Development and Application of GIS-based Information System of Landslide Hazard Map Induced by Earthquakes and Rainfall in Korea

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Abstract: Securing the slope stability for earthquake and rainfall by analysing the behaviour of slope structure is one of the most important parts in landslide disaster preparation, especially in Korea including many mountain areas. However, there is still a lack of systematic research on securing the slope stability for earthquake and rainfall in Korea. Therefore, the systematic research on factors affecting the slope stability and evaluation method of slope stability considering earthquake and rainfall induced factors should be needed. In this study, integrated information system of landslide hazard map during earthquake and rainfall was developed. The developed system built, within the frame of GIS, consists of a database (DB) containing all site information and processed data in the system in the standard data formats, and the system software performing various functions to manage and utilize the data in the database. The system software is functionally divided into an input module, earthquake-induced landslide assessment module, rainfall-induced landslide assessment module, and hazard mapping module. Study area is Cheonggye Mountain and Deogyu Mountain in Korea, and landslide hazard map is constructed by using amplification factor obtained from geometrical characteristics of slope and Severity Level linked with rainfall datasets based on the developed system.

1 INTRODUCTION

Landslides are one of the most damaging natural hazards in mountainous terrains with heavy torrential rainfall as is in the case of Korea. Debris flow damage includes losses in human life, destruction of various facilities, damages to roads, pipelines, and vehicles (Jakob and Hungr, 2005). Mostly, post-event repair processes and works have been only executed after debris-flow occurrences. Recently, there has been an increase in both the number of occurrences and costs for countermeasures of debris-flows in Korea. In order to sufficiently manage infrastructure from debris flow occurrences, a method or system to assess the hazard of debris flows during certain rainfall events in a regional scale was needed.

Meanwhile, seismically triggered landslides are one of the most damaging hazards associated with earthquakes. They can not only cause the damage to lives and structures directly, but also cease the operation of the whole social systems by making the roads and/or lifelines useless. For these reasons, securing the slope stability for earthquake by analysing the behaviour of slope structure is one of the most important parts in earthquake preparation, especially in Korea including many mountain areas. However, there is still a lack of systematic research on securing the slope stability for earthquake in Korea. In this research, the systematic research on factors affecting the slope stability for earthquake and evaluation method of slope stability considering earthquake induced factors should be needed.

Geographic Information System (GIS) technologies could provide a powerful tool to model the landslide hazards for their spatial analysis and prediction (Mukhlisin et al., 2010). This is because the collection, manipulation and analysis of the environmental data on landslide hazard can be accomplished much more efficiently and cost effectively (Carrara and Guzzetti, 1999; Guzzetti et al., 1999; Ghafoori and Lashkaripour, 2009; Mukhlisin et al., 2010). Many GIS-based analysis

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models and quantitative prediction models of landslide hazard have been proposed since the beginning of GIS application in geo-hazards research in the late 1980s (Carrara, 1983; Carrara et al., 1991, 1995, 1999; Jade and Sarkar, 1993; Chung et al., 1995, Chung and Fabbri, 1998, 1999, 2001).

In this study, integrated information system of landslide hazard map during earthquake was developed. The developed system built, within the frame of GIS, consists of a database (DB) containing all site information and processed data in the system in the standard data formats, and the system software performing various functions to manage and utilize the data in the database. The system software is functionally divided into an input module, earthquake-induced landslide assessment module, rainfall-induced landslide assessment module, and hazard mapping module. For the earthquake-induced landslide hazard, study area was Cheonggae Mountain in Korea, and two-dimensional landslide hazard map for dynamic factor of safety and Newmark displacement was constructed by using amplification factor obtained from geometrical characteristics of slope based on the developed system. And the rainfall-induced landslide hazard module was applied on three expressway sections in Korea; the Deogyu Mountain area of the Daejun-Jinju Expressway. The reliability of the assessment method was investigated by comparing actual debris-flow occurrence and non-occurrence cases.

2 FRAMEWORK FOR LANDSLIDE HAZARD ASSESSMENT INDUCED BY MULTI-SOURCE

2.1 Methodologies for Landslide Hazard Assessment during Earthquake

To evaluate the site-specific landslide hazard during earthquake for macro-zonation of Korea (over 4 km^2 unit area), the digital map contained topography layer (having digital elevation model) are usually utilized as the backbone datasets (Kim, 2014). In this study the, the systematic procedure for earthquake-induced landslide hazard assessment using digital map was newly proposed to develop the digital information system (Figure 1).

