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THEMATIC ISSUE

Glass landslide: the 3D visualization makes study of landslide transparent and virtualized

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Abstract As the global research topic, geological disasters have led to huge losses around the world yearly. In this paper, three-dimensional (3D) visualization is used as a technical method to build the 3D geological model of the HuangTuPo (HTP) landslide, and the 3D model of large field test base located in the HTP landslide, and the 3D regional geological model. These models make the landslide research digitized and transparent. Meanwhile, the preliminary studies were carried out: the comprehensive utilization of multiple scales and multiple categories of data—by "Double Center", and the 3D data integration from region to point of disasters—by the component technology, and the transparent design and construction of disaster research—by 3D model shearing. Through these methods, the surface topography and the underground geological structure of landslide can be displayed as transparent as glass, and the virtual simulation on the results of underground engineering can be carried out in advance, providing guidance for engineering design and construction.

Keywords Geological disaster · Three-dimensional (3D) visualization · Glass landslide · Aided design · Virtual construction

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Introduction

The brief introduction of HuangTuPo (HTP) landslide

HTP landslide is located in Badong County of the Three Gorges Reservoir Area (3GR), Hubei Province, consisting of four parts: the transformer substation landslide, horticultural field landslide, Linjiang I and II colluvial accumulation slides. HTP landslide is covered with loose soil and rock blocks, bed rock is Triassic mudstone, limestone and marlstone. HTP landslide located in the south-wing of a syncline, stratum incline to the north. The elevations of HTP landslide's front edge and the rear edge are 80 and 650 m, respectively. The HTP landslide, the largest landslide in 3GR, is 1.35 sq km in area and about 69,340,000 cubic meters in volume. It is endangering the security of the lives and property of more than 20,000 people. In 2009, Chinese government confirmed the movement and relocation program of HTP landslide, which led to the gradual emigration of over 10,000 residents.

The brief introduction of the large field test base of HTP landslide

The large field test base of HTP landslide, which started in 2009 and was completed in 2012, is one of the major items of geological hazard 985 platform (A key project in China) at China University of Geosciences (Wuhan). The large field test base of HTP landslide is composed of a main test footrill and two branch holes, all located in Linjiang I colluvial accumulation slide. The main hole is an arched hole which is 908 m long, 5 m wide and 3.5 m high. Both the two branch holes are also arched holes, about 183 m in total length, 3 m in width and 3.5 m in height, which penetrate into different parts of the main hole. Western branch hole penetrates the sliding surface, making it easier to observe the sliding surface directly, and to do monitoring tests in the large field test base.

The current status and development of the transparency research on geological disasters

The word "Glass landslide", derived from the "Glass Earth" (Hobbs 1999), refers to making the geological structure of landslide as transparent as glass by means of informatization and digitization. Based on the survey data and geological inference, the geological disasters transparency research realizes fully digitized the research object on the computer, which is a virtual three-dimensional (3D) research object. Through the virtual objects, the structure of geological disaster bodies and the spatial distribution of geological factors can be transparently observed, the physical and geological attributes of geological elements can be viewed, and processes can be done including various spatial measurement, cutting profile, virtual excavation of test cavern, volume calculation, etc.

In order to realize the transparency of geological disasters, all-round support from current information technology, for example, 3D visualization technologies, information systems technology and so on is necessary. 3D visualization technology has been thoroughly applied to all walks of life, and previous researches were done in this field by predecessors, such as Raper (1989), Li and Li (1997); Gong and Xia (1997); Xu et al. (1997); Zhang et al. (1999); Santos et al. (2000); Li (2000); Li et al. (2000); Wu et al. (2001); Pan et al. (2003); Wu and Sha (2003); Wu and Tong (2004); Orhan and Tosun (2010); Gemail (2012); Sun et al. (2012); Velasco et al. (2013); George et al. (2014); Häb et al. (2014); Lidal et al. (2014); Schimpf and Gossel (2014).

