The external loads

When the water was poured into stilling pool, the fluctuating pressure of different places was generated. It's regarded as the external loads during the near-field vibration analysis. In order to obtain external loads, the fluctuating pressures of different places were measured in model test, and the prototype fluctuating pressures were converted according to model and prototype relationship. For example, the prototype fluctuating pressure of a measured point was shown in Fig. 2. After the prototype fluctuating pressures of all measured points were obtained, these pressures were loaded in appropriate locations as the external loads. The vibration in the stilling pool will propagate to the surrounding area, and causing vibration in monitoring positions.

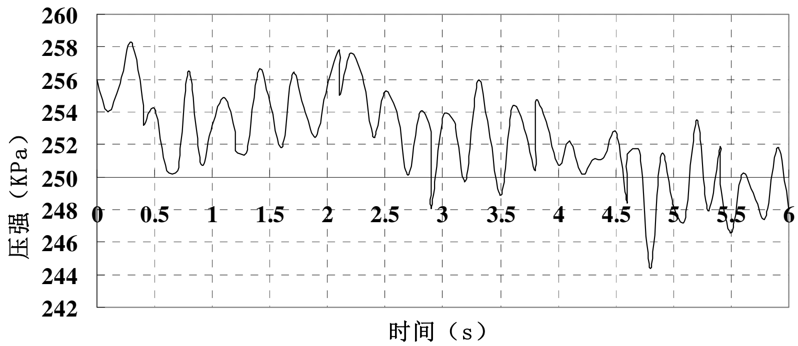

Fig. 2. The prototype fluctuating pressure of a measured point.

Back analysis

The characteristics of near-field vibration are as follows, vibration region mainly contains buildings near kindergarten A and buildings beside road B. Although buildings near kindergarten A are much closer to the stilling basin, vibration of buildings beside road B is far greater. Because the vibration of building is complex and caused by many reasons, so for simplicity, the vibration of building specially refers to the vibration of ground surface near building. The geological conditions of vibration regions are very complex, there are different sizes of fissures or faults and overburden soil, and they have good damping effect to the near-field micro-vibration. However, it is difficult to determine the size and scope of fissures and faults, and damping ratio and deformation modulus of materials cannot be accurately measured. So back analysis method (Zhou et al. 2004) was used in this paper, in which the damping and modulus were continually changed until calculation values were close to in-situ values.

As shown in Table 2, in order to select reasonable parameters, 4 cases are drafted after taking full account of geotechnical conditions and hydrodynamic loads.

Table 2. Study conditions of back analysis.

Cases	Research conditions
b1	All material parameters were selected according to Table 1
b2	Damping ratio of the material which was near kindergarten A and the depth of which was about 20m was set to 0.4, other parameters were selected according to Table 1
b3	Deformation modulus of the material which was near kindergarten A and the depth of which was about 20m was set to 20Gpa, other parameters were the same with case b2.
b4	Damping ratio of the material which was near kindergarten A was set to 0.4, other parameters were selected according to Table 1

The change law of acceleration and displacement is given in Fig. 3. In case b1 and case b2, the calculation values and the measured values are different. In case b3 and case b4, for buildings near kindergarten A, the maximum calculated displacement respectively is 7.5 um and 10.1 um, less than the measured peak value 11.01 um, and the maximum calculated acceleration respectively is 0.112 gal and 0.192 gal, close to the measured peak value 0.074 gal. Buildings beside Road B have a similar vibration law. At the same time, the calculated maximum value of buildings beside road B is greater than buildings near kindergarten A. Therefore, case b3 and case b4 are close enough to measured results. Comparing the parameters in case b3 and case b4, it is found that the deformation modulus of overburden nears kindergarten A reach 20 GPa in case b3, it is not supported by survey data. So the parameters of case b4 are used to analyze near-field micro-vibration.

