

Detection of potential leak sites in embankments using surface-wave method and electrical method

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Summary

Integrated geophysical technologies are very effective in environmental, engineering, and groundwater applications. Parameters of delineating nature of near-surface materials such as compressional-wave velocity and shear-wave velocity can be obtained using shallow seismic methods. Electric methods are primary approach for investigating groundwater and detecting seepages. A technological experiment has done for detecting and discovering hidden problems in the embankment of Yangtze River, in Songzi, Hubei, China in 2003. The multi-channel surface-wave method and a DC multi-channel array resistivity sounding technique were used to detect hidden problems inside and under dike like pipe-seeps. This paper discusses the exploration strategy and the effect of geological characteristics. A practical approach of combining seismic and electric resistivity measurements was applied to locate potential pipe-seeps in embankment in this experiment. We defined a potential leak factor based on the shear-wave velocity and the resistivity of the medium to evaluate anomalies. An anomaly found in a segment of embankment detected was verified, where a pipe-seep occurred during the 98' flooding.

Introduction

The worst flooding in decades struck villages, towns and cities along the Yangtze River in 1998. Dike collapses happened in Jiayu, Hubei and in Jiujiang, Jiangxi due to soaking in water tens of days. They cause hundreds of victims and thousands of people homeless. In addition, thousands of hidden problems in river embankments would be more serious threats. These threats actually derived in a certain distance from the construction of embankments. Most of river embankments were built in the past fifty years and under the limited financial condition. Unconsolidated materials such as sand or sandy clay under dike-body were not strengthened as building dikes. Sand and sandy clay likely liquefy under reasonable moisture and pressure. The pipe-seep often occurs where unconsolidated materials present. This weakness in the bases of dike-body requires remedying or repairing. Extremely dangerous segments of embankments need to be rebuilt. Others need to be processed using strengthening or resist-liquefying technologies. Because the thickness and strength of sand or sandy clay layer under dike-body are varying in different places, the decision for rebuilding should be supported by understanding soil nature in situ. Non-invasive detecting methods such as geophysical methods are recommended for the investigation. A technological experiment for detection of soil moisture and strength using seismic and DC-electrical methods were executed in segments of a river embankment in Songzi County, Hubei in 2003, where was a very dangerous area during 98' flooding. A seismic reflection method, a multi-channel surface-wave method, and a DC multi-electrode array resistivity sounding were implemented in hopes of formulate an effective approach to explore potential leaks inside dike.

Methodology

Investigating a sand or sandy-clay layer and detecting their strength and moisture are the primary purpose of the experiment. A pipe-seep is a kind of serious problems of embankments during flooding. Pipe-seeps are usually found in dike and present in sandy layers. Basically, shallow seismic reflection technique is of advantage to obtain the signals referring layered materials underground. The seismic reflection method was designed to explore the variation of soil layers in thickness. In our experiment, in fact, the reflection signals did not provide convincing evidences respect to soil layers under the dike-body due to the nonhomogeneity of the dike-body. The nonhomogeneity could come from remedies with various materials (such as gravel, clay, mix-materials, etc.) year by year during last fifty years. Therefore, the solution will depend mainly on a surface-wave survey and a resistivity sounding.

The shear (S)-wave velocity of near-surface materials such as soil, rock and pavement is one of key parameters in construction engineering. Shear-wave velocity can be inverted from dispersion phase velocities of surface waves (e.g., Aki and Richards, 1980, p. 664). The value of S-wave velocity represents a scalar in strength. Spectral Analysis of Surface Waves (SASW), which analyzes the dispersion curve of the ground roll to produce near-surface S-wave velocity profiles (Stokoe, et al., 1989). A technique (Park et al., 1999, Xia et al., 1999) utilizing a multi-channel recording system to estimate near-surface S-wave velocity from high-frequency (≥ 2 Hz) Rayleigh waves (Multi-channel Analysis of Surface Waves—MASW) has been applied to more and more near-surface problems. Multi-channel surface-wave data has shown great promise in detecting shallow voids and tunnels, mapping bedrock surfaces, and delineating fracture systems (e.g. Xia et al., 1998, 2002a, 2002b, 2002c, 2003, 2004). In this case, the multi-channel surface-wave approach is applied to delineate the strength of the embankment earth.