In the field of 3D information processing for geo-hazards, Chen et al. (1998) proposed to use various line signs and their combinations to generalize two types of information on rock structures and properties, establish an appropriate fitting function to achieve the 3D simulation and apply it to 3D geological structure simulation and information reproduction of the permanent ship lock slope project of the Three Gorges area. Sui et al. (2005) developed 3D visualization and analysis system TEAVIS for the Three Gorges channel, integrating services of the spatial data collection, storage, management, processing, query, analysis, and typical navigation application technologies based on GIS (Geographical Information System). Wu et al. (2006) developed Three Gorges geo-hazard survey point source information systems based on GeoView-platform. Depending on the thematic point-source survey database (attribute and space), the system combined the field data acquisition module, indoor maps assembler module and 3D visualization and analysis module. Meanwhile, according to C/S (Client/Server) and B/S (Browser/Server) binding pattern, the field data collection of the geo-hazards survey, the data consolidation and maps compiling aided by computer in the whole process were initially realized through Web. Taking Three Gorges permanent ship lock as an example, Zhai et al. (2006) described an IDL (Interactive Data Language)-based 3D modeling method, using the interface that IDL graphics object provided to create connection between the object model and the database for achieving the interactive visualization of query and the query results of data, which was a preliminary trial to the analysis of the visual query of data. Li et al. (2007) achieved the 3D digital flight simulation of the 3GR based on VR (Virtual Reality)-GIS technology, which realized the dynamic bird's eye-view of topography, physiognomy and vegetation cover and more direct, vivid and visual understanding than the two-dimensional (2-D) digital mosaic figures did. Ye et al. (2009) introduced the development of 3D visualization simulation system on flood routing of Three Gorges Reservoir, in which the flood evolution simulation was veritably and naturally, thus effectively visualized. Tian and Shen (2011) used Open Inventor to achieve the formation of ideas and technical methods of establishing 3D geo-hazards in the 3GR depending on a corner-point grid model, and applied it to 3D visual modeling of geo-hazards in the 3GR, and so on.

The difference between this paper and the researches mentioned above is: a systematic study was conducted by means of 3D transparency from points (specific disaster, such as HTP landslide) to area (geological map of regional disaster), and from overground (surface geomorphology, river system, transportation network, etc.) to underground (geological structure of disaster, spatial distribution of the geological elements, etc.). Besides, the 3D model of Linjiang I colluvial accumulation slide in HTP and the large test field was built, based on which various "transparent" simulation and analysis were carried out.

Data for this research

1. The 2D regional geological map of Zigui region in 3GR (shown in Fig. 1) is the data source and fabricating foundation for the 3D geological map.
2. The survey data of a certain landslide in 3GR is applied to building the entity 3D model of landslide in a specific region, and then integrate with the regional 3D geological surface model, in order to analyze the landslide in the model of landslide conveniently.
3. The survey data of HTP landslide in 3GR includes surface data (geological plan and surface image is shown in Fig. 2 that contains the topography, section

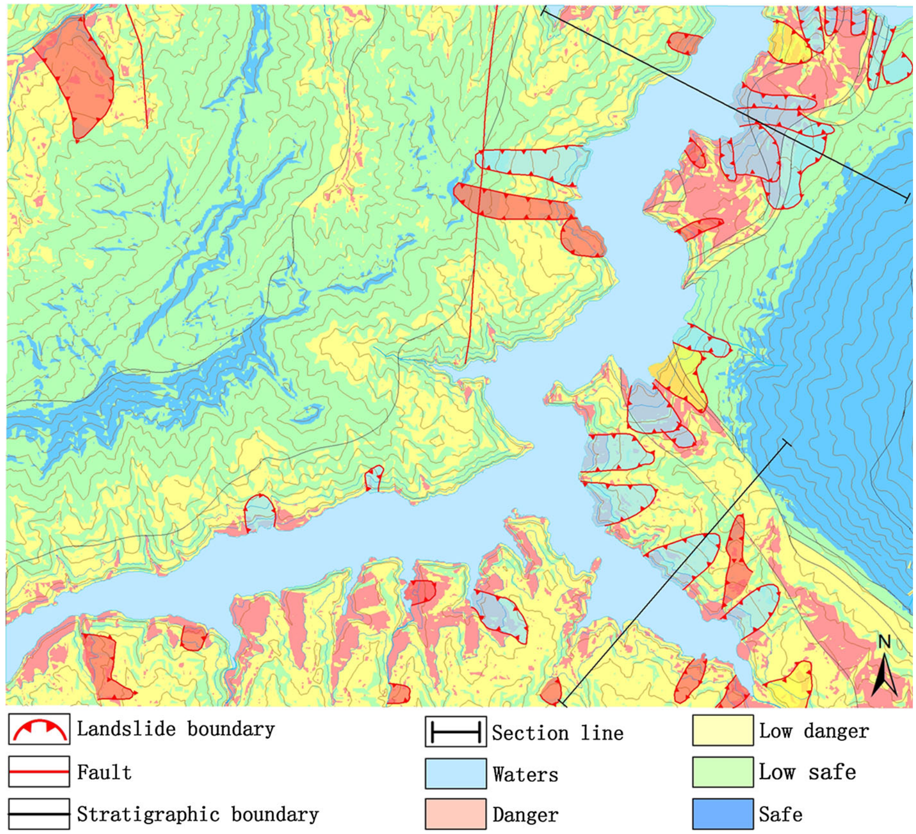


Fig. 1 A 2D geological map of a certain region at Three Gorges Reservoir Area (3GR)

layout and the large experimental hole, etc.), and the data of four sections, which are used to establish 3D entity model of HTP landslide.

