A new landslide classification method based on electrical differences and relevant examples

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Abstract. A new landslide classification method based on electrical differences is proposed in this paper. The electrical parameters are obtained by the high-density electrical method, which is commonly used in landslide exploration. In this paper, landslides are divided into four categories based on the electrical difference between overburden and bedrock, and on this basis, the landslides are further divided into four categories according to the local electrical difference of landslides, totally eight kinds of landslides. The high-density resistivity method works well for exploration of both type I and type II slides. However, for type III and type IV, other geophysical methods should be supplemented. For type V-VIII landslides, they are simplified into type I-IV landslides in sections according to their electrical characteristics. As for complex landslides caused by multiple factors, more survey lines need to be laid systematically, combined with various methods, as well as information of drilling and trenching for comprehensive prospecting. The landslide classification method proposed in this paper provides some basis and reference for landslide exploration.

1. Introduction

China is a mountainous country with landslide being one of the most common geologic hazards. It is necessary to classify landslides for better understanding and management. However, owing to the complexity of landslides, there is no unified landslide classification scheme at home or abroad [9-10]. The common classification methods are as follows: classifying by volume, sliding speed, the forming age, mechanical conditions, and so on. According to different research purposes and requirements, many previous work have proposed landslide classification methods that are beneficial to their research [1,6,14]. In recent years, our group has made a lot of geophysical explorations of landslides, and the object of investigation includes many kinds of landslides with different degree of difficulty. Many original landslide classification methods cannot meet the requirements of exploration objectives. Therefore, a new landslide classification method based on electrical differences is proposed.

As an economical and rapid means of nondestructive exploration, geophysical exploration has been recognized, and it is playing an increasingly important role in the exploration of geological disasters such as landslides. The commonly used methods include high-density electrical method, seismic refraction method, surface wave method, ground-penetrating radar method, and so on [2, 4, 8]. The high-density electrical method is the most commonly used in landslide exploration because of its low cost, high efficiency, rich information, and simple terrain correction. Many scholars have obtained good results using high-density electrical method [5,13]. It is a geophysical exploration method based on electrical differences, so the landslide classification method based on electrical differences has extensive applicability for geophysical exploration.
The high-density electrical method is a direct current method, and its principle and processing process have been introduced by many predecessors [11]. Although there are many kinds of measuring devices in the high-density electrical method, the Wenner α device with good stability is adopted in the examples given in this paper, taking into account various factors such as topographic relief, anti-interference ability, and exploration effect.

2. Landslide classification based on the difference of electrical properties between overburden and bedrock

2.1. Principle of classification

The landslide is first simplified into a two-layer landslide structure of overburden and bedrock and then classified according to the resistivity characteristics of overburden and bedrock. The combination of overburden low-resistance body with the underlying high-resistance body is the type of LR-HR. According to this principle, landslide can be divided into four categories (Table 1). For the convenience of explanation, each type of landslide is uniformly numbered.

| Landslide type | Number | Type definition |
|----------------|--------|-----------------|
| LR-HR          | I      | The overburden is characterized by low resistance; The bedrock is characterized by high resistivity. |
| HR-LR          | II     | The overburden is characterized by high resistance; The bedrock is characterized by low resistivity. |
| LR-LR          | III    | The overburden is characterized by low resistance; The bedrock is characterized by low resistivity. |
| HR-HR          | IV     | The overburden is characterized by high resistance. The bedrock is characterized by high resistivity. |

To better describe the landslide classification based on the electrical difference between overburden and bedrock, the following four points need to be explained in this paper:

1. The electrical characteristics of overburden or bedrock are relative concepts. For example, gravel soil is generally considered as a high-resistance body, but when underlying bedrock is limestone or slate, the landslide can also be characterized as a LR-HR landslide. The resistivity anomalies of the same substance in different landslides are different, which should be analyzed according to the specific situation.

2. Landslides of type III and IV do not mean that there is no difference between overburden and basement rock resistivity within them but mean their resistivity ranges are similar, and it's hard to distinguish the interface effectively by using high-density resistivity method.