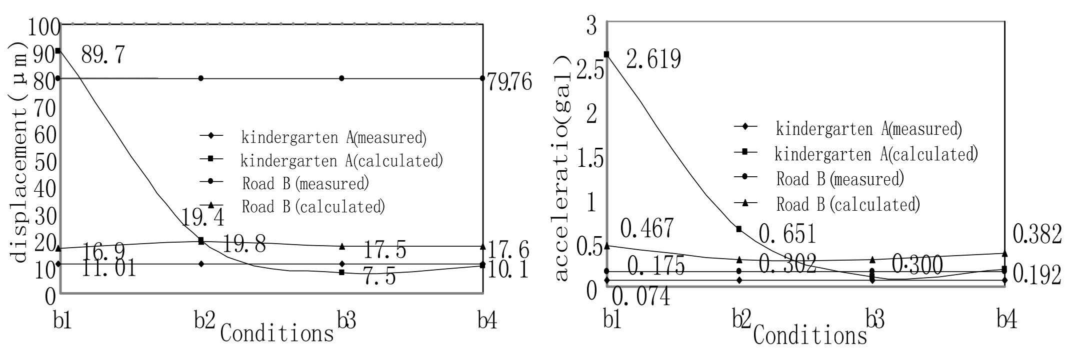

Fig. 3. Comparison of calculated value and measured value for each case.

VIBRATION SOURCE ANALYSIS

Study conditions

During flood impounding into stilling pool of hydropower project, flood discharge drives partition walls between the surface hole and middle hole, the stilling basin slab and stilling basin sidewalls vibrate, and the near-field micro-vibration begins. The vibration has a great influence on the life of nearby dwellers, so it is significant to study near-field vibration source. Based on the assumption that main vibration source is partition walls between the surface hole and middle hole, the stilling basin slab or stilling basin sidewalls or all three together, with the NASEWIN, the acceleration of buildings are calculated. The conditions of vibration source analysis are listed in Table 3.

Table 3. Study conditions of vibration source analysis.

Cases	Actual operational conditions	Assumed main vibration source
s1	1,2,4,5 middle holes partial open and flow rate is 3600 cubic meters per secondin right pool. 1 to 5 middle holes partial open and flow rate is 3000cubic meters per second in left pool	Partition walls
s2		The stilling basin slab
s3		The stilling basin sidewalls
s4		All three together

According to the conditions of vibration source, the near-field vibration is analyzed by dynamic FEM (Chang and Li 2010). In order to provide a nice contrast to the vibration intensity under different vibration source, 4 measuring points near kindergarten A and 6 measuring points beside road B are selected as study object. The locations of 10 measuring points are shown in Fig.4.

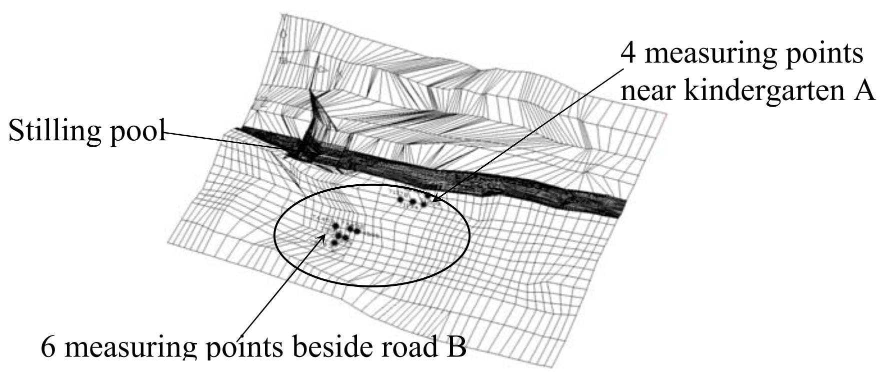

Fig. 4. The locations of 10 measuring points.

Vibration source analysis

The change rule of the horizontal maximum calculated acceleration of 10 measuring points is shown in Fig. 5. The vibration law of 6 measuring points beside road B is shown at left-hand chart and other measuring points at right-hand chart. The changing law about acceleration of 10 measuring points is consistent, namely, measuring point near kindergarten A or beside road B reveal a similar physical discipline.

