Landslide hazard early warning system in China and future trends

PINGGEN ZHOU[1] & LEIHUA YAO[2]

[1]China Institute of Geo-Environmental Monitoring, Ministry of Land and Resources. (e-mail: zhoupg@mail.cigem.gov.cn)
[2] Engineering Faculty, China University of Geosciences. (e-mail: Yaolh@263.net)

Abstract: The China Geological Hazard Information System, is a GIS which provides users with a menu interface (in Chinese) and includes 'hazard database management' and the GIS-based management of stored hazard information. The 'hazard database management' allows data input, maintenance and query of seven different databases and the production of related outputs. The databases comprise: landslides; land subsidence; debris flow; ground fissuring; land collapse in karst areas; land subsidence induced by ground water pumping and mining; and, sea water intrusion in coastal areas. For GIS-based management of hazard information, the spatial location of the seven different types of hazard can be displayed and interrogated through the GIS software. The connected databases can also be amended and the hazards graded. Associated attributes of each hazard can be conveniently displayed and related geological hazards displayed in an overlapping way to allow analysis. MS Visual Basic 6.0 and MS Visual FoxPro 6.0 are used as the system's development language and ArcView3.2, as the GIS system platform for display and management.

Résumé: Cet article décrit la manière dont les autorités chinoises organisent la prévention des glissements de terrain, et la construction d'un système d'alerte prévisionnel qui intervient dans les tous premiers moment du désastre. Ces dernières années, les chinois ont affronté le problème des glissements de terrain en développant prévention et contrôle à travers un système de « prévention à priori ». Ils ont construit un « early warning system » basé sur des investigations et des zoning sur des zones touchées par des glissements. Ce système permet d'intervenir dans la toute première phase du glissement, et a prouvé son efficacité, par la réduction des pertes et des dommages économiques.

Keywords: landslides, geological hazards, monitoring, database systems, geographic information systems

INTRODUCTION

At present, the international community has attached great importance to building capacity for the early warning and prevention and control of landslide hazards. Landslide hazard early warning systems mainly include; the long term early warning of geological hazards, based on regional landslide hazard assessment and the zoning of landslide hazard risk; medium-term early warning, based on information on landslide hazard monitoring; and, short-term early warning based on real time, automatic remote control and remote monitoring information (Hamilton et al 1997; Turner & Schuster 1996).

In recent years, a unique landslide hazard prevention and control system has been gradually established and popularized in China through the implementation of the principle of "focusing on early warning and integrating the prevention and control of the landslide hazard". The core to this is an early warning system, which includes the investigation and zoning of landslide hazards in the landslide prone area, geological hazard (mainly landslide) risk assessment for construction sites and, landslide hazard monitoring and early warning. The building of such an early warning system has reduced casualties and the economic loss caused by geological hazards across China.

CURRENT STATUS OF LANDSLIDE HAZARD IN CHINA

Landslide hazard is one of the most severe hazards affecting life and property in China. According to the Ministry of Land and Resources, in recent years, the number of casualties affected by rockfalls, landslides and debris flows reached about 1000 each year, with thousands of million Yuan economic loss (Figures 1 & 2). In 2002, 853 people died, 109 were missing and 1797 injured due to landslides, with a direct economic loss of some US$510 million.

Since the 1990s, China has successfully forecast landslides in Yuntai Mountain, Zhenjiang, Jiangsu (9.7.1991), Huangci Village, Yongjing, Gansu (31.1.1995) and Jiaojia Carbonization Plant, Yongjing, Gansu (6.2.1996) etc. Since 1998, with the implementation of a geological hazard early warning project at the National Land Resource Centre, the enhanced prevention and management of geological hazards, the national geological hazard monitoring network (combining professional check and mass monitoring) and disaster prevention has been established, which has shown obvious social and economic benefit. On June 20th 2002, a large-scale mountain landslide took place in Litai Village, Longche Countryside, Naxi District, Luzhou City, Sichuan, where the landslide mass was 1200m long and 2100m wide, damaging an area $3km^2$. Thanks to the establishment of a mass monitoring and disaster prevention network, monitoring and forecast of the hazard was timely and proper measures were taken to treat the hazard immediately after its occurrence, thus avoiding over 600 casualties.

