Chapter 1 Introduction

1.1 General

Debris flows caused by heavy rainfall in mountain areas nearby expressways lead to severe social and economic losses and sometimes even result in casualties. However, designs of road structures against these debris flow incidents are not generally carried out in a systematic way with proper concepts or procedures in Korea. Mostly, post-event repair processes and works have been executed. With increasing debris flow frequencies and repair expenses, the establishment of hazard prevention and mitigation tools for existing expressways is needed.

Various assessment methods for debris flows have been proposed based on their own established mechanisms and influence factors. Through comparison and review of existing studies including those of Lee et al. (2012), Lee and Pradhan (2007), Ayalew et al. (2004), Dai et al. (2002), and Lin et al. (2002), influence attributes and hazard assessment methods of debris flows were analyzed. Many attributes are related to the occurrence of debris flows. Geography, rainfall, geology, vegetation, wildfire history, conditions of existing structures are some of the attributes considered in past studies. Because the method for the assessment of debris flow hazards in this study was to be applied on a national scale (all expressway sections in Korea), the method needed to be simple, and also applicable on a large area. Considering the fact that it is a time-consuming and difficult task to obtain and process all the attributes stated previously in the prediction stage, it was decided that only easily accessible document data be used in the assessment process. Consequently, the Korea Expressway Corporation (hereinafter referred to as KEC) debris flow hazard assessment method was set as a fundamental assessment tool.

As a precautionary measure, the KEC method assesses the hazard of debris flows in a national scale using a limited amount of data sets. Taking into consideration the fact that obtaining various data sets for a large area is a hard and time-consuming task, only Digital Elevation Models (DEMs) and expressway design files of the assessment area were used. The DEMs that were used in the assessment process were ones provided by the Korea National Geographic Information Institute (NGII), whereas the Expressway design files were provided by the Korea Expressway Corporation. Through the application and use of only easily accessible data sets, the KEC hazard assessment method minimizes the need for tiresome and time-consuming field investigations, allowing an easy and comfortable hazard assessment of debris flows on a large area. The debris flow hazard is evaluated through two indexes: the Susceptibility Value and Vulnerability Value.

The Susceptibility Value indicates the actual possibility of whether a debris flow will occur, and can be estimated with the topography information on target locations using Digital Elevation Models (DEMs). The Vulnerability Value is used to represent whether an occurred debris flow will actually damage or have an impact on certain expressway sections, and can be assessed by the capacity of the drainage facility and the margin area for sedimentation of debris flow materials before reaching expressway structures. Acquisition of the Vulnerability Value influence factors is done through the use of expressway design files. The calculated Susceptibility Value and Vulnerability Value are used to indicate a single hazard class varying from S to E, which represents the hazard of debris flow events in a given rainfall intensity.

1.2 Aim and Scope of Study

In this paper, the KEC debris flow hazard assessment method was applied on four areas: the Juksan-Geochang area of the 88 Expressway, the Pyeongchang and Daegwanryung areas of the Yeongdong Expressway, and the Deogyu Mountain area of the Daejun-Jinju Expressway. Attributes for the assessment were processed through a newly proposed systematic sequence using the software ArcGIS 10.1. The reliability of the assessment method was investigated by comparing actual debris flow occurrence and non-occurrence cases of the selected areas.

In order to more properly represent the differences between the debris flow occurrences and non-occurrences, two approaches were carried out on the application process. First, the attribute grading standard was modified, taking into consideration the attribute values of actual debris flow occurrence cases. Second, additional attributes that may result in a higher reliability of the assessment method, such as watershed size and bending of valley were investigated.

After the modification and investigation processes as stated above, the outcomes of the modified application were verified in a quantitative way, showing results with better outcomes than before the modification was made.

1.3 Outline

Chapter 2 provides literature reviews that were carried out for the understanding of debris flow hazard assessments, and the terminology used in the process. In addition, a detailed introduction to the Korea Expressway Corporation approach, which was selected as a fundamental concept is included.

Chapter 3 provides information on the newly proposed sequence used for the acquisition of various attribute data considered in the KEC method. A detailed example on how the attribute data was obtained is also included in this chapter.

Chapter 4 presents the sites that were considered for application of the KEC method. Results of the KEC method application are provided and analyzed.

Chapter 5 proposes the modifications that were considered after reviewing the results of the KEC method application on actual sites. Grading standards were modified, and additional attributes that were not originally taken into thought were newly proposed to be considered.

Chapter 6 shows the results of the application of the modified grading standards proposed in Chapter 5.

Chapter 7 verifies the results provided in Chapter 6 in a quantitative way, making it easier to compare the application results of before and after the modification.

Chapter 8 presents a summary of the whole paper.

Chapter 2 Literature Review

2.1 Review on Terminology

Among countries and even within any one country there is seldom uniformity in terminology and the results of debris flow zoning are often not defined, and susceptibility, hazard and risk are often used interchangeably in debris flow/landslide zoning maps. A review of the experience in debris flow/landslide susceptibility and hazard zoning (Cascini et al., 2005) highlights the fact that these maps have different accuracy and reliability (Fell et al., 2008). For a more proper and appropriate understanding and assessment of debris flow/landslide hazards, the terminology used in the process were first organized and defined.

Definitions of the main terms are (Fell et al., 2008):

Landslide: The movement of a mass of rock, debris, or earth (soil) down a slope.

Debris flow: Fluid mixture of rocks, sand, mud, and water that is intermediate between a landslide and a water flood; includes mudflows and lahars (Keller and DeVecchio, 2010).

Debris flow susceptibility: A quantitative or qualitative assessment of the classification, volume (or area), and spatial distribution of debris flows which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential debris flow. Although it is expected that debris flows will occur more frequently in the most susceptible areas, in the susceptibility analysis, time frame is explicitly not taken into account.

Debris flow vulnerability: The degree of loss to a given element or set of elements within the area affected by the debris flow. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is (are) affected by the debris flow.

Debris flow Hazard: A condition with the potential for causing an undesirable consequence. The description of debris flow hazard should include the location, volume (or area), classification and velocity of the potential debris flows and any resultant detached material, and the probability of their occurrence within a given period of time.

2.2 Review on Assessment Methods

Various domestic and international papers were compared and analyzed for the selection of the framework of debris flow hazard assessment method: 1) Korea Expressway Corporation, 2008, 2) Lee et al., 2012, 3) Korea Forest Service, 4) Korea Institute of Geoscience and Mineral Resources, 2012, 5) The Seoul Institute, 2013, 6) Lin et al., 2002, 7) Ayalew and Yamagishi, 2005, Ayalew et al., 2004, 8) Dai et al., 2002, and 9) Lee and Pradhan, 2007.

The assessment methods were compared in four aspects: a) whether the acquisition of attribute data is simple/easy, b) whether the assessment method considers rainfall data, c) whether the assessment method has been verified through actual field applications, and d) whether the assessment method considers the influence of debris flows on expressway facilities. Each aspect was verified and indicated as O(suitable), Δ(moderate), and X(unsuitable) (Table 2.1).

Table 2.1 Comparison of existing debris flow hazard assessment studies

Aspect	**Domestic**					**International**			
	1)	**2)**	**3)**	**4)**	**5)**	**6)**	**7)**	**8)**	**9)**
a)	O	Δ	X	X	X	X	Δ	Δ	X
b)	O	O	Δ	Δ	O	X	X	X	Δ
c)	O	O	O	O	Δ	Δ	Δ	Δ	Δ
d)	O	X	X	X	X	X	Δ	X	X

First, when considering whether the acquisition of attribute data is simple/easy, the KEC method showed far less document data or field investigation data needed in its assessment process compared to the other methods. The KEC method assessed debris flow hazards using only a limited amount of document data such as DEMs and expressway design files. In other studies, additional attributes such as vegetation or geotechnical properties were used, making it harder to acquire such information with a limited amount of time or manpower.

Second, the KEC method, the study carried out by Lee et al., and the Seoul Institute method used rainfall data as an attribute, proposing their own rainfall thresholds. In the KIGAM method, rainfall was used in a different way, making it difficult for application on other sites. All other studies did not consider rainfall intensities in the assessment process.

Third, the domestic assessment methods were verified through the application on actual debris flow occurrence sites. However, other assessment methods did not consider applications on actual sites, and therefore were considered to be insufficiently verified.

Fourth, only the KEC method took into consideration the actual damage, risk, or hazard that may be applied on expressway facilities. Other methods only considered the occurrence possibilities of debris flow/landslides, and therefore was not appropriate for the use of debris flow hazard assessment on existing expressway facilities/sections.

As a result, the Korea Expressway Corporation method showed the most appropriate outcome, indicating suitable applications for all four aspects considered in the process.

2.3 Review on Korea Expressway Corporation Method

Considering the fact that it is a time-consuming and difficult task to obtain and process all the attributes stated above in the prediction stage, it was decided that only easily accessible document data be used in the assessment process. Consequently, the KEC debris flow hazard assessment method was set as a fundamental assessment tool.

As a precautionary measure, the KEC method assesses the hazard of debris flows in a national scale using a limited amount of data sets. Taking into consideration the fact that obtaining various data sets for a large area is a hard and time-consuming task, only Digital Elevation Models (DEMs) and expressway design files of the assessment area were used. The DEMs that were used in the assessment process were ones provided by the Korea National Geographic Information Institute, whereas the Expressway design files were provided by the Korea Expressway Corporation. Through the application and use of only easily accessible data sets, the KEC hazard assessment method minimizes the need for tiresome and time-consuming field investigations, allowing an easy and comfortable hazard assessment of debris flows on a large area. The debris flow hazard is evaluated through two indexes: the Susceptibility Value and Vulnerability Value.

The Susceptibility Value indicates the likeliness of whether a debris flow will occur in a target area and is assessed by a total of four attributes. The mean watershed slope, and area percentage of watershed with slopes over 35° are used for the assessment of debris flow initiation. The mean valley slope, and length percentage of valley with slopes over 15° are used for the assessment of debris flow movement. Other factors such as the size and shape of valley along with the variations in slope direction, properties of the subsoil, and vegetation also have an influence on the initiation and movement of debris flows. However, to simplify the method, only the slope information derived from the DEMs were considered for debris flow possibilities. Each of the influence factors are given points varying from 0 to 5 based on a certain grading standard set by past debris flow occurrence cases (Table 2.2), and adds up to a total Susceptibility Value of 20 points. For the weight considerations of the four attributes, logistic regression was carried out through SPSS. Results showed that the 4 Susceptibility Value attributes had weights of 0.27, 0.24, 0.26, and 0.23, respectively. Since the weights showed no significant difference, the attributes were considered to have identical weights.

The Vulnerability Value indicates whether an occurred debris flow will actually damage or have an impact on expressway sections. The Vulnerability Value is assessed by two attributes: the volume of margin area to deposit debris flow materials before reaching expressway structures, and the size of drainage facilities running through the expressway. For the acquisition of the attribute values, expressway design files provided by the Korea Expressway Corporation were used. Each of the attributes are given points ranging from 0 to 5 based on a grading standard (Table 2.2), and add up to a total Vulnerability Value of 10 points.

With the calculated Susceptibility and Vulnerability Value, a Hazard Class is given for a target expressway section (Fig. 4.3). The x-axis and y-axis indicate the Vulnerability Value and Susceptibility Value, respectively. Through investigations on past debris flow occurrences, the hazard classes were separated by rainfall reoccurrence period for expressway design purposes. Hazard class S indicates a likeliness of debris flow occurrences in areas with rainfall reoccurrence periods of 2 to 5 years. Hazard classes A, B, C, and D have rainfall reoccurrence periods of 5 to 20 years, 20 to 50 years, 50 to 100 years, and over 100 years, respectively. Hazard class E indicates an area with a very low likeliness of debris flow damage (Korea Expressway Corporation, 2009).

Table 2.2 Points given to attributes according to grading standard of KEC

Attribute	**Point of attribute / Grading standard**					
Mean watershed slope (°)	5	4	3	2	1	0
	≥ 35	< 35 ≥ 30	< 30 ≥ 25	< 25 ≥ 20	< 20 ≥ 15	< 15
Area percentage of watershed with slopes over 35° (%)	5	4	3	2	1	0
	≥ 40	< 40 ≥ 30	< 30 ≥ 20	< 20 ≥ 10	< 10 ≥ 1	< 1
Mean valley slope (°)	5	4	3	2	1	0
	≥ 25	< 25 ≥ 20	< 20 ≥ 15	< 15 ≥ 10	< 10 ≥ 5	< 5
Length percentage of valley with slopes over 15° (%)	5	4	3	2	1	0
	≥ 90	< 90 ≥ 70	< 70 ≥ 50	< 50 ≥ 30	< 30 ≥ 10	< 10
Volume of deposit area (m^3)	5	4	3	2	1	0
	0	≤ 100 > 0	≤ 1,000 > 100	≤ 5,000 > 1,000	≤ 5,000	No damage guaranteed
Size of drainage facility	5	4	3	2	1	0
	Waterway	≤ D1,200	≤ B2.0x2.0	≤ B4.0x4.0	> B4.0x4.0	Bridge

Chapter 3 Data Processing Sequence using GIS

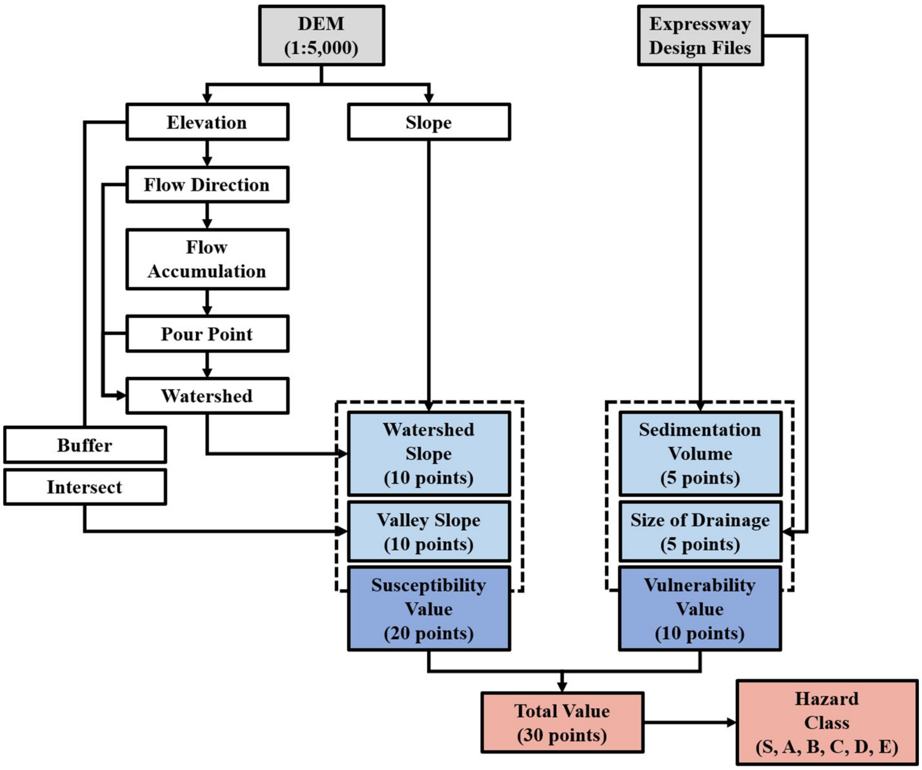


Fig 3.1 Schematic for sequence of attribute data processing

For the processing of attributes included in the KEC method, a systematic sequence using the software ArcGIS 10.1 was newly proposed (Fig. 3.1). Various ArcGIS tools such as the Spatial Analyst Tools and the Analysis tools were used for a quantitative and objective assessment of the attributes.

