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Geo-disaster Prediction and Geo-hazard Mapping in Urban and Surrounding Areas Progress Report in FY 2006

Masahiro CHIGIRA, Susumu IAI, Mamoru MIMURA, Toshitaka KAMAI, Roy, C. SIDLE, Hiroshi SUWA, Takashi SAITO and Tetsuo TOBITA

Synopsis

Urban development rapidly expanding from lowland to surrounding hills and mountains poses increasing risks in geo-hazards, including liquefaction during earthquakes, and failure of artificial and natural slopes. This paper summarizes the results of the study with respect to (1) the use of geotechnical data base for urban areas for assessing vulnerability to liquefaction hazards and identifying priority areas for improvement, (2) engineering-geological site evaluation methodology in a mountainous urban areas in developing countries, and (3) landslides induced by the construction of roads linking urban areas through mountainous areas.

Keywords: geo-disasters, hazard mapping, urban area, landslides, satellite town, road construction

1. Introduction

For the purpose of geo-disaster prediction and geo-hazard mapping in urban and surrounding areas, we studied on the development of geotechnical data base for the hazard assessment by liquefaction, engineering-geological site evaluation methodology of potential satellite towns in the earthquake-damaged town of Muzaffarabad, Pakistan, and landslide effects induced by a road construction in Yunnan, China.

2. Assessment of Liquefaction Based on the Geotechnical Database

2.1 Introduction

Geotechnical database plays a significant role to investigate the regional subsoil conditions prior to detailed investigation. Geo-Database Information Committee in Kansai has developed the geotechnical database in Kansai area (Kansai Branch of JSSMFE, 1992, Geo-Database Information Committee of Kansai, 1998, 2002). For the development of the database, urban area has been focused because of its social, economical importance. 38,000 boring data was collected and digitized. Furthermore, Research Committee on Ground in Osaka Bay (2002) has developed Geotechnical database for marine foundations in Osaka Bay with 4,200 borehole data. In this report, the Geo-databases for Kansai urban area, such as Osaka, Kobe and Kyoto are introduced. Cross-sectional view of the required underground can easily be drawn on PC together with various soil properties such as classification, gradation, the thickness of each layer, ground water level, NSPT values and so on. The regional geotechnical characteristics can easily be grasped by the distribution of those soil properties. As for the geotechnical disasters due to earthquake, liquefaction is one of the best known and symbolic. Then, the application of the Geo-database to assessment of liquefaction potential for urban areas has already effectively achieved (Geo-Database Information Committee of Kansai, 1998, 2002). The simplified procedure based on the NSPT values is used to evaluate the liquefaction potential for Kobe area and the calculated results has already been validated by comparing with the actual records of liquefaction occurrence due to the 1995 Hyogoken-Nambu Earthquake. In the present report, the usefulness of the Geo-database and its applicability to geotechnical engineering and disaster mitigation engineering are discussed by introducing the latest evaluation of liquefaction potential for Osaka Plain..

2.2 Kansai Geo-informatic Database

Kansai Geo-informatics Database (GIbase) is comprised of more than 38,000 borehole data of geotechnical investigation and has been developed by cooperation among industrial-government-academic organizations in Kansai region over the past two decades. Fig. 1 shows the historical developments of GIbase. As already stated above, many large cities such as Osaka and Kobe have been developed on the Osaka Plains and adjacent coastal area along Osaka Bay where soft grounds are widely spread. Then, the development of these coastal areas required careful site investigations with a large number of borehole data. Extensive investigations of the Osaka Bay seabed were necessary for the waterfront development, such as Kansai International Airport and Phoenix Project of landfill for waste disposals. The Research Committee on Seabed Deposit of Osaka Bay (1984 – 1991) was established by the Kansai Branch of Japanese Geotechnical Society. Then, it was succeeded to the Research Council of Geotechnical Information on Osaka Bay. Based on the research activities under this council "Geotechnical Information Databases in Osaka Bay area" was constructed as the marine database. On the other hand, the Research Committee on Utilizing of Underground Space was established in 1989, mainly for dealing with development of public infrastructures by utilizing deep underground spaces in Osaka, Kobe and Kyoto. It was succeeded to the Geo-Database Information Committee on Kansai. The research activities under this committee have produced "Geotechnical Information Database in Kansai Inland". These two databases were integrated into a single system in 2003, controlled by the Council of Kansai Geo-informatics and then the council has reorganized to form the Kansai Geo-informatics Network (KG-NET).

