

# Quick Report of the JSCE Mission for Geotechnical Survey along Jehlum and Kunhar Valleys (Ver. 1.1)

## PREFACE

A massive earthquake of M 7.6 occurred in North Eastern Frontier Area of Pakistan (Epicenter: 34.493°N, 73.629E), about 90 km NNE of Islamabad at 8:28 local time, Oct. 8, 2005. This Earthquake resulted in a wide-spread devastation. As of Nov. 8, the Pakistan government officials said at least 73,236 people had been killed, making this devastation worst that this country had ever experienced since 1900.

Japan Society of Civil Engineers (JSCE) together with Architectural Institution of Japan (AIJ) and “Engineers without Borders” (EWBJ) has been exchanging expertise opinions among Japan and Pakistan organizations for better rehabilitations since they dispatched the first advance body for a quick reconnaissance. Reflecting these discussions, JSCE decided to dispatch the 5<sup>th</sup> team to the affected area on the following missions:

1. Estimating permeability of a huge landslide mass of Hattian for a better stabilization of the soil mass, and
2. Measuring ground micro-tremors in Muzaffarabad for estimating soil profiles to understand damage distributions and thus to reflect the findings in the ongoing rehabilitation projects.

This report outlines the findings obtained through the quick four-days survey of the 5<sup>th</sup> team and proposals to mitigate earthquake-inflicted losses. Some descriptions in this report are not fully analyzed and evidenced yet, and therefore, some comments are not yet the conclusions reached after thorough discussions among the members. However, providing both Japan and Pakistan experts and persons in charge with a rough-an-ready overview will be important for taking measures for better rehabilitations and precautions against possible secondary disasters.

All the members of the 5<sup>th</sup> team are much indebted and thankful to Mr. Tahir Sharif, Director, Earthquake Reconstruction and Rehabilitation Authority,(ERRA), Government of Pakistan, Mr. Arshid Mehmood Abbasi and Mr. Zahid Amin, Chief Officer and Administrator of Municipal Corporation Muzaffarabad, Azad Kashmir, Pakistan, experts from Tobishima Co, who have taken all the trouble of providing every convenience for the team. The members are also grateful to many experts from Japan International Cooperation Agency (JICA), National Highway Authority, Pakistan (NHA), for their valuable suggestions and numerous discussions during the survey. They wish to further collaborate with Pakistan experts for possible countermeasures, e.g., reconstruction of damaged structures, retrofitting of existing structures and reducing earthquake hazards.

## STABILITY OF HATTIAN LANDSLIDE MASS

### Estimation of overall permeability

Far up in the Jehlum mountains, a huge landslide mass stopped water of a branch of the Jehlum river creating a natural dam and killing some thousands people living on the mountain side the slid down. About one year has passed since the earthquake triggered this landslide, and the water level is yet 40 m below the lowest point of the debris mass. But, the reservoir can surely be filled to its full capacity of about 62 million m<sup>3</sup>. Well planned and thorough investigations of the landslide mass is a must, and if necessary the landslide mass should be stabilized for projects currently going on downstream side. The team measured some key dimensions of the landslide mass, elevations of waters stopped behind the soil mass, and discharge of water leaking through the debris for estimating overall permeability of the landslide mass.



(a) May, 2006

(b) Sept., 2006

Fig. 1 Larger reservoir behind Hattian landslide mass

In a debris flow, larger rocks and boulders can be pushed up above smaller particles (segregation). The result of this phenomenon is the most clearly seen at the toe part of a landslide mass where its permeability is eventually larger than that of the other part of the landslide mass. However, the permeability is assumed to be uniform for the entire landslide mass herein for quick-and-ready estimation of its long-term stability. Other assumptions for this quick estimate follow;

1. Debris mass beneath its hydraulic head has a cross-section varying with distance  $x$  (see Fig. 2).
2. These cross-sections are similar in geometry.
3. Elevation of the bottom line,  $z$ , with respect to the toe elevation of the landslide mass,  $x=0$ , is congruent to the result of uniform scaling,  $\alpha$ , of the hydraulic head,  $h$ , namely  $z = \alpha h$ .
4. Width of the landslide mass beneath the hydraulic head is also proportional to the hydraulic head,  $h$ , namely  $B = \beta h$ .

