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EARTHQUAKE INDUCED SLOPE FAILURE

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SUMMARY

In order to establish some assessing criteria of the probability of slope failures, five themes are reported, i.e. field observations, seismic analysis, model simulation, soil mechanics and practice method. By field observations it is found that loose rocks, unstable slope, faults or lineaments are quite important. Slope failures often happen when earthquakes with magnitude over than 6.0 occur. The result of model simulation shows that 5 ~ 10 Hz frequency of the ground motion is very influential to move a solid substance from the ground surface. It can be put in order to check items of the topographycal and geological propeties to assess slope failures. It should be carefully under consideration to apply the best prevention method in accordance with the natural conditions of the slope.

INTRODUCTION

When erthquakes with large or middle magnitude occured, a lot of slope failures or landslips were reported all over the world. In the 1978 Izu-Oshima Earthquake, a simple relationships between static factor of safety and horizontal critical acceleration were derived and the critical acceleration for a slope was estimated by Y. Kobayashi (Ref. 1). It was concluded by E. Yanagisawa and et al. that the slope failure was caused by seismic force and by the reduction in shear resistance due to pore pressure generated by the Miyagiken-oki Earthquake of 1978 (Ref. 2).

Authors have been investigating to establish some criteria of assessing the probability of such phenomena in order to prevent tragical disasters. And they intend to approach to the applicable criteria based on engineering aspects, so this paper is only one preliminary report.

OBJECT and THEME

The object of the studies is to approach to establish applicable criteria for assessing the risk of slope failures. The study includes,

1) Field observations,
2) Seismic analysis,
3) Model simulation,
4) Soil mechanics and Practice method.

RESULT and DISCUSSION

Field Observations The type of slope failures are classified in three groups, those are loose rocks, active faults and unstable slopes. Loose rocks were released by shock and tumbled down induced by the Off-Iwate Earthquake (M=6.9, Jan. 9, 1987) and the Hyuganada Earthquake (M=6.9, Mar. 18, 1987). Rocks fell down on the track through sparse forest from the existing place 250 m above the slope, when the Off-Iwate Earthquake shocked Kamiarisu Station. Express train had safely passed the scene 9 minutes before the shock. Maximum weight of these rocks was estimated as 3 tones. Field survey of slopes should be extended to the summit of slopes for preventing of risk of these failures.

Slope failures induced by the Off-east Izu-peninsula Earthquake (M=6.7, June 29, 1980) were observed on the active faults and topographycal lineaments. One third of the house shown in Photo 1 was crushed by rocks tumbled down induced by the earthquake. The damaged house was located exactly on the lineament, which is shown on the tectonic map series " Active Faults In Izu Peninsula " (Ref. 3). Location on any active fault or lineament should be avoided for building site selection. Unstable slopes were failed by the Off-Iwate Earthquake and the Hyuganada Earthquake. Failed slopes could be identified by soil mechanics and may be protected with adequate means.

It can be clearly mentioned by these observations as follows.

1) The release of the loose rock is similar to the drop sign from the building wall by earthquake shocks.
2) A potential risk is found in the adjacent place to active faults or lineaments.
3) Unstable slope has usually poor inclination.
4) Survey of slopes should be extended from the side area of the subject to the summit of the slope.

Photo 1 Crushed house by tumbling rocks (July 14, 1980)

Seismic Analysis A map of historical earthquakes of Japan from 684 A.D., especially noted slope failures, is shown in Fig. 1 (Ref. 4). This figure shows that notable slope or moutain failures in Japan have occured especially in volcanic regions, and that areas which had more slope failures were Tohoku, Kanto, Chubu and Kyusyu districts.

Historically speaking of the occurence of slope failures induced by earthquakes in Japan in these 1300 years, it can be found that those hazards happened mainly between 700 and 900 A.D., between 1200 and 1300 A.D., and after 1600 A.D..

It is one of the impotant problems, that is, what relations are existing between erathquake magnitude (M) and the number of slope failure cases, or between epicenter distance and the number of the cases, or between hypocenter depth and the number of the cases, or such complex relations. The number of the earthquake which induced slope or mountain failures are as follows (Ref. 4).

$M \geqq 8.0$	2 cases
$8.0 > M \geqq 7.0$	23 cases
$7.0 > M \geqq 6.0$	32 cases
$6.0 > M \geqq 5.0$	3 cases.

Minimum magnitude (M) which induced slope failures was 5.7 (2 cases).

