APPLICATION OF THE STEEP SLOPE RISK ASSESSMENT USING THREE DIMENSIONAL INFORMATION DATA

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ABSTRACT:

A collapse of slope is one of the natural disasters that often occur during the early spring and the rainy season. In order to prevent this kind of disaster, safety monitoring is carried out through risk assessment. This assessment consists of various parameters such as inclination angle and height of the slope, and inspectors evaluate the score using the compass, the laser range finder, and so on. This approach is, however, consumed a lot of the manpower and the time. This study, therefore, aims to evaluate the rapid and accurate steep slope risk by using a terrestrial LiDAR which takes 3 dimensional spatial information data. 3D spatial information data was acquired using the terrestrial LiDAR for steep slopes classified as very unstable slopes. Noise and vegetation of the acquired scan data were removed to generate point cloud data with a rock or mountain model without vegetation. The RMSE of the registration accuracy was 0.0156 m. From the point cloud data, the inclination angle, height, shape, valley, collapse and loss were evaluated. As a result, various risk assessment parameters can be checked at once. In addition, it is expected to be used as basic data for constructing steep slope DB, providing visualization data, and time series analysis in the future.

1. INTRODUCTION

1.1 Background and Purpose of the Study

The Republic of Korea is mostly mountainous and has many steep slope areas. Because of these characteristics, large and small steep slope collapses occur every year, and it is one of the natural disasters that occur frequently due to the weakening of ground during the winter season and wet season.

Recently, the impact of climate change is becoming serious, and the damage is expected to a large occur. The Ministry of the Interior and Safety has revised and promulgated the "Prevention of Steep Slope Disasters Act", and it has proposed the designation, management, and maintenance plans for sloping and collapsing dangerous areas (Ministry of the Interior and Safety, 2017).

In addition, the number of occurrences of steep slope accidents is gradually increasing due to urbanization and industrialization. It is still under investigation whether collapsing accidents occur frequently either by natural disaster or by human activities (Lee et al., 2014).

The collapse of a steep slope causes damage to the infrastructure and human life. Therefore, the Ministry of the Interior and Safety of the Republic of Korea strives to prevent accidents every year by recognizing the risk of steep slopes in advance. The risk of the steep slope is evaluated by selecting the risk assessment items for each type. The disaster risk assessment evaluation deals with the steep slope risk for three slopes: natural slope, artificial slope, retaining wall and pavement. To evaluate the items in each risk assessment, the investigators directly survey the site using a clino-compass, a laser range finder, and a digital topographical map.

However, this method is time-consuming because the investigator has to search for a large area and he may in danger to injury while he is evaluating steep slopes. In addition, since the measurement is performed through simple equipment, a reliability problem may occur with respect to the evaluation value.

To solve these problems, we have been conducted the same evaluation using the terrestrial LiDAR, which can be precisely measured (Park et al., 2017; Kim et al. 2017). The terrestrial LiDAR has the advantage of acquiring three-dimensional shape information and can measure a wide range.

Therefore, this study aims to evaluate the feasibility of using the terrestrial LiDAR for precise measurement and wide area scanning in order to minimize manpower and time when performing a steep slope risk assessment.

1.2 Study area and Working Process

The study areas were located in “Hail-ri, Pyeongchang-eup, Pyeongchang-gun, Gangwon-do(Figure 1a)”, and “Bongyang-ri, Jeongseon-eup, Jeongseon-gun, Gangwon-do(Figure 1b)”. The steep slope located in Pyeongchang-gun was designated as the danger zone for risk assessment in April 2019, and disaster risk assessment grade is "D (see Table 1)". It is in contact with the road, and there is a large risk of rockfall, and no rockfall prevention facility is installed. The steep slope risk assessment rating in Jeongseon-gun was “D” grade and designated as a risk zone for collapse in March 2019. There is a river in front of the

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steep slope, and the road is adjacent. There were a lot of rocks around the road, and the rockfall prevention facilities were old.

