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Detection of concrete dam leakage using an integrated geophysical technique based on flow-field fitting method

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ABSTRACT

An integrated geophysical investigation was performed at S dam located at Dadu basin in China to assess the condition of the dam curtain. The key methodology of the integrated technique used was flow-field fitting method, which allowed identification of the hydraulic connections between the dam foundation and surface water sources (upstream and downstream), and location of the anomalous leakage outlets in the dam foundation. Limitations of the flow-field fitting method were complemented with resistivity logging to identify the internal erosion which had not yet developed into seepage pathways. The results of the flow-field fitting method and resistivity logging were consistent when compared with data provided by seismic tomography, borehole television, water injection test, and rock quality designation.

1. Introduction

Dams are among the most important engineered hydraulic structures and they frequently develop leakage problems. Since serious leakage may cause dam failure, periodic inspections are imperative and geophysical investigations are often used to detect and delineate the possible leakage paths (Karastathis et al., 2002a; Al-Fares, 2011; Bedrosian et al., 2012). The geophysical methods used depend on the type of problem to be studied (Cardarelli et al., 2014). For example, electrical methods (Aina et al., 1996; Panthulu et al., 2001; Cho and Yeom, 2007; Sjödahl et al., 2008; Oh, 2012; Fargier et al., 2014;), GPR (Georadar) (Xu et al., 2010; Prinzio et al., 2010), and seismic (acoustic) methods (Karastathis et al., 2002b; Karl et al., 2011; Cardarelli et al., 2014; Samyn et al., 2014) are generally feasible for evaluating material moisture, detecting voids, fractures and hidden objects, as well as assessing the mechanical parameters of geological units. Many successful cases in recent years have shown the effectiveness of geophysical methods for leakage detection (also see citations above).

The S dam is a concrete dam, utilized for electrical energy generation, which is located in the middle reaches of the Dadu River in western Sichuan Province (Fig. 1). When water storage began in 2012, some drainage holes in the grouting gallery were found to have high discharge (25.32 L/s–31.40 L/s) and the flow water was turbid. The drainage holes with high discharge were subsequently closed to avoid mechanical piping. These anomalous conditions implied that this dam presented safety hazards and that the mechanisms of leakage should be detected and controlled so as to maintain dam integrity and safety.

Most geophysical investigations are conducted at the slopes or on the crest of earth-rock dams. However, the S dam is a gravity dam with complex structures and a deep basement which complicate the use of any conventional geophysical method. Therefore, we proposed an integrated geophysical technique involving the flow-field fitting method and resistivity logging. Since these two geophysical methods haven't been sufficiently documented in the literature yet, their principles are introduced in Section 3.

The flow-field fitting method employed here had two main objectives: one was to find the hydraulic connections between the dam foundation and surface water, and the other was to determine the seepage locations in the survey area. Resistivity logging was used to delineate the weak zones in the dam foundation, which have great possibility of internal erosion. These detection results allowed drilling of inspection holes and subsequent application of contrasting methods (seismic tomography and water injection test) as well as validation methods (rock quality designation (RQD) and borehole television).

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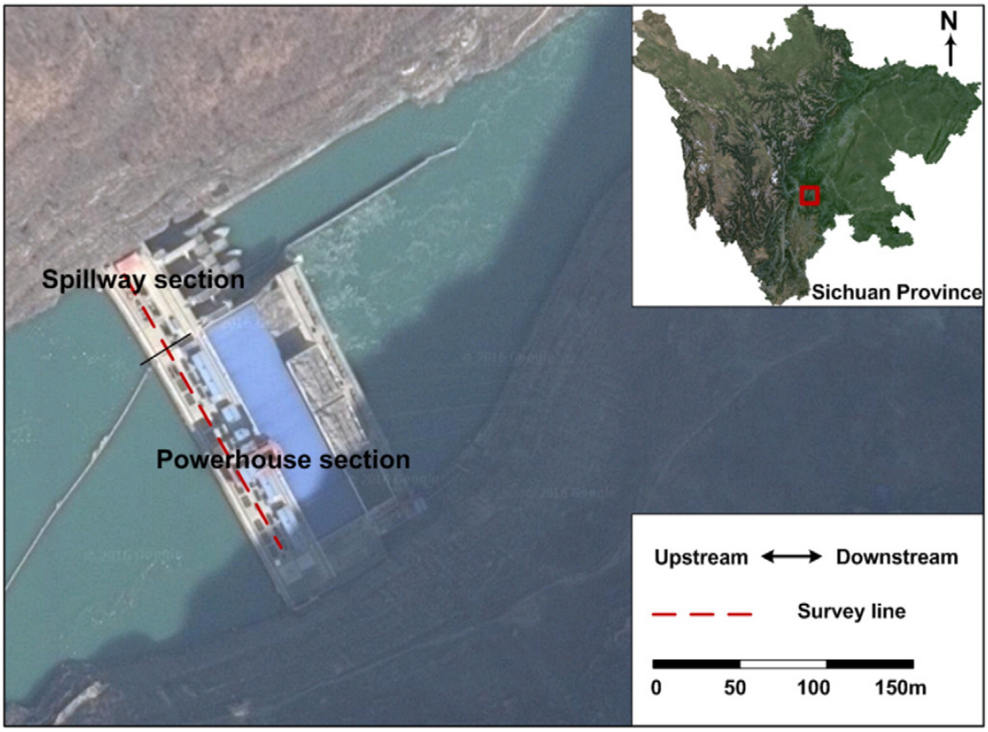