Kansai Geo-informatics Database (GIbase) was constructed by using Database for Information of Ground (DIG) system that was originally developed by Geo-Research Institute (Yamamoto et al., 1989, Iwasaki et al., 1980). The system used for DIG was constructed with a core management system assembling the boring data with its inherent format by extending the concept of relational database. It is composed of the following four functions:

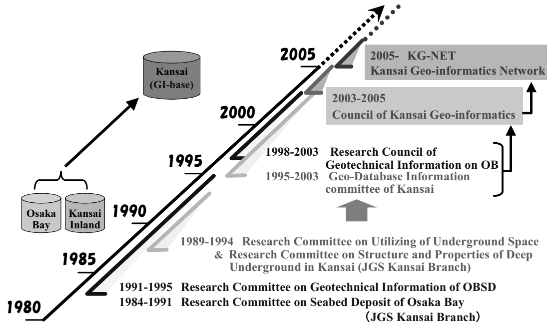


Fig. 1 History of development of GIbase

(1) Function of total control (Host DB)
(2) Function of data input control (local DB)
(3) Function of data extraction and processing (AP)
(4) Function of data addition (Layer DB)

The main operation system is controlled by UNIX whereas the local DB is controlled by WINDOWS. For personal use, the WINDOWS version is provided for data extraction and processing (AP). By utilizing these functions, GDS stores the borehole investigation data of strata identification, SPT N-value, gradation test result etc. These data are utilized for prediction of liquefaction in sandy deposits during earthquake. Table 1 shows the input data and data structure of DIG. In addition to GDS, the information related to active faults and micro-topography is also stored by Geographical Information System (GIS).

The necessary handling functions to control the Geo-informatics database, DIG consists of five components, such as reference, extraction, processing, analysis and display. The fundamental functions of DIG are as follows:

(1) Indicating the location of each boring on the map and selecting the optional ones using mouse operation
(2) Referring the boring on optional condition
(3) Creating cross-sectional view of the ground by processing the selected borings
(4) Creating a summary table for soil properties and experimental results
(5) Processing experimental data and display the distribution chart, correlation chart etc.

2.3 Adopted Procedure to Assess Liquefaction

Liquefaction has been highlighted since serious disaster induced by liquefaction occurred at Niigata Earthquake and Alaska Earthquake in 1964. A number of procedures for assessing liquefaction have been proposed and updated on the basis of the records of liquefaction by earthquakes taking place one after another. Laboratory tests such as undrained cyclic triaxial tests on reconstituted sand specimen have played significant roles for those studies on liquefaction. It is true that the experimental approach is important to know the mechanism of liquefaction, but the results from laboratory tests often have not provided a reasonable solution for the actual liquefaction disaster because liquefaction in the field is definitely the boundary value problem far from the laboratory conditions.

In the practical sense, the regional distribution of hazardous area against liquefaction due to earthquake can provide very important and useful information for disaster mitigation. For this purpose, geo-database can function efficiently. Here, simplified procedure assessing liquefaction potential is introduced and applied to evaluate the regional liquefaction potential based on the Geo-database. The calculated performance is validated by comparing with the actual records of liquefaction occurrence in Kobe area during 1995 Hyogoken-Nambu Earthquake. Then the predicted performance is also shown for Kyoto Basin.

The simplified procedure assessing liquefaction potential used in the present paper is a so-called F_L method specified in the "Specifications for highway bridges" by Japan Road Association (2002). This method has commonly used in Japan for designing the foundations. First, the safety factor against liquefaction, F_L is defined as follows:

$$F_L = R/L \tag{1}$$

Here, R denotes a liquefaction resistance and calculated by $R = c_w \cdot R_L$. The parameter, c_w is a correction factor depending on the type of earthquake. R_L is a cyclic stress ratio defining liquefaction in the laboratory. This parameter is usually derived from N_{SPT} values from standard penetration test (SPT) because it is not so common to carry out the undrained triaxial cyclic test on good quality sand samples. SPT is a simple and economical method to know the resistance of the foundation ground in the field, and commonly carried out for subsoil investigation. Naturally the Geo-database has the data of N_{SPT} profiles for almost all boring logs. Therefore, it is advantageous to introduce the present procedure for liquefaction assessment based on the N_{SPT} values. R_L can be calculated by the following equations:

