PROVISIONAL REPORT OF THE DAMAGE CAUSED BY MUZAFFARABAD EARTHQUAKE OF OCTOBER 8, 2005, PAKISTAN

-- OVERVIEW AND PROPOSALS TO MITIGATE EARTHQUAKE-INFLICTED LOSSES (Ver. 2) --

ADVANCE TEAM OF JSCE RECONNAISSANCE TEAM
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PREFACE

An intense earthquake (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. The focal depth was reported to be 26 km (USGS). Earthquakes in the northern mountainous areas of Pakistan and adjacent parts of India and Afghanistan are the result of the movement of the Indian plate subducting north beneath the Eurasian plate at a rate of 40 mm/year (USGS), and. the area affected by this earthquake is a foreland of Hind-Kush ranges including the highest peaks in the world.

Japan Society of Civil Engineers (JSCE), with the approval of the Architectural Institute of Japan, is establishing a non-profit organization (NPO) to contribute to retrofitting and reconstructing of areas affected by natural disasters. Though it is still in progress, JSCE decided that it would dispatch a quick advance team to Pakistan (Oct 24-Oct. 31). The preliminary strategy of JSCE advance team is to make a first reconnaissance laying stress on the damage to dwellings, civil infrastructures etc, and then to discuss with experts from both Japan and Pakistan organizations about better tactics for future collaborations lucrative for both Pakistan and Japanese sides. The organizations include JICA, JBIC, (Japan side) and NHA, UET, Lahore, etc. Reflecting this discussion the main body of the JSCE reconnaissance team will be dispatched.

This report outlines the findings obtained through the quick two-days survey and proposals to mitigate earthquake-inflicted losses. Some descriptions in this report are not fully evidenced yet, and therefore, some comments are not yet the conclusions reached after thorough discussions among the members. However, providing both Japan and Pakistan specialists and persons in charge with a rough-an-ready overview will be important for taking measures for the disaster relief and precautions against possible secondary disasters.

All the members of the advance party of the JSCE Reconnaissance Team are much indebted and thankful to the experts from Tobishima Co, who have taken all the trouble of arranging the schedule. The members are also grateful to many experts from Japan International Cooperation Agency (JICA), JBIC, United Nations Development Program (UNDP), National Highway Authority, Pakistan (NHA), Capital Development Authority, Pakistan (CDA), and University of Engineering and Technology (UET), Lahore, for their valuable suggestions and numerous discussions during the survey. They wish to further collaborate with Pakistan specialists for possible countermeasures, e.g., reconstruction of damaged structures, retrofitting of existing structures and reducing earthquake hazards. And lastly all the members would like to express hereby their sincere sympathy to the people affected by the devastating earthquake.

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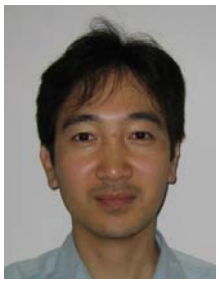

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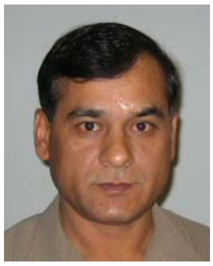


ITINERARY

Date	Description
Oct./24 (Mon)	Narita 14:00 - Islamabad 21:05 （PK853）
25 (Tue)	AM Meeting among members Meeting with JICA and JBIC ecperts PM Departure to affected areas
26 (Wed)	Whole day for investigation in Balakot area
27 (Thu)	Whole day for Investigation in Muzaffarabad area Return to Islamabad
28 (Fri)	AM Investigation of Marlgallra Tower PM Courtesy visit to Japanese Ambassador Meeting with UNDP experts
	Meeting with JICA experts
29 (Sat)	AM Briefing and discussion at National Highway Authority PM Discussion at Capital Development Authority
30 (Sun)	Meeting among members Leave Islamabad at 22:35 (PK852)
31 (Mon)	Arrive at Narita at 12:40

