A Construction of Road Slope Risk Information System Based on Web-GIS

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ABSTRACT

Korea is topographically and meteorologically prone to natural disasters. In addition to extraordinary weather, localized heavy rain is a irregular occurrence. Highway in Korea are frequently damaged by rain, wind, flood, etc. Recently, slope failures are disastrous when they occur in mountainous area adjoining highways. The accidents associated with slope failures have increased due to rapid urbanization of mountainous area. Therefore, the inspection of slope is conducted to maintain highway safety as well as road function. We developed basic function and risk management of a partial shape on highway slopes based on the internet using high surveying technology. It is important for quantitative risk evaluation of highway slopes. The management system will be developed to allow for more accurate decision-making using GIS function based on the internet

Keywords : Web-GIS, Road Slope, Risk Dangerous Information System.

1. INTRODUCTION

Korea has the distinct terrain with high east-low west[1)], and the about 70% of its territorial area consists of mountains and shows various geological characteristics. As efficient land developments becomes needed on account of the development of civilization, industrial enhancement and population growth, large-scale cut slopes are increasing due to constructions for road expansions and house lots' development cutting forestland(Ministry of Construction & Transportation, 2005). Especially, because 2/3 of an annual average rainfall pours down in the summer season, cutting slop failures cause a loss of lives and property damages every year, and, consequently, have a great ripple effect the socio-economic foundation (Shin Hyeon-jun, 1995; Ministry of Construction & Transportation, 1998; Lee Sa-ro, 2000).

In terms of natural disaster for this last decade, 280(approx. 22%) of the total 1,279 death toll were killed by landslide, particularly in case of Typhoon 'Rusa' that happened in Aug 2002, a driver who was driving his car died because he didn't recognize landslide occurrences beforehand, and then the bereaved family sued the central government for damages in connection with the accident. The court judged that the defendant should pay indemnities to the plaintiff saying " the central government should anticipate damage probability by the torrential rains to install safety facilities, nevertheless it neglected to do it. Thus the government should take a liability for damages" (Gwak Yeong-ju et al., 2005; Gwak Yeong-ju et al., 2005).

Also in Korea, it is expected that cut slopes will be increase steadily because road expansions are done largely by cutting forestland. In addition, although rainfall converges only in the summer because of climatic characteristics and the resultant slope failure causes disaster every year, management according to slope disaster risk grading is not done and comprehensive information service on slope through Web-Service is wholly lacking.

Thus, in order to minimize the victims and property damages, offer and manage the information on slope effectively, this study attempts to prevent slope failure in advance, minimize the damaged scale and offer the information on slope efficiently through slope management according to risk grading by providing the precise slope information-based web slope disaster risk information service obtained through high surveying technologies such as GNSS, ground LiDAR, etc.

2. Analyzing Domestic and Foreign Case Studies

2.1 Analysis on the domestic present condition

Domestic slope management is controlled by various management agencies. In the case of landslide and slope in urban area, these-related researches are being conducted at the Korean National Emergency Management Agency and the Korea Institute of Geoscience and Mineral Resources (KIGAM), and slopes in urban area is being managed by each local government. In the case of road, the Ministry of Construction & Transportation (MOCT) is an administrative agency on expressway but the Korea Expressway Corporation acts for MOCT, and the Expressway & Transportation Technology Institute within the Korea Expressway Corporation is carrying out researches in relation to it. In the case of general national road, the Ministry of Construction & Transportation is an administrative agency and the Korea Institute of Construction Technology is collecting data about national road-centered road slope and building up the database. Especially, the general national road within the jurisdiction of a city is being managed by the relevant mayor and other local roads are being controlled by each local government. The Korea Railroad Corporation is managing railroad and the Korea Railroad Research Institute is carrying out a research with relation to it. This study produced the slope management system for national roads controlled by the Ministry of Construction & Transportation. In Korea, the ubiquitous-based real time slope monitoring system is operating, but because it is a measuring-centered system, there is a fault that does not capture accurate location and image of slope. Also, the cut slope management system administered by the Ministry of Construction & Transportation is providing data on the priorities for financial investment in slope information service and reinforcement work, but it is difficult to perceive accurate location and 3D image of slope (Korea Institute of Construction Technology, 2005; Kang In-jun et al., 2004).]