$$\mathbf{R_L} = \begin{cases} 0.0082 \cdot \sqrt{\mathbf{N_a}/1.7} \cdots\cdots\cdots\cdots (\mathbf{N_a} < 14) \\ 0.0082 \cdot \sqrt{\mathbf{N_a}/1.7} + 1.6 \times 10^{-6} \cdot (\mathbf{N_a} - 14)^{4.5} \\ \cdots\cdots\cdots\cdots\cdots\cdots (\mathbf{N_a} \geq 14) \end{cases} \tag{2}$$

Here, N_a is a corrected N_{SPT} value in terms of the effect of fine components and expressed as follows:

$$\mathbf{N_a} = \mathbf{c}_1 \cdot \mathbf{N}_1 + \mathbf{c}_2 \qquad \text{(for sand)} \tag{3}$$

$$\mathbf{N_a} = [1 - 0.36 \log_{10}(\mathbf{D}_{50}/2)] \cdot \mathbf{N}_1 \qquad \text{(for gravel)} \tag{4}$$

Here, N_1 is a corrected N_{SPT} value in terms of confining stress. As is easily known, N_a can be calculated with mean particle size, D_{50} (in mm) and N_1 whereas more effect of fine components should be taken into account for sand with the correction coefficients c_1 and c_2. The coefficients c_1 and c_2 are assumed as follows:

$$\mathbf{c}_1 = \begin{cases} 1 \cdots\cdots\cdots (0\% \leq \mathbf{FC} \leq 10\%) \\ (\mathbf{FC} + 40)/50 \cdots (10\% \leq \mathbf{FC} \leq 60\%) \\ \mathbf{FC}/20 - 1 \cdots\cdots (60\% \leq \mathbf{FC}) \end{cases} \tag{5}$$

$$\mathbf{c}_2 = \begin{cases} 0 \cdots\cdots (0\% \leq \mathbf{FC} \leq 10\%) \\ (\mathbf{FC} - 10)/18 \cdots (10\% \leq \mathbf{FC}) \end{cases} \tag{6}$$

Here FC denotes fine components less than 74μm of diameter included in sand. As stated here, the liquefaction resistance, R_L can be derived from N_{SPT} values.

The parameter, L denotes shear stress ratio mobilized in the ground during an earthquake and is expressed in the following form:

$$\mathbf{L} = \mathbf{r_d} \cdot \mathbf{c_z} \cdot \mathbf{k_{hG}} \cdot \frac{\sigma_v}{\sigma'_v} \tag{7}$$

Here, σ_v and σ'_v are total and effective overburden stresses in kgf/cm^2, c_z is a regional correction factor (c_z = 1.0 for Osaka, Kobe and Kyoto) that is determined on the basis of the probability of earthquake occurrence, k_{hG} is a horizontal seismic coefficient at the ground surface. The parameter, r_d is a reduction factor of the shear stress ratio during an earthquake in the vertical direction to consider the non-rigid response of the ground and expressed as follows:

$$\mathbf{r_d} = 1.0 - 0.015 \cdot \mathbf{z} \tag{8}$$

Here, z denotes a depth from the ground surface. A soil layer with F_L value larger than 1.0 is considered to be non-liquefiable while liquefaction potentially takes place in the case of $\mathbf{F_L} \leq 1.0$. It is true that F_L denotes the safety factor at a certain depth but the integrated safety factor, P_L (Fig. 2) is considered to represent the liquefaction of mass foundation, which directly induces serious geotechnical disaster. In the sense, P_L has been selected as the index for assessing liquefaction potential of regional ground in this paper. The integrated safety factor, P_L against liquefaction is defined as follows (Iwasaki et al., 1980):

$$\mathbf{P_L} = \int_0^{20} \mathbf{F_L} \cdot \mathbf{w(z)dz} \tag{9}$$

Here, w is a weighting function in terms of depth. Values of F_L are determined to be zero for $\mathbf{F_L} \geq 1.0$ whereas 1- F_L for F_L <1.0.

