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# Application and Effect of Underground Magnetic Fluid Detection Technology to Detect Groundwater of Highway Slope

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# Application and Effect of Underground Magnetic Fluid Detection Technology to Detect Groundwater of Highway Slope

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**Abstract.** The dynamic information such as water level, supply source and motion direction of groundwater in slope engineering have an important influence on the selection of water drainage project. It is important to quickly and effectively ascertain the groundwater information of slope engineering. The underground magnetic fluid detection technology uses the groundwater flow system to continuously cut the magnetic force lines in the geomagnetic field to form the underground magnetic fluid and then generate induced electromagnetic fields. The dynamic information of groundwater can be detected quickly and efficiently by testing the electromagnetic field. The application results of groundwater detection technology in Shang-San Expressway in Zhejiang province to K290+400 slope show that: the results of exploration are basically consistent with the results of underground magnetic fluid detection; and groundwater distribution of slope which is tested by underground magnetic fluid detection technology is reliable. The underground magnetic fluid detection technology provides a quick and effective means for groundwater exploration of slope engineering.
**Keywords:** Underground magnetic fluid; Slope; Groundwater

## 1. Introduction

We know that the strength of rock and soil will be decreased when they absorb water. Groundwater is the most active and most common factor in many geological factors that cause geological disasters. It plays an extremely important role in the occurrence of various geological disasters (HUANG Runqiu et al., 2005). Water has two effects on the slope. First, it reduces the strength of the rock mass, especially the shear strength of the weak structural plane. Secondly, it is to change the stress state of slope rock mass (SUN Yuke, 1999). Soft rock has the characteristics of expansion deformation after water contact. The prolongation of the soft rock water saturation time leads to an increase in the porosity of the soft rock, a loose connection between the particles, and a loose and porous structure.

Finally, the soft rock will be transformed from a relatively dense, high-strength granular, dense, bar-like initial structure into a loose porous floc and petal-like structure (ZHOU Cuiying et al., 2003). The compressive strength, tensile strength and shear strength of soft rock generally obey the exponential law after the soft rock interacting with water. Its mechanical strength indexes decrease with the prolongation of the saturated water time, and eventually approaching a constant value. 6-month is the critical saturation timing at which the mechanical strength of soft rock tends to be stable (ZHOU Cuiying et al., 2005, 2010). The fast-shearing test of the low-liquid-limit sand-bearing clay in the slip zone shows that the cohesive force increases and the internal friction angle decreases as the water content increases. The cohesion will decline until it disappears as the water content increases after the water content increases to a level. The occurrence of water in the slope body leads to an increase in the bulk density of the rock and soil, an increase in the sliding force of the slope, and also a decrease in the shear strength of the rock and soil. All of them lead to instability of the slope (CHEN Xiaoping, et al., 2011). Drainage engineering can effectively control groundwater in slopes. Slope drainage is one of the most important methods commonly used in slope treatment (XU Nianfeng, et al., 2001; SUN Hongyue, et al., 2006, 2008; LIU Jianjun, et al., 2005; WANG Jiahai, et al., 2008). Dynamic information such as the water level, recharge source and movement direction of the groundwater in the slope has an important influence on the selection of the slope drainage engineering plan. It is especially important to detect the occurrence of groundwater in slopes quickly and effectively for the rescue of slope engineering.

When the groundwater flows, the magnetic field lines are continuously cut in the geomagnetic field to form underground magnetic fluid; and an induced electromagnetic field is formed. The induced electromagnetic field is affected by geological structures, structures, underground fissures and caves. The electromagnetic waves emitted by the Earth's core are refracted and reflected, and the underground magnetic fluid detection technology can detect the induced electromagnetic wave changes caused by the groundwater flow. Underground magnetic fluid detection technology has been widely used in the detection of hidden dangers in mining areas. And it has achieved good results (ZHOU Hua, et al., 2009; ZHANG Jian, et al., 2009, 2010; CHEN Hongzhao, et al., 2011; YIN Li, et al., 2014). In this paper, the magnetic fluid detection technology is used to test the K290+400 slope of Shang-San Expressway in Zhejiang Province. The detection technology is used to detect the occurrence of groundwater in the slope, and the reliability of the method is verified by the experience of the slope engineering.

