TECHNICAL NEWS

VISIT OF ATC3 COMMITTEE ON SLOPE INSTABILITY SITES IN BHUTAN

Ikuo Towhata, University of Tokyo, towhata@geot.t.u-tokyo.ac.jp
Mitsu Okamura, Ehime University, okamura@cee.ehime-u.ac.jp
Hirofumi Toyota, Nagaoka University of Technology, toyota@vos.nagaokaut.ac.jp

INTRODUCTION

Asian member societies of ISSMGE have been operating several technical committees of their own and among those committees is ATC3 that concerns geotechnical natural hazards. In the current 4 years of term, this committee is chaired by Ikuo Towhata and is working on slope problems. As a part of the ATC3 activities, three committee members made a visit to Bhutan from October 18th, 2011, to 25th, and carried out some studies in collaboration with the Department of Geology and Mines of Bhutan Government and DHI-Infra Ltd.

Figure 1 illustrates the general idea of the Kingdom of Bhutan which ranges from the lowland at its Indian border to the top of Himalaya. The size of Bhutan is 38,400 km^2 in area and its population is 700 thousands. Because of the tectonic action between the Indian Ocean Plate and the Eurasian Plate, the geology in Bhutan is highly distorted and fractured, which makes mountain slopes highly vulnerable to instability problems. The precipitation rate is 3,000 to 5,000 mm in the southern lowland, 1,200 to 2,000 mm in the lower Himalayan slopes, 500 to 1,000 mm in the central mountain regions, and less than 500 mm in Himalaya. Most precipitation takes place during the monsoon season of June to September.

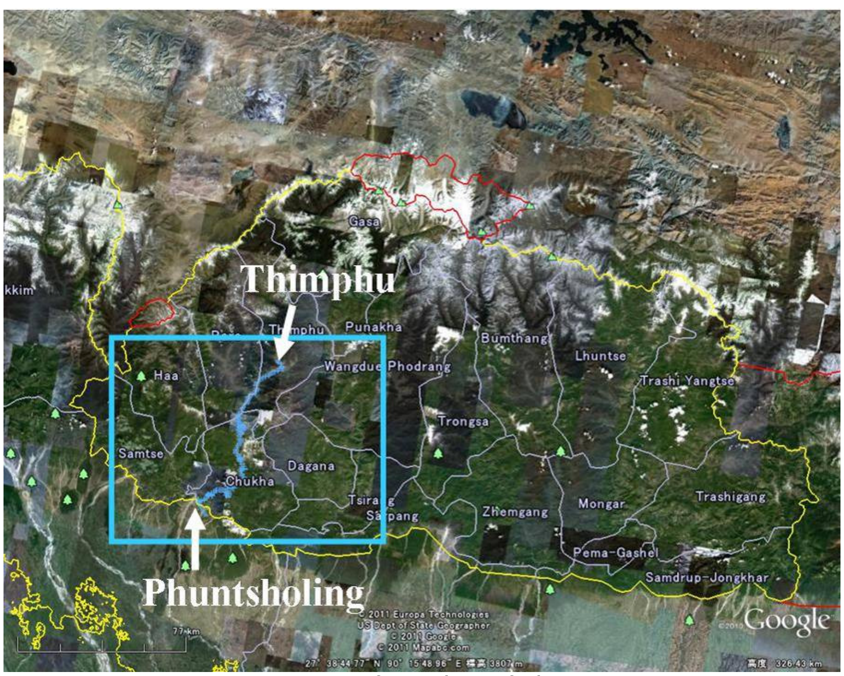

Fig. 1 Map of Kingdom of Bhutan.