2.4 Calculated performance for Osaka Plain

The distribution of the critical accelerations for Osaka Plain is shown in Fig. 3 (1) by the near fault earthquake and (2) for the subduction zone earthquake respectively. In both figures, seriously fragile area coincides with the heart of Osaka metropolitan zone. The lowlands along Yodo River as well as the reclaimed coastal area also cannot resist against liquefaction. The main reasons for those results consist in the facts that they have thick weak sandy deposits on the very thick sediments together with high groundwater tables. As the impact of the earthquake intensity by the near fault earthquake is stronger, the induced hazard by the liquefaction is more serious compared to the subduction zone earthquake with much more huge magnitude. However, another factor of duration of tremor should be considered for the subduction zone earthquake. The seismic wave with a long period is expected to propagate and keep on hitting the Osaka Plain in the case of the subduction zone earthquake, such as Tonankai/Nankai Earthquake. In summary, the level of acceleration expected on the

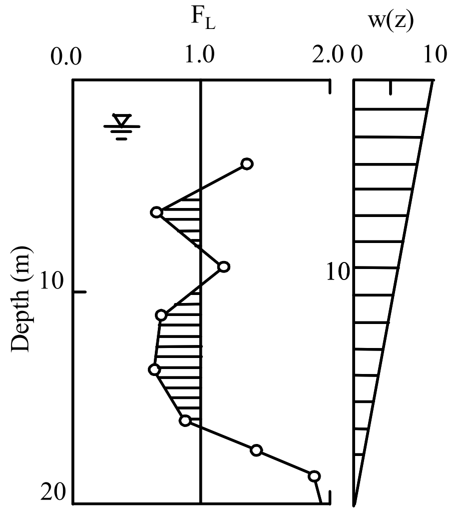
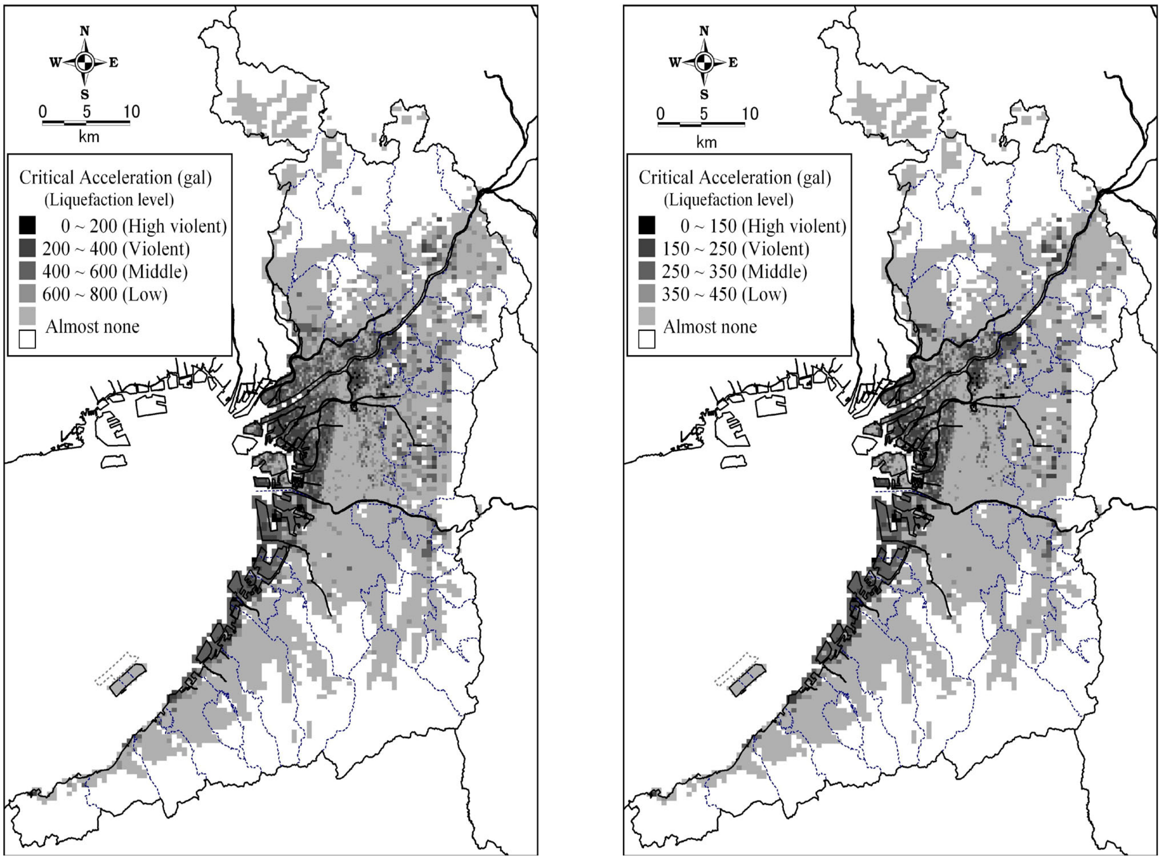