Velocity of the flow through the soil mass is given by:

$$v = k \frac{dh}{dx}, \text{ where } k \text{ is the permeability of the soil.} \quad (1)$$

Discharge of water  $Q$  through the soil mass is then;

$$Q = vA = v \cdot \frac{\beta(1-\alpha)^2 h^2}{2} = k \frac{\beta(1-\alpha)^2 h^2}{2} \frac{dh}{dx} \quad (2)$$

From Eq. (2), one obtains:

$$Qdx = \frac{k\beta(1-\alpha)^2}{2} h^2 dh$$

$$Qx = \frac{k\beta(1-\alpha)^2}{6} h^3 + C \quad (3)$$

At the toe point ( $x=0$ ),  $h \cong H_0$ , and therefore,  $C = -\frac{k\beta(1-\alpha)^2}{6} H_0^3$

At the upstream end of the landslide mass ( $x=L$ ),  $h = H_1$ , and one obtains;

$$QL = \frac{k\beta(1-\alpha)^2}{6} (H_1^3 - H_0^3) \quad (4)$$

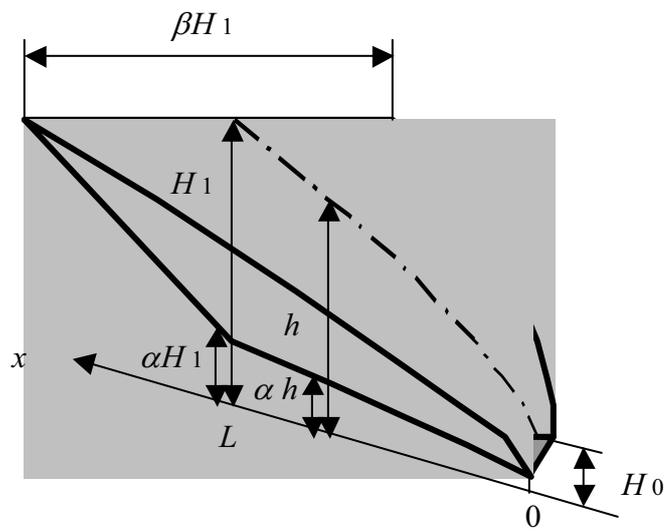


Fig. 2 Assumed geometry of soil mass beneath hydraulic head for estimating overall permeability