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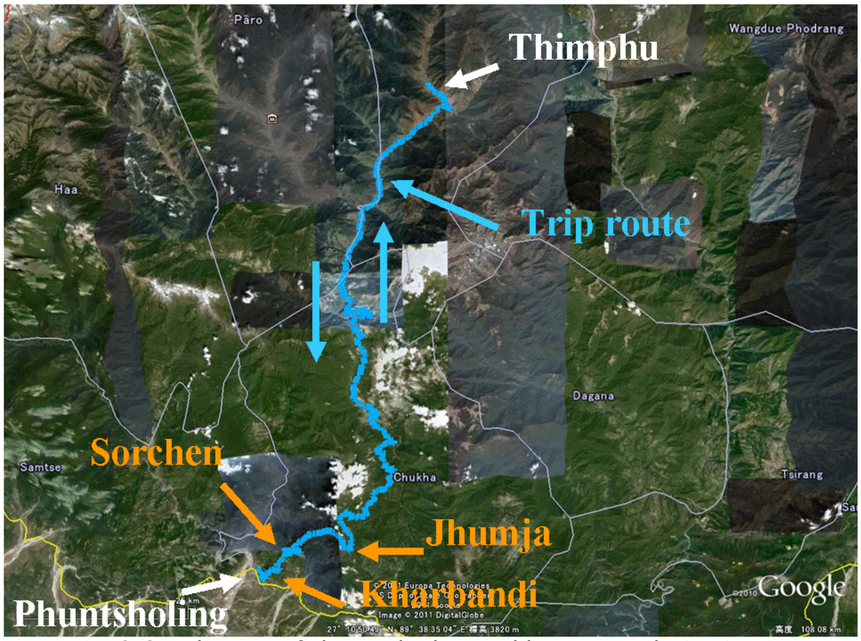

Fig. 2 Google map of the studied area (blue rectangle in Fig. 1).

Among many geohazards in this nation, 25 glacier lakes at high altitude are prone to breaching and flooding. The breaching event in 1994 caused debris flow in the downstream area, and the former capital of Punakha was affected. Although attempts are being made to construct drainage channels, working at high altitude is very difficult and risky. Because of the mission of ATC3, the present study was conducted on slope instability problems in the southern half of the country (Fig. 2).

The capital city of Thimphu has a population of 100 thousands approximately. Thimphu is located in the middle of mountainous region and there is only one major road that connects this city and India from which food, fuel, and other living substances are supplied. Thus, any slope failure along this important road would be fatal to the activities in the capital. Steep mountains and deep gorges along this important road have made road construction extremely difficult.

SLOPE INSTABILITIES

Technical visits were made of many sites of slope instability that is affecting the traffics of the nation's No. 1 highway between Thimphu (capital) and Phuntsholing (second biggest city at the Indian border); see Fig. 3. It appears that such metamorphic rocks as gneiss, schist, and phyllite with significant fissures and weathering are exposed to the air on the mountain side of the road and are causing instability problems at many places. Because the studied highway is the unique connection from outside to the capital, the slope instability is a substantial problem to the nation's economy.


Fig. 3 The highway connecting Thimphu and Phuntsholing.

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Jhumja Site

The road was opened in 1961. Fig. 4 shows that the road has subsided by 6 m over the distance of 200 m or so. The Road Department states that the subsidence occurred between 1998 and 2009, implying that the annual subsidence was about 60 cm. The typical type of rock here is gneiss and other metamorphic rocks.

It appears that this slope movement is caused by a deep-seated sliding of the rock mass, and the consequent distortion of the surface rock mass results in fracturing and stone falls (left side in Fig. 4). Another possible cause of stone fall (Fig. 5) is the mechanical weathering of the surface rock that was probably fractured by blasting construction of the road. It deserves note that major stone fall stopped in 2009 for unknown reasons.

Fig. 4 Jhumja slide.

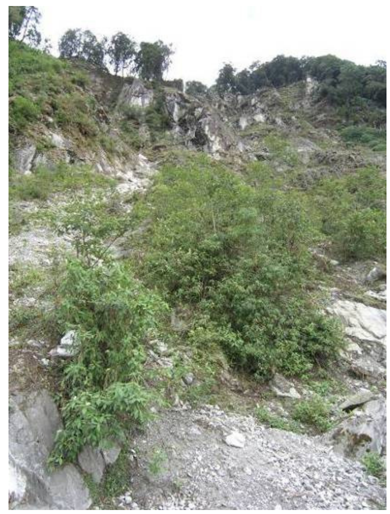

Fig. 5 Rock falls in Jhumja slide.