Fig. 2 Derivation of the Integrated Safety factor, P_L for Occurrence of Liquefaction

Osaka Plain by the subduction zone earthquake is not so severe, but the tremor continues for a long time. Here, the question arises; "Does the present evaluation with the simplified procedure based on the acceleration function well?" The contribution of the long duration of tremor with relatively low acceleration to the occurrence of liquefaction could be an issue.

2.5 Summary

The GIbase is utilized for the research of local foundations in Kansai, the primary information to construction projects and political assessment of disaster mitigation etc. As a typical example, the application to the assessment of liquefaction is explained in the present paper. Huge number of boring data is required to assess the liquefaction potential for metropolitan area, such as Kobe or Osaka, to cover the whole widely spread area. In the case, the GIbase can easily provide the necessary geological and geotechnical information which are directly connected to the various procedures to evaluate liquefaction and the induced geo-disasters. The simplified procedure to evaluate the liquefaction potential was applied to Kobe and the adjacent area and validated by comparing with the actual records of



(1) Near fault earthquake (2) Subduction zone earthquake

Fig. 3 Distribution of the critical accelerations that induces liquefaction in Osaka Plain

liquefaction occurrence. The result has been regarded as a milestone of the procedure. It is also applied to Osaka Plain. Here, the expected earthquakes are assumed to occur and the scenario earthquake induced forces are calculated based on the knowledge of seismology and earthquake engineering. The simplified method provided the local fragility for liquefaction in terms of "critical acceleration" to derive PL values of 15 that coincides with the occurrence of serious liquefaction induced disasters.

3. Engineering-geological site evaluation methodology of potential satellite towns in a mountainous urban areas in developing countries

On Saturday October 8, 2005, a large earthquake with a magnitude of Mw7.6 hit the northern Pakistan area, where the capital of Kashmir, Muzaffarabad with a population of 800,000, was heavily damaged. The local government of AJK started safety evaluation of potential satellite towns of Muzaffarabad. Chigira made a field survey for this purpose and proposed a feasible methodology for the evaluation under the project of JICA (Japan International Cooperation Agency). For the evaluation in developing countries neither without detailed maps nor with aerial photographs, satellite images are powerful tools. We successfully used images by the satellite IKONOS with a resolution of 1 m, and also made maps with scales of 1:10,000 and 1:25,000 from these images.

Most important issues to be concerned were extracted as debris flows, failures of steep terrace scarps, landslide on nearby slopes, and relative elevation of lower terraces from the nearby river. These issues are commonly expected in mountainous urban areas.