For the processing of spatial analysis based on ArcGIS, digital map (1:5,000 scales) provided by the National Geographic Information Institute of Korea was used. Of the entities within the digital map, only the topography layers (type of polyline) entities were extracted and used. With the elevation layers, triangulated irregular network (TIN) was used for construction of 2D continuous elevation and slope DEM (type of raster). According to the algorithm of TIN, TIN is a vector-based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines (Booth, 2000; Shekhar and Xiong, 2008). The vertices of each triangle are sample data points having three-dimensional coordinates. These sample points are linked with lines to form Delaunay triangles (Shekhar and Xiong, 2008). The TINs are used to store and display surface models of target area. Linked with the DEM obtained from algorithm of spatial analysis, landslide hazard during earthquake can be simply estimated through the dynamic factor of safety and the Newmark displacement derived horizontal amplification factors for flexible slope with inclined bedrock (Lee et al., 2014).

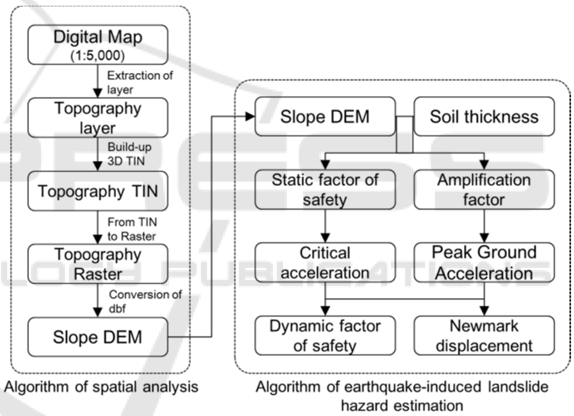


Figure 1: Systematic procedure architecture for landslide hazard assessment during earthquakes.

To evaluate the seismic stability of a landslide, both the pseudo-static method and the Newmark sliding block method (1965) are most often used simultaneously. In both methods, the target area is assumed to have an infinite slope. To obtain the factor of safety of the slope in a static condition, a relatively simple limit-equilibrium model of an infinite slope in material having both friction and cohesive strength can be used. The factor of safety (FS) in static conditions is as follows:

$$FS_{static} = \frac{c}{\gamma_t h \sin\alpha} + (1 - \frac{s\,\gamma_\omega}{\gamma_t})\frac{\tan\phi}{\tan\alpha} \quad (1)$$

The pseudo-static method for seismic slope stability is based on assumptions of the limit equilibrium and is still the most popular method in geotechnical engineering practice. The pseudo-static analysis provides an index of stability (the factor of safety) but no information concerning deformations associated with slope failure. Because the serviceability of a slope after an earthquake is controlled by deformations, analyses that predict slope displacements provide a more useful indication of the seismic slope stability (Kramer, 1996; Yin 2014). Newmark's method (1965) is a landslide model to determine the cumulative displacement of a landslide as a rigid-plastic block that slides on an inclined plane.

2.2 Methodologies for Landslide Hazard Assessment during Rainfall

For the processing of attributes included in the KEC method, a systematic sequence using the software ArcGIS 10.1 was newly proposed (Figure. 2). Various ArcGIS tools such as the [Spatial Analyst Tools] and the [Analysis Tools] were used for a quantitative and objective assessment of the attributes.

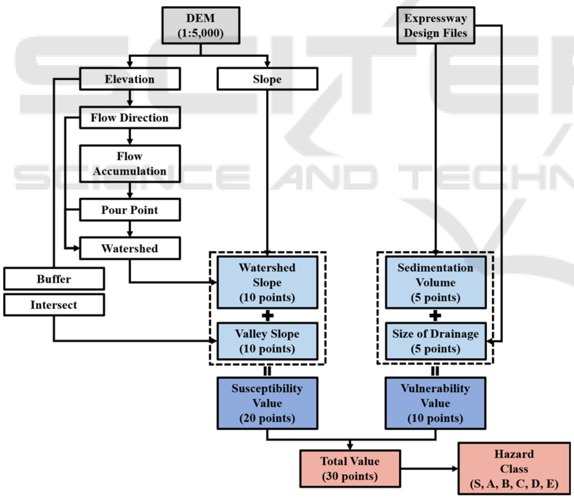


Figure 2: Systematic procedure architecture for landslide hazard assessment during rainfall.