(a) Pyeongchang-gun (b) Jeongseon-gun

Figure 1. Study area

This study proceeds as shown in Figure 2. After selecting a suitable position to scan a wide range of origin, three dimensional spatial information is acquired through scanning. The acquired spatial information is included vegetation, automobiles, etc., and removed noise for accurate analysis. After that, the necessary information is obtained and utilized for the part corresponding to the disaster risk assessment item.

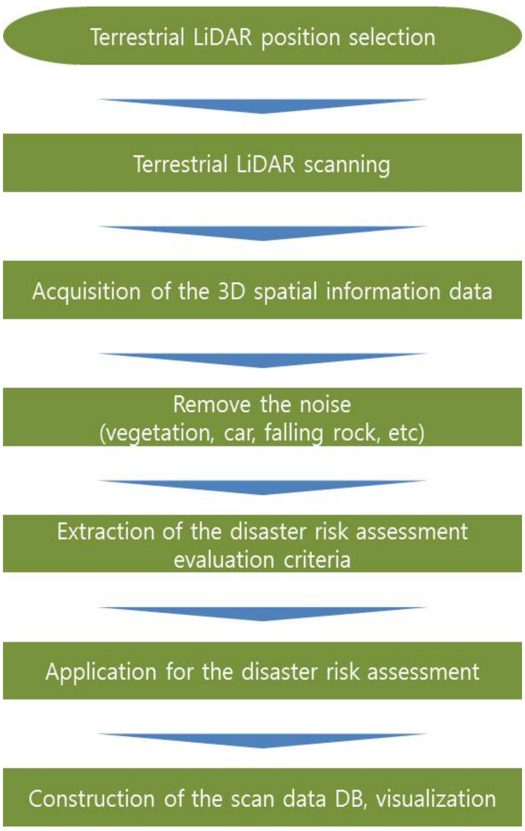

Figure 2. Flow chart of study

2. DISASTER RISK ASSESSMENT

The steep slope disaster prevention legislation aims to notify the danger zone of steep slope collapse and to protect the people from collapse risk. In the case of "D" and "E" grades in the risk grade, it is designated as a collapse hazard and is managed. However, even if it is not "D" or "E" grade, if there is concern about the damage of the person in the collapse according to the local conditions of the steep slope, it can be managed and designated as a collapse hazard area. Table 1 shows the scores and content of each grade.

Grade	Disaster risk assessment scores			Contents
	Natural slope(°)	Artificial slope(°)	Retaining wall and pavement (°)	
A	0 ~ 20	0 ~ 20	0 ~ 20	Even though unexpected collapse occurs the damage is low
B	21 ~ 40	21 ~ 40	21 ~ 40	No risk of disasters, but need periodic management
C	41 ~ 60	41 ~ 60	41 ~ 60	There is a risk of disasters and it is necessary to continuously check and develop a maintenance plan if necessary
D	61 ~ 80	61 ~ 80	61 ~ 80	Need to establish maintenance plan because of high risk of disaster
E	Over 81	Over 81	Over 81	The risk of disaster is very high, so it is necessary to establish a maintenance plan

Table 1. Assessment scores and contents by grade

There are three types of steep slopes: natural slope, artificial slope, retaining wall and pavement. There is a disaster risk assessment table for each type and the final risk score is calculated and graded by the evaluation table. In this study, the mountainous area was selected as the study area, so the risk assessment was performed on the natural slope evaluation table. Table 2 shows the hazard level of natural slope and mountainous area, and shows each evaluation item. There are two categories of hazard assessment charts for natural slope and mountainous areas. Each category is composed of detailed evaluation items. The inclination angle of the slope is measured using the inclinometer (clino-compass, etc.). The slope height is surveyed by a laser distance measurement until it reaches the top of the steep slope. The shape of the mountain area is obtained by using the digital topographic map to grasp the profile of vertical shape of the steep slope and determine the transverse shape at the discretion of the investigator. Other ground transformation, cracks, surface of slope valley, collapse, loss history, surrounding environment, etc. are investigated by the investigator while looking directly at the mountain. As the investigator directly identifies and evaluates the results, it takes a lot of time and subjective judgment to intervene, which may cause problems in making an accurate evaluation.

