam varied obviously, after experiencing the water level at EL 2575.04m. The radial displacement in No.9 dam monolith reached the maximum towards downstream respectively in January and February, 1990. Those of dam crest got to 16.28mm on January 5th 1990. Then the dam body deformed towards upstream as the reservoir level fell off, especially the deformation trend of the observing points above EL 2530m towards upstream was quite obvious. For example, the dam crest turned deformation towards upstream -0.4mon August 20th 1990, and -4.72mm on August 30th 1991. It is the second 'doubtful point of deformation'.

(3) The third 'doubtful point of deformation' was that the tangential displacement of No.13 dam monolith had obvious trend towards left bank after July, 1989.

3.2 Real-time Analysis Expert System for Longyangxia Dam

According to the above design idea and the condition of Longyangxia Dam, 'Real-time analysis expert system for Longyangxia Dam' is developed to evaluate the work conditions of Longyangxia Dam and successfully analyze the doubtful points of deformation during dam operation. The following is to introduce the processes and results of its analysis and evaluation.

3.2.1 General flow of the system work

The system judges, infers and analyzes the observed data based on collecting data, applying knowledge, calculation and analysis, reasoning and judgment, etc. Figure 3 shows the general flow of the system work.

(1) Establish database

The database of ORACLE is used to manage and store the data of Longyangxia Dam. It is divided into two sections as following:

① Original database

Input the original data of dam safety, operation and monitoring into the database. These data come from technical design instructions, reports of project completion, operation reports, hydrographic and geological data, observations from monitoring system. The original database is based on these data.

② Generation database

Generation database is used to manage the data which are compiled, preprocessed, analyzed and back analyzed.

(2) Call method base

In the on-time analysis of Longyangxia Dam, the following sections in method base are mainly called:

