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

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1. Introduction

The study of the hydrogeological characteristics of slopes in mountainous areas has been gained importance in the last years. The studies are mainly focused in the management of water resources or the assessment of water related natural disasters. Recently in Japan the studies of slopes affected by gravitational deformation have become an important research topic because of the correlation of the deformation and the occurrence of deep-seated landslide (DSL) generated by heavy rainfalls. However, the hydrogeological responses to rainfall and the interaction with the geological features generated in deformed slopes are not clear. This study presents different type of groundwater responses observed in bedrock of a gravitationally deformed slope. The study of these response can improve the understanding of the generation mechanism of DSLs triggered by heavy rainfalls.

2. Study Area and methodology

The study was carried out in Tsubonouchi study site, in Kii peninsula. In 2011 after the pass of the typhoon Talas, three landslides were generated in this area. The slope with the biggest DSL observed was instrumented with 27 boreholes. For this study only the boreholes upslope of the DSL scarp were used. In the upslope zone where identified deformation features by observation in the LiDAR Images before and after the DSL occurrence and fieldwork visit. These features where correlated with features observed in the borehole core samples. In hydrogeological terms, the boreholes were mainly screened in bedrock depth and where the fracturing level condition allow it. In the boreholes were conducted continuous measurement of the groundwater levels during 2015. The record of groundwater levels was analyzed using correlation analysis (cross correlation) with rainfall and also analysis of groundwater peaks and antecedent precipitation index, API.

3. Results and discussion

Using the LiDAR images were identified areas of deformation in the slope with different levels of deformation. These areas of deformation where partially characterized by levels of fracturing observed in the bedrock in the borehole cores samples and some other features that can be related to deformation processes. In terms of groundwater response, there were no a clear type of response to rainfall associated to each deformation area. However, the boreholes in more deformed areas also showed an attenuation of the rainfall pulse. For the same pulses of rainfall the more deformed areas tends to show less number of peaks than areas with less fractured. The flow pattern in a media dominated discrete fractures (less fractured) seems to be more sensible to each pulse of rainfall compared to intense fractured zones where

the pattern of flow tend to behave more like homogeneous media. This also is observed in the time of response. The more like homogeneous media zones showed to have more delayed and longer responses. However, this is a simplified observation, the detailed analysis of the boreholes cores showed sections or bands with different degrees of fracturing. These bands were located between sections of low fractured bedrock. In some case the bedrock was presented practically pulverized. According to previous studies these highly fractured sections could be related to mechanical fracturing generated by deformation that can eventually generate slip surfaces for DSLs. In hydrogeological terms, these areas showed to control the characteristics of the response of the groundwater level measured in boreholes. From the data it is possible to assume that these high fractured section could determine important flow paths of water, controlling the peaks of groundwater levels measured. However, in some cases the extension of the pulverized section compromised the stability of the borehole therefore the section was protected by casing. This situation restrict the observation of groundwater in depth. Moreover, the suggested flow paths generated by the high fractured section were not clearly connected between boreholes. The projection of these highly fractured section in the slope is still not clear. The chemical analysis of the groundwater should help in the determination of flow paths. 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.