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<table>
<tr><th colspan="4">Division</th><th colspan="6">Assessment criteria and scores</th></tr>
<tr><td rowspan="24">Risk of Collapse</td><td colspan="3" rowspan="2">Angle of inclination(°)</td><td>Under 20</td><td>20~30</td><td>34~43</td><td>44~53</td><td>Over 54</td></tr>
<tr><td>2</td><td>4</td><td>6</td><td>8</td><td>10</td></tr>
<tr><td colspan="3" rowspan="2">Height(m)</td><td>Under 25</td><td>25~49</td><td>50~59</td><td>60~69</td><td>Over 70</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td colspan="3" rowspan="2">Vertical shape of a steep slope</td><td>Convexity</td><td>Linear</td><td>Concavity</td><td>Combining form</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td colspan="3" rowspan="2">Traverse shape of a steep slope</td><td>Descent</td><td>Parallel</td><td>Ascend</td><td>Combining form</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td colspan="3" rowspan="2">Ground transformation and crack</td><td>Absence</td><td>existence</td></tr>
<tr><td>0</td><td>5</td></tr>
<tr><td colspan="2" rowspan="4">Surface of slope valley</td><td rowspan="2">Valley length(m)</td><td>0~10</td><td>11~30</td><td>31~50</td><td>Over 51</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td rowspan="2">Valley width(m)</td><td>Over 3</td><td>2~3</td><td>1~2</td><td>Under 1</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td colspan="3" rowspan="2">Soil layer depth</td><td>0~20</td><td>21~50</td><td>51~70</td><td>71~90</td><td>Over 91</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td colspan="3" rowspan="2">Upper external forces</td><td>None</td><td>Field, paddy field, tomb</td><td>A power linen tower, house</td><td>Railway</td><td>Road</td><td>Forest road</td></tr>
<tr><td>1</td><td>2</td><td>4</td><td>6</td><td>8</td><td>10</td></tr>
<tr><td colspan="3" rowspan="2">Groundwater state</td><td>Dry</td><td>Dampness</td><td>Surface water</td><td>water</td></tr>
<tr><td>0</td><td>2</td><td>4</td><td>6</td></tr>
<tr><td colspan="3" rowspan="2">Collapse and loss history</td><td>None</td><td>Rockslide</td><td>Under 10%</td><td>10~20%</td><td>Over 20%</td></tr>
<tr><td>0</td><td>2</td><td>4</td><td>6</td><td>8</td></tr>
<tr><td colspan="3" rowspan="2">Protection facilities state</td><td>Good</td><td>Bad</td><td>Very bad</td><td>absence</td></tr>
<tr><td>0</td><td>2</td><td>4</td><td>5</td></tr>
<tr><td rowspan="10">Social influence</td><td colspan="3" rowspan="2">Surrounding environment</td><td>Woods and fields, park</td><td>Housing site, road, railroad</td></tr>
<tr><td>3</td><td>5</td></tr>
<tr><td rowspan="6">The number of people affected /Number of roads/ Traffic volume</td><td rowspan="4">The road near by steep slope</td><td rowspan="2">Number of roads (one way)</td><td>Under 1 lane road</td><td>2 lane roads</td><td>Over 3 lane roads</td></tr>
<tr><td>1</td><td>4</td><td>7</td></tr>
<tr><td rowspan="2">Traffic volume</td><td>Under 500</td><td>500~5,000</td><td>5001~20,000</td><td>20,001~35,000</td><td>Over 35,001</td></tr>
<tr><td>1</td><td>2</td><td>4</td><td>6</td><td>8</td></tr>
<tr><td rowspan="2">Other areas steep slope</td><td rowspan="2">The number of people affected</td><td>0</td><td>1~4(people)</td><td>Over 5(people)</td></tr>
<tr><td>0</td><td>10</td><td>15</td></tr>
<tr><td colspan="3" rowspan="2">Distance between steep slopes and adjacent facilities</td><td>None</td><td>Slope height more than 2 times</td><td>Less than 2 times slope height</td><td>Within slope height</td><td>Less than 1/2 times slope height</td></tr>
<tr><td>0</td><td>1</td><td>4</td><td>7</td><td>10</td></tr>
</table>