① Structural analysis

■ Finite element analysis for the structures near dam region

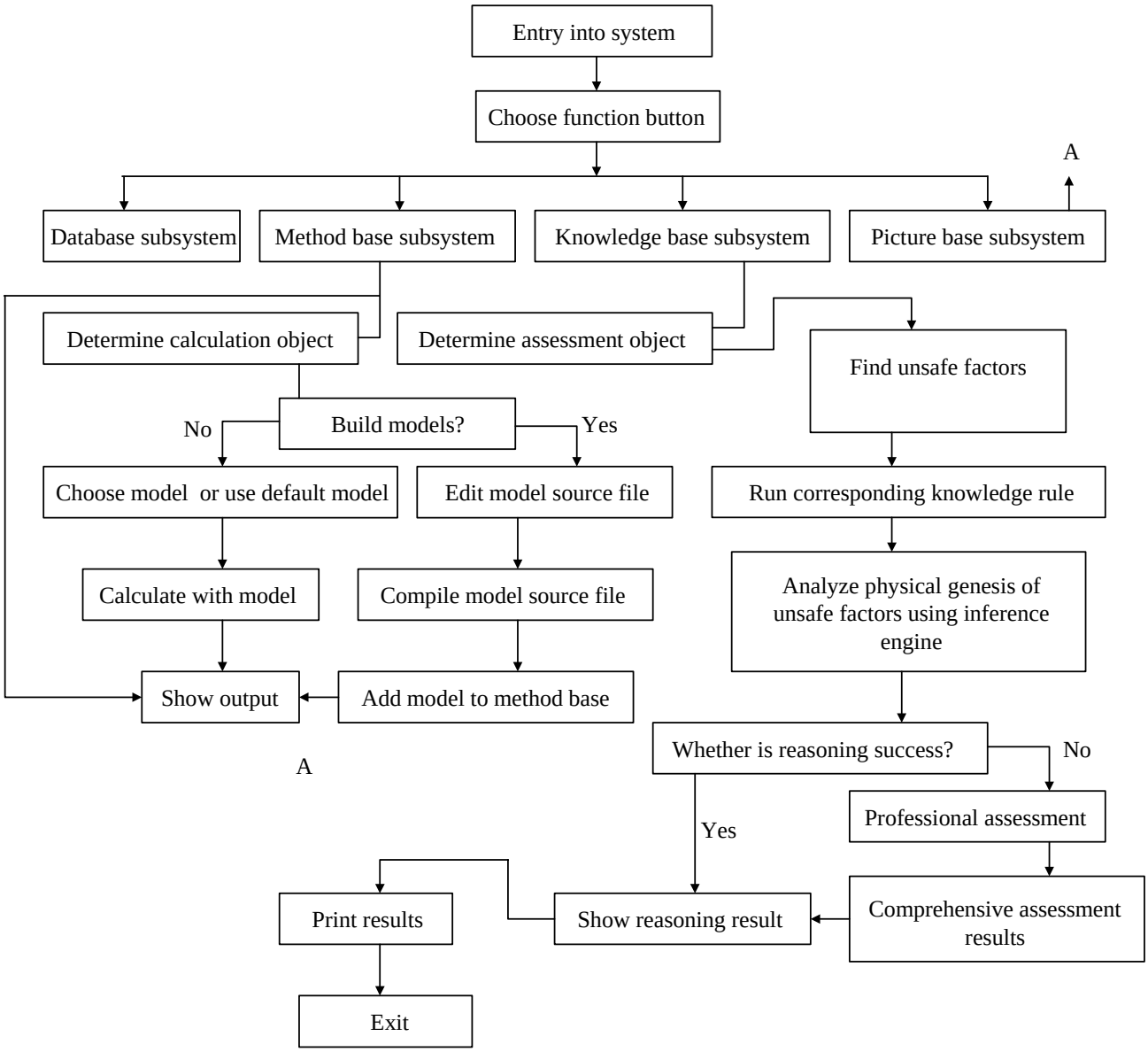

Figure 3. Analysis flowchart of real-time analysis expert system for Longyangxia Dam.

Three-dimensional finite element model is adopted. Dam body uses isoperimetric element with 20 nodes, and dam foundation uses isoperimetric element with 8 nodes. The node distribution takes account of many factors such as vertical measuring point and thermometer-meter position. The fractures of F_{18}, F_{72}, F_{71} are simulated. With graph base, three-dimensional finite element mesh is drawn. This mesh has 1532 isoperimetric elements, 2614 nodes. 44 groups of cases are calculated.

■ Finite element analysis for Large-scale reservoir block

In order to understand the effect of deformation of reservoir block to structure condition of dam body, with three-dimensional finite element, the system calculates the deformation of dam, dam base, reservoir block, and radial and tangential displacements of every measuring point of dam body cause by 5 kinds of water level (2483.3, 2540, 2575, 2600, 2610m). The range of finite element model is following as. Length is 130km (120km upstream, 10km downstream). Width extends 5km of the water surface width according to normal water level. Depth of bedrock is 8km. The model considers the effect of main fractures. The isoperimetric elements with 8 to 20 nodes are adopted. The layer height of element and position of nodes take account of displacement measuring point. It is divided into 6256 elements, 9841 nodes totally.

② Build mathematic models

Build the statistic models of deformation of main monolith ($4^{\#}$, $9^{\#}$ and $13^{\#}$), gravity monolith ① of left bank, gravity monolith ② of right bank. For main monolith ($4^{\#}$, $9^{\#}$, $13^{\#}$), except collaterally building statistic model, mixed model and deterministic model of measuring point, build statistic model and mixed model of beam orientation, arch orientation and the whole space displacement field, and separate every component of models. Generate actual measurement graph of every measuring point and its fitted value and every component and its error line.

③Inversion analysis

Elastic and deformation modulus are inversed with comprehensive analysis method. The result is shown in Table 1.

Table 1. Elastic modulus of dam body and deformation modulus of foundation of different monolith.

Monolith	Items					
	Deformation modulus of foundation ($\times 10^4$MPa)			Elastic modulus of dam body ($\times 10^4$MPa)		
	Design value (a)	Inversion Value (b)	(b-a)/a	Design value (a)	Inversion Value (b)	(b-a)/a
$9^{\#}$	2.16	1.96	-9.1%			
$13^{\#}$	1.96	1.86	-5.0%	1.96	2.12	8%
$4^{\#}$	1.76	1.62	-8.3%			

④ Judgment of safety degree

■ Safety degree of stability

Using the stress results calculated by 3D-FEM, and calling the analysis program of stability in method base, we check the most dangerous slide plane (F_{73}-F_{215} as its ground plane, and high-angle facture in NW290° direction as its slip plane). The result shows that the stability of abutment is guaranteed when the water level is below 2600m, after the foundation is strengthened.

■ Safety degree of strength

Using the stress results analyzed by FEM and observed data, we can infer that the safety factor of strength of Longyangxia Dam is high when it is under high water level (2600m).

(3) Application of knowledge base

With the management system of knowledge base, the knowledge on Longyangxia Dam is input. According to the rules and criterion in knowledge base, the system implements real-time analysis for the original information of Longyangxia Dam. The following doubtful points are found.

① According to the judgment criterion of space-time distribution and monitoring model, it is known that the mutative values of radial displacement towards downstream of 9^{th} monolith above elevation 2497m are about 5.8mm ~ 6.99mm in June 1986. The variance exceeds the observed error. That's the first doubtful point of deformation.

