Analysis of Seismic Motion Characteristics That Contribute to Earthquake-Induced Landslides: Case Study of the 2004 Chuetsu and 2007 Chuetsu-Oki Earthquakes in Japan

Ryo Endo[1*] and Hiroyuki Fujiwara[2,1]

[1]University of Tsukuba, Tsukuba, Japan
[2]National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Japan

(*Corresponding E-mail: rendo.geomorphology@gmail.com)

Abstract: Earthquake-induced landslides can cause extensive damage; therefore, conducting rapid predictions immediately after an earthquake is crucial for risk mitigation. In this study, we investigated the seismic indexes that contribute to sediment transport with respect to the 2004 Chuetsu and 2007 Chuetsu-Oki earthquakes that occurred in Japan. The impacts of the indexes were assessed using correlation analyses. The results indicated that the "peak ground displacement x slope angle" was the largest contributions on small landslides and "squared velocity x slope angle" was on large landslides. In addition, small landslides correspond better to the seismic motion indexes than large landslides; this indicates that large landslides are more influenced by geology and/or ground properties in addition to seismic motion and slope angle.

Keywords: ***Seismic motion, 2004 Chuetsu earthquake, 2007 Chuetsu-Oki earthquake, Earthquake-induced landslides.***

Introduction

Earthquake-induced landslides can cause extensive damage to life and property. Therefore, rapid landslide prediction immediately after an earthquake is crucial for ensuring subsequent mitigation actions. With respect to seismic motion, peak ground acceleration is often used to assess earthquake-induced landslide distribution (Wartman et al., 2013). Previous studies investigated the relationships between various seismic indexes and landslide distribution (Dahal et al., 2023), but few examples exist, such as the 2015 Gorkha Earthquake in Nepal. To address the gap in literature, in this study, we investigated the seismic motion indexes that could have contributed to the earthquake-induced landslides.

Study Area

The two earthquakes considered in this study were the Chuetsu (Mw = 6.6, which occurred on October 23, 2004) and Chuetsu-Oki (M_w = 6.6, which occurred on July 16, 2007) earthquakes (Figure 1). Both the earthquakes were caused by reverse faults. A total of 4438 and 172 landslides occurred during the 2004 Chuetsu (Sekiguchi and Sato, 2006) and 2007 Chuetsu-Oki (Koarai and Sato, 2008) earthquakes, respectively.

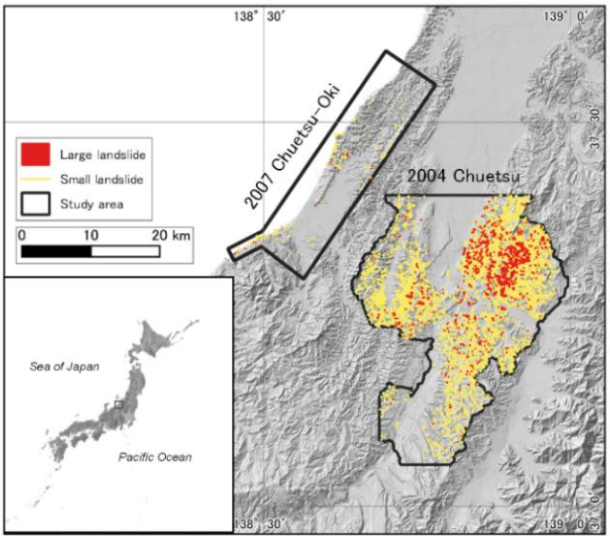

Figure 1, Study area for the 2004 Chuetsu and 2007 Chuetsu-Oki earthquakes.

Methodology and Material

Earthquake-induced landslides are affected by the ground characteristics; therefore, in this study. We evaluated the relationship between landslides and a specific index that was obtained by multiplying seismic motion with slope angle, using correlation analyses. The data used in this study are provided in the following subsections.

Landslides Inventory

The landslide inventory data used in this study were Suzuki et al. (2017) and Geospatial Information Authority of Japan (2007). In these data, the landslides were categorized into large and small landslides; the landslide densities were calculated for each 250-m grid unit.