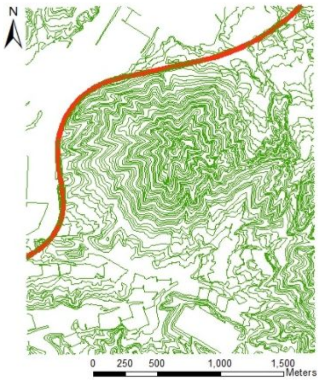
3.1 Attribute Processing for the Susceptibility Value

For the processing of watershed slope and valley slope data sets, Digital Elevation Models (DEMs) provided by the National Geographic Information Institute (NGII) of Korea were used. Numerical maps with the highest resolution provided by the NGII were those of 1:1,000 scales. However, 1:1,000 scale numerical maps were only provided for major urban areas such as Seoul. 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.

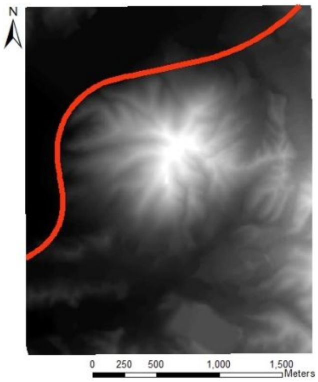
Of the entities within the DEMs, only the Polyline entities were extracted and used. Because the system focuses on the debris flow hazard assessment of expressway facilities, the expressway layers were selected. For the processing of slopes in the region of interest, elevation layers were also selected (Fig. 3.2(a)). With the elevation layers of DEMs, elevation and slope rasters with the smallest cell sizes possible were obtained (Fig. 3.2(b), Fig. 3.2(c)). Because the minimum cell size that could be considered with 1:5,000 DEMs were 5 meters, rasters with cell sizes of 5 by 5 meters were processed. Based on the elevation rasters, the flow direction data sets were computed (Fig. 3.2(d)). The [Flow Direction] tool creates a raster of flow direction from each cell to its steepest downslope neighbor (Olivera et al., 2002). From the flow direction raster, the flow accumulation data sets were obtained (Fig. 3.2(e)). 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.

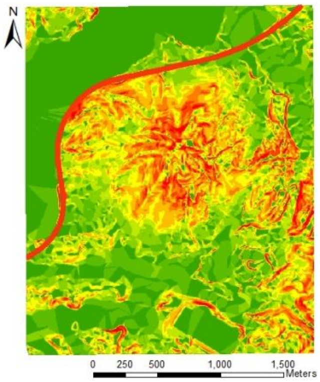
After setting a pour point (output point) on the route of the assessed expressway, the flow direction and pour point were taken into consideration to obtain the watershed (Fig. 3.2(f)). The [Watershed] indicates the drainage areas contributing flow from the land surface to the water system (Olivera et al., 2002). Through the [Extract by Mask] tool, the slopes of the cell sin 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 (Fig. 3.2(g)).



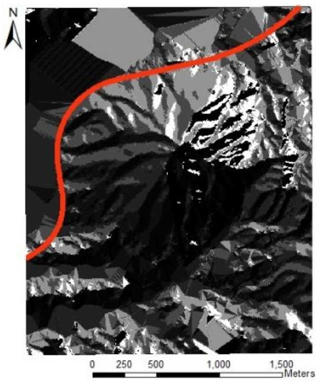
(a) Polyline entity of DEM



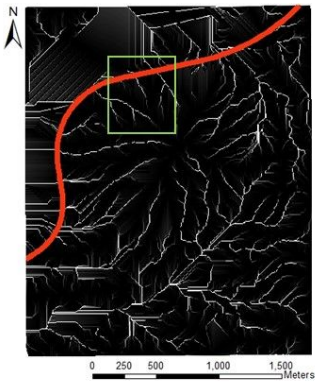
(b) Elevation layer



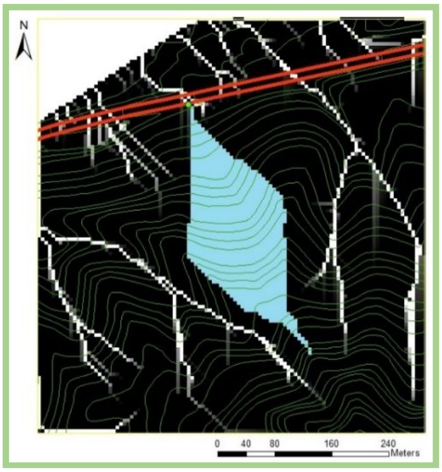
(c) Slope layer

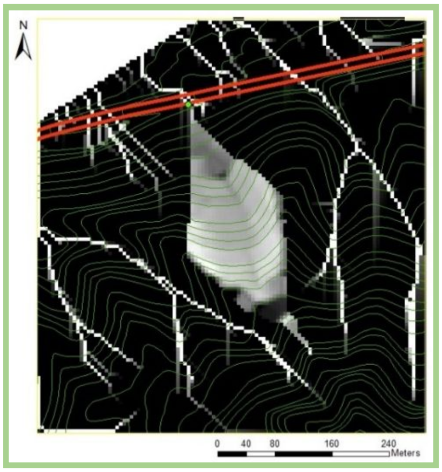


(d) Flow direction



(e) Flow accumulation





(f) Watershed (g) Watershed slope

Figure 3.2 Details of sequence application for watershed slope attributes

Because the slope rasters indicate the steepest slope with regard to their surrounding pixels, and not the slope in the valley direction, previously obtained slope rasters could not be implemented for the attributes related to the valley. Other means were used for the acquisition of valley slope data. An approach assessing the slope through the elevation rasters in the valley direction was proposed, and applied.

From the flow accumulation layer, the valley shapes in the watershed were obtained. The valley paths were then manually plotted on the elevation layer. The elevation of the cells that are in the path of the valley were obtained through the [Extract by Mask] tool using the plotted valley path and elevation layer. With the length of the plotted valley path, and the total elevation difference between the expressway and the highest point in the valley path, the mean valley slope was simply calculated (Eq. 1).

$$\text{Mean valley slope } (\Phi_i) = tan^{-1}\left(\frac{\Delta H}{L_{path}}\right) \qquad (1)$$

where, ΔH: Elevation difference between expressway and highest point in valley path

L_{path}: Length of plotted valley

Considering the fact that the assessment method is planned to be implemented on a real-time hazard assessment method, the method needed to properly assess debris flow hazards in a precautionary fashion. In the estimation and prediction stage, the valley in which a debris flow will initiate is unknown. Therefore, for watersheds with more than one valley, all valleys in the watershed were considered in the process. The mean valley slopes for each valley were calculated, and were averaged using the valley lengths as weight factors (Eq. 2).

$$\text{Overall mean valley slope} = \frac{\sum_{i=1}^{n}(\Phi_i \cdot L_i)}{\sum_{i=1}^{n} L_i} \tag{2}$$

where, Φ_i: Mean valley slope of individual valley

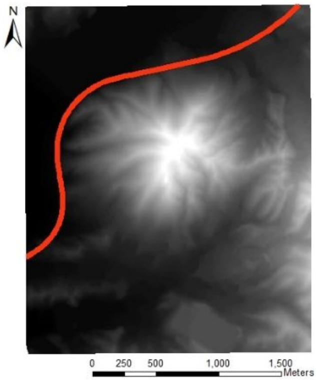
L_i: Length of individual valley

The extracted cells obtained through the [Extract by Mask] tool did not properly represent the valley directions, showing abrupt valley direction changes in right angles (Fig. 3.3(c)). In order to appropriately assess the slopes in the actual flow directions of the valleys for the calculation of the length percentage of valley with slopes over 15°, additional ArcGIS tools were used. The extracted valley path elevations cells were converted to points through the [Raster to Point] tool, and were assigned XY coordinates (Fig. 3.3(d)). With the [Buffer] tool, a buffer of 1.5 meters was set around the manually plotted valley path (Fig. 3.3(e)). In order to obtain the valley path points that are positioned inside the 1.5 buffer zone of the plotted valley path, the [Intersect] tool was used. Through the process, only the valley path points that were in the vicinity of the actual valley path were obtained (Fig. 3.3(f)). Using the .dbf files of extracted points, the slope between the cells in the direction of the valley travel path was calculated using Microsoft EXCEL. Through the calculation results of the .dbf files, the distances between cells with slopes over 15° were obtained, as a result, allowing the calculation of the length percentage of valley with slopes over 15°. As in the mean valley slope calculation process in watersheds with more than one valley, the length percentage of valley with slopes over 15° was calculated using a similar process (Eq. 3).

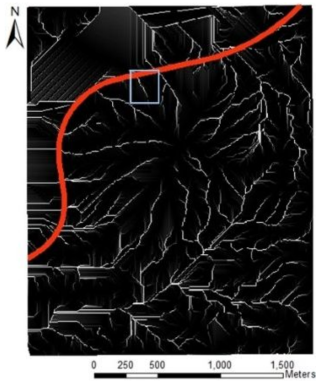
Overall length percentage of valley with slopes over 15°

$$= \frac{\sum_{i=1}^{n}((L_{15})_i)}{\sum_{i=1}^{n} L_i} \qquad (3)$$

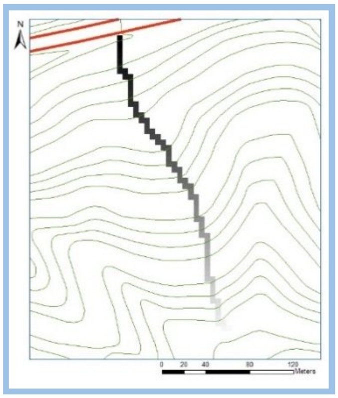
where, $(L_{15})_i$: length of valley with slopes over 15° for individual valley



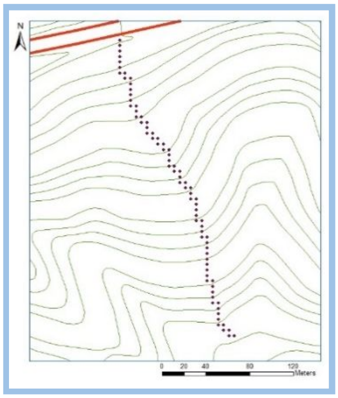
(a) Elevation



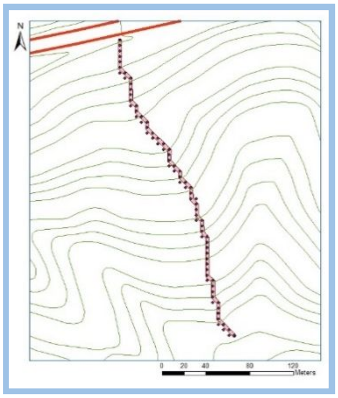
(b) Flow accumulation

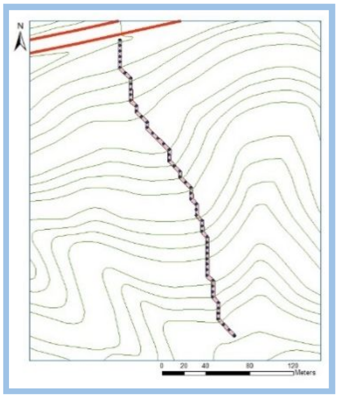


(c) Elevation extracted for cells on valley path



(d) Cell elevation converted to points





(e) Buffer applied on valley path (f) Intersect of Buffer and cell points

Figure 3.3 Details of sequence application for valley slope attributes

3.2 Attribute Processing for the Vulnerability Value

By the expressway design files, the volume of area available for sedimentation was calculated by simplifying the area as a triangular pyramid bounded by the valley and expressway embankment (Korea Expressway Corporation, 2009) (Fig. 3.4). The volume of the margin area of sedimentation is calculated using Eq. 4. The drainage facility information of each watershed was obtained through expressway design files, and attribute points were determined according to a grading standard set by the KEC (Table 2.2).

