SOME CONSIDERATIONS ON THE MECHANISM OF SLOPE FAILURES INDUCED BY RAINFALLS AFTER EARTHQUAKE

Nobuyuki Torii[1] and Takashi Okimura[2]

On January 17th, 1995, the Kobe earthquake (Mj=7.3) fatally damaged Kobe city in Japan. In the Rokko Mountains located behind the urbanized area of this city, the earthquake triggered 747 slope failures. Furthermore 938 slopes failed additionally by post-quake rainfalls till the end of Oct. 1995. The bed rock type of the Rokko Mountains is granite, and the surface is covered with decomposed granites soil. Therefore, it has a long history of slope disasters due to heavy rainfall. However, these post-quake rainfalls were little amount of rainfall and intensity in comparison to the warning rainfall level obtained empirically before the Kobe earthquake in the Rokko mountains. These phenomena were reported at another earthquake, like 1999 Taiwan chi-chi earthquake[1)], 2001 Geiyo earthquake, Japan[2)]. In this study, we performed analytical and experimental studies in order to make clear the mechanism of slope failures due to rainfalls after the earthquake.

ANALYTICAL STUDY

The seismic response analysis was applied to failed sites triggered by the earthquake and the post-quake rainfalls at Gosukebashi area in the Rokko Mountains in order to look into the dynamic response property. We used analysis code "Super FLUSH/2D"[3)], which is 2D-equivalent linearization analysis. The result of the analysis is shown in Fig. 1. From this figure, the peak of maximum response acceleration appeared over 550 gal and the peak of maximum shear strain appeared 10^{-3} level at failed slope by earthquake. Because these slopes were affected by strong seismic motion, slope failures were generated during the earthquake. While, at failed slope by post-quake rainfalls, the peak of maximum response acceleration appeared around 450 gal and the peak of maximum shear strain appeared 10^{-4} level. Although this level of shear strain does not lead failure, it begins to generate some deformation. This result means that some slopes, where failure did not occur during the quake, although they were affected by seismic motion, failed by the post-quake rainfalls.

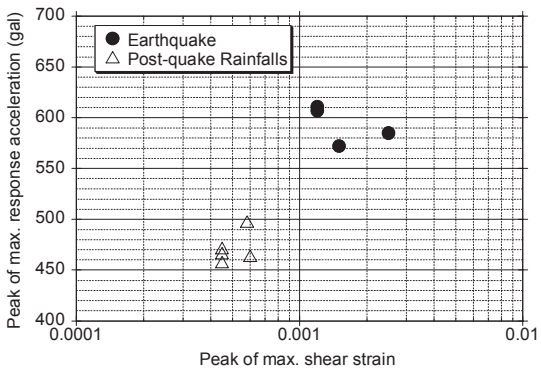

Fig. 1: Relationship between peak of max. response acceleration and max. shear strain at failed part

EXPERIMENTAL STUDY

The experiments using the triaxial test apparatus were carried out to experimentally clarify the effect of the seismic motion and the post-quake rainfalls on the soil shear strength. Concretely, in order to examine the effect of the cyclic load and the submergence on the shear strength of the soil, consolidated drained shear test (CD triaxial test) performed under four

1 Assistant Professor, Research Center for Urban Safety and Security, Kobe University, 1-1 Rokkodai-cho, Nada-ku, 657-8501 Kobe, Japan (Tel.: +81-78-803-6437; Fax: +81-78-803-6394; email: torii@kobe-u.ac.jp)
2 Professor, Research Center for Urban Safety and Security, Kobe University, 1-1 Rokkodai-cho, Nada-ku, 657-8501 Kobe, Japan

kinds of different conditions (see Fig. 2). The decomposed granite soil on slip surface has the skeletal structure. Therefore, the undisturbed sample is needed as a specimen of the experiment. But, it is not so easy to take a sample as undisturbed condition and undisturbed sample seem to have some variation. In order to make uniform specimen of the experiment which has the skeletal structure, we used the decomposed granite soil with the gypsum. The result of experiment is shown in Fig. 3. From this figure, the soil shear strength was reduced by 35% because of saturation and the soil shear strength was reduced by 18% because of cyclic loading. In addition, the soil shear strength was reduced by 32% because of saturation after the cyclic load was given. These mean that the soil shear strength was decreased because the skeletal structure of the soil was destroyed by the seismic motion and decreasing of the shear strength was generated additionally by increasing of the degree of saturation due to the rainfall after the earthquake.

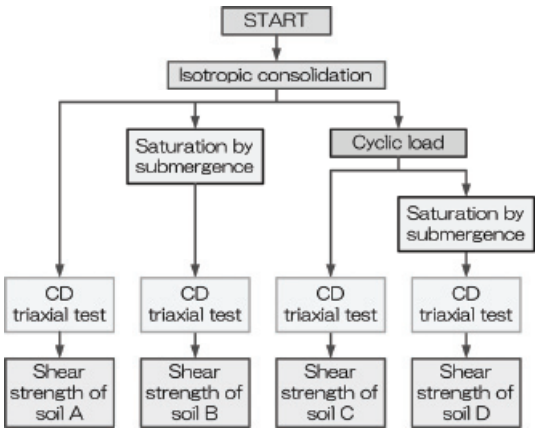

Fig. 2: Flowchart of experiment

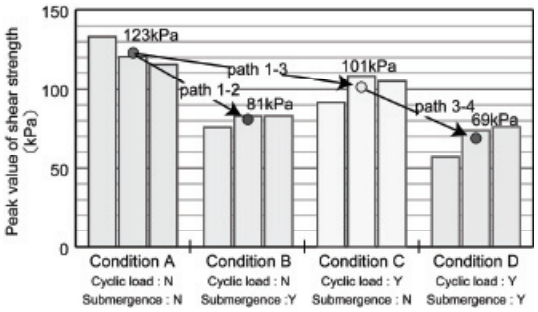

Fig. 3: Comparison of soil shear strength

SUMMARIES

In this study, we performed analytical and experimental studies in order to make clear the mechanism of slope failures due to rainfalls after the earthquake. The results of analytical and experimental studies are summarized as follows: 1) The seismic motion affected on failed slopes by post-quake rainfall, although the effect was smaller than the failed slopes by the earthquake. Therefore, the seismic motion plays an important role for the occurrence of not only earthquake-induced failure but also post-quake rainfall-induced failure. 2) The skeletal structure was destroyed by the effect of seismic motion, and as a result the soil shear strength dropped. And, decreasing of the shear strength was generated additionally by the effect of the rainfall after the earthquake. This is one of mechanism that many slope failures occurred by rainfalls after the Kobe earthquake.

REFERENCES

1) LIN, C. W. et al.: Impact of Chi-Chi Earthquake on the occurrence of landslides and debris flows: Example from The Chenyulan Riverwatershed, Nantou, Taiwan, *Engineering Geology*, vol.71, pp.49-61, 2004.
2) MORIWAKI, T. et al.: Influence of 2001 Geiyo earthquake on slope failure disaster due to rainfall in Kure, *Proceedings of 49th Geotechnical Symposium*, pp.307-314, 2004(in Japanese).
3) JISHIN KOUGAKU KENKYUSHO Inc. and KOZO KEIKAKU ENGINEERING Inc.: Manual of Super FLUSH/2D VERSION3.1, 155p., 1996(in Japanese).

Keywords: Slope Failure, Post-quake Rainfall, Dynamic Response Property and Soil Shear Strength.