For the processing of watershed slope and valley slope datasets, DEMs provided by NGII of Korea were used. Numerical maps with the highest resolution were those of 1:1,000 scales. However, 1:1,000 scale numerical maps were only provided for major urban areas. Because numerical maps of the highest resolution provided for the whole Korean Peninsula were those of 1:5,000 scales, numerical maps with the scale of 1:5,000 were implemented in the attribute processing for the Susceptibility Value.

Of the entities within the DEMs, only the polyline entities having to elevation value were extracted from numerical map and used for construction of DEM. Because the system focuses on the debris flow hazard assessment of expressway facilities, the expressway layers were selected. For the processing of slopes in the surround area of expressway, elevation layers were also selected. With the elevation layers of DEMs, elevation and slope raster with the smallest cell sizes possible were obtained. Because the minimum cell size that could be considered with 1:5,000 DEMs were 5 meters, raster with cell sizes of 5 by 5 meters were processed. Based on the elevation raster, the flow direction data sets were computed. The [Flow Direction] tool creates a raster of flow direction from each cell to its steepest downslope neighbour (Olivera et al., 2002). From the flow direction raster, the flow accumulation datasets were obtained. The [Flow Accumulation] tool creates a raster of accumulated flow into each cell. With a flow accumulation grid, valleys may be defined through the use of flow accumulation value (Olivera et al., 2002). For a more accurate visualization of valley areas, the properties of the flow accumulation grids were altered in various ways. Through trial and error, along with comparison with the actual field investigations, the standard deviation of 0.1 was concluded to visualize the valleys in the most appropriate and realistic way.

After setting a pour point (output point) on the route of the assessed expressway, the flow direction and pour point were taken into consideration to obtain the watershed. The [Watershed] indicates the drainage areas contributing flow from the land surface to the water system. Through the [Extract by Mask] tool, the slopes of the cell in the watershed area were obtained. Through the histogram in the raster properties, the values for attributes of mean watershed slope and area percentage of watershed with slopes over 35° were acquired.

2.3 System Program

Based on the design schema described above, the system structure consisting of a database and three modules was established, as shown in Figure 2. The spatial database using GIS platform is the backbone of the developed system. It stores not only primary collected field data such digital map, and topography layer, rainfall datasets but also secondary processed data obtained from the application of the modules of the system. An input module provides an effective way to store and arrange all collected field data in the DB according to standard data formats (Figure 3). In the earthquake-induced landslide assessment module, spatial analysis algorithm using digital map and landslide hazard estimation algorithm are designed as functional program language for automatically systematic procedure (Figure 1). The debris flow framework has four functional phases with the database based on proposed schematic sequence of debris flow hazard assessment (Figure 2). The hazard mapping module provides visual functions such as 2D plane views, and 3D views together with tabular formats in real-time.

With system software installed in a client PC, connected to the server by network, a user manages and utilizes the information in the DB. The system software focuses on user friendly functions and real-time applications. In particular, field data can be entered into the DB very simply. Once stored in the DB, all data can be utilized without difficulty in each module of the system software.

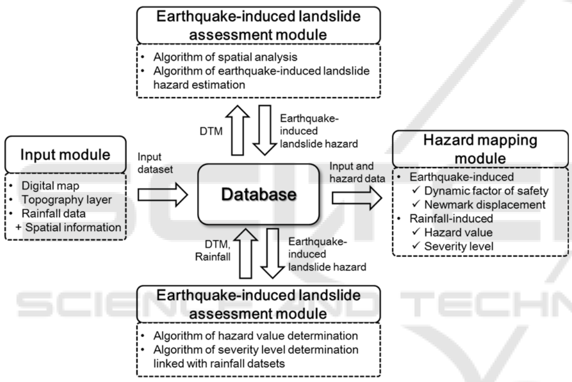


Figure 3: Composition of framework for landslide hazard assessment during earthquakes and rainfall.

Microsoft SQL Server was chose for the GDBMS (Geospatial DataBase Management System) of the developed system because of the robustness and scalability of its GDBMS. Residing on the DB server, the GDB contains information on all seven classes: three primary collected field data and four processed data. The data was standardized by accompanies by establishing a relation between geographic locations and other attribute information. The primary classes of the data model and relations between these classes are shown in Figure 4.

