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A New Tailings Dam Stability Monitoring Technique Using Guided Waves

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Abstract: *In this paper a new tailings dam stability monitoring method is proposed based on guided wave inspection technique. Crushed stone aggregates with different volume were firstly buried in a drilled hole located in a tailings dam experimental model and a round steel rod was placed in the centre of crushed stone aggregates. Then tailings dam failure experiments were conducted. During the dam break process, tailings deformed and guided waves were excited by collision and friction between the rod and aggregates. Based on that, guided wave event rate, energy rate and energy fractal dimension versus time relationships were obtained. Results show that guided wave event rate and energy rate increase sharply and reach the maximum on the verge of tailings dam break, while guided wave energy fractal dimension increases at first and then decreases sharply before tailings dam break. So the change trend of guided wave event rate, energy rate and energy fractal dimension can be treated as precursor characteristics of tailings dam break and guided wave parameters as new indicators can be used in tailings dam stability monitoring.*

Keywords: tailings dam break, guided waves, monitoring

1. INTRODUCTION

Tailings are a waste product of the mining industry and dams are constructed to create storage areas for the disposal of tailings. The mining industry has been plagued with failures of tailings dams. As a result tailings dam has become one of the major hazard sources in the mining industry. Mine tailings dam failures, which are disastrous with the serious damage and the loss of lives, are occurring at relatively high rates. Many dam break accidents of tailings dam have happened in recent years in China. On September 8th 2008, a tailings dam which belonged to Xinta Mining Corporation in Shanxi Province collapsed and about 277 people died, 4 people disappeared and 33 injured in that accident. Another dam break accident happened on 12th of March 2017 in Tonglushan mine, Huibei Province. And the length of dam breach was around 200 meters with about 200,000 cube tailings sand leaking into farmland. Two people died and one missed in that accident while the land and groundwater was seriously polluted.

Tailings dam safety has been increased in importance all over the world due to the recent failures that have occurred and the increased consciousness among the people and society and media interest. Many techniques have been applied to monitor the stability of tailings dam in recent years. Li and Wang(2011) analyses the feasibility and advantages of using GPS technology in tailings dam deformation monitoring. Combined with modern computer technology, network technology, image and video transmission technology and GPS satellite positioning technology, the factors that affect the safety of tailing dam are given by Hu and Liu(2011). With the development of internet technologies(Sun et al., 2010), a novel tailings dam monitoring and pre-alarm system (TDMPAS), which is based on the internet of things (IOT) and cloud computing (CC), is achieved with the abilities of real-time monitoring of the saturated line, impounded water level, dry beach elevation and the dam deformation.

We find that there are few reports about motoring the stability of tailings dam using acoustic method. Guided wave is an elastic wave propagating in structures with finite dimension(Rose and Zhang, 2001; Wang et al., 2009) . Due to its long distance propagation properties and its cost efficiency, guided waves are widely used in structural health monitoring fields. In this paper, a tailings dam failure monitoring method based on guided wave technology is proposed.

2. TAILINGS DAM FAILURE MONITORING EXPERIMENT

When tailings dam is deforming, friction happens between tailings sand and acoustic wave excited by the friction can't be easily captured because of acoustic wave' rapid attenuation in tailings sand. So we suppose that Crushed stone aggregates are buried in tailings sand and a round steel rod is installed in the centre of aggregates. Friction and collision happens between the aggregates and steel rod caused by tailings dam's deformation, as a result, guided wave can be excited in the steel rod and be easily captured by the transducer attached on top of the rod.

2.1. Experimental apparatus and material

Guided wave signal acquisition system is 16-channel PCI-2 AEwin which is a product of Physical Acoustics Corporation (PAC). Transducers used in the experiment are UT1000, which are also from PAC. The operational frequency range of UT 1000 is 60~1000 kHz. The gain of preamplifier is set to 40 dB.
Steel rods (figure 1) with diameter of 14mm, 18mm and 22mm are chosen and crushed stone aggregates (figure 2) with particle size 5-10mm, 10-16mm and 16-20mm are used in the experiment.

