Detection of deep-seated gravitational slope deformations by numerical analysis and aerial photo interpretation in Typhoon Talus in 2011

*Teruyuki Kikuchi[1], Satoshi Nishiyama[2]

1. J-POWER Design. co. ltd., 2. Graduate School of Environmental and Life Science, Okayama University, Okayama, Japan

1. Introduction
Predicting the geomorphic characteristics of catastrophic landslides is important if associated hazards are to be mitigated. Such landslides tend to occur suddenly, and a single event can destroy entire villages in just a few minutes. Deep-seated gravitational slope deformations (DGSDs) have been previously identified as topographical precursors of DLs. At present, the most widely used methods for predicting landslides are statistical and experiential analyses. Qualitative methods rely on the proficiency of the expert performing the interpretation and, thus, lack objectivity; however, quantitative methods do not allow for subjective assessment and, therefore, decrease the ability to correctly evaluate actual, localized phenomena. The purpose of this study was to analyze the precursory topographic features of catastrophic DLs induced by Typhoon Talas in 2011 using numerical analysis and aerial photo interpretationof these landslides before the events .

2. Method
Effective selection of landslide condition parameters is important for numerical analysis. In this study, using three of the main parameters (topography, geology, and environment) proposed by Aleotti and Chowdhury (1999) as a reference, a total of 4 parameters were selected: slope angle, eigenvalue ratio, underground openness, and topographic wetness index. The area over which numerical analysis was conducted consisted of a 0.014-km2 area, which included the landslide area and the surrounding areas. DEM data were obtained by the Kinki Regional Development Bureau in 2009 using LiDAR. The DEM data have a 1-m mesh.
We investigated whether the interpretation of aerial photographs taken between 1994 and 2012 showed the progress-over-time of deformation at a given location on the Kii Peninsula where a DL was induced by torrential rains.

3. Result
Numerical analysis results and histograms of the various parameters are shown in Fig. 1, respectively. The statistical characteristics of each parameter inside and outside the DL area are shown in Table 1.
Mean eigenvalue ratios based on relative frequency distributions differed outside (5.11) and inside (5.78) the DL area. In general, the frequency distribution of eigenvalue ratios inside the DL area was higher than that outside the DL area, indicating the existence of flat surfaces. Mean slope angles based on relative frequency distributions differed outside (39.78) and inside (38.43) the DL area. The frequency distribution of slope angles inside the DL area was lower than that outside the DL area, indicating that the area was characterized by gentle slopes. Gentle slope areas within the DL area were observed at the central and higher elevation areas of the slope. These locations featured flat surfaces and the trend in slope angle was similar to that observed for the eigenvalue ratios. Mean underground openness based on relative frequency distributions differed outside (78.57) and inside (80.06) the DL area. The frequency distribution of underground openness inside the DL area was higher than that outside the DL area,

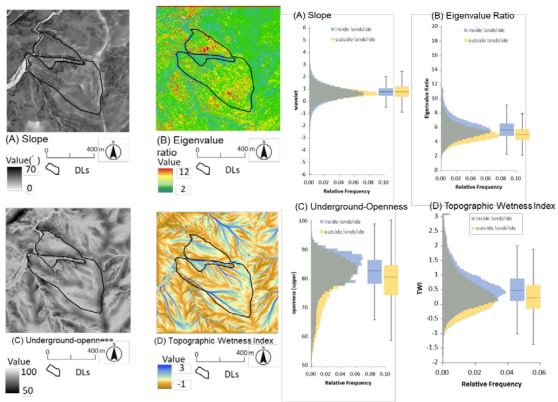
indicating the presence of a large area with gentle slopes, as was the case with overground openness.

4. Discussion
By studying the time-series images taken in landslide areas, we identified DGSD that did not fail before Typhoon Talas. The reason why the typhoon induced catastrophic failures in only a limited number of the gravitationally deformed slopes may be related to slope instability associated with undercutting.
We conducted a numerical analysis using DEM data for a 0.014-km2 area containing the DL and surrounding areas. Slope angle, underground openness all indicated the presence of numerous gentle slope areas and extensive catchment basins inside the DL area. In the southern area outside of the DL, even in areas where some of the red dots are concentrated, there is a region that is not part of the catchment area that is stable. No red dots are present in the catchment area in the northern area outside the DL, and this area is stable. In this way, it is possible to clarify the relationship between numerical analysis and understand how the collapse of DLs at locations with unique topography occurred.

Keywords: Deep-seated gravitational slope deformation, Landslide, Numerical analysis

Table 1. Statistical characteristics inside and outside the deep-seated landslide examined in this study

Parameters	Side	Mean	Minimum	Maximum	Standard deviation
Slope	Inside	38.43	0.87	73.33	6.91
	Outside	39.78	0.33	72.92	8.78
EV	Inside	5.78	1.08	38.24	1.78
	Outside	5.11	0.28	39.63	1.51
Underground openness	Inside	80.06	37.18	105.19	6.48
	Outside	78.57	33.53	107.49	7.25
TWI	Inside	0.52	-1.96	5.53	0.66
	Outside	0.32	-2.39	8.15	0.69



(1) Numerical analysis results (2) Histograms and box plots

Fig 1. Numerical analysis results and Histograms and box plots