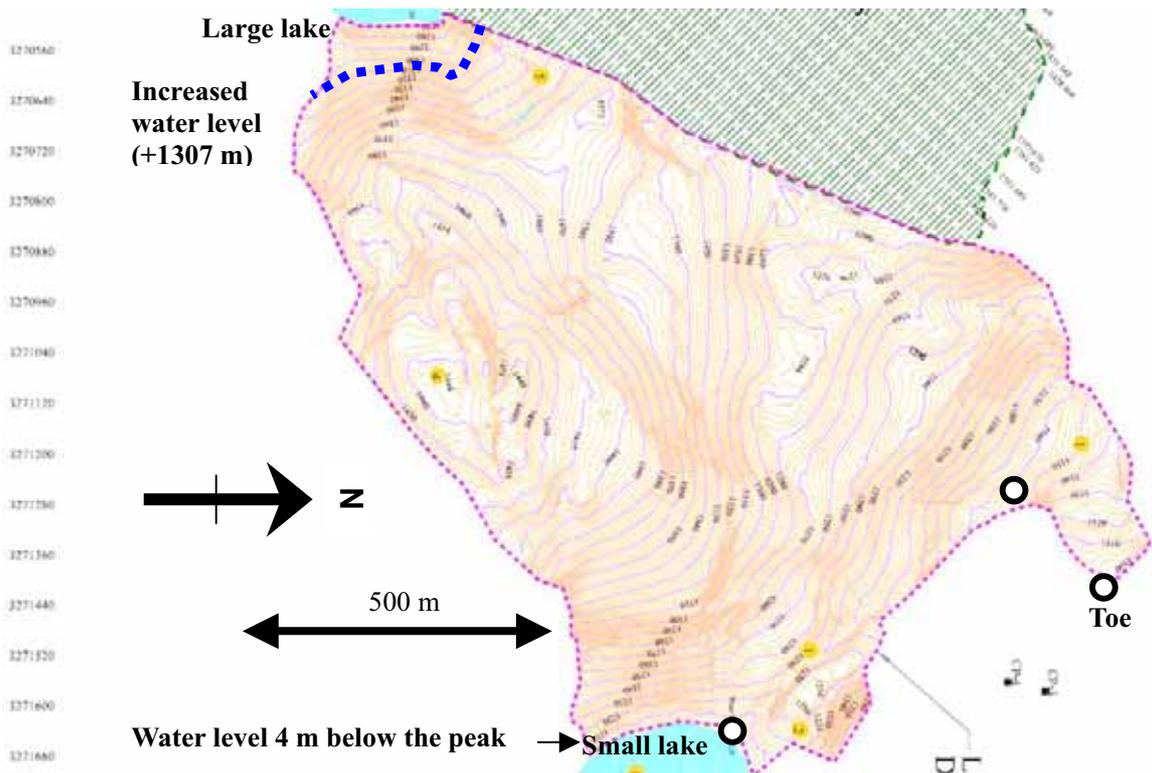
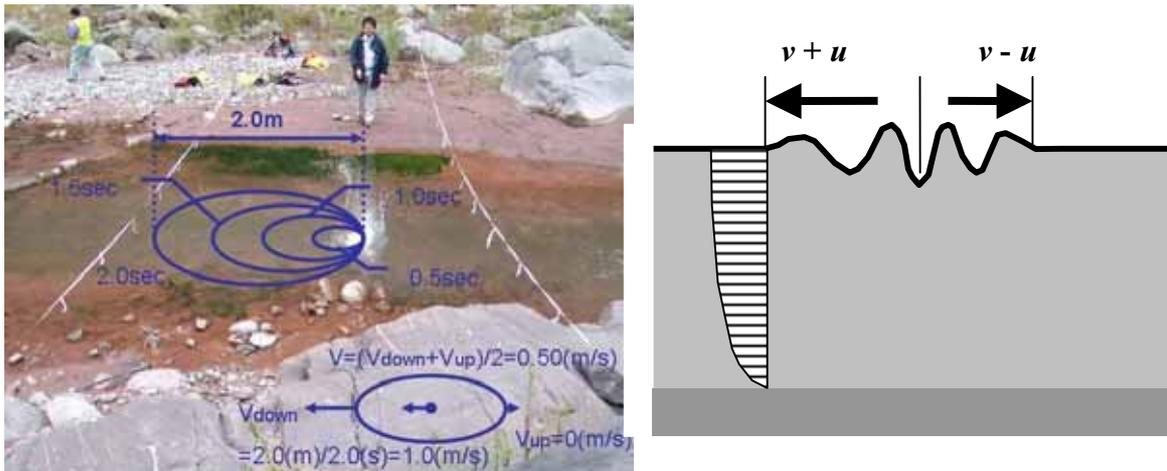


Fig. 3 Hattian landslide mass (provided by the Geological Survey of Pakistan)



Throwing a stone onto a river surface, a wave travels in all directions with a velocity,  $v$ , which is approximately given as a function of water depth  $h$  and wave length  $\lambda$  by:

$$v = \sqrt{\frac{g\lambda}{2\pi}} \sqrt{\tanh \frac{2\pi h}{\lambda}} \quad (a1)$$

However, the presence of a steady water flow of laminar features,  $u$ , will change its velocities in upstream and downstream directions to be:

$v_{up} = v - u$  and  $v_{down} = v + u$ , respectively.

Video-filming the wave pattern allows both  $v_{up}$  and  $v_{down}$  to be measured, and one obtains:

$$v = \frac{v_{down} + v_{up}}{2}, \text{ and}$$

$$u = \frac{v_{down} - v_{up}}{2}.$$

When  $\lambda \gg h$ ,  $h$  will be obtained by Eq. (a1).

Fig. 5 Measuring flow velocities

Table 1. Parameters for Equation (4)

	Small lake (S)	Large lake (L)
$\beta$	5	2.5
$\alpha$	0.6	0.5
$L$	1000 m	1500 m
$H_0$	0 m	0 m
$H_1$	98 m	204 m

As shown in Fig. 3, the landslide mass has created two lakes. Parameters in Eq. (4) for the two lakes are shown in Table 1.