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Resistivity imaging is now becoming widely used in environmental and engineering applications. The method is popular in the investigation of groundwater (e.g. Saksa and Paananen, 1992; Sandberg, 1993; Benson et al., 1997; Khair and Skokan, 1998) as well as the monitoring the leakage in an embankment dam (e.g. Johansson and Dahlin, 1996; Sjöedahl et al., 2003). The multi-channel data acquisition system is suitable to be used for obtaining the variation of resistivity in depth with many different electrode separations along a line. The approach has a dense enough data cover laterally and gets a resistivity image with higher resolution (e.g. Griffiths et al., 1990; Griffiths and Barker, 1993; Dahlin and Loke, 1998). The resistivity sounding data are acquired by using the multi-channel array system in the experiment in hopes of evaluating the moisture in the embankment earth.

Conventionally, lower S-wave velocity signifies lower shear modulus (softer) or more pores and lower resistivity suggest the possibility of higher moisture. However, inhomogeneous materials greatly impact understanding their nature based on measurements from either seismic or electric methods. The lateral comparison hardly gives enough evidence to indicate potential leak sites in an earth embankment due to no knowledge on properties of materials inside and under the dike. Another problem is that porous material like sand or sand clay could produce higher resistivity signals in dry situation even though the earth embankment usually is wet.

We define a balance factor to integrate the signals from the both of measurements. The balance factor combines S-wave velocity and resistivity acquired by

$$F = \frac{k_V}{v_s} + \frac{k_R}{R}, \quad (1)$$

where F is the balance factor or a potential leak factor, v_s , R are the S-wave velocity and the resistivity, respectively, and k_V and k_R are weighting constants. Two constants are usually determined by background values of v_s and R .

Obviously, the potential leak factor depends on S-wave velocity and resistivity and would indicate higher fatality for causing leak or pipe-seep where the S-wave velocity and resistivity in a profile drop accordantly. The potential leak factor is helpful to estimate the dangerous degree and to quantify the possibility of causing leaks.

Data acquisition

Data were acquired from the embankment segments in Songzi, Hubei, on the south side of Yangtze River (Figure 1). Two methods were executed along the same line on the top of dike in order to compare and combine measurements. The entire profile along the embankment was designed up to five kilometers. Several seepages were found in the area of these segments during 98' flooding.

The standard common midpoint (CMP) roll-along technique (Mayne, 1962) was used to acquire seismic data with a 24-channel seismograph. 4.5-Hz geophones were spaced one meter apart. The source-to nearest-receiver offset was 10 meters. The recording geometry provided the optimum geophone spread for examining earth materials at the site between 1 m and to 30 m in depth (Xia et al., 2003; Zhang, et al., in press). 2-D shear-wave velocity fields were calculated from inversion of Rayleigh-wave phase velocities (Xia et al., 1999).

The computer-controlled multi-electrode data acquisition system was used to acquire resistivity data with Wenner array. Surveying scheme was designed as the figure of switching separation from 1 to 17 m in the range of 60 electrode channels with the uniform space of 3 m. Data, picked up sequentially from the protocol of extending separation of injecting and measuring electrode-couples, were expected to delineate the earth at the site in depth range simulated corresponding to those of the seismic data. Extension of the line was achieved through the roll-along technique. Resistivity data for imaging on cross-sections were calculated by employing 2D-resistivity inversion software released by AGI Inc. (provided by Geometrics Inc.).

An example from data interpretation in filed

Results of Segment 9 were shown in Figure 2. From image of contoured S-wave velocities (Figure 2a) a lower velocity zone appears in area between station K72000 and K70150 along profile. More than 25% drops in S-wave velocity relative to the background delineate the unconsolidated material in the depth of 10-25 m below the surface of the dike. The resistivity image (Figure 2b) gives correlative signals around the lower S-wave velocity zone shown Figure 2a. The zone of lower resistivity was interpreted the indication to higher moisture within the dike. Imaged potential leak factor shown in Figure 2c are calculated based on $k_V=80$ and $k_R=5$. A critical value of the potential leak factor (F) can be determined by analyzing and comparing entire measurement. For this experiment, the critical value was determined as 1.8. The zone circled by the contour lines at the critical



Figure 1. The location of the experiment in the satellite image.

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value indicates the location occurred a pipe-seep during 98' flooding, which was reported by Hubei Bureau of Embankment Construction in 1998.