Sorchen Site

Road is affected by stone falling and slope instability at Sorchen (Fig. 6). The fallen stones deposit in the lower part of the slope (Fig. 7) and are prone to further failure, closing the road, in rainy seasons. The base of the slope consists of fractured Quartzite which is subject to hydration, weathering, and deterioration.

The surface weathering and instability may be mitigated by removal of unstable materials at the slope surface and then covering the surface by shotcrete, thus isolating the rock from external actions. However, this mitigation measure is temporary and the problem may start again in near future. The fundamental problem at the Sorchen site is the geology. Fig. 8 indicates that three slope failures are aligned in a narrow range, suggesting the effects of the regional distribution of vulnerable rock (Quartzite and Phyllite). Because of this reason, the mitigation at the slope surface is nothing more than a temporary action and more fundamental mitigation such as changing the road route is desired.

Fig. 6 Failure of cut slope at Sorchen.

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Fig. 7 Deposit of stones at bottom of Sorchen site.

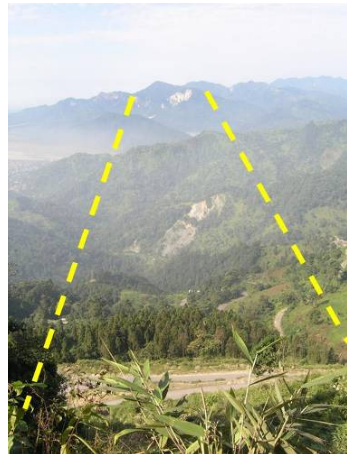

Fig. 8 Series of slope instability to the south of Sorchen site.

Kharbandi Site

The Karbandi site is located immediately behind the town of Phuntsholing and the road is located at the top of a saddle topography. Fig. 9 shows that the head scarp of the eroded cliff is approaching the main road. The rate of erosion is approximately of the order 1 m / year at the slope shoulder, according to the past observation. Fig. 10 indicates the erosion and gully formation. Phyllite forms this valley. At some time in the past, a minor action at the bottom of the valley triggered a small erosion and instability, and then the problem has been developing into a bigger scale. At this moment there is no efficient measure to stop this erosion at a reasonable cost, and the nation's most important road is going to be in a critical situation.

The local geology is composed of phyllite which is vulnerable to fracturing caused by hydration and reduced overburden pressure (Fig. 11). There are some more sites of similar problem (Fig. 12).

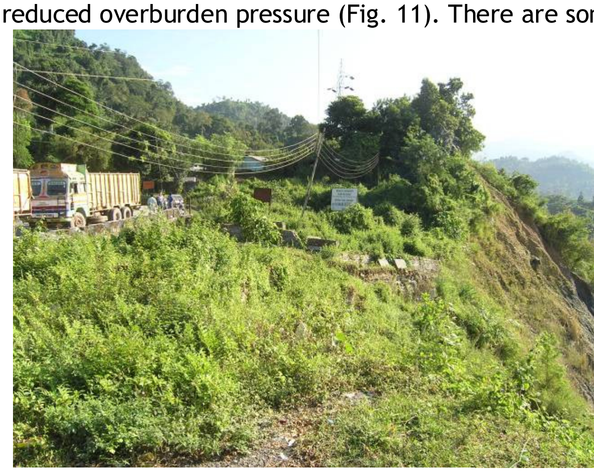

Fig. 9 Karbandi slope subjected to material det erioration and erosion.

Fig. 10 Ongoing erosion at Karbandi.

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Fig. 11 Breakage of Phyllite rock by we athering and water action.