From Eq. (4), the entire discharge through the landslide mass is given by;

$$Q = \left\{ \frac{k\beta(1-\alpha)^2}{6L} (H_1^3 - H_0^3) \right\}_s + \left\{ \frac{k\beta(1-\alpha)^2}{6L} (H_1^3 - H_0^3) \right\}_L \quad (5)$$

To estimate the discharge,  $Q$ , flow velocities of water seeping out from the toe of the landslide mass were measured first (see Fig. 4). Assuming laminar flow, the discharge  $Q_{total}$  of the stream starting from the toe was estimated to be about  $0.5 \text{ m}^3/\text{s}$ . However,  $Q_{total}$  is not identical to  $Q$ . Some amount of water may be from other sources. Discharge of waters seeping out at higher elevation of the landslide mass ( $W$ ) are to be excluded from  $Q_{total}$ . Therefore the following two cases were considered:

(1)  $Q = Q_{total} = 0.5 \text{ m}^3/\text{s}$

(2)  $Q = Q_{total} - W$

$W$  was most clearly observed at Point #5 in Fig. 3, and measured to be  $W \cong 0.25 \text{ m}^3/\text{s}$ .

Substituting all given parameters in Eq. (5), permeability coefficients  $k$  is obtained for both Case #1 and #2 as:

$$k = \begin{cases} 7 \times 10^{-4} \text{ m/s} & \text{for Case \#1} \\ 3.5 \times 10^{-4} \text{ m/s} & \text{for Case \#2} \end{cases}$$

These values should go through thorough verifications to be sure, but they indicate that the landslide mass is highly permeable. With this permeability, discharges  $Q_{small}$  and  $Q_{large}$  from small and large lakes are obtained from Eq. (5) as shown in Table 2.

	Case #1	Case #2
$Q_{small}$	$0.087 \text{ m}^3$	$0.044 \text{ m}^3 + 0.25 \text{ m}^3$
$Q_{large}$	$0.413 \text{ m}^3$	$0.206 \text{ m}^3$
Total	$0.5 \text{ m}^3$	$0.5 \text{ m}^3$

\* Note:  $0.25 \text{ m}^3$  was added to the discharge estimated from Eq. (5) to describe the contribution of water seeping out at higher elevations than the toe part.

### Discussions and recommendations

Hattian Landslide mass is seemingly stable with high permeability of  $10^{-4}$  to  $10^{-3} \text{ m/s}$  order. Moreover, courser debris gathered at the toe slope of it could increase the permeability even more. The toe part will thus function as a filter eventually making the landslide mass stable. When the full capacity of the upper larger lake was reached ( $H_1 = 264 \text{ m}$ ,  $\alpha = 0.28$ ), the discharge from the large lake can reach its peak value as shown in Table 3.

	Case #1	Case #2
$Q_{large, peak}$	$1.85 \text{ m}^3/\text{s}$	$0.93 \text{ m}^3/\text{s}$

If the total discharge  $W_{large}$  flowing into the large lake exceeds this leaking discharge, water will overflow the spillway. To avoid erosion, the bottom of the spillway is to be covered up with large rocks.

The high permeability for the landslide mass suggests that the entire debris mass has relatively large void ratio, and the debris mass may change its entire volume slowly. Uneven subsidence or upheaval due to local deformation may cause some functional problems of the spill way. It is therefore

recommended that several reference points are put on the landslide mass for monitoring volume change of the landslide mass.

Another possible threat of overflowing will be a landslide which can be triggered by the increased reservoir water level. This will be the worst scenario not only because it can cause a tsunami surging over the landslide mass and therefore flooding downstream side but also because the dwellings on top of the landslide will be destroyed.

It is therefore strongly recommended that the followings are monitored for long term;

- 1) Total discharge through the landslide mass,  $Q$ , monitored at the toe.
- 2) Upper stream discharges  $W_{large}$  and  $W_{large}$  flowing into small and large lakes, respectively,
- 3) Precipitations, and
- 4) Crack openings (if found to be potentially dangerous).

### Notes from Meetings

with Dr. Kauser, at GSP 2006/11/18

#### Hatian recommendations notes:

- Water & Power Authority (Wapowera) has been in charge of permeability measurements.
- GSP will take the idea of put reference points on the landslide mass positively, and map out tactics for it.
- Possibility to use SAR for estimating deformations of dam will be discussed with appropriate persons at the Geographical Survey Institute of Japan.
- GSP has been monitoring crack openings. A crack was reportedly opened 5 cm up during this monsoon season. Mapping all these cracks found in the vicinity of the Hattian landslide mass can provide a good perspective for the scale of a possible landslide.
- A seminar is now being organized by both GSP and the Japan Society of Landslides. It will be held at Islamabad on Dec. 26, 2006. Organizers include Prof. Marui, Yagi, Chigira, Kanada-san (Secretary), etc.
- JSCE team will prepare 2 reports for the GSP publication in March 2007. Deadline is set at 15-30 January.