DB is the basic data format for GISs to refer to attribute information, and to correlate and analyse various datasets spatially. DB of the developed system was established based on a two-dimensional coordinate system. Sub-areas for a wide target area are generally used in fields to promote the efficiently of site-specific landslide hazard management. Also, a digital map can be used as basic topographical information of the system because it offers an easy way to construct topographical information for a target area. And topography layer (polyline) and digital terrain model (raster) are extracted from digital map to construct the DEM having numerical spatial information.

Earthquake-induced landslide hazard information consists of DEM information contained spatial analysis results and hazard parameters. Spatial analysis results contain the slope DEM, and soil thickness DEM. And the hazard information (dynamic factor of safety, Newmark displacement) are automatically determined and stored in to database with DEM.

Rainfall-induced landslide hazard information is constructed according to the three phases. The first phase, linked with the digital numerical map and DEM, the watershed DEM and valley layer are extracted using ArcGIS desktop program and input system DB. And second phase, the susceptibility value and venerability value for target route are constructed into DB combined with geospatial information. And the third phase, to transmit the reliable rainfall monitoring data for target route from the widely distributed meteorological observatory server in real-time basis, the routes completed site investigation for debris flow hazard were grouped into the same datasets focusing on the adjacent rainfall station in certain area. In addition, the rainfall value for debris flow hazard assessment are automatically computed based on monitoring criterion with rainfall recurrence periods for road design in Korea as soon as input rainfall monitoring data to DB. Finally, following rainfall threshold level for debris flow hazard (from KEC method), severity levels composed of safe, caution, and danger are determined as map symbol at target route in real-time and alarmed as sound signal and message window to notify the hazard status.

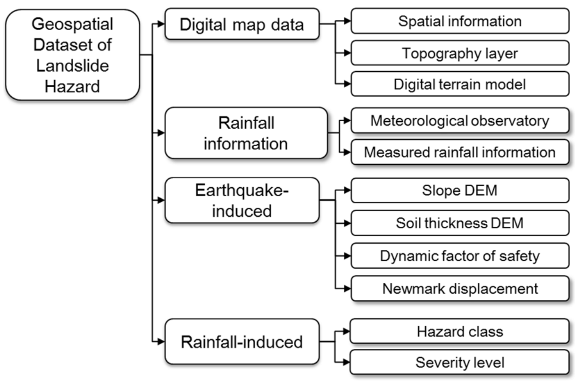


Figure 4: Database schema.

Management of input or analysis results data is the fundamental and indispensable function to run the system software based on the DB. Therefore, prior to input of attribute information, landslide hazard information must be inputted in the DB. Management of data is performed in the independent window form according to the database structure. Based on the management module, sub-modules are combined using management program with automated linking procedure: input module, earthquake-induced landslide assessment module, rainfall-induced landslide assessment module and hazard mapping module.

The main management program has various functions: menu (①), visualization tool (②), layer content (③), map view (④), set-up window of earthquake scenario (⑤), spatial coordinate content (⑥). From the menu, when users select the menu function, the related sub-modules can be implemented as sharing database. And site information inputted from input modules and landslide hazards estimated proposed assessment framework are visualized on the map view, which display the 2D spatial distribution of the satellite map.

Project information and topographic information of site information are managed in a same window form, because this information generally is used to identify locations of attribute information spatially. Also, digital or satellite map are directly converted into topographic information. Considering the efficiency of data management, input of geographic information for sub-area information and attribute information was designed to be performed in input window forms for attribute information. Geographic information for attribute information is used to display locations of attribute information on topographic map, that is, background map. The window forms for management of geographic information for target site are shown Figure4.

Even though the earthquake and rainfall events are rapidly occurred at wide region, site-specific earthquake-induced landslide hazard assessment, which is established by considering the amplification factor obtained from geometrical characteristics of slope. And these methods are not simply applied at various site conditions, as providing possible landslide hazard in every instance. Therefore the wizard functions for sequential earthquake-induced landslide hazard assessment are developed in the integrated system. And the wizard functions upon were arranged at left-side of window form (⑤). Users want to see desired information in the DB in user-friendly and functional manner. The output of attribute information, which is provided by graphic user interface (GUI), can be displayed in a tabular form and graphic form. Tabular forms are generally used to input, edit and view information in the DB, and graphic forms provide intuitive views of the spatial relationship between attributive information.