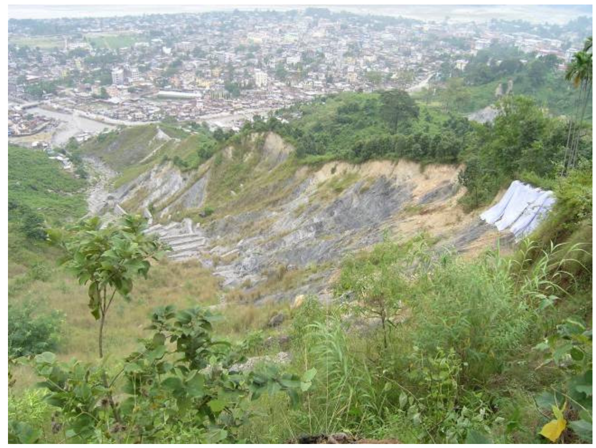

Fig. 12 Instability of Phyllite slope near

Figure 13 illustrates the site of stone falls during an earthquake in neighboring Sikkim on September 18th, 2011, with M=6.9. This cliff was formed in a terrace deposit and is composed of rubbles and stones. After the seismic disturbance, more stones are falling during rains and the road traffic at the bottom is not safe. Currently there is no rule in Bhutan about responsibility for the stabilization of such a slope. It is interesting that some parts of the top of this cliff are stabilized by simple masonry walls, thereby causing no slope instability.

Fig. 13 Seismic falling of debris from cliff of terrace deposit in Phuntsholing.

SEMINAR AT DGM

Prior to the field trip, a half-day seminar was held at the Department of Geology and Mines (DGM), Government of Bhutan. Because of the aim of the visit, the topics of three of us focused on instability problems in natural slopes. A group photo of participants after the seminar is shown in Fig. 14.

Fig. 14 Group photograph of authors and seminar participants at DGM.

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Talk by Ikuo Towhata

This talk addressed the field monitoring and early warning by which people are able to evacuate in advance and fatal disaster is avoided. A secondary disaster during restoration of damage is avoided as well. Because the location of future failure in a natural slope is difficult to foresee due to complicated variation of local slope angles, types of rocks, extents of weathering, and local hydrology, it is more desirable to install many monitoring sensors at any suspected parts of a slope than to pursue accurate observation. Thus, the costs for manufacturing of a sensor and its installation as well as operation have to be low.

The authors' attention has been focused on rainfall-induced quick failure of surface unstable materials in slopes. Surface failure is small in size but many in number and affects people's life and property all over the world. In contrast, a deep-seated large slope failure is not necessarily the target of study.

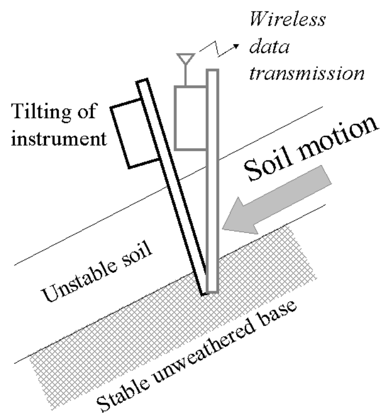

Fig. 15 Working mechanism of tilting sensor.

The proposed inexpensive sensor is intended to monitor movement of the surface unstable layer during heavy rainfall. For its working mechanism, see Fig. 15. Former studies (Farooq et al., 2004, and Orense et al., 2004) showed that soil exhibits minor deformation prior to the rain-induced failure. Thus, the developed sensor monitors deformation of slopes during heavy rainfall. The sensor is placed at the top of a rod which is penetrated in advance into ground until reaching a stable base layer. When the surface weathered soil starts to move during rain, the rod tilts and the tilting angle is monitored by the sensor. The recorded data is sent through wireless to an office and, if the extent of the data exceeds a threshold, caution or warning is sent to the local community.

The Three Gorge Dam in China produced a huge reservoir and the rising of the water level caused slope instabilities along the lake. The proposed tilting sensors were installed at one of such sites (Fig. 16). The slope had been distorted already upon the installation.