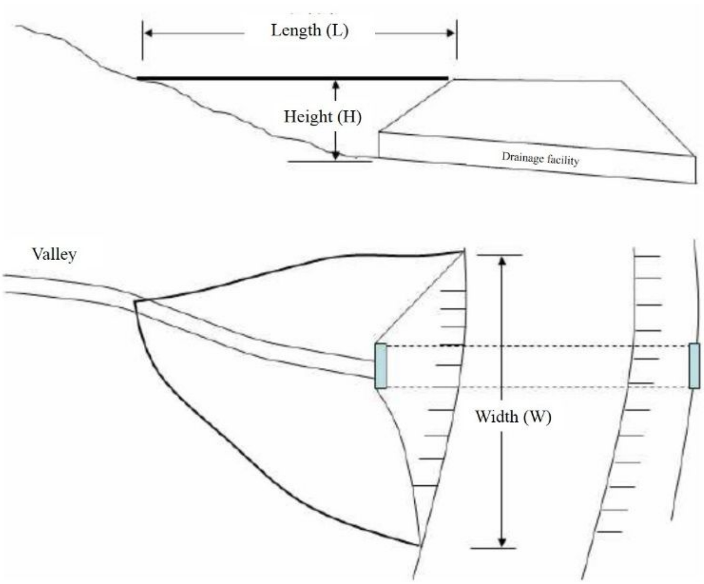


Figure 3.4 Schematic of sedimentation volume

$$\text{Sedimentation volume} = \frac{1}{6}(L \times H \times W)$$

Chapter 4 Application of Korea Expressway Corporation Method on Sites

4.1 Areas of Interest

The Juksan-Geochang area of the 88 Expressway, the Pyeongchang area of the Yeongdong Expressway, the Deogyu Mountain area of the Daejun-Jinju Expressway, and the Daegwanryung area of the Yeongdong Expressway were selected for investigation of their debris flow hazards. In the summer of 2006, the Juksan-Geochang area faced several debris flows during a heavy rainfall event. The rainfall intensity at that time was 121.0mm/day, and 31.5mm/hr. Many debris flows occurred in the Pyeongchang area during a heavy rainfall event (244.0mm/day, 66.0mm/hr) in the summer of 2006. In the summer of 2005, debris flows occurred in the Deogyu Mountain area of the Daejun-Jinju Expressway. The rainfall intensity in the region at that time was 312.0mm/day and 54.5mm/hr. During the 2002 Rusa typhoon event, debris flows occurred in the Daegwanryung region. The rainfall intensity of the area at the time was 701.5mm/day and 60.5mm/hr. When comparing all target areas, the Pyeongchang and Deogyu Mountain areas had similar rainfall intensities, indicating same rainfall reoccurrence periods. The Daegwanryung area indicated more than twice of the Pyeongchang and Deogyu Mountain areas when comparing daily rainfall, whereas the Juksan-Geochang area had the lowest daily rainfall.

For each area, a test bed area was set for the application of the assessment method. A test bed with a length of 2.5km along the 88 Expressway was chosen for the Juksan-Geochang area. The lengths of the test beds for the Pyeongchang, Deogyu Mountain, and the Daegwanryung areas were 11km, 15km, and 20km respectively. All existing watersheds in the selected expressway test beds were analyzed. Of all the watersheds in the selected regions, areas with expressways positioned in bridges and tunnels, or near vast areas of fields were excluded from the analysis due to their very low damage likeliness. Since reported debris flows were based on the damage that was made to road structures, areas without any damage were not reported. Thus, no debris flow damages were reported in regions where the volumes of sedimentation-possible areas are vast, and consequently were not considered in the analysis process. After the exclusion of aforementioned sites, the watersheds were then classified by whether debris flow damages have been reported or not. Areas with debris flow damages reported are hereinafter referred to as “occurrences”, and those without damage reports as “non-occurrences”. As a result, 9 debris flow occurrences and 7 non-occurrences were analyzed for the Juksan-Geochang area. 18 debris flow occurrences and 14 non-occurrences were analyzed for the Pyeongchang area. 12 debris flow occurrences and 8 non-occurrences were analyzed for the Deogyu Mountain area. 5 debris flow occurrences and 8 non-occurrences were analyzed for the Daegwanryung area.

Figure 4.1 Overview of assessed target regions

4.2 Results of Application on Selected Sites

Applying the assessment method on the selected four sites, along with the use of ArcGIS 10.1, attribute data sets were processed (Fig. 4.2). Specific attribute datasets are presented in the Appendix.

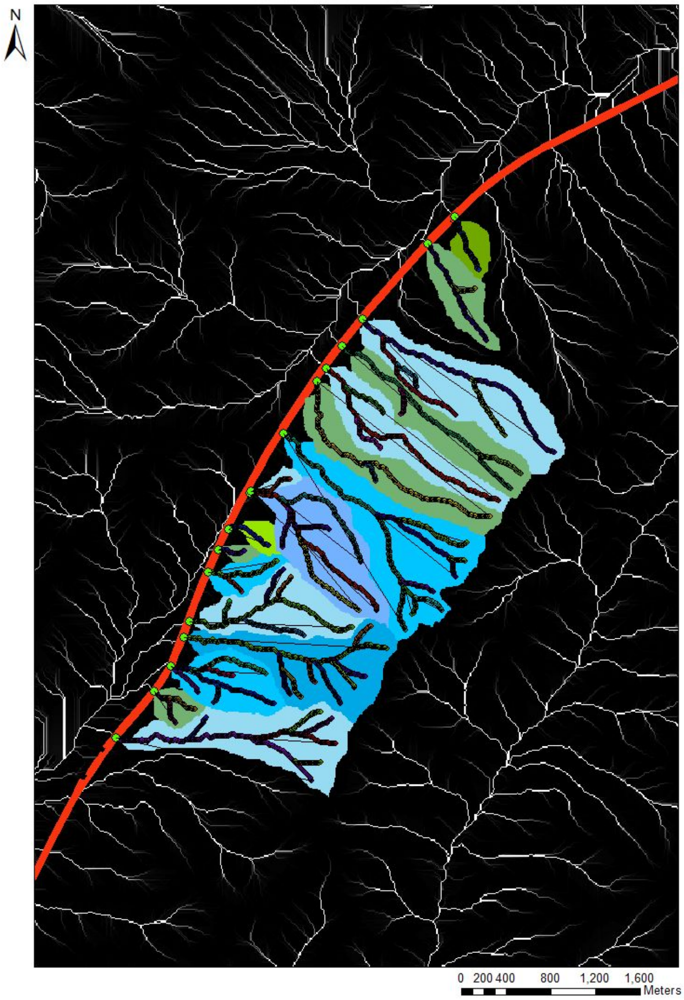


Figure 4.2 Overview of data set processing in Juksan-Geochang area

20	E (20)	D (21)	D (22)	C (23)	B (24)	B (25)	B (26)	A (27)	S (28)	S (29)	S (30)
19	E (19)	D (20)	D (21)	C (22)	B (23)	B (24)	B (25)	A (26)	S (27)	S (28)	S (29)
18	E (18)	D (19)	D (20)	C (21)	C (22)	B (23)	B (24)	A (25)	A (26)	S (27)	S (28)
17	E (17)	D (18)	D (19)	C (20)	C (21)	B (22)	B (23)	A (24)●	A (25)	S (26)	S (27)
16	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	B (23)	A (24)●	A (25)	S (26)
15	E (15)	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	A (23)	○○A (24)	A (25)
14	E (14)	E (15)	D (16)	D (17)	C (18)	C (19)	B (20)	B (21)	B (22)●	A (23)	A (24)
13	E (13)	E (14)	D (15)	D (16)	C (17)	C (18)●	C (19)	B (20)	B (21)●	B (22)	A (23)
12	E (12)	E (13)	D (14)	D (15)	C (16)	C (17)	C (18)	B (19)	B (20)	B (21)	B (22)
11	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)	B (19)	B (20)	B (21)●
10	E (10)	E (11)	E (12)	D (13)	○D (14)	○C (15)	C (16)	C (17)	C (18)	B (19)	B (20)
9	E (9)	E (10)	E (11)	D (12)	D (13)	○C (14)	C (15)	C (16)	C (17)	C (18)	B (19)
8	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	C (14)●	C (15)	C (16)	C (17)	○C (18)
7	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	C (14)●	C (15)●	C (16)	C (17)
6	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)	C (14)	C (15)	C (16)
5	E (5)	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)	D (14)	D (15)
4	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	○D (14)
3	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	D (12)	D (13)
2	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	E (12)
1	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)
0	E (0)	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)
Susceptibility/ Vulnerability	0	1	2	3	4	5	6	7	8	9	10

● : Occurrence
○ : Non-occurrence

Occurrence average
Hazard Value: 11.780
Vulnerability Value: 7.440
Total Value: 19.220

Non-occurrence average
Hazard Value: 10.140
Vulnerability Value: 7.430
Total Value: 17.570

(a) Juksan-Geochang area on 88 Expressway

20	E (20)	D (21)	D (22)	C (23)	B (24)	B (25)	B (26)	A (27)	S (28)	S (29)	S (30)
19	E (19)	D (20)	D (21)	C (22)	B (23)	B (24)	B (25)	A (26)	S (27)	S (28)	S (29)
18	E (18)	D (19)	D (20)	C (21)	C (22)	B (23)	B (24)	A (25)	A (26)	S (27)	S (28)
17	E (17)	D (18)	D (19)	C (20)	C (21)	B (22)	B (23)	A (24)	A (25)	S (26)	S (27)●
16	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	○B (23)	A (24)	A (25)●	S (26)
15	E (15)	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	A (23)	○A (24)	A (25)●
14	E (14)	E (15)	D (16)	D (17)	C (18)	C (19)	B (20)	B (21)	B (22)	A (23)●	A (24)●
13	E (13)	E (14)	D (15)	D (16)	C (17)	C (18)	C (19)	B (20)	B (21)●	B (22)●	A (23)
12	E (12)	E (13)	D (14)	D (15)	C (16)	○C (17)	C (18)	B (19)	B (20)●	B (21)	B (22)●
11	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)●	B (19)●●	B (20)	B (21)
10	E (10)	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)	○○B (19)	○B (20)
9	E (9)	E (10)	E (11)	D (12)	D (13)	C (14)	C (15)	C (16)●	C (17)●	○C (18)●	B (19)●
8	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	C (14)	○○C (15)●	C (16)	C (17)	○C (18)
7	E (7)	E (8)	E (9)	E (10)	D (11)	○D (12)	○D (13)	C (14)●	C (15)	C (16)	C (17)
6	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)	C (14)	○C (15)	C (16)
5	E (5)	E (6)	E (7)	E (8)	E (9)	○D (10)	D (11)	D (12)	D (13)	D (14)	D (15)
4	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	D (14)
3	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	D (12)	D (13)
2	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	E (12)
1	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)
0	E (0)	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)
Susceptibility/ Vulnerability	0	1	2	3	4	5	6	7	8	9	10

● : Occurrence
○ : Non-occurrence

Occurrence average
Hazard Value: 11.667
Vulnerability Value: 8.556
Total Value: 20.223

Non-occurrence average
Hazard Value: 9.357
Vulnerability Value: 7.643
Total Value: 17.000

(b) Pyeongchang area on Yeongdong Expressway

20	E (20)	D (21)	D (22)	C (23)	B (24)	B (25)	B (26)	A (27)	S (28)	S (29)	S (30)
19	E (19)	D (20)	D (21)	C (22)	B (23)	B (24)	B (25)	A (26)	S (27)	S (28)	S (29)
18	E (18)	D (19)	D (20)	C (21)	C (22)	B (23)	B (24)	A (25)	A (26)	○S (27)	S (28)
17	E (17)	D (18)	D (19)	C (20)	C (21)	B (22)	B (23)	A (24)	A (25)	S (26)	S (27)
16	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	B (23)	A (24)	A (25)	S (26)
15	E (15)	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	A (23)	A (24)	A (25)
14	E (14)	E (15)	D (16)	D (17)	C (18)	C (19)	B (20)	B (21)	B (22)	A (23)	A (24)●
13	E (13)	E (14)	D (15)	D (16)	C (17)	C (18)	C (19)	B (20)	B (21)	B (22)●	A (23)
12	E (12)	E (13)	D (14)	D (15)	C (16)	C (17)	C (18)	B (19)	○B (20)●	B (21)●	B (22)●
11	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)●●	○C (18)●	B (19)	B (20)	B (21)●●
10	E (10)	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)	B (19)	B (20)
9	E (9)	E (10)	E (11)	D (12)	D (13)	C (14)●	C (15)	C (16)	C (17)	○C (18)	B (19)
8	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	C (14)	○C (15)	C (16)	○C (17)	C (18)●
7	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	C (14)	○C (15)	C (16)	C (17)
6	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)	C (14)	C (15)	C (16)
5	E (5)	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)	D (14)	D (15)
4	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)	○D (13)	D (14)
3	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	D (12)	D (13)
2	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	E (12)
1	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)
0	E (0)	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)
Susceptibility/ Vulnerability	0	1	2	3	4	5	6	7	8	9	10

● : Occurrence
○ : Non-occurrence

Occurrence average
Hazard Value: 11.250
Vulnerability Value: 8.333
Total Value: 19.583

Non-occurrence average
Hazard Value: 9.625
Vulnerability Value: 8.250
Total Value: 17.875

(c) Deogyu Mountain area on Daejun-Jinju Expressway

20	E (20)	D (21)	D (22)	C (23)	B (24)	B (25)	B (26)	A (27)	S (28)	S (29)	S (30)
19	E (19)	D (20)	D (21)	C (22)	B (23)	B (24)	B (25)	A (26)	S (27)	S (28)	S (29)
18	E (18)	D (19)	D (20)	C (21)	C (22)	B (23)	B (24)	A (25)	A (26)	S (27)	S (28)
17	E (17)	D (18)	D (19)	C (20)	C (21)	B (22)	B (23)	A (24)	A (25)	S (26)	○S (27)
16	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	B (23)	A (24)	A (25)	S (26)●
15	E (15)	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	A (23)	○A (24)	A (25)
14	E (14)	E (15)	D (16)	D (17)	C (18)	C (19)	B (20)	B (21)	B (22)	A (23)	A (24)
13	E (13)	E (14)	D (15)	D (16)	C (17)	C (18)	C (19)	B (20)	B (21)	B (22)	A (23)
12	E (12)	E (13)	D (14)	D (15)	○C (16)	C (17)	C (18)	B (19)	B (20)	B (21)	B (22)
11	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)	B (19)	B (20)	B (21)
10	E (10)	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)	B (19)	B (20)
9	E (9)	E (10)	E (11)	D (12)	D (13)	○C (14)	C (15)	○C (16)	C (17)	C (18)	B (19)
8	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	C (14)	C (15)	C (16)	C (17)	C (18)
7	E (7)	E (8)	E (9)	○E (10)	D (11)	D (12)	D (13)	C (14)	C (15)	C (16)	○C (17)
6	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)	C (14)	C (15)	C (16)
5	E (5)	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)●	D (13)	D (14)	D (15)●
4	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	D (14)
3	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	○D (12)	D (13)●
2	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	E (12)
1	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)●	E (11)
0	E (0)	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)
Susceptibility/ Vulnerability	0	1	2	3	4	5	6	7	8	9	10

● : Occurrence
○ : Non-occurrence

Occurrence average
Hazard Value: 6.000
Vulnerability Value: 9.200
Total Value: 15.200

Non-occurrence average
Hazard Value: 9.875
Vulnerability Value: 7.125
Total Value: 17.000

(d) Daegwanryung area on Yeongdong Expressway

Figure 4.3 Susceptibility and Vulnerability Values of debris flow occurrence and non-occurrence cases

Applications of the KEC method show results which roughly coincide with actual debris flow occurrences and non-occurrences (Fig.