3. Even if the overburden and bedrock material of a landslide are similar, they are not necessarily the same type. For instance, when the overburden is gravel soils and the underlying bedrock is phyllite, the landslide can be I or IV type due to difference of factors such as gravel content, degree of rock weathering, strata age, etc.

4. When there are multiple lithologies in overburden or bedrock, the material below or above the undulating surface of the bedrock should prevail.

2.2. Relevant examples

Landslide of type I is the most common. Samples in most of the literature are also such landslide. Example in figure 1 is located in Houshan landslide of Pinghetownship primary school, Wushan County, Three Gorges Reservoir Region, the profile shown in the longitudinal survey line. The covering layer is quaternary clay, characterized by low resistance characteristics, with resistivity from 5 to 50 Ω·m; The bedrock is Triassic badong group sandstone, characterized by high resistance characteristics, with resistivity from 40 to 200 Ω·m.
Figure 2 shows an example of Dagouli landslide in the Pingya Tibetan Township, Wuducounty, and the profile shown is the horizontal survey line of the landslide. Covering layer is quaternary gravel soils, characterized by high resistance characteristics of resistivity from 200-2000 Ω•m; Bedrock is Silurian carbonaceous phyllite, characterized by low resistance, with resistivity from 10 to 100 Ω•m. Despite the existance of internal fault effects, the structure of landslide is clear and conforms to Ⅱ type of landslide.

**Figure 1.** Resistivity inversion profile of Houshan landslide.

**Figure 2.** Resistivity inversion profile of Dagouli landslide.

**Figure 3.** Resistivity inversion profile of Suoertou landslide.
Figure 4. Resistivity inversion profile of Ganjiagou landslide.

Covering layer and the bedrock of III type landslide feature low resistance, with no obvious interface. Example in figure 3 is located in Suoertou landslide of Zhouqu County, Gannan. The profile shown is a horizontal survey line in the middle of the landslide. The anomaly of high resistance zone in the electrical profile is caused by the influence of active fault. The overburden, characterized by low resistance, is mainly quaternary carbonaceous gravel soil. The middle bedrock is Devonian carbonaceous slate, which is also characterized by low resistivity. There is no obvious resistivity difference between overburden and bedrock, so it is difficult to make effective exploration of landslide structure with the method of high density.

Both of covering layer and bedrock are of high resistance in IV type landslide, thus there is no obvious interface. Example in figure 4 is located in Ganjiagou landslide, Hanwang town, Wudu. The profile shown is a longitudinal survey line of the landslide. The overburden mainly consists of slip and pile-up gravel soil, which is characterized by high resistance. The bedrock mainly consists of strongly weathered silurian phyllite, which is also characterized by high resistance. There is no obvious resistivity difference between overburden and bedrock, so it is difficult to make effective exploration of landslide structure with high density.

2.3. Discussion and survey countermeasure

Any landslide can be classified into the above four categories according to the difference of materials electrical properties above and below the undulating surface. On the whole, the high-density resistivity method worked well for landslide exploration of type I and II, whereas it can't classify the structure of landslides for type III and IV effectively. So before the exploration of landslide, a general evaluation of characteristics of electrical response to landslides needs to be made, if exploration objects are landslides of III or IV type, researchers should supplement other geophysical method for integrated geophysical prospecting. Generally, when the overburden is relatively loose, which has obvious velocity difference with the underlying bedrock, if there is no special exploration requirement, it is suggested to add geophysical methods based on elastic waves, such as Rayleigh surface wave method, seismic refraction method, etc.

Based on a large number of landslide survey examples, the author recommends the seismic refraction tomographic method here, which effectively overcomes the shortcomings of the general refraction interpretation method [3,7], with simple terrain correction and convenient operation.

