

## **Reply for Anonymous Referee #1**

**Thank you very much for referee's sincere comments.**

**Authors corrected the pre-existing manuscript taking into account the comments. The corrected or additionally incorporated parts in the revised manuscript were underlined and red letters. For the specific comments from anonymous referee #1, authors' corrections are as follows:**

### **Comment #1**

In this paper, authors developed a method to assess debris flow hazard for expressways in a simple way. Even though it is well described and fairly well written, the method seems unreasonable to assess the hazard level correctly. Therefore to be published in the journal, it is required to be revised.

### **Revision #1**

Authors really appreciate reviewer's valuable and encouraging comments on our manuscript. Also, the original manuscript was corrected and improved considering the remarks and suggestions from reviewer acting as a referee. So in this response to reviewer comments, the revision of the original manuscript and point-by-point response were prepared. Author's corrections were described in the Revisions #1 to #3 presented below.

### **Comment #2**

Basically the method results in poor assessment for the hazard based on the real occurrence data as shown in Table 5 as the authors also agreed in their paper. It seems mainly because of the scoring system that they adopted using several attributes. First of all, they included the vulnerability value in the score, but it does not distinguish between the areas of occurrence and those of non-occurrence as revealed in Table 5. Also they did not give an explanation on why they selected the attributes and gave the points according to the evenly divided values without any weightings which is very critical to review the paper.

### **Revision #2**

Authors appreciate reviewer's sincere recommendation on our manuscript to making the paper near perfect. According to your comments, authors also agreed that the proposed framework (system) can't perfectly distinguish the total Hazard Value differences between occurrences and non-occurrences for the three target areas. Authors developed a simple method (but not limited to its current one) to assess debris flow hazard for expressway management. First of all, this has never been tried in Korea and the method has limitations due to the wide coverage area and usage of available data throughout the whole expressway constructed in Korea. The reason of uncertainty or limitations of proposed framework is constraints of influencing factor and grading standard for determination of debris flow index.

Prediction concerns either where or when debris flow will occur, depending on the type of movement and the scope of the forecasting. Many attributes (geography, rainfall, geology, vegetation, wildfire history, and conditions of existing structures) are related to the mechanism/initiation of debris flows. To obtain information on the influencing factors other than topographical properties (elevation, slope, valley and watershed) and rainfall data, field surveys should be thoroughly conducted throughout entire expressway facility sections. Because the assessment of debris flow hazards in this study is to be applied on a regional scale, the method needed to be simple, and also applicable for the macro-zonation of debris flow hazards. And other factors such as the size and shape of valley along with the variations in slope direction, properties of the subsoil, geological properties, and vegetation also have an influence on the movement of debris-flows.

However, to simplify the method, only the slope information was considered for debris-flow movement possibilities. Considering that obtaining and processing all the attributes stated above in the prediction stage is a time-consuming and difficult task, it was decided that only easily accessible document data (such as digital maps, geological maps, etc.) were to be used in the site-specific assessment process. For example, the spatial correlations (for site-specific micro-scale area) between influence of debris flow and geological or vegetation characteristics was not perfectly set up in Korea. First of all, since there are mostly occurred macro- or micro-scale

debris flow events induced by regional torrential rains, Korea, the application of reliable document data is necessary to immediately evaluate the site-specific debris flow hazard for the wide coverage area. Consequently, the KEC debris flow hazard assessment method was set as a fundamental assessment tool owing to its simplicity. Authors also corrected the original manuscript considering clarification of selection of attributes (influencing factors) offered as following:

[lines 18-31 of page 3]

“To obtain information on the influencing factors other than topographical properties (elevation, slope, valley and watershed) and rainfall data, field surveys should be thoroughly conducted throughout entire expressway facility sections. Because the assessment of debris flow hazards in this study is to be applied on a regional scale, the method needed to be simple, and also applicable for the macro-zonation of debris flow hazards. And other factors such as the size and shape of valley along with the variations in slope direction, properties of the subsoil, geological properties, and vegetation also have an influence on the movement of debris-flows. However, to simplify the method, only the slope information was considered for debris-flow movement possibilities. Considering that obtaining and processing all the attributes stated above in the prediction stage is a time-consuming and difficult task, it was decided that only easily accessible document data (such as digital maps, geological maps, etc.) were to be used in the site-specific assessment process. For example, the spatial correlations (for site-specific micro-scale area) between influence of debris flow and geological or vegetation characteristics was not perfectly set up in Korea. First of all, since there are mostly occurred macro- or micro-scale debris flow events induced by regional torrential rains, Korea, the application of reliable document data is necessary to immediately evaluate the site-specific debris flow hazard for the wide coverage area. Consequently, the KEC debris flow hazard assessment method was set as a fundamental assessment tool owing to its simplicity.”