（a）14mm （b）18mm （c）22mm

Figure 1. Steel rods with different diameter

（a）5-10mm （b）10-16mm （c）16-20mm

Figure 2. Crushed stone aggregates with different particle size

2.2. Experimental model

Figure 3 shows the simplified model of tailings dam stability monitoring using guided wave. Tailings sand from a tailings dam in Jiangxi Province, China was used to build an experimental model in the laboratory. The experimental model is illustrated in figure 4. The tailings dam model's size is 1.5 m in length * 0.7 m in width* 1.0 m in height. The slope angle of tailings dam is 45 degree. To setup guided wave monitoring system in the tailings dam, two holes with diameter of 75mm and 40 cm deep are firstly drilled vertically from the top the tailing dam model. The distance between the two holes is 20cm. Then a steel rod is installed in the centre of hole, after that crushed stone aggregates are poured into the hole until it is full. Acoustic transducers UT1000 are attached to the exposed end of steel rods.

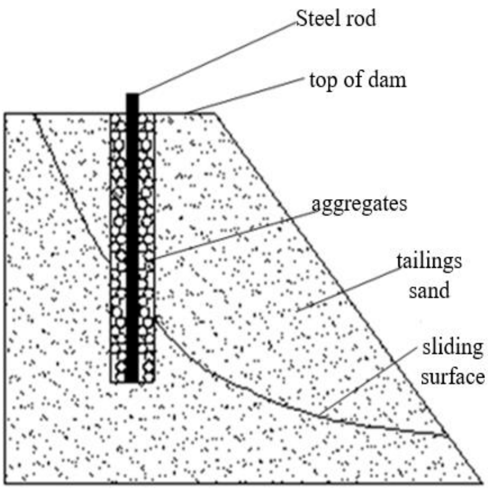

Figure 3. Simplified model of tailings dam

Figure 4. Experimental model

3. ANALYSIS OF GUIDED WAVE PARAMETERS

During the tailings dam failure process, guided wave parameters like event rate and energy rate versus time were obtained and guided wave fractal dimension was extracted from the parameters. Guided wave event rate, energy rate and fractal dimension were used to describe the failure process of tailings dam. Steel rods with four different diameters and crushed stone aggregates with four kinds of particle size produce 16 combination of guided wave monitoring system, so 16 tailings dam failure experiments were conducted.

Tailings dam failure includes four stages: micro crack stage, macroscopic stage, close to dam break stage and after dam break stage. Due to the result similarity of 16 tailings dam failure experiments, only one tailings dam failure experiment result is showed as follows and the diameter of steel rod is 14mm and particle size of crushed stone aggregates is 16-20mm.

3.1. Guided wave event rate

Guided wave event rate versus time result during tailings dam failure process is illustrated in figure 5. At micro crack stage (50-100s), guided wave activity is not obvious and the average event rate is 13 per second. When it comes to macroscopic stage (100—130s), the average event rate reaches 75 per second, which is a great increase compared with that at micro crack stage. While at close to dam break stage (130-150s), guided wave event rate increases sharply to the maximum value 380 per second and

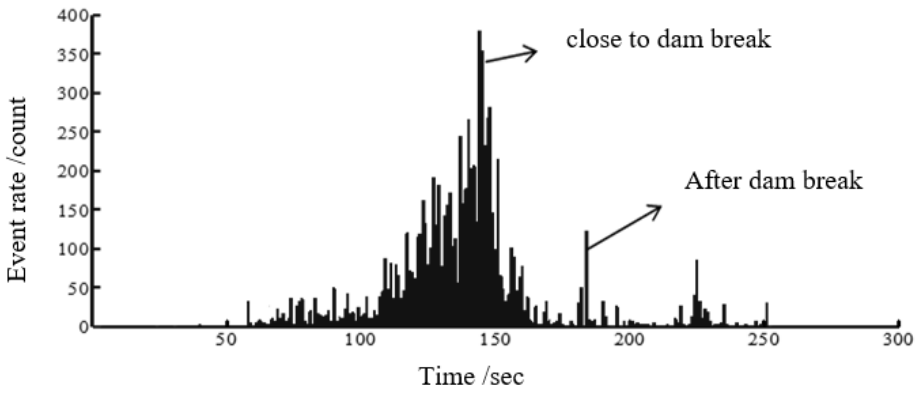

Figure 5. Guided wave event rate versus time

the average number is 200 per second. After dam break(150-250s), the event rate decreases rapidly and the average event rate is only 15 per second. So the phenomenon of rapid increase in guided wave event rate can be treated as a premonition of tailings dam failure.

