A Blasting Sources-Based Approach to Inspection of Faults in Dam

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Abstract: An approach to inspection of incipient faults in dams by non-destructive testing is a so far emerging inspection technology in the world. In this paper, inspection principles, system integrity and key items for the new blasting source-based technology for inspection of incipient faults in dams, different from common non-destructive testing, are presented, following briefing experiences in dam inspection by elastic wave CT in recent years. Specific procedures and goals for further spreading and application as well as conclusion are introduced finally.
Key words: blasting source; dam; inspection of incipient fault; elastic wave; dynamic monitoring; excitation signal

1 Introduction

There are to date more than 80 000 dams and reservoirs built or under construction in China, of which nearly 5 000 are higher than 30 m and 200 higher than 100 m. These dams and reservoirs have contributed not only to the control and reduction of flooding and effective utilization of valuable water resources, but to energy supply to national economic construction and people's daily life; however, upon failure they could bring about immeasurable damages and losses. As the saying goes, dam safety monitoring is just like a dam doctor and a safeguard for dams and reservoirs.

In China, dam safety monitoring has experienced a developmental process from visual inspection to inspection by simple apparatuses and inspection by instrumentation and automatic monitoring. Especially with rapid development of instrumentation technology in the last 20 a, technologies for dam safety monitoring have correspondingly thrived. The establishment and normal operation of the safety monitoring systems have provided an important scientific foundation for highly effective and safe operation of all dams across China.

At the end of the last century, a CT chromatography was applied to projects and successful results were obtained in other countries. Studies of dam CT in China date back to the beginning of the 1990s, including mainly electromagnetic wave CT and elastic wave CT, associated with reflecting and transmission methods. The elastic wave can be used for inspection mainly based on variable factors of medium physical properties, with a large inspection range of influences mainly from excitation energy, reception precision of instrument and medium resistance, resulting in its wide application in the non-destructive testing field. In recent years, as a result of many achievements made in inspection instrumentation and analytical methods in China, especially with the rapid development of acoustic wave instrumentation, vibration monitoring cells and reception & processing instrumentation, as well as the long-term accumulated experience in analytical methods and engineering, an entirely new approach to inspection of incipient faults in dams seems ready to come out.

2 Principle and Integrity of System

2.1 Principle

The technology for blasting source-based inspec-

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tion is practically based on the elastic wave that originates initially from seismic shock waves and can be transmitted in a certain direction when blasting occurs nearby the dam and sensors are used to receive acoustic parameters of the elastic wave, including the peed and amplitude of the wave, time and frequency of transmission resulting from reflection and refraction of the elastic wave when it encounters the interior faults in a dam. Through analysis of the acoustic parameters and variations in waveform we can identify material boundary conditions, faults in the dam and their extents, as well as dynamic mechanical properties of dam materials. Given blasting parameters and dynamic physical models, the anticipated working performance of the dam and safety magnitude under various operational conditions can be predicated and an overall and scientific 'physical examination' over the dam can be realized before formal operation.

The reflection wave is generally used to inspect the incipient faults in the dam, and the range or size and depth of the fault can be identified in light of the strength and time of reflected signals. The depth of the fault can be established by the following formula:

$$H = V_p \times t/2$$

where H—distance between fault location and measurement point;

V_p—S longitudinal wave speed; and t—reflecting time.

Generally, the vibration from the epicenter radiates forward the surrounding medium in longitudinal wave (P) and transversal wave (S) forms and produces reflection and refraction or transformation of waveforms when it passes through different physical boundaries and may also transmit across the boundary plane or lamination, regarded as a surface wave, under certain conditions. This seismic wave radiating from the epicenter to the measuring point, in different vibration forms and along different transmission routes, is called the seismic phase.

The analysis of reflection waves should be based on analysis of the seismic phase of longitudinal waves, primarily including analysis of the transmission process of the seismic wave from the epicenter to the reflecting boundary surface by wave theory so as to obtain a theoretical know of seismic phase characteristics, and analysis of the data on measured waves so as to study and reveal kinematical and dynamic characteristics of the seismic phase. Generally the analysis of the seismic phase includes analysis of the epicenter, radials, traveltime, initial moment direction of the seismic phase, waveform, amplitude and spectrum of the wave. An overall and integral analysis of the information and data will greatly be helpful to the judgment and the accuracy of analysis.

Considering complex dam structures, materials and boundary conditions, the transmission of elastic waves in a dam would be unintelligible. Due to limits in instrumentation and analytical methods, faults and their locations inspected by CT may be in a large range with a problem in accurate positioning. A common practice is to use scanning positioning within a large area and then to conduct a dense scanning of elastic waves by sending concentrative energy to the questionable area and validate it by common boring. Finally the faults can be eliminated by way of consolidation to a satisfactory effect in inspection of and precaution against incipient faults.