## 2. Principle and Method of Underground Magnetic Fluid Detection Technology

### *2.1. Principle of Underground Magnetic Fluid Detection Technology*

When the internal geomagnetic field source of the Earth to emit from the earth's core and penetrate geological bodies of different structures, they will be refracted, reflected. And it also interacts with the flowing groundwater. All of them will produce natural electromagnetic coupling effects. Electromagnetic signals that penetrate to ground contain signals of different effects, and the different geological structures show different characteristics. Underground magnetic fluid detection system is through the probe to receive underground magnetic fluid electromagnetic wave signals which is emitted from the inside of the earth to ground. Then, the signals are transmitted to the underground magnetic fluid detector through the detection cable, and the characteristic information is extracted by the detector and sent to the host computer for comprehensive analysis to obtain the detection results.

The underground magnetic fluid detection technology uses the earth electromagnetic field as the working field source. The magnetic field in the Earth is emitted from the Earth's core. When it penetrates the ground, it is coupled with different geological bodies in different stratas, such as refraction and reflection, and interacted with groundwater such as old water and water-conducting faults. These conditions will have a natural electromagnetic coupling effect. Electromagnetic signals that penetrate the ground exhibit different characteristics in different geological structures and groundwater. Such as the figure 1, B is the component of the geomagnetic field in the orthogonal direction, and V is the flow velocity and direction of groundwater in the fault. According to the law of electromagnetic induction, an alternating induced electromotive force is generated in the E direction. The data acquisition module of the system can detect the static information of the earth electric field through the probes T1 and T2, and it can also detect the alternating induced electromotive force, thereby obtaining the dynamic information of the underground magnetic fluid.

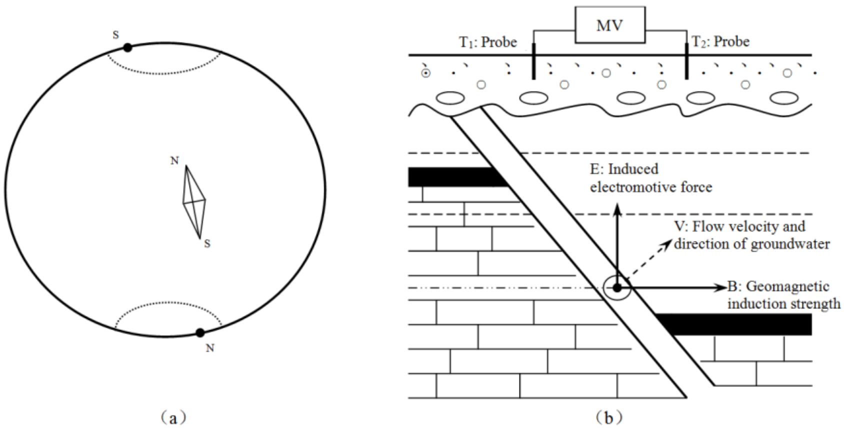


**Figure 1.** Electromagnetic Coupling Principle (YIN Li et al., 2014)

### 2.2. *Operation Method of Underground Magnetic Fluid Detection Technology*

As shown in Figure 2, the test uses four-channel acquisition. The four channels include two electricity tracks $E_x$, $E_y$ and two magnetic tracks $H_x$, $H_y$. The acquisition signal frequency is 256Hz, and the test depth is about 20-30 meters. The sensor type and sensor distance for the four channels are set separately, and the time for collecting the signal is 5 minutes. The magnetic sensors of the 4 tracks are placed horizontally in the north and the east, and they are perpendicular to each other. Four channel sensors are placed in the soil. And make sure the sensor is in good contact with the soil. The electromagnetic wave signals are collected after the check is correct.

