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RESEARCH ARTICLE

SELF-POTENTIAL METHOD FOR DETECTION OF WATER LEAKAGE THROUGH DAMS

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ABSTRACT

The self-potential (SP) method is a passive, non-invasive and cost-effective geophysical method based on the measurement of electrical potential naturally occurring on the earth's surface. One of the main causes for the electrical potential at the earth's surface is water seepage under the ground. In this work, we perform the SP measurement on a small artificial earthen dam built at Thuyloi University. Our result shows that the selection of electrode types is crucial in the SP measurements. Namely, Cu/CuSO4 porous pots are much better than copper stake electrodes for the SP measurement. Additionally, it is shown that the SP measurement using suitable electrodes can be applied to detect underground water leakage and flow direction in the dam based on an anomaly and variation of electric potential with position on the survey area.

KEYWORDS

Streaming potential, electrodes, zeta potential, leakage.

1. INTRODUCTION

The flow of water through the subsurface soil or rock generates natural measurable electrical voltages called streaming potential or self-potential (SP) (Jouniaux and Ishido, 2012). The SP method plays an important role in geophysical applications, environmental applications, medical applications and others. For example, the SP method can be used to detect areas of seepage through water retention structures such as dams, dikes, reservoir floors, and canals (Wurmstich and Morgan, 1994; Corwin and Hoovert, 1979; Morgan et al., 1989; Revil and Pezard, 1998). Monitoring of SP anomalies has been proposed as a means of predicting earthquakes (Mizutani et al., 1976; Trique et al., 1999). The reason for the SP is directly related to the existence of an electric double layer (EDL) between the fluid and the solid surface (Jouniaux and Ishido, 2012; Thanh et al., 2015). Namely, when a mineral like silica is in contact with water, its surface gets charged because of chemical reactions between the surface sites and the water.

The surface charge repels ions in the electrolyte whose charges have the same sign as the surface charge and attracts ions whose charges have the opposite sign in the vicinity of the electrolyte-silica interface. This leads to the charge distribution known as the EDL (Figure 1). The EDL is made up of the Stern layer, where cations are adsorbed on the surface and are immobile due to the strong electrostatic attraction, and the diffuse layer, where the ions are mobile. The streaming current associated with the flow of the pore water corresponds to the electrical current generated by the drag of charges in the EDL coating the surface of minerals in contact with water. This streaming current is then balanced by conduction current, leading to the so-called streaming potential (Jouniaux and Ishido, 2012; Thanh et al., 2015).

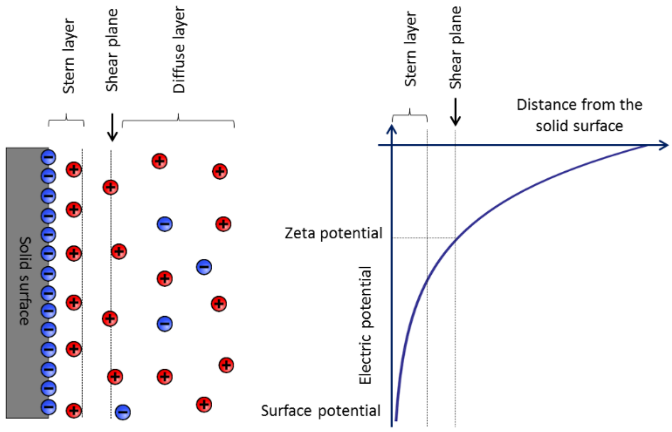

Figure 1: Stern model for the charge and electric potential distribution in the EDL at a solid-liquid interface (Thanh et al., 2015; Thanh et al., 2019).

In Vietnam, there are thousands of lakes and dams with the presence of 13.200 of kilometers of dikes (Hung et al., 2014). Most of them are old earth dams and earth dykes with potential problems which can lead to dam or dyke failure. Therefore, it is very important to have early-warning systems to monitor lake, dam and dyke safety by detecting unusual water leakage underground. The SP measurement is one of the effective techniques to recognize those possible problems before the failure can occur based on an anomaly of measured electrical potential on the surface (see illustration in Figure 2). In this work, we focus on performing the SP measurement at a small scale on the artificial dam built at Thuyloi University to detect water leakage through the dam. From that, we find out

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which types of electrode is the best for the SP measurement and get experience for field survey later. This paper includes four sections. Section 2 describes the procedure for data acquisition. Section 3 presents the results and discussion. Conclusions are provided in the final section.

