国際共同研究（課題番号：30W-03）

課題名：A comparison study on the earthquake-induced flowsliding phenomena occurring in Chinese loess and Japanese pyroclastic deposited areas

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研究場所：斜面災害研究センター，熊本県南阿蘇村,中国甘粛省南部，中国寧夏レス地区

共同研究参加者数：　16 名 (所外 10 名，所内 6 名)

・大学院生の参加状況：10 名（修士 7　名，博士 3 名）(内数)

・大学院生の参加形態　[研究打ち合わせ及び現地調査・計測の参加，研究成果の紹介および議論]

研究及び教育への波及効果について

Ten graduate students participated in this project, four of them from graduate school of science, Kyoto University, two from Toyama Prefectural University, and four from Lanzhou University. Through involving this project, the students elevated their understanding not only on the initiation and movement mechanisms of landslides during earthquakes, but also on the methodology in conducting scientific research.

研究報告

(1)目的・趣旨

Chinese loess and Japanese pyroclastic soils are both unconsolidated sediments, and are very susceptible to liquefaction that favorites the occurrence of fluidized landslides during earthquake and/or water infiltration. To mitigate the hazards and risks from fluidized landslides, understanding their initiation and movement are of great importance. Nevertheless, the dynamic mechanism of the fluidized landslides is still poorly understood, especially for Chinese loess and Japanese pyroclastic deposited areas, although numerous flowsliding phenomena had been recorded in these areas. Therefore, the aims of this study were to: (1) analyze the features of some fluidized landslides occurring in Chinese loess and Japanese pyroclastic deposited areas during recent earthquakes; (2) examine the initiation and movement mechanisms of these fluidized landslides.

(2)研究経過の概要

On July 22, 2013, an earthquake occurred in Dingxi, Gansu, with a magnitude of Ms 6.6 and focal depth of about 20 km. This earthquake had caused at least 95 deaths and 2300 injured. More than 20000 buildings had collapsed or damaged, and many buildings were buried in landslides triggered by the earthquake. Among these landslides, two ($4.2x10^4$ and $3.3x10^4$ m^3 respectively) occurred on Yongguang area were the most catastrophic, whose displaced materials fluidized and travelled a long distance, resulting in 4 deaths. To understand the initiation and movement mechanisms of these landslides, we made detailed field survey and examined the geotechnical properties of the soil layers on the source areas. We also conducted ERT survey to measure the moisture/water content distribution along the travel paths of the displaced landslide materials. We took sample from the source area and examined their shear behaviors under different initial states by employing ring shear apparatus in Kyoto University. For further comparison, we also examined the distribution and features of those landslides triggered by the 1920 Haiyuan earthquake in China.

Secondly, field survey was conducted on those landslides triggered by the 2016 Kumamoto earthquake on Minami Aso area, Kumamoto, Japan. The features of some typical landslides occurring on the pyroclastic deposits during the earthquake were examined. The most catastrophic landslide occurring on Takanodai area had been examined in details. We investigated the formation of tephra layers of the slope and the geotechnical properties of each layers, especially of the layer along the sliding surface. We took samples from each layer for measuring the in-situ density, water content and permeability. In-situ direct shear box tests were also performed on these samples. We analyzed the minerals of the soil layers along the sliding surface and examined the undrained shear behaviors of these samples. Finally, we also conducted ERT survey on the slope to better understanding the infiltration process of rainwater within the slope.

(3)研究成果の概要

The main results could be summarized as follows.

(1) Yongguang landslide was triggered on the toe part of a huge old landslide. Groundwater of this old landslide emerges as springs on the toe part. As the result, the loess layer on the toe part was in high moisture content, such that slope instability could be easily triggered by the earthquake.

(2) The movement of displaced material from Yongguang landslide was greatly controlled by the moisture of the displaced landslide material and also by the moisture of the material along the travel path. Undrained shear tests on the saturated loess showed that the loess is highly liquefiable. The loess around the landslides area are rich in sodium chlorate, but the loess on the source area of the landslides showed small content of sodium chlorate, suggesting that the leaching of sodium chlorate solution on the source area due to the long-term groundwater discharge might also favorite the initiation and movement of the landslides by reducing both the peak and residual shear strengths of the displaced landslide materials.

(3) For the landslide on Takanodai area, the sliding surface outcropped on the middle part of the source area has a thin layer of whitish soil that is underlain by clayey soil layer. Investigation through trial pits and trenches immediately below the scarp revealed that above this whitish soil layer is yellow pumice that was deposited about 26 ka ago. Samples taken from the pumice layer had their natural moisture contents being 133~178%, and dry densities 0.44~0.56 g/cm^3. Undrained ring shear tests on these samples showed that when the moisture content is high enough (close to fully saturated state), the samples are every prone to suffer from liquefaction failure behavior when subjected to cyclic loading, and high pore-water pressure could also be generated within those sample with lower saturation degree after the shear failure was triggered.

(4) For Takanodai landslide, halloysite was formed within the pumice layer overlain the sliding surface. The in-situ direct shear box tests on intact samples revealed that the whitish pumice layer on the bottom of the yellowish pumice containing halloysite has very small peak and residual shear strengths. TEM-based observation reveals that the halloysite shapes tubular. Undrained shear tests on the mixtures of yellowish pumice with different halloysite contents revealed that adding halloysite can lower the undrained peak shear strength and then favorite the initiation of slope instability.

(5) ERT surveys on the slope of Takanodai area during and immediately after a rainfall showed that the moisture of the tephra layers above the clayey soil layer (whose upper boundary formed the sliding surface of Takanodai landslide) is general high, but could be remarkably and quickly changed after the rainfall, indicating the nature of high permeability of the tephra layer. The clayey soil layer forms an impenetrable barrier to groundwater flow.

(4)研究成果の公表

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