with Mr. Firdaus Alam, Joint Secretary

at MOC (Ministry of Communication)

- MOC will collaborate with appropriate organizations including ERRA, GSP, etc for measures discussed for both Hattian landslide issues and rehabilitation of Muzaffarabad.

with Mr. Tahir Sharif, Director (Infrastructure),

at ERRA (Earthquake Recovery and Rehabilitation Authority)

- Improvement of workmanship will be one of keys for future disaster prevention. Confined masonry. Dry masonry was proposed by a NGO, but ERRA, as a responsible organization, doesn't allow building dwellings with such material.
- People living along rims of terraces of weakly cemented sediments including conglomerates possibly need to be evacuated.

### Estimation of geological structure in Muzaffarabad

We have performed microtremor measurements at selected locations along three lines as shown in Figure 6 below. Here follows a brief description and analysis of the results.

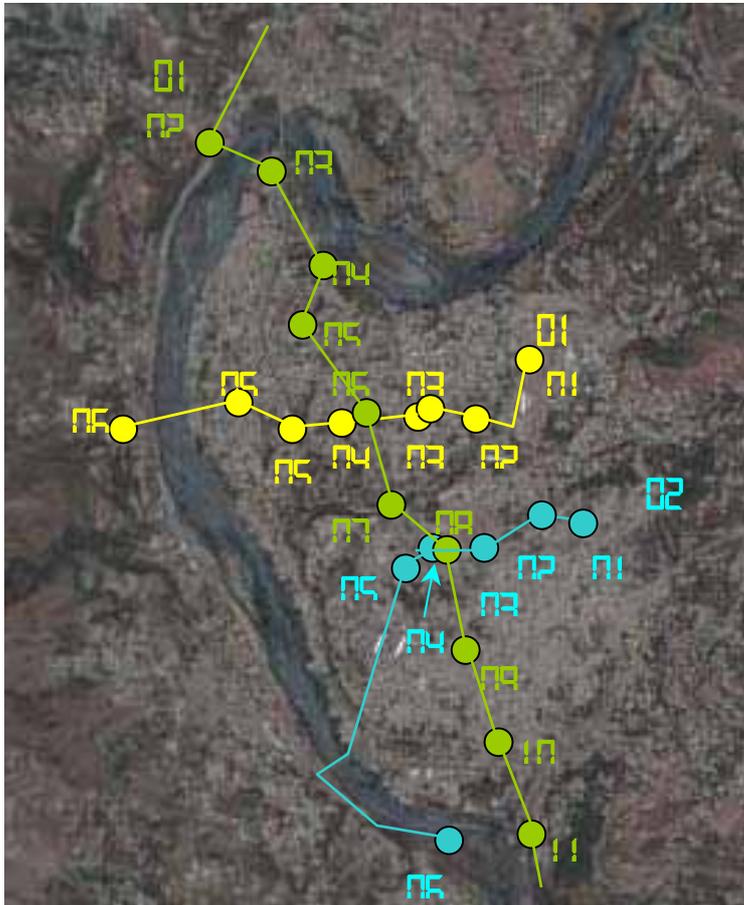


Fig. 6. North-South trending microtremor observation line.

Starting with the North-South trending line Figure 6 (crosssection NS) shows how the elevation changes from 690 meter at point NS02 and NS03 to 720 meters at point NS04- NS06, reaches a maximum elevation of 740 meter at point NS07- NS09 and then decreases to 710 m at point NS010 and 690 m at point NS011.

Figure 7 show how the soil deposit's fundamental vibration frequency decreases from 20 Hz at point NS03 to 11Hz at point NS04 and to 7 Hz at point NS05 indicating and increasing thickness of sediments overlying the bedrock. Point NS02 in the north and point NS11 in the south are very close to engineering bedrock. Continuing further south we see that frequency increases again to 8 Hz at point NS06 and to 20Hz at point NS07. Most likely the sediment layer is very shallow at point NS07. Frequency decreases again moving up to the top of terrace 1 indicating and increasing thickness of the sedments at point NS08' compared to NS07. At point NS09 and NS10 the sediments are assumingly thicker as frequency has decreased to 7 Hz at point NS10.