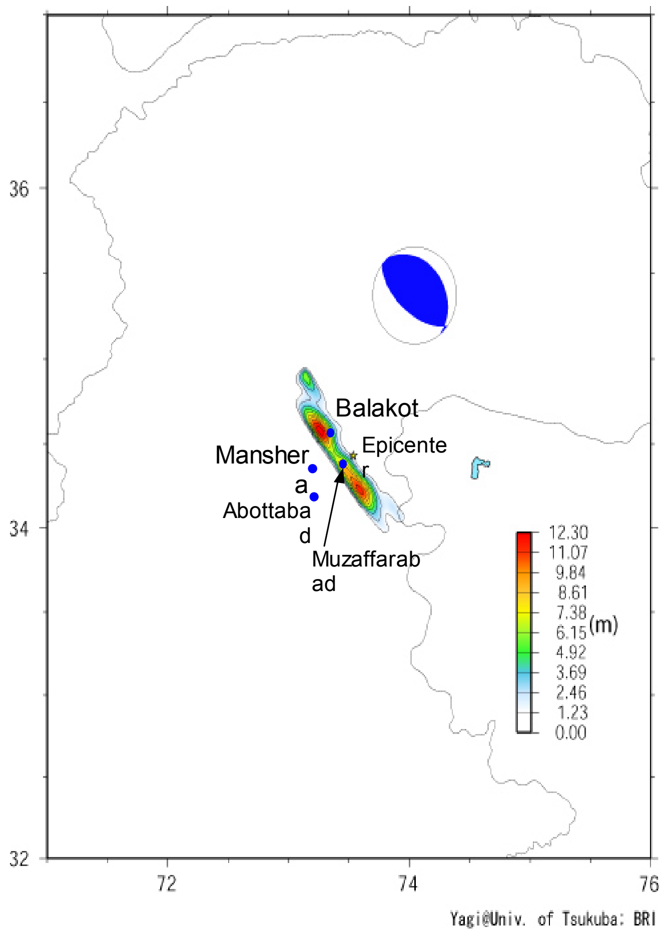


Fig.1. Source Process of Pakistan earthquake: contours show the slip on the fault surface (http://www.geo.tsukuba.ac.jp/press_HP/yagi/EQ/2005Pakistan/)

FINDINGS AND REMARKS

Intense shake in Balakot

A SE-NW trending fault system (including Murree and Muzafarabad faults) goes across Muzaffarabad and extends further up to Balakot, while another fault system (including Panjal and Garhiharib faults) goes north up through the valley of River Kunhar. These two fault systems merge at around Balakot (Geological map of Garhi Habibullah Area, District of Muzaffarabad, Geological Survey of Pakistan, April, 2004). According to the seismic source inversion based on long period seismograph data by Yagi (http://www.geo.tsukuba.ac.jp/press_HP/yagi/EQ/2005Pakistan), asperities (places of relatively large slip) exist on the north and the south edges of the former fault system (Fig.1), and both the major event and its aftershocks took place along the fault.

According to Yani Najman (2002), these two fault systems make up a wedge. This wedge cuts deep into high-raised mountains of red-purple shale (Balakot formation). Balakot is located at the wedge's northern apex.