2.2 Analysis on the foreign present condition

This study compared and analyzed the cases of Japan and Hong Kong, the advanced countries in slope management, to examine domestic and foreign conditions. Japan is carrying out various analyses through 3D modeling by using GIS technology. Particularly, Japan is offering various information service, including data on slope failure-inducing factors such as rainfall, snowfall, thawing season, etc., 3D image analysis and mapping of slope failure effect according to the predicted slope failure point at the occurrence of slope failure, in order to prevent slope failure (Japan Association for Earthquake Engineering, 2004).

In Hong Kong, the Civil Engineering Department(土力工程處) equivalent to the Ministry of Construction & Transportation of Korea established database on all slopes within Hong Kong and is managing those by using GIS system. Especially, it is executing a Landslip Preventive Measures (LPM) program, and focuses on the standardization of methods for reducing losses due to slope failure, securing ground stability and evaluating & reinforcing slope stability. In addition, 'LPM' classified slopes through a mapping project of landslip risk grading, and is managing slopes according to the classified slope codes and also plans to carry out researches on a total of 5,500 slopes from 1995 until 2010. Also, it is producing, revising and managing a map of accurate slope location and scale by using aerial photographs, satellite images, etc(Kottegoda, Rosso, 1997).

3. Study Model and How to Construct Data

3.1 Selecting research model area

This study selected 1.8km road slope of Miryang~Changnyeong section of national road 24 line that is being managing by the Jinyeong national road management office as a study model area. The study area is a curved pass road of mountainous terrain and this study chose 11 slopes located in 1.8km section of the direction of Changnyeong starting from Bubuk-myeon, Miryang-si as study subjects. Figure 1 is the satellite image of study model area.

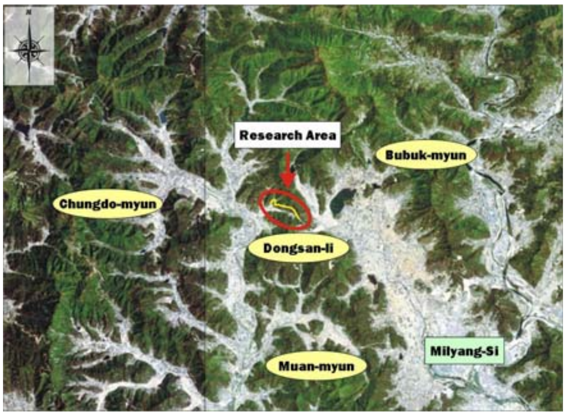

Figure 1. Study model area

The study area has rock-falling risks and is mainly composed of volcanic rocks (Jusan andesitic formation, andesitic porphyry, etc.) geologically from the Mesozoic Cretaceous Yucheon Group, Gyeongsang Supergroup, Korea, quartz porphyry intruded by the rocks and the Quarternary alluvial layer covering these all ground layer in the form of unconformity. The bed rock of geologies in the study area is composed of neutral pyroclastic rocks (Jusan andesitic formation; andesitic lapilli tuff) and soil layer consists of piedmont sediment and weathered residual soil, and its partial sections are accompanied with colluvial soil originated from landslide. The geological structure is accompanied with small-scale fault & fragmental zone of fault within bed rock and a large number of fracture zones, and indicates overall fragile state of ground. Also it involves thick weathering alteration zone and core stone and indicates heterogeneous lithology in the up-and-down and lateral directions. Figure 3 shows the geological structure of study area (Editorial Department, Technical Management Company, 2001; Lee Jeong-in, Hoek & Bray, 1996).

Colluvial soil & weathered soil	Weathered rock & soft rock	Fresh rock and above
		
.Piedmont sediment containing breccia .Initial topographical weathered residual soil	.Phenomenon of fragmentation around the fragmental zone of fault .Discriminative weathering of bed rock	.Good rock bed of fine and massive texture .Andesitic lapilli tuff

Figure 2. Geological composition of the study area

3.2 How to Construct Data

In order to determine correct position and physical boundary of slope, the control points were selected using a Miryang-si's numerical map of scale 1: 5,000 published by the National Geographic Information Institute. Also X, Y and H of absolute coordinates were acquired for settling accurate starting & ending points of road slope. First GPS control point surveying was carried out by using triangular control points in the study area in order to determine accurate position of slope, and Table 1 shows the results of control coordinates. The slope condition surveying on 11 slopes was performed by utilizing Total-Station equipment in order to obtain exact starting & ending points and image of slope on the basis of these control points and exact coordinates on important joint directions for facilities or management of slope were calculated (Yu Mok-mo, 1998).