4.3). 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.

In the Daegwanryung case (Fig. 4.3(d)), occurrence cases showed large Vulnerability Values, regardless of the Susceptibility Values. Through this case, it was presumed that with very high intensities of rainfall, debris flow occurrences are not governed by the Susceptibility Value but by the Vulnerability Value.

Although the sites other than the Daegwanryung case showed results that generally presented higher Susceptibility and Vulnerability Values in the occurrence cases, it did not properly represent the total value differences between the occurrence and non-occurrences. In order to appropriately represent the differences between occurrences and non-occurrences of debris flows, modifications were made on the grading standard of the KEC method. The grading standards for attributes were revised to more well-founded ones that took into consideration the attribute values of both occurrences and non-occurrences, maximizing the distinction between the two instances.

Chapter 5 Revision of Korea Expressway Corporation Method

5.1 Grading Standard Modifications

The existing KEC method designated points to each attribute according to a grading standard set based on past debris flow occurrences. However, it did not take the non-occurrence cases into consideration. In addition, the grading standard was set using all existing data sets of each attribute, and calculating the maximum, minimum, and median values. In order to appropriately represent the differences between debris flow occurrences and non-occurrences, modifications were made on the assessment method. The grading standards for attributes were revised to more well-founded ones that took into consideration the attribute values of both occurrences and non-occurrences, maximizing the distinction between the two instances.

5.1.1 Susceptibility Value Grading Standard Modifications

The Pyeongchang and Deogyu Mountain areas showed the highest number of debris flow occurrence sites, and thus, provided a large pool for analysis. The two areas were also considered as sites with the same rainfall reoccurrence period of 50 to 100 years. Therefore, the Susceptibility Value grading standard was modified based on debris flow occurrence and non-occurrence cases of the Pyeongchang and Deogyu Mountain areas. To change the grading standards, the average values of each attribute were calculated. When calculating the average values, sites that showed proper outcomes were not taken into consideration. Because the sites in interest were the ones that showed mixed results between occurrences and non-occurrences, only the ones that showed mixed results were considered in the average calculating process. For example, occurrence cases which showed considerably high total values, such as 25 and higher, and non-occurrence cases with total values of 11 and lower were not considered when calculating the average.

After calculating the average values for each attribute for the occurrence and non-occurrence cases of the Pyeongchang and Deogyu Mountain areas, the values were compared, and a criterion for the grading standard was set. Through various applications on different criteria, the one which indicated the highest difference between the occurrence and non-occurrence cases was chosen for each attribute. The modified Susceptibility Value grading standard was set as Table 5.1.

Table 5.1 Modified Susceptibility Value grading standard

Attribute	Point of attribute / Grading standard					
Mean watershed slope (°)	5	4	3	2	1	0
	≥ 30	< 30 ≥ 28	< 28 ≥ 26	< 26 ≥ 24	< 24 ≥ 22	< 22
Area percentage of watershed with slopes over 35° (%)	5	4	3	2	1	0
	≥ 32	< 32 ≥ 25	< 25 ≥ 18	< 18 ≥ 11	< 11 ≥ 4	< 4
Mean valley slope (°)	5	4	3	2	1	0
	≥ 19	< 19 ≥ 17	< 17 ≥ 15	< 15 ≥ 13	< 13 ≥ 11	< 11
Length percentage of valley with slopes over 15° (%)	5	4	3	2	1	0
	≥ 67	< 67 ≥ 61	< 61 ≥ 55	< 55 ≥ 49	< 49 ≥ 43	< 43

5.1.2 Vulnerability Value Grading Standard Modifications

The Vulnerability Value grading standard was also modified based on the debris flow occurrence and non-occurrence cases of the Pyeongchang and Deogyu Mountain areas due to reasons stated in the previous section.

Considering the fact that only a very few number of the considered sites had deposit areas with volumes exceeding 2,000m^3, the grading standard was modified. The highest grading standard was altered from 5,000m^3 to 2,000m^3, and the other standards were also modified accordingly. In addition, the grading standard for the size of drainage facility was also modified. The KEC method originally classified the drainage facility measurements by a certain grading table as in Table 5.2. However, the original grading standard did not properly represent the drainage facility size differences. For example, the D1,200 size drainage facility was designated a larger point than the B1.0x1.0 size facility even though the D1,200 size drainage facility has a larger cross-sectional area of 1.131m^2 compared to the 1.0m^2 of the B1.0x1.0. In order to take into consideration the size differences of each drainage facility, the cross-sectional areas were set as the classifying standard. As a result, the Vulnerability Value grading standard was modified as in Table 5.3.

Table 5.2 Drainage facility standard before modification

Drainage facility measurement (KEC)	Cross-sectional area (m^2)	Point
None	0.0	5
Waterway	0.0	5
D800	0.503	4
D1,000	0.785	4
D1,200	1.131	4
D2,000	3.142	3
D2,500	4.909	3
B1.0x1.0	1.0	3
B1.5x1.2	1.8	3
B1.5x1.5	2.25	3
B1.5x2.0	3.0	3
B2.0x2.0	4.0	3
B2.0x2.5	5.0	2
B3.0x3.0	9.0	2
B3.5x3.5	12.25	2
B4.0x4.0	16.0	2
B2.0xD2.0	19.0	1
B4.5x4.5	20.25	1
B3.0xD3.0	26.0	1
Bridge	36.0	0

Table 5.3 Modified Vulnerability Value grading standard

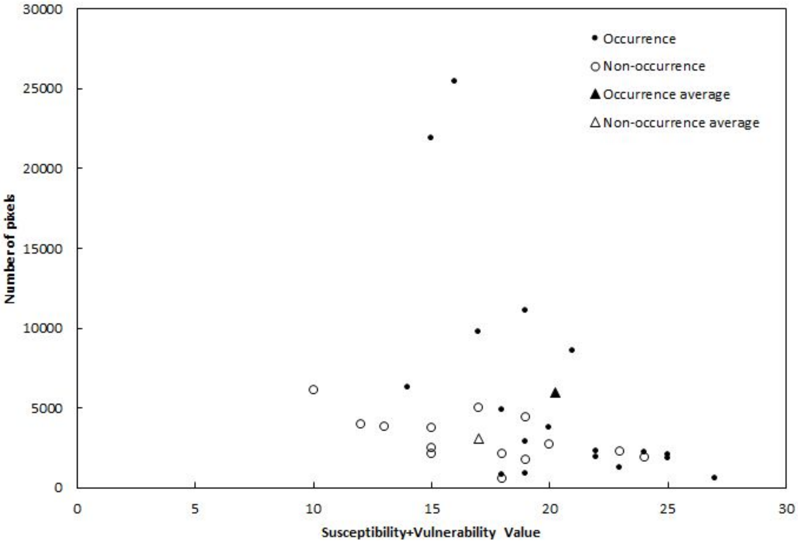
<table>
<tr><th rowspan="2">Attribute</th><th colspan="6">Point of attribute</th></tr>
<tr><th colspan="6">Grading standard</th></tr>
<tr><td rowspan="2">Volume of deposit area (m^3)</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>0</td><td>≤ 100
> 0</td><td>≤ 500
> 100</td><td>≤ 2,000
> 500</td><td>> 2,000</td><td>No damage guaranteed</td></tr>
<tr><td rowspan="2">Size of drainage facility (cross-sectional area, m^2)</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>0</td><td>≤ 1.0
> 0</td><td>≤ 4.5
> 1.0</td><td>≤ 16.0
> 4.5</td><td>≤ 25.0
> 16.0</td><td>> 25.0</td></tr>
</table>

5.2 Consideration on Additional Attributes

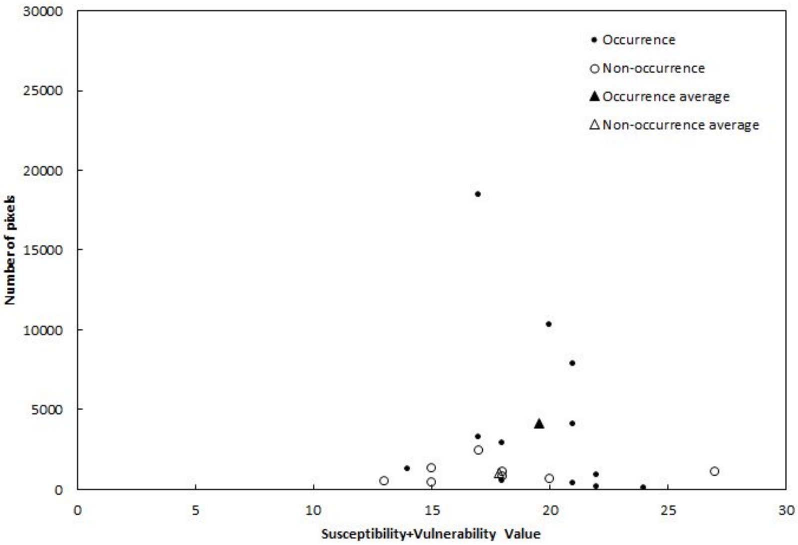
The KEC method used only a limited amount of information in order to make the assessment process simple and objective: numerical map data (DEMs) and expressway design files. Among these limited data, only the slope attributes derived from the numerical map data were used. Due to this limitation in data use, the KEC method showed some discrepancies in the results of debris flow hazard assessment. To properly assess the hazard of debris flow occurrences, attributes other than those regarding the slope should be considered. After analyses on three cases of debris flow occurrences, two additional attributes were considered to be related to the occurrence of debris flows: watershed size and bending of valley.

5.2.1 Consideration on Watershed Size

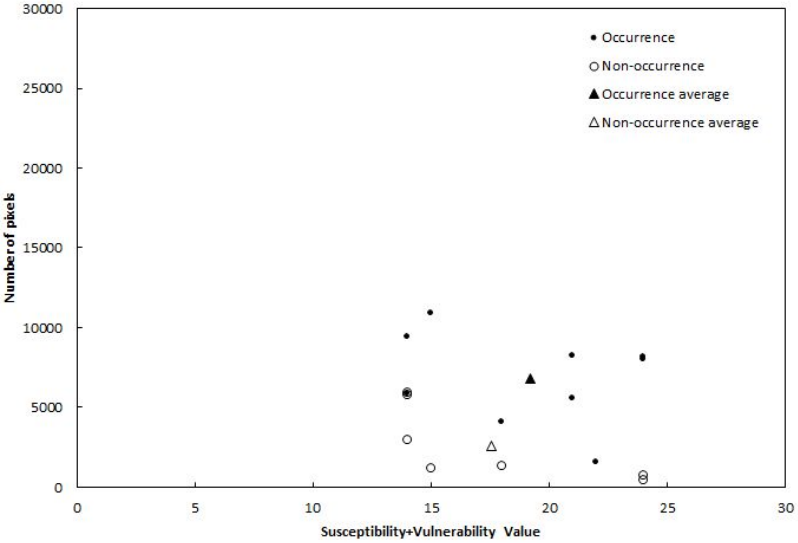
The debris flow occurrence and non-occurrence cases were compared by their watershed size, which can be quantified as number of pixels (cells). Each pixel has a size of 5 by 5 meters, an area of $25m^2$. Consequently, the watershed size is equal to the number of pixels in the target area multiplied by $25m^2$. Fig. 5.1 indicates the total Susceptibility and Vulnerability Values of areas by number of pixels consisting the watershed area.