The acceleration of the buildings beside road B is 0.4 gal to 1.0 gal in case s4. If partition walls of surface hole and middle hole are assumed to be the vibration source (case s1), the acceleration of the buildings beside road B is close to zero. If the stilling basin slab is assumed to the main vibration source (case s2), the acceleration of the buildings beside Road B is 0.38 gal to 0.88 gal. If the stilling basin sidewalls are assumed to the main vibration source (case s3), the acceleration of the buildings beside road B is 0.38 gal to 0.58 gal. As shown at right-hand chart, the acceleration of buildings near kindergarten A is 0.11 gal to 0.34 gal in case s4, and the acceleration almost reaches the zero bound if vibration source is assumed to partition walls(case s1). The acceleration of buildings near kindergarten A is 0.06 gal to 0.24 gal if vibration source is assumed to the stilling basin slab (case s2). The acceleration of buildings near kindergarten A is 0.06 gal to 0.21 gal if the stilling basin sidewalls are assumed to vibration source (case s3).

From above discussion, it can see clearly that the contribution of stilling basin slab and stilling basin sidewalls to near-field micro-vibration is enormous, while the near-field vibration caused by partition walls is not obvious. So it is hold that the stilling basin slab and the stilling basin sidewalls are the main vibration sources.

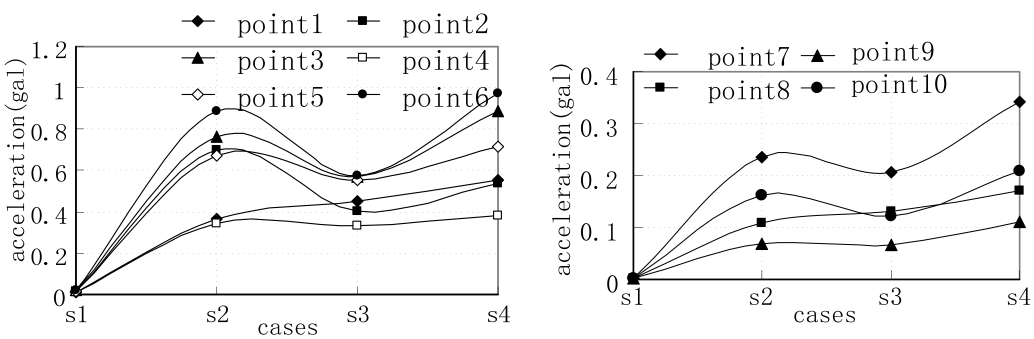

Fig. 5. The horizontal maximum calculated acceleration of 10 measuring points.

THE STUDY OF MEASURES FOR VIBRATION REDUCTION

Study conditions

Although it was determined that main vibration sources were the stilling basin slab and the stilling basin sidewalls, it is difficult to weaken the near-field vibration by optimizing the design of the main vibration source, because the construction of stilling basin has completed and the stilling basin is hard to be changed. As we know the near-field vibration is mainly caused by fluctuating water pressure, and fluctuating water pressure is different under different flow rate, so it is possible to reduce the near-field vibration by optimizing the patterns of gate opening. The distribution of surface holes and middle holes is shown in Fig. 6.

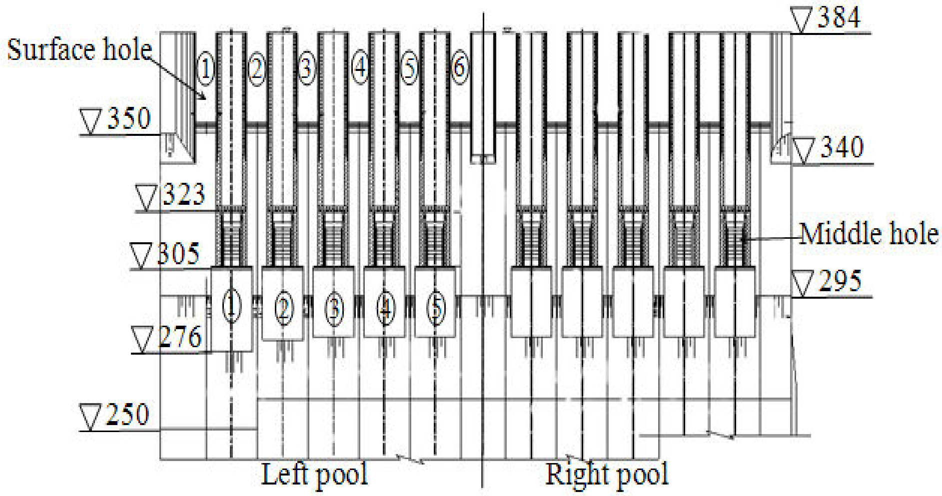

Fig. 6. The distribution of surface holes and middle holes.