For example, at the time of the Southern Kanto Earthquake (M=7.9, Sep. 1, 1923), slope failure area were counted about 82 km^2 in Kanagawa Prefecture (Ref. 5). And the report of Odawara Police Station says, "In the quite wellknown beautiful Hakone Mountain from Yumoto to Miyanoshita , all national roads and climing railway have fallen down or been throughly buried. All beautiful green mountains have been changed to red skin. " (Ref. 6).

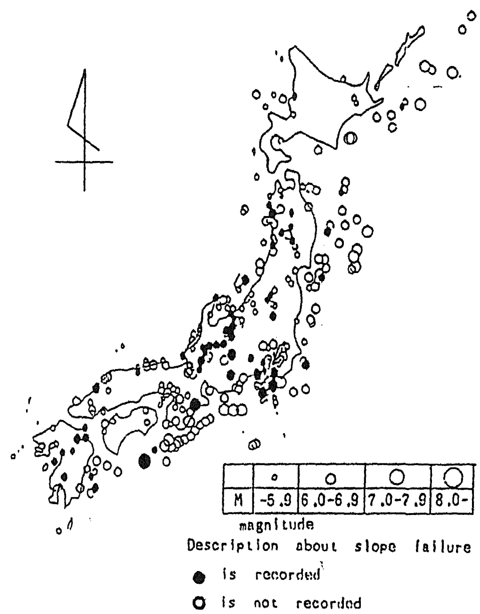

Fig. 1 Map of Epicenters of Historical Earthquakes (684 ~ 1984)

<u>Model Simulation</u> At the Western Nagano Prefecture Earthquake (M=6.8, Sep. 14, 1984), rocks and other many materials jumped off from the ground by certain forces. Experimental results of the relations between the horizontal jumping distance (2 m), frequency range (5 ~ 10 Hz), velocity (6 m/sec) of the ground surface and acceleration (300 m/sec^2) of ground surface were estimated (Ref. 7).

Supposing that a solid substance exists on the horizontal ground surface which has simple harmonic vibration, the relation is known as follows.

$$v_\tau = v_0 \sin \omega \tau \qquad (1)$$

$$-g = v_0 \, \omega \cos \omega \tau \qquad (2)$$

$$m v_\tau^2 = m \, g \, H \qquad (3)$$

Next formula can be derived.

$$H = \frac{1}{2g} \left(v_0^2 - \frac{g^2}{\omega^2} \right) \qquad (4)$$

where

g = acceleration of gravity
τ = time when ground acceleration becomes $-g$
v_τ = vertical velocity at time τ
ω = angular frequency of ground
v_0 = vertical velocity amplitude of ground surface

m = mass of the solid substance
H = absolute jumping height of the solid substance from time τ

These relations are shown in Figs. 2, 3. Fig. 2 shows that jumping height is over than 10 cm when frequency of the ground motion is over than 5 Hz and acceleration amplitude is over than 5 g. It can be clearly known from Fig. 3 that jumping height is kept as a nearly constant distance in any vertical velocity amplitude, when frequency of the ground motion is over than a certain value. Velocity amplitude is supposed to depend on the potential energy of the hypocenter area, the hypocenter mechanism and the amplification by mountains. The prediction of these failure phenomena is quite vital to the prevention of debacles of slopes or mountains.

It is quite impotant that 5 ∼ 10 Hz frequency of the ground motion is very influential to move a solid substance from the ground surface.

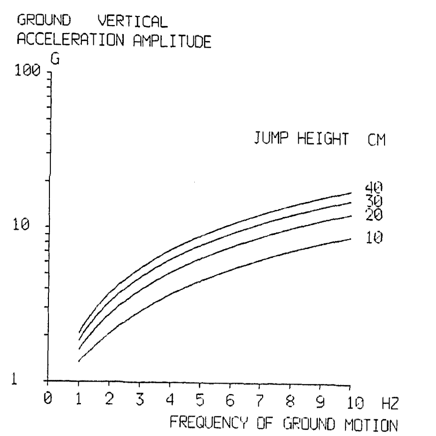

Fig. 2 Jump Hight and Vertical Acceleration Amplitude of Ground

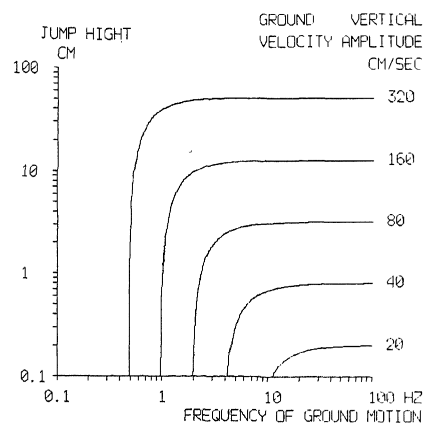

Fig. 3 Jump Hight and Vertical Velocity Amplitude of Ground

Soil mechanics and Practice method The feature of slope failures is classified in two types in relation to those mechanics shown in Fig. 4; (1) fall, (2) slip. And in another aspect, it's also classified in three styles with respect to failure morphology shown in Fig. 5 : (3) shallow surface failure, (4) deep failure, and (5) deep and wide failure.

