Journal of Nepal Geological Society, 2000, Vol. 22, pp. 387–392

Geological hazards and their control in China

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ABSTRACT

The paper describes the main types of geological hazard and associated risk in China. The engineering geological achievements and problems are also discussed together with the developing trends and strategies for controlling the geological hazards within the next 10 years. The paper summarises the mechanism of failure of mass movements in China as well as the various combinations of engineering geological and geotechnical measures for controlling different types of geological hazard. A good hazard monitoring system (which is made up of three types of monitoring method) and efficient administrative arrangements are stressed.

CHARACTERISTICS OF GEOLOGICAL HAZARD IN CHINA

The natural hazards caused by geological processes are quite severe and frequent in China. There are more than 20 types of geological hazard in the mainland of China (Table 1). Nowadays, the human activity is intensifying or inducing these hazards. The geological hazards are becoming one of the major issues in land use planning, construction, and safety of human life and property. The economic losses by main geological disasters in China are summarised in Table 2.

Earthquake is the most severe geological hazard induced by natural and human activities. The State Seismology Bureau of China carries out the research and monitoring of it. Ground fissure is also quite severe hazard to cities. Thousands of large ground fissures have been investigated in over 200 Chinese cities or towns. Typically in Xi'an, an ancient capital of China, 11 ground fissures are still active and bring significant economic losses every year.

Rockfall, landslide, and debris flow are distributed mainly in Northwest and Southwest China. The hazards are frequent and severe, thousands of rockfall, landslides, and debris flows are induced by the heavy rain and improper human activity every year. For example, on 3 June 1980, the Yancihe rockfall, which was induced by mining activities, killed 234 people. On 17 August 1982, the Jipazhi Landslide, which was induced by a heavy rain, disrupted the navigation in the Yangtze River and it cost US$ 8 million to maintain it. On 7 March 1983, the Salashan loess landslide induced by irrigation buried 3 villages and killed 237 people. Land subsidence has caused severe damage in Shanghai, Tianjin, Changzhou, Suzhou, Wuxi, Ningbo, and other 40 cities.

Karst collapse causes losses of people's life and property. The Tai'an karst collapse (1987, the Shandong Province) and the Wafangdian karst collapse (1987, the Dalian City) disrupted the railway. The Lujiajie karst collapse (May 1988, Wuhan) destroyed 11 houses. The Mahu land collapse in the karst area (6 January 1996, the Jiujiang City of the Jiangxi Province) buried more than 10 houses and killed 23 people.

Table 1: Main types of geological hazard in China

Category	Subcategory
Earthquake	Natural and man-induced earthquakes
Slope movement	Landslide, rockfall, debris flow
Ground deformation	Land subsidence, land collapse, ground fissures
Land degradation	Land erosion, land desertification, salinisation and water-logging
Oceanic disasters	Rising of sea level, seashore erosion, seawater intrusion, tsunami, submarine slide
Special soil disasters	Loess collapse, expansive soil, quick clay, soft soil, liquefaction of soil, and ground freezing
Anomaly of water environment (lake, reservoir)	Siltation, bank failure, seepage, trigger of earthquake
Underground mining disasters	Water burst, mud burst, bottom squeezing, rock burst, gas burst

Table 2: Direct economic losses from geological disasters in China (modified after Duan and Luo 1993)

Type	Annual economic losses (million US dollars)
Earthquake	125
Slope movement (landslide, rockfall, debris flow)	450
Land subsidence	12.5
Land collapse	55
Ground fissure	5
Gas burst in mines	1.25
Water burst in mines	37.5
Seawater intrusion in aquifers	30

Loess, frozen ground, expansive soil and the like have a wide distribution in China. For example, 90% of buildings were damaged in the Yun County (the Hubei Province) due to swelling of the expansive soil. The expansive soil is also the big hurdle to the railway (founded in 1996) from the Kunming City to the Nanning City. The loess and frozen areas not only are prone to sliding but also pose difficulties in excavating foundations.

The geological hazards are closely related to human activities. With the economic development and urbanisation, a large number of construction works were undertaken, and the geological hazards induced by human activities increased rapidly. The amount of geological hazards in 1980s–1990s is more than two times the amount in 1960s–1970s.

ACHIEVEMENTS OF GEOLOGICAL HAZARD CONTROL IN CHINA

The Chinese government emphasises the geological environment protection and geological hazard prevention. Some remarkable achievements in the field of geological environment protection and geological hazard prevention have been made in the last 20 years.