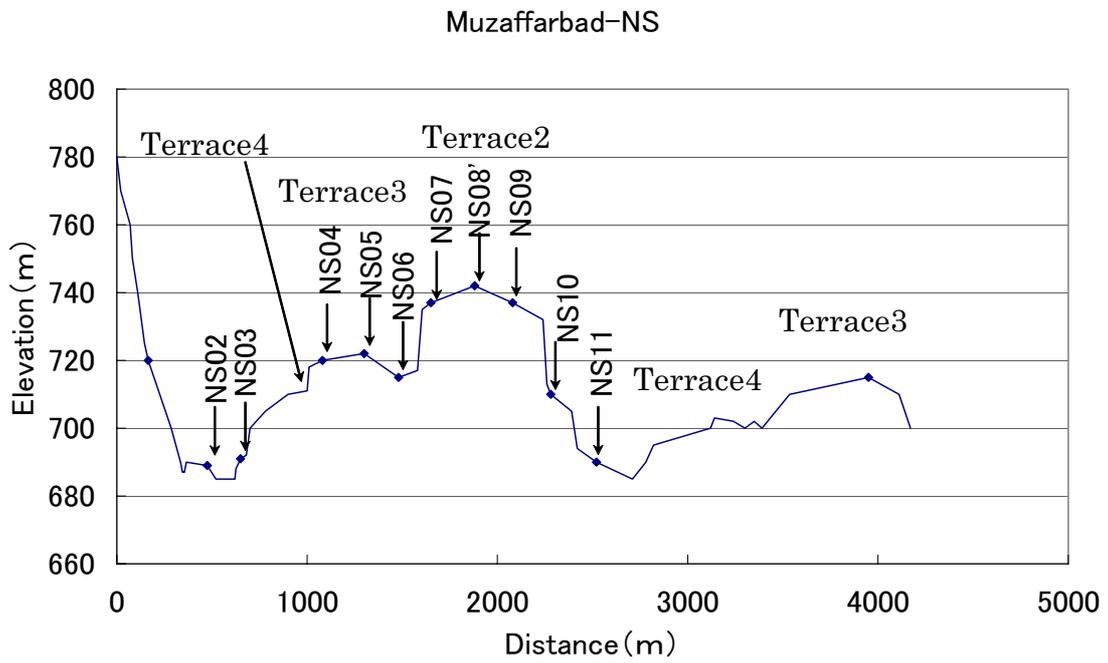
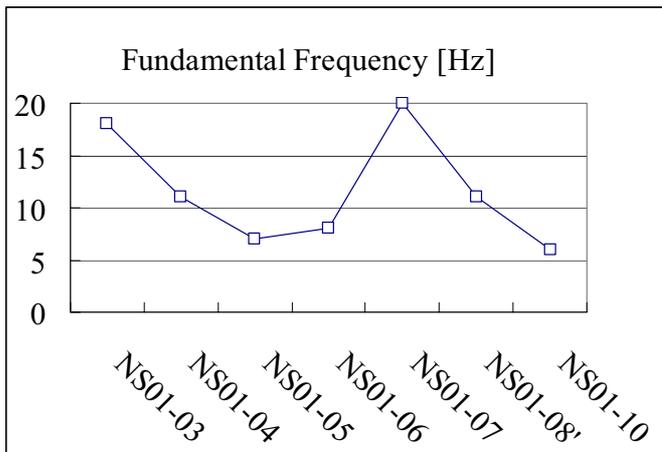


Figure 7. North-South cross section.



