GEOTECHNICAL ISSUES CAUSED BY THE MAY 12th 2008, WENCHUAN EARTHQUAKE, CHINA

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ABSTRACT: A devastating earthquake occurred in Longmen-Shan Mountainous terrain, Chendu, China on May 12, 2008. With the Grants-in-Aid for Scientific Research, Ministry of Education, Culture, Sports, Science and Technology, Japan, and the network of Japanese experts in the field of seismology, geology and earthquake engineering planed to organize a team (Leader: K. Konagai, the first author) asking collaboration from Chinese organizations and experts with the China Earthquake Administration (CEA) as its core, with the support from Ministry of Science and Technology of China. This report describes briefly findings obtained through the authors' reconnaissance, highlighting some geotechnical issues for better rehabilitations.

Key Words: Wenchuan Earthquake, geotechnical issues, rehabilitations

INTRODUCTION

An earthquake of magnitude 7.9 struck northwestern Sichuan province of China. Chinese Ministry of Civil Affairs stated that 69,197 were confirmed dead, and 18,222 listed as missing as of May 21st. This earthquake was remarkable in terms of length of activated fault in which a 280km long fault dislocation, a thrust formation appearing along the toe of steep ranges of Longmenshan Mountains, which was one of the longest fault offsets ever to appear inland. With this long fault in mountains, there is a serious concern that huge amount of debris deposits have been created in the zone along the fault stretch. In fact, a number of bare slopes were found exposed on satellite photographs including the world largest landslide with an area of about 50,000m^2 (Chigira et al., 2008). Large earthquakes that hit mountainous terrains often cause long-lasting problems of frequent debris flows. In Hietsu Earthquake, Japan (1858), a huge landslide mass of about 400 million m^3 blocked the upper reach of Joganji River. It was estimated that debris flow as a result of failure of this landslide mass would have raised the level of Toyama plane, along lower reach of Joganji River, by about 1 to 2 meters. To control the debris mass flow, a number of check dams have been constructed so far and the current annual expenditure for debris flow control for Joganji River system reached 5 billion JPY. The October 8, 2005 Kashmir Earthquake, Pakistan is another case history. The earthquake induced slope failures created debris sources along the steep slopes. During monsoon of 2006, about 10 months after the earthquake, a debris flow occurred at Ghari Habibullah Khan leaving about 4 to 6 meters thick debris deposits at the exit of a canyon onto a flat plain along Kunhar River. Even within the city of Muzaffarabad, people living along valleys scratching terraces are suffering from debris from mountains rising behind, with their dwellings being half and/or entirely buried in debris. Future flows will most likely follow the gorges crossing roads and will suspend traffic. Clearing the debris

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remaining on the roads would be just a stopgap. One of the feasible ideas discussed among Japanese and Pakistani experts was to connect existing roads point-wise by constructing new bridges etc. A cost-effective bypass could be constructed allowing bi-directional traffic to be realized. Experiences are now being shared among these experts.

After the 2008 devastating Wenchuan Earthquake in Sichuan Province, international academic societies expressed great deal of condolences and showed great concerns to the related scientific issues. With the Grants-in-Aid for Scientific Research, Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT hereafter) and the network of Japanese experts in the field of seismology, geology and earthquake engineering planed to organize a team (Leader: K. Konagai, the first author) asking collaboration from Chinese organizations and experts with the China Earthquake Administration (CEA) as its core, with the support from Ministry of Science and Technology of China. Japanese nominees and experts from CEA have come to a firm common understanding that China-Japan joint investigation will contribute remarkably in learning lessons from the tragic devastations in a scientific manner and therefore in quick and rational rehabilitations.

Total seven sub-groups were organized to cover 7 subjects, respectively. They include (1) slope failures and remedial measures, (2) civil infrastructures and remedial measures, (3) houses and buildings, (4) seismology, (5) active fault, (6) geodesy and (7) rescue, restoration and economic damages. They have made total 20 reconnaissance trips. This report shows some findings from the authors' quick two-days survey (July 27-30, 2008). More details will appear in the MEXT final report.