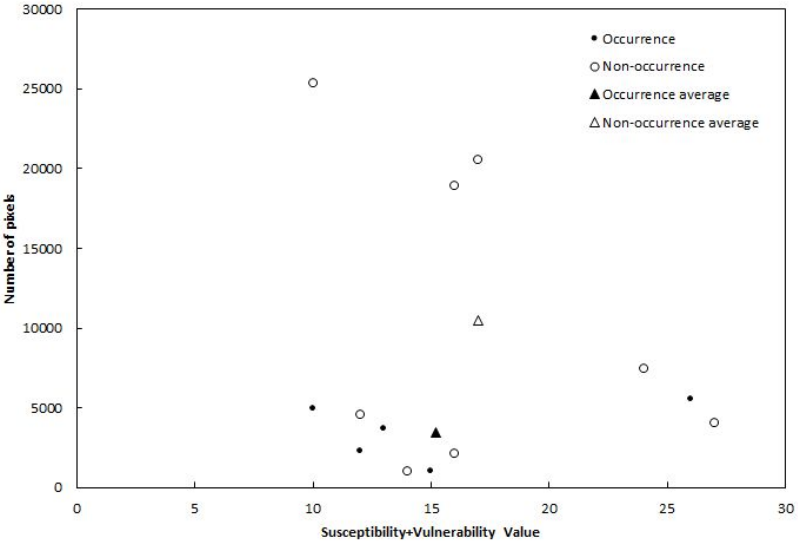
(a) Pyeongchang area of Yeongdong Expressway



(b) Deogyu Mountain area of Daejun-Jinju Expressway



(c) Juksan-Geochang area of 88 Expressway



(d) Daegwanryung area of Yeongdong Expressway

Figure 5.1 Susceptibility and Vulnerability Values by number of pixels

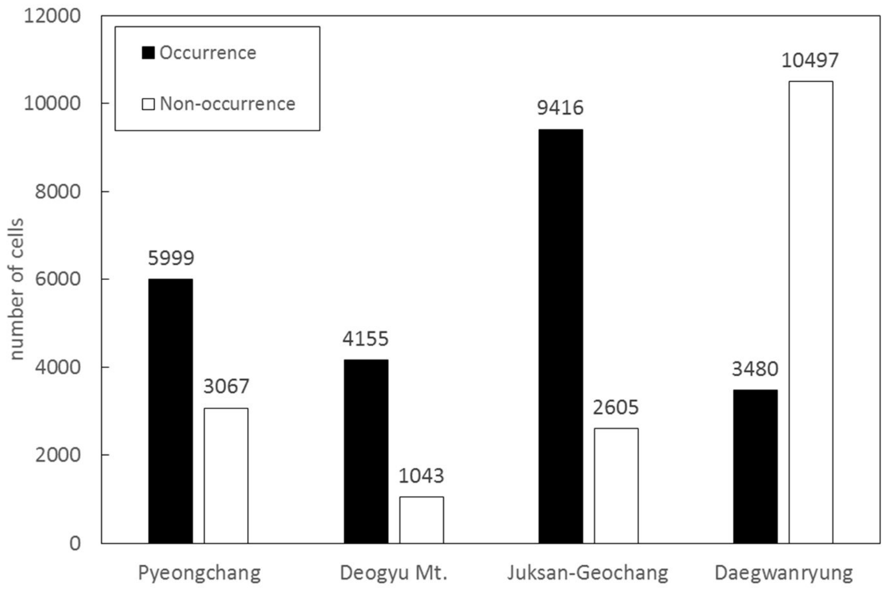
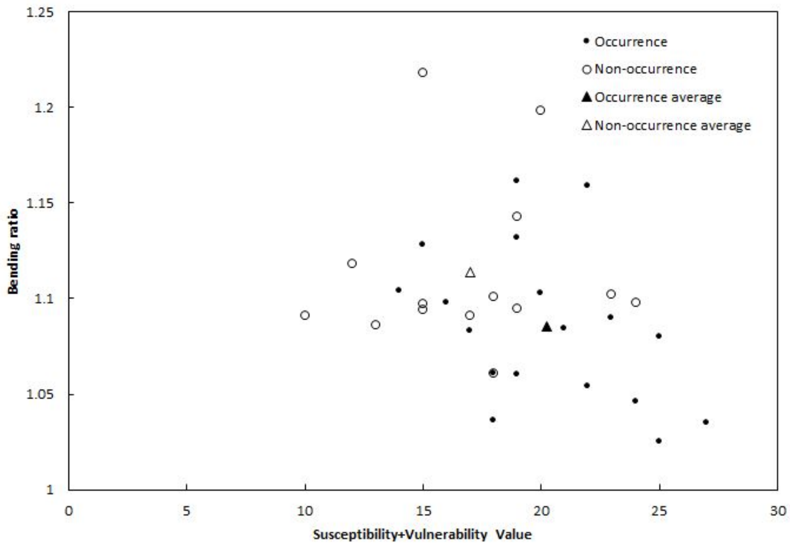


Figure 5.2 Overall average number of pixels for applied areas

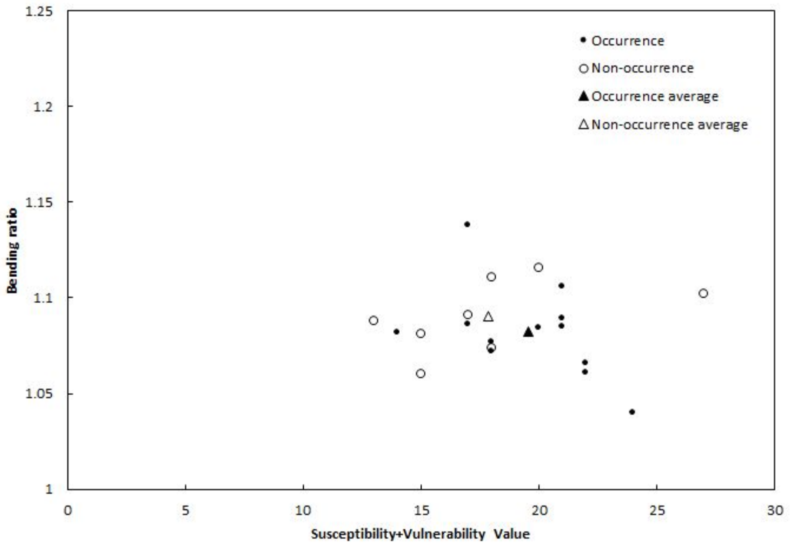
As seen in Fig. 5.1(a) through Fig. 5.1(c), the likeliness of debris flows increase with larger watershed areas due to the higher existence possibilities of regions with debris flow initiation topography characteristics. Debris flow occurrences tend to have higher Susceptibility + Vulnerability Values and watershed sizes than non-occurrences for both the Pyeongchang and Deogyu Mountain, and Juksan-Geochang areas. However, the results of the Daegwanryung area did not coincide with the other cases. In the Daegwanryung case, debris flows occurred even in watersheds with low numbers of pixels. The cause for this discrepancy is assumed to be the very high intensity of rainfall (700mm/day) in the Daegwanryung region as was for the results of Fig. 4.3. It is anticipated that with a very high intensity of rainfall, debris flows initiate regardless of the topography or watershed size. Watershed sizes rather influence the sedimentation capabilities of the region in these precipitation conditions. Larger watersheds have a higher chance of providing more deposit areas for debris flow materials than smaller watershed areas, which lowers the possibilities of damage on expressways. This displays the same tendency as the analysis of Fig. 4.3. The Vulnerability Value, which indicates the deposit volumes of a watershed, has a higher influence on debris flow hazards than the Susceptibility Value in cases where rainfall intensities are very high (700mm/day).

5.2.2 Consideration on Bending of Valley

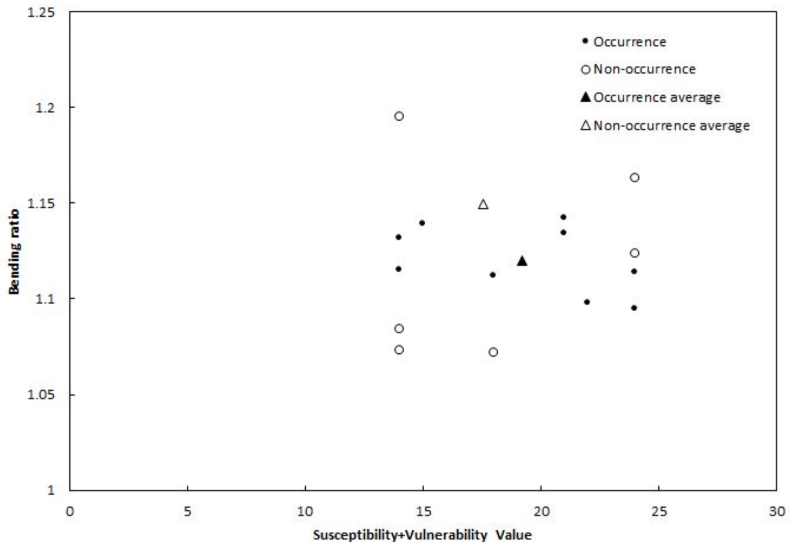
The debris flow occurrence and non-occurrence cases were compared by the bending of valley. There is no objective tool in the program ArcGIS that represents the bending of the valley or the flow direction changes of the valleys. Therefore, for the bending of the valley, the ratio between the actual travel path of the valley, and the distance of the valley between the initiation point and the output point (bending ratio) was used. Fig. 5.3 indicates the total Susceptibility and Vulnerability Values of areas by bending ratio.



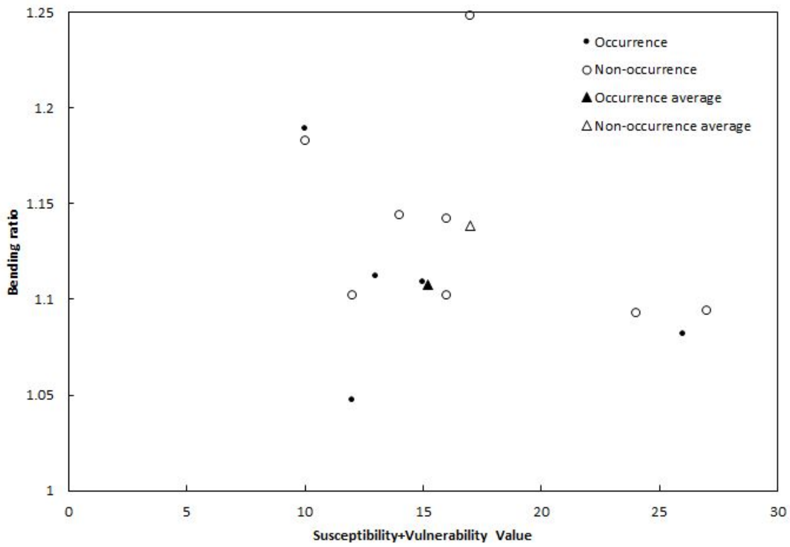
(a) Pyeongchang area of Yeongdong Expressway



(b) Deogyu Mountain area of Daejun-Jinju Expressway



(c) Juksan-Geochang area of 88 Expressway



(d) Daegwanryung area of Yeongdong Expressway

Figure 5.3 Susceptibility and Vulnerability Values by bending ratio

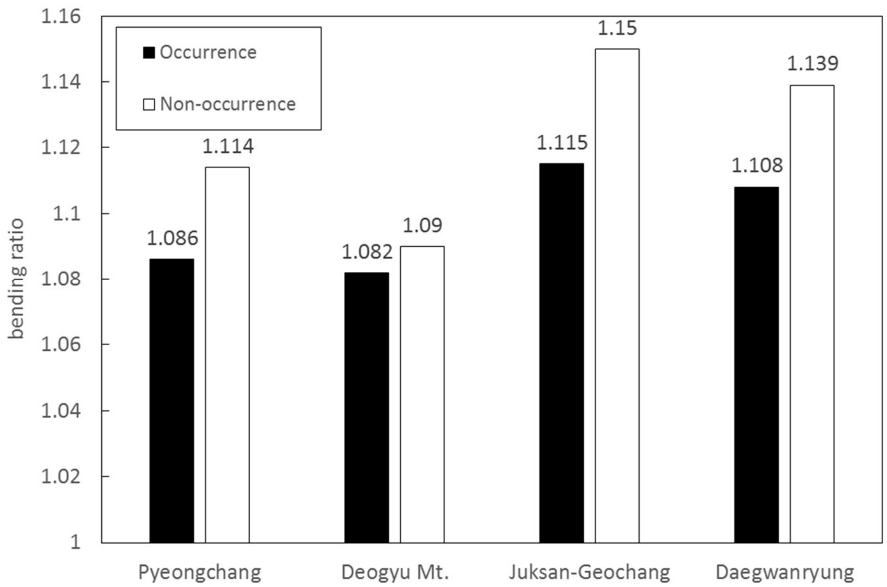


Figure 5.4 Overall average bending ratio for applied areas

With a higher bending ratio, the possibilities of sedimentation and resistance against debris flows increase, consequently lowering the possibilities of debris flow damage on road structures. As seen in Fig. 5.4 the non-occurrence cases have higher valley bending ratios than the occurrences. Thus, the higher the bending ratio, the lower the likeliness of damage on road structures becomes.

By considering additional attributes, considerations on watershed area and bending of valley were proposed, and may possibly act as a foundation for future implementations on other hazard assessment application methods.

Chapter 6 Application of Modified Grading Standard

20	E (20)	D (21)	D (22)	C (23)	B (24)	B (25)	B (26)	A (27)●●	S (28)	○S (29)	S (30)
19	E (19)	D (20)	D (21)	C (22)	B (23)	B (24)	B (25)	A (26)	S (27)●	S (28)	S (29)
18	E (18)	D (19)	D (20)	C (21)	C (22)	B (23)	B (24)	A (25)	A (26)	○S (27)	S (28)
17	E (17)	D (18)	D (19)	C (20)	C (21)	B (22)	B (23)	A (24)	A (25)	S (26)	S (27)
16	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)●	B (22)	B (23)	A (24)●	A (25)	S (26)
15	E (15)	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	A (23)	A (24)	A (25)
14	E (14)	E (15)	D (16)	D (17)	C (18)	C (19)	B (20)	B (21)	B (22)	A (23)	A (24)
13	E (13)	E (14)	D (15)	D (16)	C (17)	C (18)	C (19)	B (20)	B (21)	B (22)	A (23)
12	E (12)	E (13)	D (14)	D (15)	C (16)	C (17)	C (18)	B (19)	B (20)	B (21)	B (22)
11	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)	B (19)	B (20)	B (21)●
10	E (10)	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)	B (19)	B (20)
9	E (9)	E (10)	E (11)	D (12)	D (13)	○○C (14)	C (15)	C (16)	C (17)	C (18)	B (19)
8	E (8)	E (9)	E (10)	D (11)	○D (12)	D (13)	C (14)	C (15)	C (16)	C (17)	C (18)
7	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)●	D (13)	C (14)	C (15)	C (16)	C (17)
6	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)	C (14)	C (15)	C (16)
5	E (5)	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)	D (14)	○D (15)
4	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)●	D (13)	D (14)
3	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	D (12)	D (13)
2	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9) ●	E (10)	E (11)	E (12)
1	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	○E (11)
0	E (0)	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)
Susceptibility/ Vulnerability	0	1	2	3	4	5	6	7	8	9	10

● : Occurrence
○ : Non-occurrence

Occurrence average
Hazard Value: 12.778
Vulnerability Value: 9.000
Total Value: 21.778

Non-occurrence average
Hazard Value: 10.000
Vulnerability Value: 7.571
Total Value: 17.571