4. The design data from the large experimental hole of HTP landslide are used to establish the 3D model of the large experimental hole, and integrate the tunnel model with the 3D geologic model of HTP landslide.

Methods

The research method and process are shown in Fig. 3.

First, various types of data, as shown in detail in 2 (Data for this research), were collected and arranged for the study. Data normalization is standardized extraction and processing of the collected data for 3D modeling, such as removing the unwanted ancillary data like legend and drawing frame. Database intake is the management of relevant data needed through attribute and space database, such as drilling data, geological attribute data, section data, surface and cavern image data, etc.

Data 3D change is express 2D data in 3D form, such as the 3D expression of 2D sections, proving ground (hole) 3D space exhibition, etc. 3D modeling is to establish a 3D model of the studied area, namely the virtual and digitized study object. Data integration is a process which links all disaster survey data to the 3D model as much as possible and turns the 3D model into detailed and digitized virtual body for the practical study object, such as attached geological age, geological description, depth, elevation and physical properties to the strata surface or strata body, or make the strata surface (a solid unit in space) associated with these data, for convenient call and display.

The 3D display of landslide elements is comprehensive on the aspects of space in a transparent or translucent way, which may keep out each other, in order to observe comprehensively the spatial distribution of the landslide elements. Model shear is the integration of the large-scale test site (hole) model and the 3D landslide model as a whole model, thus a variety of geological phenomena encountered, and the monitoring or testing data can be clearly displayed on the tunnel wall (shear plane).

Aided drawing is a process in which a variety of geological maps can be drawn, such as the cross-sectional view through the aid of 3D model and database. Transparentizing analysis is a variety of inquiries, statistics, analysis and calculations on the “transparent” disaster body (3D model), such as to view where the coordinate points the cavern and the slip surface meet, to analyze the spatial distribution of the slip surface, and to calculate the total or local volume of landslide, etc.

