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Reconnaissance report on geotechnical damage caused by an earthquake with JMA seismic intensity 7 twice in 28 h, Kumamoto, Japan

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Abstract

An earthquake with magnitude 6.5 occurred at 21:26 p.m. on April 14, 2016 with its epicenter (N: 32°42'00" E: 130°48'00") near the Aso Kumamoto airport (4 km northeast of Mashiki), at a focal depth of approximately 10 km. The second earthquake (M7.3) occurred at 1:25 a.m. on April 16, 2016 with the epicenter (N: 32°48'00", E: 130°48'00") at a focal depth of 12 km. These earthquakes were caused by two active faults: the Futagawa and Hinagu faults. These two seismic events are referred to as the 2016 Kumamoto Earthquake. This was the fourth earthquake with seismic intensity of 7 ever recorded in Japan. The Kumamoto prefecture was severely and locally damaged by the earthquakes, feeling strong seismic activity twice in 28 h. In particular, the second earthquake triggered landslides, rock falls, wide area liquefaction, and ground fissures. As of May 20, 2016, over 1500 aftershocks have occurred. An active fault with ground fissures and complex deformation of the ground was observed around Nishihara, Mashiki, Kashima, Mifune, south Kumamoto, and Kousa along the Futagawa and Hinagu fault zones. Meanwhile, many slope failures and landslides occurred in Aso. Despite only mild rain, a significant slope failure destroyed the Aso-ohashi bridge, and shut down national route R57; leading to severe destruction in and around Mashiki, Nishihara, and Aso, the most populous area in the Kumamoto prefecture.

After the foreshock on April 14, the Japan Geotechnical Society (JGS) organized an investigation team to support the recovery of the damaged sites and to study the potential of secondary disasters. The JGS worked quickly to conduct diagnostic investigations of a river dike for slope failures and landslides should there be heavy rainfall. The investigation team consisted of 9 sub-groups: (1) active fault and earthquake motion, (2) geo-disasters, such as slope failures, debris flow, and landslides, (3) liquefaction, subsidence, and port damage, (4) river dikes and dams, (5) disaster waste, (6) road, retaining walls, and earth reinforced structures, (7) historical heritage, (8) oita, and (9) southern Kyusyu. Since the 2011 Tohoku Earthquake off the Pacific Coast, an attempt has been made to recycle disaster waste as construction material. Hence, this investigation team also involves a subgroup for investigation of disaster waste. This reconnaissance report introduces the geological features in the Kumamoto prefecture, discusses the 2016 Kumamoto earthquake, and then summarizes results reported by subgroups 1–5. All results reported in this paper were obtained from April 14 to June 16, 2016.

Keywords: Active fault; Slope failure; Debris flow; Landslide; Liquefaction; Road subsidence; River dike; Disaster waste

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1. Introduction

1.1. Summary of events

Kumamoto prefecture is located in the central of Kyushu district, western Japan, as shown in Fig. 1. The first earthquake of magnitude 6.5 occurred at 21:26 p.m. on April 14, 2016 with its epicenter (N: 32°42'00" E: 130°48'00") near the Aso Kumamoto airport (4 km northeast of Mashiki), at a focal depth of approximately 10 km, as shown in Fig. 2. The first earthquake killed 9 people and damaged structures built before modern earthquake-resistant design standards were implemented. The second earthquake (M 7.3) occurred at 1:25 a.m. on April 16, 2016 with the epicenter (N: 32°48'00", E: 130°48'00") at a focal depth of 12 km and killed 32 people. Both of the epicenters have been plotted near the junction of the Futagawa and Hinagu active fault zones, and aftershocks have occurred along the fault zones. The two shocks have also caused a lot of ground fissures and complex deformation of the ground surface around Nishihara, Mashiki, Kashima, Mifune, and Kousa along the fault zones, as shown in Fig. 2. Severe damage spread from Mifune to Aso. Some of the fissures had characteristics of right-lateral strike-slip faults that were predicted at the Futagawa and Hinagu fault zones by investigations of the Headquarters for Earthquake Research Promotion. These two earthquakes would be caused by the movements of the Futagawa and Hinagu active fault zones, therefore. These earthquakes were named the 2016 Kumamoto Earthquake, and it was the fourth earthquake with a seismic intensity of 7 ever recorded in Japan. The second earthquake triggered landslides, rock falls, liquefaction, ground fissures, and significant damage of river dikes. In the Oita prefecture, another earthquake of seismic intensity 6 occurred 32 s later. The first earthquake was called “foreshock” and the second one was renamed “main shock” by the Japan Meteorological Agency, JMA. Though just the foreshock, it was destructive enough to cause severe damage to many buildings and houses. Meanwhile, many slope failures and landslides occurred in Aso. Despite lack of heavy rain, a slope failure destroyed Aso-ohahi, and national route 57 connecting central Kumamoto to Aso was closed to traffic. Thus, parts of Aso such as Nishihara village, a popular area for domestic and foreign tourists, were isolated. At the same time, the Kyushu express highway near the Mashiki interchange was severely damaged when the pier of a viaduct caved in. These areas have relatively high groundwater levels so that well water is available easily. In addition, it was reported that these areas were historically often the sites of river channels; hence, liquefaction phenomena were observed in many locations. The Kyusyu highway is the main artery in the region, and it took 13 days to restore partial functionality.

