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Causes and prevention and control measures for geological disasters: case studies from landslides and debris flows

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Abstract. Geological disasters are highly hazardous, and the corresponding means of measures should be selected for different monitoring and prevention, depending on the diversity of the size, type and level of the geological hazard. This paper focuses on two geological disasters, landslides and debris flows, which are different in nature but related to geological and other conditions highly prevalent in China's mountainous areas. The main causal mechanisms of landslide hazards include geological, climatic, and triggering conditions. Monitoring methods are mainly through instrumentation, which allows for more accurate monitoring of deformation and changes in water volume. The main mechanisms for debris flow hazards include geological, material, and water conditions. Monitoring debris flows includes mud level monitoring, rainfall monitoring and other monitoring such as infrasound monitoring. In disaster management, consideration should be given to the prevention and control of the natural environment as well as to the regulation and restriction of human production and living activities, with particular attention to the early prevention and control of special disaster-prone areas.

Keywords: Geological Disasters, Monitoring Methods, Landslides, Debris Flows.

1. Introduction

Geological disasters are generally associated with great hazards, both for the natural environment and the safety of human life and property. For example, China has a large area and population, with complex natural landforms, changing geological and hydrological conditions, and a concentration of human production and living activities. As a result, geological hazards are widespread, diverse, intense, and dangerous, among the most widespread worldwide. Among them, landslides and mudslides are one of China's most dangerous sudden geological hazards. Debris flows cause direct economic losses of more than \$2 billion and casualties of more than 300 people every year [1]. Historically, more than ten vicious debris flows have killed more than 100 people, which have become an important cause of restricting the socio-economic development of some southern western regions of China. The study of geological hazards is of great positive significance in protecting people's lives and property and promoting the harmonious and sustainable development of the national economy and the environment.Geological disasters are divided into different types according to the mechanism of their genesis and properties, such as earthquakes formed by crustal movements, induced by rainfall, and over-mining to form landslide disasters. The different causes and triggers lead to different types of development and have obvious differentiated characteristics, so each treatment is different. Depending on the diversity of the scale, type, and grade of geological hazards, there are differences in the choice of the means of measures corresponding to different pre-disaster monitoring and post-disaster prevention and control.

Therefore, this paper summarizes the types of geological disasters, focuses on the causal mechanisms of the two main hazards, debris flows and landslides, and proposes monitoring and management means.

2. Geological hazard concepts and classification

2.1. Concepts

Geological hazards are caused by natural or human, or both, induced by a combination of causes, making the living environment geotechnical body subject to more intense destructive geological actions or processes, and usually resulting in the loss of human life and property [2]. Some of these are directly caused by human engineering activities, while others are secondary geological hazards that accompany excessive human engineering activities. The development of geological hazards and the degree of hazard-related influencing factors are abundant. They are influenced by geological and environmental conditions such as natural landforms, tectonic activity, topographic lithology, and geotechnical structure, in addition to meteorological factors such as rainfall and triggering factors such as human economic and engineering activities.

2.2. Classification

Based on geological hazards, there are different types of hazards depending on the criteria of how they are classified. There are various types of geological hazards, and the factors for the occurrence of geological hazards are topographical conditions, geological and tectonic conditions, hydrogeological conditions, and meteorological factors, which are diverse and complex. According to the preliminary mechanism of geological hazards and the degree of hazard, and combined with the actual cases in China, geological hazards are initially classified into 10 major categories and 38 sub-categories [3].

There are more types of geological hazard development in China, and they are widely distributed. In terms of specific types of development, there are mainly earthquakes, landslides, mudflows, ground subsidence, ground settlement, ground cracks, ground collapse, soil erosion, land desertification, land salinization, mining and underground engineering disasters, coastal erosion, and soil and water environmental anomalies [2]. In terms of spatial distribution, the phenomenon of regional divisional zones is an obvious characteristic. For example, the north-eastern part of the North China Plain and the north-western plateau region are arid areas with significant desertification effects; the south-western hilly mountains are subject to frequent rainfall-induced landslides and mudslides; and the eastern coastal areas are extensively damaged by seawater intrusion, storm surges and desertification.

3. Causes, monitoring, and management of landslides

3.1. Causes

A landslide is a process in which a body of rock and soil on a slope slides along a sliding surface or sliding zone under the action of gravity and water [4]. There are many factors influencing the genesis of landslides, mainly geological conditions, climatic conditions, and other induced conditions.