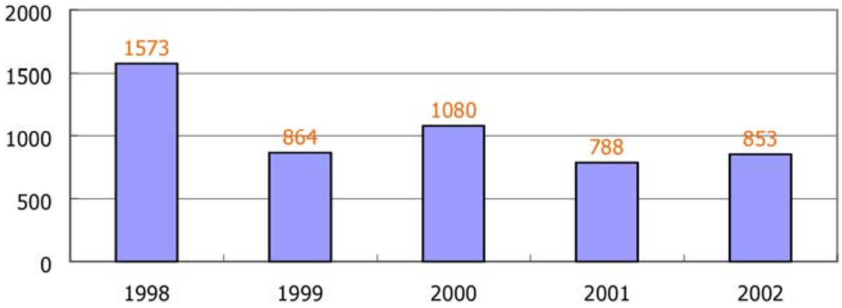

Figure 1 Death toll due to landslides in China 1998 to 2002

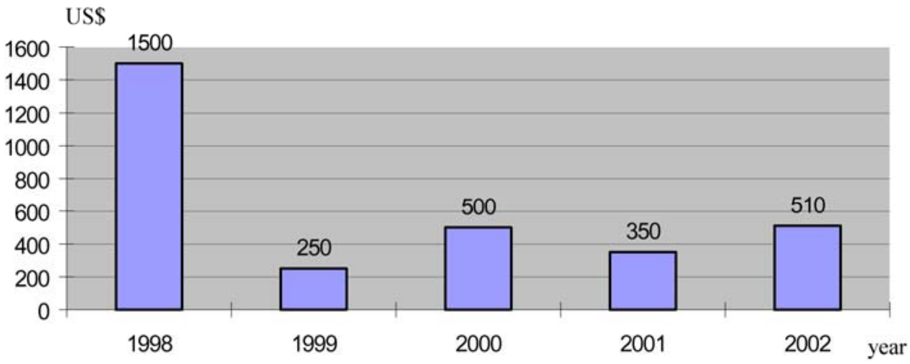

Figure 2 Direct economic loss due to landslides in China 1998 to 2002 (in millions US$)

CREATING AN EARLY WARNING SYSTEM IN CHINA

To conduct landslide disaster investigation and mapping in landslide-prone cities and counties

It is a long-term task to carry out landslide disaster investigation and mapping in landslide-prone cities and counties. By the end of 2004, more than 600 cities and counties in mountainous areas of China have completed landslide disaster investigation and mapping (scale: 1:100,000) and set up corresponding information systems and simple monitoring and disaster prevention networks for residents. Specifically this includes:

- Identifying landslide prone areas. Investigating potential landslide locations within cities, towns, factories and mines, villages (including remote residential settlements), important transportation mainlines, engineering infrastructure and giving a primary assessment of their stability and hazard. Investigating disaster areas inflicted by landslides, landfalls and debris flows. Finding out the relative distribution, scale, structural features, affecting factors and inducing factors and assessing their revival possibility and hazard.
- Assisting the local government in setting up a simple monitoring and disaster prevention network against landslide disasters for the residents and working out disaster precautionary plans for important potential landslide spots.
- Educating relative personnel within the mentioned counties (cities) on landslide disaster mitigation knowledge and, based on investigation results, direct monitoring and warning work against geological hazards.
- Assisting the local government in working out prevention and management plans against landslide disasters.
- Setting up information systems on landslide disasters based on a county (city) as a single unit.

Applying landslide-dominated geological hazard assessment to construction and land development sites.