BEICHUAN AREA

Slope failures

Beichuan is a county under the jurisdiction of Mianyang Municipality in Sichuan province. This town was most seriously damaged by the earthquake and was under strict security conditions being completely separated with a fence by the Chinese army. Fig. 1 shows the route for the authors' survey (July 27^{th}) and locations of photos. Photo 1, the view of the downtown after the earthquake, was taken through the fence at the northern end of the route (31°49'09.7"N, 104°27'05.7"E presumed location from Google map). Some findings and/or indications from these photos are:

(1) The shake must have been intense enough to destroy many houses and buildings to be sure, but two major slope failures on both sides of the city have certainly caused fatal and wide-spread damage to built-up downtown areas of the city.

(2) The western slip surface is about 300 m high, and dips about 35 degrees east-northeast. The landslide mass from this west slope was about 400 m wide and surged about 430m of downtown area. The landslide reached its maximum thickness near its distal end because of being slowed down as it traveled further onto the built-up area. The total volume of the soil mass was estimated to be about 5,200,000 m^3 presuming its average thickness as 30 m.

(3) The eastern slip surface was about 300 m high, and dips about 40 degrees northwest. The landslide mass was about 400m long, 400 m wide and 20m thick. The volume of the landslide mass was presumably 3,200,000 m^3. The landslide mass included much larger rocks than those in the mass from the west slope.

(4) There are some dolomite rocks exposed along the eastern mountain slopes. Solubility of dolomite allows water to seep easily through its cracks and water enlarges the cracks in such a way that cavity systems are formed in its interior. Dolomite rocks are often weak enough and eventually break into pieces.

