Water Science and Engineering 2017, 10(1): 78–85

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Water Science and Engineering
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Prototype observation and influencing factors of environmental vibration induced by flood discharge

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Received 28 January 2016; accepted 11 November 2016
Available online 9 March 2017

Abstract

Due to a wide range of field vibration problems caused by flood discharge at the Xiangjiaba Hydropower Station, vibration characteristics and influencing factors were investigated based on prototype observation. The results indicate that field vibrations caused by flood discharge have distinctive characteristics of constancy, low frequency, small amplitude, and randomness with impact, which significantly differ from the common high-frequency vibration characteristics. Field vibrations have a main frequency of about 0.5–3.0 Hz and the characteristics of long propagation distance and large-scale impact. The vibration of a stilling basin slab runs mainly in the vertical direction. The vibration response of the guide wall perpendicular to the flow is significantly stronger than it is in other directions and decreases linearly downstream along the guide wall. The vibration response of the underground turbine floor is mainly caused by the load of unit operation. Urban environmental vibration has particular distribution characteristics and change patterns, and is greatly affected by discharge, scheduling modes, and geological conditions. Along with the increase of the height of residential buildings, vibration responses show a significant amplification effect. The horizontal and vertical vibrations of the 7th floor are, respectively, about 6 times and 1.5 times stronger than the corresponding vibrations of the 1st floor. The vibration of a large-scale chemical plant presents the combined action of flood discharge and working machines. Meanwhile, it is very difficult to reduce the low-frequency environmental vibrations. Optimization of the discharge scheduling mode is one of the effective measures of reducing the flow impact loads at present. Choosing reasonable dam sites is crucial.

Keywords: Flood discharge; Environmental vibration; Vibration characteristics; Influencing factor; Prototype observation

1. Introduction

Design for flood discharge and energy dissipation in high dams is a crucial part of water conservancy and hydropower engineering construction. The ample energy of high-speed flow needs to be dissipated safely and quickly with a limited amount of energy dissipators. As a result, the flood discharge and energy dissipation design are directly related to the safety of the hydraulic project. In the process of energy dissipation with rolling, shearing, and friction of flow, the energy dissipation structure is constantly under the impact of high-speed flow, and strong vibrations are induced. Many discharge structures have been damaged worldwide. For example, the stilling basin slab of the Sayano-Shushenskaya Hydropower Station in the former Soviet Union was twice destroyed, and the nearly 8 m-thick bottom floor was set off by a huge flow load, shocking the world (Wang and Luo, 2012). When the Wuqiangxi Hydropower Station in China was discharging a

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This work was supported by the National Natural Science Foundation of China (Grants No. 51479124 and 51109143), the Open Cooperation Fund of State Key Laboratory of Hydraulics and Mountain River Engineering (Grant No. SKHL1422), and the Nanjing Hydraulic Research Institute Foundation (Grant No. Y115006).

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Peer review under responsibility of Hohai University.

http://dx.doi.org/10.1016/j.wse.2017.03.001

flood, the large-area stilling basin slab with a 3-m thickness was set off and the scour depth of bedrock was nearly 30 m (Lian, 1998). The stilling basin guide walls of the Texarkana Hydropower Station in the USA, the Bapa Zschinsky Hydropower Station in the former Soviet Union, and the Wanan Hydropower Station in China have experienced hydraulic damage (Lian and Ma, 2007). In recent years, flow-induced vibration has been a focus in high-speed flow fields, and a great amount of progress has been made in model tests, numerical analysis, and prototype observation after years of continuous research (Wang and Yan, 2013; Wang et al., 2009, 2014). A variety of research could lead to the end of severe vibrations of discharge structures.