Table 2. Natural slope and mountainous disaster risk assessment table

3. TERRESTRIAL LIDAR SURVEY

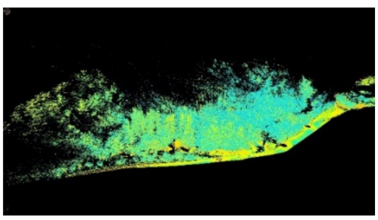
The terrestrial LiDAR is a measuring instrument that can acquire precise point cloud data using reflected values after reaching an object by launching a laser. The equipment used in this study is RIEGL's VZ-2000(Figure 3). The VZ-2000 is equipped with the latest wavelength technology, and is a laser scanning device that can acquire coordinates through GPS mounting. In addition, it can measure at a faster scan speed than other measurement equipment, and has high accuracy, high precision and full automatic processing performance. And real-time geo-referencing technology does not require a separate survey. Other specifications of the equipment are shown in Table 3.

Figure 3. VZ-2000 terrestrial LiDAR

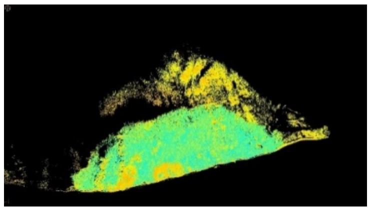
Division	Specification				
Laser scanning speed	50 kHz	100 kHz	300 kHz	5500 kHz	1 MHz
Effective Measurement Rate(meas./sec)	21,000	42,000	122,000	230,000	396,000
Measurement Range	2,050 m	1,800 m	1,000 m	750 m	580 m
Number of Targets per Pulse	15	15	15	9	2

Table 3. VZ-2000 specification

Since the steep slope of this study is difficult to scan at once because of its size, laser scanning was performed twice. 262,238,568 point cloud data were acquired through laser scanning of steep slopes of Pyeongchang-gun. And 174,825,712 point cloud data were obtained from the steep slopes of Jeongseon-gun. Figure 4 is shown steep slope point cloud data obtained from each study area as stated.



(a) Pyeongchang-gun



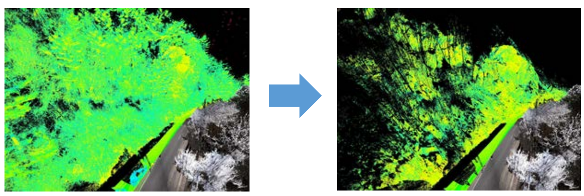
(b) Jeongseon-gun

Figure 4. Scanning point cloud data of the steep slopes

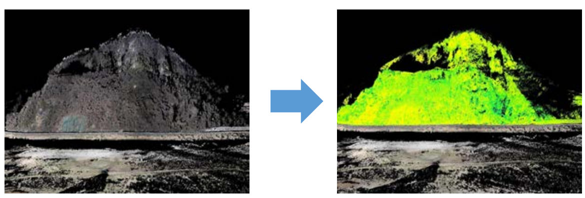
As a result of matching of the scan data obtained at 2 regions, the RMSE was 0.0156 m, which is good. Various noise such as vegetation, stone, automobile, and street light of the acquired point cloud data are major obstacles to the risk assessment of steep slopes. Therefore, noise removal is essential for accurate numerical acquisition and evaluation. The vegetation filter extracted multiple targets from the original point cloud and selected the same point as the total returned reflected from the laser pulse. After that, based on the corrected reflectivity information, it is separated using the reflectance of the vegetation. Vegetation can be greatly reduced based on the corrected reflectivity information for the remaining points, but it is difficult to remove it correctly because tree trunks are similar to the ground. In order to compensate for this, the threshold value should be applied and the reflectance value should be removed with a difference.

$$\boldsymbol{E_n = \min(Z_n) \quad D_n = \max(Z_n)} \quad (1)$$

The above formulas have been used for aircraft altitude measurement data(Vosselman, 2000) and applied to terrestrial LiDAR datasets. A custom morphological filter(Haralick and Shaprio 1992), composed by an erosion (E) operator followed by a dilation (D) operator, in the so-called morphological "opening" operation which is applied to maximum and minimum laser elevations falling inside a regular grid as in the equation. Where Z_n is the height of the points inside the window of size C at the nth iterations. The results before and after removing vegetation are shown in Figure 5. After removing vegetation and noise cleanly, accurate DEM data were generated to facilitate risk assessment.