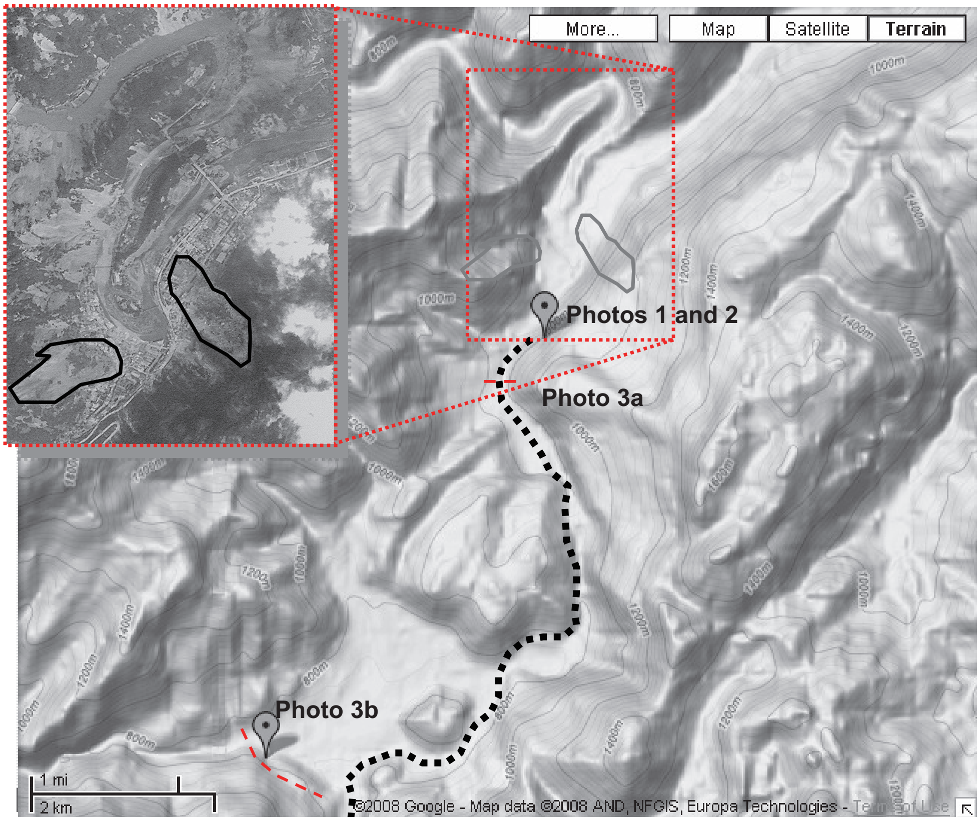
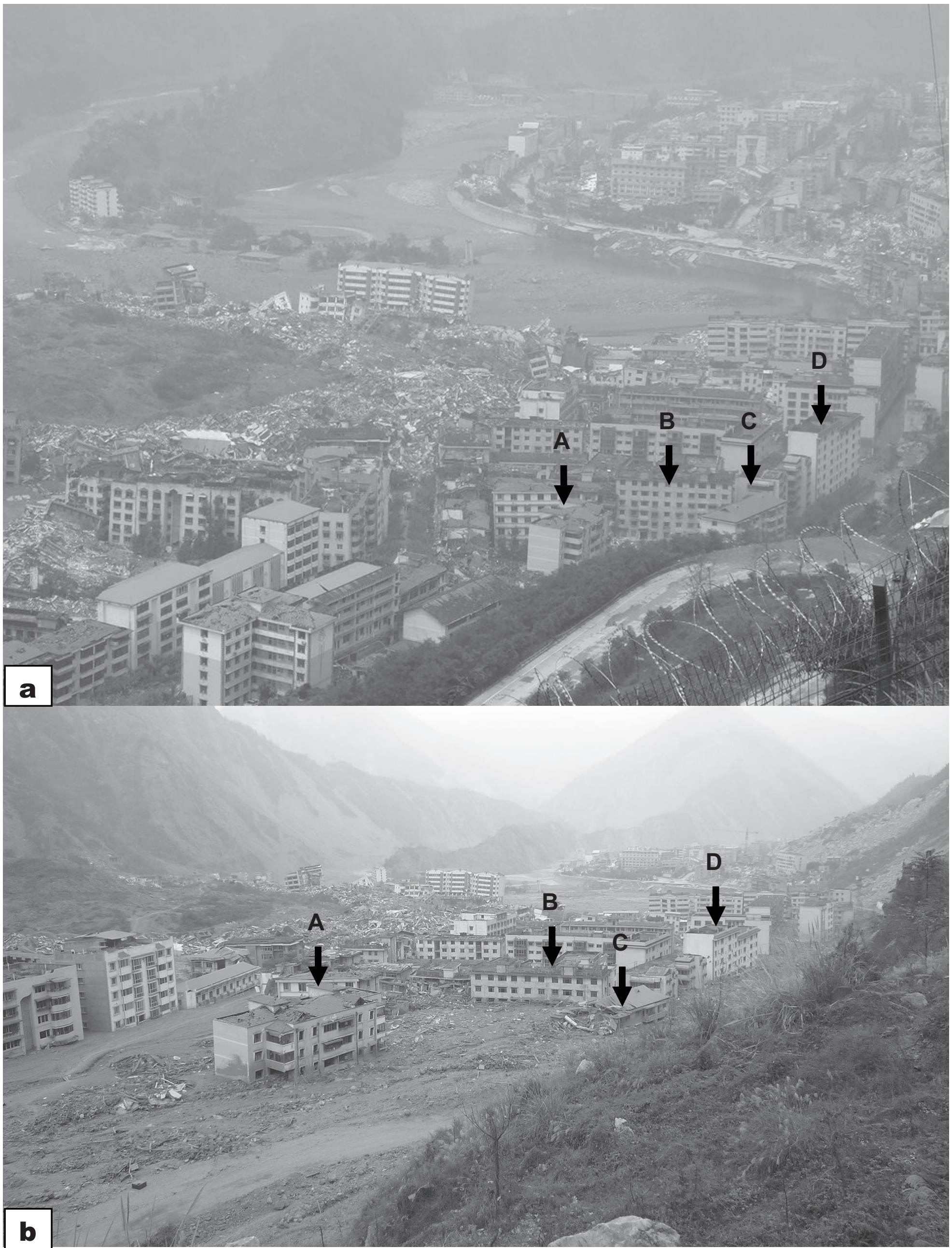


Fig. 1. Beichuan and its vicinity: Thick broken line shows the route for the authors' survey.