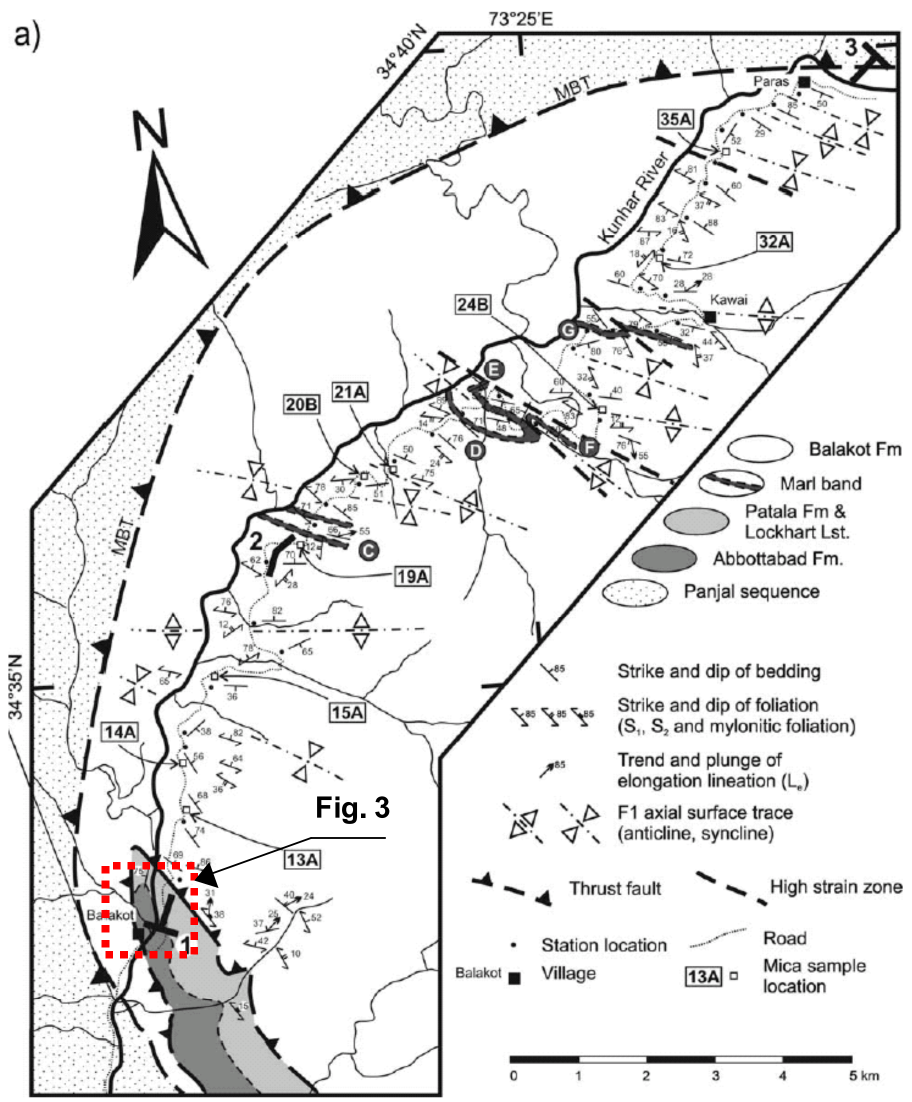


Fig. 2. Geological map of Kaghan Valley, Hazara-Kashmir Syntaxis, Pakistan (after Yani Najman, 2002)