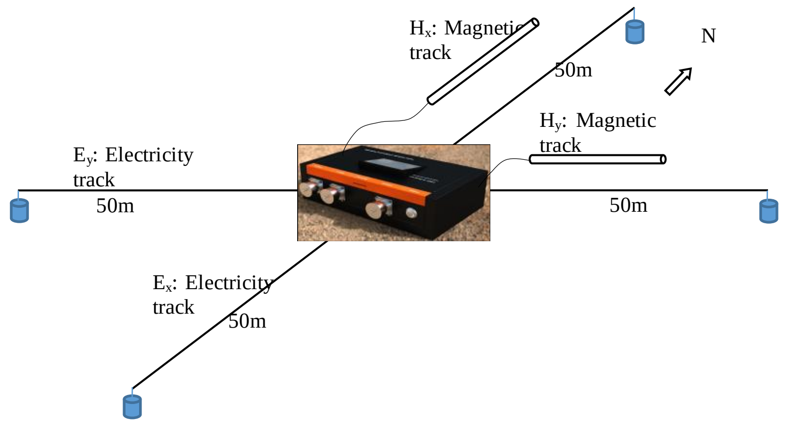


**Figure 2.** Principle of Four Channel Collection Mode

### 2.3. *Data Processing*

Based on the electromagnetic field theory, the relationship between the frequency *f* of the natural electric field detection and the corresponding depth *h* detected by the detector can be obtained according to the Maxwell equation (DONG Songgui, 1991).

$$h = 1/b = k_0\sqrt{\rho/f} = 503.3\sqrt{\rho/f} \tag{1}$$

In equation (1): $\rho(\Omega m)$ is the resistivity of the probe point on earth's surface; $k_0$ is the depth calibration coefficient, which is generally 503.3.

The flow rate and flow velocity of groundwater change with time, so the induced electromotive force generated by flowing water can be expressed as *e(t)*, then the relationship between *e(t)* and groundwater reserve $s_w$ is as follow.

$$s_w = \int_0^T \pi De/4BKdt = \pi D/4BK \int_0^T edt \tag{2}$$

*T* is the period of change in groundwater dynamic information. The natural electric field detecting instrument can detect the change period *T* and comprehensive value of induced electromotive force *e(t)* in period *T*. So that the groundwater reserve $s_w$ can be simply estimated by the formula (2).

## 3. Application of Underground Magnetic Fluid Detection Technology in Expressway Slope

### *3.1. Basic Information of K290+400 Slope of Shang-San Expressway*

The detected slope is 290,400 meters away from Shangyu in Shang-San Expressway. It is near Panlongling tunnel. The north of the slope is Shang-San Expressway; West of the slope is the Panlongling management room on the upper third line; East of the slope is the right entrance of the No. 1 tunnel of the Shang-San Expressway. The slope type is rock slope, which length is 211 meters, and the maximum height of the slope is 26.0 meters, and the slope angle is 42 °. The protection method of the first grade slope is the masonry retaining wall, which height is 7.9 meters and slope rate is 1:0.47; The protection method of the second grade slope is anchor shotcrete and SNS protection net, which height is 18.1 meters and slope rate is 1:0.31. The soil in the slope area is mainly the residual slope layer and the fully weathered bedrock layer. The thickness of the residual slope layer is generally 1.4-3.2 meters, and soil is thicker in local. The rock formation is mainly the Upper Jurassic basalt rock; The medium-micro-weathered rockmass is mainly hard rock hard rock; The strongly weathered basalt body is dark red, partially brownish yellow and yellowish gray; Medium-micro-weathering basalt rock is blue-gray and partially brown-red. An inactive fault is about 40m from the slope; The cracks in the slope area are relatively developed, partially penetrated, and mud-intercalated, forming a small fracture (layer) crack, which poses a great potential threat to the stability of the slope. The joint fissures are relatively developed in the slope area; They are mainly a hard structural planes, and filled with calcite veins, a few filled mud.

### *3.2. Detection Scheme of K290+400 Slope*

The K290+400 slope seepage of the Shang-San Expressway in the direction of Sanmen County was On-the-spot investigated; then the test points and the detection lines were selected. According to the geographical environment of the slope, 2 measuring lines and 7 measuring points were selected. Each measuring point is 10m apart. Measuring line 1 includes measuring point 1, measuring point 2, measuring point 3 and measuring point 4; Measuring line 2 includes measuring point 5, measuring point 6 and measuring point 7. The two measuring lines are approximately parallel to the slope surface. In this test, each measurement point is detected 3 times; the detection frequency is 2048 Hz; and the test time is 360 s.