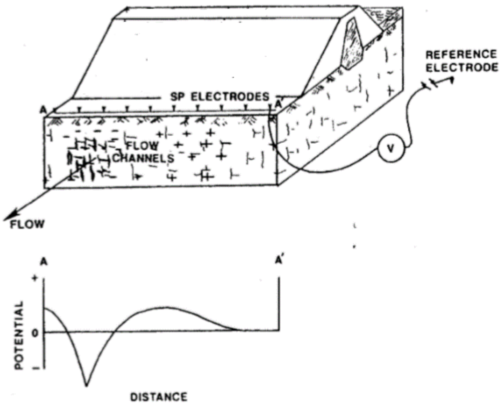


Figure 2: Illustration obtained for an electrode array set up on the surface of a dam and the SP anomaly generated by water underground leakage (https://www.kau.edu.sa/Files/0003035/Subjects/SP.pdf).

2. Data Acquisition

Figure 3: The artificial dam built at Thuyloi University for the SP measurement.

The artificial dam for the SP survey was built at Thuyloi University as shown in Figure 3. The height and length of the dam are 3 m and 10 m, respectively. When the dam stores water (left side of Figure 3), there is water leakage intentionally generated at specific locations through the body dam (right side of Figure 3). We measure the electrical potential distribution on the dam surface using the basic equipment shown in Figure 4. It consists of a pair of electrodes (a pair copper stakes or a pair of $Cu/CuSO_4$ porous pots), a wire reel and a digital high impedance multimeter (10^6 Ω) with a precision of 0.01 mV (Pentelis and Marios, 2015). Electrodes are deployed on a grid of 1.0 m×1.0m spacing on a survey area of 8m×1.5m as shown in Figure 3 or in Figure 5a. Note that for the SP measurement, the $Cu/CuSO_4$ porous pots are placed in deep holes and copper stakes are hammered into ground so that they are in contact humid soil.

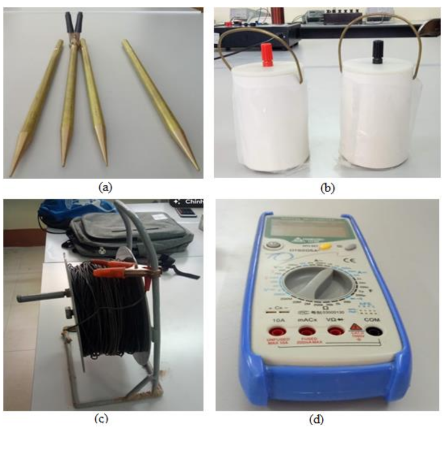


Figure 4: Equipment used for the SP measurement: (a) copper stake electrodes; (b) electrodes of Cu/CuSO4 porous pots; (c) wire reel; (d) multimeter.

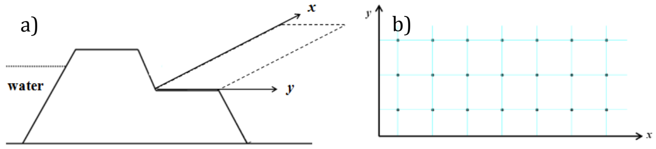


Figure 5: (a) Across sectional area of the dam and areas selected for the SP measurements; (b) a grid of 1.0 m×1.0m spacing for deployed electrodes.