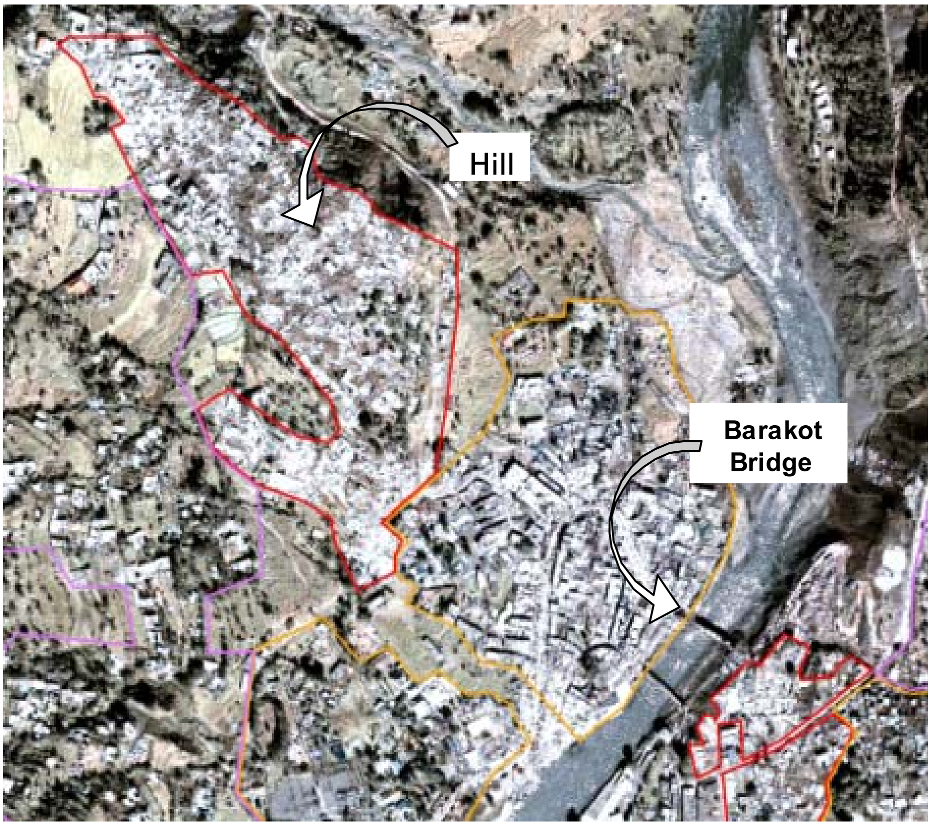


Fig.3. Satellite imagery of central Balakot from IKONOS
(UNOSAT: http://unosat.web.cern.ch/unosat/asp/)

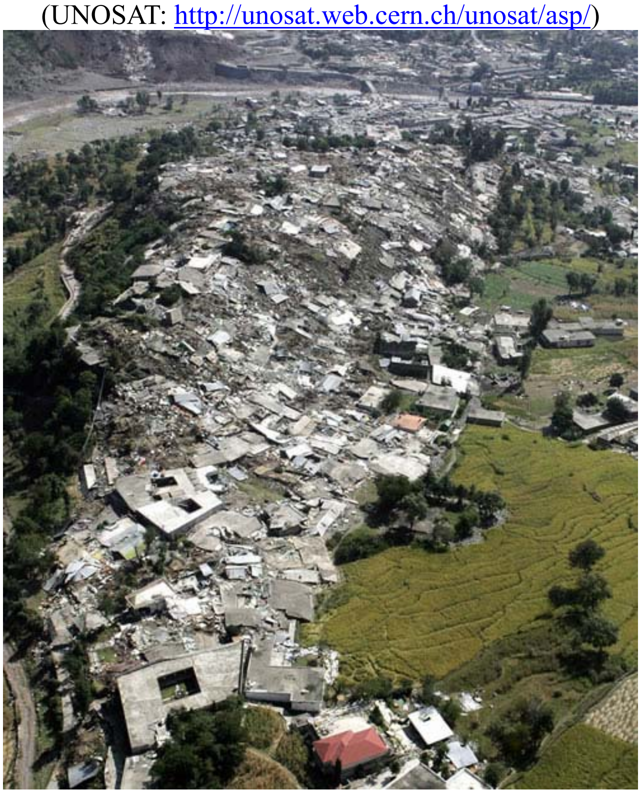


Fig. 4. Long-Bean-shaped hill in Balakot: Entire cluster of houses on the hillside were flattened
(Yahoo News Photo (Reuters), http://news.yahoo.com/news?tmpl=story&u=/051009/ids_photos_wl/r2506774501.jpg)

There is a NW-SE trending long-bean-shaped hill at northwestern part of the city (**Figs. 3 & 4**). The hill is independent among the other mountains surrounding the city, and about 700 m long, 300 in wide and 70-80 meters high. It has an asymmetric transverse cross-section (elevation) with a steep cliff on its NE side, and a gently dipping slope on the other SW side. One of the most spectacular aspects of the earthquake effect to Balakot was that almost all houses covering the SW-dipping gentle hillside were completely flattened (**Fig. 4**). Seriously damaged area including this hillside seemingly extends belt-wise from NW to SE crossing River Kunhar. The contrast between the belt and other areas was clear (see red (catastrophic damage), yellow (extensive damage) and pink (moderate damage) zones in Fig. 2).

