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Unzen Volcano : the 1900-1992 eruption

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18. Slope Stability of Mt. Mayuyama under the Volcanic Activity of Unzen Volcano

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Introduction

Mt. Mayuyama, one of the Unzen volcanoes, is situated in the east of Mt. Fugen and in the west of Shimabara City. When Unzen Volcano erupted in 1792, one of the worst natural disasters in Japan occurred due to the collapse of Mt. Mayuyama, which is called "the Shimabara Catastrophe" (Katayama, 1974; Ohta, 1987). Unzen Volcano have now become increasingly active again after a 200 years lull, so people are anxious about that the mountainside of Mt. Mayuyama might again collapse heavily.

In this paper, the stability of Mt. Mayuyama and the volume and the transport distance of the avalanche are studied by using an approximate method, under some assumptions on the ground conditions and on the causes for slope collapse (Iryo, 1992).

Stability analysis of Mt. Mayuyama

We will discuss the magnitude of earthquakes and the ground water level as the most important factors, when considering the possibility of the collapse of Mt. Mayuyama.

(1) The slopes studied and the ground conditions

We have selected 15 slopes shown in Fig. 18-1 for stability analyses, based on topographical features of Mt. Mayuyama. Among them, the collapse of the north-east slope (L-3) would cause the most serious damage to Shimabara City, thus we will discuss the stability of L-3 in detail in the following. The soil parameters used for the stability analyses are determined by the back analyses of the collapse in 1792. We will employ the modified circular slip method by Fellenius, in which the ground water level and the seismic intensity are taken into consideration.

(2) Effects of earthquake vibrations

If an earthquake will occur due to the volcanic activity of Unzen Volcano, the earthquake center will be close to Mt. Mayuyama. Thus values of seismic intensities in both horizontal and vertical directions can be taken as the same, *i.e.*, $k_h = k_v$, which are used throughout in the following slope stability analyses. Figure 18-2 shows the change of stability on the L-3 slope due to the increase of seismic intensity of $k_h = k_v$. The vertical coordinate indicates a ratio of the safety factor during the earthquake (*Fss*) to that of the slope at rest (*Fso*), *Fss*/*Fso*. The value of *Fss*/*Fso* properly decreases with an increase of seismic intensity, and the rate of the decrease for the upward direction is larger than that for the downward direction in the vertical accerelation. Therefore, we have carried out the analytical study on the influence of the ground water level under the conditions of $k_h = k_v$, considering upward direction in the vertical acceleration. The safety level on the mountainside decreases about 20 percent compared with that at rest for a seismic intensity of $k_h = k_v = 0.1$, and the level decreases substantially to below 50 percent for an earthquake with $k_h = k_v = 0.3$.

(3) Influence of the ground water level

Figure 18-3 shows the relationship between the ground water level and the slope stability on the mountainside, in which the ground water levels in the mountain are measured from the mountain top. Isopleths of the seismic intensity $k_h = k_v$ are