Seismic motion

13 seismic indexes (Table 1) were calculated from the acceleration waveforms of the K-NET, Kik-net (ground surface) (National Research Institute for Earth Science and Disaster Resilience), Japan Meteorological Agency and Niigata Prefecture.

Table 1, Seismic indexes calculated in this study.

Seismic index	Formula
Peak Ground Acceleration	$PGA = \max\ (\lvert a(t) \rvert)$
Peak Ground Velocity	$PGV = \max\ (\lvert v(t) \rvert)$
Peak Ground Displacement	$PGD = \max\ (\lvert d(t) \rvert)$
Significant Duration	$T_d = T_{5-95\%}\ ([a(t)]^2)$
Arias Intensity	$I_a = \frac{\pi}{2g} \int_{t_1}^{t_2} [a(t)]^2\, dt$
Root Mean Square Acceleration	$A_{rms} = \sqrt{\frac{1}{T_d} \int_{t_1}^{t_2} [a(t)]^2\, dt}$
Root Mean Square Velocity	$V_{rms} = \sqrt{\frac{1}{T_d} \int_{t_1}^{t_2} [v(t)]^2\, dt}$
Root Mean Square Displacement	$D_{rms} = \sqrt{\frac{1}{T_d} \int_{t_1}^{t_2} [d(t)]^2\, dt}$
Cumulative Velocity	$CAV = \int_{t_1}^{t_2} \lvert (a(t) \rvert\, dt$
Cumulative Displacement	$CAD = \int_{t_1}^{t_2} \lvert (v(t) \rvert\, dt$
Squared Acceleration	$A_{sq} = \int_0^{T_{all}} [a(t)]^2\, dt$
Squared Velocity	$V_{sq} = \int_0^{T_{all}} [v(t)]^2\, dt$
Squared Displacement	$D_{sq} = \int_0^{T_{all}} [d(t)]^2\, dt$

Here, a(t): acceleration, v(t): velocity, d(t): displacement.

Slope angle

The 250-m grid slope-angle data used in this study were obtained from the Digital National Land Information of the Ministry of Land, Infrastructure, and Tourism.

Result, Discussion and Conclusion

We calculated Kendall correlation coefficients between the density of large and small landslides, and "seismic index × slope angle" indexes. The results are shown in Figure 2. The correlation coefficient of "PGD × slope angle" index was the largest for large landslides and that of "V_{sq} × slope" were the largest for small landslides, respectively.

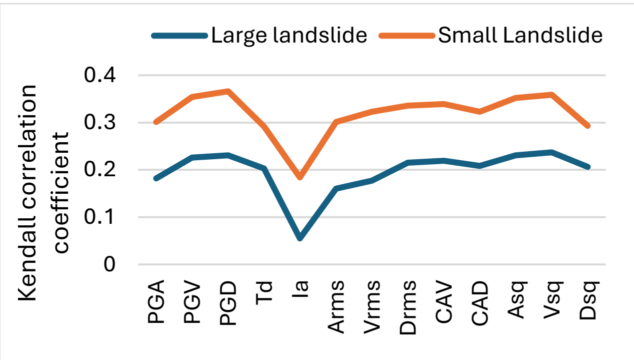

Figure 2, Kendall correlation coefficient between landslide density and "seismic index × slope angle" indexes.

The tendency for PGD to have larger correlation coefficients than PGA and PGV is consistent with the case in the 2015 Gorka Earthquake in Nepal (Dahal, 2023): displacement contributed more to landslides than those related to velocity and acceleration and velocity.

On the other hand, a comparison between the large and small earthquake-induced landslides revealed that all the seismic indexes exhibited a higher correlation with small landslides. This indicates that compared to small landslides, large landslides are more influenced by geology and/or ground properties in addition to seismic motion and slope angle.

In the future, we plan to analyze the impacts of other indexes, such as geology, and compare them to seismic indexes.

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