Photo 1. Downtown of Beichuan County. Two major built-up areas were completely destroyed by two major slope failures.



Photos 2a and 2b. South built-up area of Beichuan County. Photo 2a was taken on July 27th, 2008 while Photo 2b shows the same area in December, 2008, buried beneath thick debris mass. (Photo 2b by Maki, N., DPRI, Kyoto University)

At later date, on September 24th, it was reported that two-day heavy rain at Beichuan county triggered debris flow and larger parts of the southern half of the city was buried. As a consequence, the plan to preserve quake-devastated Beichuan as an earthquake museum was put on hold. Photo 2b (by Maki, N.) shows the debris mass remaining in the southern part of the city. Comparing Photos 2a and 2b, the debris mass which have been carried over the three months (September, 2008 to December, 2008) is estimated to be about 10 to 12 m thick at this location.

Fault ruptures

Fault ruptures appeared in Beichuan and its vicinity. Densmore et al. (2007) described the detailed geomorphologic features of the terrains along the Longmen-Shan fault (see Fig. 2). One of the observed rupture (Point A in Fig. 2) appeared almost on this recognized fault trace, while the other (Point B in Fig. 2) appeared off the trace. As is often the case, the thrust faults seem to make up a wide brush, which extend across the central areas of Beichuan. Some serious devastations and landslides may have been due to fault offsets. To have a clear perspective on how the area should be rehabilitated, fault traces are to be precisely mapped.

