GEER Reconnaissance of the 2016 Kumamoto Earthquakes

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Key Facts

- Hazard Type: Earthquake
- Date of the disaster: April 14th to 16th, 2016
- Location of the survey: Kumamoto, Japan
- Date of the field survey: May 11th through 13th, 2016
- Survey tools: Terrestrial LiDAR, Unmanned Aerial Vehicle (UAV), Digital Photographs, Manual Surveys
- Key findings: (1) major surface fault rupture occurred through a water reservoir, (2) an unusual "depression zone" occurred in part of the Aso Caldera, (3) a unique pre-and post-event aerial LiDAR data set is available to study surface fault rupture through an embankment, (4) a relatively small amount of liquefaction occurred, possibly a result of soil plasticity and sediment geology, (5) a valuable non-displacement lateral spread was observed at a major bridge.

Key Words : *Kumamoto earthquakes, surface fault rupture, liquefaction, lateral spreading, LiDAR, UAV*

1. INTRODUCTION

The Geotechnical Extreme Events Reconnaissance (GEER) Association, funded by the United States of American National Science Foundation (US NSF), conducted a brief reconnaissance of the Kumamoto region following the April 16th M_W 7.0 earthquake (M_{JMA} 7.3) and the foreshocks of April 14th and 15th. The GEER team visited Kumamoto and the surrounding region and documented the effects of the earthquakes between May 11th and May 13th, 2016. The GEER reconnaissance effort has been documented in a GEER Report[1]. Five major case histories (Fig.1) were identified as a part of the GEER reconnaissance. This factsheet summarizes those five

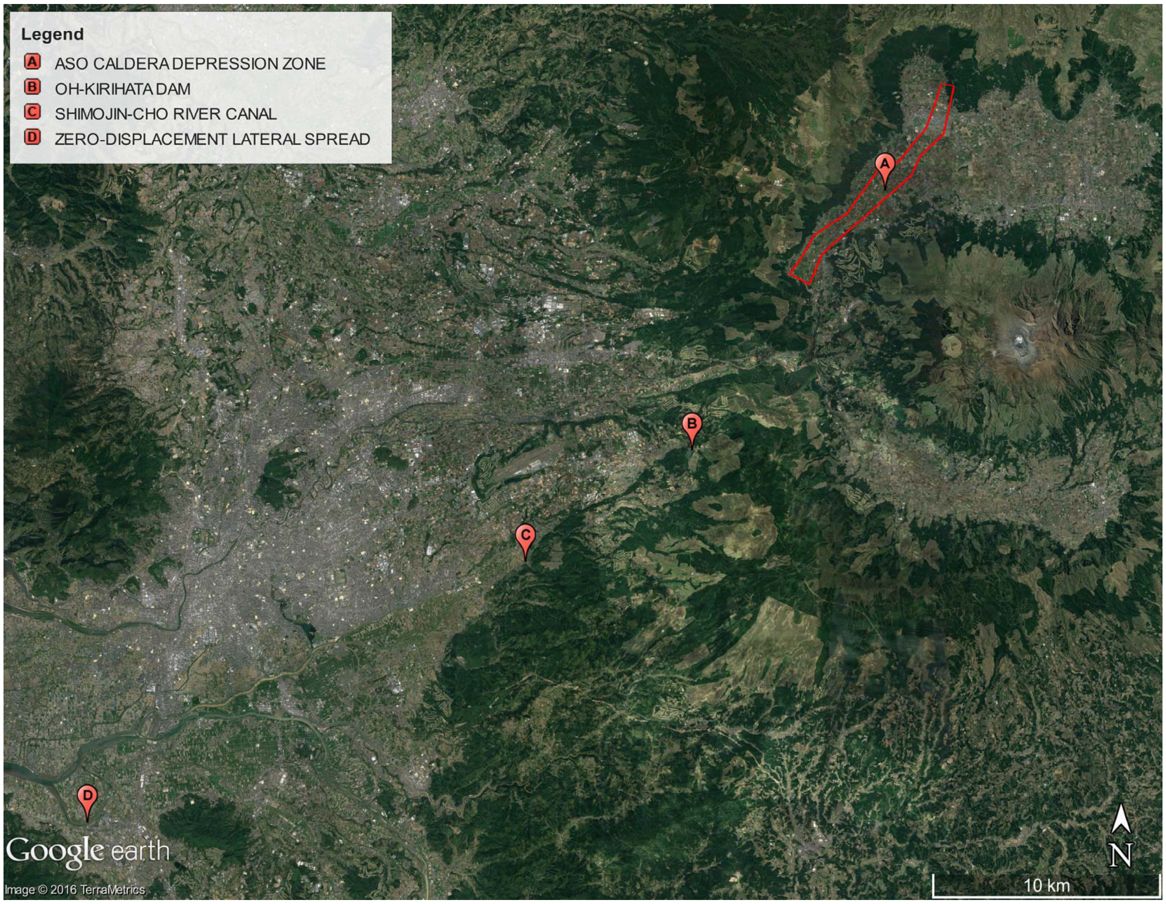

Fig.1 Overview map including locations of major case histories.

major case histories, as documented by the GEER reconnaissance team.