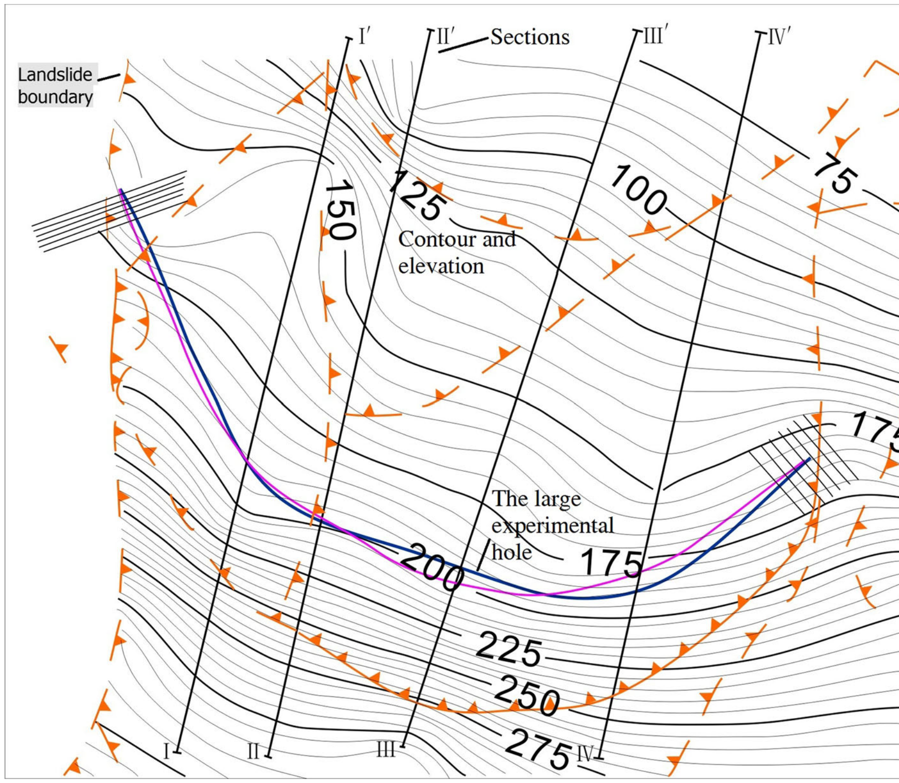


Fig. 2 The geological plan of the HTP landslide

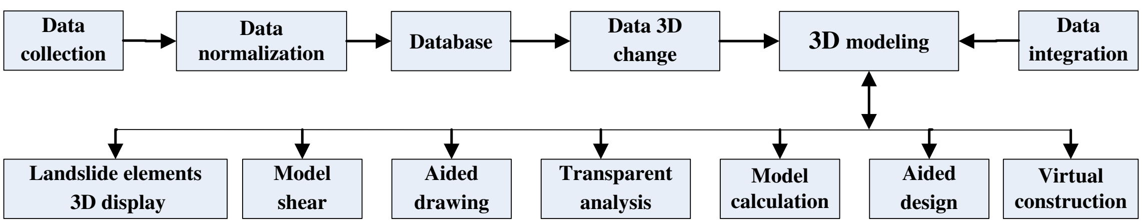


Fig. 3 The flow chart of research method

Model calculation is a variety of spatial measurements and volume statistics, such as computing the construction quantity of a certain length of the experimental hole. Aided design and virtual construction refer to carrying out the digitized previews and analysis of the design and construction in "transparent" disaster body, which is to make the design or construction programs clearer. This part of the work can be done in the 3D geological model repeatedly before design or construction, and thus the aim of aided design or virtual construction can be achieved.

Results

The 3D model of HTP landslide and the large-scale test field (tunnel) model are shown in Figs. 4, 5, 6, 7, 8.

Figure 4 is the 3D transparent display of the surface, drillings and sections of HTP landslide. The surface image is the screenshots from Google Earth, and drillings and sections are the results of three dimensionalized processing of investigation data.

Figure 5 is the established 3D model of landslide, including the 3D geological models of the landslide and the large proving ground (hole), both of which integrate together through model shear. Because the landslide has been wholly included in the model which is not set transparently, it is impossible to view the sliding surface from the side, nor can the distribution of experimental holes in the landslide be viewed.

In Fig. 6, the landslide model is sectioned at the place where the experimental hole passes through the sliding surface. On the cross-section (side section), three-layer structure of the landslide (slip mass, sliding surface, sliding bed) can be clearly seen. Compared with the whole model, the experimental holes with 5 m × 3.5 m size are displayed smaller. The left one in Fig. 7 shows the enlarged experimental hole, in which the experimental hole, slip mass, sliding surface and sliding bed could be clearly seen. The right one in Fig. 7 is

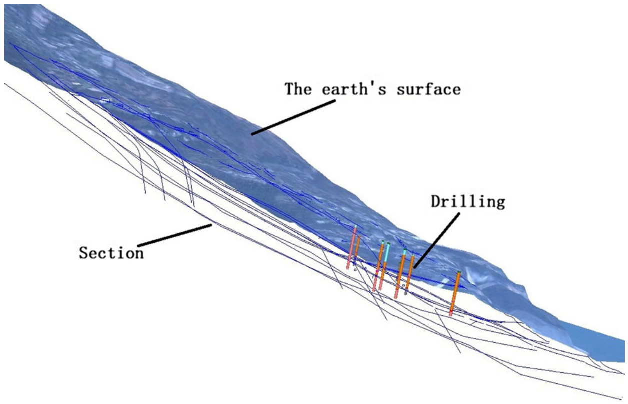


Fig. 4 The surface and sections

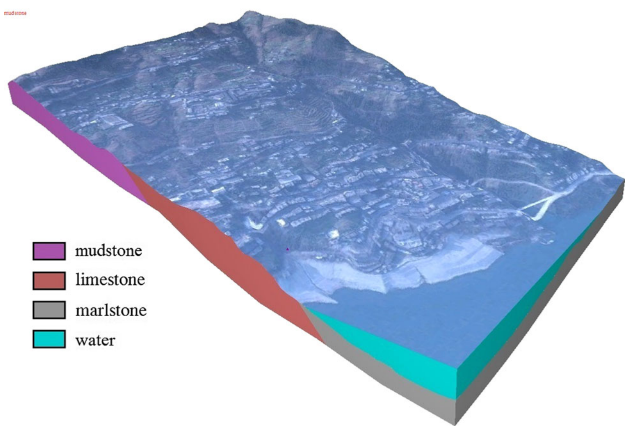


Fig. 5 The 3D model of HTP landslide

"entering" the experimental hole, where the geological conditions of the tunnel face and side walls at any location in the experimental hole can be observed clearly.

Figure 8 is the 3D landslide model which is set transparently. Thereby, through the surface and slip mass, the spatial distribution of landslide's slip surface, overall structure of the landslide, spatial distribution of large test field can be observed, section can be dealt with at any location and at anytime, the geological attributes anywhere can be displayed, and the spatial measurements, statistics and calculations can be carried out as well.

This achievement can display all kinds of geographical and geological elements of HTP landslide in a transparent mode, and a variety of research and analysis for the landslide can be done in the transparent mode.

