WEB-BASED GEOGRAPHIC INFORMATION SYSTEM FOR CUT-SLOPE COLLAPSE RISK MANAGEMENT

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ABSTRACT: Topographical features in South Korea is characterized that 70% of territory is composed of the mountains that can experience intense rainfall during storms in the summer and autumn. Efficient planning and management of landscape becomes utmost important since the cutting slopes in the mountain areas have been increased due to the limited construction areas for the roadway and residential development. This paper proposed an efficient way of slope management for the landslide risk by developing Web-GIS landslide risk management system. By deploying the Logistic Regression Analysis, the system could increase the prediction accuracy that the landslide disaster might be occurred. High resolution survey technology using GPS and Total-Station could extract the exact position and visual shape of the slopes that accurately describe the slope information. Through the proposed system, the prediction of damage areas from the landslide could also make it easy to efficiently identify the level of landslide risks via web-based user interface. It is expected that the proposed landslide risk management system can support the decision making framework during the identification, prediction, and management of the landslide risks.

Keywords: Geographic Information System, Cut-Slope collapse, risk management, WebGIS

1. INTRODUCTION

South Korea has clear landscape pattern of high east and low west which displays 70% of mountain area with diversity of geological characteristics. Because of civilization development, industrialization, and population growth, a demand for an efficient land development is necessary[1]. Consequently, road construction and expansion of residential section have caused an increase of slanted surface from cutting the ground. Particularly, two thirds of the annual rainfalls concentrate in summer, and the concentrated rainfalls cause the accidents from the landslides with significant casualty and property losses, increasing the impact on the society and economy in the nation [2].

The present status of the natural disaster in South Korea during the last decade indicates the total casualty of 1,279. Also, approximately 22 percent of the total casualty, which is about 280 people, was killed by a landslide or a collapse of slanted surface from cutting the ground [3]. For a particular case of typhoon 'Rusa' in August, 2002, the family of the deceased driver sued the government because the driver could not notify the landfall and died. In this case, the judgment was given for the plaintiff with the decision that, "the government should pay the compensation because they should have set the safety facilities for the possibility of damage from the concentrate rainfall [4,5]."

Similarly, the industrial revolution of the mountain area enormously increased throughout the United States due to the city expansion and boosting of the people's interest in leisure. The industrial revolution is still in process, such as cutting the mountain to construct the highways and houses. Due to the environmental changes from cutting the mountain, the disaster occurs more than 25 cases annually, and it results the economical losses of $10 to $20 billion dollars annually [6,7]. In general, the landslide occurs along with an earthquake, a typhoon, and a rainfall. The United States Geological Survey (USGS) has operated the Landslide Hazard Program (LHP) to reduce the environmental and the economic damages that were caused by cutting the mountain area. From the middle of 1970s, USGS collected the information regarding the landslide accidents and researched on the emergency situation and its disaster control. Through the data collection and investigation on the landslides, USGS provided the steady and constant data information that the governments can use for making decisions and management systems. After applying the LHP strategies, the United States successfully executed the landslide mitigation practices resulting in significant reduction of economic losses .

This paper will discuss the necessity of providing the Web support information services for the slope management through obtaining the accurate information by advanced measuring technologies, such as Global Navigation Satellite System (GNSS) and the LiDAR (Terrestrial LiDAR). Also, the paper proposes the Web-based geographic information system that will support the efficient management for landslide risks and accident preparedness.

2. BACKGROUND OF CASE STUDIES

2.1 USA

In the United States, the slope disaster has been managed by USGS and the Federal Emergency Management Agency (FEMA). The USGS has a total controlling of disasters caused by landslides throughout the entire nation. They have set the national land slide hazards mitigation strategy (NLHMS) for nation, states, counties, and laboratories to cooperate together. Also, by launching the National Landslide Information Center (NLIC), they offer the recent case information of landslide disasters and suggest the useful guideline for disaster prevention. They have been extensively researching on a slope and landslide mechanism through LHP program, and more recently, they are operating LiDAR for mapping the areas where the landslides could occur. In addition, they are also educating the guideline of emergency preparedness to citizens, and operating the real time monitoring system for prompt decision making. Similarly, the FEMA is developing Response Resources and Sustainability (RRS) program based on GIS to forecast the losses of casualty and facility damages, and they have established Mapping and Analysis Center (MAC) to support the national level geographic information system and management [6,7].