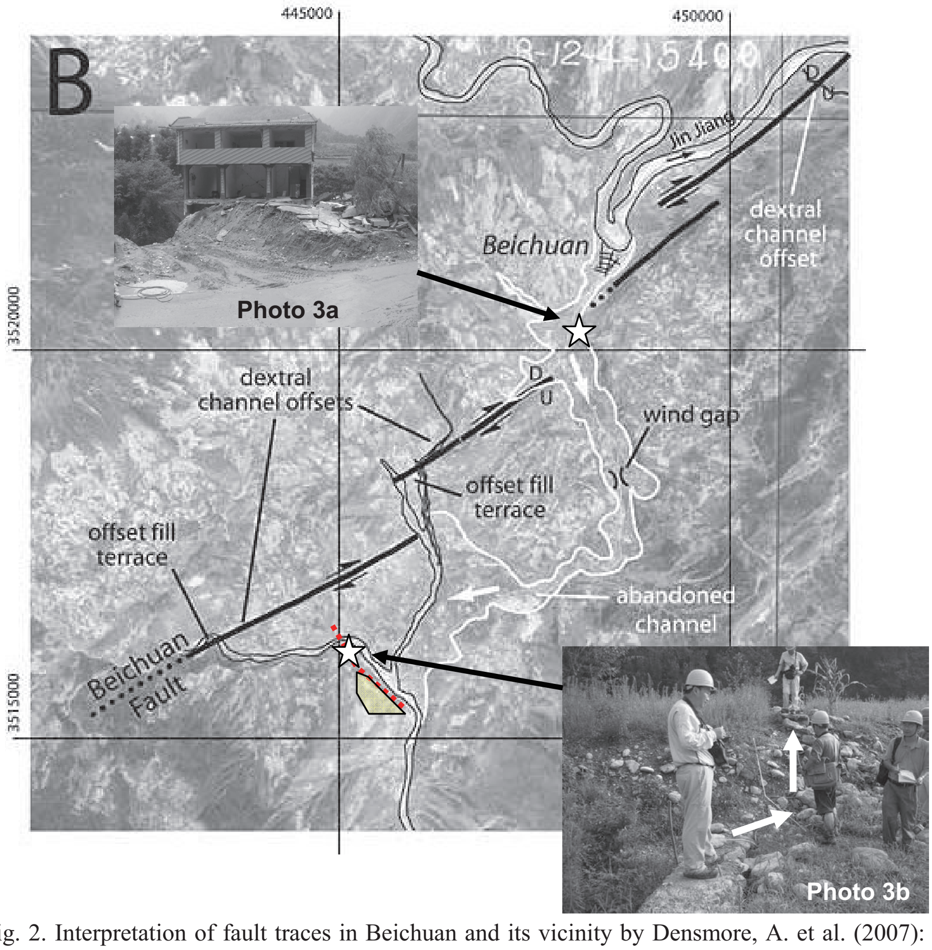


Fig. 2. Interpretation of fault traces in Beichuan and its vicinity by Densmore, A. et al. (2007): Thick lines show interpreted fault traces. Thin white lines show margins of abandoned channel of the Jin Jiang; white arrows show inferred flow direction. The Jin Jiang is now diverted at Beichuan and flows northeast, parallel to the Beichuan fault.

QINGCHUAN AREA

Being located near the northern end of recognized fault rupture, Qingchuan County has continuous aftershocks of high magnitude since the Wenchuan Earthquake. The shake there must have been responsible for a number of landslides and debris mass flows including the following two stopping flows of TongHe River and its tributaries. A large debris flow occurred on a mountain slope at TongHeKuo (Fig. 3 and Photo 4). The source area was about 400 m higher than the photo-shooting location. The debris mass rushed down the gully and surged up the hill, where the photo 4 was taken. After making a turn over the hill, it went down about 2km along the main stream of the TongHe River. The debris mass was reportedly responsible for the loss of about 400 people at TongHeKuo village. The mass stopped flows of both TongHe river and its tributary (Photo 4). Judging from the marks of maximum water level and from the estimated present water depths, the debris mass was estimated to be about 20 m at the merging section of TongHe River and the tributary. The flow has left an S-shaped trace along the valley and segregation was clearly observed. One more example is about 4km upstream side of the TongHe village (Photo 5). The landslide mass was responsible for complete destruction of four villages and about 400 lives were reportedly lost in the landslide mass. The maximum depth of the stopped water was estimated to be 25m. However, it was lowered to 10m after constructing an emergent spill way. The valley area between these two landslide masses has been called "ShiBan-Gou" (Slate-Valley in English). A lot of weathered slates were exposed on both sides of the valley.