Fig. 1. Location of investigation area.

2. Study area

The dam foundation was built on medium-thick layered dolomite and dolomitic limestone of the Dengying Formation of the Upper Sinian system. Geologic structures encountered beneath the dam include fault fracture zones and interlayered fracture zones (Fig. 2). From the point of view of hydrogeology, the lithology of the dam foundation is soluble karstic rock dominated by dissolution cavities. As the permeability in this formation is mainly controlled by lithology, geological structure and karst development, the permeability distribution is extremely uneven.

The S dam is 101 m high with a maximum elevation of 662.5 m and a crest length of 222.5 m. In this paper, the study area is the spillway section of S dam (between X = 140 m to X = 170 m), which is a small segment of the entire survey line shown in Fig. 1. Since leakage detection concentrated on the dam foundation, the geophysical investigation could be implemented in the grouting gallery. The grouting gallery had a single-row of drainage holes on the downstream side of the grout curtain, with depth of 40–45 m, spacing of 2 m and a slope of 15° in the downstream direction (Fig. 3). The concrete surfaces in the grouting gallery restricted the placements of conventional geophysical sensors so in order to ensure penetration depth and resolution, we implemented the flow-field fitting method and resistivity logging in the drainage holes.

Discussion of survey area values of temperature, saturation, dissolved solids and porosity are pertinent since they may influence resistivity (Sjödahl et al., 2008; Hornbostel et al., 2013; Merritt et al., 2015; Gunn et al., 2015). The influence of water temperature in the drainage holes, which varied between 15°Cand 17 °C, is negligible. The investigation in this paper was conducted in the drainage holes which were filled with water, and the water level (611.0 m) of the grouting gallery is less than the upstream water level (657.4 m) and the downstream water level (627.3 m), so the saturation of the concrete and the rock below the gallery are similar. Many researchers have studied the relation between resistivity and total dissolved solids (TDS) (Ebraheem et al., 1990; Ebraheem et al., 1997; Sherif et al., 2006), which are a measure

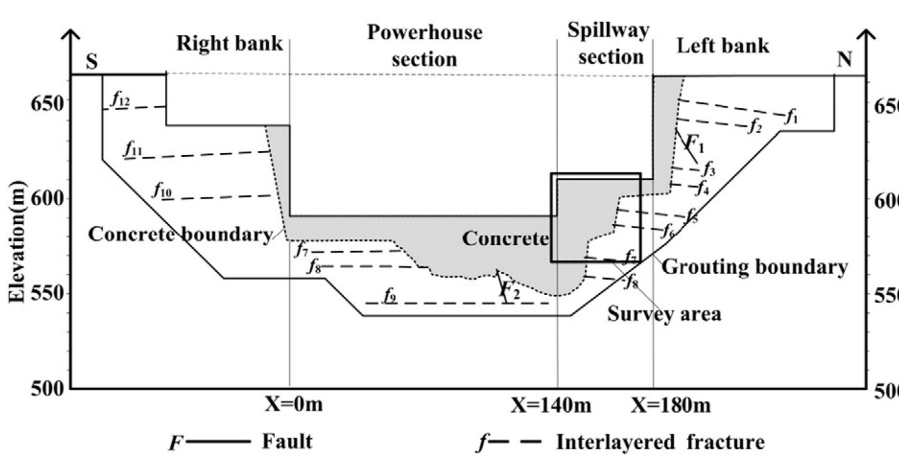

Fig. 2. Geological map of S dam site.