2.2 Japan

Public Works Research Institute (PWRI) in Japan has been also operating for landslide management system. PWRI developed the measurement and slope monitoring system to automatically track and control the landslide accidents by adopting total station and 3-D coordination system with fiber-optic sensors. Also, both the government and private companies have been working together to accomplish the strategy for the continuous management every year. Especially, the case of highway prevention system in Hyogo, Japan, gave useful information about prevention guideline of the highway disasters based on GIS, and presented the most important standard regulation of highway to local civilians on how to prevent the accident from the landslide disasters. The prevention system in Hyogo also offered a service that anyone can access to the archival information of the collapse cases collected by every minute, hour, and day at anytime, and at anywhere. Moreover, they provided the real-time road signs to give the drivers warning for any disastrous situation, and they also placed the camera in the dangerous areas to monitor the road condition and the landslide accidents. The camera monitoring system was also connected with the internet system and provided the website for the people to monitor the road condition and to inform the road collapse accidents in real-time to help the drivers and travelers. Also, the camera monitoring system helped the researchers to visit the area for field inspection less frequently because they could still collect the information and analyze the data through remote control system provided by the camera [8]

2.3 Hong Kong

Civil Engineering Department(CED) of Geotechnical Engineering Office(GEO) in Hong Kong National Authority has been executing Landslip Preventive Measures(LPM) program and focuses on the reduction of road collapses and its damages. Also, they put their focuses on the development of standards for risk mitigation, stability analysis of foundation and slope, evaluation of the risk level, and slope maintenance. Since 1995, Hong Kong has operated LPM program in which they planned to research with the total 5,500 slopes until 2010. In this research, the slopes were categorized according to the risk level of landslide, and major risky areas have been continuously monitored and controlled through the LPM program.

3. ANALYSIS MODEL

3.1 Area Selection

The 1.8 km national highway 24 from Mil-Yang to Chang-Nyung in South Korea was selected for the research model. This highway is managed by Jin-Young highway control office, and the investigated area has a curved uphill roadway surrounded by the mountain. Eleven slopes in 1.8 km roadway from north of Mil-Yang to Chang-Nyung was considered in this research. Figure 1 demonstrates a satellite image of this area.

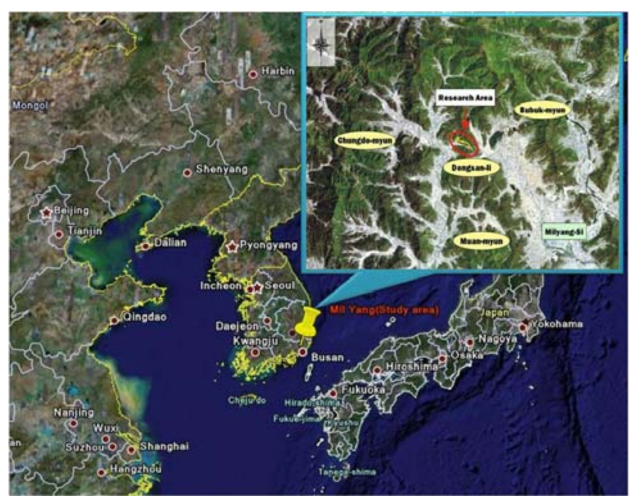

Figure 1. Demonstration of satellite image at the proposed research area

The research model area is in danger zone for falling rocks that consist of Cretaceous volcanic rocks (such as Andesitic rocks and Andesite Porphyry), brecciated Quartz Porphyry, and Quaternary of alluvium. Bedrock in the considered slope area consists of Mesozoic

Cretaceous neutral pyroclastic rocks (e.g. Andesitic rocks and Andesitic Lapilli Tuff). The soil layer consists of the foot of mountain sediment and Weathered Residual soil, and some areas contain Colluvial soil that causes the landslides. Its geological structure has the weak ground condition because it has a small scale of fault, fragmental zone of fault, and many Clarion-Clipperton fracture zones in the bedrocks. Also, the bedrock has thick weathered alteration zone and core stone with structurally inhomogeneous rocks [9].