On November 1st, 1999, the Ministry of Land and Resources issued its {1999}392 declaration, requiring an assessment of geological hazard for development land in landslide prone areas. This means that geological hazard assessment is required during the site-selection phase of urban construction projects, construction projects in landslide and other geological hazards prone areas, as well as engineering and construction projects likely to induce geological hazards. Geological hazard assessment on construction land covers disasters including: rockfalls, landslides, debris flows, land collapse, ground fissures, land subsidence and so on. The area under this assessment shall not be limited to just the area of construction land, it shall be determined by the characteristics of the construction project and its geological conditions. If the hazards are within the construction site, then the assessment may only cover the construction site. However, if the sources or influences of hazards are beyond the construction site, then the scope of assessment shall be properly expanded according to the category and features of the geological hazard. Geological hazard assessment should also consider the possibility that construction may induce or aggravate existing geological hazards. It should also consider the hazard that the project construction could be inflicted by geological hazards and appropriate precautionary plans. Geological hazard assessment shall be divided into three categories (Category I Assessment, Category II Assessment, Category III Assessment) according to the complexity of geological conditions and importance of the construction projects. As to linear or large-area projects, emphasis shall be placed on geological hazard prone areas and dangerous areas, as well as individual locations with serious geological hazards.

Construction of a monitoring network for landside disasters

On June 26th 2002, the Tibet Geo-Environment Monitoring Centre was set up in Lhasa, establishing 31 provincial geo-environment monitoring institutions in all the provinces, national municipalities and autonomous regions in China. Now throughout the country, a national geo-environment monitoring network has come into being, made up of 31 provincial geo-environment monitoring centres and 217 regional (city) geo-environment monitoring stations. Professional monitoring of landslide disasters throughout the country and the direction of simple monitoring and disaster prevention work for residents in landslide prone areas, have been progressing on the basis of this network.

In the Three Gorges Reservoir Area, landslide disaster monitoring has been conducted in important cities and landslide prone areas.

In the Three Gorges Reservoir Area of the Yangtze River, the government has: set up a landslide disaster monitoring centre; a GPS monitoring network of the reservoir area; more than 100 landslide monitoring stations; selected more than 1000 landslide spots to build up simple monitoring and disaster prevention networks for local residents; and, trained more than 800 amateur surveyors, which together with professionals, form a precautionary system, operated and managed by county, town and village institutions. Multiple parameter-and-dimensional monitoring systems have been set up on important landslide spots, such as the Lianziya hazardous rock mass, the Huanglashi landslide, the Huangtupo landslide and the Baota landslide etc. Especially on the Lianziya hazardous rock mass by Yangtze River, different kinds of monitoring apparatus are systematically installed, to which functions directly send data to computers. Relative databases and survey and forecast software are also developed, forming a survey and forecast system in combination with hardware and software. For the Ya'an Gap landslide in Sichuan Province, a survey and forecast demonstration has been conducted, with the establishment of a multi-parameter monitoring system, including ground displacement survey, underground displacement survey, ground fissure survey, underground water survey and rainstorm survey - employing new technologies and methods, including GPS, GIS and automatic monitoring technology.

Regional forecast and warning on landslides induced by rainstorms

Based on landslide disaster investigation and hazard assessments (1:100,000) in cities and counties carried out since 2003, various geo-environment monitoring institutions have cooperated with meteorological centres in conducting statistical studies on the relationship between rainfall and subsequent landslides to establish a judgement basis and statistical forecast model for rainfall induced landslides. They also cooperate in conducting regional forecast and warning on landslides induced by rainstorms. The meteorological centre transmits rainstorm forecast data to the landslide disaster forecast and warning centre (including the China Institute of Geo-Environmental Monitoring and all the provincial geo-monitoring centres), and the latter produces regional forecasts and warning graphs for landslides induced by rainstorms which are published on websites and broadcast on TV. At present, most provinces (national municipalities and autonomous regions) in China have conducted regional forecasts and warnings on landslide induced by rainstorms, duly reminding the residents and local governments as a result. Unfortunately, a lack of precision in terms of surveys and insufficient rainfall auto-monitoring stations have affected the accuracy of the forecast and warning work.