Achievements of investigation and theoretical studies

The main activities undertaken were: investigation of geological hazard-prone areas including the survey, assessment, monitoring, and forecasting of geological hazards in major economic and industrial zones, main traffic routes, major rivers, important sites, and other regions; conducting the research in geological environment protection and geological hazard prevention; compilation and publication of a series of environmental geological maps and geological hazard maps (1:500,000 – 1:6,000,000) of China as well as each province; publication of the geological hazard control atlas (1:10,000 – 1:100,000) as well as the landslide and avalanche atlas of the Three Gorges area of the Yangtze River, and other important areas; and the assessment of the legislative aspect of the geological hazard management in the nation and each province.

The methods of environmental geo-engineering for controlling the geological hazards have evolved gradually. The prevention and control of geological hazards should be carried out by studying the mechanism of failure, mastering key factors and causes, and applying suitable measures and methods. The prevention and control measures are effective only when the environmental protection is taken into consideration.

Raising the ability of monitoring, prediction, and control of geological hazards

There is a nationwide geological environmental monitoring network (groundwater monitoring network and the monitoring stations for some major geological hazards), which consists of 1 state centre and 29 provincial general stations. There are 20,738 spots for groundwater monitoring, of which 1,422 are the state-level ones. From these stations, it is possible to monitor the groundwater regime and the tendency of some geological hazards.

There are many engineering projects for controlling the main geological hazards. More than 70 projects for controlling the main geological hazards have been funded by the central government since 1994. For example, the control of the Lianziya dangerous rock mass and the Huanglashi Landslides in the Three Gorges of the Yangtze River has already been carried out successfully, and it guarantees the safe navigation and construction of the Three Gorges Project. The Jipazi Landslide, which occurred on 18 July 1982, is located on the left bank of the Yangtze River in the Yunyang County of the Chongqing City. The activities included the draining out of water from the sliding body and installing a monitoring network for controlling the landslide and assuring safe navigation in the river. The ratio of total project cost to the economic benefits from this project is in the order of 1:10 – 1:20.

As a result of the successful prediction of the Xintan Landslide on 12 June 1985 in the Zigui County of the Hubei Province, all the 1,317 people from the town were evacuated to the safe place and could avoid the disaster. The Yuantaishan Landslide (July 1991, the Jiangsu Province) was very successfully predicted and all the 133 people were evacuated to the safe place three hours earlier the disaster took place. The successful prediction of the Huangchi Landslide (June 1996, the Lanzou City of the Gansu Province) saved the life of hundreds of people.

Since 1991, the Ministry of Land and Resources (formerly, the Ministry of Geology and Mineral Resources) has been strengthening the monitoring and forecasting system of natural disasters in the rainy season. For example, in the rainy season of 1998, forty-eight landslides were successfully monitored and forecasted, and more than 4,300 people were rescued.

The risk assessment and control plan of the geological hazards in the entire Beijing City were accomplished in 1994. These works have played a vital role in decision-making for geological hazard mitigation in Beijing.

In Shanghai and Tianjin, the rate of land subsidence has decreased from more than 50 mm/year to less than 10 mm/year by limiting and adjusting the groundwater withdrawal.

Methodology and technology on survey, monitoring, forecasting, and prevention of geological hazards have been worked out. At present, various kinds of monitoring and forecast instruments, such as the telemetric monitoring and warning system of landslide, the auto warning system of rockfall and debris flow, and the warning system of land subsidence and ground fissure are developed.

Setting up the administration system frame

The Ministry of Land and Resources is responsible for monitoring, assessment, and management of geological environment protection and geological hazard control. The three-class management structure (i.e., state-, province-, and county-level) has been created. Besides the earthquakes, in which the State Seismology Bureau of China undertakes the research and monitoring, the Ministry of Land and Resources undertakes the administration of geological hazards (especially, landslide, rockfall, debris flow, land collapse, land subsidence, ground fissure, and sea water intrusion in the aquifer of coastal areas).

The regulations of geological environment protection and geological hazard control are being formulated. Some concerned national laws and regulations have been validated and carried out. The Ministry of Land and Resources issued the special national regulations of geological hazard control on 6 March 1999. Local laws and regulations are also operating in some provinces.

Other activities undertaken are: raising community awareness of hazard reduction, educating, and popularising the geological environment protection and geological hazard control through all other possible means. The China Association of Geological Hazards and Research has been founded for promoting the academic exchange, awareness creating, training, and consulting services.