3.2. Guided wave energy rate

Guided wave energy rate is defined as total guided wave energy releasing in 1 second. Figure 6 shows guided wave energy rate versus time result during tailings dam failure process. Guided wave activity is not obvious and the average energy rate is 8 mv/s at micro crack stage (50-100s). While at macroscopic stage (100—130s) more guided wave energy releases and the average energy rate increases to 80 mv/s. At close to dam break stage (130-150s), the energy rate reaches peak value 1300 mv/s and average value is 400 mv/s. Then the average energy rate drops to about 13 mv/s at after dam break stage (150-250s). Variation of guide wave energy rate at close to dam break stage can also be used for the prediction of tailings dam failure.

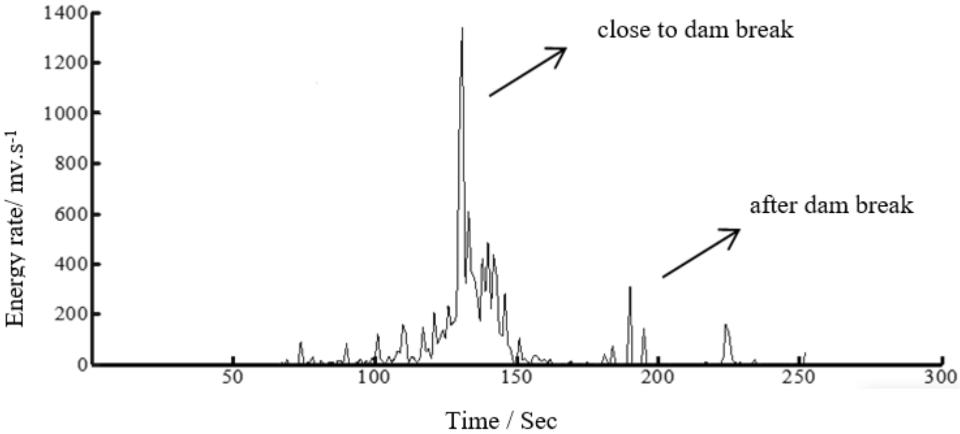

Figure 6. Guided wave energy rate versus time

3.3. Guided wave fractal dimension

Based on the analysis of guided wave parameters (just like energy and count), we find that there are some chaotic characteristics of parameters at time domain. And fractal is an effective tool to describe chaotic characteristics. Increasing of fractal dimension value means that it goes further into a chaotic state and on the opposite, it develops to an ordered state.

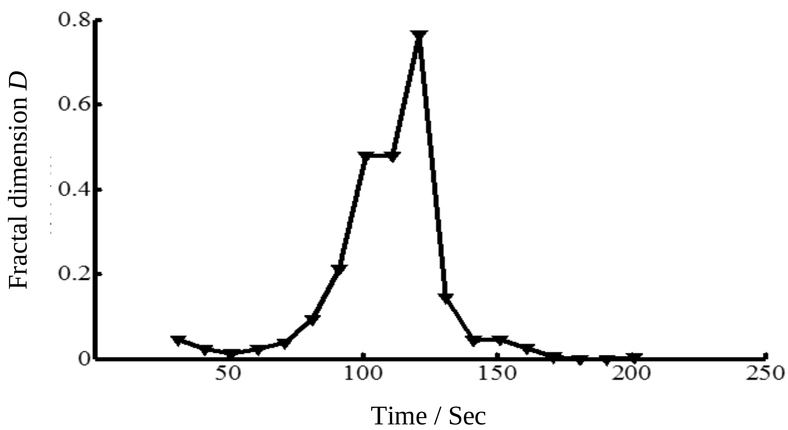

Figure 7. Fractal dimension *D* versus time

Fractal dimension *D* value is obtained from G-P algorithm (Grassberger and Procaccia, 1983) and Fractal dimension *D* versus time is illustrated in figure 7. Fractal dimension *D* value increases during 50-120s and when it climbs to the peak the fractal dimension *D* value suddenly decreases. So the variation trend of fractal dimension D during tailings dam failure can be used for tailing dam stability monitoring too.

4. CONCLUSIONS

Tailings dam failure process has four stages: micro crack stage, macroscopic stage, close to dam break stage and after dam break stage. Guided wave activities are not obvious at micro crack stage and guided wave event rate and energy rate keep in low value. Guided wave event rate and energy rate increase sharply at macroscopic stage and reach the maximum value at close to dam break stage and then event rate and energy rate decrease rapidly at after dam break stage. So variation of guide wave event rate and energy rate at close to dam break stage can also be used for the prediction of tailings dam failure.
During tailing dam failure experiment, fractal dimension *D* value increases quickly before it reaches the peak and then a sudden decrease happens. This trend can also be used for tailing dam stability monitoring.

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