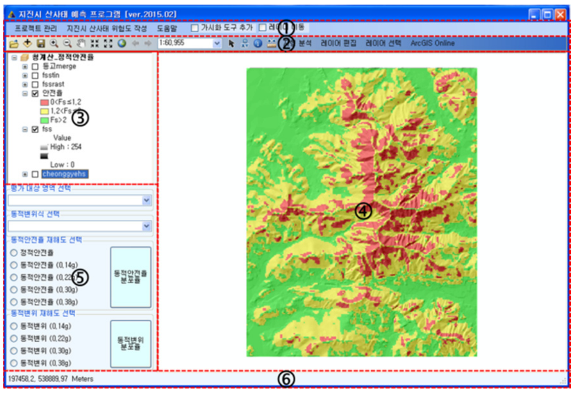


Figure 5: Main management program of integrated information system.

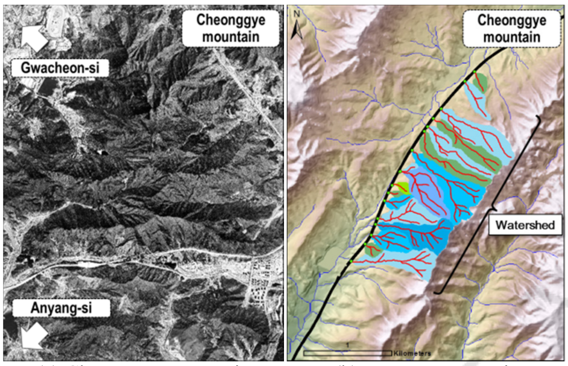
The hazard mapping module displays all attributive information in the database by using tables and graphics according to its characteristics either, on screen or as a document. Also, all data in DB can be output as a chart or a graphic. The graphic functions display interpolated data with field data over an arbitrary domain at same time. All of the charts, graphs and drawings can then be printed. Especially, the debris flow hazard can be visualized and forecasted as 2D maps overlain by satellite images as a background maps. And the severity level can be determined using zonation criteria in real-time.

In this proposed framework, the computer-based method for real-time assessment of spatial debris flow hazard was embedded based on a stand-alone system developed using Microsoft Visual BASIC, the Esri ArcGIS developer tool (Esri, 2006; Lee and Wong, 2001). The ArcGIS developer tool was mainly used for development of the database, evaluation of the results, and spatial visualization.

3 SYSTEMATIC FIELD APPLICATION

3.1 Simulation Conditions

In this research, to validate the applicability and effectiveness of the integrated landslide hazard assessment system based on GIS, the systematic field application was performed. For the earthquake-induced hazard, Cheonggae Mountain in Korea is selected as the target area, and the GIS technique is used to construct a hazard map. Using the developed system program, a pseudo-static analysis is used to determine the factor of safety, and Newmark sliding block analysis is used to determine the seismic displacement. Figure 6 describes the satellite map for target area.



(a) Cheonggye Mountain (b) Deogyu Mountain

Figure 6: Simulation tests conditions of earthquake scenarios for the Cheonggye Mountain and rainfall scenarios applied watershed analysis for the Deogyu Mountain, Korea.

To construct a hazard map for a seismic landslide, ArcGIS ver. 10.1, provided by Environmental System Research Institute, Inc.(ESRI), and a 1:5,000 digital map provided by National Geographic Information Institute are used. According to the soil survey of a site, the *SPT-N* value from a standard penetration test is from 20 to 50. In this study, the soil survey information is assumed to govern our entire target area, and the *SPT-N* value of 35 is used to construct a hazard map. From the *SPT-N* value, the internal friction angle of 40° is predicted by empirical correlation between *N* and friction angle suggested by Meyerhof in 1956. In this analysis, both c and S are assumed zero, and γt is assumed to be 18 kN/m^2 in eq (1). Case of 0.14 g as peak ground acceleration (PGA) is used in this analysis, and the information of the amplification factor corresponding to the slope is used to evaluate ac. And the Newmark displacement was calculated using the representative empirical formula (proposed by Ambraseys and Menu, 1988).