DEVELOPING TRENDS AND STRATEGIES FOR MITIGATION OF GEOLOGICAL HAZARDS

Although China has made a significant success in geological environment monitoring and mitigation of geological hazards, there are still many problems to be solved. The most important four tasks to be carried out within this decade are the following:

- to continue disseminating scientific knowledge and technical know-how of geological environment protection and geological hazard mitigation, and to raise the community awareness;
- to establish and extend the monitoring and forecasting system and information database;
- to establish a unified system of geological environment management and work out an efficient plan for geological environment protection and geological hazard mitigation; and
- to reinforce the legal aspect of geological hazard control, improve the education system, and strengthen the administration and management.

The research on geological hazards in China

There are various types of research being carried out in China for the mitigation and control of geological hazards. Some of the important ones are described below.

Research on the role of groundwater in triggering geological hazards

Many geological hazards are associated with the effect of water. Some of them are: landslides caused by infiltration of precipitation, mass movements related to surface runoff and water storage in a reservoir, land collapse in karst areas due to overdraft, land subsidence caused by overdraft, and foundation subsidence caused by soil liquefaction. All these are closely related to groundwater. The adverse impact of groundwater on rock or soil leads to the deformation and destruction of the rock or soil mass. Therefore, it is an urgent task to strengthen the research on the groundwater effect.

Dynamics of geological hazards

The investigation of geological hazards should include the human beings and geological environment, and the complexity of this geological environment should also be considered. Only then, the failure mechanism and development process of geological hazards can be mastered. The research should include diversified techniques and findings from various disciplines. The latest achievements of non-linear sciences are used to reveal the mechanism of failure, kinematics, and dynamics of geological hazards.

Engineering and technological research on the control of geological hazards

On the basis of the research on mechanism of failure and kinematics of geological hazards, the research on engineering and technology for the control of different kinds of geological hazard should be undertaken. The studies on surface and subsurface drainage techniques should be emphasised for the control of a large-scale landslide triggered by precipitation. Some other large-scale geological hazards, such as silting at the outlet of Yangtze River and the suspended load in the Yellow River, need the research on a set of engineering and administrative measures. The effective control of any geological hazard is possible only by integrating such various measures (Fig. 1).

Investigation and zonation of geological hazards in China

The investigation of geological hazards consists of the status recognition, the prediction of the trend, and its risk assessment. The dangerous region can be drawn out on a risk map by integrating the research on the mechanism of geological hazards and prediction of other environmental conditions (such as precipitation, river variations, earthquake, and large human engineering activities). A plan for mitigation of geological hazards should also be prepared for each geological hazard-prone area or special region (urban area, industrial area, large-scale construction site etc). All types of information on investigation and planning should be stored in a database and linked to the public information system.

Monitoring, forecasting, and information system of geological hazards

Monitoring is the basis for controlling the geological hazards. It is also indispensable for acquiring dynamic data in the whole process of occurrence and development of geological hazards, their exploration, and design and construction of mitigation measures. The monitoring system consists of three types of method: simple observation of surface deformations, ground instrumental monitoring, and spatial remote sensing coupled with the nationwide groundwater monitoring network of China.

Direct observation of surface macro deformations

The development of geological hazards will surely be accompanied by associated changes in the landscape, displacement of the ground, and alteration in hydrodynamic regime. Although the indications of geological hazards are diversified and complicated, there is still some regularity. A large number of observations and analyses are needed to discriminate macro deformation traces. That is why the veteran geologists always emphasise that the field geological investigation is the basis of geological work. For example, during the formation of landslides, the tension cracks have different indications, that is, arc-shaped tension cracks occur near the crown of the landslides, and swelling mounds and transverse cracks are present near the toe. The observation of groundwater can reveal the state of landslide (Schuster 1978, Wang and Du 1996). Other geological hazards, such as an earthquake and karst collapse, also have their indicators in the field.

Ground instrument monitoring

Ground instrument monitoring includes surface displacement monitoring, subsurface displacement monitoring (displacement monitoring in underground tunnel and drill hole inclinometer monitoring), groundwater monitoring, and physical monitoring (such as sonic ejection, electromagnetic monitoring, and monitoring of earth stress). A rational integration of the monitoring network in terms of specific geological hazards can effectively capture the dynamic information and mechanism of failure. Sonic ejection

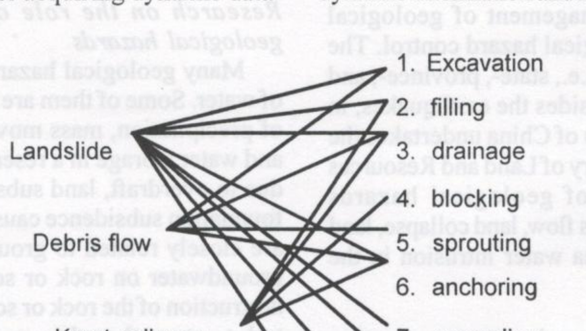

Fig. 1: The main types of geological hazard and their control measures (Modified after Hu 1993)

