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Application of shallow high-resolution transient electromagnetic method (TEM) in geological investigation of debris flow

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Abstract: In the investigation of debris flow, the detection of the source area of the post-disaster debris flow is an important basis for evaluating the distribution of the debris flow accumulation layer and the subsequent control. In this paper, a shallow high-resolution TEM is used to detect the debris flow source area in Dashigou village, Yongji County, Jilin Province. The purpose of this investigation is to determine the depth range of debris flow damage. The detection results show that there is an obvious low resistance zone at about 10 m depth along the survey line, which is in good agreement with the drilling data and the high density electrical detection. It is proved that the depth is the maximum impact depth of the debris flow. The practical engineering proves that the method has high resolution in shallow layer detection, high efficiency and convenience in field acquisition. The maximum detection depth range of this method is 30–40 m, which meets the requirements of high efficiency and accurate detection for regional debris flow source area, and has high practical application value.

Keywords: shallow layer; high resolution; transient electromagnetic method; debris flow

0 Introduction

Geological disasters such as debris flow occur frequently due to human and environmental factors, which seriously threaten the safety of residents' lives and property (Liu, 2014; Peng, 2005; Xie *et al.*, 2013). The natural factors causing debris flow include: (1) landform; (2) loose provenance; (3) continuous rainfall or storm (Li *et al.*, 2014). In the actual geological disaster management, landform and continuous rainfall or storms are more difficult to control. Therefore, in order to reduce the threat of debris flow disaster, it is very important to accurately identify the distribution, properties, thickness and depth and undulating morphology of debris flow accumulation. For northeast China, more than 90% of mudslides occurred between July and August suddenly, which are concentrated and destructive (Du, 1995; Song & Sun, 1996). In addition, compared with southwest China, the lithology of debris flow in northeast China mainly comprises granite, gneiss, clastic rock and quartzite, with less clay in weathered products, so there is less viscous debris flow in northeast China. The debris flow accumulation is dominated by larger block of rocks. Therefore, it is very important to choose an efficient, convenient and accurate detection method.

At present, the common means of geological hazard exploration of debris flow include engineering geological survey, geophysical survey, drilling, rock sample test and analysis, etc. (Xue & Liu, 2018; Zhao, 2008). However, because debris flow geological hazards usually occur in locations with poor envi-

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ronment and complex geology it is very likely that it will cause secondary harm to residents and damage to properties. Moreover, the common methods of engineering geological survey cannot meet the engineering needs in precision and efficiency. Compared with the common engineering geological exploration methods, the geophysical exploration has many advantages, such as low survey cost, high survey efficiency, intuitive survey results, high safety and so on. Because the geological disasters of debris flow often occur in shallow part, it is often mainly based on high density electric method, bottom radar method, shallow seismic exploration, shallow transient electromagnetic and other shallow detection methods (Jin *et al.*, 2005; Li *et al.*, 2014; Shanmugam, 1996; Zhao *et al.*, 2001). Of which the TEM has the characteristics of high sensitivity and convenient detection. At present, it has achieved very good application effect in engineering investigation (Guo *et al.*, 2006). The types of transient electromagnetic devices mainly include: large fixed source return device, central return device, overlapping wire return device, dipole-dipole device, electro-dipole wire return device (Wang *et al.*, 2017). In this paper, the high-speed mode of transient electromagnetic is used to achieve a shallow high-resolution acquisition. Its high-speed and high-precision is suitable for the geological investigation of shallow debris flow. Combined with drilling data and high density electrical detection results, the advantages and accuracy of this method in detecting the thickness of debris flow accumulation are verified.

1 Overview of the Project

The studied area is located at the front end of the transition from Changbai Mountain to Songliao Plain, whose geographical location belongs to Dashigou village, Yongji County, Jilin Province. The landform is mainly low hills, and the whole terrain gradually flattens from southeast to southwest. The Dashigou area is dominated by medium height mountain, the terrain shows irregular groove, and fluctuates greatly, forming local steep topography. The flow of water in the Dashigou is from south to north, the overall terrain is high in the south and low in the north, and high vegetation covers both sides of gully. The photo of site is shown in Fig. 1.