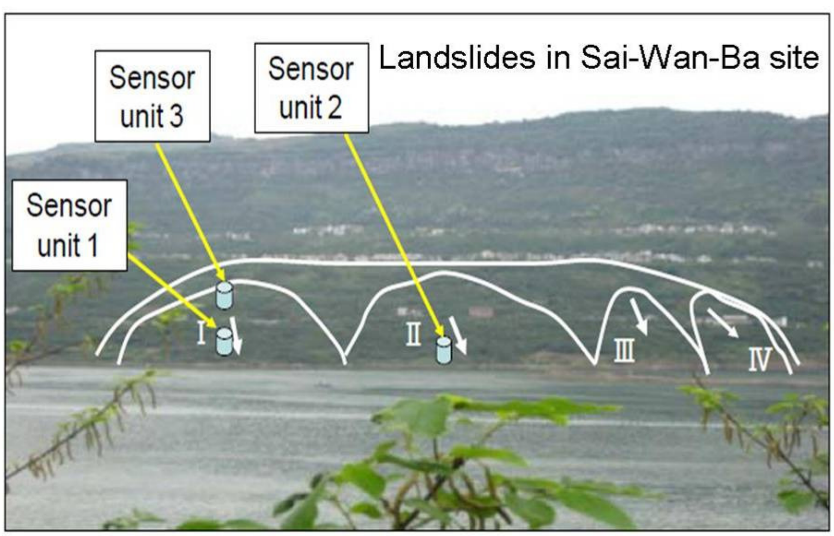

Fig. 16 Validation site at Three Gorge Dam Reservoir in China.

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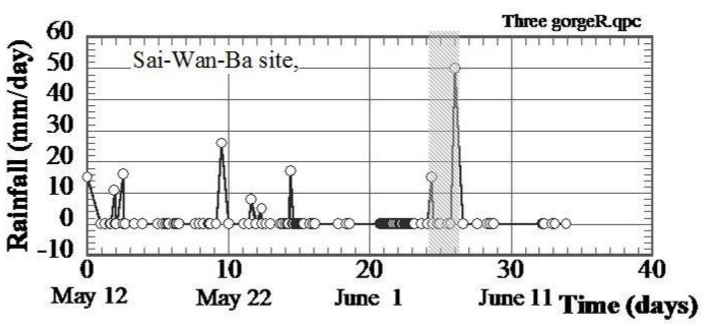
One of the monitored slopes failed on June 7th and 8th, 2009, during rain (Fig. 17). Fig. 18 shows the monitored records of tilting angles and precipitation. It is seen that the final failure (large angle) was preceded by minor rate of ground distortion. By comparing the recorded rate of tilting with the current proposal of threshold rates of tilting;

Caution if rate of tilting angle > 0.005 degree / hour, and
Alert / Evacuation if the rate > 0.1 degree / hour,

it is found that these warning thresholds are consistent with the records. However, it is thought that the threshold for the first caution is still subject to discussion.

Fig. 17 Failed slope at Three Gorge Dam Reservoir

(a) Rainfall records



(b) History of tilting angle

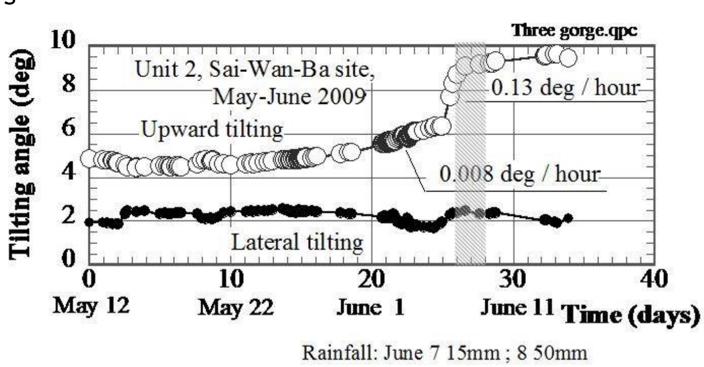


Fig. 18 Monitored records at the Three Gorge Dam Reservoir.