And the classification of grading standard or weighting function was established based on logistic regression using debris flow case histories at the national-wide expressway area in Korea. Each of the influential factors are given points from 0 to 5 based on the grading standard set considering past debris flow occurrence cases for ten years, 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 the Statistical Package for Social Science (SPSS). The occurrence of debris flow is kind of the binary item which is ‘zero’ as happening while as ‘one’ for no occurrence. Hence, the logistic regression is used frequently to carry out the multivariable analysis. Results of about 30 logistic regression analyses 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. In the same way,

each of the attributes is given points ranging from 0 to 5 based on a grading standard, and these points are added up to provide the total *Vulnerability Value* of 10 points. Thus authors prepared the above mentioned presentation at the revised manuscript:

[lines 16-23 of page 4]

“(…) Each of the influential factors are given points from 0 to 5 based on the grading standard set considering past debris flow occurrence cases for ten years (Table 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 the Statistical Package for Social Science (SPSS). The occurrence of debris flow is kind of the binary item which is ‘zero’ as happening while as ‘one’ for no occurrence. Hence, the logistic regression is used frequently to carry out the multivariable analysis (Ohlmacher et al. 2003). Results of about 30 logistic regression analyses 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.”

In addition, the modifications on framework were considered for three testbed sites according to the clarification of attributes and grading standards. 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 can be made on the assessment method. Therefore, to modify 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. After calculating the average values for each attribute for the occurrence and non-occurrence cases of the three target areas, the each attributes were compared. And a criterion for the grading standard was set based on logistic regression. 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 re-established as Table 6. The *Vulnerability Value* grading standard was also modified based on the debris-flow occurrence and non-occurrence cases of the three target areas. Considering the fact that only a very few number of the considered sites had deposit areas with volumes exceeding 2000 m<sup>3</sup>, the grading standard was modified. The highest grading standard was altered from 5000 m<sup>3</sup> to 2000 m<sup>3</sup>, and the other standards were also modified accordingly.

Based on the same condition of application for three target area, the *Hazard Value* and *Hazard Class* were determined using revised grading standard. The spatial pattern of occurrence

case at the scoring chart was distributed on *Hazard Class* of S, A, and B having the high potential of debris flow, as shown in Fig. 12. On the contrary, the points of non-occurrence case were distributed on *Hazard Class* of C, D, and E having comparatively lower potential of debris flow. In addition, the average value of the *Susceptibility Value*, *Vulnerability Value*, and *Hazard Value* of occurrence cases are distinguishable 1.58 times greater than those of non-occurrence cases (Table 7). The difference between *Hazard Value* of occurrence and non-occurrence cases based on revised grading standard are 1.37 times greater than difference (1.15) of application results using existing standard. Moreover, the framework has potential to be upgraded with more data accumulation and more case histories, considering locality of debris flow potential in Korea. Also, attributes other than those regarding the slope should be considered such as watershed size and bending of valley. According to Kim et al. (2014), With larger watershed sizes, both the debris-flow initiation risk and occurrence risk increase. An objective standard was set for the assessment of bending of valley (bending ratio). With larger bending ratios, more debris-flow materials are subjected to sedimentation, lowering the possibility of damage on road structures. Thus, the above modified parts underlined in the manuscript are as follows:

[lines 10-34 of page 11 and lines 1-6 of page 12]

### **“5.3 Modifications on framework**

The existing KEC method designated points to each attribute according to a grading standard set based on a few case studies of 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 can be made on the assessment method. The results of three applications showed the highest number of debris-flow occurrence sites. Therefore, to modify 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. After calculating the average values for each attribute for the occurrence and non-occurrence cases of the three target areas, the each attributes were compared. And a criterion for the grading standard was set based on logistic regression. 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 re-established as Table 6. The *Vulnerability Value* grading standard was also modified based on the debris-flow occurrence and non-occurrence cases of the three target areas. Considering the fact that only a very few number of the considered sites had deposit areas with volumes exceeding 2000 m<sup>3</sup>, the grading standard was modified. The highest grading standard

was altered from 5000 m<sup>3</sup> to 2000 m<sup>3</sup>, and the other standards were also modified accordingly.

Based on the same condition of application for three target area, the *Hazard Value* and *Hazard Class* were determined using revised grading standard. The spatial pattern of occurrence case at the scoring chart was distributed on *Hazard Class* of S, A, and B having the high potential of debris flow, as shown in Fig. 12. On the contrary, the points of non-occurrence case were distributed on *Hazard Class* of C, D, and E having comparatively lower potential of debris flow. In addition, the average value of the *Susceptibility Value*, *Vulnerability Value*, and *Hazard Value* of occurrence cases are distinguishable 1.58 times greater than those of non-occurrence cases (Table 7). The difference between *Hazard Value* of occurrence and non-occurrence cases based on revised grading standard are 1.37 times greater than difference (1.15) of application results using existing standard. Moreover, the framework has potential to be upgraded with more data accumulation and more case histories, considering locality of debris flow potential in Korea. Also, attributes other than those regarding the slope should be considered such as watershed size and bending of valley. According to Kim et al. (2014), With larger watershed sizes, both the debris-flow initiation risk and occurrence risk increase. An objective standard was set for the assessment of bending of valley (bending ratio). With larger bending ratios, more debris-flow materials are subjected to sedimentation, lowering the possibility of damage on road structures.”