PROSPECTS FOR CREATING GEOLOGICAL HAZARD EARLY WARNING SYSTEMS

The trend for the creation and development of a landslide hazard early warning system

Landslide risk assessment and integrated disaster mitigation technologies

As a means of long-term warning, the risk assessment of geological hazards cannot yield a specific time when a particular disaster could happen, but with the results of hazard and risk assessment, we can mitigate geological hazards by engineering measures and administrative measures, such as mapping and land use planning (Bernknopf et al 1988). Now, risk assessment and integrated disaster mitigation technologies in China have taken on many important changes, including: (1) attaching great importance to integrated studies on regional and urban multi-category disasters while continuing to strengthen single-category disaster studies; (2) stressing studies on the social attributes of disasters while continuing to strengthening studies on natural attributes of disasters; (3) that disaster mitigation work has transited from passive emergency disaster relief into active disaster prevention, with systematic disaster mitigation measures including disaster surveys, reports, preventions, counter-actions, reliefs and financing construction projects, and that at the same time, the nation has done a lot in establishing integrated disaster information systems, making disaster mitigation planning, conducting integrated disaster forecasts and setting up integrated disaster mitigation demonstrative areas. However, compared with developed countries, our disaster mitigation still has a long way to go in extent, profundity and applicability.

Geological hazard monitoring and survey technologies and methods

Landslide monitoring and survey technologies and methods have much developed globally. They have developed from the manual survey towards a trend for automatic and high-precision telemetry systems. The survey apparatus is now highly precise, of good quality, with wide applications, abundant survey content and highly automated (Lahusen 1996; Reid & Lahusen 1998). In recent years, with the development of electro-photographic laser technology and computer technology, various advanced high-precision electro-theodolite and laser telemeters have come out successively, serving as effective new means for landslide survey. At present, most landfall and landslide survey apparatus widely used in China are contact-style, generally with poor applicability due to their universal defects of low precision, poor auto-memory, non-automatic data transmission or short transmission distance. They are also vulnerable to disturbance by artificial factors and meteorological and climatic abnormities. As apparatus installation, survey and data processing are time and energy consuming, China has only established real-time survey systems on a few landslide sites.

Landslide disaster forecast and warning technologies and methods

The forecast and warning methodology studies, at home and abroad, are concentrated on the following methods: (1) phenomenon forecast method on landslide transformation auspices; (2) S-T curve variety trend judging method; (3) Saito method and upgraded Saito method (Saito 1965); (4) statistical mathematical model method; (5) golden section method; (6) non-linear dynamic model forecast method; (7) rainfall parameter forecast method (Keefer et al 1987); (8) acoustic emission parameter forecast method; and, (9) multi-parameter forecast method. Over recent years, landslide forecast and warning studies, at home and abroad, have flourished a lot, but since the ‘Saito method’, born in 1965, such forecasting studies have made little progress. As for the effects of the methods; methods (1), (2) and (3) have contributed to the successful forecast before a landslide happens; methods (4), (5) and (6) all verify landslides after it happens, so they are difficult to conclude their true usefulness. The other methods are still under investigation. This shows that; current studies are dominated by qualitative or semi-quantitative forecasting, mainly based on geological analysis and judgment by experience; and, trend pattern quantitative forecasting, based on survey data. Landslide forecast and warning studies, at home and abroad, are mainly oriented to quantitative landslide forecasting and warning theories based on qualitative geological analysis and actual survey. As the geological process of a landslide is complex, the various endangering conditions and inducing factors, as well as random and unstable changes and dynamic information on landslide changes, are difficult to capture. Furthermore, current dynamic survey technology on landslides is not mature and landslide theories are not perfect, consequently, landslide survey and forecasting has to be regarded as a very difficult frontier theme.