2.2 System Assembly and Key Techniques

The blasting source-based system for inspection of incipient faults in a dam consists of dynamic excitation emitting system, receiving system, data logging system, and analysis & processing of the data. For the structure of a typical system, see Fig. 1.

2.2.1 Dynamic excitation system

The design of a blasting source is a key technique for this system. According to specific structural features of the dam, a blasting source can be designed with a sinusoid of blasting strength as the function of time. The blasting source can be ignited by microsecond delay blasting to achieve systematic and consecutive excitation signals; if necessary, an interferometry-double source blasting can be used to improve the accuracy of inspection and analysis. The geometrical location of the blasting source is taken at the geometrical center of the dam or at a certain point on the central line geometrically as shown in Fig. 2.

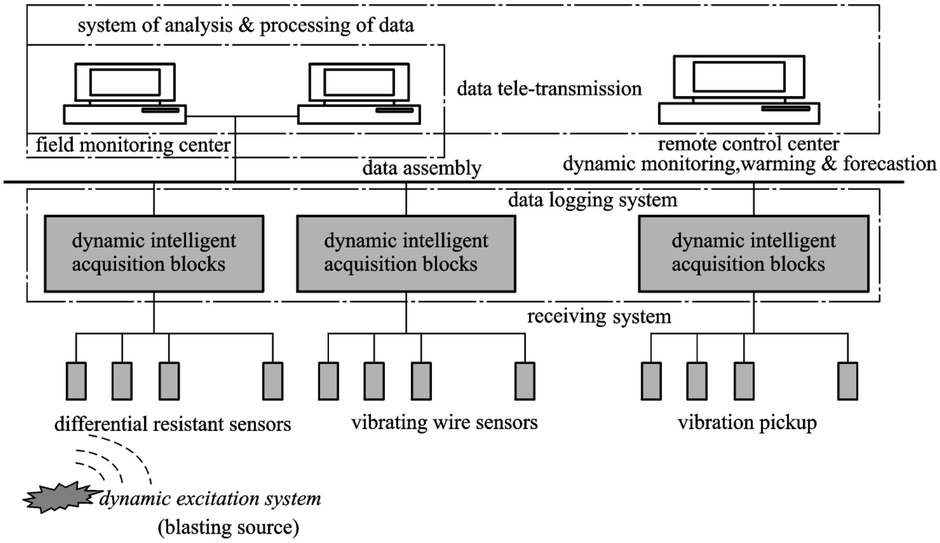

Fig. 1 Schema of the blasting source-based system for inspection of incipient faults in the dam

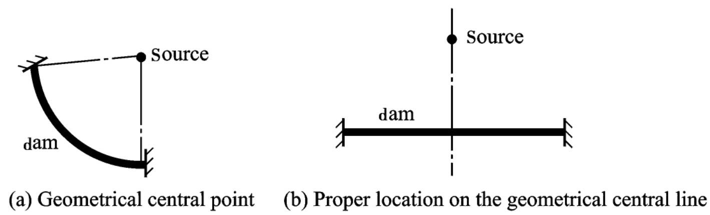

Fig. 2 Selection of the location of the blasting source

2.2.2 Receiving system

The receiving system is mainly composed of dynamic signal vibration pickups. The vibration pickups can be arranged rationally on the built dam to receive blasting-induced vibration signals, in addition to those received by a great number of instruments embedded in the dam. For projects to be built, dynamic sensors can be placed in safety monitoring design in accordance with dam safety monitoring and control requirements. Because of the complexity of the structure, materials and boundary conditions of the dam, the received waveforms would be complex. How to identify and collect useful information is very important. Through optimized design of the blasting source and arrangement of the sensors, and by simplifying complex problems, we can generally make waveform characteristics easier to be identified. The measurement lines, for example, are used instead of measurement points and more measurement points are placed at intervals along the wave radiating routes, etc.. Optimum measurement point arrangement is another key technique for this system, which needs to accumulate more experience in the inspection practice and to be improved and optimized continuously.

2.2.3 Data logging system

The data logging system used mainly to amplify and process analog signals received by sensors and to transit them into such digital signals as transmission and storage, includes traditional data acquisition and a recording system for internal observation instruments and inspection and a recording system for elastic waves, with requirements for simultaneous acquisition from multiple channels, stronger anti-interference ability, larger dynamic range, wider frequency band, rapid sampling speed, etc.. It is important that two systems should be linked for simultaneous acquisition for the sake of analysis.