3.1 Outline of the geology and geomorphology

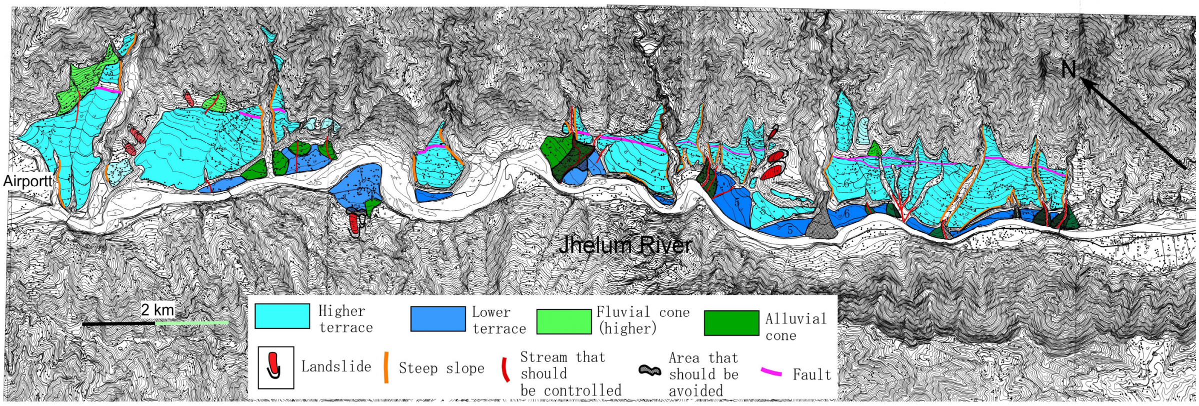


Fig. 4 Locations of the candidate sites for new satellite towns (number 1 to 7). Legends are the same with those in the following figures. Contour interval is 10

The areas of potential satellite towns shown in Fig. 4 are underlain by the Miocene Murree Formation consisting of alternating beds of sandstone and mudstone as bedrock, which is covered by Quaternary terrace and fluvial cone deposits. Along the Jhelum River are developed river terraces particularly on its right bank; widely developed terraces are higher and lower terraces as shown in Fig. 4. The higher terraces are 50 to 100 m high above the Jhelum River and the lower terraces are several to 30 m high above the Jhelum. The lowermost terrace is thus close to the river in elevation. Along with the terraces are fluvial cones; some are along the upper peripheries of higher terraces and some are on lower terraces with current riverbeds on them. The higher terraces have steep terrace scarps, some of which were steepened by slope failures during the earthquake. We observe many landslide bodies on slopes in the surrounding areas and some landslides are near candidate sites as is seen in Fig. 4.

3.2 Hazards to be assessed

Debris flows

Debris flow activity is determined from the morphology of fluvial cones, which could be identified by using IKONOS images and field survey. Most of the candidate sites were located on a higher or lower terrace and fluvial cones were developed. Some sites involved fluvial cone with high debris flow activity, which should

Fig. 5 Slope failures on the terrace scarp of site 7. The depositional area can be divided into three zones by the density of debris: massive area, densely scattered area, and sparsely scattered area The inclination of the lines connecting these edges and the top of the source area could be used to delineate safety zones