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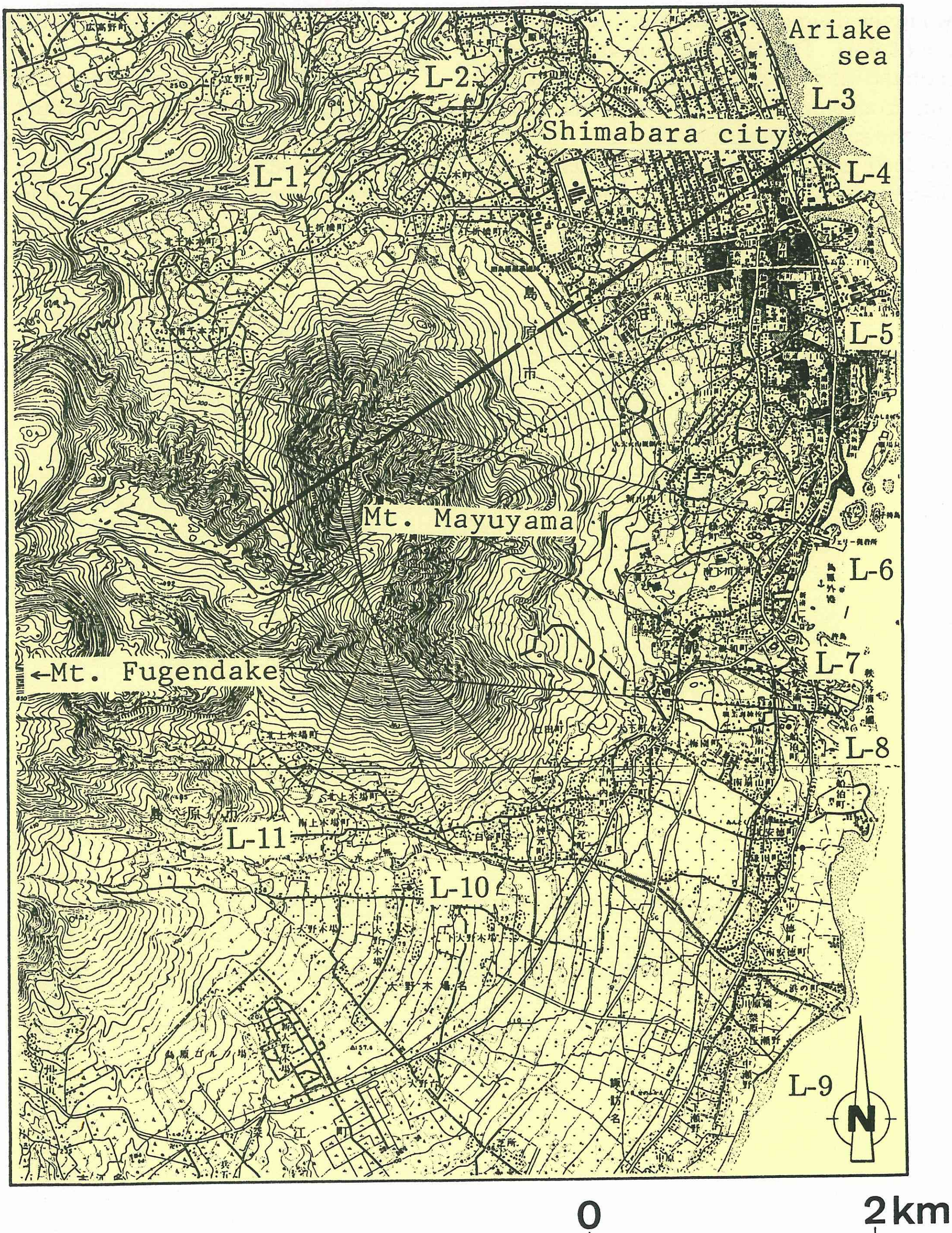

Fig. 18-1. The geographical features of Mt. Mayuyama and lines of analyzed slopes

shown in the diagram for the values of 0.00, 0.01, 0.02 and 0.03. The influence of ground water level on the safety factor of the slope appears at a certain ground water level and becomes significant as the seismic intensity increases. The safety factor decreases at a rate of about 10 percent per a 100-meter rise of the ground water level.

(4) Thickness of the potential landslide mass

The relationship between the ground water level and the thickness of the potential landslide mass (D) is shown in Fig. 18-4, where isopleths of seismic intensity are also drawn.

When the ground water level goes up to a certain level, the thickness of the potential