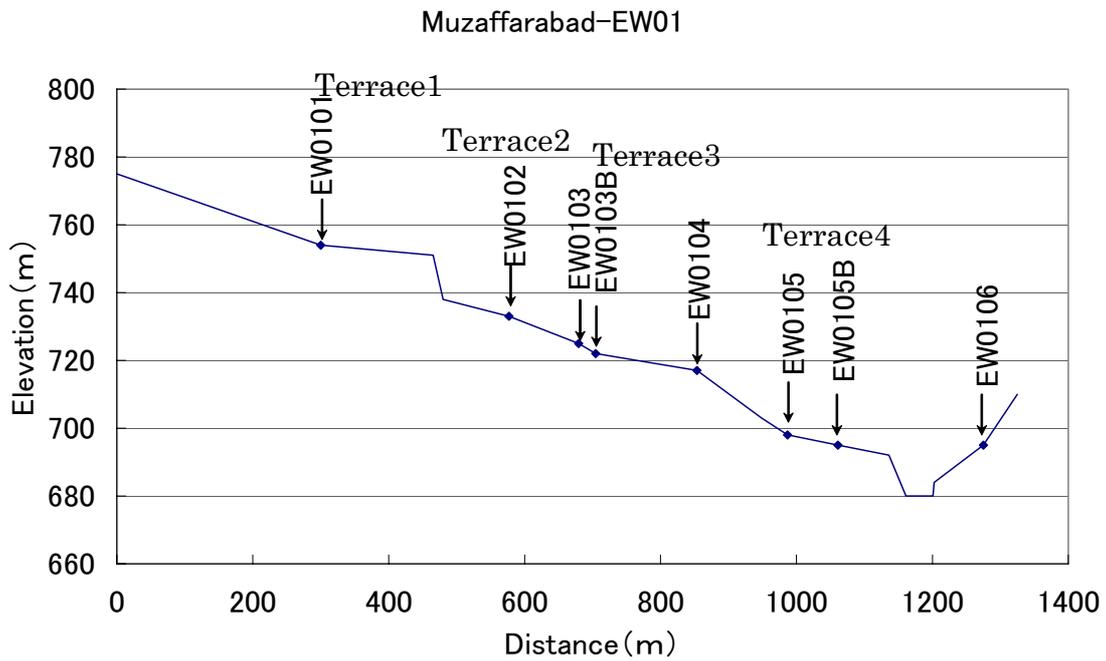


Figure 8. East-West 01 Cross section.

**East-West (EW02) trending microtremor observation line.**

To keep this report we refrain our selves to describe the East-West 02 trending lines. The frequency is relatively low (4 to 5 Hz) at point EW0201 and point EW0202 which is as expected; Sediments thicker than 40 meter were observed at these points. Going down to points EW0203, EW0204 and EW0205 increases again and reaches a maximum of 12 Hz at EW0204. At point EW0206 we observed bedrock and observed frequency was difficult to interpret. The frequency seemed to be close to 8 Hz but more detailed analysis may reveal a higher frequency as expected.

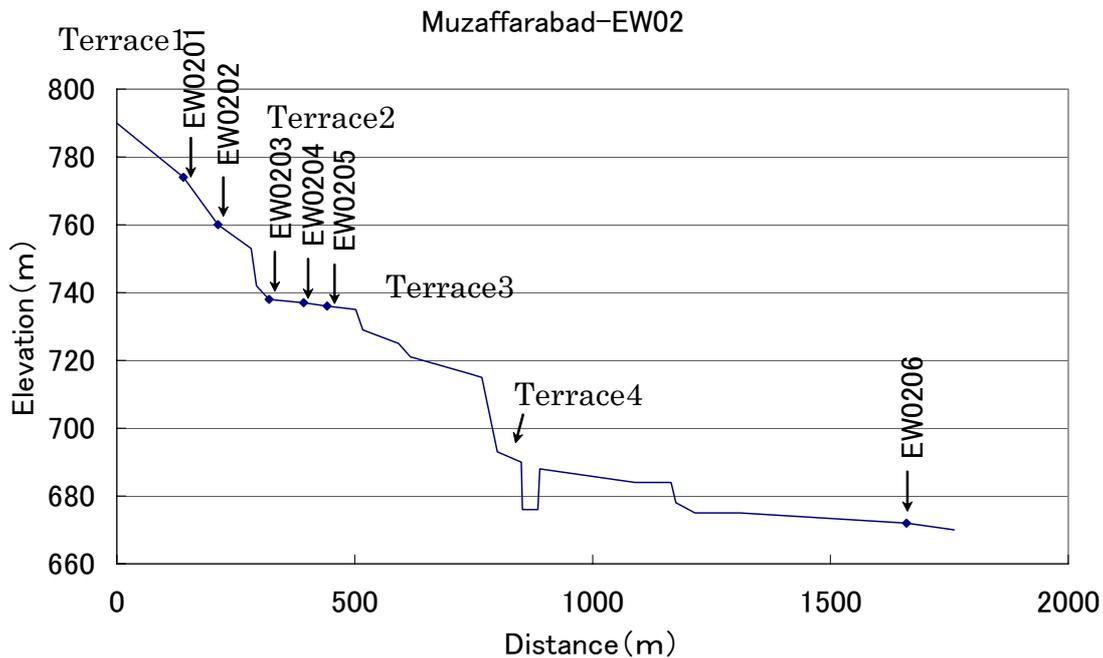
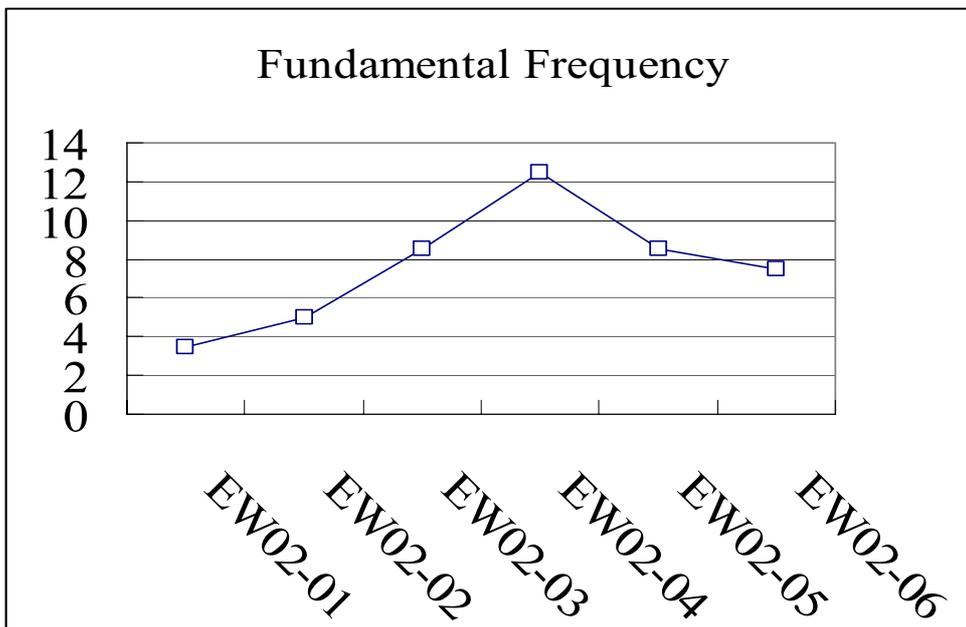