Table1. Results of control coordinates using GPS

coord. / Point	X	Y	Z
PN01	226713.076m	170013.341m	70.178m
PN02	226897.594m	170132.895m	86.691m
Spectrum survey 3.41 KOR Project: C:\GPS_PROCESS\PNU_ROAD.spr Coordinate System : Virtual East Origin [Transverse Mercator] Datum : KOREAN Geoid Model : World Grid 96 Unit : Meters Local Time Zone : GMT+9.00h			

Figure 3 indicates the surveying results on the present condition of 11 slopes.

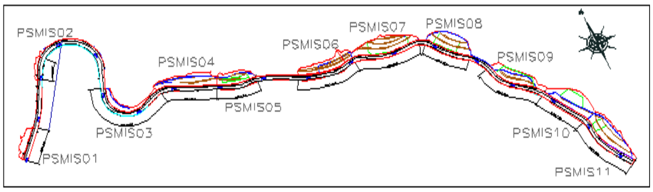

Figure 3. 3D route surveying DB

And figure 4 shows photographs of slopes in the study area.


Figure 4. 11 slopes in the study subject area

Also, the slope failure-induced factors such as groundwater, valley part(with/without), the upper slope-inclination, weathering degree, kinds of discontinuous planes, slope history, etc were examined by performing Face Mapping in order to grasp the slope characteristics, and each slope's characteristics were perceived. And specific numbers on 11 slopes in the study area were given in order of PSMIS 01 from Changnyeong to Miryang. Table 2 shows the results of Face Mapping on 11 slopes, which have influence on slope failure significantly.

The GIS database is established by using ArcGIS software on the basis of data collected in this way. Figure 5 indicates attribute data of 11 slopes.

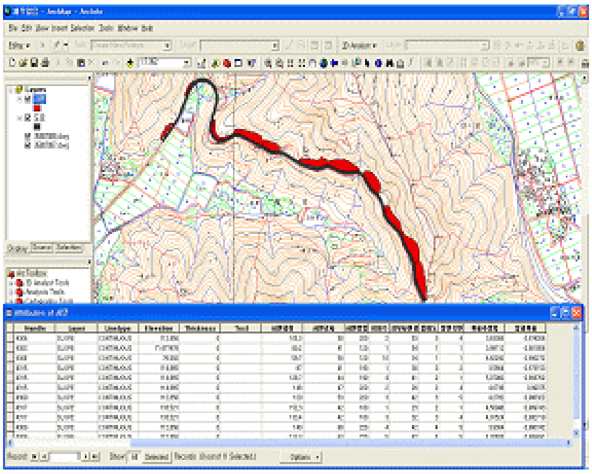
Figure 5. Attribute data input used GIS Tool

4. Disaster Risk Grading & Application of Web-GIS

4.1 Applications of Logistic Statistical Analysis & Probability Theory

The GIS data established until now provide only simple geographic and characteristic information on slopes. Therefore, logistic regression analysis, a stochastic statistical theory, was performed to grasp the risk degree of slope failure. Regression analysis is one of the most widely-used general statistic methods when one indicates the relationship between reaction and explanatory variables. When the reaction variable is a categorical type to indicate responses on two or more several categories, a logistic regression model applies to it. Binary logistic regression analysis was performed to model the influence of input variable on slope failure and a total of 10 input variables were used. The basic data used in this analysis carried out the optimum regression analysis with variables examined by sampling a total of 422 places on the basis of slope failure-occurred places. The variable selection methods of binary logistic regression analysis are simple input, backward elimination and phased input methods, and this study chose simple input method. This is because simple input method is suitable when one made a comparative analysis of the input variables which were chosen through variables and regression analysis selected by a survey of public servants and researchers of the Korea Institute of Construction Technology, the Korea Expressway Corporation, etc. Table 4 shows the goodness-of-fit results of logistic regression used simple input method, and DF indicates the degree of freedom and S.E. presents the standard deviation. Pr indicates the influence on slope failure, and as it is close to 0, its influence is high. In this model, 7 input variables of the geometrical and geotechnical items of the slope stability-appraisal data were selected and included.

Table 3. Face Mapping Results of 11 slopes

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

Table 4. Goodness-of-fit results of Regression Analysis for imple Input Method

Parameter	DF	Estimate
Intercept	1	3.9291
Slope length	1	0.0166
Slope inclination	1	-0.0551
Direction of slope	1	-0.00005
Underground water	1	0.2452
Inclination of the upper slope	1	0.0149
Weathering degree	1	-0.0985
Type of discontinuity	1	0.0445

The logistic regression model adapted from these results is expressed like Eq (1) if p is the estimate of the probability that slope failure will occur.