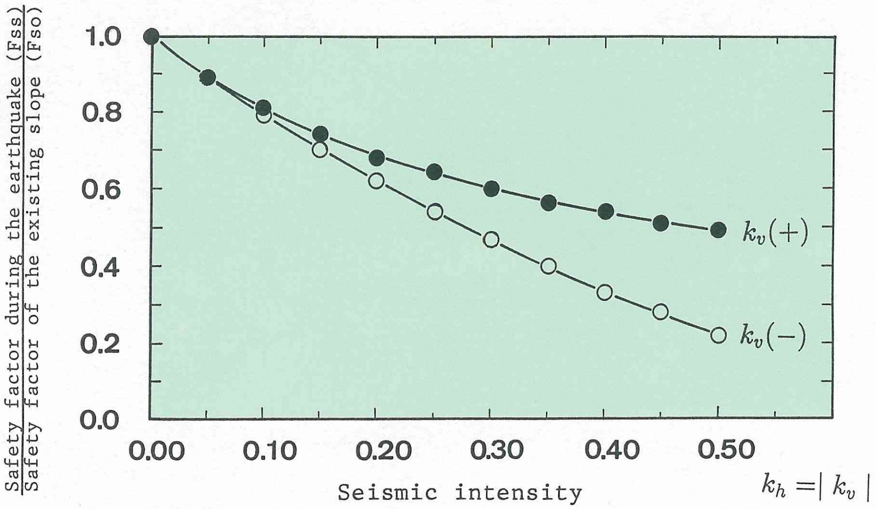

Fig. 18-2. Influence of seismic intensity on the stability of L-3 slope.

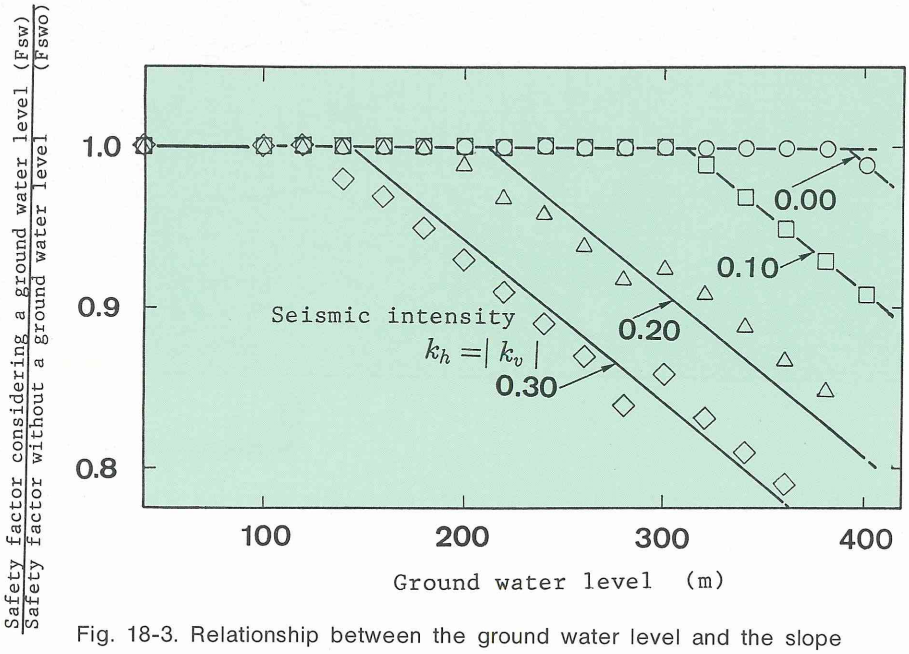

Fig. 18-3. Relationship between the ground water level and the slope stability on the mountainside.