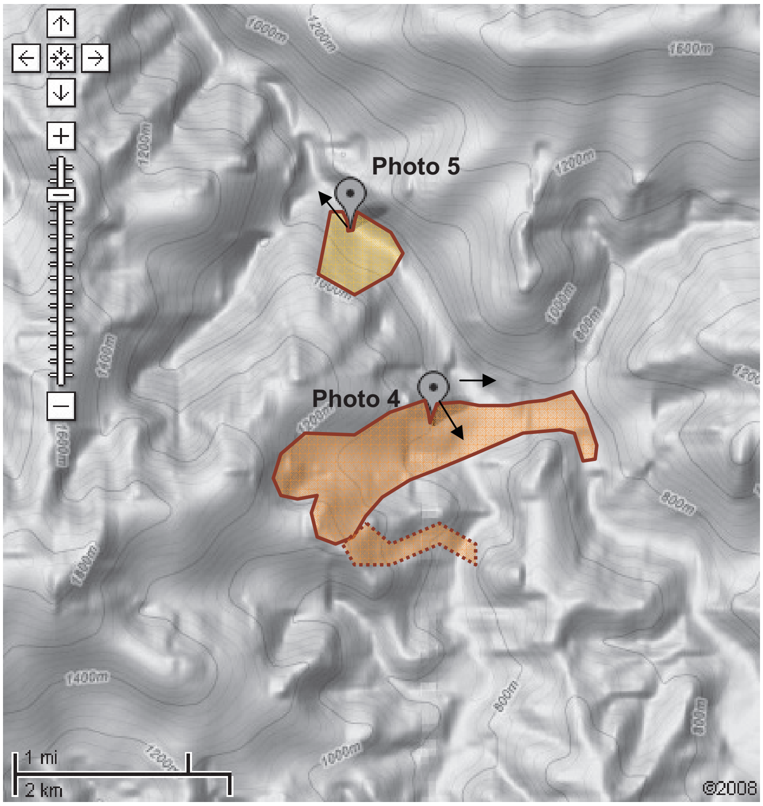


Fig. 3. Two major landslides at TongHeKuo, QingChuan County (from Google map)

Photo 4. Debris mass flowed down to TongHeKuo village: The debris mass is stopping waters of the major flow of TongHeKuo river (left) and its tributary (right). (Photo taken on July 28, 2008, at 32°23'55.1"N, 105°07'13.3"E: Location estimated from Google earth: See Fig. 3)

Photo 5. Landslide mass at "ShiBan-Gou" (Slate-Valley in English): (Photo taken on July 28, 2008, at 32° 25'55.5"N, 105° 06'32.2"E: Location estimated from Google earth: See Fig. 3)

YINGXIU AREA

YingXiu was one of the most severely devastated areas nearby the epicenter. At about 2 km southwest of YingXiu, the distal end of a large debris mass along NiuJuan Valley is reaching Ming Jiang River (Photo 6). The volume of the entire debris mass is estimated to be about 5 million m^3. This flow left its marks along NiuJuan Valley and the flow along a curved channel had enough momentum to surge up along its outer bank. Assuming that the line connecting available traces of debris along banks represents inclined mud flow surface, the following equation is obtained.

$$\theta \cong \text{centrifugal force / gravitational force } = \left(\frac{mv^2}{R}\right)/(mg) \quad (1)$$

where, R = radius of curvature, and one obtains:

$$v \cong \sqrt{Rg\theta} \tag{2}$$

Necessary parameters for Eq. (2) at the curve in Photo 6 are roughly estimated from the photo and the topographical map (Fig. 4) as:

$$\theta \cong 0.13\,, \qquad R \cong 400\text{ m},$$

Substituting these parameters in Eq. (2) yields:

$$v \cong \sqrt{Rg\theta} = 22\text{m/s} \tag{3}$$

Sabo Technical Center uses the following equation for estimating debris velocity:

$$v \cong \sqrt{Rg\theta/\alpha} \quad \text{with} \quad \alpha \quad \text{empirically set at 10} \tag{4}$$

And the velocity will be:

$$v \cong 7\text{m/s} \tag{5}$$

Going up along the NiuJuan Valley, there is the point where the debris mass from the source area flowed down to the valley (Photo 7). The debris mass scraped off vegetations on this slope, and either surged or jumped about 40-45m up on the other side of the valley. NiuJuan Valle at this location is about 150m wide. These traces are to be carefully measured for estimating velocities of debris mass flows at different locations. Debris flows are long-lasting problems affecting seriously rehabilitation strategies for the devastated areas.

