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Geotechnical and infrastructural damage due to the 2016 Kumamoto earthquake sequence

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ABSTRACT

An active sequence of earthquakes (foreshock, main-shock, and aftershocks) hit the Kumamoto area (Japan) in April 2016, resulting in 69 deaths and considerable economic loss. The earthquakes induced numerous ground failures and cascading geo-hazards, causing major damage to important infrastructures. The main damage patterns include: (a) surface rupture with widespread subsidence of the surface ground, resulting in damage and disruption to transport infrastructure; (b) landslide and slope failure of mountains causing severe damage, collapse and near-collapse of bridges; and (c) liquefaction in some areas of Kumamoto City. Following the earthquakes, field surveys were conducted to study the damages and to understand the main cause of the observed failures. This technical note provides a summary of the geotechnical and infrastructural damage in Kumamoto and the lessons learnt and future research needs are also highlighted.

1. Introduction

1.1. Overview of the earthquake damage

A sequence of two strike-slip earthquakes occurred on 14th and 16th April 2016 in Kyushu Island, southern part of Japan. Japan Meteorological Agency (JMA) reported a magnitude of M_J6.5 (moment magnitude Mw6.1) for the 14th April foreshock and M_J7.3 (moment magnitude Mw7.1) for the 16th April main-shock, respectively. The total number of fatalities due to the earthquakes is reported to be 69, while the total number of casualties was 1747. The estimated total economic loss is 24–46 billion US dollars. The earthquakes destroyed 8050 houses and 24,147 buildings suffered major damage. Historically, there have been damaging earthquakes in the Kumamoto region. For instance, the M6.3 1889 earthquake caused notable damage in Kumamoto City (20 deaths, 54 injuries, and 239 house collapses). However, the damage severity and earthquake impact of the 2016 earthquakes are far greater than these relatively recent damaging earthquakes in Kumamoto.

The earthquakes triggered numerous landslides in the mountainous areas of Kumamoto and destroyed major infrastructure and facilities. In the plain areas of Kumamoto, several sections of Kyushu Expressway (bridges and road surface cracks) were damaged due to the ground shaking, induced subsidence, fault movement and liquefaction. This resulted in major disruption of the regional traffic network. The operation of the railways was also severely affected due to derailment of trains (both Shinkansen and local train) and damage to the railway tracks owing to large landslides. Following the earthquakes, a series of damage surveys were carried out to record and understand the various aspects of the damage. The aims of the paper are to:

(a) Summarize the seismological aspects of the earthquakes together with the details of the fault rupture and characteristics of the input motion in the near-fault region.
(b) Present the observed damage of buildings, bridges and infrastructures with a focus on the geo-hazards.

2. Seismological aspects of the earthquake

The double events that occurred on 14th and 16th April were of

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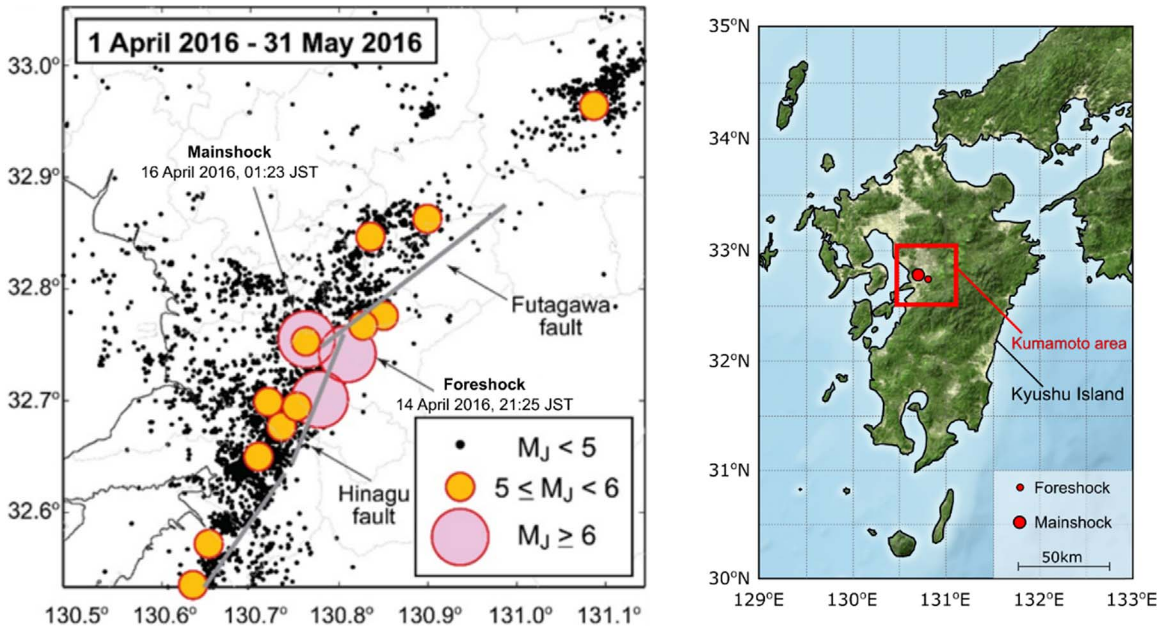