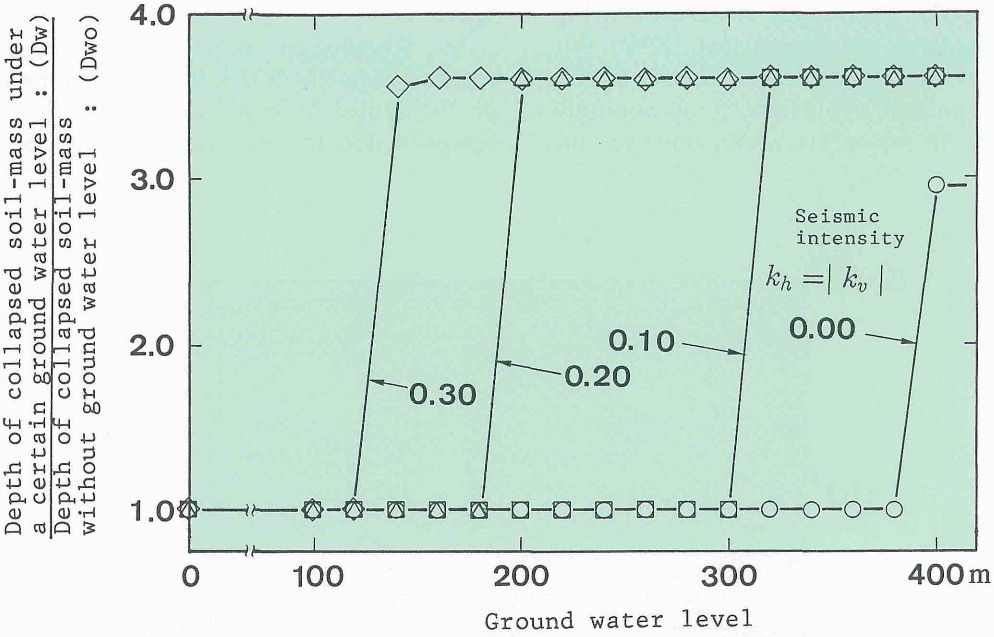

Fig 18-4. Relationship between the ground water level and the depth of potential landslide mass.

landslide mass abruptly increases, so that the scale of the collapse becomes substantially large.

Volume and transport distance of a landslide mass

(1) Volume of the potential landslide mass

A mode of mountainside collapse caused by earthquakes can be considered as follows.

When the first sliding occurs, the mountainside becomes more unstable and the second and third slidings are triggered by the first one. Collapses of the north-east slope of Mt. Mayuyama based on this progressive sliding model are analyzed. An example of vertical cross section of Mt. Mayuyama is demonstrated in Fig. 18-5. Volume of the potential landslide mass increases with the increase seismic intensity as shown in Fig. 18-6, where the range of estimated volume depends on the three dimensional shape of the landslide mass.

(2) Transport distance of a landslide mass

Since the north-east slope of Mt. Mayuyama faces Shimabara City in the east and the Ariake Sea in the far east, it is very important to take countermeasures against possible disasters due to the mountainside collapses. The transport distance of a landslide mass due to the mountainside collapse depends on several factors such as the cause of collapse, thickness, volume and initial velocity of the landslide mass, water and air contents in the mass, roughness of the slope, and so on. In order to predict the transport distance of a potential landslide mass, about 70 examples of mountainside collapse in the world are statistically treated by the Scheidegger's method, in which a ratio of the height to the transport distance of the landslide mass, H/L, is related to the volume, V. (Scheidegger, 1973; Hsu, 1975;

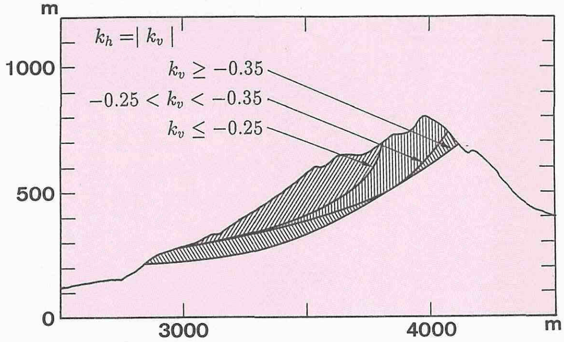

Fig. 18-5. One example of vertical cross section of collapses on the L-3 slope.

Moriwaki, 1987). The results are shown in Fig. 18-7. Examples of Mt. Mayuyama (1792), Mt. Okuyama (1982) and Mt. Chitsukiyama (1985), which are representative examples of mountainside collapses in Japan, are also included in this figure.

