Research on Technology to Grasp the Conditions of Slopes Close to Roads Early after an Earthquake

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1. Background and purpose

In the 2016 Kumamoto Earthquake, the functions of roads were affected by ground deformation, and some of these roads took a long time to investigate and restore because they were located close to steep slopes (**Photo 1**). Based on this lesson, in order to make decisions as quickly as possible on whether roads along such slopes are passable or not immediately after an earthquake and on emergency opening, it is considered that one of the most important factors is the early and comprehensive grasp of the existence, extent, and degree of deformation on the slopes. Therefore, in order to present a maintenance management method that contributes to the early and comprehensive grasp of the deformation of road slopes that are not easily accessible, we are studying the possibility of using existing technologies to detect deformations and the matters etc. that should be considered when acquiring data and interpreting the acquired information for implementation in maintenance. This paper reports the knowledge obtained based on the measurements made on the restoration sites of the Kumamoto Earthquake with regard to the issues that should be considered in implementation.

Photo 1: Road close to the steep slope

2. Study method

(1) Shape measurement method

This paper provides the results of three times of measurements made in March, August, and November at the lower slope of the Toshita Ohashi Bridge (**Photo 1, right**), where the progress of restoration work and vegetation conditions were different. In the measurement, we used two types of laser scanners, i.e., UAV-mounted laser scanner and terrestrial laser scanner (TLS), as a technique that has the potential to grasp the shape of steep slopes in planes without close proximity (**Photo 2**).

(2) Verification method by comparison of measurement results

After creating a TIN model, in which the 3D shape of the slope consists of a triangular surface, using the 3D point group data acquired by each technique, we calculated the difference between the vertical coordinates of the point group and the TIN model (**Fig. 1**) for various cases with different measurement time and methods, to create a difference diagram and compare the measurement results. The comparison was made focusing on the four sites shown in **Fig. 2** in order to verify the influence of topographical conditions and surface properties on the measurement results in addition to the shape change caused by the construction of the restoration work. Of the sites on which results of study were introduced in this paper, at Site 2, mortar was sprayed from March to November, while at Site 3, the construction of slope frames and in-frame anchors was carried out from March to August.

Photo 2: Technology used in the study

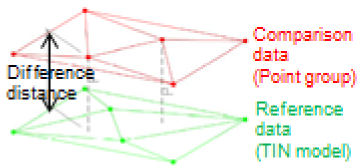

Fig. 1: Image of the difference calculation

Fig. 2: Points of focus in comparison of measurement results

3. Verification by comparison of measurement results

(1) Verification of basic measurement accuracy

Fig. 3 shows the difference diagram of measurement results between the TLS and UAV laser at Site 2 in November after the mortar spraying. The difference was close to zero on all the sides, and the average of the absolute difference was small at 0.023 m. If the conditions are smooth shape and little vegetation, it is possible to identify shape changes with a size of about 2 cm at minimum.

(2) Verification of issues to be considered in implementation

Fig. 4 shows the difference diagram in the results of UAV laser measurements before and after the construction of the slope frame and in-frame anchors at Site 3 (March and November). In both March and November, the surface point density was above 100 pts/m^2 over the entire surface. In this Figure, the area where a pressure receiving plate with a design thickness of 30 cm has been installed is colored red to represent a positive difference of 30 cm, which indicates that the change in areal shape due to installation could be grasped.

Fig. 5 shows the difference diagram of measurement results between the TLS and UAV laser in November after the installation of the slope frame and in-frame anchors at Site 3. The surface point density of the UAV laser is more than 100 points/m^2 over the entire surface, while that of the TLS is as small as 20 points/m^2.

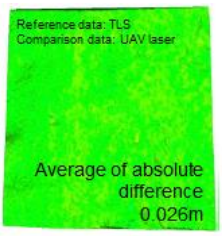

Fig. 3: Difference diagram **(Nov., Site 2, Difference between TLS and UAV laser)**

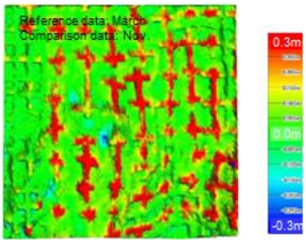

Fig. 4: Difference diagram **(Site 3, UAV laser, Difference between March and November)**

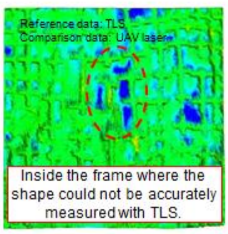

Fig. 5: Difference diagram **(Nov., Site 3, Difference between TLS and UAV laser)**

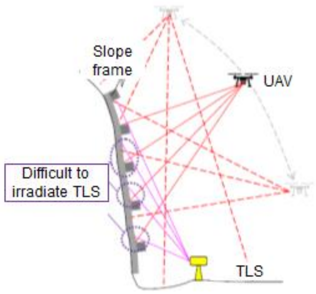

Fig. 6: Examples of conditions that make TLS irradiation difficult.

Fig. 5 shows that while there are many areas where the difference is close to zero, a portion of the frame is colored blue to represent a negative difference of 30 cm, which indicates that the TLS measures the slope as a convex shape better than the UAV laser.

This means that the shape of the concave in the frame could not be accurately measured by the TLS due to the relationship between the location of the measurement device installation and the shape of the measurement target (**Fig. 6**). On the other hand, when the UAV laser, which moves the position of the measurement device, is used, it was confirmed, as compared with the case of the TLS, that the flight route greatly affected the measurement accuracy, although the shape of the concave could be captured.

In general, it is assumed that when surveying the location and shape of topography and landforms, the manual established by the Geospatial Information Authority of Japan are often referred to. However, from the results stated above, for the purpose of maintenance of road slopes, it would be necessary not only to follow the manual but also to use the data acquired by an appropriate measurement method that considers the shape, surface properties, and field conditions of the measurement target in order to ensure the required measurement accuracy. As a proposal for specific requirements, it was confirmed that it may be effective to set the required surface point density according to the shape and surface properties of the measurement target.

From the measurement results of other sites not specified in this paper, some issues on data processing were also identified, including the fact that the method of calculating the difference of vertical coordinates adopted in this study may not be sufficient to grasp the shape change because the change in vertical coordinates of neighboring data is large due to the topography, especially in steep areas, and that the calculation results may differ depending on the method of creating TIN models and filtering vegetation. These data processing methods need to be considered in implementation, and studied as a subject for future research.

4. Prospect for future research

Considering that the accuracy varies greatly depending on the surface properties of slope, it is necessary to present the concept of setting the measurement method according to the measurement target and field conditions, the concept of setting data processing method, etc., as well as specific application methods considering the limitations of accuracy from the results of verification at the points of focus. The study on the concept of setting deformations as the measurement target and the required accuracy should also be consistent with the study on the performance expression mechanism of earthwork structures.