Bedrock groundwater responses to rainfall in a deformed slope affected by deep-seated landslide

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1. Introduction

Recently in the Japanese territory the hydrology of slopes affected by gravitational deformation have become an important research topic because of the correlation of the deformation and the occurrence of rain-induced deep-seated landslide (DSL). The hydrogeological responses of the deformed slopes to rainfall events have started to be observed in different areas throughout the Japanese territory by direct observations (boreholes) or indirect (Electrical resistivity imaging, ERI). However, the interaction of groundwater flow paths and the geological features generated in deformed slopes are not clear. This study presents different type of bedrock groundwater responses in a gravitationally deformed slope by direct observation in boreholes. The study aims to identify in these type of response evidences of deformation characteristics. The final goal of this study is to improve the understanding of the timing and the mechanism of DSLs triggering by heavy rainfalls.

2. Study area and methodology

The study is carried out in a slope affected by a DSL after the pass of the typhoon Talas (2011) in Tsubonouchi, Kii peninsula. 13 boreholes out of 27 constructed in the slope were used for this groundwater observations. The boreholes were located upslope of the DSLs scarp (Figure 1). LiDAR Images before and after the DSL occurrence were used to identify surface deformation features. These deformation features were correlated with bedrock fractures observed in the borehole core samples. For groundwater observations the boreholes were screened mainly in bedrock depth and where the bedrock fracturing conditions permit it.

In the boreholes the groundwater levels were continuously recorded of during the rainy season of 2015. The groundwater levels records were analyzed using correlation analysis (cross correlation) with rainfall and also analysis of groundwater peaks and antecedent precipitation index, API.

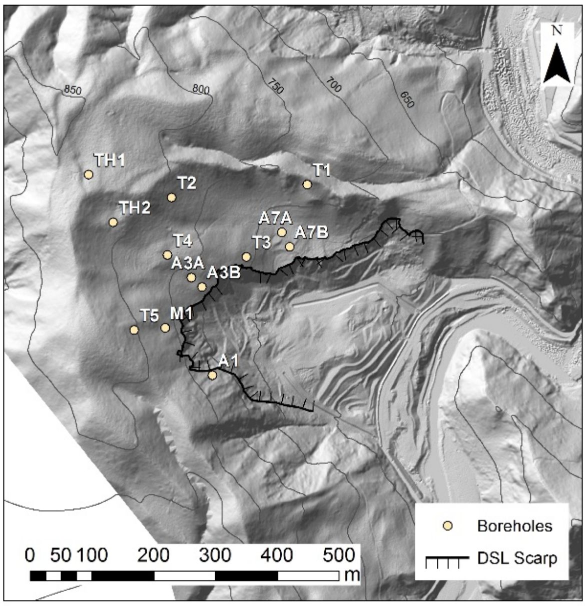

Figure 1. Studied slope and borehole locations upslope the DSL scarp.

3. Results and discussion

Different areas of deformation were identified in the slope using the LiDAR images. These areas of deformation were partially characterized by fracturing levels observed in the bedrock (in borehole cores samples) and some other features that can be related to deformation processes in the slope. There were no a clear type of response associated to each deformation area (Figure 2). However, the boreholes in more deformed areas (more fractured) tended to show an attenuation of the rainfall pulse. This could means that for the same number of rainfall pulses, more deformed areas tends to show less number of peaks (and more delayed) than areas less deformed. The groundwater responses in a bedrock dominated by discrete fractures (less fractured) seems to be more sensible to each pulse of rainfall compared to intense fractured bedrock where the groundwater flow pattern tend to behave similarly to a homogeneous media. However, this analysis is related to an average fracture condition observed in the boreholes core samples.

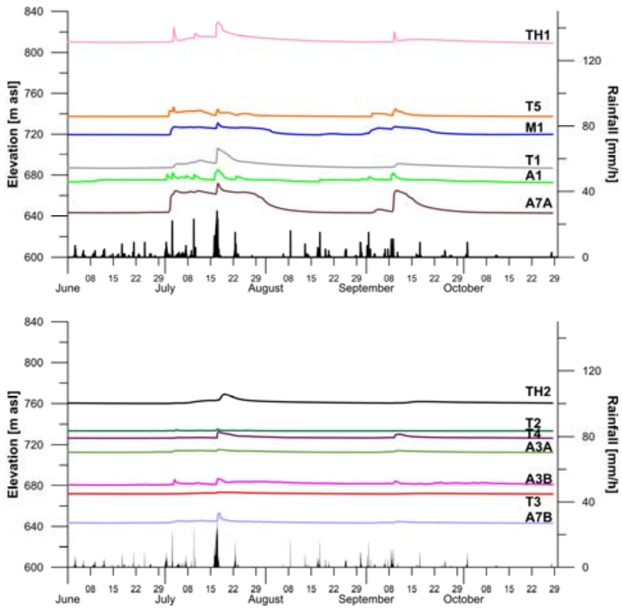

Figure 2. Groundwater hydraulic head measured in observation boreholes.

The detailed observation of the cores showed sections or bands with high levels of fracturing at different depth in the bedrock. In some case the bedrock was observed practically pulverized. These bands were located between sections of less fractured bedrock. According to previous studies, the highly fractured sections (HFS) could be related to mechanical fracturing generated by deformation that can eventually became the slip surfaces of DSLs. In hydrogeological terms, these HFS showed to restrict the elevation of the peaks and generates steps in the groundwater levels, more clearly observed during the recession. With this it is possible to imply that these HFS could generate important flow paths of groundwater and determine the pressure head at different depth in the slope. However the extension of these HFS throughout the slope, between boreholes, is not completely clear therefore the hydraulic connectivity is also not clear. Moreover, in many cases the large extension in depth of the HFS compromised the stability of the borehole therefore the whole section was protected by casing. This situation restrict the observation of groundwater in depth and the depth of the screening also determined the groundwater response characteristics.

The chemical analysis of the groundwater or a tracer analysis should help in the determination of flow paths generated by these HFS. Nevertheless it seems that the system can be modeled as a set of leaky confined aquifer where the bands of highly fractured bedrock represent the confined aquifer limited by the less fractured section of bedrock

4. Conclusions

The study presented here showed examples of groundwater responses to rainfall in a slope gravitationally deformed and affected by DSL. The responses of groundwater seems to be dependent in bands of highly fractured bedrock that can be associated to the deformation of the slope. It is not clear the interconnection of these bands throughout the slope but they showed to represent an important agent in determine the flow paths of groundwater. More studies are required in order to determine the role of these highly fractured bands in the mechanisms of DSLs generation.

5. Acknowledgements

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