Discussion

Integration mode of data in geological disaster transparency research

In geological disaster transparency research, a complete digital virtual research object is needed, and the integration

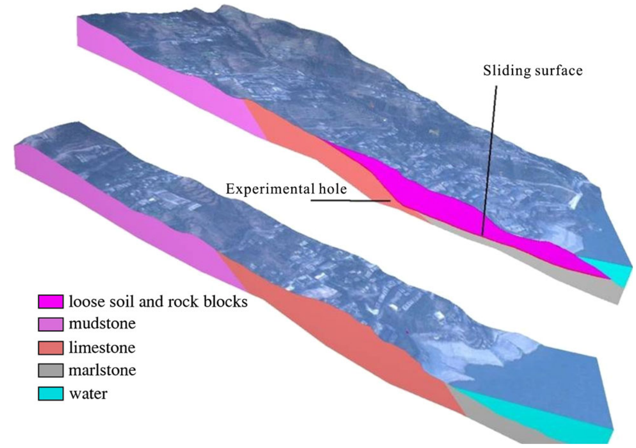


Fig. 6 Open model, showing the tri-layer structure of landslide

and support of a large number of spatial and attribute data are required (Rink et al. 2013a, b). The datum integration model in this study is as shown in Fig. 9, and the system is integrated in the "double C (Center)" mode of the database and 3D model (Liu et al. 2008).

The first C (Center) is database: to establish a complete numerical virtual disaster body, the support of a large number of data is required, such as the preliminary work data (fundamental geographic data and geological data, etc.), engineering surveying and mapping data, drilling data, field survey data, mountain engineering (footrill, exploratory trench, etc.) data, geophysical prospecting data, test data, sampling data and other basic data. Moreover, the geological map, profile map, bore hole columnar section and other map data are needed as well. Furthermore, the surface image, Adit photos (or sketch map) and other image data are demanded, which can be stored in the attribute-space database. Because the database manages all the survey and the original data, 2D graphic data of assisted generation and 3D model data of interaction generation, and moreover, it provides data support to the aided drawing, design and the creation of 3D model and draft compiling, it can be taken as access and management center of data (one of the "C: Center"s in Double "C"s).

The second C (Center) in "Double C" is 3D model: 3D model is the digital reconstruction of the studied area. In practical work, all the geological analysis are carried out centering on the research object; therefore, the digital research area, namely the 3D model (maybe a simple surface model initially), can be taken as the research carrier and application center of the system. With the development and perfection of 3D model, various works can be conducted intuitively in the 3D model, such as query, statistics, calculation, mapping, geological analysis, and draft compiling. For example, the work of statistics, calculation and analysis can be carried out in this delineated area of the 3D model.

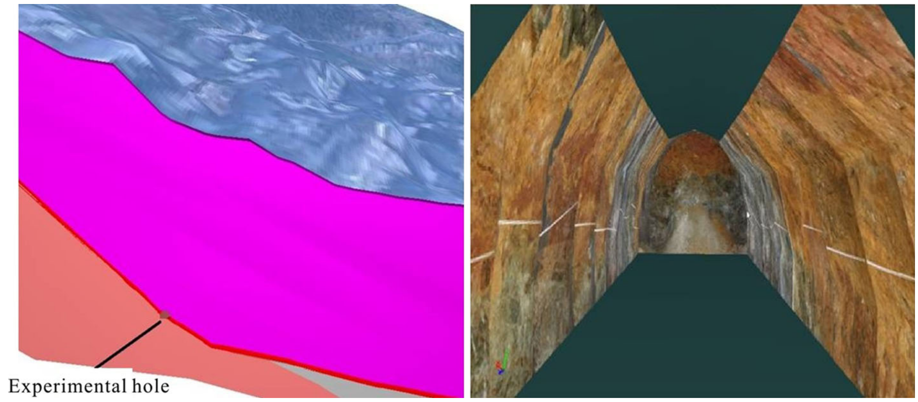


Fig. 7 The enlarged view of the experimental hole (part), the tunnel face and side walls