Important services such as gas lines and water supply lines were likely damaged by several impacts such as seismic loading, liquefaction, and self-loading of structures due to soil fluidization. Recovered water lines were impure as the tap water of Kumamoto is provided by groundwater, which was disturbed by the earthquake; hence, it took several weeks to draw clear groundwater. Many geotechnical problems were reported daily. Table 1 is summary of earthquake occurrences more than JMA seismic intensity of 6 in Kumamoto and Aso. Affected citizens did not know they experienced two M 7 earthquakes in 28 h. The Southern Hyogo prefecture earthquake in 1995 induced conflagration damage (Japanese Geotechnical Society, 1996), and the 2011 earthquake off the Pacific Coast of Tohoku caused a Tsunami (Japanese Geotechnical Society, 2012); however, the Kumamoto earthquake did not have any conflagration damage, and there was no resultant Tsunami.

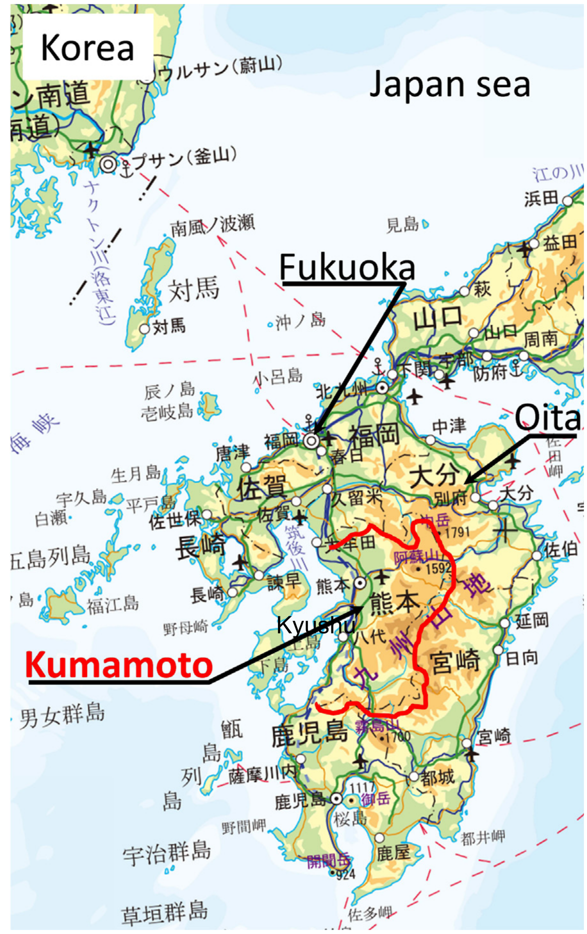

Fig. 1. Location of Kumamoto prefecture in Kyushu (red line is a revision from Geospatial Information Authority of Japan (2016a)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

1.2. Scope

Fig. 3 illustrates Japanese design criterion for structures. After the Southern Hyogo prefecture earthquake in 1995 and the 2011 Tohoku earthquake, Japanese design criterion was shifted from the allowable stress design for level 5 of seismic intensity, to the design for level 6–7 of seismic intensity (Kawabata, 2007). Therefore, structures built to current seismic criteria should have been resilient to seismic intensity 6–7, but actual results differed. We question the reason for this inconsistency. It is well