2.2.4 Data analysis and processing system

The data analysis and processing system is responsible for filtration and extraction of waveforms, calculation and analysis of acoustic parameters during transmission of elastic waves, reproduction of dam vibration characteristic parameters, and CT imaging of waves at testing sections, including such functions as analysis of frequency spectrum, digital filtration, differential and integral calculus, energy equilibrium, wave smoothing, dynamic and static correction, exponent amplification, analysis of small waves, etc.

3 Implementation Procedure

During the construction and operation of water resources and hydroelectric projects in China, some organizations have employed acoustic waves or vibration excitation methods to non-destructive inspection of local structures or components of a dam, with extensive experience and sound foundation for practical application of a blasting source-based inspection of incipient faults in the dam. Inspection of faults in the Fengman dam in northeast China was conducted by elastic wave scanning for several times, acquiring much sectional waveform information; and an elastic wave CT was used on the Three Gorges project to inspect the base slab of the shiplift, water conveying tunnels for the double-lane & five-step shiplock, and the dam concrete for the second-phase work, with much sectional CT video information.

Moreover, during the removal of the cut-off walls in the second-phase earth & rock cofferdam in the Three Gorges project, China Gezhouba Group Corp. conducted a systematical monitoring of blasting, including vibration parameters, attenuation characteristics, water shock wave, fluctuation pressures, dynamic strain, and macro influence on the dam, accumulating valuable information and experience in design of the blasting source, acoustic parameters of the structural vibration, and structural dynamic responses.

While a non-destructive inspection of concrete structures by the elastic wave has been applied widely to the hydroelectric projects, an integral inspection of faults in hydraulic structures with blasting source-based technology will depend on the following new developments:

(1) As a result of the complexity of hydraulic structures, a quite big number of tests should be needed, compared with conventional methods, to correct and optimize analytical models;

(2) The design of the blasting source must be carefully conducted and some model tests should be needed to establish main design parameters for the blasting source; and

(3) Dynamic testing behaviors of secondary acquisition for existing external observation instruments should be improved to achieve a real dynamic acquisition.

This blasting source-based inspection system used in hydraulic structures can be set up according to the following three procedures:

(1) The blasting source is designed under specific conditions and requirements to provide proper excitation signals to structures, and an overall inspection of faults can be made by a full-section elastic wave CT image taken from acoustic parameters of elastic waves inspected and received by vibration pickup sensors embedded on the surface of the structures.

(2) To improve and perfect the existing observation system and enable it to realise an automatic dynamic monitoring of key projects or key locations, so as to enhance the time resolution and reliability of safety monitoring and control.

For the issue about whether dynamic monitoring is needed for the hydraulic structures, many people in the past believed that the hydraulic structure had a lower self-vibration frequency with a lower response to the harmful vibration, and that it was more preferable to conduct a macro rather than micro monitoring and to make external observations rather than internal observations. But everything always have two sides of their own. Whatever micro structural damages there occur is invisible, but at present they also can be measured by advanced instruments. For example, the fracturing of concrete is a process from micro to macro damages, presenting stress concentration first at the initial phase, then cracking and rupturing, and finally resulting in a failure of concrete cohesion resisting against tensile stress. If changes in stress concentration and even initial cracking are monitored in advance, timely measures for load releasing and consolidation would be taken to prevent further development of cracks. The current dam safety monitoring systems at home and abroad all use static observation methods to take data on stress, deformation and displacement and make evaluations of dam behaviours. The dam operation, however, is a dynamic process, which is important especially during flooding, earthquake, and dramatic variation of water level or flow. At this point, in static observations, many incorrect data cannot be screened out, leading sometimes to a misunderstanding of dam behaviours, thereby working an adverse impact on right and timely decision-making, and, in this case, even disastrous faults, such as dam-breaking, might be neglected. The real-time monitoring over dam behaviours can be conducted only through dynamic observations.

(3) A dynamic mechanical model is first set up on the basis of dynamic monitoring. By given energy from the blasting source to exciting structures and dynamic receiving system, changes in dynamic mechanics and acoustic parameters can be inspected. Through analysis of data on a dynamic mechanical model, the anticipated resistance of a dam can be determined. Therefore, the working life and safety of a dam can be predicted through this non-destructive testing with relatively high accuracy.

4 Conclusion

The blasting source-based inspection of incipient faults in dams is a sophisticated and cross-disciplinary technology integrated with a sufficient knowledge of hydraulic structures, blasting mechanics, acoustics, informatics, automation, etc.. In spite of some results we have achieved in key technical areas, a practicable dam inspection technology applied to projects will need concerted efforts of technicians from technical fields.

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