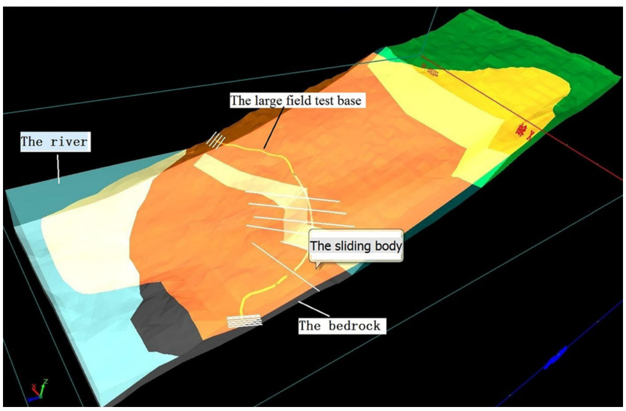


Fig. 8 Transparent landslide

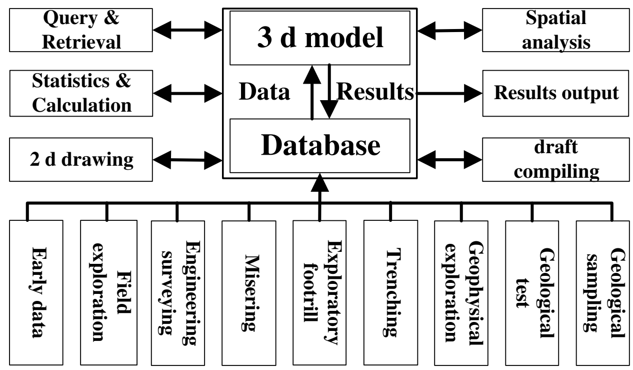


Fig. 9 Data integration mode

Therefore, centered by database and 3D model, the integration model of Double C is formed to provide various anaylsing tools and all-sided data support for the transparency research of geological disasters.

The 3D integration method from area to point (namely from region to disaster point)

The 3D integration method from area to point and from upground to underground is shown in Fig. 10 (Junqi Liu et al. 2012).

The raw data in geological disaster are managed by the attribute and space database of geological disaster, which is the data source of the 3D model of regional surface and 3D solid model of hazards.

The fabrication of regional disaster geological graphic model needs to call 2D topographic map or DEM from the attribute—space database to generate a 3D ground surface. Then through superimposing various geographic elements, geological elements and regional surface images, a 3D regional disaster geological map will be completed, as shown in Fig. 11. (Fig. 11 is the 3D model of Fig. 1).

With the computer-aided design technology (CAD technology), the mapping and geological data in attribute—space database are used to generate specific 2D topographic maps of a disaster body, exploration section and drilling histogram. The 3D modeling needs to call the disaster topographic map which is then superimposed by the image of the disasters ground surface to generate a 3D model of disaster body on the ground, and then call the drilling histograms and exploration sections of disaster body, using the two-body 3D data structures and vector cutting modeling method (Liu and Mao 2009), to create underground 3D model of disaster body. Combining the ground and underground 3D models, the specific 3D solid model on ground and underground of the disaster body has been finally established, which is shown in the inset (the small one) in Fig. 12.

In the component technology, the regional 3D model and the solid model of specific disaster are connected, making the solid model of disaster be called by the regional model, as shown in Fig. 12. With the logic relation described above, attribute—space database, 3D map of regional geo-hazards and the solid model of every disaster body in this area can be integrated together, which can serve for the mechanism studies, governance and