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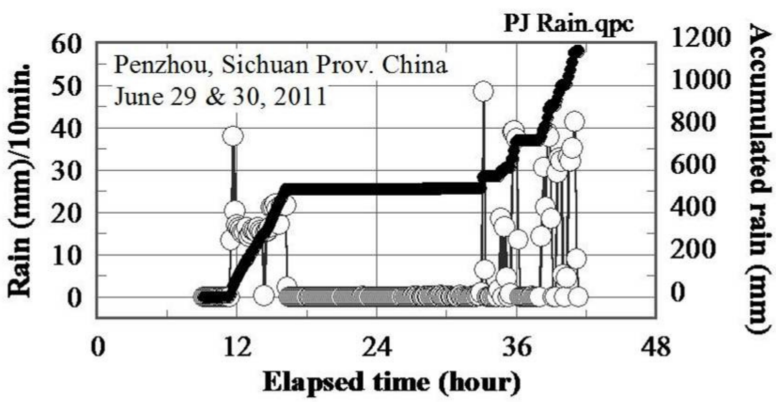
An artificial rainfall test was conducted in Sichuan Province of China in June 2011 in collaboration with the Chengdu Institute of Mountain Hazards and Environment. Fig. 19 illustrates the ongoing artificial rainfall, and finally an excavated trench face fell down (Fig. 20). The obtained record in Fig. 21 demonstrates that the rate of tilting angle is consistent with the proposed threshold as mentioned above.

Fig. 19 Artificial rainfall on slope in Sichuan Province, China.

Fig. 20 Rainfall-induced failure of a cut slope.

(a) Rainfall



(b) tilting angle

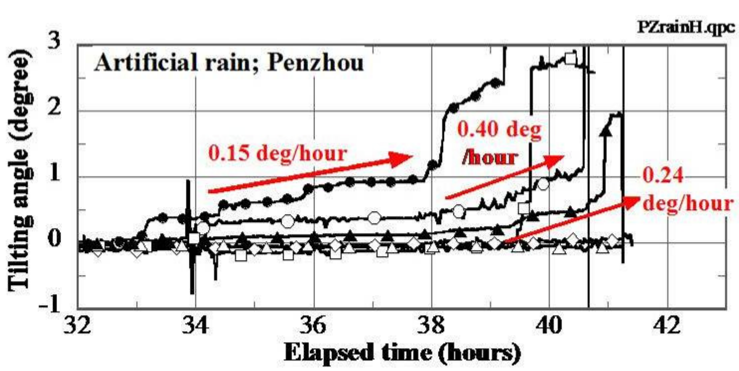


Fig. 21 Monitored records during artificial rainfall.

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To date, many early warning projects monitor only rainfall. The rainfall threshold to issue warning is relatively easy, but it relies on empirical correlations and may not be good enough for a particular slope subject to locally different slope angles and geology. In this regard, monitoring any movement directly is more promising and should be utilized in combination with the rainfall threshold.

Talk by Mitsu Okamura

Fig. 22 Retaining wall sliding down with road embankment.

An attempt was made to interpret the seismic stability of road embankments resting on sloping ground with retaining walls (Fig. 23). For pseudostatic calculation of stability, appropriate values of seismic coefficient were assessed by using an empirical correlation with the JMA scale of seismic intensity. The bearing capacity of a retaining wall was determined simply on the basis of cone penetration tests. As a consequence, Fig. 24 illustrates that the extent of damage is well correlated with the factor of safety greater than or less than unity. Thus, the use of seismic factor of safety with a CPT correlation of soil strength and pseudostatic seismic action is meaningful in evaluation of damage extent in the concerned type of structures.