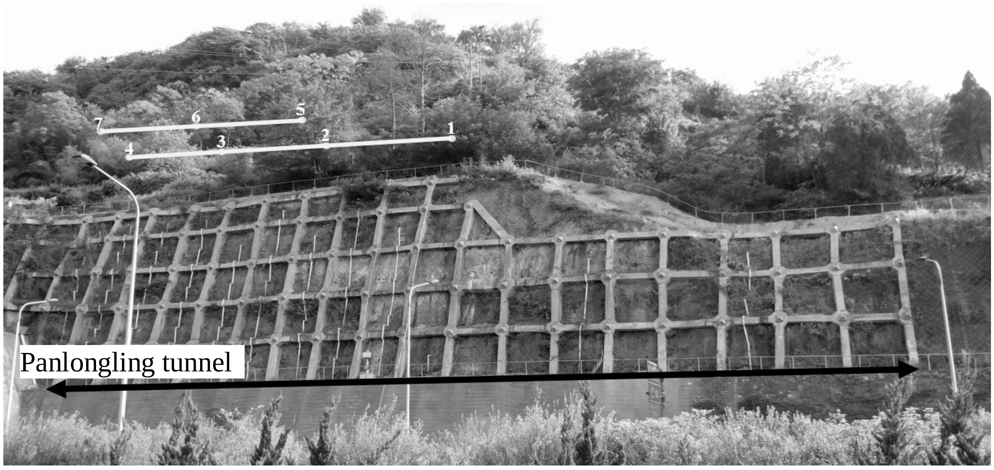


**Figure 3.** Test Point Layout for K290+400 Slope

### *3.3. Analysis of Detection Results*

The underground magnetic fluid distribution map of the K290+400 slope of the Shang-San Expressway in the direction of Sanmen County can be obtained through the inversion of the test results of line 1 and line 2. The inversion results show that the groundwater depth of the K290+400 slope of the Shang-San Expressway in the direction of Sanmen County is affected by the topography. The slope top (measuring point 5) has a relatively high terrain, where the groundwater level is shallow; and the depth is about 12 meters. The terrain on both sides of the slope (measuring point 1, measuring point 7) is relatively low, the groundwater depth is deeper; and the depth is 32-50m. The detection results show that the groundwater flows along the slope to where the groundwater table is deeper; in addition, the groundwater tends to seep or flow along the slope to the highway subgrade. In this test, the slope body has been reinforced and the slope body has been provided with drainage measures. In the field survey around the slope we found that there was groundwater flowing out of the slope and flowing to the road. Not only the drainage facilities have water overflow, but also groundwater seepages on the slope. The results of the magnetic fluid detection are consistent with the field survey.

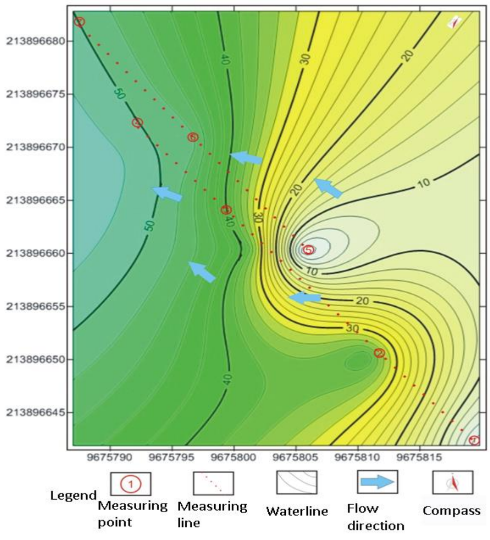


**Figure 4.** Buried Depth Contour Line of Magnetic Fluid

The exploration project revealed that the groundwater depth of the slope is 10.4-15.9m. The slope is in the hard block-like rock mass and deluvial layer; the bedrock is strong-middle weathering. The structural planes (joint, fissure, etc.) generated by various stresses is unevenly developed. The heterogeneity and anisotropy are significant. The water permeability is very different. In the strongly weathered and moderately weathered rock mass, the cores are breaked; and the joints and fissures are developed, and the water permeability is strong. This layer is an important drainage channel for groundwater. The joints and fissures in the medium to micro-weathered rock are mostly closed; and the water permeability is weak.

