Large-scale Landslide Analysis Subjected to the 2016 Kumamoto Earthquakes

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ABSTRACT: On April 16, 2016, the main-shock of the Kumamoto earthquakes (M_w7.0) struck beneath the Kumamoto City and generated numerous landslides around the Aso area. Among the landslides, the Aso-bridge landslide is the largest one triggered in this disastrous event, wiping out a bridge completely and causing great chaos on the traffics. For the purpose of examining the behavior of this large-scale landslide during the main-shock, simplified sliding block concepts and finite element codes are conducted in this study. This work concludes that (a) the slope of the Aso-bridge landslide, about 710 m high and with a dip angle of 33^o, is marginal stable in the absence of earthquake; (b) the failure surface obtained by finite element codes, incorporating the dynamic ground responses and coupled stress-flow analyses, is in satisfactory agreement when compared with that of the actual failure surface; (c) it is revealed that the initiation-time of the Aso-bridge landslide falls between 18.45 to 21 s of the recorded signals. This work demonstrates that the simplified sliding concepts and the finite element codes can be applied to analyze the Aso-bridge landslide with a reasonable agreement; however, care needs to be taken to ensure that an appropriate level of detail is included in the analysis.

1 INTRODUCTION

The 2016 Kumamoto earthquakes, comprising a main-shock and a fore-shock, are a series of earthquakes hit beneath Kumamoto City of Kumamoto Prefecture in Kyushu Region, Japan. At least 49 and about 3,000 people were killed and injured, respectively, due to the quakes. The main-shock, with a magnitude of 7.0, struck at a depth of 10 km at 16:25 UTC on April 15 2016 while the foreshock earthquake, with a magnitude of 6.2, hit at a depth of about 11 km at 12:26 UTC on April 14 2016 (JMA 2016). Following the main-shock, severe damage occurred in Kumamoto City and numerous earthquake-induced landslides were discovered in various locations causing great risks for the society.

In light of the fact that the mechanism of the Aso-bridge landslide is yet to be understood, we report an attempt in this paper, using an approach that is based on conceptually simplified sliding block concepts and numerical finite element codes to explore the arose questions. Note that the finite element codes can take into account the dynamic ground responses as well as the nonlinear behavior of geomaterial. Incorporations of the simplified sliding block approach (Newmark 1965; Keefer 1984; Jibson 2007; Chen et al. 2014) and the finite element codes provide a promising approach for evaluation of the Aso-bridge landslide.

The main focus is on the relationship between the seismic signals and the landslide, as well as to understand the potential failure surfaces. Along with the aforementioned analysis, the permanent displacement of the landslide, based on Wilson and Keefer (1983), is also evaluated.

2 ASO-BRIDGE LANDSLIDE

The Aso-bridge landslide is located near the Kumamoto City of Kumamoto Prefecture in Kyushu Region, Japan, occupying an area of approximately 180,000 m^2 (~18 ha). There was extensive mass movement on a slope approximately 360 m long with an inclined angle of 33 degrees (Fig. 1).

The landforms of the Aso-bridge landslide, both before and after the sliding, obtained using the Digital Elevation Models (DEMs) with 10 m resolution in horizontal direction reveal that the Aso-bridge could suffer from two mechanisms: (1) the large-scale landslide occurred immediately from the ridge of the slope when the main-shock hit; (2) subjected to the main-shock, the foot of the slope failed, resulting in the large-scale landslide due to the lack of passive support from the toe.

3 GROUND MOTION

The ground motion records (main-shock) used in this study are sourced from the OHDU station. The station is approximately 10 km west of the Aso-bridge landslide. Due to the fact that the input ground accelerations obtained from the station are associated with high-frequency ambient noise, the polarization of the seismic waves in the horizontal plan does not show any clear directional tendency. It is observed that the obtained displacement trajectory, as it has filtered out the high-frequency noise, might have revealed a reasonable time interval of the landslide initiation-time.

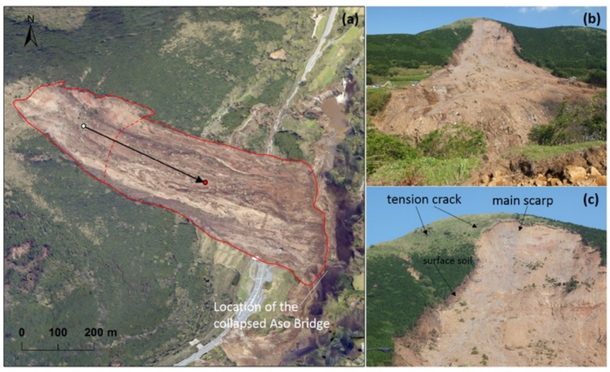

Fig. 1. Aso-bridge landslide.