3.2 Data Collection

In order to measure an accurate location of the slope and a physical boundary, we used a Mil Yang City 1:5,000 digital map generated by the national geographic information institute (NGII). To get the exact starting/ending points and slope boundary, the absolute coordinates of X, Y, and H were measured. Firstly, the reference coordinates were obtained from GPS measurements by using the trigonometric method for accurate determination of the slope location. Based on the reference points, slope survey was performed to measure starting/ending points and slope shape at eleven different types of slope by using total station equipment [10]. The preliminary survey could estimate the accurate coordinates of facilities at the slopes and the major joint direction.

In addition, Face Mapping was performed to identify the characteristics of the slopes, such as the information about underground water, existence of valleys, angle of upper slope, level of weathering, type of surface discontinuity, and failure history. The eleven slopes were then given their own number from Chang-Nyung (PSMIS 01) to Mil Yang (PSMIS 11). Table 1 describes Face Mapping results that are considered important factors to affect the landslide. From those collected information, GIS database was constructed by using Arc GIS.

4. RISK MANAGEMENT

4.1 Logistic Regression Analysis

Due to the limited capability of GIS that can simply support the geographic and abstract information, Logistic Regression Analysis based on the statistics was executed to predict the risk level of slope failure [11~13]. The regression analysis is one of the popular methods to determine the relationship between response and explanatory variables. Typically, the Logistic Regression Analysis is used when the response variables are obtained from two or more categories. In this paper, Binary logistic regression analysis was applied to model the influence of the slope failure using total ten input variables. Total 422 samples measured from the locations of slope failure were executed in this analysis. Among Simple Enter Method, Backward Elimination, and Stepwise Method, this paper adopted a Simple Enter Method as a variable selection method. Likelihood ratio from the regression analysis is shown in Table 2 where DF and S.E represent the degree of freedom and standard deviation, respectively. Also, Pr represents the impact factor contributable to the slope failure, where the number close to zero means high impact factor for slope failure. In this model, total 7 input variables were selected from the geometrical and geotechnical categories used for evaluating the stability of the slope.

The result from the Logistic Regression Analysis can be expressed in Equation 1, where p is the probability that the slope failure can occur. Main advantage of the Logistic Regression Analysis is that it directly shows the probability of the slope failure as a value according to variation of the input variables. Based on the GIS database, the probabilistic risk degree of the slope failure can be obtained by using the equation of failure probability, expressed in Equation 2.

Table 1. Face Mapping Result

Slope No.	Slope length (m)	Ground-water	Valley Part (with/without)	Weathering degree	Type of discontinuity	Direction of inclination (degree)	Inclination of the upper slope (degree)	Slope inclination (degree)	Failure history
PSMIS01	80.2	Dried	with	MW~CW	fault	132	10	48	Yes (circular arc)
PSMIS02	59.7	Dried	without	SW~MW	joint	121	30	70	falling rock
PSMIS03	182.1	Dried	with	MW~HW	joint	218	0	70	No
PSMIS04	128.7	Dried	without	MW~CW	fault	202	20	45	Yes (circular arc)
PSMIS05	91.7	Dried	with	SW~HW	fault	203	20	45	surface loss
PSMIS06	133.4	Dried	with	CW~RS	soil slope	186	20	45	Yes (circular arc)
PSMIS07	152.3	Dried	with	SW~MW	fault	189	20	58	falling rock
PSMIS08	105.3	Dried	without	SW~CW	fault	226	25	45	No
PSMIS09	140.7	Dried	with	MW~HW	fault	220	25	48	falling rock
PSMIS10	113.3	Dried	without	HW~RS	joint	241	25	45	surface loss
PSMIS11	158.8	Dried	with	HW~RS	joint	249	10	38	surface loss