3.1.1. Geological conditions. Geological conditions include lithological, geomorphic, and tectonic conditions.

In terms of lithology, landslides mainly occur in unconsolidated Quaternary sediments of muddy sedimentary rocks and metamorphic rocks, such as mudstone, shale, marl, micaceous rock, slate, schist, and loess. This is followed by hydrophilic clay minerals, such as montmorillonite, illite, and

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kaolinite, which absorb water and are softer, adding to the load on the rock, making it easier for the original rock and soil to change the pre-existing stress balance and slide.

In terms of geomorphology, the most important factors leading to landslides are the slope and the spatial. If the slope is moderate enough to ensure sufficient sliding force, but also has a suitable water table so that the water content of the landslide is high and there is enough space for sliding, the landslide is more likely to occur.

In terms of the geological structure, it mainly relies on the creation of slip surfaces to influence the occurrence of landslides. In the weak zone of rock layers such as the original fault surface, laminated surface, joint surface, and cleavage surface, with the effect of water infiltration, the friction is reduced to weaken the anti-slip force and the slip surface is developed to cause landslides.

3.1.2. Climatic conditions. Climatic conditions are mainly influenced by precipitation factors [4]. Excess surface water from rainfall infiltrates downwards into the landslide body and the slip surface, reducing the friction coefficient between the original rock bodies, increasing the lubrication effect, and reducing the anti-slip force. Secondly, the rise in groundwater level also reduces the slip resistance, making landslides more likely to occur.

3.1.3. Induced conditions. The induced conditions are mainly divided into two aspects: the influence of the earth's internal dynamics and man-made changes in external dynamics.

3.1.3.1. Earthquakes. According to the seismic data of the past half century, a historical earthquake landslide and landslide distribution map of China has been compiled [5]. It can be found that earthquake-induced landslide collapse disasters, especially in mountainous areas. The areas where landslides accompany earthquakes are highly coincident with the north-south seismic zone, where the number and intensity of earthquakes are high, and the terrain is complex, and the geological conditions are favorable for landslides and cave-ins to occur. The damage caused by strong earthquakes is greater than that caused directly by the earthquake. The country has many earthquakes, and many earthquake collapses and slides occur mainly in the earthquake-prone western region, with the most occurrence of seismic slides on slopes in Sichuan and Yunnan provinces.

3.1.3.2 Human activities. Human activities such as excavating unstable slopes, construction of highway projects, and accumulating waste rock on slopes all break the mechanical balance of the original rock mass. Human activities, either directly or indirectly, induce the formation of landslides, such as mining. In recent years, with the construction of social production and life, people's demand for energy has increased, and most of the mining areas in China, mainly in the north, have entered the deep mining stage, the geological conditions of the mines themselves are strewn with faults and veins, and the engineering geological environment is complex. The frequent blasting vibrations also increase the likelihood of geological hazards such as landslides and debris flows [6].

3.2. Landslide monitoring

The monitoring of geological hazards is of positive significance in safeguarding human life and property and in ensuring that production works are carried out properly. Monitoring methods are divided into the following three main categories.

3.2.1. Manual observation. In the early days, under the limitation of equipment and technology, landslide monitoring in China mainly relied on macroscopic manual observation of changes in the ground surface. It is mainly based on abnormal changes in landforms, hydrology, and environment that can be visually detected obviously [7]. The method is characterized by its intuitive reliability, simplicity, and the economy of monitoring method and feasibility. The specific monitoring process monitors are regular real-time visual observations of macroscopic signs of deformation such as bulging, slumping, abnormal hydrological conditions, abnormal surrounding fauna, and various

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anomalies associated with them. The landslide deformation is obtained at any time by recording and marking the location of cracks that have occurred with markers such as wooden strips and signs, and by setting up simple measurement monitoring tools at cracks in the original rock mass of the landslide. Periodically measure changes in markers such as changes in crack length, width, depth, and the direction of crack extension. It is suitable for monitoring the different deformation stages of various landslides and more suitable for the public to carry out preliminary monitoring and prevent disasters to safeguard life and property. At the same time, this monitoring method also has obvious shortcomings and limitations, the observation is limited to the generated phenomenon monitoring rather than the essential monitoring, the accuracy is low, and at the same time, it needs to invest a lot of human labor, and it cannot achieve the real full time automated electronic real-time monitoring.

3.2.2. Technical and instrumental observations. Instrumentation and technical monitoring are mainly focused on two aspects: one is for monitoring existing deformations such as cracks and displacements, and the other is for the main triggering factors, i.e. water quantity, such as rainfall monitoring and spring flow monitoring.