Through lots of model tests, fluctuating pressure of water in stilling basin is obtained. And these data is used in the near-field vibration calculation by dynamic FEM. Gate opening patterns of different conditions are listed in Table 4.

Table 4. Study conditions of different gate opening patterns.

cases	Gate opening patterns	Discharge(m^3/s)	Water level (m) upstream	Water level (m) downstream
g1	1,2,4,5 middle holes partial open in right pool. 1to 5 middle holes partial open in left pool.	6600	370	273.0
g2	2, 4 middle holes partial open in right pool.	3000	370	273.0
g3	1to 5 middle holes partial open in right pool.	3000	370	273.0
g4	1 to 6 surface holes partial open and 1to 5 middle holes partial open in right pool.	9000	370	277.25
g5	2, 5 surface holes fully open and 2, 3, 4 middle holes partial open in right pool.	9000	380	277.25
g6	surface holes fully open and 1,2,4,5 middle holes partial open in right pool.	12000	370	279.57
g7	surface holes fully open and 2,4 middle holes partial open in right pool.	14950	380	288.16
g8	surface holes fully open and 1,3,5 middle holes partial open in right pool.	17400	380	290.52

Analysis of measures for vibration reduction

The change law of maximum horizontal acceleration of 10 measuring points is shown in Fig. 7. The comparison analysis of the acceleration leads out the following rule.

In case g2 and case g3, the discharge of surface and middle hole, water level upstream and water level downstream are the same, but gate opening patterns are different. The acceleration of measuring point 2 is 0.392 gal and 0.387 gal, and the acceleration of measuring point 8 is 0.118 gal and 0.110 gal. For case g4 and case g5, except for the gate opening patterns and water level upstream, other conditions are the same. The acceleration of measuring point 2 is 0.523 gal and 0.439 gal, and the acceleration of measuring point 8 is 0.145 gal and 0.124 gal. With the comparison of 4 cases, it is found that gate opening patterns of middle hole have less influence on near-field vibration, while gate opening patterns of surface hole have a great influence. So vibration can be remarkable reduced by optimizing gate opening patterns, such as near-field vibration can be reduced by closing the gate of surface holes near partition walls.

In case g5 and case g6, the discharge of surface and middle hole respectively are 9000 and 12000 cubic meters per second. The acceleration of measuring point 2 is 0.439 gal and 0.562 gal, and the acceleration of measuring point 8 is 0.124 gal and 0.158 gal. For case g7 and case g8, water level upstream are similar, other conditions are different. The acceleration of measuring point 2 is 0.558 gal and 0.567 gal, and the acceleration of measuring point 8 is 0.161 gal and 0.163 gal. Therefore, flow rate play a significant role in causing near-field vibration. When the flow rate of single pool is lower than 12000 cubic meters per second, as the flow rate increases, the near-field vibration becomes stronger and stronger. The flow rate of single pool is higher than 12000 cubic meters per second, the near-field vibration is almost unchanged with the flow rate, and the vibration is hardly changing by optimizing gate opening patterns at this time.