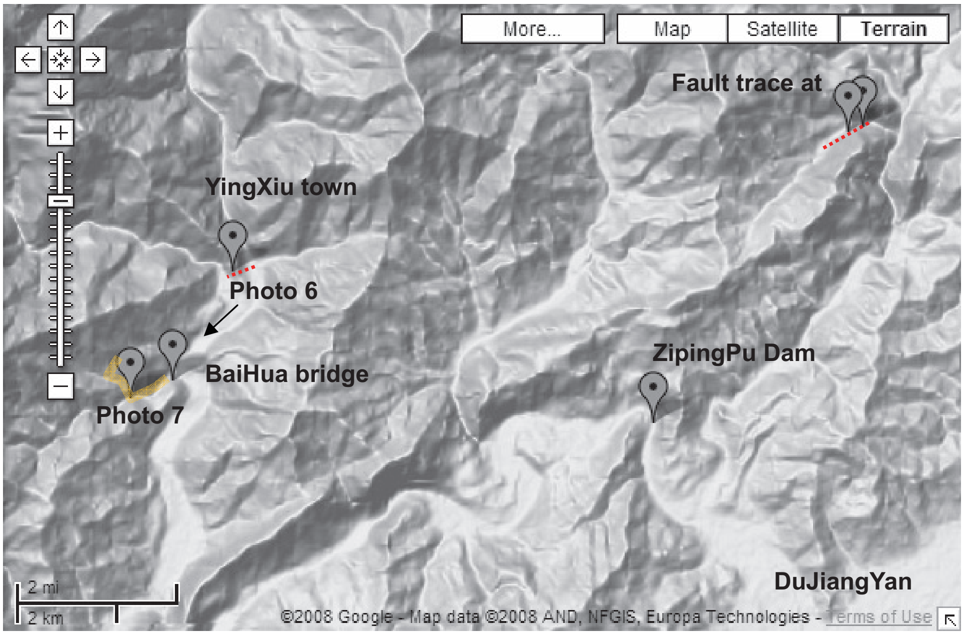


Fig. 4. YingXiu county and its vivinity:

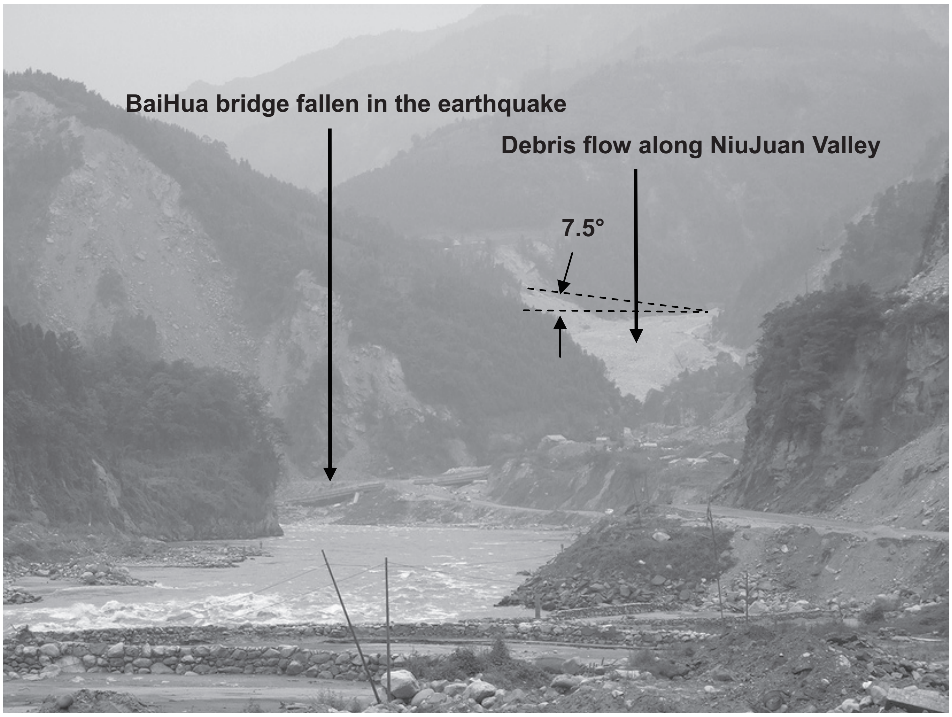


Photo 6. Debris mass flow reaching Ming Jiang River (Photo taken on July 29, 2008, at 31° 03'09.1"N, 103° 28'43.2"E: Location estimated from Google earth: See Fig. 4)