Table 2. Likelihood ratio from the regression analysis

Parameter	DF	Estimate	S.E.	Wald Chi-Square	Pr>Chi -Square
Intercept	1	3.9291	2.1197	3.4361	0.0638
Slope length (SL)	1	0.0166	0.00543	9.3741	0.0022
Slope inclination (SA)	1	-0.0551	0.0243	5.1535	0.0232
Direction of slope(SD)	1	-0.00005	0.00242	0.0004	0.9841
Underground water(UW)	1	0.2452	0.2296	1.1411	0.2854
Inclination of the upper slope(UA)	1	0.0149	0.0131	1.2911	0.2558
Weathering degree(W)	1	-0.0985	0.26	0.1348	0.7135
Type of discontinuity (DC)	1	0.0445	0.1484	0.090	0.7641

$$p = 3.9291 + 0.0166SL - 0.0551SA - 0.00005SD + 0.2452UW + 0.0149UA - 0.0985W + 0.0445DC$$
……………………………………………………Eq(1)

$$p' = \frac{\exp(p)}{1+\exp(p)}$$
…………………………………..Eq(2)

where, SL is slope length, SA is slope angle, SD is slope direction, UW is under water, UA is upper slope angle, W is level of weathering, and DC is type of discontinuous surface.

Table 3 represents the probabilistic risk degree of the slope failure based on the equation of failure probability.

Table 3. Probabilistic risk ratio of the slope failure (ordered by ranking)

Risk Ratio	Slope No.	Risk Ratio	Slope No.
1	PSMIS 11	8	PSMIS 05
2	PSMIS 09	9	PSMIS 03
3	PSMIS 04	10	PSMIS 01
4	PSMIS 06	11	PSMIS 02
5	PSMIS 07		
6	PSMIS 08		
7	PSMIS 10		

The result shows that the highest probability of slope failure occurred at PSMIS 11, while the lowest probability occurred at PSMIS 02. In fact, the stereographic projection indicated that PSMIS 11 has high probability of wedge failure. Even in the field inspection with the Face Mapping, PSMIS 11 area was severely weathered with slacking of bedrocks, and the entire slopes were sandy soil. Especially, thick weathered residual soil has been developed in the upper parts of the slopes, and extensive soil losses caused by the rainfalls were observed in this area.

4.2 System architecture

A Web-GIS landslide risk management system was developed from the result of Logistic Regression Analysis. Demand analysis was performed through expert survey to obtain the taxonomy of the system functions, which is described in Figure 2.

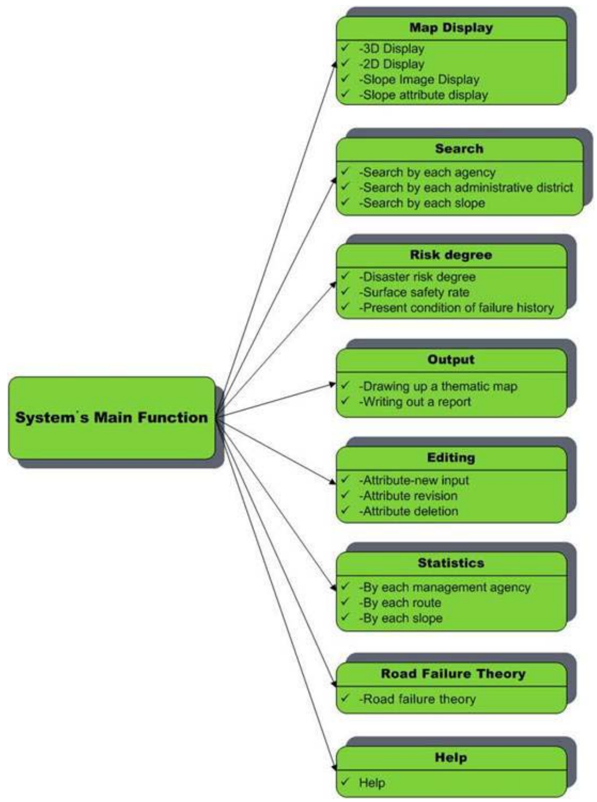

Figure 2. System's main menu

Software components used to develop the proposed system include Apache Web Server, Tomcat JSP Container, and CyberMap Web Server Engine. CyberMap Web server, used in this research, has a distinguished feature of fast indexing that aids the navigation of large collections of data retrieved from search engine, which is best fit to the requirement of the proposed system. Hardware components include Intel Xenon 2.0GHz Dual, memory 2GB, and two SCSI 72.8GB hard disks