As Scheidegger pointed out, there is a correlation in which *H*/*L* decreases as the volume of the landslide mass increases. We should, however, note that the transport distance greatly

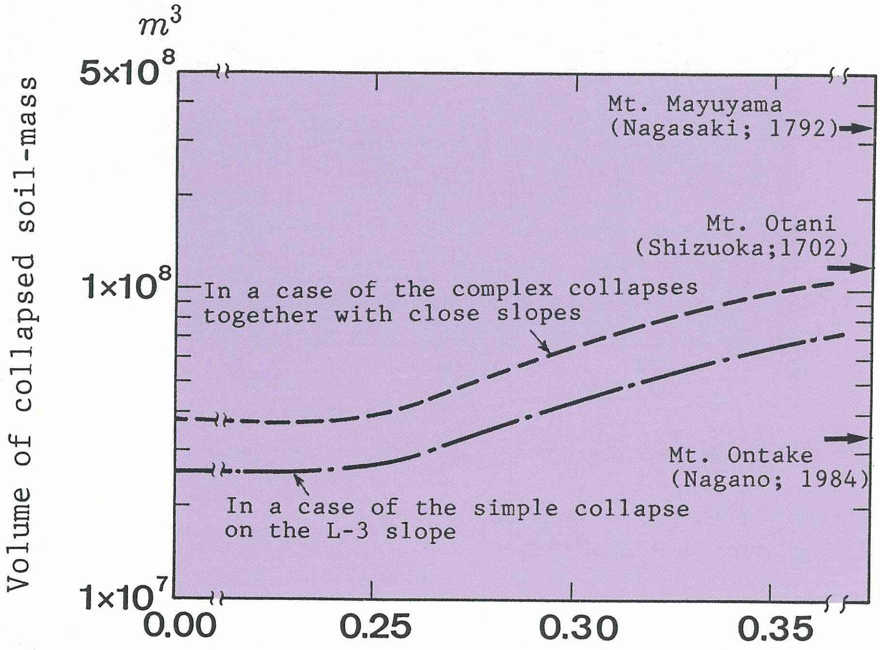

Fig. 18-6. Relationships between the seismic intensity and the predicted volume of landslide mass.

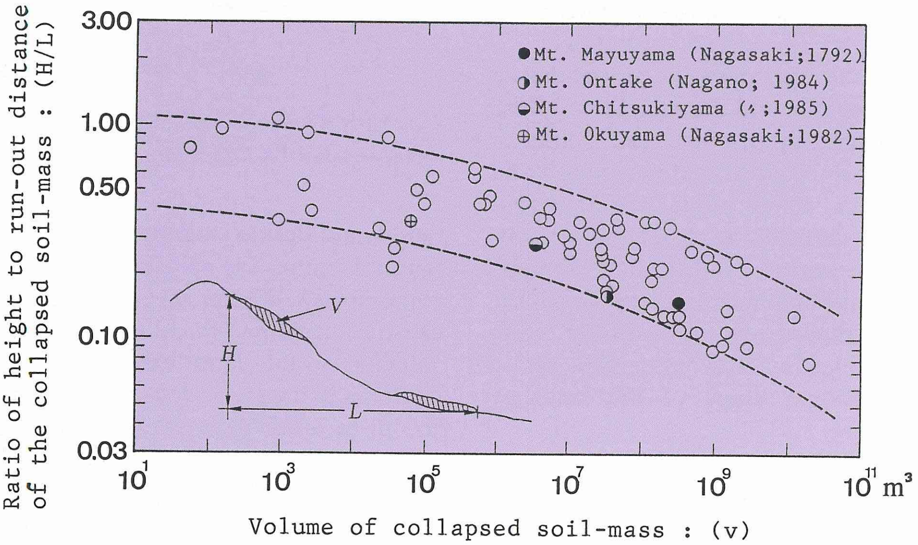

Fig. 18-7. Relationship between the volume of potential landslide mass and the ratio of height to the transport distance of landslide mass.