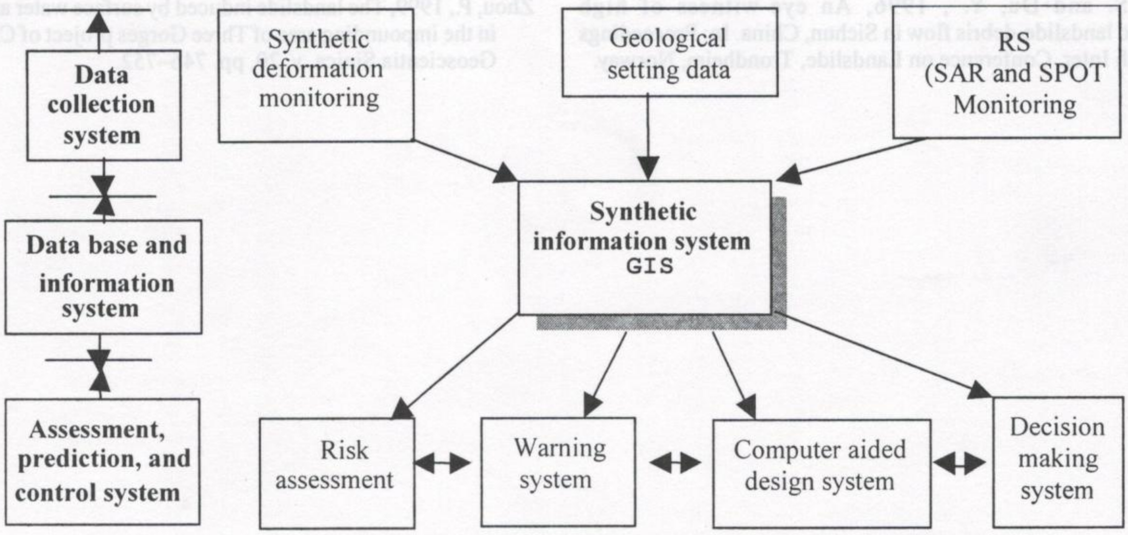

Fig. 2: Geological hazard warning systems in the impounding area of the Three Gorges Project (Modified after Zhou 1999)

information and other physical variations can also be helpful in distinguishing the state of landslides.

Remote sensing, real-time monitoring, and warning systems

Remote Sensing (RS), Geographic Information System (GIS), and Global Positioning System (GPS) can be integrated to monitor landslides, land subsidence, and other natural disasters. During the next ten years, a specialised system of real-time monitoring and appraisal of geological hazards will be created in China. This system is highly effective for the real-time monitoring of the collapse, landslide, debris flow and land subsidence, flood, and drought. A combination of remote sensing data, telemetric information, and computer-based automatic control techniques will realise the three-dimensional data collection, their integration, and processing. Hence, the dynamics of a disaster can be assessed instantaneously and used to forecast the geological hazards. The self-adaptive discrimination models, artificial neural net methods, digital modelling, and GIS techniques are effective to set up a real-time prediction model of the geological hazards, and need to be further studied. Fig. 2 is the example of a real-time monitoring and warning system. Such systems will be located in the urban area of Shanghai (mainly for land subsidence) and in the impounding area of the Three Gorges Project (mainly for slope movement).

Administration system, policies, standardisation, laws, and regulations

The administration for the control of geological hazards in China needs to be strengthened. Firstly, the scope of work and fund source should be specified for the prevention and control of geological hazards. Secondly, standardisation is needed. For the prevention and control of specific geological hazards, it is required to work out a standard procedure of survey, design, construction, and monitoring. Thirdly, the prevention and control of geological hazards should be carried out in accordance with strict regulations and bylaws. For the sustainable economic development of a region, specific administrative policies should be formulated for the mitigation of each type of geological hazard.

CONCLUSIONS

Geological hazards can be regarded as a negative effect of the geological environment, while rational development and utilisation of resources is regarded as positive effect of the latter. The occurrence and development of natural geological hazards usually do not depend upon human wills, but those man-made geological hazards are usually related to improper human activities. Excessive exploitation of resources brings about serious consequences; for example, uncontrolled mining of underground deposits results in land collapse, excessive exploitation of groundwater results in land subsidence. In order to prevent the man-made geological hazards, the human activities have to be scientifically regulated and abided with the law of natural development, otherwise the nature will punish the human beings.

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