Figure 9. East-West 02 Cross section



**Summary**

Point NS02 in the north and point NS11 in the south are very close to engineering bedrock. Most likely the sediment layer is very shallow at point NS03 close to the river and at NS07 on top of the 1

terrace. Vibration frequency decreases moving up to the top of terrace 2 indicating an increasing thickness of the sediments at point NS08' compared to NS07. In general the points located on terrace 2 (NS07, NS08', NS09, EW0203, EW0204, and EW0205) show higher fundamental frequencies indicating very shallow sedimental layer.

### **Discussions and recommendations**

IKONOS Satellite imagery of Muzaffarabad area shows cluster-wise distribution of damage in urbanized zones of the city. This distribution seems to be related to the thickness of weakly cemented sediments with inclusion of conglomerates. As the thickness increases, damage seems to be more severe like east part of the market (such as Zones #13, #14 in the JICA master plan for rehabilitating the city). As described in the JICA master plan, locating open spaces and expanding wider road network will make the area more robust against possible future disasters, allowing easy and quick access to the area, and thus providing refugees with spaces for shelters and necessary goods.

However, urgent needs of Muzaffarabad will be more related to other geotechnical/geological issues rather than a possible massive earthquake. The Zenkoji Earthquake, which jolted central part of Japan in 1847, tells that an earthquake can cause long lasting geotechnical hazards. Chausu-yama landslide for example, whose movement began to be accelerated 30-40 years after the Zenkoji earthquake, needed necessary measures up until late 1900's.

Among options for rehabilitating Muzaffarabad, one feasible idea will be to lay out satellite towns outside the municipal boundary as described in the JICA master plan. Staying a little off unstable rims of terraces, terraces will be appropriate locations for developing satellite towns. One difficulty, if any, will be maintenance of roads, which will have to cross gorges from mountains rising behind dislocated seismic faults (such as Tanda and Jelum faults) cutting deep down to lower elevations. During the earthquake slope failures created debris deposits beneath the mountains and during heavy rains debris flows can occur. These flows will most likely follow the gorges, namely branches of the Jehlum and Nihlum rivers crossing roads and suspending traffic. Clearing debris remaining on the roads would be just a stopgap. Connecting existing roads point-wise by constructing new bridges etc, a cost-effective bypass can be constructed allowing bi-directional traffic to be realized.