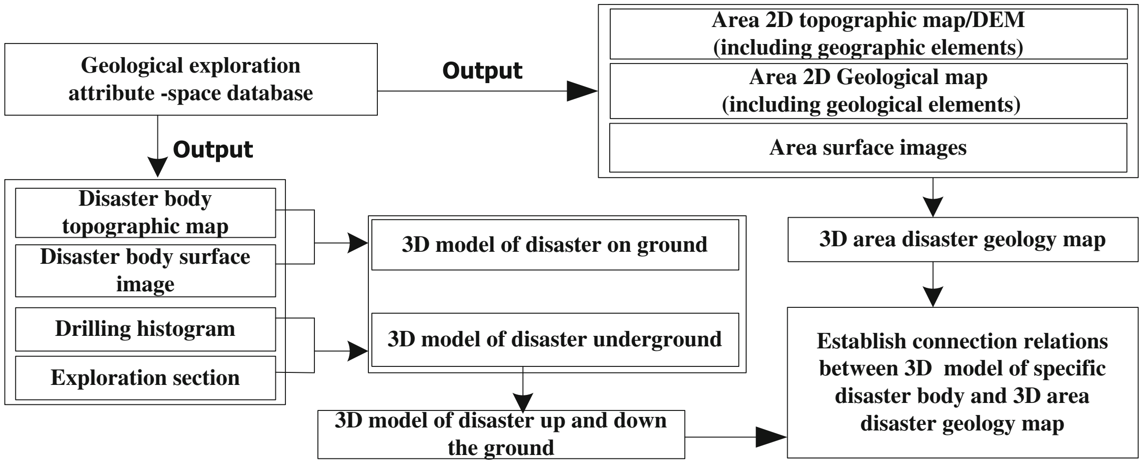


Fig. 10 The diagram of integration methods from the area to the point

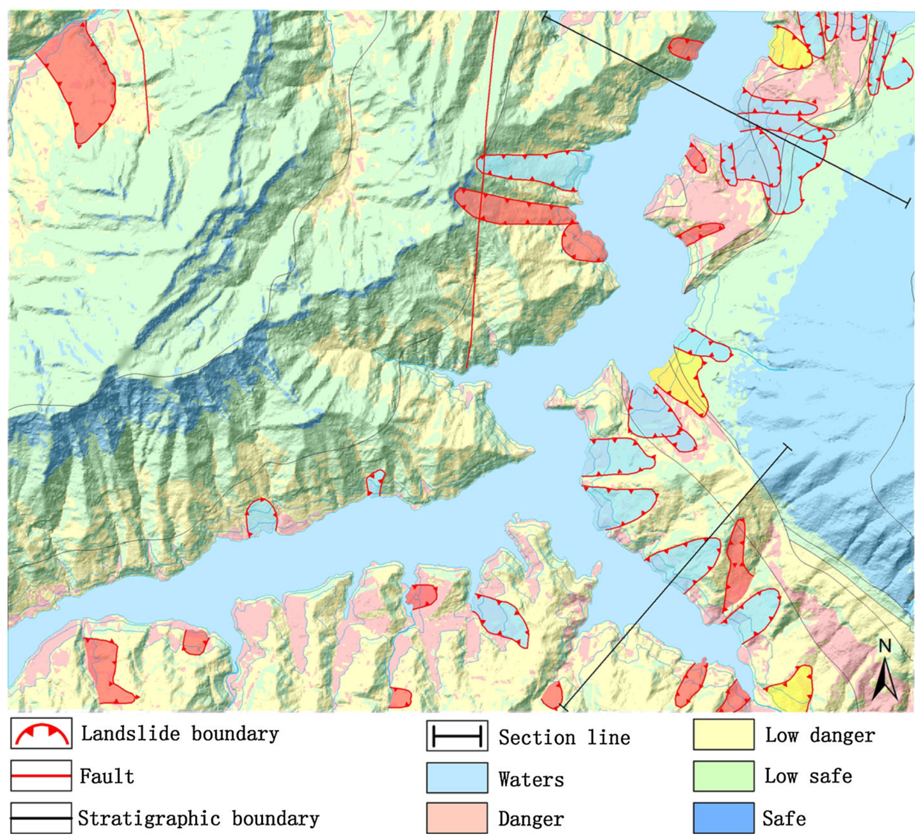


Fig. 11 Regional 3D geological map

precaution of geological disasters from area to point, and from ground to underground.

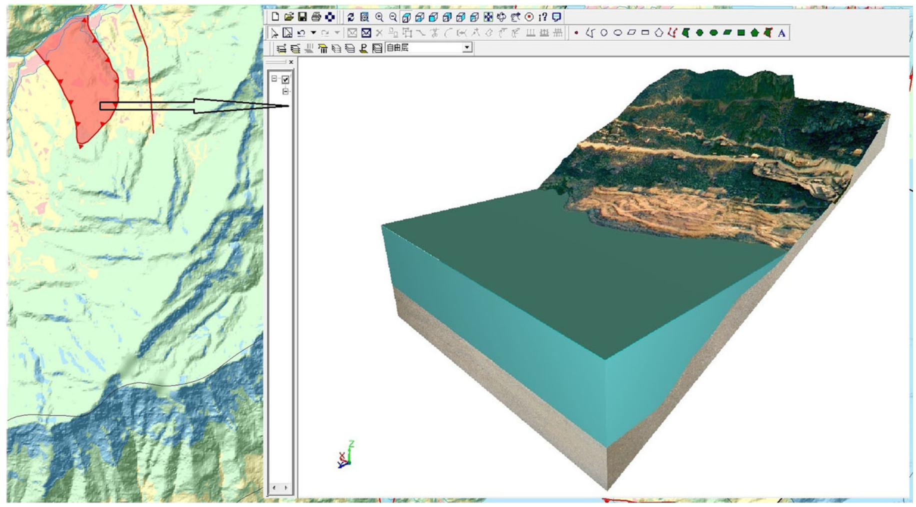
Transparent design and virtual construction

After a 3D solid model of the geological disaster body is built, the design proposal can be simulated repeatedly based on the model, and predictable suggestion can be given to specific construction in advance as well.

Design proposal can be further clarified in the 3D geological model

According to the preliminary design proposal, a linear shaped 3D model of the experiment hole is established, and then sheared and cut by the 3D solid model of disaster body, with the part of geological model in the experiment hole abandoned, in order to complete the integration of the two models, as shown in Figs. 4, 5, 6, 7, 8.