[Table 6]

**Table 6.** Modified points given to attributes according to grading standard of KEC.

| Classification                             |                                      |   | Scoring Criteria  |        |
|--|--------------------------------------|---|-------------------|--------|
|  |                                      |   | Scoring Index     | Points |
| <i>Susceptibility Value</i><br>(20 Points) | Initiation Assessment<br>(10 Points) | Mean Slope of Watershed<br>(Unit : °)                           | - Higher than 30° | 5      |
|  |                                      |   | - 30°~28°         | 4      |
|  |                                      |   | - 28°~26°         | 3      |
|  |                                      |   | - 26°~24°         | 2      |
|  |                                      |   | - 24°~22°         | 1      |
|  |                                      |   | - Under 22°       | 0      |
|  | Movement Assessment<br>(10 Points)   | Area Percentage of Watershed with Slopes over 35°<br>(Unit : %) | - Higher than 32% | 5      |
|  |                                      |   | - 32°~25%         | 4      |
|  |                                      |   | - 25°~18%         | 3      |
|  |                                      |   | - 18°~11%         | 2      |
|  |                                      |   | - 11°~4%          | 1      |
|  |                                      |   | - Under 4%        | 0      |
|  |                                      | Mean Valley Slope<br>(Unit : °)                                 | - Higher than 19° | 5      |
|  |                                      |   | - 19°~17°         | 4      |
|  |                                      |   | - 17°~15°         | 3      |
|  |                                      |   | - 15°~13°         | 2      |
|  |                                      |   | - 13°~11°         | 1      |

|                                       |   |   |   |   |
|---------------------------------------|---|---|---|---|
|                                       |   |   | - Under 11°   | 0 |
|                                       |   | Length  | - Higher than 67%   | 5 |
|                                       |   | Percentage of   | - 67%~61%   | 4 |
|                                       |   | Valley with   | - 61%~55%   | 3 |
|                                       |   | Slopes over 15°   | - 55%~49%   | 2 |
|                                       |   | (Unit : %)  | - 49%~43%   | 1 |
|                                       |   |   | - Under 43%   | 0 |
| Vulnerability<br>Value<br>(10 Points) | Debris Storage,<br>Sedimentation<br>Availability<br>(5 Points)      | Volume of<br>Deposit Area<br>(Unit : m <sup>3</sup> )                                 | - No accumulation area (0m <sup>3</sup> )                   | 5 |
|                                       |   |   | - 0m <sup>3</sup> ~100m <sup>3</sup>                        | 4 |
|                                       |   |   | - 100m <sup>3</sup> ~500m <sup>3</sup>                      | 3 |
|                                       |   |   | - 500m <sup>3</sup> ~2,000m <sup>3</sup>                    | 2 |
|                                       |   |   | - Higher than 2,000m <sup>3</sup>                           | 1 |
|                                       |   |   | - Excessive volume of deposit area,<br>No damage guaranteed | 0 |
|                                       | Debris Passage<br>through<br>Expressway<br>Facilities<br>(5 Points) | Size of Drainage<br>Facility<br>(Unit : Cross-<br>sectional Area,<br>m <sup>2</sup> ) | - Waterway  | 5 |
|                                       |   |   | - Lateral drains below D1,200                               | 4 |
|                                       |   |   | - Waterway box below B2.0x2.0                               | 3 |
|                                       |   |   | - Waterway box below B4.0x4.0                               | 2 |
|                                       |   |   | - Waterway box below B3.0xD3.0                              | 1 |
|                                       |   |   | - Bridges   | 0 |

[Table 7]

**Table 7. Average of Susceptibility Value, Vulnerability Value, and Hazard Value of occurrence and non-occurrence cases based on modified grading standard.**

|                 | Occurrence case         |                        |                 | Non-occurrence case     |                        |                 |
|-----------------|-------------------------|------------------------|-----------------|-------------------------|------------------------|-----------------|
|                 | Susceptibility<br>value | Vulnerability<br>value | Hazard<br>value | Susceptibility<br>value | Vulnerability<br>value | Hazard<br>value |
| Pyeongchang     | 13.53                   | 9.50                   | 23.03           | 8.52                    | 5.62                   | 17.00           |
| Deogyu Mountain | 14.62                   | 8.52                   | 23.14           | 9.01                    | 6.92                   | 17.57           |
| Juksan&Geochang | 15.31                   | 9.02                   | 24.33           | 7.12                    | 7.55                   | 17.88           |
| Average         | 14.47                   | 9.01                   | 23.50           | 8.22                    | 6.70                   | 14.91           |

**Comment #3**

I also found some typos with incorrect year compared to that in references. The references should be also reordered alphabetically.

**Revision #3**

We really appreciate your detailed review on our manuscript. Authors corrected the typos and rearranged references list. Accordingly references of manuscript were added or modified. The modified part was expressed red and underlined letters, on the whole manuscript.