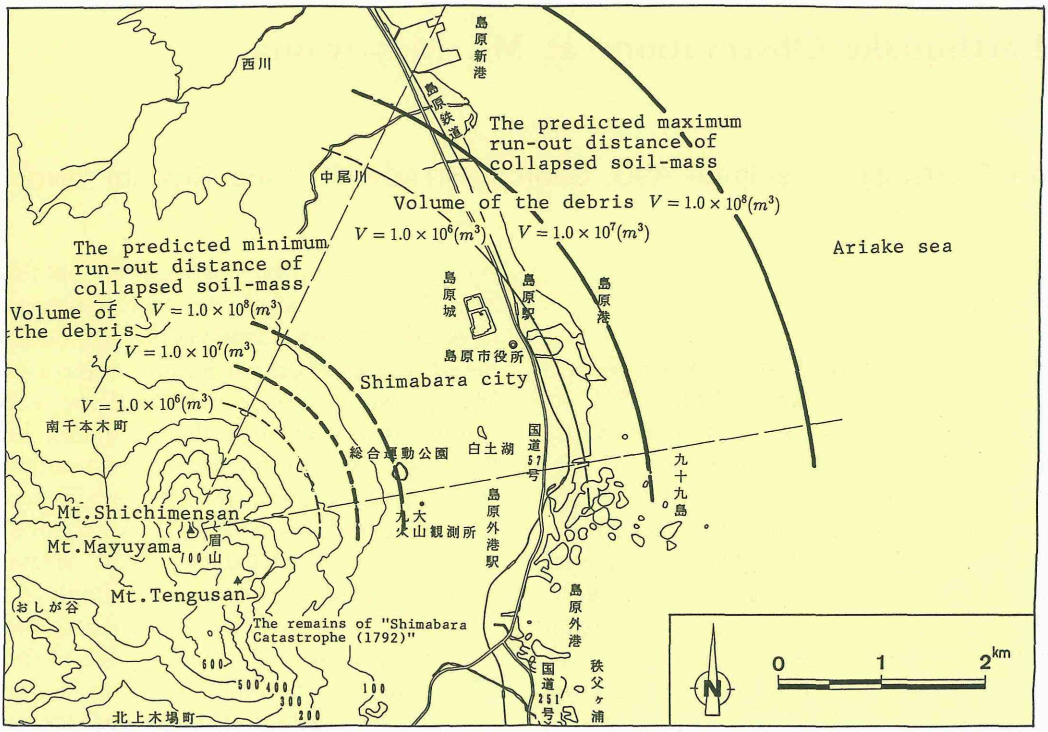

Fig. 18-8. The prediction of the maximum and minimum transport distance of the landslide mass on the northeast slope of Mt. Mayuyama.

increases as the volume increases, because Fig. 18-7 is a logarithmic plot. If the volume of the landslide mass is predicted, the maximum and minimum values of the transport distance of the mass can be estimated from Fig. 18-7. As described above, the volume of the landslide mass depends on many factors such as the seismic intensity, the ground water level, the collapse mode, and so on. For the case of collapse of the north-east slope of Mt. Mayuyama, it is very difficult to determine which parameters are the most important. However, we have made a possible prediction shown in Fig. 18-8 for the sake of countermeasures against the potential disasters, in which the predicted maximum and minimum values of the transport distance are shown for some values of the volume of landslide mass. It should be noted again that the results in Fig. 18-8 are preliminary because of some uncertain factors in the analysis.

Conclusions

The results of the slope stability analyses of Mt. Mayuyama and the studies on the volume and the transport distance of the landslide mass can be summarized as follows.

1) The stability of Mt. Mayuyama during earthquakes with intensity of 0.1 to 0.2, decreases by 20-40 % compared with that at rest.

2) The stability of the slope decreases about 10 % per a 100 meters rise of ground water level in the mountain.

3) The rise of ground water level greatly influences the thickness of the landslide mass, and therefore the volume of the mass.

4) The statistical treatment of the historical examples of collapses, shows that the ratio of the height to the transport distance of the landslide mass, H/L, is related to the volume, V.

5) If the volume of the landslide mass is predicted accurately, the maximum and minimum values of the transport distance of the mass can be estimated.