3.2.2.1 Monitoring of deformation and displacement. The main method pairs are mapping technology precision measurement method, GPS and remote sensing monitoring method, etc., and borehole detection method [7]. The first two are for surface displacements and fractures, while the third method is for deep displacement monitoring. Displacement and fractures are necessary, but not sufficient, conditions for landslides to occur. Surface deformation and deep deformation may differ and not coincide exactly. For these reasons, most instrumental monitoring methods for deformation and displacement are also difficult to predict landslide hazards accurately. Remote sensing and GPS techniques for landslide monitoring rely mainly on the establishment of high-precision measurement control networks. The advantage is that the implementation of automated electronic monitoring can be completed. The borehole detection method, i.e. using a borehole inclinometer to drill into the deep strata and obtain deep deformation.

3.2.2.2 Monitoring of water quantity. The main monitoring of rainfall, spring flow, and groundwater level monitoring.

3.3. Prevention and management

3.3.1. Prevention and control measures for the natural environment. Landslide prevention should correspond to the causes and triggers of landslides. The three main aspects are the adjustment and improvement of geological conditions, the adjustment of the original rock physics equilibrium conditions, and the adjustment of the hydrological conditions of the triggers.

3.3.1.1 Adjustment and improvement of geological conditions. For the mainly unconsolidated Quaternary sediments and clastic rocks, grouting, electrochemical reinforcement, and additional vegetation are used to consolidate and stabilize them. Grouting is used to reinforce rock formations that are soft, easily deformed, and prone to slippage. Adding vegetation to the slope relies on the consolidation of the soil and loss of rock masses by the root system of the vegetation.

3.3.1.2 Mechanical equilibrium adjustment. In the mid-20th century, China mainly used the methods of lowering the foot of the slope and backfilling the foot of the slope with weight loss at the top to keep the landslide in a more stable state for a short period, but these methods did not last long and when other conditions changed such as sudden rainfall and man-made mining, the landslide would appear again. In the next decade or so, China began to adopt anti-slip pile reinforcement, using high-strength materials such as steel bars that are not easily bendable, inserted into the borehole, and poured with concrete to ensure the mechanical balance of the landslide and improve its mechanical stability.

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Other methods, such as pincer reinforcement, netting and slurry spraying, and the addition of retaining walls, are all used to strengthen the mechanical balance [8].

3.3.1.3 Adjustment of hydrological conditions. For surface water, such as water left on the surface after heavy rainfall, interception, and diversion, the surface has been infiltrated into the slide body of groundwater to take pooling and diversion.

3.3.2. Measures for human activities. Limit over-exploitation of opencast mines, incorporate landslide control into the design of slopes in the design of opencast mines, change the design in unstable localized sections, strengthen control of blasting during production, and limit the felling of vegetation on slopes.

4. Causes, monitoring, and management of debris flows

4.1. Causal mechanisms of debris flows

A debris flow is a special type of flood that is mainly developed in mountainous areas and consists of a combination of unconsolidated rock and water bodies. It is a geological disaster characterized by high velocity, high flow, high material capacity, and high destructive power. Therefore, the main influencing factors of a debris flow are the original geological conditions, the source conditions, and the water conditions.

4.1.1. Geological conditions. Geological conditions include the original lithology, topography, and tectonic geology. In terms of lithology, the debris flow is mainly carried by the unconsolidated sediments of the Quaternary period, easily weathered and denuded loess layer and the debris rock body that rolls down after breaking the stress equilibrium [9]; in terms of topography, such as steep valley hills, high slope, and deep "v" shape, wide upstream and narrow downstream, the water source at the mouth of the mountain is mixed with sediment and gravel easy to gather excessively, forming debris flow. In terms of tectonic geology, existing faults, slip surfaces, landslides, and other localized collapses and soil and rock tumbling processes are more likely to provide conditions for debris solids to cause debris flows to occur.

4.1.2. Material source conditions. Solids are the basic source condition for debris flows to occur. The solids in a debris flow are distinctly different from those of a normal river in that the solids content is high and the particle size difference is very large. Mudflows often carry a large amount of debris of terrestrial origin, with a wide range of rock grain sizes, from coarse to fine: conglomerate, sandstone, siltstone, and mudstone. These loose solids are mainly derived from the loose fragmentation of pre-existing seismic hills, regional landslide failures, and the natural tumbling of unconsolidated rock masses.

4.1.3. Water conditions. Water sources are the power carriers of large amounts of mud and rocks. Climate is an important factor affecting the formation of mudflows, especially since the influence of daily or monthly rainfall is significant, and debris flows tend to occur during periods of intense rainfall or at the center of heavy rainfall. It is usually associated with short periods of intense precipitation and rainfall convergence. During rainfall the water-saturated capacity of the debris material on the slope increases, the unconsolidated material continues to absorb water, the pore water pressure is high, the shear strength is low and under the action of gravity, the water-saturated debris material flows down the slope [10]. In contrast to heavy precipitation, prolonged drought can cause land cracking, making abrupt short periods of precipitation more likely to infiltrate the rock mass and increase the risk of debris flows.