2. OH-KIRIHATA DAM

The Futagawa fault ruptured through an approximately 0.5-km long by 0.25-km wide water reservoir (32.8413°, 130.9317°). The fault rupture passed through the western flank of the reservoir and through the main spillway. No catastrophic release of water occurred; however, the reservoir experienced significant damage, both as a result of the surface fault rupture and as a result of the strong ground motions. This presents a valuable case history of the response of dams to surface fault rupture.

GEER made extensive terrestrial LiDAR, UAV, photographic, and manual surveys of the reservoir to record the damage caused by the earthquake. The reservoir was almost fully drawn down at the time of GEER's reconnaissance, with only minor emergency repair work done, so the GEER team had extensive access to the reservoir to record damage.

GEER is currently working on developing three-dimensional models of the reservoir, dam, and spillway to fully document the condition of the reservoir after the earthquake. A preliminary view of the spillway from the UAV-generated 3D model is provided in Fig.2. Preliminary, interactive 3D models are available at: http://prismweb.groups.et.byu.net/JD/App/.

3. ASO CALDERA DEPRESSION ZONE

In the Aso Caldera, an approximately 10-km long "zone of depression" resulted from the Kumamoto earthquake mainshock[2)]. The zone of depression (32.9565°, 131.0368°) was typically 30-m to 110-m wide with roughly vertical offsets on each side of the depression zone of about 0.5 m to 2.5 m with a minor strike-slip component. The cause of the zone of depression is of interest. Potential causes include liquefaction, earth compaction, lateral spreading, and fault rupture.

The GEER team made extensive UAV flights over approximately 4-km of the depression zone to create a large, unique three-dimensional model of the ground deformations. Extensive terrestrial LiDAR data was also acquired over a large portion of the depression zone where a bridge crossed the depression. Extensive photographing and manual mapping

Fig.2 Three-dimensional model of the spillway generated by UAV data.

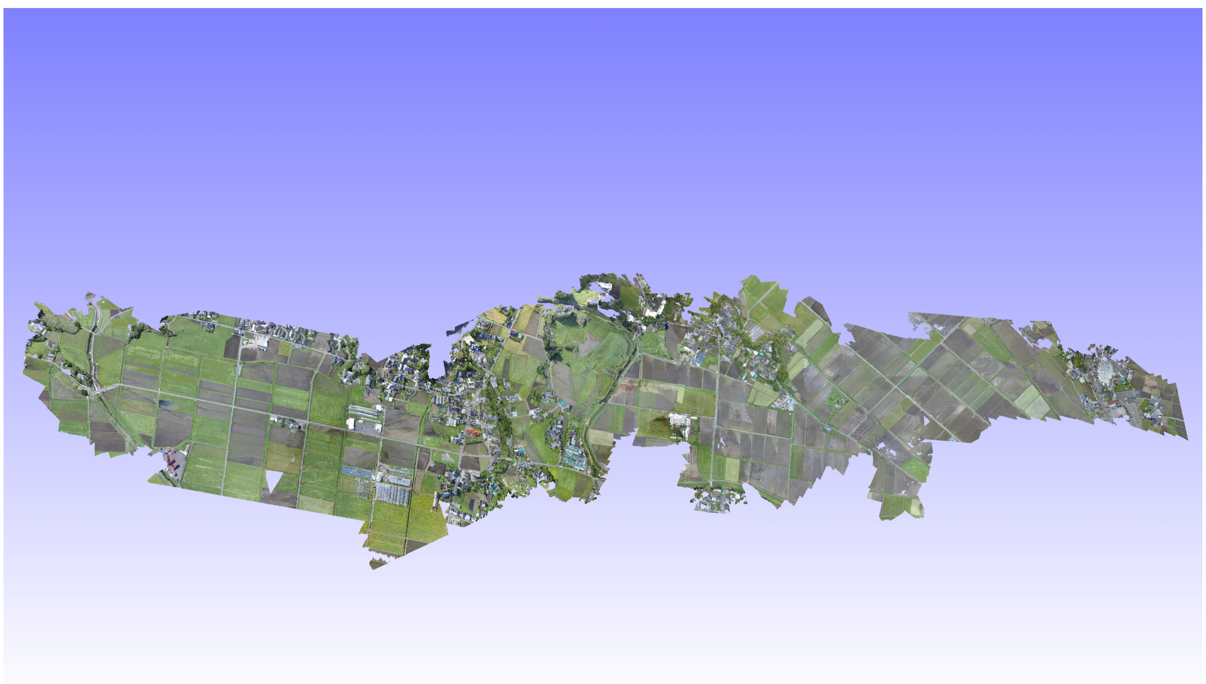

Fig.3 Overall 3D model of the depression zone generated from UAV data.