Fig. 1. Spatial distribution of earthquakes (foreshock, main shock and aftershocks).

right-lateral strike-slip type occurring at shallow depths with the respective focal depths of 11 km and 12 km and originating from different active faults which are very close. A very active sequence of earthquakes was also observed in the Kumamoto region, after the triggering foreshock event of 14th April 2016 as depicted in Fig. 1. The first event originated from the northern segment of the Hinagu fault, while the latter was caused due to the Futagawa fault which runs NE of the Hinagu fault, see Fig. 1 which also shows the spatial distribution of earthquakes occurring over a period between 1 April 2016 and 31 May 2016. The foreshock induced an active sequence of dependent events, clustering along the Hinagu fault. Subsequently, the mainshock occurred on the southern tip of the Futagawa fault, and triggered an even more active subsequence of aftershocks. The aftershock sequence is not only concentrated along the Futagawa-Hinagu faults but also in the Aso region. The migration of seismic activities over a relatively wide spatial scale is a notable feature of the 2016 Kumamoto earthquake sequence. Further details of the seismological aspects can be found in Goda et al. [4] and Fujiwara et al. [3].

The JMA intensity of 7 (highest intensity in the JMA intensity scale) was recorded in Mashiki Town during both the foreshock and the mainshock (i.e. double shocks) and thus many buildings had collapsed. Fig. 2a shows observed velocity time-histories (3 components) at KMMH16 for the main-shock. KMMH16 is a KiK-net station in Mashiki Town; two sets of 3-component ground motion data are available, one at ground surface and the other at the borehole. The blue curves are for the ground surface recordings, whereas the red curves are for the borehole recordings. The significant amplification of the ground motions can be visually inspected by comparing the blue and red curves. Another notable observation is that for the velocity time-histories for the main-shock, relatively large long-period velocity waves are present at both ground surface and borehole (particularly for vertical motions). This indicates that site amplification for short-period components is significantly influenced by near-surface soil characteristics, while that for long-period components is more coherent at ground surface and borehole. The latter may also be attributed to the ground surface rupture near the Mashiki areas. To examine the spectral content of the observed ground motions at KMMH16, 5%-damped response spectra for the main-shock are calculated and shown in Fig. 2b. The results for the ground surface motions are presented with solid lines, while those for the borehole motions are shown with broken lines. The comparison of

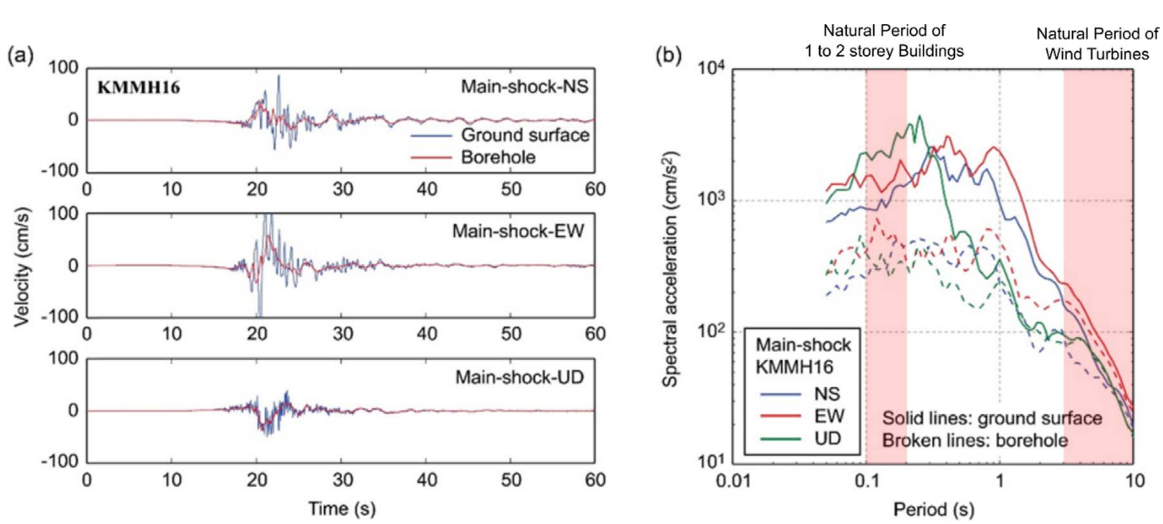

Fig. 2. (a) Earthquake velocity time histories; (b) Acceleration spectra. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article).