3. Landslide classification based on local electrical difference of landslide
3.1. Principle of classification
Classification based on electrical difference between overlay and the bedrock can meet the requirements of general landslide structure exploration, but for detailed exploration of complex landslide, it appears to be powerless. Therefore, based on the classification of overburden - bedrock electrical difference, complex landslide is further divided into four categories according to the part where physical property changes. Classification results are shown in Table 2.

| Landslide type                                      | Number | Type definition                                                                 |
|----------------------------------------------------|--------|---------------------------------------------------------------------------------|
| Hybrid electrical property in covering layer       | V      | Different electrical materials are distributed in different regions, resulting in the mixed electrical characteristics of the overburden. |
| Hybrid electrical property in bedrock              | VI     | Lithologies with different electrical property are distributed regionally, resulting in the mixed electrical characteristics of bedrock. |
| Interference by electric property of fracture      | VII    | The change of electrical characteristics of the landslide owing to the existence of faults. |
| Hybrid of composite electrical property            | VIII   | Contains two or more characteristics of the above three types.                   |

3.2. Relevant examples
Figure 5 shows the longitudinal survey line of the Dujiagou landslide in Liangshui town, Wudu. The overlying layer is mainly composed of loesssilty clay and gravel, which are staggered, making the electrical property of the covering layer disorderly. The upper part of the landslide is mainly the contact between gravel soil and bedrock, which is characterized by "high resistance-high resistance"; the lower part is mainly the contact between silty clay and bedrock, which is characterized by "low resistance-high resistance". The landslide manifest integrally as V type landslide.

![Figure 5. Resistivity inversion profile of Dujiagou landslide.](image)

Figure 6 shows the longitudinal survey line of Selbu landslide in Hanbantownship, Zhouqu. The landslide is located in Heiyougou, and the pingding-huama fault zone passes through the trench. The landslide bedrock is mainly Silurian carbonaceous phyllite, which is characterized by low resistance. A number of high-resistivity band anomalies have been found in the low-resistivity bedrock, and the abnormal response has been confirmed as active fault influence by other object detection lines, and the fault properties have been determined. Affected by faults, there are breakage inside the bedrock, and basement rock resistivity is obviously influenced, so the landslide belong to the VII type landslide. After
determining the influencing factors of fractures, landslide structure is clear on the whole, which can be simplified as II type of landslide.

3.3. Discussion and survey countermeasure

In general, landslide of type V and VI is processed in segment. For the Dujiaogu landslide, the upper part can be simplified as IV type landslide supplemented with other geophysical methods (as shown in figure 5), the lower part can be simplified to I type landslide.

For landslide of type VII, it is necessary to define the response characteristics of high-density electrical method to fault anomalies, and then lay out survey lines such as seismic reflection method nearby. After the property of the fault is determined and the influence of the fault is eliminated, it can be further simplified to other types of landslide.

Landslides of VIII type are relatively common in complex landslides, like the world-famous Suoertou landslide in Zhouqu. The integral form of this landslide is controlled by fault zone [12], and the underlying lithology is mainly composed of phyllite, carbonaceous slate, and sandstone, while the covering layer is mainly composed of bedrock weathering residues, loess, stone and gravel soil, which piled up in staggered order. The electrical structure of the whole landslide is messy, so the exploration is extremely difficult. For this kind of landslide, a variety of methods are needed, and only using several survey lines combined with ground investigation, drilling, trench, and other information can obtain useful exploration results.

4. Conclusions

With a large amount of geophysical data of landslide, a new method of landslide classification based on electrical difference is proposed. The main points are summarized as follows:

(1) The electrical data in this paper are all obtained from the high-density electrical method, which needs to take targeted measures to obtain high-quality data in the prospecting. Electrical difference is a relative concept, which has nothing to do with the magnitude of resistivity of the substance.

(2) Based on electrical difference between the covering and the bedrock, landslides can be divided into four categories (I - IV). Such type of classification can meet the needs of general stratum structure exploration of landslide. High density is very effective for landslide of type I and II, especially when there is great difference between the covering and the bedrock. For landslides of type III and IV, other methods are needed to complement for comprehensive geophysical research.

(3) Based on the differences of local electrical property, landslides are divided into four categories, and this way of classification is suitable for detailed exploration of complex landslides. To facilitate research, landslides of type V - VIII can be simplified to I - IV type in segmentation based on the electrical characteristics, for particularly complex landslides, it is required to combine other geological information with a variety of methods and multiple line system for exploration.
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