Conclusions

Geophysical technologies can play an important role in leakage detection in embankments and in quality control of construction. Because river-embankments are built with materials of various physical properties like soil, sand, gravel, and even concrete, a single geophysical method, in some case, may not give convincing evidences for identifying anomalies such as the hidden problems and potential leaks in embankment. Integrated geophysical approaches can delineate targets in multi-aspects and present a practical solution. For embankments the moisture is one of important safe-factors. Geophysicists usually apply resistivity methods to detect the conductivity of earth and then estimate the moisture. Since the variations of several properties of earth simultaneously affect resistivity observation, this method cannot ensure real wetness. The S-wave velocity of rock or soil is mainly determined its shear modulus. Theoretically, S-waves do not propagate in a liquid. A medium with considerable moisture could be of a lower S-wave velocity than that of the dry one (Assefa et al., 2003). Apparently, the S-wave velocity can also be used to estimate the moisture inside embankment. Combining resistivity and S-wave velocity to identify potential leaks is a practical attempt in our experiment. Constants k_I , k_R in equation (1) are determined by background values of v_s and R through entire profile when no drill data are available. The adjustment for the values of constants should refer to anomalies at seepages if available.

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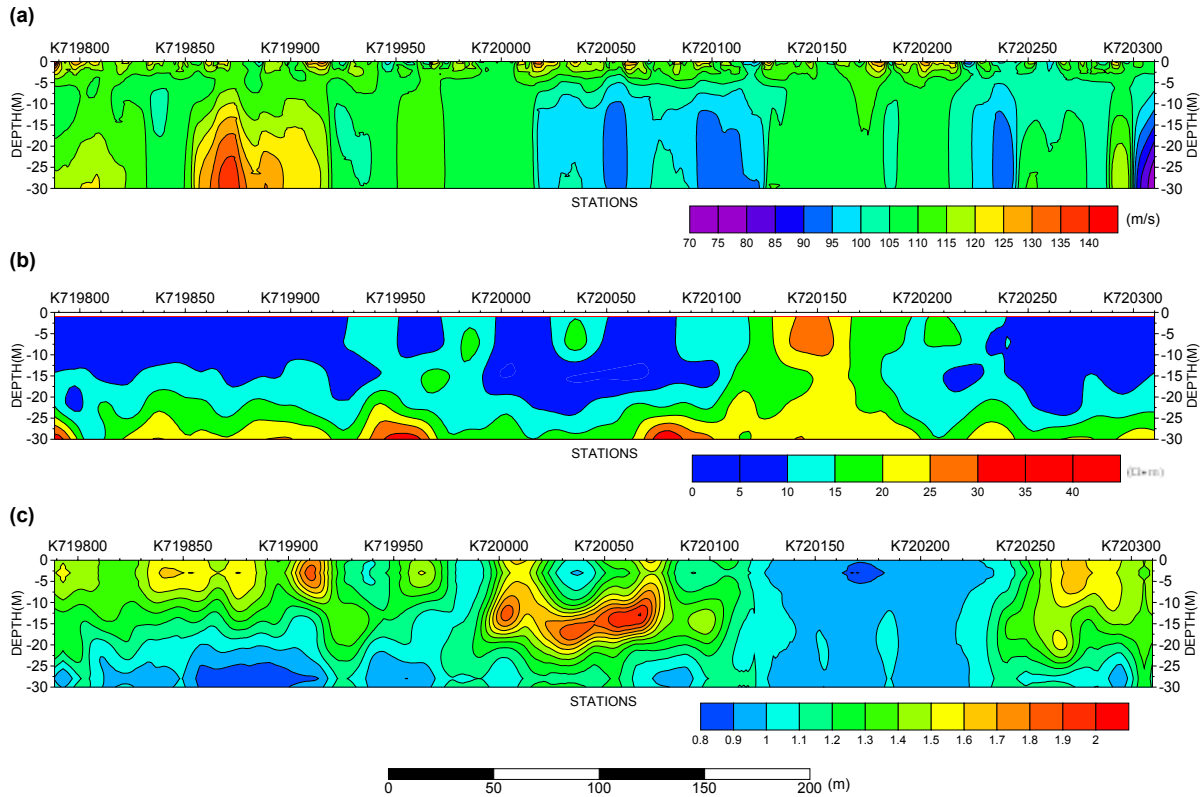


Figure 2. Results of the real-world example at the embankment segments in Songzi, Hubei, on the south side of Yangtze River. (a) Shear-wave velocities. (b) Resistivities. (c) Potential leak factors. The critical value of 1.8 or higher indicates the location occurred a pipe-seep during 98' flooding.