Logit(p)=3.9291+0.0166×Slope length-0.0551×slope inclination-0.00005×Direction of slope+0.2452×Underground water+0.0149×Inclination of upper sloope-0.0985×Weathering degree+0.0445×Type of discontinuity Eq(1)

If Eq (1) is expressed in an equation of failure probability, it is equal to Eq (2).

P=1/[1+EXP{-logit(p)}] Eq(2)

The biggest advantage of logistic regression analysis is to estimate the slope failure probability on a given input variable value numerically. Consequently, this study applied formula (2), an equation of failure probability, on the basis of the already established GIS DB and made a slope failure-probability-risk finally.

Table 5 indicates the slope failure-probability-risk depending on an equation of failure probability.

And figure 12 is a probability map obtained using the numerical map of the study area.

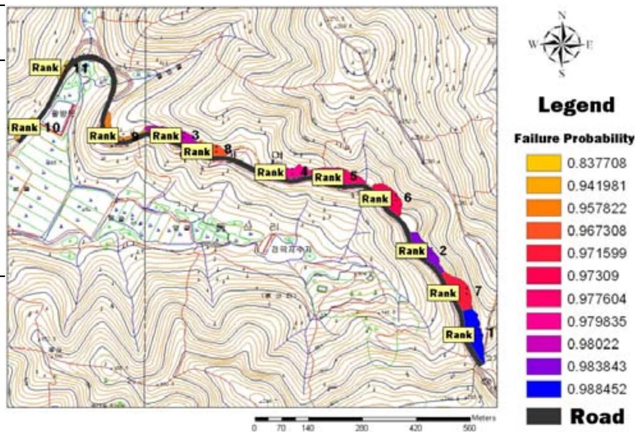

Figure 6. Slope failure risk probability ranking

Analysis showed that the PSMIS 11th slope had the highest failure probability and the PSMIS 02 slope had the lowest failure probability. Actually, the PSMIS 11th slope had the possibility of wedge failure according to the results of stereographic projection. Because weathering and transmutation are serious generally also in a field survey through FaceMapping, most of the bed rocks were fragmentated and all slope sections were transformed into sandy soil. Also, thick weathered residual soils were developed in the upper part of slope and slope surface losses by rainfall were observed much.

4.2 System Architecture

The web-based road slope management system architecture integrated and explained the contents of web components,

Table 5. Failure Probability Risk Ranking

Slope No.	Slope Length (m)	Slope Inclination (°)	Direction of Inclination (°)	Ground-water	Valley Part (with /without)	Inclination of the upper slope(°)	Weathering degree	Type of discontinuity	Failure history
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PSMIS10	113.3	45	241	Dried	without	25	HW~RS	joint	surface loss
PSMIS05	91.7	45	203	Dried	with	20	SW~HW	fault	surface loss
PSMIS03	182.1	70	218	Dried	without	0	MW~HW	joint	No
PSMIS01	80.2	48	132	Dried	with	10	MW~CW	fault	Yes (circular arc)
PSMIS02	59.7	70	121	Dried	without	30	SW ˜ MW	joint	falling rock

architecture & user page, Java applet architecture and technical architecture for realizing these with regard to development system. JSP user page architecture candidates for web component-based system implementation are generated and architecture-related quality elements are identified on the basis of the architecture requirements of use case model. The architecture of this system web-based road slope management system should be modified and maintained, and has WEB GIS realm-common architecture.

The web-based road slope management system of this study was constructed in component-based JSP environment, and it was composed of JSP environment' sub component. Therefore, the software & technical architectures of the web-based road slope management system are identical with the existing JSP-basde web system, and the requirements derived at a work analysis stage are reflected in the user page architecture. Figure 13 is one that schematizes this system's architecture.

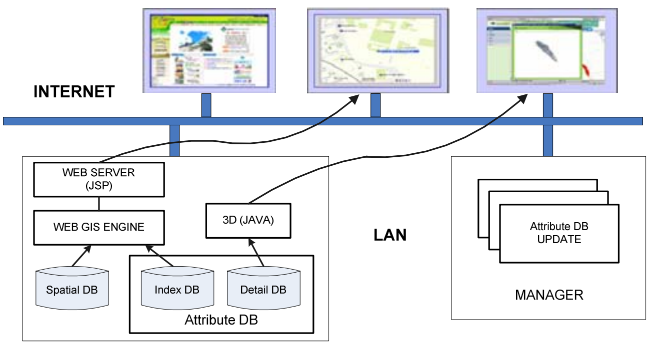

Figure 7. System architecture

Table 7 indicates the system architecture configuration, and the Map Server of this study used CyberMap Web Server, a domestic self-engine. The biggest characteristic of this server is rapid indexing, and because such characteristic was suited to this study, this server was selected.