There are two bridges within this belt, Balakot bridge of National Route #15 (3-span RC arch, Fig. 5) and a pedestrian suspension bridge about 100 m downstream side (Fig. 6). The entire deck of the Balakot bridge shifted over its two piers about 1m from north to south downstream side and a half meter towards the left abutment. The right masonry tower of the suspension bridge suffered a clear cut off at the level of 2m above the riverbed, and moved about 1m towards downstream side. Both clearly show that the shake there was very intense in NS direction, the direction in which the seismic soil wedge is pushed. Measuring traces of strong ground motions remaining in structures, which are seen everywhere and have common features, will provide useful information for discussing shakes at particular areas.

In our short preliminary investigation, only the direction of strong motion was estimated by measuring inclinations and directions of the inclined lampposts. We took total 9 lampposts (Fig.7) lining Route #15 (Fig.6). Two lampposts (1, 7) were standing almost upright and slightly damaged. Three lampposts (4, 5, 6) had screws broken at their base plates (22.5cm×22.5cm) and stood loose. Four lampposts (2, 3, 8, 9) were bent at their toes and inclined north. All these show that the ground motion was strong in NS direction.

Fig. 5. Balakot bridge of National Route #15: The entire deck moved about 1m downstream side.

Fig. 6, Suspention bridge near Balakot bridge: The right tower was cut off and shifted towards downstream side.

Lamppost

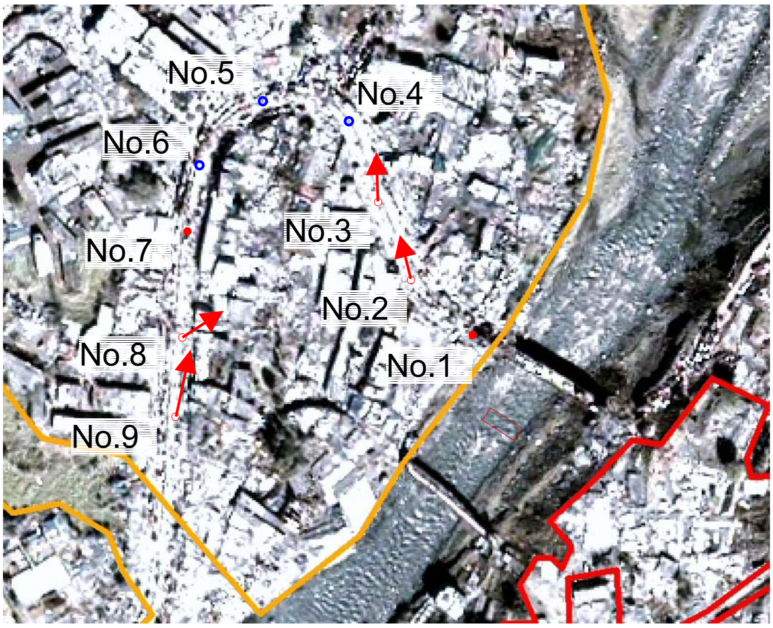


Fig. 7. Location and the inclination of the lampposts (●: sound, ○: shaky, ○: bent). Arrows show the direction and the amount of the inclination (20degree=1cm). Imagery taken from UNOSAT website (http://unosat.web.cern.ch/unosat/asp/)

Fig. 8. Terrace slope northeast of Balakot bridge

Soil-Foundation problems

Walls of structures are mostly made from cement sand blocks. Roofs are made from RC slabs. Almost complete collapses of these structures were often found on sloping grounds. These houses were attached to each other. When one house anywhere on the slope collapsed, it triggered the collapse of the others in domino-like manner and the result was the collapse of entire houses. Half-detached or completely detached houses also suffered cracking, but there were some narrowly escaped from complete collapse.