The types of groundwater in the slope range are loose rock pore phreatic water of the Quaternary period and bedrock fissure water. Pore phreatic water mainly occurs in elluvium-deluvial layer containing clayey gravel sands and fully weathered rock layer. It is distributed in the shallow part of the slope of the mountain, which mainly receives rainwater and infiltration of farmland irrigation. And it infiltrates into the bedrock fissure or excretes along the slope. The bedrock fissure water mainly receives atmospheric precipitation, overlying pore diving and infiltration replenishment of bedrock fissure water. It flows down along the fracture zone. It is mainly excreted along the slope or the middle of the slope surface; but it is partially cut off and exudes on the slope surface. The discharge of groundwater is consistent with the distribution of the fracture zone of the formation and it is discharged to the valley.

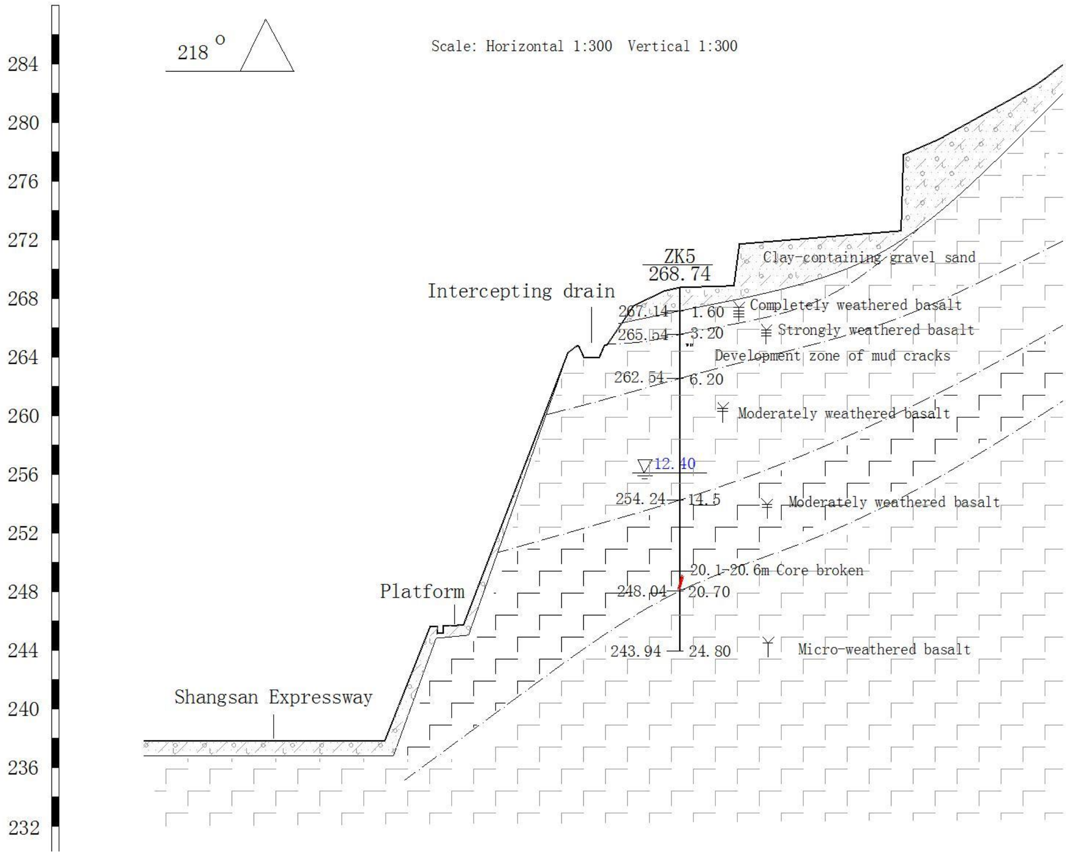


**Figure 5.** Geological Cross-sections for K290+400 Slope

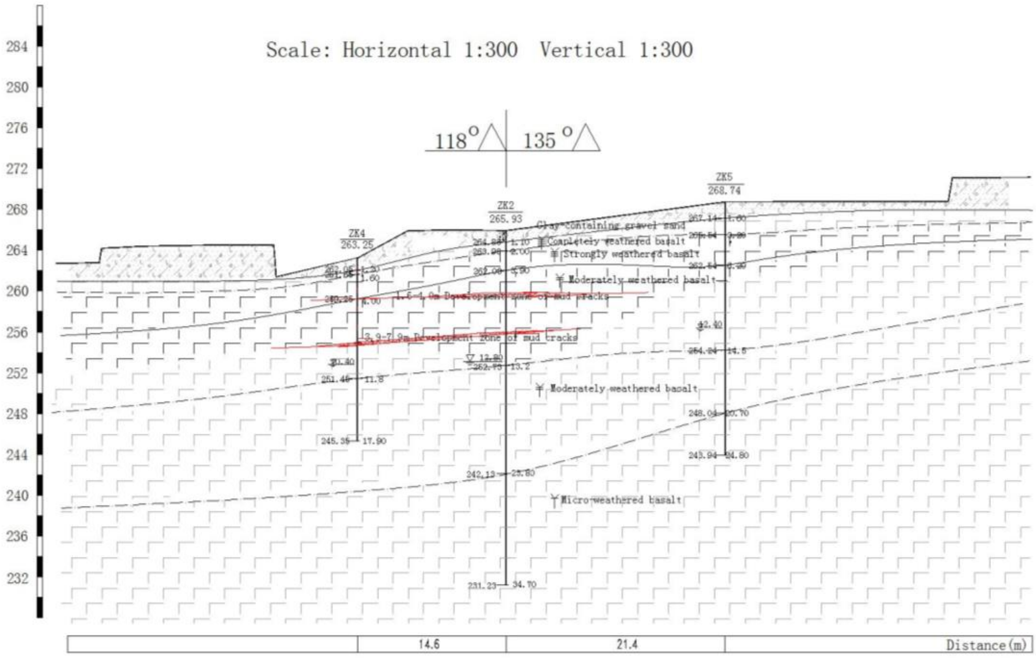


**Figure 6.** Geological Profile for K290+400 Slope

Figure 5 shows that the micro-weathered bedrock surface has a large variation along the dip of K290+400 slope; and the basement rock surface is sharply cut near the slope. Therefore, the groundwater will tend to flow along the slope; and it is consistent with the detection results of the magnetic fluid at the measuring point 5 (in Figure 4). Figure 6 shows that the micro-weathered bedrock surface has less variation along the trend of K290+400 slope; and Panlongling tunnel has a strongly-moderately weathered rock layer with a deeper buried. Therefore, groundwater will flow in this layer (in Figure 4). The magnetic fluid detection results of the line 2 show that the groundwater depth changes little; and the groundwater flows down the slope towards the Panlongling tunnel. Those detection results are consistent with the exploration results.