of the deformation was also completed by GEER. A composite overview of the entire UAV-generated preliminary 3D model is presented in Fig.3. A preliminary, interactive 3D model of a residential house that was located immediately on the hanging wall of the depression zone is available at: http://prismweb.groups.et.byu.net/JH/App/.

4. SHIMOJIN-CHO RIVER CANAL

A unique aspect of the 2016 Kumamoto earthquake is the availability of pre- and post-mainshock aerial LiDAR. Asia Air Survey conducted a detailed aerial LiDAR survey shortly after the initial foreshock of much of the Futagawa and Hinagu faults. After the mainshock occurred, these aerial surveys were then re-conducted, making generation of a detailed earthquake-induced displacement model pos-

Fig.4 The terrestrial LiDAR setup and damage to the canal embankments. The main fault crossing is at the location of the repairs visible in the photograph.

sible. In addition, it appears that the Geospatial Information Authority of Japan (GSI) also conducted an aerial LiDAR survey of an even greater zone in 2005 from which a comparison can be made.

Since this represents a relatively unique dataset for analyzing ground deformation resulting from surface fault rupture, GEER visited a number of sites in the aerial LiDAR coverage zone. Of particular interest was a location where the Futagawa fault crossed a canal embankment (Fig.4; 32.7974°, 130.8535°). The response of the embankment to underlying fault rupture might be useful for studies on the performance of levees, dams, and other earth structures subjected to surface fault rupture. GEER therefore conducted a detailed terrestrial LiDAR scan of this area to compare again the aerial LiDAR data.

Although the canal was not full of water at the time of the earthquake, the damage observed by GEER was relatively minor, despite measured fault displacements of about 57 cm horizontal and 28 cm vertical. A second, conjugate fault, with opposite direction strike-slip motion, also happened to cross the canal embankment at roughly the same location, making the deformation field relatively complex. The estimated displacement on this fault was about 29 cm horizontal and 13 cm vertical.

5. PAUCITY OF LIQUEFACTION

One of the striking features of this earthquake was the relatively low number of liquefaction sites observed given the extremely high ground motions recorded throughout the Kumamoto region and the large areas mapped as young alluvial deposits. GEER did visit a number of sites where liquefaction was observed, and other reconnaissance teams also observed a number of areas of liquefaction; however, many more areas of liquefaction was expected based on the team's experience documenting liquefaction after earthquakes. A detailed map of liquefaction observed by GEER and as reported by others is provided in Fig.5.

It is therefore of interest to determine the specific reasons why more liquefaction did not occur. Reasons for non-liquefaction may include low ground-