4.3 Implementation

The proposed Web-GIS landslide risk management system is implemented through a case study to demonstrate the information services for accurate positioning and visualization of the slopes. The system has a variety of user-friendly interfaces, and also has projection tools, such as zoom, move, distance measure, area calculation, prints, etc., available with system's main functions listed in Figure 2. Figure 3 illustrates one of the main features in the proposed system where typical cross section area with 3D slope shape can be represented through Triangulated Irregular Network (TIN). In addition, it is possible to view the individual layer from the 3D slope shape [14-15].

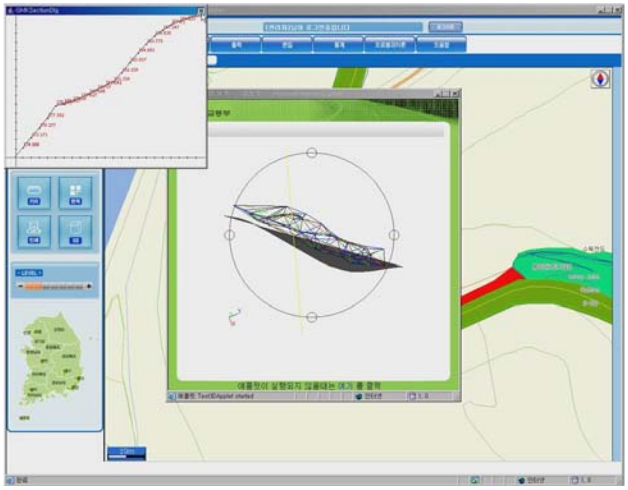

Figure 3. Screenshot of 3D slope TIN and cross section area

Figure 4. Screenshot of reporting page

Figure 4 shows the reporting page of the disaster level of roadways that displays the summarized information of geographical terrain, survey pictures, precipitation chart, cross section of slopes, and major factors for landslide. This information is represented and printed in an integral drawing for future landslide risk management and maintenance plan.

In this system, the historical landslide records on a slope will help manage an efficient maintenance strategy to prevent possible landslide disaster. In addition, user can view the detailed pictures of the slope by clicking the circled section that represents the risk area of landslide. Also Face-map from a high resolution survey enables to get vertical and horizontal data through a Web that can help recognize and analyze the slope without drawings and field visit. The categorized statistics according to administration office, route, and slope type at typical slope location, and the categorized information can be represented by pie-chart.

Editing tool is provided to insert, modify, and delete a data. In addition, user can upload image files to the system in real-time in order to update any change that have been observed from field investigations.

5. CONCLUSIONS

This paper proposed a Web-GIS landslide risk management system to improve the slope management practice that could minimize the landslide risks. In order to derive the equation of failure probability, slope survey was conducted to measure the accurate geometry of eleven different types of slope, and Logistic Regression Analysis was performed using historical landslide records to enhance the prediction accuracy. The conclusions of this research are summarized as follows:

First, past researches on slope management system analyzed the slope location and shape as a point regardless of slope's scale. However, the proposed research utilized LiDAR, GPS, and Total Station to accurately measure the slope location and shape, and the user friendly interface can support the slope management more interactively and thoroughly.

Second, the proposed paper adopted Logistic Regression Analysis from the probability equation of landslide, and applied to the eleven investigation areas. The results showed that the highest probability of landslide was at PSMIS 11. The expert's field investigation also confirmed that the slope at PSMIS 11 is the most dangerous location for landslide mainly due to the outer layer sweep.

Finally, the proposed Web-GIS offers a feature that is capable of directly investigating the additional objects near the slope by converting the numerical map to BaseMap. In addition, 3D slope model with TIN provides an interface to analyze the detailed shape of slope's cross section area. Also, historical records of the slope can be stored in a database that helps a thorough understanding of slope management and emergency preparedness of landslide disaster.

Future research will investigate the feasibility of ubiquitous computing that will collect and analyze the diverse information of the slope in real-time with enhanced accuracy and efficiency.

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