Hills and terraces near the northern end of Balakot basin are composed of either highly weathered sand rock or conglomerate of rounded to sub rounded boulders, cobbles, gravel, sand, silt, clay and other suspended matters that River Kunhar (or glacier) have carried over centuries (See Fig. 8). They are heterogeneous in nature. Foundations of buildings on these terraces may have not been properly designed. Fig. 9 shows a foundation found in the rubble covering up the entire slope of the abovementioned long-bean-shaped hill. The foundation was lying on the sandy slope surface with its column-foundation joint intact, indicating that the foundation didn't suffer any cracking but the foundation lost its soil support. A similar pattern of damage was also found in Muzaffarabad (Fig. 10). Houses along the rim of the terrace were completely destroyed, while those on the flat land are seemingly standing upright. Soil cracks were visible along the rim.

Fig. 9. Foundation and column of a dwelling at the long-bean-shaped hill

Fig. 10, Houses along terrace rim and those on flatland, north of Muzaffarabad: Cracks open along the rim

Landslides

A white landslide belt extends straight from Muzaffarabad to Balakot. According to the Geological map (Geological Survey of Pakistan, 2004), this belt coincides with the Paleocene rock layer appearing directly above the Muzaffarabad fault. The rock is rich in limestone and calcareous shale, and they are noticeably weathered. A massive landslide occurred over about 1 km distance along the west mountainside rising northeast of Muzaffarabad. Cone-shaped piles of white/gray debris cover the mountainside (Fig. 11). These cones have roughly three different stripes of color (white, light gray and gray from the top to the toe) reflecting the effect of segregation. Since that slope was inaccessible, the angle of repose was estimated using a laser theodolite and satellite imageries of the area. The angles suggest possible distal ends of debris.