For rainfall-induced hazard, debris flows occurred in the Deogyu Mountain area of the Daejeon-Jinju Expressway in the summer of 2005 (312.0mm/day and 54.5mm/hr). All existing watersheds in the test beds were analysed. Of all the watersheds in the selected regions, the areas with target structure (expressways) positioned on bridges and tunnels, or near vast areas of fields were excluded from the analysis due to their very low likelihood of damage according to the condition of debris-flow.

3.2 Landslide Hazard Map

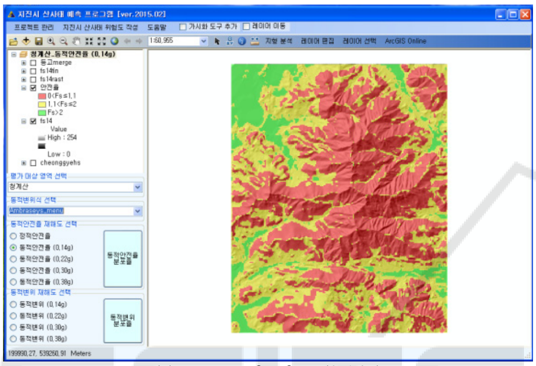
3.2.1 Earthquake-induced Landslide

By using the slope DEM, soil depth, and internal friction angle information, the factors of safety for static and seismic slope stability are obtained. Figure 5 shows the results on the factor of safety under four cases of different PGAs. The severity class of dynamic factor of safety was categorized 3 levels ('Low', 'Moderate', 'High'). From Figure 7, the factor of safety lower than 1 ('High' level) is common in the four case for the Cheonggye Mountain. And the area that has the distribution of the factor of safety lower than 1 increases as the PGA increase. In addition, the area that has the distribution of the factor of safety higher than 2 decreases as the PGA increases.

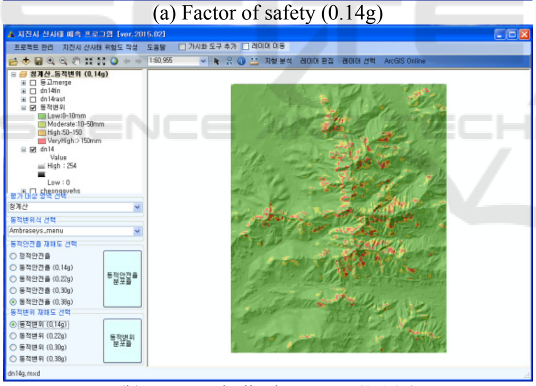
Figure 7 shows the results of Newmark displacement for each PGA event. The yield acceleration is calculated, with factor of safety from eq (1), and the Newmark displacement in each case is calculated. And the severity class of Newmark displacement was categorized 4 levels ('Low', 'Moderate', 'High', 'Very high'). In case of 0.14g, displacement more than 99% area is produced within 10mm because most of the factor of safety values in each case is higher than 1, as shown in Figure 7(a), and many factors are assumed or neglected in this analysis. On the other hand, most of target area (more than 85%) for PGA events (0.22g, 0.30g, 0.38g) was evaluated as 'High' level or 'Very high' level. Considering synthetically the dynamic factor of safety and Newmark displacement, it is possible that the Cheonggye Mountain can be damaged 'High' level ($0<FS\leq 1$, displacement>50mm), in condition of PGA event more than 0.22g.

3.2.2 Rainfall-induced Landslide

Applications of the rainfall-induced landslide hazard assessment module show results which roughly coincide with actual debris flow occurrences and non-occurrences (Figure 8(a)). Occurrence cases are roughly positioned in the upper right-hand side, which indicate higher Susceptibility and Vulnerability Values, whereas non-occurrence cases are located on the lower left side, with relatively lower Susceptibility and Vulnerability Values. Although this tendency may seem correct to some extent, it does not always show flawless results. In the hazard classes of C and D, both debris flow occurrence and non-occurrence cases are mixed up, not always indicating a result in which occurrences have higher hazard classes, and non-occurrences with lower classes. Figure 8(b) represented Severity Level and Hazard Value for rainfall scenarios. Among 17 pour point (or watershed), 6 danger sections were predicted and 5 caution and 6 safe sections were determined, in case of rainfall event recorded as 312.0mm/day.