(1) Fall : One of the typical failure such as some overhanging blocks falling down from the slope by its self weight. The falling face is just standing up nearly vertically, and some tension resistance works at the face.
(2) Slip : *To slip down on the slide plane in a slope. Shearing resistance of* soils works on the slide plane.
(3) Shallow surface failure : On the occasion of the slope composed with easily eroded soils, sand, volcanic ash or weathered granite, the surface of the slope can be easily fallen down by earthquakes' shock, surface water flow, or permeated water.
(4) Deep failure : Deep failure happens often when the direction of joint or

stratification of alternation of strata with crystalline shist, sandstone or shale is nearly same as that of the slope, when there are large faults or cracks with fracture zone in the slope, and when these dips are same as inclination of the slope.

(5) Deep and wide failure : In case of the slope composed with talus, volcanic ash, alterated tuff, semi-solidificated siltstone or mudstone over the wide area with fault fracture zones, deep and wide failures or landslides often occur by ea·thquakes or groundwater.

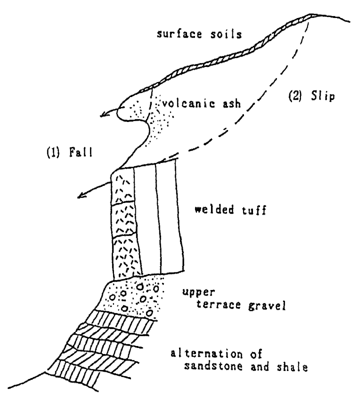

Fig. 4 Failure of fall and slip

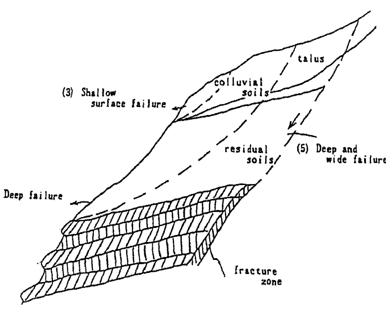

Fig. 5 Shallow and deep failure

So it is necessary to consider the topographycal and geological property of the slope. Then it is put in order shown as Table 1 to check items in order to establish certain criteria of assessing the probability of slope failure.

In practice of preventing slope failures, the design of the construction should be carefully matched with the natural conditions of the local and neighboring area. In accordance with the angle of slopes, soil properties, or failure mechanism, it should be under consideration to apply the best method, i.e. slope cover method, surface water and groundwater drainage method, failure prevention method by structures, and so on.

CONCLUSION

At the first stage of the study of establishing criteria, it can be certainly explained as follows :

(1) None loose rock should be found in upper side of a slope.
(2) Any active fault or lineament should not be found in the adjacent area of the subject.
(3) Natural slope should be steep.
(4) Slope failures happen to occur when the magnitude of the earthquake is over than 6.0.
(5) 5 ～ 10 Hz frequency of the ground motion is quite influential to move a solid substance from the ground surface.
(6) It is necessary to check items shown in Table 1.

(7) It should be under consideration to apply the best prevention method in accordance with the natural conditions.

In order to accomplish better criteria of assessing slope failure, dynamic analysis of the slope and ranking up of these assessment points are the next work of this study.

Table 1 Topographycal and geological check list for assessing probability of slope failures

Section	Item		Assessment
Topography	Feature	Lineament Irregularity of the contour line Marks of old failure	Location, Existense Existense, scale, Quantity
	Inclination of surface		Inclination angle
	Ground water	Spring, Seepage	Existense, Quantity
	Botanical group	Acerose, Deciduous, Shrub, Uncovered	Existense, Distribution density
Geology	Basement	Geologic time Strike, Dip Joint, Stratification Weathering	Palaeozoic, Mesozoic, Cenozoic Palaeogene, Neogene Quaternary Direction, Angle Progress stage Phase
	Surface	Volcanic ash, Loam, Kuroboku soils, Akahoya soils, Pyroclastic flow, Residual soils, Colluvial soils, Talus	Layer thickness, Relative density, Consistency

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