Most studies on environmental vibrations have concentrated on the field of urban traffic (Lee and Wang, 2012; Xia et al., 2009; Fukada et al., 2012; Pérez et al., 2011; Sharp et al., 2014), which is significantly different from flow-induced vibration. Environmental vibrations induced by flood discharge always exist, but not enough attention has been paid to them because hydropower stations are usually far away from urban and rural areas. Therefore, there is a lack of relevant records and cognition about environmental vibrations induced by hydraulic loads of flood discharge. Numerical simulation of water through the radial gates of the Caruchi Dam, in southern Venezuela, and its relation to the vibration of spillways and adjacent control building has been conducted, and the structural vibration source was determined in the case of gate openings of up to 5 m above the normal values (Sanchez and Salazar, 2010). Prototype dynamic testing of the left guide wall of the Three Gorges Dam has been carried out under the condition of flood discharge, and the regularity of distribution of the root mean square (RMS) of dynamic responses on the guide wall has been examined (Huang and Li, 2011). The vibration responses of the Qianjiang Tunnel under the impact of the sea bore of the Qiantang River have been monitored and the main frequency of vibration was about 2 Hz (Cai and Huang, 2013). The effect of vibrations of the Zhigulevskii hydropower structure on soils in the nearby territories of Tolyatti City (Shumakova and Kotlyakova, 2010) and the vibration source and shock absorption scheme of near-field vibrations caused by flood discharge (Yin and Zhang, 2014) have been studied.

Recently, a wide range of unexpected environmental vibrations have appeared in Shuifu County near the Xiangjiaba Hydropower Station when flood discharge structures have begun to release floodwater, leading to a certain negative effect on daily production and human livelihoods, because the county is very close to the stilling basin and the shortest direct distance is only 0.5 km. In this study, systematic prototype observation was conducted to investigate the severe environmental vibrations caused by flood discharge. High-accuracy and high-sensitivity vibration sensors (the 941 sensor, made in China) in three directions, specially designed for monitoring of low-frequency vibrations, were employed to measure the vibration displacement, velocity, and acceleration. More than 30 monitoring sites were located within a radius of 2.5 km from the center of the stilling basin. As shown in Fig. 1 and Table 1, the monitoring sites were set in the guide wall, stilling basin slab, underground power house, soil surface, residential buildings, and a large-scale chemical plant in the county. Some of these hydraulic structures, such as the guide wall and the underground power house, were built on hard rocks. However, most of the area of the county is artificial backfill and many residential buildings have been built on soft soil foundations. Cases with a series of discharge from 6600 m^3/s to 0 m^3/s and different discharge scheduling modes were observed. Based on the monitoring data, time domain statistics analysis and frequency domain spectrum analysis procedures such as the fast Fourier transform (FFT) were conducted to describe the vibration characteristics of the vibrations of flood discharge structures, the underground power house, the soil surface, residential buildings, and the large-scale chemical plant in the county caused by flood discharge. Influencing factors and damping measures are proposed.

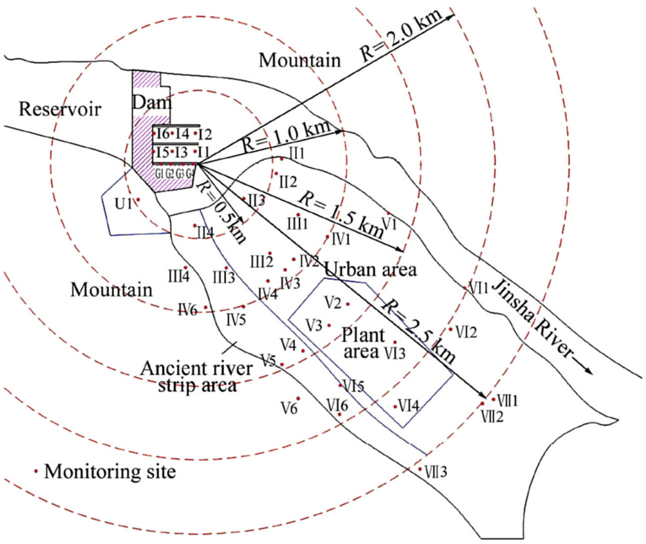

Fig. 1. Location of monitoring sites.

2. Vibration characteristics of hydraulic structures

2.1. *Slab of stilling basin*

The project's flood energy dissipation works contained two adjacent stilling basins, and a cross-section of the spillway is shown in Fig. 2. The stilling basin mainly consisted of a slab, a guide wall, and an end ridge, and there were many galleries in

Table 1
Location and number of monitoring sites.

Location	Measuring site number
Stilling basin slab	I1–I6
Guide wall	G1–G4
Underground power house	U1
Soil surface	II1–II4, III1–III4, IV1–IV6, V1–V6, VI1–VI6, VII1–VII3
Residential building	II2, III1, IV1, IV2, IV5, V6, VII1
Chemical plant	V2, V3, VI3, VI4