In summary, the comprehensive exploration results and the underground magnetic fluid detection results are basically the same. So the groundwater detection groundwater distribution results are credible.

## 4. Conclusion

The dynamic information of groundwater in the slope body has an important influence on the scheme selection of the slope drainage project. The underground magnetic fluid detection technology can detect the induced electromagnetic field by continuously cutting the magnetic field lines while the groundwater is flowing the magnetic field lines in the ground magnetic field. So that it can quickly and effectively detect the dynamic information of the groundwater.

(1) The detection results show that the groundwater of the K290+400 slope of the Shang-San Expressway in the direction of Sanmen County flows along the slope to where the groundwater table is deeper. In addition, the groundwater tends to seep or flow along the slope to the highway subgrade. The results of the magnetic fluid detection are consistent with the field survey.

(2) The cores of the strongly weathered and moderately weathered rock mass are breaked in K290+400 slope, and the joints and fissures are developed, and the water permeability is strong. This layer is an important drainage channel for groundwater. Groundwater is mainly affected by atmospheric precipitation and overlying Quaternary diving infiltration recharge. The groundwater excretes along the fracture zone, and it mainly discharges along the slope toe or the middle of the slope.

But some groundwater is cut off by slope and exuding on the slope. The discharge of groundwater is consistent with the distribution of the fracture zone of the formation and it is discharged to the valley. The comprehensive exploration results and the underground magnetic fluid detection results are basically the same. So the groundwater detection groundwater distribution results are credible.

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