4 METHODOLOGIES

An Integrated Factor of Safety Approach

In this study, conceptually simplified sliding block concepts were employed to estimate the permanent displacement and initiation-time interval of the Aso-bridge landslide without onerous complexity. The present methodology is similar to those described by Keefer (1984), Jibson (2007), and Chen et al. (2014), and is based on Newmark (1965).

In addition, to compensate the fact that the Newmark's approach is most suitable for a static problem yet the seismic problem is typically a dynamic one, and further noting that the directivity effect of seismic acceleration is important, the present study also considered the equations of Huang et al. (2001). Consequently, by integrating the above mentioned theories, the FS values of the dynamic earthquake-induced landslide can be evaluated subject to the normal and tangential ground accelerations to the dip-direction. Based on the method, the identified initiation-time of the Aso-bridge landslide appeared to be between 18.45 to 19.15 s, when the FS noticeably drops below one (FS < 1.0). Details of the equations can be found in Hung et al. (2017).

Finite Element Method

The slope stability, the dynamic ground responses, and the nonlinear behavior of geomaterial were considered using the finite element codes Plaxis 2D (Plaxis 2016). Note that the authors have successfully applied the software in analyzing complicated geotechnical problems (Hung et al. 2014; Ling & Hung et al. 2016). Consequently, such commercial software was utilized in this study.

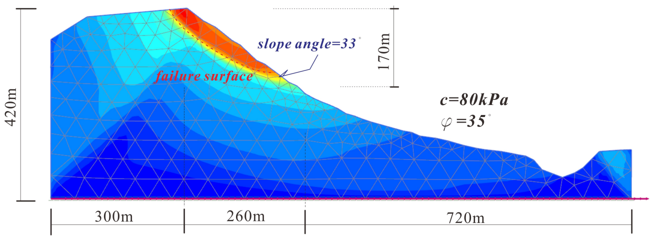

Fig. 2. Slope stability of the Aso-bridge slope.

The ground motion input (dip-direction) used in the analysis corresponds to the timeframe of 15 – 40 s with a duration of 25 s, in which the most ground motions were included. The dynamic ground motions were assumed to be given at the bottom and were modeled by imposing a prescribed displacement based on the ground acceleration record. Details pertaining the method are documented in Hung et al. (2017). Fig. 2 shows finite element analysis of the Aso-bridge landslide slope stability.

5 RESULTS AND CONCLUSION

Results

The yield acceleration value, obtained by the Newmark's concept and the finite element slope stability analysis, is 80 gal. Noting that the initial FS in the absence of an earthquake should be greater than 1.0, it is thus evident that the estimated yield acceleration of 80 gal is appropriate. The Aso-bridge landslide might have been activated between 20.3 and 21 s, when the permanent displacement reached 5 and 10 cm, respectively, as shown in Fig. 3.

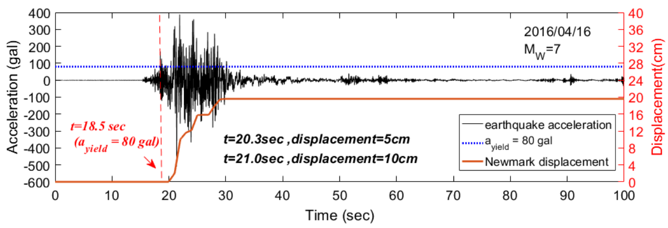

Fig. 3. Newmark's displacements and the thresholds of 5 and 10 cm.

Conclusion

This study described the application of simplified sliding block concepts and finite element codes to explore the Aso-bridge landslide induced by the main-shock of the Kumamoto earthquakes. Comparisons were made between analyzed and observed results and the level of agreement ascertained. From the results of this study the following conclusions can be drawn:

- For the Aso-bridge landslide, incorporation of the simplified sliding block concepts and the finite element codes can be applied to evaluate the potential failure mechanisms to this disastrous event. The initiation-time and failure surface are reasonable and the agreement between the analyzed and observed results are satisfactory.
- The recorded ground accelerations, in the horizontal plane, does not show any clear directional tendency; however, it was revealed that the first apparent displacements are in good parallel to the dip-direction of the Aso-bridge landslide.
- The initiation-time of the Aso-bridge landslide was revealed by (a) the directional tendency of the first apparent displacement, (b) FS, and (c) threshold displacement. The likely initiation-time is between 18.45 and 21 s.

6 ACKNOWLEDGEMENT

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