Because of the small survey area, we use the fixed-base technique in which one electrode is left as a reference at a fixed point (reference electrode where the electrical potential is assigned as zero) and the second (rolling electrode) is moved at every point on the selected grids (dots in Figure 5b). A reference electrode needs to be installed very carefully at a proper area, avoiding locations with animal or human disturbances, and far from metallic pipelines, boreholes, fences and other sources of noise. For electrodes of $Cu/CuSO_4$ porous pots, they are covered by isolated materials to prevent direct sunlight (for more details, see http://corry.ws/PDF/SP_field_manual.pdf). The difference of electrical potential between the reference and rolling electrodes is measured by the consequent movement of the rolling electrode. Hence, we obtain the electrical potential distribution on the survey area. Note that for the large scale of survey areas (kilometers long), one has to use the gradient technique (consequent movement of the reference electrode). However, this technique results in large errors related to different polarization of the reference electrode due to different ground conditions. Nonpolarized electrodes ($Cu/CuSO_4$ porous pots) are mostly used for the SP measurement (https://www.kau.edu.sa/Files/0003035/Subjects/SP.pdf; Pantelis and Marios, 2015; Corry et al., 1983; Aal et al., 2004; Revil and Jardani, 2013; Milsom, 2001). However, copper-clad steel electrodes are also reported to be possible (https://archive.epa.gov/esd/archive-geophysics/web/html/self-potential_(sp)_method.html; -Guyer, 2015). Therefore, before performing the SP measurement, we do a test on the sensitivity of two types of electrodes and find out which one is best for the SP survey.

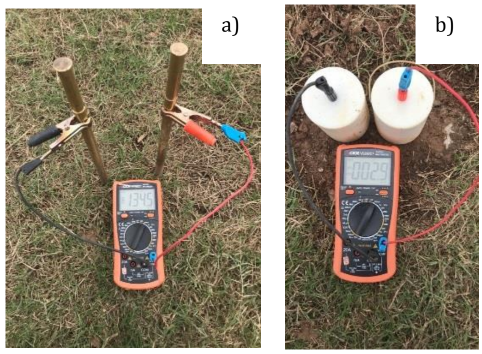


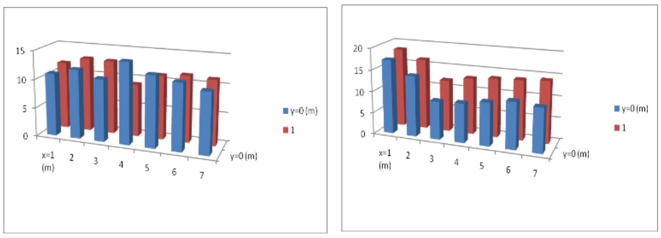
Figure 6: Electrical potential difference when two electrodes are placed at the same location for (a) copper stakes and (b) for Cu/CuSO4 porous pots.

3. Results and Discussion

3.1 Sensitivity of electrodes

Firstly, we hammer a pair of copper stakes into ground at the same location and measure the electrical potential difference between them. The measured value is remarkably large for our test place (134.5 mV as shown in Figure 6a). This value should have been approximately zero because the electrical potential is almost the same at the same location. The reason for such a large value of the electrical potential difference between two copper stakes is a polarization voltage generated when they are in contact with humid soil. The magnitude of polarization voltages depends on the used metals (Milson, 2001). It suggests that a pair of copper stakes is not a good candidate for the SP measurement. We do the similar test for a pair of $Cu/CuSO_4$ porous pots and the measured electrical potential difference is now 2.9 mV as shown in Figure 6b. Therefore, it is more suitable to use electrodes of $Cu/CuSO_4$ porous pots for the SP measurement as reported in literature (https://www.kau.edu.sa/Files/0003035/Subjects/SP.pdf; Pantelis and

Marios, 2015; Corry et al., 1983; Aal et al., 2004; Revil and Jardani, 2013; Milsom, 2001).



(a) (b)

Figure 7: Electrical potential distribution (in mV) on the survey area using Cu/CuSO4 porous pots: (a) without leakage and (b) with leakage.