Fig. 12 The solid model of specific landslide called from regional 3D model



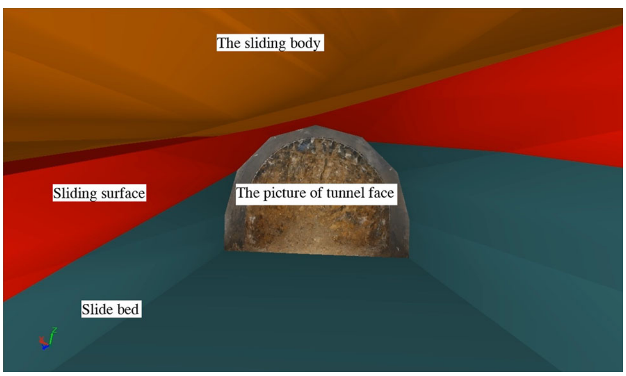


Fig. 13 The partially enlarged drawing after shearing between landslide geological model and the experiment hole model

The marks of various geological intersecting lines are left in the section (intersecting surface), so the intersecting lines between experiment hole and each of geological elements can be seen on walls of the experimental hole, as shown in Fig. 13, from which the results of design and construction can be achieved, and thus the design scheme can be adjusted constantly to perfect, making the design plan further clearer.

Predictable guidance for the construction

Since geological model and design model have both been established, and the result of shear between the two models is the possible outcome of practical construction, therefore, during the construction process, a series of parameters could be displayed or calculated at any time, such as the time and the type of rock, the hardness and other physical parameters of the rock, the extending length of the rock, and the expected volume of the earthwork, which can provide a predictable guidance for construction.

The relationship among the main hole, branch hole and the slip surface is shown in Fig. 14 (left), which has been reversed (upside down) for observation. The lower curved surface is the water surface, the middle curved surface is the slip surface, and the linear part is the main and branch holes. The enlarged view of the main hole, the branch hole and the sliding surface is shown in Fig. 14 (right), by which we can accurately calculate the coordinate point where the branch hole, extending out of the main hole from this direction, meets the sliding surface, and what geological conditions may be encountered along the way, which can do virtual simulation in advance and supply predictive guidance advice for the construction.

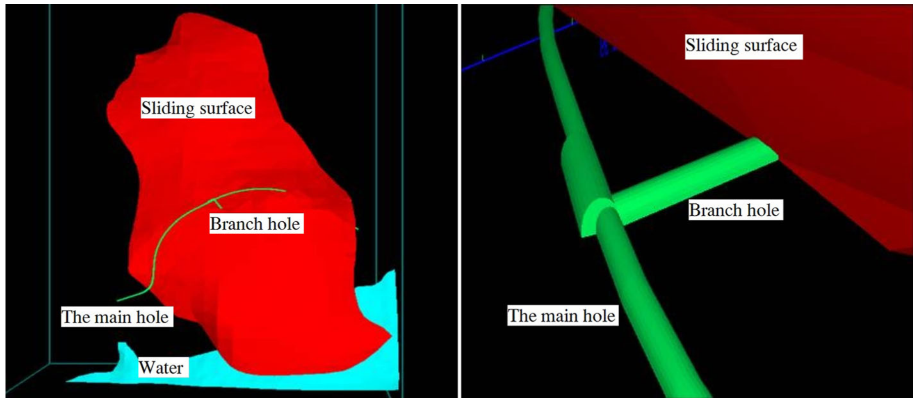
Conclusions

The integration model of Glass Landslide is Double Center. One is database, which is a data center providing all of the property data and spatial data for Glass Landslide. The other is 3D model, the digital research area and the application center of Glass Landslide. And all sorts of landslide analysis are based on 3D model. The integration model of Glass Landslide can integrate all kinds of data and techniques effectively.

The digital virtual reproduction of the research object (geological disaster body) can be made in computer with combination of information technology such as database, the 3D visualization, etc., and engineering exploitation technique. The research object can be observed and analyzed in a transparent way indoor, and the virtual simulation of research or management scheme can be carried out, which provides more direct and convenient support and service for the research, management and prediction of disasters.

Compared with traditional research, as a carrier of the Glass Landslide, the 3D model which is virtual and could be observed lucidly integrates the survey data, design data,

Fig. 14 The spatial relations among the slip surface, the main hole and the branch hole is transparently display in the 3D model



etc. It not only could provide more comprehensive data support, but also more intuitive insight and various spatial analysis tools for the landslide research. At the same time, it can support to optimize the design scheme and provide predictive guidance advice for construction.

This technology has been planned to conduct initially widespread applications in the related departments of the 3GR, basically reaches the aim of geological disaster data management, 3D modeling, virtual design and construction, and provides more analyzing methods for the research and governance of geological disasters.

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