(a) Juksan-Geochang area on 88 Expressway

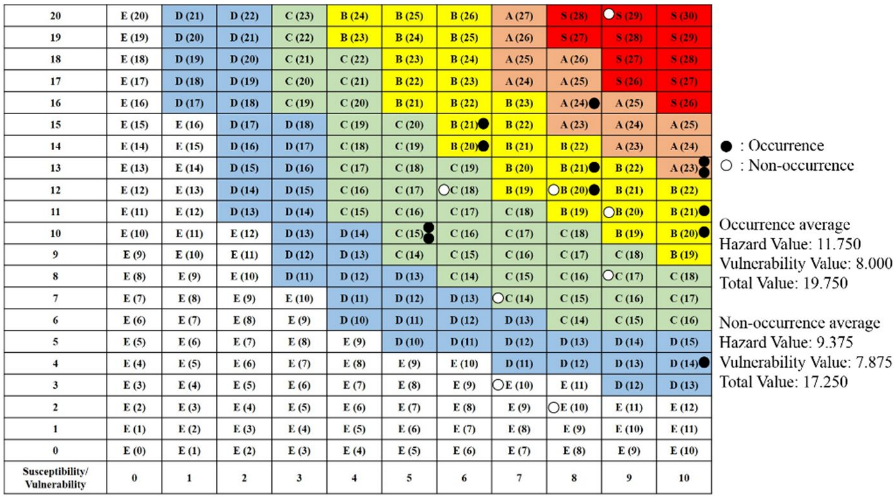
20	E (20)	D (21)	D (22)	C (23)	B (24)	B (25)	○B (26)	A (27)	S (28)	S (29)●	S (30)
19	E (19)	D (20)	D (21)	C (22)	B (23)	B (24)	B (25)	A (26)	S (27)	S (28)	S (29)●●
18	E (18)	D (19)	D (20)	C (21)	C (22)	B (23)	B (24)	A (25)	A (26)	S (27)	S (28)
17	E (17)	D (18)	D (19)	C (20)	C (21)	B (22)	B (23)	A (24)	A (25)	S (26)●	S (27)
16	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	B (23)	A (24)●	○A (25)	S (26)
15	E (15)	E (16)	D (17)	D (18)	C (19)	C (20)	B (21)	B (22)	A (23)	A (24)●	A (25)●
14	E (14)	E (15)	D (16)	D (17)	C (18)	C (19)	B (20)	B (21)	B (22)●●	A (23)	A (24)
13	E (13)	E (14)	D (15)	D (16)	○C (17)	C (18)	C (19)	B (20)●	B (21)●	B (22)	A (23)
12	E (12)	E (13)	D (14)	D (15)	C (16)	C (17)	C (18)	B (19)	B (20)●	B (21)	B (22)
11	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	C (18)	B (19)	B (20)	B (21)
10	E (10)	E (11)	E (12)	D (13)	D (14)	C (15)	C (16)	C (17)	○C (18)	○B (19)	B (20)
9	E (9)	E (10)	E (11)	D (12)	D (13)	C (14)	C (15)	C (16)	C (17)	C (18)	○B (19)
8	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	C (14)	C (15)	C (16)●	C (17)	C (18)
7	E (7)	E (8)	E (9)	E (10)	D (11)	D (12)	D (13)	○C (14)	C (15)●	C (16)	C (17)
6	E (6)	E (7)	E (8)	E (9)	D (10)	D (11)	D (12)	D (13)●	○C (14)	C (15)	C (16)●
5	E (5)	E (6)	E (7)	E (8)	○ E (9)	D (10)	○D (11)	D (12)●	D (13)	D (14)	○D (15)
4	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	D (11)●	○D (12)	D (13)	D (14)
3	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	○ E (9)	E (10)	E (11)	D (12)	D (13)
2	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)	E (12)
1	E (1)	E (2)	E (3)	E (4)	○ E (5)	E (6)	E (7)	E (8)	E (9)	E (10)	E (11)
0	E (0)	E (1)	E (2)	E (3)	E (4)	E (5)	E (6)	E (7)	E (8)	E (9)	E (10)
Susceptibility/ Vulnerability	0	1	2	3	4	5	6	7	8	9	10

● : Occurrence
○ : Non-occurrence

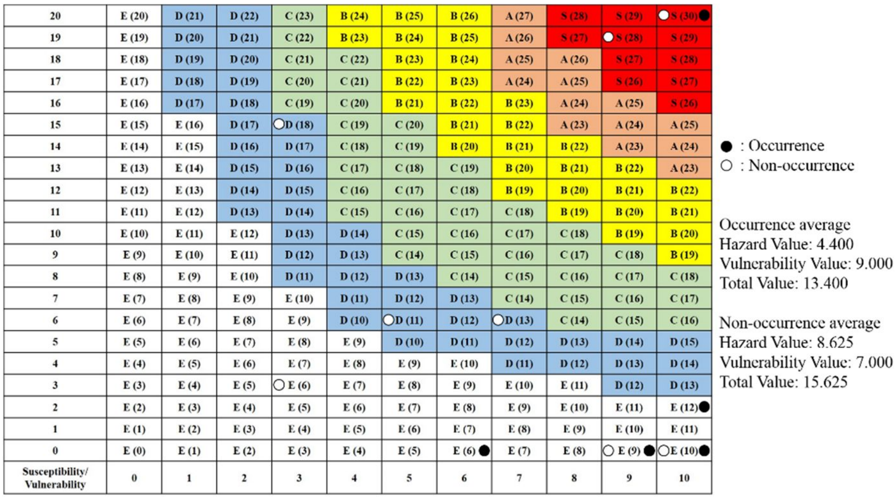
Occurrence average
Hazard Value: 12.222
Vulnerability Value: 8.500
Total Value: 20.722

Non-occurrence average
Hazard Value: 8.143
Vulnerability Value: 7.071
Total Value: 15.214

(b) Pyeongchang area on Yeongdong Expressway



(c) Deogyu Mountain area on Daejun-Jinju Expressway



(d) Daegwanryung area on Yeongdong Expressway

Figure 6.1 Modified Susceptibility and Vulnerability Values of debris flow occurrence and non-occurrence cases

Through application of the modified grading standard on selected sites, results showed that the distributions of debris flow occurrence and non-occurrence cases indicating more proper outcomes than before the modification. However, it is not easy to compare or visualize the degree of modification through the results as shown in Fig. 6.1. Therefore, a verification process was carried out for a quantitative and objective comparison.

Chapter 7 Verification of Modified Assessment Method Application

Because the results of the application of the modified assessment method is not clearly, quantitatively visualized, a verification process was carried out. By analyzing whether the values of all the considered sites had changed in an improved way or a worsening way, Table 7.1 was obtained as a result. The "Improved change" indicates the occurrence sites having a larger total value, and non-occurrences having a lower total value than before. The "Worsened change" indicates the opposite alternation in the total value compared to before the modification.

Table 7.1 Total count and percentage of value change directions of considered regions

	Total count	**Improved change**	**No change**	**Worsened change**
Pyeongchang	32	21	3	8
Deogyu Mt.	20	8	5	7
Juksan-Geochang	16	9	2	5
Daegwanryung	13	6	0	7
Sum	81	44	10	27
Percentage (%)	100.0	54.32	12.35	33.33

A total of 81 sites were considered in the process. As a result, 44 sites underwent improvements in the total values. 27 sites were worsened, and 10 sites did not face any changes. From the percentage, it can be seen that more than half were subject to improved changes. When considering both sites with improved or no changes, it can be said that two thirds of the considered sites showed results that demonstrated a better outcome through the modification.

Chapter 8 Conclusions

For the assessment of debris flow hazards, the Korea Expressway Corporation (KEC) method was selected as a fundamental concept through analysis and consideration on various methods. The selected method uses numerical map data (DEMs) and expressway design files for an effective objective and quantitative analysis, minimizing the need for tiresome field investigations. For the assessment of debris flow attributes, a sequence for the process was newly proposed using the software ArcGIS. After application of the method on four regions of South Korea, the following conclusions were made:

1) The KEC debris flow hazard assessment method agrees with actual debris flow occurrences and non-occurrences to some extent. However, the method does not perfectly fit due to the limitation in data considered in the process.
2) The Daegwanryung case showed opposite results to the other cases due to the high intensity of rainfall (700mm/day). In order to properly assess debris flow hazards, the degree of rainfall should be considered in the process.

In order to minimize the mixed up results in the hazard class between occurrence and non-occurrence cases, and properly represent the differences between the cases, two modification methods were proposed.

1) ***Modifications in grading standard***

Existing grading standards set by the KEC were modified based on actual past debris flow occurrence and non-occurrence cases. Through investigations on a total of four expressway sections, new grading standards for both the Susceptibility and Vulnerability Values were proposed.

2) ***Consideration on additional attributes***

With larger watershed sizes, both the debris flow initiation possibility and occurrence likeliness increase. However, as in the Daegwanryung case, when the rainfall approaches a certain limit (700mm/day), the results showed opposite tendencies. With high intensities of rainfall (700mm/day), the Vulnerability Value governs the occurrence of debris flows. Therefore, the degree of rainfall should be considered in the hazard assessment process.

An objective standard was set for the assessment of bending of valley (bending ratio). With larger bending ratios, more debris flow materials are subject to sedimentation, lowering the possibility of damage on road structures. After application on the selected regions, debris flow occurrences had lower bending ratios than non-occurrence cases. The bending ratio was therefore concluded to have an effect on debris flow occurrence hazards.

Results of the consideration on additional attributes may possibly act as a foundation for future implementations on other hazard assessment application methods

The modified grading standard was again applied on the selected sites. Through the modification, outcomes showed improved results. For a more quantitative and objective comparison of before and after the modification, a verification process was carried out. By analyzing whether the values of all the considered sites had changed in an improved way or a worsening way, it was concluded that two thirds of the considered sites showed results that demonstrated a better outcome through the modification.

References

Ayalew, L., Yamagishi, H., Ugawa, N. (2003), “Landslide Susceptibility Mapping using GIS-based Weighted Linear Combination, The Case in Tsugawa Area of Agano River, Niigata Prefecture, Japan”, Landslides, Vol.1, pp.73-81.

Ayalew, L., Yamagishi, H. (2005), “The Application of GIS-based Logistic Regression for Landslide Susceptibility Mapping in the Kakuda-Yahiko Mountains, Central Japan”, Geomorphology, Vol.65, pp.15-31.

Cascini, L., Bonnard, C., Corominas, J., Jibson, R., Montero-Olarte, J. (2005), “Landslide Hazard and Risk Zoning for Urban Planning and Development”, Landslide Risk Management, Taylor and Francis, London, pp.3-26.

Dai, F.C., Lee, C.F. (2002), “Landslide Characteristics and Slope Instability Modeling Using GIS, Lantau Island, Hong Kong”, Geomorphology, Vol.42, pp.213-228.

Expressway and Transportation Research Institute, Korea Expressway Corporation (2009), “Development of Debris Flow Hazard Analysis Method and its Application”, Korea Expressway Corporation Research Report. (in Korean)

Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., Savage, W.Z. (2008), “Guidelines for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning”, Engineering Geology, Vol.102, pp.85-98.

Keller, E.A., DeVecchio, D.E. (2010), "Mass Wasting", Natural Hazards: Earth's Processes as Hazards, Disasters, and Catastrophes, Prentice Hall, New Jersey, pp.206-241.

Korea Forest Service (2013), "Landslide Information System".

Korea Institute of Geoscience and Mineral Resources (2003), "Investigation on Landslide Prediction and Mitigation Techniques", KIGAM Research Report. (in Korean)

Lee, S., Pradhan, B. (2007), "Landslide Hazard Mapping at Selangor, Malaysia using frequency ratio and logistic regression models", Landslides, Vol.4, pp.33-41.

Lee, S.W., Kim, G.H., Yune, C.Y., Ryu, H.J., Hong, S.J. (2012), "Development of Landslide-Risk Prediction Model through Database Construction", Journal of Korean Geotechnical Society, Vol.28(4), pp.23-33. (in Korean)

Lin, P.S., Lin, J.Y., Hung, J.C., Yang, M.D. (2002), "Assessing Debris-flow Hazard in a Watershed in Taiwan", Engineering Geology, Vol.66, pp.295-313.

Olivera, F., Furnans, J., Maidment, D., Djokic, D., Ye, Z. (2002), "Drainage Systems", ArcHydro: GIS for Water Resource, ESRI Press, California, pp.55-86.

Olivera. F., Maidment, D., Honeycutt, D. (2002), "Hydro Networks", ArcHydro: GIS for Water Resource, ESRI Press, California, pp.33-54.

Seoul Institute (2013), “Comprehensive Report on Slope Stability and Landslide Mitigation System Research”, Seoul Institute Research Report. (in Korean)

Appendix A. Attribute Datasets before Grading Standard Modification

The following tables indicate the specific attribute datasets before the grading standard was modified.