3.2 SP measurement using Cu/$CuSO_4$ porous pots

Applying the above-mentioned procedure for SP measurement, we obtain the variation of electrical potential with position on the survey area using Cu/$CuSO_4$ porous pots for both cases: without leakage (the dam reservoir is empty) and with leakage (the dam reservoir is full of water as shown in the left side of Figure 3). The results without leakage and with leakage are shown in Figure 7a and Figure 7b, respectively. It is seen that when there is no water leakage, no anomaly in the electrical potential is observed as expected (Figure 7a). Magnitude of the measured electrical potential is around 10 mV. That is simply due to electrical potential difference between the reference electrode and rolling electrode (they are around 20 m apart). For the case of water leakage, we find an anomaly observed in the range *x* = 3 - 4 m (electrical potential in that range is smaller than that in surrounding areas) as shown in Figure 7b. That anomaly can be explained by the water leakage that has been intentionally generated under the survey area in the range *x* = 3 - 4 m (see the cross-sectional area of the dam with leakages in Figure 8). Additionally, we also observe an increase of electrical potential in the water direction (electrical potential increases with an increase of *y*) as shown in Figure 7b. The reason is that for most soil-water systems, gradient of electric potential is opposite to gradient of liquid pressure difference and therefore, electric potential related to the seepage of water through retention structures increases in the flow direction and vice versa (Thanh et al., 2019; Thanh and Sprik, 2016).

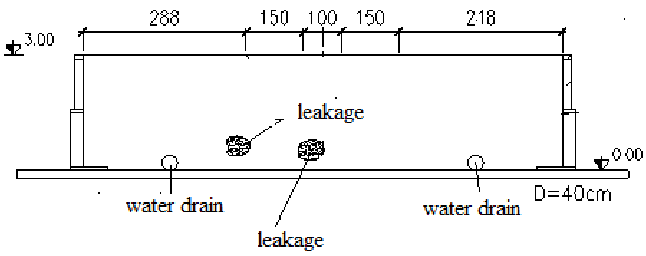


Figure 8: Cross sectional area of the dam with intentionally generated leakages

3.3 SP measurement for copper stake electrodes

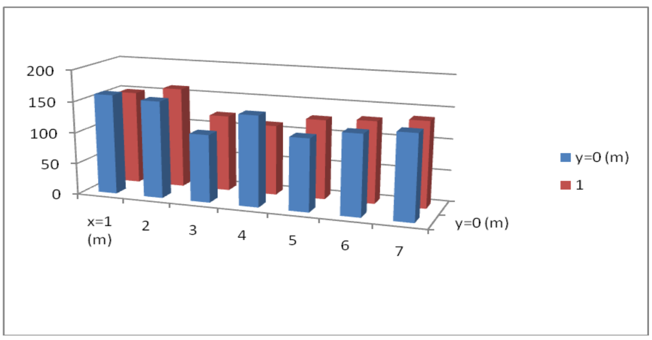


Figure 9: Electrical potential distribution (in mV) on the survey area using copper stake electrodes.

Figure 9 shows the electrical potential distribution on the survey area using copper stake electrodes for the case of water leakage. It is seen that even there is water leakage but we nearly do not observe an anomaly in the electric potential. The magnitude of the measured electrical potential using copper stakes (around 120 mV) is much larger than those using Cu/CuSO4 porous pots (around 10 mV). The reason is due to the electrical polarization strongly occurring for copper stakes as previously mentioned. Additionally, it is found that when we hammer copper stakes into ground, it may take 5 minutes to get a stable value for the electrical potential. The reason may be that copper stakes become electrically charged when they are rubbed against soil. Therefore, it takes time to discharge and reach equilibrium for metal electrodes. These drawbacks of using copper stake electrodes will result in the large error in the SP measurement and influence data interpretation.

4. Conclusions

In this work, we have presented the brief theory of the SP as well as its possible application in detection of water leakage through dams. Then we perform the SP measurement at an artificial earthen dam that we built at Thuyloi University using two different types of electrodes (Cu/CuSO4 porous pots and copper stakes). It is seen that selection of electrode types is crucial in the SP measurements. Namely, copper stake electrodes are not very suitable for the SP survey. The reason is that when two metal stakes come into contact with moisture in the ground, a polarization voltage is created, which strongly disturbs the SP measurements. Additionally, it takes long time to reach a stable value for electrical potential. Therefore, using non-polarizable electrodes like Cu/CuSO4 porous pots when performing SP measurements is a way to avoid that problem. Our results show that the SP measurement using suitable electrodes can be applied to detect underground water leakage and flow direction in the dam based on an anomaly and variation of electric potential with position on the survey area. In next step, we will apply this technique as well as gained experience to detect water leakage in real water retention structures such as Da Bac lake (Ha Tinh province) and Ba khe lake in Vietnam (Nghe An province).

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