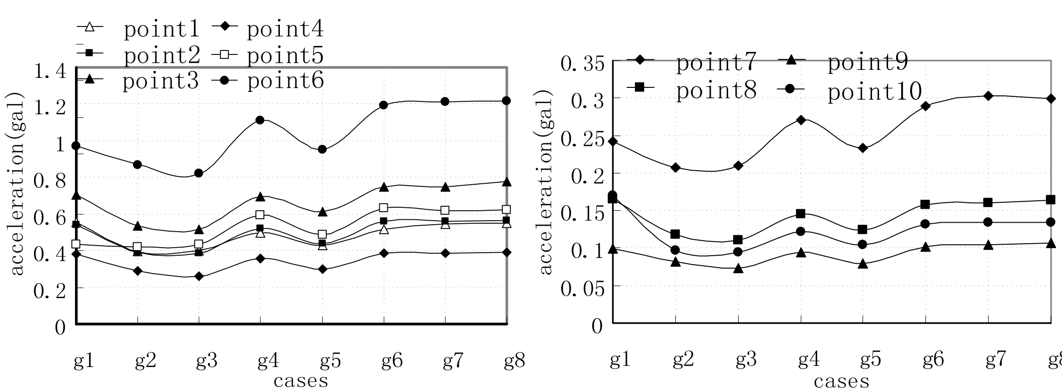

Fig. 7. The horizontal maximum calculated acceleration of 10 measuring points.

CONCLUSIONS

In order to determine main vibration source and propose efficient measures to reduce nearby vibration of a hydropower project, the back analysis method and dynamic FEM were adopted in this paper. The following conclusions were obtained:

(1) In order to accurately simulate near-field vibration, optimum dynamic parameters such as damping ratio and deformation modulus were reached by back analysis method. Results show that the vibration of case b4 matches best with in-situ results, so the parameters of case b4 are reasonable for analyzing near-field vibration.

(2) Based on case b4, the near-field vibration under different vibration sources is calculated by dynamic FEM. The results show that the stilling pool slab and stilling pool sidewalls are main reasons causing near-field vibration.

(3) Comparing the near-field vibration under different gate opening patterns, it is found that the threshold of the flow rate of single pool is 12000 cubic meters per second. If the flow rate of single pool is less than the threshold, the change of opening pattern and the flow rate have a big influence on the vibration, so the near-field micro-vibration is reduced by optimizing gate opening patterns. If the flow rate of single pool is higher than the threshold, the near-field vibration increases slowly with the increase of the flow rate, and near-field vibration of different gate opening patterns does not change significantly.

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Studies on Water Plugging with Grouting Technique in Surrounding Rocks with Fissures of Deep Mining

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ABSTRACT: The seepage effect problem caused by the deep mining engineering has come into focus following the damage and collapse of water inflow during the mining production, principally due to the formation pressure and high hydrostatic pressure. Although treated by interception and grouting with Portland cement slurry, air shaft water inflow of Tangkou Mining (1044m, Jining, China) still reached about 170 m^3/h because of the seepage effect. If the water inflow was not managed effectively and efficiently, it would cause great economic losses and casualties. A method of grouting and anchoring for water plugging was presented in this paper. Considering the size of rock fissures was very fine, ultra-fine cement was taken as grouting material. Thus, experimental investigations of ultra-fine cement viscosity were performed. It is found that water-cement ratio 1:1 and Naphthalene based superplasticizer 1.5% are optimum to viscosity of ultra-fine cement. As a result, water inflow was successfully controlled by the method of grouting and anchoring with ultra-fine cement slurry. The drainage fee $434,286 could be saved per year.

INTRODUCTION

Air shaft of Tangkou Minging (1044 m, Jining, China), through the Quaternary, Jurassic and Permian successively, has the relatively complex hydro-geological conditions. The Jurassic (thickness 516 m) and Permian (thickness 311 m), especially the Jurassic, are mainly composed of siltstone, fine sandstone and mudstone. According to the water pressure test, water inflow reaches 776.16 m^3/h. Therefore, before shaft excavation, ground pre-grouting is applied to prevent the large water inflow. During the shaft excavation, comprehensive measures including a total of six face pre-grouting, water interception and water drainage are taken to control the water inflow. So the water inflow was eventually reduced to 28.26 m^3/h.