Table A.1 Attribute datasets of occurrence sites in Juksan-Geochang area

occurrence	106.69		107.09		107.22		107.28		107.56	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	30.5	4	29.7	3	31.993	4	29.296	3	30.463	4
wtrshd area % exceeding 35˚	41.501	5	36.31	4	45.331	5	31.665	4	33.529	4
aver. valley slp	20.533	4	18.126	3	22.466	4	18.151	3	19.694	3
valley lgth % exceeding 15˚	68.234	3	59.144	3	76.947	4	62.41	3	65.732	3
Susc. Value	16		13		17		13		14	
sedimentation vol.	666.6667	3	1166.667	2	66.66667	4	0	5	0	5
drainage facility	0	5	B1.5x1.5	3	B2.0x2.0	3	B2.0x1.5	3	B1.5x1.0	3
Vuln. Value	8		5		7		8		8	
Total Value	24		18		24		21		22	

occurrence	107.84		107.94		108.27		108.61	
	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	24.771	2	21.457	2	21.529	2	24.395	2
wtrshd area % exceeding 35˚	24.54	3	4.113	1	4.937	1	11.491	2
aver. valley slp	16.391	3	14.342	2	11.999	2	13.638	2
valley lgth % exceeding 15˚	55.23	3	48.651	2	35.615	2	46.737	2
Susc. Value	11		7		7		8	
sedimentation vol.	0	5	0	5	0	5	500	3
drainage facility	0	5	B2.0x2.0	3	B2.5x2.0	2	B1.5x1.5	3
Vuln. Value	10		8		7		6	
Total Value	21		15		14		14	

Table A.2 Attribute datasets of non-occurrence sites in Juksan-Geochang area

non-occurrence	106.94		107.65		107.76		108.16		108.48	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	24.605	2	31.674	4	31.98	4	19.772	1	23.824	2
wtrshd area % exceeding 35˚	10.948	2	46.25	5	48.172	5	0.795	0	11.184	2
aver. valley slp	15.531	3	19.728	3	19.273	3	11.496	2	15.052	3
valley lgth % exceeding 15˚	60.643	3	56.591	3	69.023	3	28.708	1	51.896	3
Susc. Value	10		15		15		4		10	
sedimentation vol.	1250	2	0	5	0	5	0	5	1000	2
drainage facility	B1.5c1.0	3	D800	4	D1000	4	0	5	B3.5x3.5	2
Vuln. Value	5		9		9		10		4	
Total Value	15		24		24		14		14	

non-occurrence	108.85		108.94	
	value	pt	value	pt
aver. wtrshd slp	24.285	2	22.823	2
wtrshd area % exceeding 35˚	11.02	2	11.76	2
aver. valley slp	14.822	2	14.504	2
valley lgth % exceeding 15˚	58.915	3	34.559	2
Susc. Value	9		8	
sedimentation vol.	400	3	0	5
drainage facility	B3.5x3.5	2	none	5
Vuln. Value	5		10	
Total Value	14		18	

Table A.3 Attribute datasets of occurrence sites in Pyeongchang area

occurrence	186.6		186.7		186.97		187.05		187.2	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	26.686	3	24.121	2	26.442	3	28.057	3	24.97	2
wtrshd area % exceeding 35°	15.908	2	11.271	2	20.71	3	15.789	2	11.377	2
aver. valley slp	11.75	2	10.32	2	9.953	1	15.593	3	18.107	3
valley lgth % exceeding 15°	34.287	2	23.713	1	27.069	1	65.014	3	82.63	4
Susc. Value	9		7		8		11		11	
sedimentation vol.	0	5	0	5	0	5	0	5	0	5
drainage facility	none	5	B3.0x2.5	2	B4.0x4.0	2	B4.0x4.0	2	B1.5x1.5	3
Vuln. Value	10		7		7		7		8	
Total Value	19		14		15		18		19	

occurrence	187.24		187.45		187.7		187.9		202.4	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	31.583	4	31.321	4	30.031	4	33.921	4	26.412	3
wtrshd area % exceeding 35°	42.483	5	38.791	4	26.445	3	55.636	5	18.016	2
aver. valley slp	15.453	3	17.658	3	27.01	5	19.821	3	12.933	2
valley lgth % exceeding 15°	53.876	3	69.654	3	96.075	5	80.656	4	44.326	2
Susc. Value	15		14		17		16		9	
sedimentation vol.	0	5	0	5	0	5	0	5	0	5
drainage facility	waterway	5	waterway	5	waterway	5	D1000	4	B2.0x2.0	3
Vuln. Value	10		10		10		9		8	
Total Value	25		24		27		25		17	

occurrence	188.83		189.03		189.3		189.4		189.64	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	30.374	4	32.07	4	30.857	4	30.597	4	25.4	3
wtrshd area % exceeding 35°	33.82	4	39.61	4	34.63	4	35.434	4	14.909	2
aver. valley slp	14.841	2	14.987	2	14.174	2	14.097	2	12.671	2
valley lgth % exceeding 15°	50.906	3	48.964	2	49.609	2	57.903	3	36.591	2
Susc. Value	13		12		12		13		9	
sedimentation vol.	0	5	0	5	0	5	0	5	0	5
drainage facility	B2.0x2.0	3	waterway	5	B2.0x2.0	3	D1000	4	B3.0x2.5	2
Vuln. Value	8		10		8		9		7	
Total Value	21		22		20		22		16	

occurrence	188.2		190.8		206.3	
	value	pt	value	pt	value	pt
aver. wtrshd slp	28.963	3	30.879	4	25.278	3
wtrshd area % exceeding 35˚	26.869	3	36.743	4	5.926	1
aver. valley slp	14.459	2	15.592	3	13.302	2
valley lgth % exceeding 15˚	51.598	3	61.103	3	50.498	3
Susc. Value	11		14		9	
sedimentation vol.	0	5	0	5	0	5
drainage facility	B2.0x2.0	3	D1000	4	D1200	4
Vuln. Value	8		9		9	
Total Value	19		23		18	

Table A.4 Attribute datasets of non-occurrence sites in Pyeongchang area

non-occurrence	186.53		193.36		195.94		198.15		199.36	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	23.858	2	24.736	2	28	3	28.257	3	24.558	2
wtrshd area % exceeding 35˚	11.744	2	20.697	3	24.408	3	31.097	4	16.596	2
aver. valley slp	12.877	2	8.452	1	9.237	1	11.015	2	12.311	2
valley lgth % exceeding 15˚	54.081	3	17.611	1	13.608	1	21.658	1	37.384	2
Susc. Value	9		7		8		10		8	
sedimentation vol.	0	5	2000	2	0	5	0	5	0	5
drainage facility	D1200	4	B2.0x2.0	3	B3.5x3.5	2	none	5	waterway	5
Vuln. Value	9		5		7		10		10	
Total Value	18		12		15		20		18	

non-occurrence	201.00		201.38		202.16		204.93		188.62	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	30.201	4	30.899	4	23.537	2	27.753	3	32.52	4
wtrshd area % exceeding 35˚	32.927	4	34.79	4	10.648	2	16.878	2	49.946	5
aver. valley slp	14.937	2	20.493	4	12.151	2	14.684	2	15.677	3
valley lgth % exceeding 15˚	46.768	2	72.493	4	35.571	2	57.068	3	56.839	3
Susc. Value	12		16		8		10		15	
sedimentation vol.	2333	2	2000	2	3500	2	none	5	none	5
drainage facility	B2.0x2.0	3	none	5	none	5	D1200	4	D1000	4
Vuln. Value	5		7		7		9		9	
Total Value	17		23		15		19		24	

non-occurrence	205.16		206.12		205.90		207.70	
	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	25.143	3	24.62	2	18.488	1	18.119	1
wtrshd area % exceeding 35˚	7.13	1	3.644	1	0.213	0	2.148	1
aver. valley slp	16.704	3	14.149	2	15.05	3	12.124	2
valley lgth % exceeding 15˚	66.637	3	46.842	2	48.527	2	23.604	1
Susc. Value	10		7		6		5	
sedimentation vol.	none	5	none	5	none	5	2400	2
drainage facility	D1000	4	B4.5x4.5	1	D1200	4	B2.0x2.0	3
Vuln. Value	9		6		9		5	
Total Value	19		13		15		10	

Table A.5 Attribute datasets of occurrence sites in Deogyu Mountain area

occurrence	139.39		139.5		139.6		145.6		145.8	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	21.097	2	25.851	3	27.387	3	26.294	3	24.789	2
wtrshd area % exceeding 35˚	1.355	1	8.511	1	2.469	1	14.044	2	19.101	2
aver. valley slp	20.334	4	25.617	5	28.094	5	17.484	3	17.53	3
valley lgth % exceeding 15˚	80.714	4	86.817	4	100	5	67.717	3	45.278	2
Susc. Value	11		13		14		11		9	
sedimentation vol.	0	5	0	5	0	5	1250	2	400	3
drainage facility	none	5	D1200	4	none	5	D1000	4	B4.0x4.0	2
Vuln. Value	10		9		10		6		5	
Total Value	21		22		24		17		14	

occurrence	145.9		146.05		146.3		147		147.2	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	27.016	3	27.118	3	20.824	2	25.09	3	25.426	3
wtrshd area % exceeding 35˚	22.465	3	19.872	2	4.209	1	16.42	2	22.318	3
aver. valley slp	17.115	3	19.173	3	15.87	3	16.882	3	17.642	3
valley lgth % exceeding 15˚	44.468	2	71.317	4	41.238	2	59.427	3	57.444	3
Susc. Value	11		12		8		11		12	
sedimentation vol.	0	5	0	5	0	5	500	3	0	5
drainage facility	none	5	D1200	4	none	5	B2.0x2.0	3	B2.0x2.0	3
Vuln. Value	10		9		10		6		8	
Total Value	21		21		18		17		20	

occurrence	150.2		154.9	
	value	pt	value	pt
aver. wtrshd slp	25.071	3	27.917	3
wtrshd area % exceeding 35˚	7.56	1	19.225	2
aver. valley slp	21.636	4	17.557	3
valley lgth % exceeding 15˚	70.305	4	67.378	3
Susc. Value	12		11	
sedimentation vol.	0	5	533.3333	3
drainage facility	none	5	D1000	4
Vuln. Value	10		7	
Total Value	22		18	

Table A.6 Attribute datasets of non-occurrence sites in Deogyu Mountain area

non-occurrence	139.4		139.3		145.86		146.2		147.22	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	22.375	2	19.854	1	21.193	2	14.711	0	25.426	3
wtrshd area % exceeding 35˚	0.094	0	2.856	1	7.059	1	0	0	22.318	3
aver. valley slp	19.83	3	17.656	3	13.965	2	12.861	2	17.642	3
valley lgth % exceeding 15˚	76.085	4	63	3	30.923	2	46.606	2	57.444	3
Susc. Value	9		8		7		4		12	
sedimentation vol.	0	5	0	5	500	3	0	5	0	5
drainage facility	D800	4	D800	4	none	5	D1200	4	B2.0x2.0	3
Vuln. Value	9		9		8		9		8	
Total Value	18		17		15		13		20	

non-occurrence	149.94		155.54		154.88	
	value	pt	value	pt	value	pt
aver. wtrshd slp	23.251	2	32.067	4	27.257	3
wtrshd area % exceeding 35˚	9.138	1	35.511	4	16.223	2
aver. valley slp	14.932	2	25.193	5	15.832	3
valley lgth % exceeding 15˚	60.645	3	90.109	5	62.954	3
Susc. Value	8		18		11	
sedimentation vol.	0	5	0	5	533.333	3
drainage facility	B4.0x4.0	2	D1000	4	D1000	4
Vuln. Value	7		9		7	
Total Value	15		27		18	

Table A.7 Attribute datasets of occurrence sites in Daegwanryung area

occurrence	217.2		230.9		231.8		231.7		233	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	31.86	4	16.577	1	21.635	2	23.296	2	17.352	1
wtrshd area % exceeding 35˚	42.168	5	0.109	0	2.696	1	8.284	1	0.774	0
aver. valley slp	19.587	3	7.437	1	6.642	1	7.107	1	4.939	0
valley lgth % exceeding 15˚	71.211	4	13.477	1	19.928	1	19.276	1	8.641	0
Susc. Value	16		3		5		5		1	
sedimentation vol.	0	5	0	5	500	3	0	5	0	5
drainage facility	none	5	none	5	D1000	4	none	5	D1000	4
Vuln. Value	10		10		7		10		9	
Total Value	26		13		12		15		10	

Table A.8 Attribute datasets of non-occurrence sites in Daegwanryung area

non-occurrence	215.29		231.52		231.66		228.1		229.1	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	20.995	2	18.696	1	23.087	2	21.282	2	21.443	2
wtrshd area % exceeding 35˚	3.534	1	0	0	2.439	1	2.745	1	2.855	1
aver. valley slp	10.514	2	8.356	1	15.017	3	16.019	3	13.399	2
valley lgth % exceeding 15˚	30.324	2	12.101	1	50.544	3	59.701	3	44.17	2
Susc. Value	7		3		9		9		7	
sedimentation vol.	0	5	0	5	10000	1	133.3333	3	10000	1
drainage facility	none	5	D1000	4	D1000	4	D1000	4	B2.5x2.5	2
Vuln. Value	10		9		5		7		3	
Total Value	17		12		14		16		10	

non-occurrence	217.42		220.52		220.68	
	value	pt	value	pt	value	pt
aver. wtrshd slp	32.297	4	31.171	4	27.291	3
wtrshd area % exceeding 35˚	41.136	5	27.182	3	18.163	2
aver. valley slp	23.018	4	24	4	18.181	3
valley lgth % exceeding 15˚	75.02	4	86.967	4	76.356	4
Susc. Value	17		15		12	
sedimentation vol.	0	5	0	5	2000	2
drainage facility	none	5	D1000	4	B3.0x3.0	2
Vuln. Value	10		9		4	
Total Value	27		24		16	

Appendix B. Attribute Datasets after Grading Standard Modification

The following tables indicate the specific attribute datasets after the grading standard was modified.