Fig. 1 Site photo of post-disaster debris flow in Dashigo

Fig. 2 Debris flow accumulation in the studied area

It is understood that mudslides occurred in the area in August 2017 and July 2016, and debris flow piles continued to slide. This phenomenon poses a serious threat to the lives and property of the residents. Therefore, in order to prevent the existing debris flow accumulation layer from further sliding, it is very important to accurately detect the thickness and distribution of debris flow accumulation, the depth of bedrock and the undulating morphology. The strata in the depth range of this survey are mainly composed of debris flow accumulation layer and granite bedrock. As shown in Fig. 2, there is a lot of gravel piled up in the gully.

The main factors affecting the formation conductivity are mineral composition, rock lithology, rock porosity and water content and so on (Song *et al.*, 2005). There is a certain electrical difference between the debris flow accumulation layer and the granite under it. Therefore, the shallow TEM is used to detect the thickness and distribution of debris flow accumulation layer, based on relevant theories.

2 Detection method and line arrangement

Transient electromagnetism is a time domain artificial source electromagnetic detection method based on the principle of electromagnetic induction (Xi *et al.*, 2016). It uses an ungrounded return line or a grounding wire source to send a pulsed magnetic field to the ground, and under its excitation, the inductive eddy current excited by the target body will produce an inductive electromagnetic field that changes over time. Through the observation of two fields, the purpose of detecting underground geological bodies is achieved. The transient electromagnetic detection instrument of this project adopts the TEM-31 type machine of Geopen Company, which has a built-in small power transmitter, integrates launch and receiving engineering, and contains two acquisition modes, conventional (TEM) and high speed (HTEM). Of which the high-speed acquisition mode has the characteristics of short acquisition time and more samples, and is thus applied to the investigation of shallow geological bodies. The fundamental frequency is 25 Hz, 6-gear emission voltage, the sampling frequency is 1 000 kHz, the number of stacking is 128 times, and the gain is 1. The launch line frame is 4 m × 4 m, the coil turns are 27, the material is tin-coated copper, the resistance is 8.7 ohms, and the equivalent area of the receiving coil is 3 000 m^2.

The site condition in the Dashigou ditch is poor, the gully has a lot stone accumulation and some damaged houses, and the terrain in the transverse direction of the ditch fluctuates greatly, with lush vegetation surrendering.

According to the site survey and engineering requirements, three survey lines ae arranged in the debris flow deposit area, S1 and G1 are long survey lines arranged along the ditch. At the same time, in order to facilitate comparison verification, S1 and G1 are placed in the same position as the ditches. The S2 is a measuring line arranged along the transverse direction of the ditch. Among them, S1 and S2 are TEM measurement lines, and G1 is high-density electrical measurement line. The lines of S1 and G1 are all from south to north, starting in the vicinity of a building in the ditch and ending in the villager's compound at the mouth of the ditch, which is about 1 100 m. The measuring line is S2 from east to west, and the length of the line is about 310 m. The line layout and location diagram are shown in Fig. 3.

3 Explanation of outcome information

3.1 Explanation of results of TEM

Fig. 4 is the shallow high-resolution transient electromagnetic results section from S1 measurement line. It can be seen that its resistivity along the direction of the line changes a little, but with obvious variation along the depth. The resistivity increases obviously with depths, with an obvious boundary surface in the middle. The boundary is underlain by granite bedrock, and overlain by debris flow accumulation layer. The thickness of debris flow stacking layer gets thinner from south to north, which is the same as the actual survey results. Due to the vertical invasion of the river, the area is partially rich in water in the debris flow accumulation layer forming a low resistance body.

In order to verify the reliability of the results of shallow high-resolution transient electromagnetic detection, drilling of ZK7#, ZK4#, ZK2# and ZK8# are arranged at 220 m, 540 m, 750 m and 900 m of the measuring line respectively. According to the drilling data, the depth of the bedrock is shown to be 10.2 m at the drilling site of the ZK7#, and the result of the shallow TEM is 10.4 m. At ZK4# drilling site, the bedrock depth is shown to be 9.5 m, and 9.8 m is detected by shallow TEM. At the ZK2# drilling, the bedrock depth is shown to be 9.2 m, and the shallow TEM is detected 9.5 m. At the ZK8# drilling site, it is shown that the bedrock depth is 9.1 m, and the shallow TEM detects 9.2 m. From the above comparison, the detection results of TEM are basically consistent with the situation revealed by drilling.