After the completion of the shaft excavation, the shaft lining appears fissures due to the high formation pressure and high hydrostatic pressure. Some researchers have studied that seepage effect increases obviously with the increase of shaft depth (Huang and Wang 2003; Zhang 2010). As a result, a large area of water inflow like sweat oozing reaches about 170 m^3/h which goes far beyond 10 m^3/h (MOHURD China, GBJ213-90). If the water inflow is not managed effectively and efficiently, it will cause hazards to the ventilation system, great economic losses and casualties.

The size of the fissures is less than 0.2 mm in the air shaft of Tangkou Mining, so the large solid particle in Portland cement slurry is difficult to be injected in the micro-fissures. Finally, traditional grouting method using Portland cement slurry fails to produce the desired effect. Li and Jiang (2005) indicated that the chemical slurry was too costly. Besides, it was toxic and polluted the environment. Given all this, ultra-fine cement slurry is adopted as grouting material, with the purpose of filling the fissures and plugging the water inflow.

Accordingly, the objectives of this study are to (1) investigate the optimum water-cement ratio and compliance dosage of Naphthalene based superplasticizer; (2) determine the grouting anchor size according to the water inflow and rock conditions; and (3) evaluate the effect of grouting with ultra-cement slurry.

GROUTING METHOD AND MATERIAL

Grouting method

Some researchers have studied that Grouting and anchoring method using anchor with holes instead of common grouting pipes can simultaneously achieve rock reinforcement and water plugging (Lin 2004; Wang 2000; Yang 2001). These reports mainly introduced its function for rock reinforcement. However, it is mainly used for water plugging in this grouting project. Its mechanism rests on the difference between the slurry and water in quality, density and viscosity. Moreover, the slurry has the characteristic of fast-setting. Thus, the slurry may drive the water far away from shaft under grouting pressure. Grouting and anchoring method can form three waterproof barriers that barrier in shaft lining, barrier behind shaft lining and surrounding rock barrier. So these barriers may turn shaft lining into surrounding rock to plug water and withstand the water pressure, meaning passive water plugging is changed to active water plugging. Thereby, the safety of shaft lining could be greatly improved, especially the shaft lining joints. In addition, the slurry may cement the fractured rocks as a whole and improve their strength. As a result, these surrounding rocks and grouting anchors become a part of the support structure, the same change from passive supporting to active supporting. Mechanism of grouting and anchoring method is shown in Fig. 1.

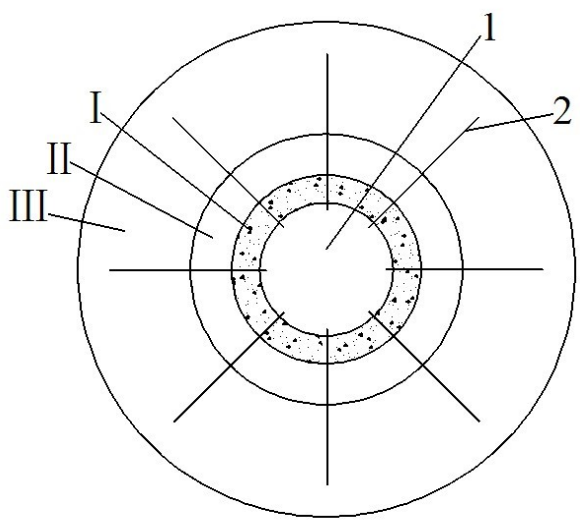

Fig. 1. Mechanism of water plugging with grouting and anchoring method
1-shaft lining; 2-grouting anchor; I - barrier in shaft lining;
II - barrier behind shaft lining; III - surrounding rock barrier.

Grouting material

Cui (2003) investigated the selection principle of grouting material is that the fissures width is much larger than the size of solid particles in slurry. Compared with the Portland cement slurry and chemical slurry, ultra-fine cement slurry, a new grouting material, has the advantages of low water separation, high strength of consolidated stones, good durability and ability to be injected in the micro-fissures reported by Fan (2008). The optimum water-cement ratio (W/C) and compliance dosage of Naphthalene based superplasticizer are investigated by experiments.

Water-cement Ratio (W/C)

MFC-GM8000 Ultra-fine cement used in this experiment was produced by Jiangmen Zhongjian Technology & Development Co., Ltd of Guangdong province in