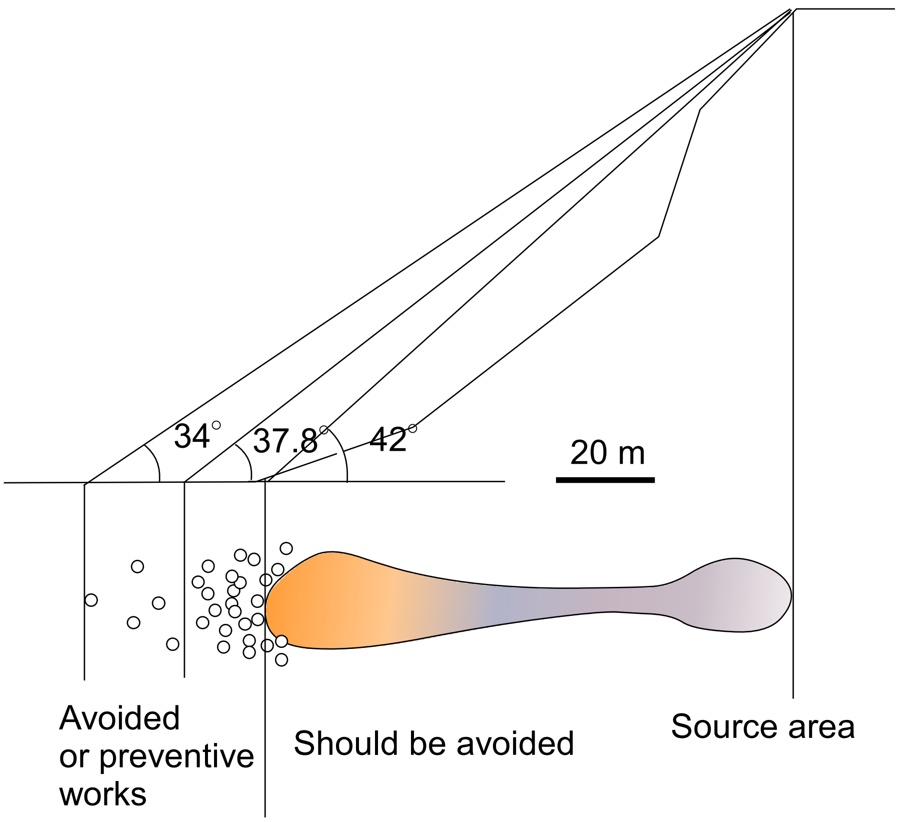


Fig. 6 Cross section along the source and depositional areas of a slope failure at an edge of a steep terrace scarp at site 7

be avoided rather than constructing costly construction works.

Failures of steep terrace scarps

Terraces commonly accompany steep terrace scarps, where slope failures are likely to occur. We cannot predict potential site of this kind of a failure, so making some criteria to set a safety area from the failure of the scarp is proposed. One option is to take account of angles to the edge of a terrace scarp. When we observe the deposits by this type of failure, we can divide the depositional area into three: areas of massive debris, densely scattered debris, and sparsely scattered debris (Fig. 5). Figure 6 is a cross section showing this idea. Forty two degrees was an angle connecting the edges of the scarp and the massive debris area in this case. Massive debris areas should be avoided but other areas may be protected by some kind of walls or nets. Collecting this kind of data would be helpful to set some criteria for safety.

Distance from the edge of a terrace surface

Careful examination should be made whether cracks are made or not near the edges of the terraces, when higher terraces surrounded by steep terrace scarps. For the safety, it is recommended to take some distance, security fringe, from the edges of the terraces. This distance could be determined by the stable inclination (maybe around 40˚) of the scarps. Figure 7 shows an idea to set a security fringe from the edge of a terrace above a steep scarp. Draw a line with an inclination of long-term stable terrace scarp from the foot of a steep scarp and obtain an intersection point with the terrace surface. The area between the terrace edge to the intersection could be a security fringe.

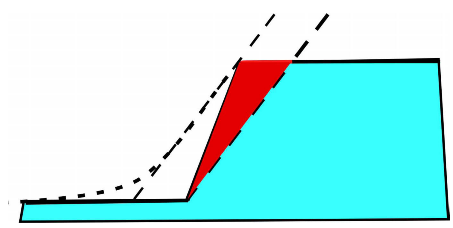


Fig. 7 Schematic sketch for the setting of security fringe

Landslides on nearby slopes

When using an area, which is close to nearby landslides, it is recommended to take some clearance from the toe of the landslide. Activity of landslide should also be estimated by using criteria, such as cracks, tilted trees, water conditions, and so on.

4. Landslides from mountain roads linking urban and residential areas, Yunnan, China

4.1 Introduction

Mountain roads produce the most sediment per unit area impacted of all widespread land uses; however, these impacts are not widely recognized or accepted by many government agencies, environmental groups, and international organizations (Sidle and Ochiai, 2006). In developing countries of Southeast and East Asia, poorly planned and constructed mountain roads contribute to widespread sedimentation in streams and rivers and frequently cause casualties and property damage (e.g., Haigh, 1984; Sidle et al., 2006). Secondary roads are particularly problematic due to the lack of attention to construction and maintenance. Even in Japan, which arguably invests the greatest amount of resources in structural erosion control along road corridors, road-related landslide disasters still occur.

Roads excavated into mountainsides cause landslides by: (1) undercutting steep slopes, thus removing support; (2) overloading and oversteepening fillslopes, including within the road prism; and (3) altering natural hydrologic pathways and concentrating water onto unstable portions of the lower hillslope (Sidle and Ochiai, 2006). Additionally, roads intercept subsurface flow from cutslopes during storms and concentrate overland flow on their compacted or paved surfaces. This water is then discharged downslope at concentrated drainage points where it may cause extensive surface erosion and even channel headcutting (Sidle et al., 2004). Road and drainage design, road construction practices, and particularly road location can ameliorate these impacts; however, any road cut into a steep hillslope will exert some destabilizing affect.