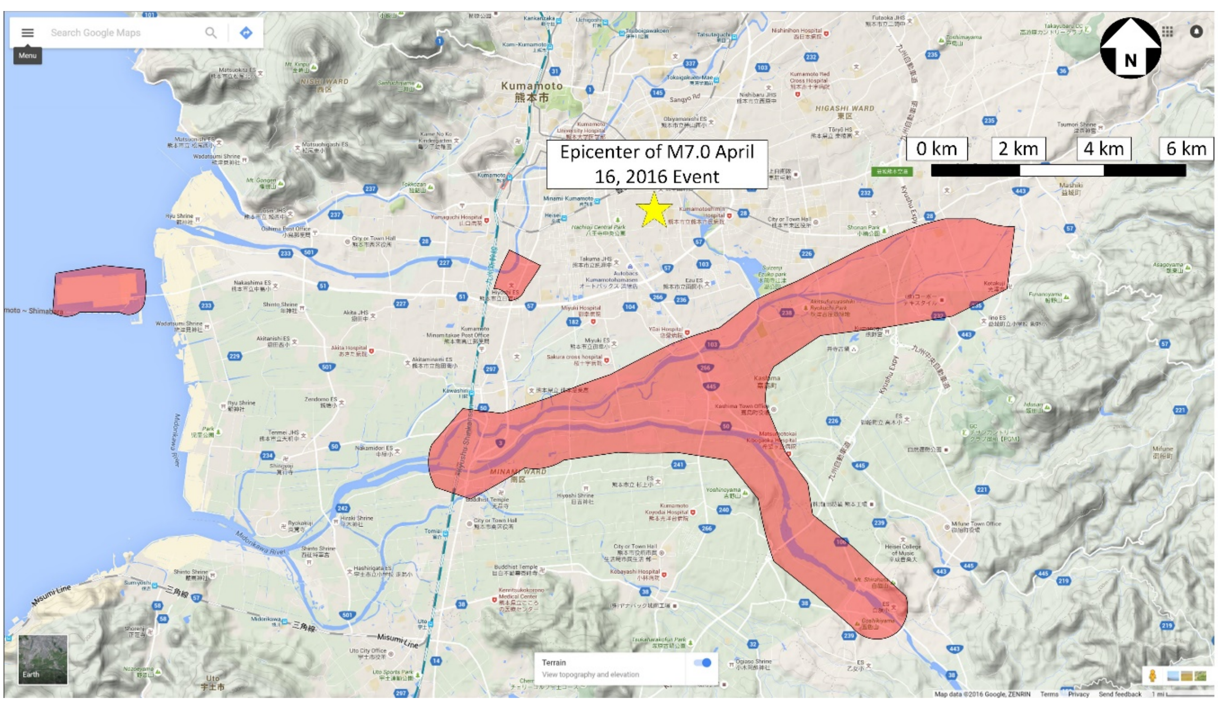

Fig.5 A map produced by GEER of observed liquefaction in the Kumamoto region.

water levels, plastic (non-susceptible) soils, high soil relative density, age of the soil, volcanic geologic origin of the sediments, and non-surface expression of liquefaction. The GEER team expects that the soil plasticity, resulting from the volcanic origin of the sediments, is the most likely cause. The authors recommend that further studies (e.g., soil borings, laboratory testing, and in-situ testing) be conducted at liquefaction and non-liquefaction sites, where liquefaction would otherwise have been expected, to determine the causes of low amounts of liquefaction resulting from the Kumamoto earthquakes.

6. ZERO-DISPLACEMENT LATERAL SPREAD

In addition to the relatively low amount of liquefaction observed, a relative lack of liquefaction-induced lateral spreading was noted by GEER. One case history in particular, a bridge along Route 501 crossing the Midorikawa River near Minamihashiri-kami (Fig.6; 32.6934°, 130.6480°), may be valuable for understanding the lack of observed lateral spreads. The GEER team observed almost no visible movement of the bridge, the abutments, or the banks of the river. Only one minor sand boil, directly beneath the bridge in front of one of the abutments was observed, indicating that some liquefaction did occur at the site.

Based on boring logs from the construction of the bridge provided to GEER, very loose sands were reported here (with some SPT results as low as zero) at relatively shallow depths. Given these site conditions, lateral spreading would likely have been expected; however, none was observed to have occurred.

While some of the lack of lateral spreading may be attributable to the same cause as the lack of liquefaction, at this site liquefaction was observed. Therefore, the GEER team speculates that the plasticity, fines content, or angularity of the particles may have contributed to the relative lack of lateral displacement. Similar to the lack of liquefaction, the authors recommend that further soil testing be conducted here to evaluate this case history and add it to the wider database of lateral spreading case histories.

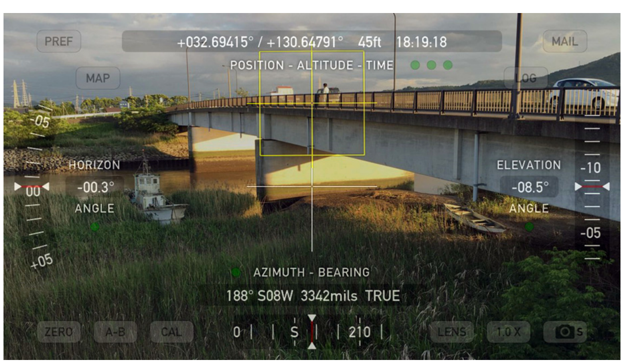

Fig.6 The Route 501 bridge that was not subjected to visible lateral spreading as would have been expected given the soil conditions at the site.

7. CONCLUSIONS

These five case histories documented by GEER will provide valuable insights for the performance of engineered structures and systems in earthquakes. We recommend that future studies be conducted to evaluate in a more detailed way the specific causes and effects of each case history. It is the mission of GEER to quickly gather the perishable data documenting the damage that occurred and make detailed measurements of that damage before significant repair work is done. We hope that the information gathered by GEER serves to further research into the response of infrastructure to large earthquakes.

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