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Groundwater responses to rainfall in a slope affected by deep-seated landslides in Tsubonouchi area

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1. Introduction

The occurrence of deep-seated landslides (DSLs) triggered by heavy rainfalls have been increased during the last years in Japan. In 2011, approximately 70 DSLs occurred in Kii peninsula, mainly in the prefecture of Nara and Wakayama. These DSLs were generated by heavy rainfalls caused by the pass of the typhoon N0 1112, Talas, from September 2nd to September 5th. Since these catastrophic events, many areas of DSLs in kii peninsula have been intensively monitored using sets of boreholes. These boreholes are aimed to observe the groundwater characteristics in the slope affected by DSLs and eventually improve the understanding of the DSLs generation mechanism in the area. Previous studies suggest that the hydrogeological characteristics of bedrock and the groundwater flow pattern may be linked to the mechanisms of DSL generation, however the relationship is not well understood.

2. Study Area

From the DSLs study sites in Kii peninsula, this study will presents the observations obtained in Tsubonouchi area. The Tsubonouchi study site is located 50 km to the south of the city of Nara, in the Tenno river basin. In the area three DSLs were generated in 2011, however the hydrolgeological observation were carried out in the largest DSLs only (Figure 1). The studied DSLs have a maximum depth of 30 m and mobilize approximately 1,200,000 m3 of material which include bedrock and mostly material from a deposit of old landslide events (old landslide scarp in figure 1). The bedrock is mainly sedimentary rock, sandstone shale interbeded part of the Shimanto belt accretionary wedge complex. The bedrock is moderate to high fractured and the fractures can be observable even in depth of approximately 50 m below the ground surface.

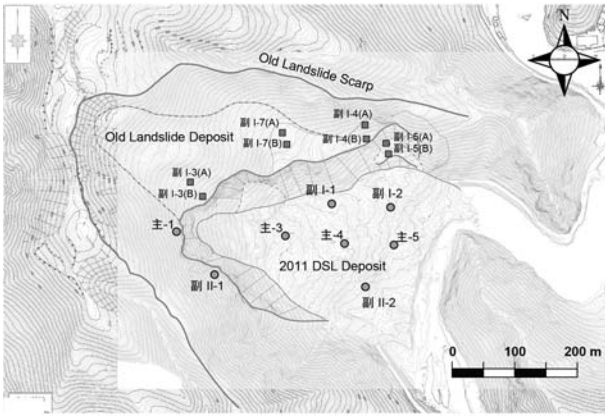

Figure 1. DSL in Tsubonouchi study site and boreholes location

3. Methodology

The hydrogeological observations in Tsubonouchi are based on two sets of boreholes. The first set (circles in figure 1) correspond to 9 boreholes separated in tree lines along the DSL installed in 2012. Additionally, another set of boreholes where installed upslope to the DSL scarp (squares in Figure 1) in 2013. The depth of boreholes range from 47 to 65 m and they are screened only at depth where the bedrock was identified, therefore the groundwater levels measured correspond to the hydraulic head in bedrock and not always include the soil or deposit cover. The groundwater levels were measured in intervals of 10 min.

4. Results and discussion

The boreholes showed significant differences in the responses depending on their location (Figure 2). In many cases they showed to be very responsive to single rainfall events even for very deep water tables (40 m below the surface aproximately). The most significant changes in groundwater levels were observed in the boreholes 主-1, Bor 副Ⅱ-1, Bor 副Ⅰ-7(A) and partially Bor 副Ⅰ-1. The core description of boreholes 主-1 and Bor 副Ⅱ-1 showed that these boreholes were drilled mainly in bedrock with less than 2 m of soil cover approximately, therefore significant changes in groundwater level can be expected (主-1: 8-10m; Bor 副Ⅱ-1: 8-12m) (Padilla *et al.*, 2014). In the area of Bor 副Ⅱ-1, the identification of several tension cracks in surface suggest the active gravitational deformation of the slope which is not observed for the area for the borehole 主-1. This could determine the characteristics of the deep, short and rapid responses of Bor 副Ⅱ-1, similar to the observed in Wanitsuka