4.2. Monitoring of debris flows

The causes of debris flows are divided into geological, material, and water sources, and monitoring needs to be based on these three aspects. Due to the sudden nature of mudflows, macroscopic human monitoring is less accurate and less timely [11]. Monitoring is mainly based on semi-automatic or fully automatic detection methods such as mud level monitoring, rainfall monitoring, and infrasound monitoring.

4.2.1. Mud level monitoring. The mud level, flow rate, and flow data are automatically collected through the monitoring of ultrasonic mud level meters in the automatic mud level monitoring stations [1]. If the set threshold value is reached, it is automatically reported through the communication terminal and the monitoring process is controlled remotely.

4.2.2. Rainfall monitoring. Rainfall monitoring is mainly based on hourly rainfall maps and macro monitoring of rain information. Specific further refined monitoring still relies on automatic telemetry rainfall systems. A certain amount of rainfall monitoring stations are placed in ditch domains prone to mudslides [1]. And through the historical rainfall, hydrological situation, regional climate, etc. to determine the threshold value of local rainfall monitoring, to establish the mudslide early warning system.

4.2.3. Other monitoring. The rest is mainly based on sonic monitoring, which consists mainly of monitoring the vibrational sound waves generated by friction and collision in the flow of mudslides, which usually propagate in the direction of the gully bed [12]. Because they are mostly infrasound sound waves below 20 dB, they can be well differentiated from other frequency sound waves, improving monitoring accuracy and precision.

4.3. Debris flow management

Debris flows are associated with two aspects, a large amount of unconsolidated sediment and gravel, and the water bodies that carry them [13]. Management should therefore focus on both the solids and the water column, one or the other being essential.

4.3.1. Material source management. Management of existing deposits. The main methods are drainage, containment, removal, and consolidation. There are specific methods such as building tunnels or aqueduct bridges to pass underneath the debris flow while allowing it to drain from above; building slopes, retaining walls, barred dams, silt storage sites, support and retaining works, etc.; such as planting different kinds of trees to prevent soil erosion and consolidate the originally loose rock mass.

4.3.2. Water management. Because heavy precipitation often induces mudflows, and the spatial and temporal conditions are closely related to precipitation, water management is also particularly important. Temporally, mudflows occur with regularity, and the cycle of mudflow activity is highly consistent with that of heavy rainfall and flooding [14]. When heavy rainfall and flooding overlap seasonally, they often form a time of high debris flow activity. Spatially, they tend to occur at narrow mountain outfalls or where floodwaters converge. Water management relies on drainage projects such as diversion dykes, rapids, and bunds, as well as increased monitoring of high-hazard areas corresponding to high seasons.

4.3.3. Special areas. Special areas, such as the "2010.8.13" mudflow in the Wenchuan earthquake zone in Sichuan Province, China, for example, because of the large amount of debris deposited in the ditch after the Wenchuan earthquake, and the instability of the ditch wall rock, the region has many ditch areas in the spatial and temporal concentration of mass debris flow [15]. Early and systematic control of such areas should be carried out in terms of physical and water sources. Multiple control measures should be implemented simultaneously, not just focusing on one aspect. Education activities on mudslide prevention and control should also be launched in areas prone to mudslides to raise awareness of geological hazards.

5. Conclusion

Geological disasters normally result in significant hazards, affecting both the natural environment and the safety of human life and property. Geological hazards are divided into various types according to their causes, mechanisms, and properties. The different causes and contributing factors result in distinctly differentiated characteristics. Hence each geological hazard is dealt with differently. Depending on the diversity of the scale, type, and extent of geological hazards, people choose the corresponding means of measures to monitor and prevent them.

This paper focuses on two geological disasters, landslides and debris flows, which are different in character but related in nature, and are highly prevalent in the mountainous regions of China.

The main causal mechanisms of landslide hazards include geological conditions, climatic conditions, and induced conditions. The triggering conditions are divided into two main categories: geodynamic and anthropogenic influences. Monitoring methods are divided into two main types: manual macro-monitoring and electronic monitoring, with instrumentation more accurately monitoring deformation and changes in water volume. Prevention and management mainly include the prevention and control of the natural environment, such as improving the geohydrological conditions to stabilize the mechanical balance and regulating and restricting human production and living activities.

The main causal mechanisms of debris flow hazards include three factors: geological conditions, physical conditions, and water conditions, and correspond to three monitoring and management methods. Monitoring of debris flows includes mud level monitoring, rainfall monitoring, and other monitoring such as infrasound monitoring. Management focuses on the joint management of both solid and water sources, with particular attention to early prevention and control of special hazard-prone areas.

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