Planned studies on key technologies for landslide disaster early warning

Application of remote sensing technology

For large-scale landslide disaster monitoring applications on important projects, in important regions and the detections of regional landslides, it is planned to use high-resolution remote sensing images, combined with ground surveys, to conduct landslide disaster investigation and hazard assessment (scale: 1:50,000) in landslide prone areas.

Automatic landslide monitoring and survey technology as well as mid-term and short-term forecast technology studies

It is planned to establish automatic landslide monitoring and survey system based on multiple parameters. Besides typical survey parameters, methods such as infrared and laser locating three-dimensional survey and photographic image analysis survey are employed to survey micro-motions of landslides on the ground. Methods such as seepage deformation propagation and deep displacement acoustic transmission surveys in boreholes provide important parameters for judging the situation of a landslide deep underground. It is also planned to study basic characteristics, structures and critical information of typical landslide disasters, to conduct simulation experiment studies on formation and development process of typical landslide disasters and to develop mid-term and short-term landslide survey technologies and methods based on GIS information and AI technologies.

Regional forecast and warning on landslides induced by rainstorms

Based on regional landslide disaster investigation and hazard assessment (scale: 1:50,000), it is planned to improve the landslide-related rainfall criterion and forecast model and to enhance space precision and time accuracy of regional forecast and warning on landslides induced by rainstorms by adding automatic rainfall survey apparatus and conducting profound studies on the relationship between rainfall and the subsequent landslide.

GIS-based landslide disaster risk assessment technologies and integrated geological hazard information management and decision-making supporting systems

Based on 3S technology, it is planned to develop a geological hazard data collection, through cataloguing, data storage and database technological modules and therefore build up an integrated technological platform for information management. This will help establish a geological hazard integrated information management centre, to study and develop geological hazard numerical and physical simulation technology, to develop geological hazard surveys, dangerous area mapping and risk assessment technological modules and to conduct studies on geological hazard prevention and also harness auxiliary decision-making modules.

Corresponding author: Dr Pinggen Zhou, China Institute of Geo-Environmental Monitoring, Ministry of Land and Resources, No.20 Dahuisi Street, Haidian Distrct, Beijing, 100081, China. Tel: +86 10 62179926. Email: zhoupg@mail.cigem.gov.cn.

REFERENCES

TURNER, A.K. & SCHUSTER, R.L. 1996. *Landslides: Investigations and Mitigation.* Transportation Research Board, Special Report 247.

BERNKNOPF, R.L., CAMPBELL, R.H., BROOKSHIRE, D.S. & SHAPIRO, C.D. 1988. A probabilistic approach to landslide hazard mapping in Cincinnati, Ohio, with applications for economic evaluation. *Bulletin of the Association of Engineering Geologists*. **25**(1) 39-56.

KEEFER, D.K, WILSON, R.C., MARK, R.K., BRABB, E.E., BROWN, W.M., ELLEN, S.D., HARP, E.L., WIECZOREK, G.F., ALGER, C.S. & ZATKIN, R.S.1987. Real-time landslide warning system during heavy rainfall. *Science*. 238 (4829), 921-925.

LAHUSEN, R.G. 1996. *Detecting debris flows using ground vibrations*. U.S. Geological Survey Fact Sheet. 236-96.

REID, M.E. & LAHUSEN, R.G.1998. *Real-time monitoring of active landslides along Highway 50, El Dorado County.* California Geology.

HAMILTON, R & OTHERS. 1997. *Report on early warning capabilities for geological hazards.* IDNDR Scientific and Technical Committee, Washington, D.C. USA. IDNDR Secretariat, Geneva **51**(3), 17-20.

SAITO, M. 1965. Forecasting the time of occurrence of slope failure. *Proceedings of 6th International Congress of Soil Mechanics and Foundation Engineering, Montreal*. **2**, 537-541.