Particular landslide and erosion problems from mountain roads are apparent in developing countries of Asia where road systems are rapidly expanding due to presumed needs for economic and social development, national defense, increasing tourism, and linking towns and urban areas (Haigh, 1984; Sidle and Ochiai, 2006). Here we present some of the first comprehensive road erosion/landslide information for the rapidly developing region of northern Yunnan Province, China, along the new Weixi – Shangri-La road.

4.2 Study area and methods

The new road was constructed in 2002 through steep mountains along the headwaters of the Mekong River to expedite travel to Weixi in northwestern Yunnan Province, China. The 28 km road was blasted into weathered igneous rocks along the steep mountainsides, exposing cutslopes up to 80 m high and depositing the waste rock and soil onto the oversteepened fillslopes. Due to the uniformly steep gradients below the road, much of the landslide sediment resulting from this road construction deposited directly into the Mekong tributary or its riparian area. During construction it appears that little or no action was taken to control blasting and virtually no attention was paid to road location and erosion control. In summer 2006, six people traveling down this portion of the Weixi – Shangri-La road in a minivan were killed by a landslide originating from a steep cutslope that was blasted into the mountainside.

To assess landslide erosion along this road, a 23.5 km segment of the road was categorized as moderately severe, severe, or very severe, and a representative 0.75 to 0.90 km stretch of road in each group was then surveyed in detail for landslide erosion. Dimensions of all landslides were measured in each surveyed section and converted to mass using the bulk density of the soil and rock materials (1.73 g $cm^{-3)}$. Dry ravel erosion was significant on exposed cut and fill slopes and estimated as follows based on data collected in Japan: 20 m^3 ha^{-1} yr^{-1} on the steepest slopes (> 40°), half of this value (10 m3 ha^{-1} yr^{-1}) on slope gradients from 30 to 40°, and no ravel was assumed on slopes < 30°.

4.3 Results of the landslide inventory

Slightly more landslides were inventoried along cutslopes compared to fillslopes, but the rate of landslide sediment production from fillslopes was about 17 and 100-times higher than rates from fillslopes for the severe and very severe erosion sections, respectively (Fig. 8). In the very severe landslide category, five large landslides were measured (> 10,000 m^3); these comprised the bulk of the landslide erosion in this category. The smaller cutslope failures were often trapped on the road surface, while the fillslope failures typically traveled directly down the steep hillside and impacted the Mekong River tributary. Dry ravel erosion, while significant, was typically several orders of magnitude lower than road-related landslides (Fig. 8). Landslide sediment produced from landslides along this road connecting the town of Weixi exceeds values reported from forest roads in highly unstable mountainous terrain of western North America by more than 175-fold; for the most unstable part of this road these differences were greater than 600-fold (Sidle and Ochiai, 2006). As such, these are the highest rates of landslide erosion ever reported along roads.

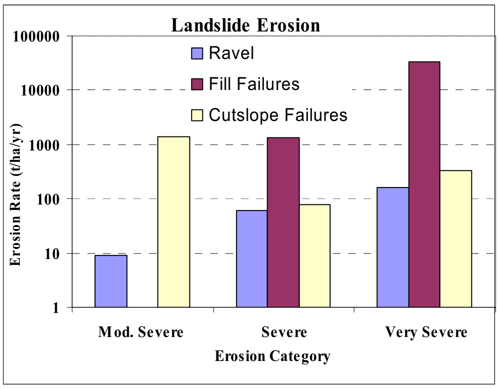


Fig. 8 Landslide erosion rate

Acknowledgments

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都市および周辺地域における地盤災害予測とハザードマッピングに関する研究
平成18年度報告

千木良雅弘・井合　進・三村　衛・釜井俊孝・Sidle，R.C.
諏訪　浩・斉藤隆志・飛田哲男

要旨

低平地を中心として急速に周辺丘陵地へと拡大する都市域では，地震時液状化，宅地造成地盤崩壊，人工・自然斜面崩壊など，地盤災害の危険性が増している。本論文では，平成１８年度のとりまとめとして，都市域の地盤情報データベースの地盤ハザード評価への適用，発展途上国の山間地大都市近郊におけるサテライトタウンの地盤災害評価手法，道路建設に伴う土砂流出評価についてとりまとめた。

キーワード: 地盤災害，ハザードマッピング，都市域，崩壊，サテライトタウン，道路建設