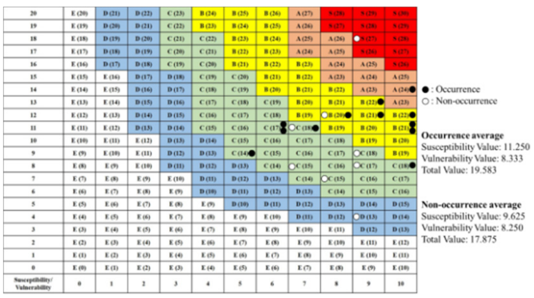


(a) Factor of safety (0.14g)

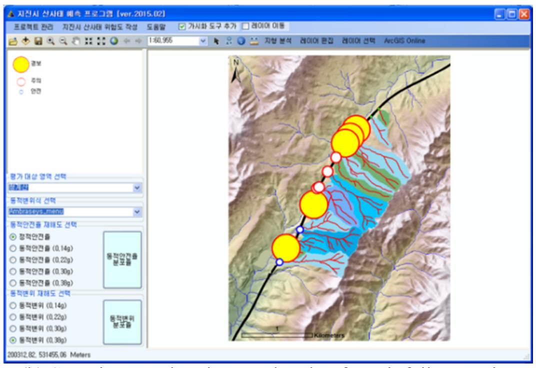


(b) Newmark displacement (0.14g)

Figure 7: Example of application results of earthquake-induced landslide hazard.



(a) Susceptibility and Vulnerability Values of debris flow occurrence and non-occurrence cases



(b) Severity Level and Hazard Value for rainfall scenarios

Figure 8: Application results of earthquake-induced landslide hazard.

4 CONCLUSION AND DISCUSSIONS

In this study, integrated information system of landslide hazard map during earthquake and rainfall was developed. The developed system built, within the frame of GIS, consists of a database (DB), and the system software performing assessment of earthquake-induced and rainfall-induced landslide hazard. The system software is functionally divided into an input module, earthquake-induced landslide hazard assessment module, rain-induced landslide hazard assessment module, and hazard mapping module. Study area is Cheonggae Mountain and Deogyu Mountain in Korea, and two-dimensional landslide hazard map for earthquake-induced landslide parameters (dynamic factor of safety and Newmark displacement) and rainfall-induced landslide parameters (Severity Level and Hazard Value) were constructed by using methodologies for landslide hazard assessment during earthquake and rainfall based on the developed system. And a summary of the results is as follows.

(1) Developed program based on GIS is useful for the construction of a landslide hazard map. However, many factors for soil characteristics are neglected or assumed specific values in this analysis. Therefore, more exact data regarding soil characteristics, such as cohesive strength, internal friction, degree of saturation covering a larger area, are required to construct a more accurate seismic hazard map.

(2) Prediction of soil depth, yield acceleration and seismic displacement, rainfall correlations between hazard value using empirical equations should be verified with actual field data to construct a more accurate landslide hazard map

induced by multi-sources.

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REFERENCES

Ambraseys, N. N. and Menu, J. M., 1988. Earthquake-Induced Ground Displacements, *Earthquake Engineering and Structural Dynamics*, 16, 985–1006.

Booth, B., 2000. *using ArcGIS 3D Analyst: GIS by ESRI*. Esri Press.

Carrara, A., 1983. Multivariate Methods for Landslide Hazard Evaluation, *Mathematical Geology*, 15, 403–426.

Carrara, A., and Guzzetti, F., 1999. Use of GIS Technology in the Prediction and Monitoring of Landslide Hazard, *Natural Hazards*, 20, 117–135.

Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V., and Reichenbach, P., 1991. GIS Techniques and Statistical Models in Evaluating Landslide Hazard, *Earth Surface Processes and Landforms*, 16, 427–445.

Carrara, A., Cardinali, M., Guzzetti, F., and Reichenbach, P., 1995. *GIS Technology in Mapping Landslide Hazard. in: Carrara, a., Guzzetti, F. (Eds.)*, Geographical Information Systems in Assessing Natural Hazards. Kluwer Academic Publishers, Dordrecht, the Netherlands, 135–175.

Chung, C. F., and Fabbri, a. G., 1993. Representation of Geoscience Datafor Information Integration, Journal *of Non-Renewable Resources*, 2(2), 122–139.