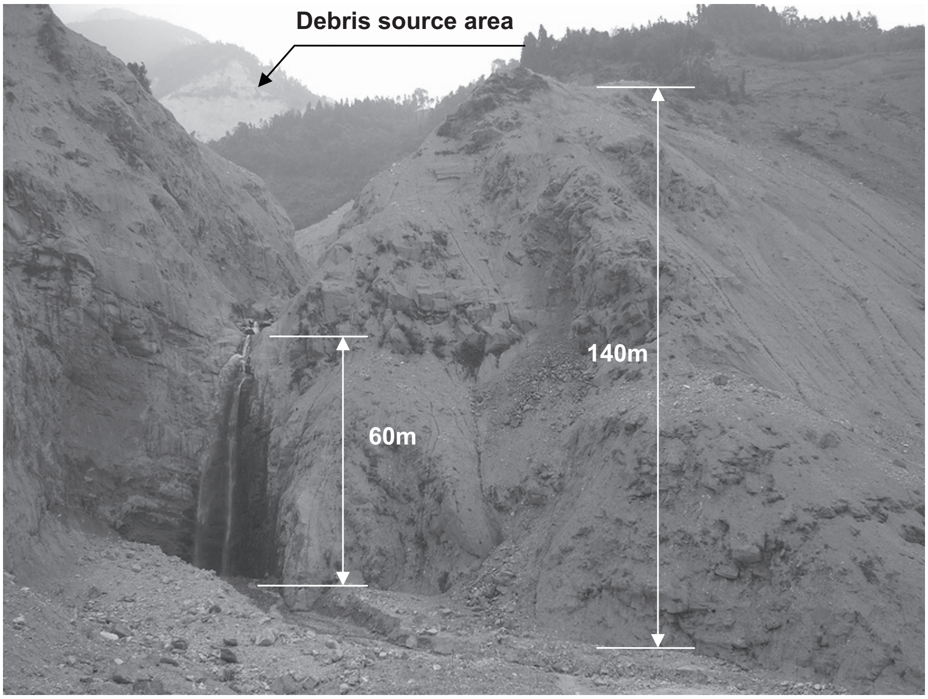


Photo 7. Debris trace: NiuJuan Valle at this location is about 150m wide. (Photo taken on July 29, 2008, at 31° 02'27.4"N, 103° 27'48.5"E: Location estimated from Google earth: See Fig. 4)

SUMMARY

The May 12th, 2008, Wenchuan Earthquake was remarkably large in terms of the length of the activated fault, affected areas, estimated cost of rehabilitation etc. With the Grants-in-Aid for Scientific Research, Ministry of Education, Culture, Sports, Science and Technology, Japan and the network of Japanese experts in the field of seismology, geology and earthquake engineering organized a team (with the first author as the leader) asking collaboration from Chinese organizations and experts with the China Earthquake Administration as its core. Based on the authors' first reconnaissance trip, this quick report summarized some geotechnical aspects of the damage.

It was shocking that a two-days heavy rain at Beichuan county on Sept. 23rd and 24th triggered a debris mass flow, and larger part of the southern half of the city was buried. Rehabilitation issues often attract less attention than issues that arise in the immediate aftermaths of earthquakes, and have never been given prominent coverage by news media. This event at Beichuan reminds us of some long-lasting issues after devastating earthquakes. Both the 1999 ChiChi earthquake, Taiwan and the 2005 Kashmir earthquake, Pakistan for example, formed a great number of debris deposits along their activated faults. Heavy rains in the monsoon of 2006 that followed the Kashmir earthquake were responsible for raising river beds. At Ghari Habibullah village, 4 to 5 kilometers west of the northern segment of the Muzaffarabad fault, about 4 to 6 meters of thick debris deposits were formed at the exit of a canyon onto a flat plain along the Kunhar River (Konagai, 2009). The ChiChi earthquake was followed by a number of typhoons in rapid succession. They included Toraji and Nari in 2001, Mindulle and Aere in 2004. About 3.9 typhoons on the average over the past ten years (1996-2005) have hit Taiwan, causing a three-fold increased risk of debris flows. As a result of these typhoons, an increase of river bed elevations of about 4 to 8 meters have been reported (W.F. Lee, 2007).

In order to have a clear perspective for dealing with long-lasting landform changes, monitoring landforms at different times is strongly recommended.

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