Table 7. System onfiguration

Software	Hardware
- Apath WEB Server -Tomcat JSP Container -CyberMap WEB Server	- CPU : Intel Xenon 2.0GHw Dual - Memory : 2GB - HDD : SCSI 72.8GB*2

4.3 Main Functions of System

The purpose of this system is to provide Web-GIS based-slope disaster risk information service, and is offering accurate location and shape information of slope. Figure 14 displays the main screen of this system, and figure 15 shows the search results through search by each management agency.

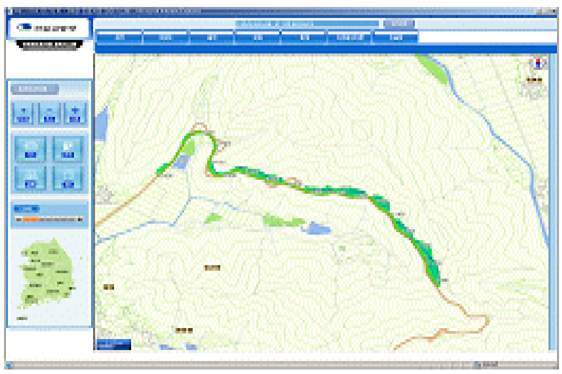

Figure 8. Main screen

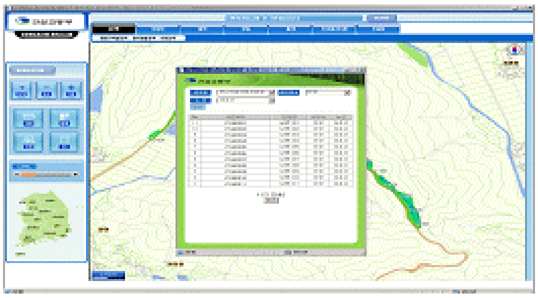

Figure 9. Search by each layer

Figure 16 indicates a risk-calculating function in which the public officials in charge of slope-related service or the general public can generate the slope disaster risk grading by selecting input value easily.

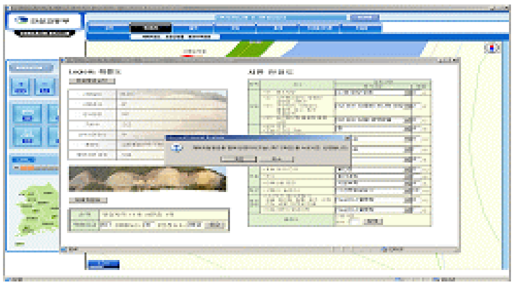

Figure 10. Calculation of risk degree-barrier grade

5. Conclusion

The purpose of this study is to manage slope efficiently and systematically by providing Web-GIS-based slope disaster risk information service in order to minimize loss of life and property due to road slope occurred frequently by torrential rain every year and the resultant social and social economic damages. The findings are as follows:

First, failure probability scores are being computed by a distribution point list in the existing study, but an failure probability equation was estimated by using logistic regression analysis, a statistical method, and applied to slope in the study area using it. PSMS 11th slope had the highest failure probability within the study area, and it was judged that its failure risk was high due to surface loss in an actual field survey too.

Second, slope attribute information-centered management are being carried out by using a symbol rather than an accurate location or shape of slope in the existing slope management system, but precise surveying of the present condition was performed by utilizing GPS and Total-Station in order to represent exact location and profile of slope in this study and accuracy improvement of slope and 3D slope image display were possible by implementing Face Mapping with it. Also, vertical and traverse maps of slope through were produced easily through 3D slope condition.

Third, the existing slope management system was a simple web-based slope information service-centered system and was difficult to represent accurate slope location or manage it according to disaster risk grade. Therefore, this study expressed it on a numerical map through actual surveying of slope condition and could easily grasp exact location and image of slope through internet by constructing Web-GIS based-system. Also, this system could manage slope more systematically according to slope disaster risk grading than the existing method by producing slope images & various thematic maps according to slope disaster risk grading and providing information such as the history map of the predictive damage at the occurrence of an actual slope failure.

In the future this system's database not only should be maintained, repaired and updated continually for implementing the revision, supplement and update of database according to data acquisitions of slope risk factor, but also could provide service in consideration of tying of the database to the third NGIS project that is being propelled. And Web GIS-based system should be expanded through standardization work considered various terrains and geological conditions.

6. Acknowledgement

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