Chung, C. F., and Fabbri, a. G., 1998. Three Bayesian Prediction Models for Landslide Hazard. in: Buccianti, a. (Ed.), *Proceedings of International Association for Mathematical Geology 1998 Annual Meeting (IAMG.98)*, Ischia, Italy, October 3 – 7, 1998, 204–211.

Chung, C. F., and Fabbri, a. G., 1999. Probabilistic Prediction Models for Landslide Hazard Mapping. *Photogrammetric Engineering and Remote Sensing (PE&RS)*, 65 (12), 1388–1399.

Chung, C. F., and Fabbri, a. G., 2001. *Prediction Models for Landslide Hazard using Fuzzy Set Approach. in: Marchetti, M., Rivas, V. (Eds.)*, Geomorphology and Environmental Impact Assessment. a.a. Balkema, Rotterdam, 31–47.

Chung, C. F., Fabbri, a. G., and Van Westen, C. J., 1995. *Multivariate Regression Analysis for Landslide Hazard Zonation. in: Carrara, a., Guzzetti, F. (Eds.)*, Geographical Information Systems in Assessing Natural Hazards, Kluwer Academic Publishers, Dordrecht, the Netherlands, 107–133.

Cho, S. W., Chung, E. S., and Kim, M. M., 2003. Estimation of Slope Movement by Earthquake Loading in the Region of Moderate Seismicity, *Journal of Korean Society of Civil Engineers*, 23(4), 259–264.

Esri, 2006. *Arcgis 9: using Arcgis Desktop*. ESRI Press.

Ghafoori, M., Lashkaripour, G. R., 2009. A Geomorphological Approach to Landslide Susceptibility Assessment in Zoshk Valley, NE Iran. *in the 1st Regional Conference on Geo-Disaster Mitigation and Waste Management*.

Guzzetti, F., Carrara, a., Cardinali, M., and Reichenbach, P., 1999. Landslide Evaluation: a Review of Current Techniques and Their Application in a Multi-Scale Study, Central Italy, *Geomorphology*, 31, 181– 216.

Jakob, M., Hungr, O., 2005. Debris-Flow Hazards and Related Phenomena, *Springer*,

Jade, S., and Sarkar, S., 1993. Statistical Models for Slope Stability Classification, *Engineering Geology*, 36, 91–98.

Jibson, R. W., 1993. Predicting Earthquake-Induced Landslide Displacements using Newmark's Sliding Block Analysis, *Transportation Research Record 1411, Transportation Research Board*, Washington, D.C., 9–17.

Kim, H. S., 2014. *Integrated Earthquake Hazard Assessment System with Geotechnical Spatial Grid Information based on GIS*, Seoul National University.

Kramer, S. L., 1996. *Geotechnical Earthquake Engineering*, Prentice-Hall, NJ.

Lee, J. Y., Han, H. T., Baek, Y, Park, D. H., Lee, J. H., Park, I. J., 2014. Development of Prediction Method Considering Geometrical Amplification Characteristics of Slope II: Construction of Landslide Hazard Map during Earthquakes in Seoul, *J. Korean Soc. Hazard Mitig*, 14(5), 85–92.

Lee, J., Wong D. W. S., 2001. *Statistical Analysis with Arcview GIS*, John Wiley & Sons, Canada.

Meyerhof, G. G., 1956. *Penetration Tests and Bearing Capacity of Cohesionless Soils*, ASCE Journal of the Soil.

Mukhlisin, M., Idris, I., Salazar, a. S., Nizam, K., and Taha, R., 2010. GIS based Landslide Hazard Mapping Rediction in Ulu Klang, Malaysia. *ITB Scientific Journal*, 2A(2), 163–178.

Newmark, N. M., 1965. Effects of Earthquakes on Dams and Embankments, *Geotechnique*, 15(2), 139–160.

Olivera, F., Furnans, J., Maidment, D., Djokic, D., Ye, Z., 2002, *Drainage Systems, Archydro: GIS for Water Resource*. ESRI Press, California.

Shekhar, S., and Xiong, H., 2008. *Encyclopedia of GIS*. Springer Science & Business Media.

Yegian, M. K., Marciano, E., and Ghahraman, V. G., 1991. Earthquake -Induced Permanent Deformations: Probabilistic Approach, *Journal of Geotechnical Engineering, ASCE*, 117(1), 35–50.

Yin, K. S. P. C. Y. *Landslide Science for a Safer Geoenvironment*.