② According to the judgment criterion of space-time distribution and monitoring model, it is known that after Longyangxia Dam suffering the first high water level reaching 2575.04m on November 27^{th} 1989, 9^{th} and 13^{th} monolith above 2530m elevation have great radial displacement and amplitude. That's the second doubtful point of deformation.

③ According to the judgment criterion of mechanical rule and time-effect criterion, it is known that the 13^{th} monolith has obvious tangential displacement towards left bank after July 1989. It doesn't conform to the mechanical rule of arch dam. That's the third doubtful point.

The inference engine is called to analyze the physical geneses of doubtful points.

(4) Inference and solution by inference engine

From the above analysis, there are three doubtful points during operation process of Longyangxia Dam. This system uses normal inference method to seek the genesis at first. The structural analysis programs in method base are called to simulate the structural deformation under external load from database. In addition, the system matches it with information in knowledge base to deduce the geneses.

① Analyze the physical genesis of the first doubtful point

■ The water level is between 2535.87m to 2537.78m, which is lower than the highest water level in the past. There is no remarkable temperature change or earthquake. Therefore, the environment can not bring the first doubtful point.

■ Large-scaled measures are not adopted during dam operation.

■ The variation of other observations around PL3 is little.

It is drawn form above analysis that the abnormal variation is caused by systematic error from the observation system of PL3 pendulum, which has changed with unconventional variation law since Dec, 1988. On June 5^{th}, 1989, it starts to change in a discontinuous way. It checked out that the free deformation of pendulum is stopped by obstacle in the pendulum well and the deformation is restored after the elimination of obstacle on July 10^{th} ,1989. Therefore, the discontinuity is not caused by the structural behavior.

② Analyze the physical genesis of the second doubtful point

■ From the direct and inverse analysis of method base, it shows that for the comparatively larger amplitude of radial displacement of monoliths $9^{\#}$ and $13^{\#}$ above the elevation 2580m, the external cause is mainly the deformation of temperature-change and the batholiths deformation.

■ Before Aug. 20^{th}, 1990, the elevation of sealing arch is at 2580m, the left-bank gravity pier has not built and the bank monolith is higher than elevation 2610m, so it comes up the structure condition of arch dam below the elevation 2560m and causes comparatively larger displacement amplitude above elevation 2560m. Therefore, the comparatively lower sealing arch elevation is the internal cause of the increasing amplitude above elevation 2560m.

③ Analyze the physical genesis of the third doubtful point

The physical genesis of the third doubtful point of deformation is mainly the gradually increasing pore water level of $30^{\#}$, $34^{\#}$, $36^{\#}$ in the right of monolith $13^{\#}$ from July 5^{th}, 1989, which respectively reaches 14.87m, 15.88m, 4.06m on Aug. 5^{th} with a rising tendency, while pore water level in the left bank changes little. So it equals a lateral water pressure on

the right of monolith 13#, causing deformation toward left bank.

④ After the action of high water level, the dam body and dam base experience a process of deformation adjustment, then the dam body (especially the deflection line of monolith 4#) approaches to the calculated value by mathematical model of spatial displacement field, which shows deformation of the dam approaches to normal.

3.3 The assessment of working behavior at the initial operation of Longyangxia Dam

According to the synthetic analysis and judgment of expert system, the assessment of working behavior at the initial operation of Longyangxia Dam is as follows:

① After experiencing high water level (2575.04 m), there is an adjustment process at the dam base and dam body. The deformation of the dam body is approximate to the calculated value by 3-D FEM, design value and calculated value by mathematical model of spatial displacement field, which shows deformation of the dam approaches to normal.

② The dam is once challenged by earthquake of the 6.9 magnitude, the displacement changes little.

③ From the results of inverse analysis, we can infer that the stabilization of dam abutment is guaranteed after the reinforcement of dam base and the strength assurance coefficient is improved.

Therefore, the deformation behavior at the initial operation of Longyangxia Dam is normal, and the strength and stabilization is estimated to meet the safety demand at water level 2600 m after the reinforcement of dam base.

4 CONCLUSIONS

The system is developed by compactly linking Long Yang Gorge project. Combining with the facts of the project, especially the key problems, we build the system of One Machine Four Bases, and reach the goal of real-time analysis. However, because Long Yang Gorge Dam is still in the impounding stage, the water level has not reach that in design operating mode, and the dam may appear new condition as water level raising in the future. The knowledge base and the knowledge of reasoning machine need to be perfected and supplemented. As the perfection and automation of the monitor system of Long Yang Gorge Dam, the system will play more important part. Meanwhile, combining Danjinkou Dam, Gutianxi 3 grade Dam, develops dam safety comprehensive assessment supporting expert system. Running about 2 years, get the actual effect of real-time monitor the tow dams, and obvious social economic benefit.

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