Table B.1 Attribute datasets of occurrence sites in Juksan-Geochang area

occurrence	106.69		107.09		107.22		107.28		107.56	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	30.5	5	29.7	4	31.993	5	29.296	4	30.463	5
wtrshd area % exceeding 15˚	41.501	5	36.31	5	45.331	5	31.665	4	33.529	5
aver. valley slp	20.533	5	18.126	4	22.466	5	18.151	4	19.694	5
valley lgth % exceeding 15˚	68.234	5	59.144	3	76.947	5	62.41	4	65.732	4
Susc. Value	20		16		20		16		19	
sedimentation vol.	666.6667	2	1166.667	2	66.66667	4	0	5	0	5
drainage facility	0	5	2.25	3	4	3	3	3	1.5	3
Vuln. Value	7		5		7		8		8	
Total Value	27		21		27		24		27	
occurrence	107.84		107.94		108.27		108.61			
	value	pt	value	pt	value	pt	value	pt		
aver. wtrshd slp	24.771	2	21.457	0	21.529	0	24.395	2		
wtrshd area % exceeding 15˚	24.54	3	4.113	1	4.937	1	11.491	2		
aver. valley slp	16.391	3	14.342	2	11.999	1	13.638	2		
valley lgth % exceeding 15˚	55.23	3	48.651	1	35.615	0	46.737	1		
Susc. Value	11		4		2		7			
sedimentation vol.	0	5	0	5	0	5	500	2		
drainage facility	0	5	4	3	5	2	2.25	3		
Vuln. Value	10		8		7		5			
Total Value	21		12		9		12			

Table B.2 Attribute datasets of non-occurrence sites in Juksan-Geochang area

non-occurrence	106.94		107.65		107.76		108.16		108.48	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	24.605	2	31.674	5	31.98	5	19.772	0	23.824	1
wtrshd area % exceeding 15˚	10.948	1	46.25	5	48.172	5	0.795	0	11.184	2
aver. valley slp	15.531	3	19.728	5	19.273	5	11.496	1	15.052	3
valley lgth % exceeding 15˚	60.643	3	56.591	3	69.023	5	28.708	0	51.896	2
Susc. Value	9		18		20		1		8	
sedimentation vol.	1250	2	0	5	0	5	0	5	1000	2
drainage facility	1.5	3	0.503	4	0.785	4	0	5	12.25	2
Vuln. Value	5		9		9		10		4	
Total Value	14		27		29		11		12	

non-occurrence	108.85		108.94	
	value	pt	value	pt
aver. wtrshd slp	24.285	2	22.823	1
wtrshd area % exceeding 15˚	11.02	2	11.76	2
aver. valley slp	14.822	2	14.504	2
valley lgth % exceeding 15˚	58.915	3	34.559	0
Susc. Value	9		5	
sedimentation vol.	400	3	0	5
drainage facility	12.25	2	0	5
Vuln. Value	5		10	
Total Value	14		15	

Table B.3 Attribute datasets of occurrence sites in Pyeongchang area

occurrence	186.6		186.7		186.97		187.05		187.2	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	26.686	3	24.121	2	26.442	3	28.057	4	24.97	2
wtrshd area % exceeding 15˚	15.908	2	11.271	2	20.71	3	15.789	2	11.377	2
aver. valley slp	11.75	1	10.32	0	9.953	0	15.593	3	18.107	4
valley lgth % exceeding 15˚	34.287	0	23.713	0	27.069	0	65.014	4	82.63	5
Susc. Value	6		4		6		13		13	
sedimentation vol.	0	5	0	5	0	5	0	5	0	5
drainage facility	0	5	7.5	2	16	2	16	2	2.25	3
Vuln. Value	10		7		7		7		8	
Total Value	16		11		13		20		21	

occurrence	187.24		187.45		187.7		187.9		202.4	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	31.583	5	31.321	5	30.031	5	33.921	5	26.412	3
wtrshd area % exceeding 15˚	42.483	5	38.791	5	26.445	4	55.636	5	18.016	3
aver. valley slp	15.453	3	17.658	4	27.01	5	19.821	5	12.933	1
valley lgth % exceeding 15˚	53.876	2	69.654	5	96.075	5	80.656	5	44.326	1
Susc. Value	15		19		19		20		8	
sedimentation vol.	0	5	0	5	0	5	0	5	0	5
drainage facility	0	5	0	5	0	5	0.785	4	4	3
Vuln. Value	10		10		10		9		8	
Total Value	25		29		29		29		16	

occurrence	188.83		189.03		189.3		189.4		189.64	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	30.374	5	32.07	5	30.857	5	30.597	5	25.4	2
wtrshd area % exceeding 15˚	33.82	5	39.61	5	34.63	5	35.434	5	14.909	2
aver. valley slp	14.841	2	14.987	2	14.174	2	14.097	2	12.671	1
valley lgth % exceeding 15˚	50.906	2	48.964	1	49.609	2	57.903	3	36.591	0
Susc. Value	14		13		14		15		5	
sedimentation vol.	0	5	0	5	0	5	0	5	0	5
drainage facility	4	3	0	5	4	3	0.785	4	7.5	2
Vuln. Value	8		10		8		9		7	
Total Value	22		23		22		24		12	

occurrence	188.2		190.8		206.3	
	value	pt	value	pt	value	pt
aver. wtrshd slp	28.963	4	30.879	5	25.278	2
wtrshd area % exceeding 15˚	26.869	4	36.743	5	5.926	1
aver. valley slp	14.459	2	15.592	3	13.302	2
valley lgth % exceeding 15˚	51.598	2	61.103	4	50.498	2
Susc. Value	12		17		7	
sedimentation vol.	0	5	0	5	0	5
drainage facility	4	3	0.785	4	1.131	3
Vuln. Value	8		9		8	
Total Value	20		26		15	

Table B.4 Attribute datasets of non-occurrence sites in Pyeongchang area

non-occurrence	186.53		193.36		195.94		198.15		199.36	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	23.858	1	24.736	2	28	4	28.257	4	24.558	2
wtrshd area % exceeding 15˚	11.744	2	20.697	3	24.408	3	31.097	4	16.596	2
aver. valley slp	12.877	1	8.452	0	9.237	0	11.015	1	12.311	1
valley lgth % exceeding 15˚	54.081	2	17.611	0	13.608	0	21.658	0	37.384	0
Susc. Value	6		5		7		9		5	
sedimentation vol.	0	5	2000	1	0	5	0	5	0	5
drainage facility	1.131	3	4	3	12.25	2	0	5	0	5
Vuln. Value	8		4		7		10		10	
Total Value	14		9		14		19		15	

non-occurrence	201.00		201.38		202.16		204.93		188.62	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	30.201	5	30.899	5	23.537	1	27.753	3	32.52	5
wtrshd area % exceeding 15˚	32.927	5	34.79	5	10.648	1	16.878	2	49.946	5
aver. valley slp	14.937	2	20.493	5	12.151	1	14.684	2	15.677	3
valley lgth % exceeding 15˚	46.768	1	72.493	5	35.571	0	57.068	3	56.839	3
Susc. Value	13		20		3		10		16	
sedimentation vol.	2333	1	2000	1	3500	1	0	5	0	5
drainage facility	4	3	0	5	0	5	1.131	3	0.785	4
Vuln. Value	4		6		6		8		9	
Total Value	17		26		9		18		25	

non-occurrence	205.16		206.12		205.90		207.70	
	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	25.143	2	24.62	2	18.488	0	18.119	0
wtrshd area % exceeding 15˚	7.13	1	3.644	0	0.213	0	2.148	0
aver. valley slp	16.704	3	14.149	2	15.05	3	12.124	1
valley lgth % exceeding 15˚	66.637	4	46.842	1	48.527	1	23.604	0
Susc. Value	10		5		4		1	
sedimentation vol.	0	5	0	5	0	5	2400	1
drainage facility	0.785	4	20.25	1	1.131	3	4	3
Vuln. Value	9		6		8		4	
Total Value	19		11		12		5	

Table B.5 Attribute datasets of occurrence sites in Deogyu Mountain area

occurrence	139.39		139.5		139.6		145.6		145.8	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	21.097	0	25.851	2	27.387	3	26.294	3	24.789	2
wtrshd area % exceeding 15˚	1.355	0	8.511	1	2.469	0	14.044	2	19.101	3
aver. valley slp	20.334	5	25.617	5	28.094	5	17.484	4	17.53	4
valley lgth % exceeding 15˚	80.714	5	86.817	5	100	5	67.717	5	45.278	1
Susc. Value	10		13		13		14		10	
sedimentation vol.	0	5	0	5	0	5	1250	2	400	3
drainage facility	0	5	1.131	3	0	5	0.785	4	16	2
Vuln. Value	10		8		10		6		5	
Total Value	20		21		23		20		15	

occurrence	145.9		146.05		146.3		147		147.2	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	27.016	3	27.118	3	20.824	0	25.09	2	25.426	2
wtrshd area % exceeding 15˚	22.465	3	19.872	3	4.209	1	16.42	2	22.318	3
aver. valley slp	17.115	4	19.173	5	15.87	3	16.882	3	17.642	4
valley lgth % exceeding 15˚	44.468	1	71.317	5	41.238	0	59.427	3	57.444	3
Susc. Value	11		16		4		10		12	
sedimentation vol.	0	5	0	5	0	5	500	2	0	5
drainage facility	0	5	1.131	3	0	5	4	3	4	3
Vuln. Value	10		8		10		5		8	
Total Value	21		24		14		15		20	

occurrence	150.2		154.9	
	value	pt	value	pt
aver. wtrshd slp	25.071	2	27.917	3
wtrshd area % exceeding 15˚	7.56	1	19.225	3
aver. valley slp	21.636	5	17.557	4
valley lgth % exceeding 15˚	70.305	5	67.378	5
Susc. Value	13		15	
sedimentation vol.	0	5	533.3333	2
drainage facility	0	5	0.785	4
Vuln. Value	10		6	
Total Value	23		21	

Table B.6 Attribute datasets of non-occurrence sites in Deogyu Mountain area

non-occurrence	139.4		139.3		145.86		146.2		147.22	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	22.375	1	19.854	0	21.193	0	14.711	0	25.426	2
wtrshd area % exceeding 15˚	0.094	0	2.856	0	7.059	1	0	0	22.318	3
aver. valley slp	19.83	5	17.656	4	13.965	2	12.861	1	17.642	4
valley lgth % exceeding 15˚	76.085	5	63	4	30.923	0	46.606	1	57.444	3
Susc. Value	11		8		3		2		12	
sedimentation vol.	0	5	0	5	500	2	0	5	0	5
drainage facility	0.503	4	0.503	4	0	5	1.131	3	4	3
Vuln. Value	9		9		7		8		8	
Total Value	20		17		10		10		20	

non-occurrence	149.94		155.54		154.88	
	value	pt	value	pt	value	pt
aver. wtrshd slp	23.251	1	32.067	5	27.257	3
wtrshd area % exceeding 15˚	9.138	1	35.511	5	16.223	2
aver. valley slp	14.932	2	25.193	5	15.832	3
valley lgth % exceeding 15˚	60.645	3	90.109	5	62.954	4
Susc. Value	7		20		12	
sedimentation vol.	0	5	0	5	533.333	2
drainage facility	16	2	0.785	4	0.785	4
Vuln. Value	7		9		6	
Total Value	14		29		18	

Table B.7 Attribute datasets of occurrence sites in Daegwanryung area

occurrence	217.2		230.9		231.8		231.7		233	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	31.86	5	16.577	0	21.635	0	23.296	1	17.352	0
wtrshd area % exceeding 15˚	42.168	5	0.109	0	2.696	0	8.284	1	0.774	0
aver. valley slp	19.587	5	7.437	0	6.642	0	7.107	0	4.939	0
valley lgth % exceeding 15˚	71.211	5	13.477	0	19.928	0	19.276	0	8.641	0
Susc. Value	20		0		0		2		0	
sedimentation vol.	0	5	0	5	500	2	0	5	0	5
drainage facility	0	5	0	5	0.785	4	0	5	0.785	4
Vuln. Value	10		10		6		10		9	
Total Value	30		10		6		12		9	

Table B.8 Attribute datasets of non-occurrence sites in Daegwanryung area

non-occurrence	215.29		231.52		231.66		228.1		229.1	
	value	pt	value	pt	value	pt	value	pt	value	pt
aver. wtrshd slp	20.995	0	18.696	0	23.087	1	21.282	0	21.443	0
wtrshd area % exceeding 15˚	3.534	0	0	0	2.439	0	2.745	0	2.855	0
aver. valley slp	10.514	0	8.356	0	15.017	3	16.019	3	13.399	2
valley lgth % exceeding 15˚	30.324	0	12.101	0	50.544	2	59.701	3	44.17	1
Susc. Value	0		0		6		6		3	
sedimentation vol.	0	5	0	5	10000	1	133.3333	3	10000	1
drainage facility	0	5	0.785	4	0.785	4	0.785	4	6.25	2
Vuln. Value	10		9		5		7		3	
Total Value	10		9		11		13		6	

non-occurrence	217.42		220.52		220.68	
	value	pt	value	pt	value	pt
aver. wtrshd slp	32.297	5	31.171	5	27.291	3
wtrshd area % exceeding 15˚	41.136	5	27.182	4	18.163	3
aver. valley slp	23.018	5	24	5	18.181	4
valley lgth % exceeding 15˚	75.02	5	86.967	5	76.356	5
Susc. Value	20		19		15	
sedimentation vol.	0	5	0	5	2000	1
drainage facility	0	5	0.785	4	9	2
Vuln. Value	10		9		3	
Total Value	30		28		18	

초 록

최근 증가하는 토석류 발생 빈도 및 발생 시 예상되는 인명, 재산상의 피해 등을 고려할 때, 이를 사전에 예측할 수 있는 기법의 개발은 매우 중요하다. 토석류 위험도는 지형, 지반, 강우, 식생 등 다양한 인자에 의해 결정되며, 특정 지점이 아닌 고속도로와 같은 광범위한 구간을 대상으로 할 경우 단계적 절차에 의한 평가가 필요하다. 국내외 여러 연구와 비교 분석한 결과 한국도로공사 방법이 적용성, 편리성 면에서 가장 적절한 위험도 평가 방법임을 확인할 수 있었다. 한국도로공사 토석류 위험도 평가 방법은 고속도로를 피해 대상으로 하여 재해도로 표현되는 지형적 특성과 취약도로 표현되는 배수시설 규격 특성 고려하여 위험도를 객관적이고 빠르게 평가한다.

이 체계를 이용할 경우 수치지도와 종평면도를 포함한 고속도로 시설물 도면으로부터 토석류 위험도를 평가하는 것이 가능하다. 또한 GIS를 기반으로 개발할 경우, 지형 특성을 효율적, 객관적으로 반영할 수 있다. 이 방법이 추후 실제 공용 고속도로에 적용이 된다면 위치 별 토석류 위험도 등급을 평가하여, 수치지도 상에 입력하면 강우계측 정보와 연계하여 준실시간으로 토석류 발생 위험도를 예보할 수 있을 것으로 기대된다.

본 연구에서는 한국도로공사 토석류 위험도 평가 체계를 GIS 기반으로 평가할 수 있는 절차를 개발 및 제안하고, 실제 과거 토석류 발생 사례 네 개 지역에 적용하였다. 그 결과에서 나타나는 문제점을 보완하기 위해 영향 인자를 재분석하여 등급 체계를 수정하였으며, 또한 추가적인 영향 인자를 고려하여 추후 평가 방법 중에 포함시켜 평가를 수행할 수 있는 가능성을 확인하였다. 수정된 평가 방법을 선택한 네 개 지역에 대하여 다시 적용하였고, 이를 통해 개선된 결과를 확인할 수 있었다. 개선된 정도를 객관적, 정량적으로 살펴보기 위해 검증 작업을 수행하였으며, 이 과정을 통해 평가 방법의 수정을 통하여 확실히 개선된 결과를 살펴볼 수 있었다.

주요어 : 토석류, GIS, 재해도, 취약도, 위험도 평가

학 번 : 2013-20917