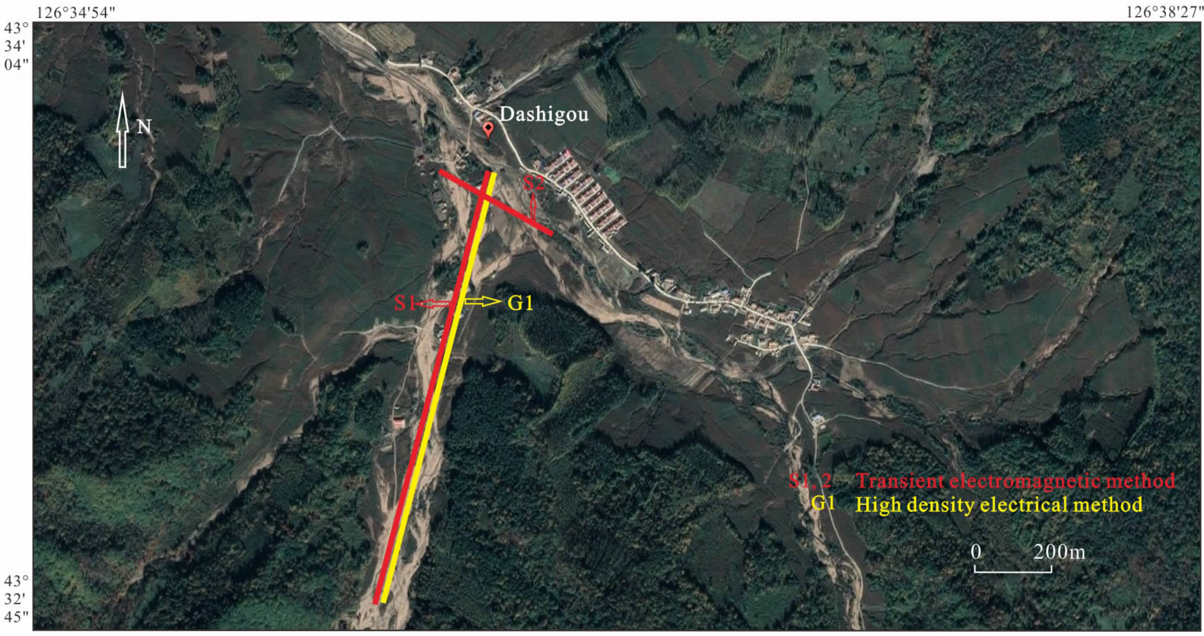

Fig. 3 Schematic diagram of measure line arrangement inside the ditch

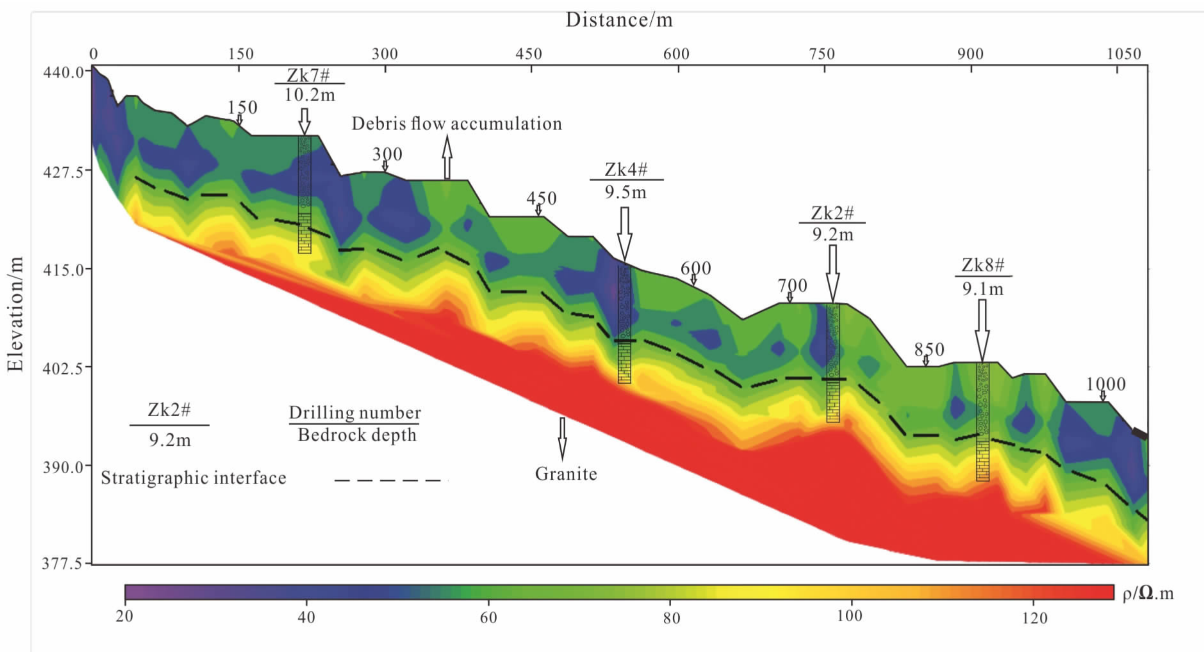

Fig. 4 Results diagram of shallow high resolution TEM for S1 measurement line

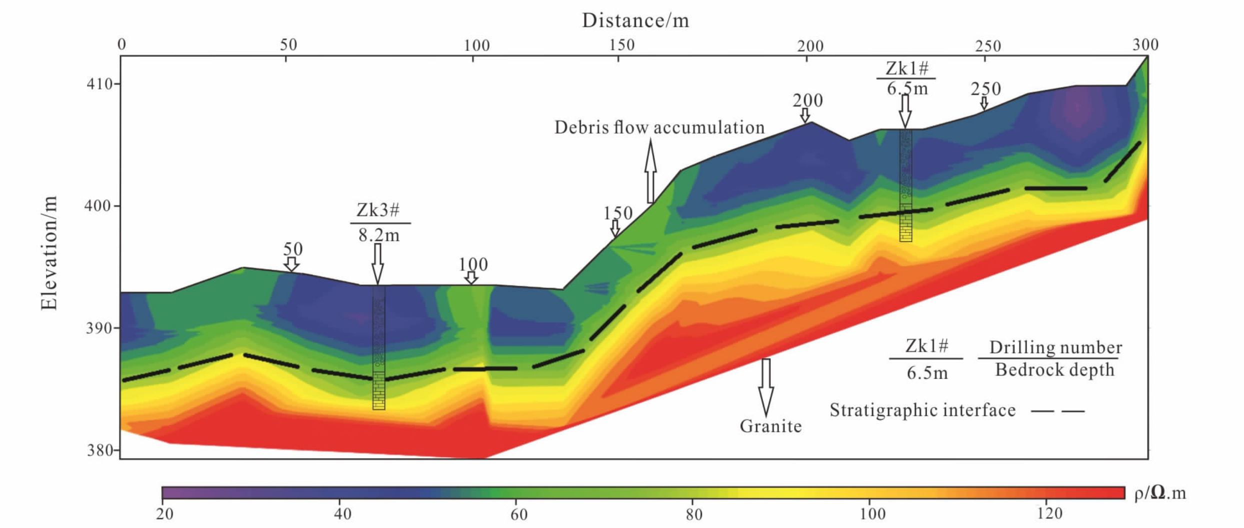

Fig. 5　Results diagram of shallow high resolution TEM for S2 measurement line

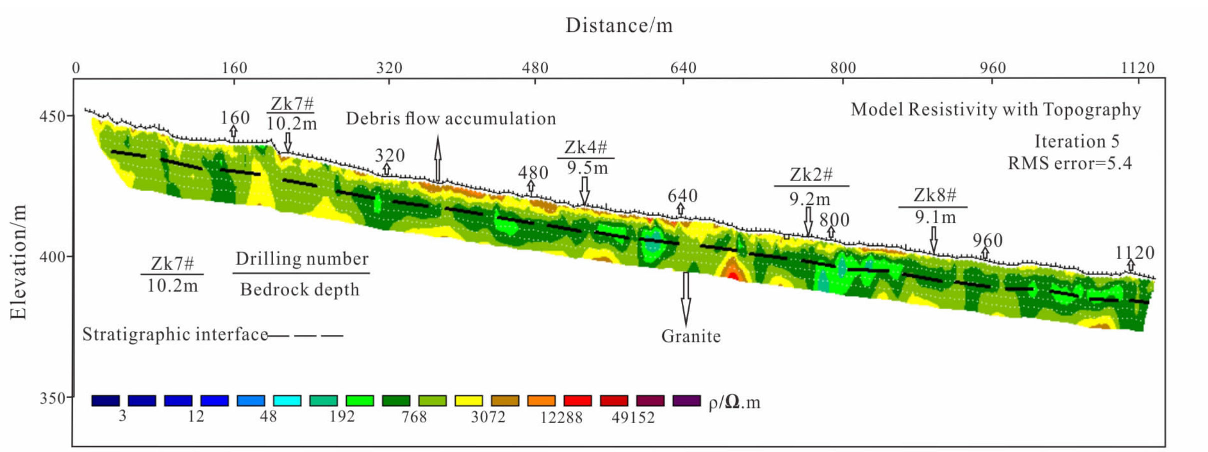

Fig. 6　Results diagram of High density electrical method for G1 measurement line

Fig. 5 is the S2 shallow high-resolution transient electromagnetic result diagram, of which resistivity changes little along the line direction, but varies greatly along the depth direction, and the difference is obvious, and there is an obvious interface in the middle. As shown in Fig. 5, there exists granite bedrock below the stratigraphic interface, above are debris flow accumulation layers. It also indicates that the thickness of debris flow from east to west is decreasing gradually. According to the site survey, it was found that the debris in the east was slipping down from the west, which further confirmed the accuracy of the method. As shown in the Fig. 5, in the locations of 75 m, 210 m and 290 m, there are three large low-resistance bodies. According to the site survey, there is a puddle and water vertically invaded downward forming water-enriched debris flow accumulation.