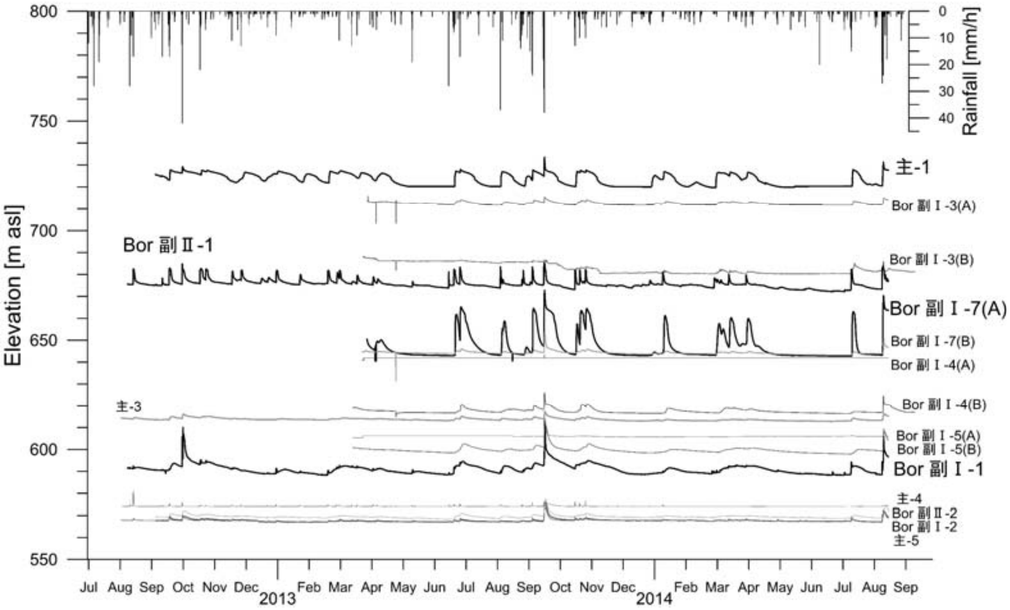

Figure 2. Groundwater levels in boreholes of Tsubonouchi study site.

mountain study site by Padilla *et al.* (2014) with similar deformation conditions. The largest change in hydraulic heads was observed in borehole Bor 副Ⅰ-7(A) with maximum elevation of 25m that reach 12 m below the ground surface (672.863 m asl). This borehole was built over the old landslide deposit which have a depth of 37.2 m (648 m asl). The borehole is screened below 31 m therefore the measurements represent the hydraulic head in the deposit cover and bedrock. The borehole Bor 副Ⅰ-7(B), located next to the borehole Bor 副Ⅰ-7(A) and only screened in the bedrock does not show the large response as observed in Bor 副Ⅰ-7(A). The main difference between 副Ⅰ-7(A) and 副Ⅰ-7(B) lies on the larger depth of high fractured bedrock below the deposit cover observed in 副Ⅰ-7(A) core.

In other hand, the borehole Bor 副Ⅰ-1 showed a 25 m fluctuation for the greatest rainfall event recorded. This borehole, installed in the 2011's DSLs deposit (32 m of deposit), showed a double peak response; A very fast first peak followed by a smooth and delayed peak. For the highest rainfall events, the borehole shows a single peak with a very short delay after the rainfall peak. These bimodal response behaviour has been commonly described in fractured media where the first peak represent to rapid flows through open fracture systems. This first peak showed short delays after the rainfall peak (less than 20 hours, Figure 3) similar to the delay of the borehole Bor 副Ⅱ-1 peaks. This may suggest fast flows which may not be directly associated to vertical infiltration of water. For greater rainfall events, the delay of groundwater peak showed to be short for all the boreholes observed whether or not the bedrock is covered by a thick landslide deposit. Relatively rapid groundwater flow paths seems to determine the responses observed in boreholes in Tsubonouchi area, however a more detailed analysis of flow path is required.

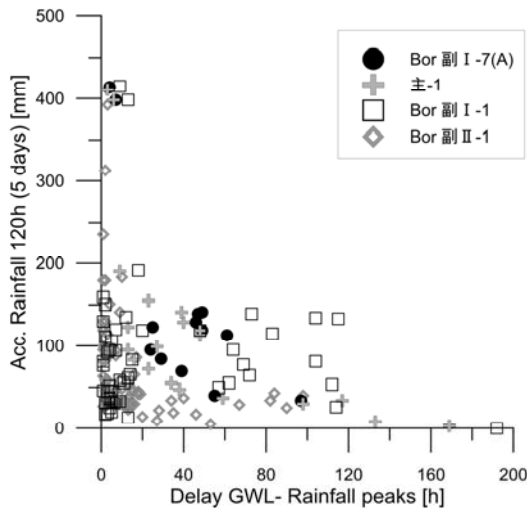

Figure 3. Delay time between GWL peak and rainfall peak vs accumulated rainfall in 5 days.

5. Conclusions

The study presented here represent the first result of the analysis of hydrogeological observation, based on hydraulic heads fluctuations, in Tsubonouchi study site. The observations agrees with the importance of the bedrock groundwater flows in the response of slopes to rainfalls. Even though for the 2011 DSLs event most of the material removed were part of deep old landslide deposit, the data suggest that the bedrock groundwater flows could play an important role in the condition that generates the DSLs. However this implications must be corroborated by chemical analysis of groundwater, with the use of tracers, to clarify the flow paths in bedrock.

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Reference:

Padilla C, Onda Y, Iida T, Takahashi S, Uchida T. 2014. Characterization of the groundwater response to rainfall on a hillslope with fractured bedrock by creep deformation and its implication for the generation of deep-seated landslides on Mt. Wanitsuka, Kyushu Island. Geomorphology, **204**: 444-458. DOI: DOI 10.1016/j.geomorph.2013.08.024.