(a) Pyeongchang-gun



(b) Jeongseon-gun

Figure 5. Before and after vegetation removal

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4. RESULT

After acquiring three dimensional spatial information data through the terrestrial LiDAR, noise for vegetation is removed. Length, angle of inclination and danger area, etc. are then analysed by using last calculated point cloud. First, study area's steep slope is analysed and Table 4 is shown the overall slope specification.

Division	Pyeongchang-gun	Jeongseon-gun
Length(m)	227.1	590.1
Height(m)	59.1	180.3
angle of inclination(°)	44.6	41.44
Vertical shape of a steep slope	Combining form	Linear
Traverse shape of a steep slope	Combining form	Parallel
Valley length(m)	None	192.3
Valley width	None	2.2
Upper external forces	2	None
Collapse and loss history	2	2
Protection facilities state	None	2
Surrounding environment	5	5
Number of roads (one way)	1	1
Distance between steep slopes and adjacent facilities	None	None

Table 4. Target steep slope risk assessment

In the case of the steep slope of Pyeongchang-gun, rocks that were lost from the original slope were piled up in the lower part of the slope in some areas and phenomenon for failing rocks occur consistently. Also, steep rock face slope has 75 degree slope (Figure 6). Overall, it was confirmed that the surface of the slope is highly weathered and falling rocks in the form of wedge failure due to many joints are generated.

Unlike steep slopes of Pyeongchang-gun, steep slope of Jeonngseon-gun were equipped with falling rock prevention walls and retaining walls and weathering has progressed significantly in some sections of rocks. The presence of the old valley seen in the field was confirmed in the LiDAR data, and a lot of fell rocks were actually scattered around it (Figure 8).

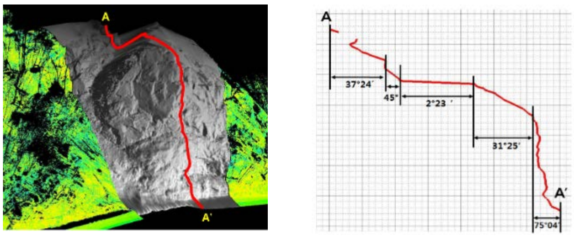

Figure 6. Pyeongchang-gun steep slope collapsing danger zone

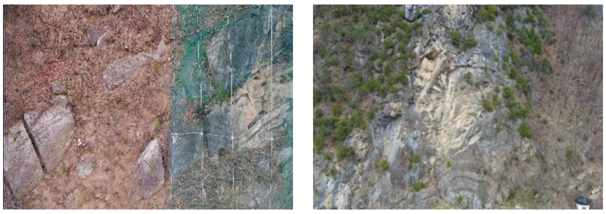

Figure 7. Jeongseon-gun steep slope falling rock prevention and rock

Figure 8. Jeongseon-gun steep old valley confirmed by LiDAR

The evaluation items (ground transformation and crack, soil layer depth, groundwater level) excluded from Table 4 are considered to be required to be accurately evaluated through field surveys.

5. CONCLUSION

This study used the terrestrial LiDAR, which can perform wide area scanning, to solve the existing inaccurate numerical calculation, high manpower and time consuming when evaluating the steep slope risk assessment. It was possible to acquire data in a wide range slope for about 10 minutes and to easily obtain height, length, angle of inclination, shapes and so on. However, terrestrial LiDAR data cannot explain the characteristics for underground conditions, and groundwater level. This is considered to be supplemented by the fusion analysis using the drone in the future.

The steep slope scan data can be stored in a three dimensional shape, which can later be used as big data through building the steep slope database. In addition, three dimensional shape data can be used as basic data for time series analysis because it can easily grasp the state through visualization.

In the future, it will be necessary to perform the risk assessment of steep slopes for more diverse mountain areas, to secure more reliability and to research and develop more precise noise elimination.

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