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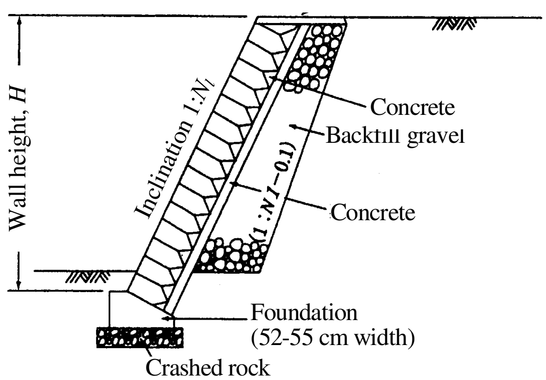

Fig. 23 Standard cross section of masonry retaining wall.

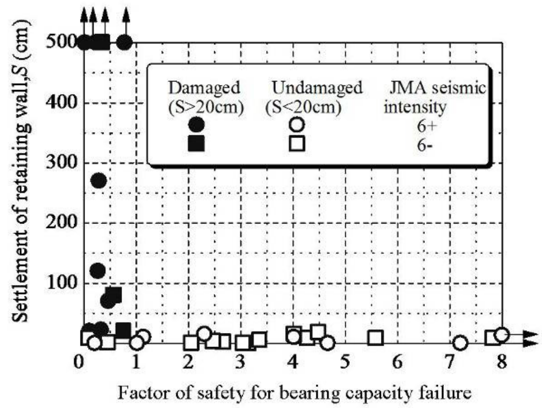

Fig. 24 Relationship between settlement of retaining wall and factor of safety.

Talk by Hirofumi Toyota

This talk addressed the observation of slope failures during natural disasters that occurred in the Chuetsu area of Niigata, Japan.

Many natural disasters, such as earthquakes, heavy rainfalls and snowfalls, occurred in the recent times in the Chuetsu region of Niigata, Japan, between 2004 and 2011. Slope failures during the time are summarized here and, in particular, the progress of the slope damage is examined, from the perspective of compound disasters. Further, the importance of local geology force and ground water condition is stressed as the reasons for the occurrence of numerous landslides during the 2004 Chuetsu Earthquake

Figure 25 illustrates a geological map of the severely damaged area during the Chuetsu Earthquake. More than 3,000 slope failures occurred during the earthquake. Although there had been many landslide-prone areas in the massive mudstone area, most slope failures during the earthquake occurred in the sandstone-dominated area despite that there had been only a small number of the landslide-designated slope therein.

Figure 26 shows the general behavior of ground water level in the concerned area. Ground water level was high at the time of the Chuetsu earthquake because of the typhoon rain a few days before. In general, groundwater level rises during the snow-melting season and suddenly drops after snow melting in May. Hence, landslides frequently occur in April and May. However, large mass movement did not occur significantly during the snow-melting season after the quake, probably because the seismically-affected slopes became stable after the quake and the seismically-induced deformation.

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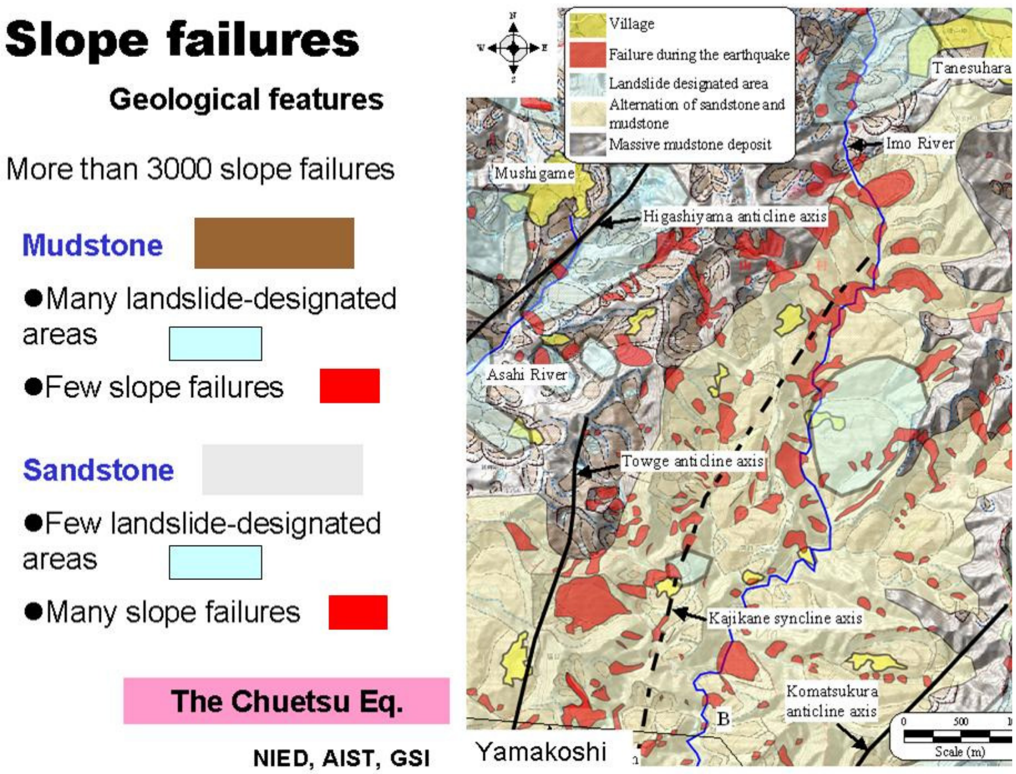