In order to verify the accuracy of the detection results of shallow high-resolution TEM, the drilling of ZK3# and ZK1# are arranged at 75 m and 240 m of the measuring line respectively. At ZK3# Drilling site, the bedrock depth is shown to be 8.2 m, and 8.6 m is detected by TEM, while at ZK1# Drilling site, the bedrock depth is shown to be 6.5 m, and the TEM detects 6.6 m. It shows that the results of drilling are basically consistent with the results of transient electromagnetic display, which further reflects the accuracy of shallow high resolution transient electromagnetic detection.

3.2 Explanation of the results of multi-electrode resistivity method

In order to further verify the accuracy of shallow TEM, the results of high density electrical method is further analysed below. As shown in Fig. 6, the thickness of debris flow accumulation layer decreases gradually along the measuring line from south to north. Because the S1 line and the G1 line are in the same position, so for the G1 measurement line, in the locations of 220 m, 540 m, 750 m and 900 m, it can also correlate with drilling ZK7#, ZK4#, ZK2#, ZK8#. At the ZK7# of the borehole, the depth of the bedrock shown is 10.2 m, while 9.6 m is detected by multi-electrode resistivity method. At the drilling site of ZK4#, the bedrock depth is shown to be 9.5 m, and 9 m is detected by high-density electrical method, and at the drilling site ZK2#, the bedrock depth is shown to be 9.2 m, and 8.6 m is detected by high density electrical method. In the drilling site ZK8#, the bedrock depth is shown to be 9.1 m, and 8.2 m is detected by high-density electrical method.

Through the comprehensive analysis of the two methods of shallow high resolution TEM and multi-electrode resistivity, the thickness of debris flow accumulation layer obtained by TEM and high density electric method has high consistency, and all reflect the slight decrease of debris flow accumulation thickness of the measuring line from south to north, which is also consistent with the actual drilling data.

4 Conclusions

(1) The thickness and morphology of debris flow accumulation layer in Dashigou are detected by shallow high resolution TEM, and the accuracy of this method is further verified by drilling data and multi-electrode resistivity method, which provides reliable geological data for the prevention of debris flow disaster in this area.

(2) The shallow high resolution TEM and high density electric method are used for the detection, showing highly consistent results. However, relatively, the shallow high resolution TEM has higher resolution along the direction of the measure lines and depth direction. Moreover, the shallow high resolution TEM has higher consistency with drilling data. The shallow high resolution TEM method in debris flow source area detection has the characteristics of economy, efficiency and precision, and can be widely used in the investigation of debris flow disaster.

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