Fig. 25 Slope failures during the Chuetsu Earthquake on simplified geological map.

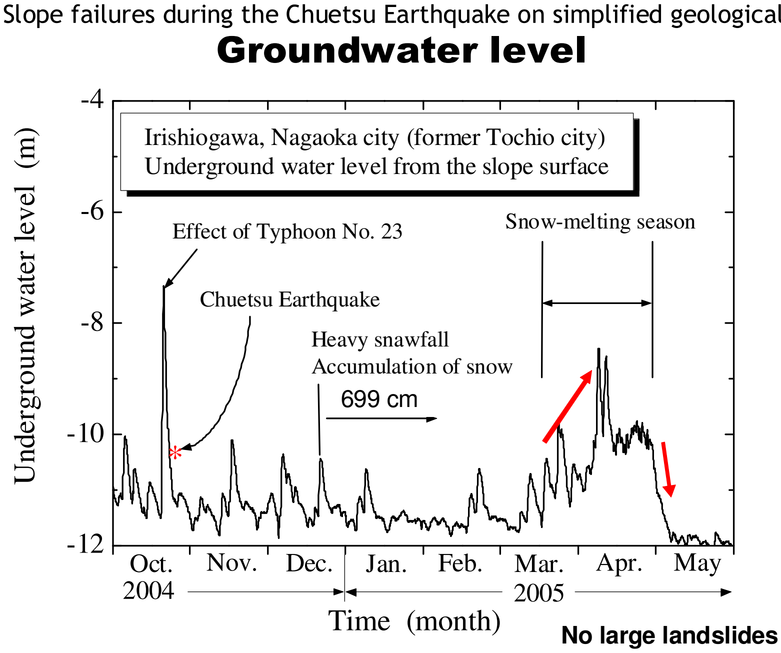

Fig. 26 Ground water level measured in an old landslide area.

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ACKNOWLEDGEMENT

The present ATC3 visit to Bhutan was made possible by contribution of Dr. Karma of DHI-Infra Ltd. and Mr. Samten Wangdi of DGM The development of tilting angle sensor has been made by Dr. T. Uchimura of University of Tokyo and Dr. Wang Lin of Chuo Kaihatsu Corporation. The field validation tests in China were conducted in collaboration with Prof. J.P. Qiao and his colleagues at the Chengdu Institute of Mountain Hazards and Environment, China. These efforts and contributions are deeply appreciated by the authors. Last but not least, after all technical works the authors visited a classic *dzong* (compound of religious and administrative institutes) in a local town of Wangdi Phodrang (Fig. 27). The well preserved building in this dzong was one of the highlights of the visit to Bhutan. It is desired that the good tradition of this country will last forever.

Fig. 27 Wangdi Phodrang Dzong.

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