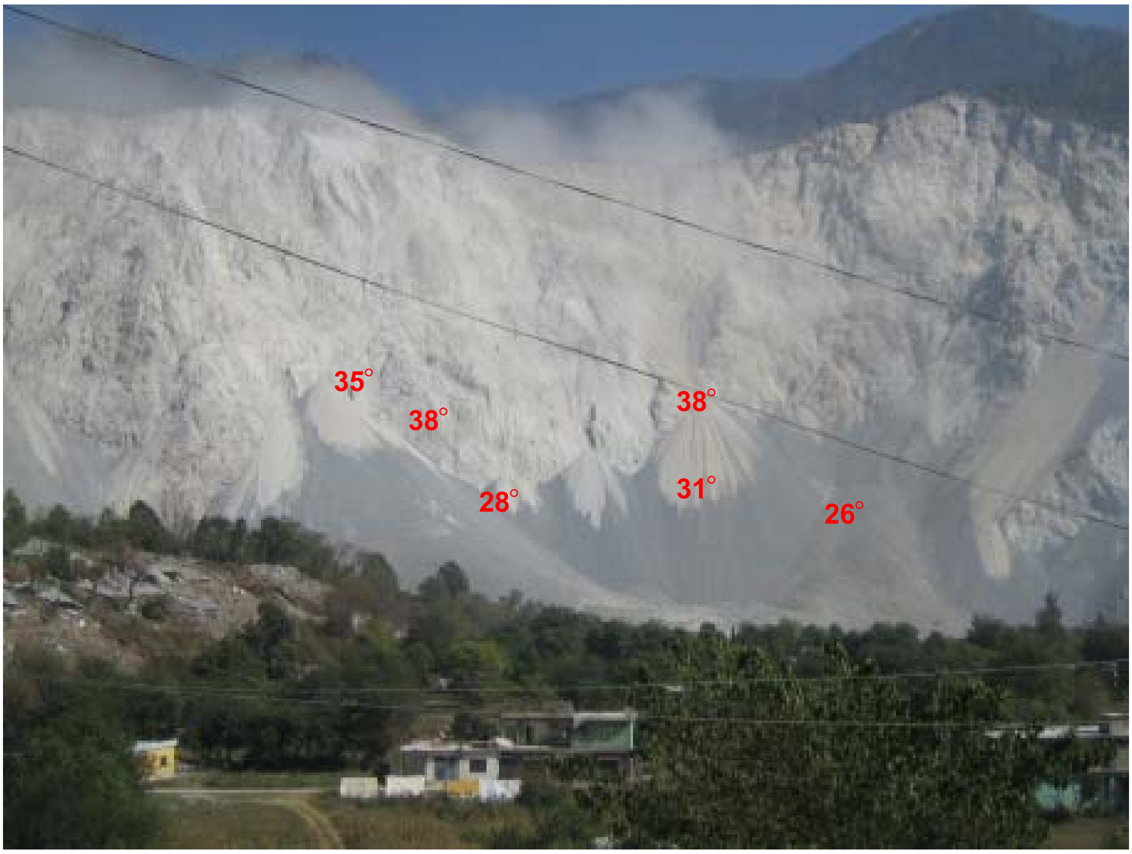


Fig. 11. Massive cliff failure (Muzaffarabad)

RECOMMENDATIONS TO MITIGATE EARTHQUAKE=INFLICTED LOSSES

Soils, foundations and dwellings

1. There is a need to study engineering (physical) and geological features of soils and rocks of mountains existing in the affected areas for rational measures to stabilize slopes.
2. Where possible, two or more storey structures should be constructed on piles. Where not possible or difficult such as on slopes, shallow foundations can be used if they are properly designed to withstand/resist differential settlement. Providing a connecting beam on or slightly below the ground level can reduce the effect of the differential settlement.
3. Frame structure buildings consisting of RC columns, beams and slabs will be more resistant. Alternatively, if affordable, steel frame structures will definitely be more resistant.
4. If possible, houses on slopes should be kept detached from each other.

This Earthquake was yet another evidence of the high seismic vulnerability of adobe and un-reinforced masonry structures (Kucha houses). Although it is possible to ban the use of stones and clays as a construction material, and although the number of these stone and clay adobes is decreasing, many people with limited resources will continue to live in Kucha houses. Since people are familiar with gabions, there may be useful application of gabions.

Just for readers' information, here follows the proposals made by Fatima Mariha, Fumio Yamazaki and Kazuo Konagai (1991) shortly after their reconnaissance trip through areas affected by the Hindukush earthquake of February 1, 1991.

SUGGESTIONS FOR EARTHQUAKE RESISTANT KUCHA STRUCTURE

During an earthquake, the loss of human lives is mainly due to the collapse of Kucha type of structures. These structures can be regarded as non-engineered as their design does not follow the standards to resist the lateral earthquake forces. Pakistan as well as most of the earthquake-prone developing countries has a serious problem with these non-engineered structures. Unfortunately, this problem is increasing rather than decreasing because of growing population, poor economic conditions, scarcity of wood, cement and stee1, 1ack: of understanding of earthquake features, etc.

Factors affecting the Damage

The structural action and damage mechanism can be generalized as under:

Defects in the structural configuration

Unsymmetrical geometry, both in plan and elevation and big openings for door and windows in the walls are found to be some of the main factors responsible for the damage.

Foundation failure

Liquefaction of soil, occurrence of soft pockets or settlement of soil result in inadequate foundation support. This leads to the structural failure of rather sound structures. Shallow foundations fail earlier during an earthquake.

Lack of structural integrity

Failure of connections between wall and wall, roof and wall and foundation and wall may cause failure of structure. Heavy weight of roof and poor connections with other elements may result in severe damages.

Poor construction quality

Poor quality of construction, like the use of weak materials, poor workmanship, inadequate skill in bounding units, improper connection between the members, etc., results in the failure of the structures.

General suggestions to improve construction standards
The study of the failure mechanism of the Kucha structure leads to the following general suggestions to improve the design and construction for earthquake resistance.

a) The site should be selected carefully. Construction should be done only on stable slopes. Loose sands should be avoided.
b) Symmetry and rectangularity should be maintained in the planning of the house.
c) Shallow foundations should be avoided. The walls should be well rested over the foundations.
d) Quality of mortar should be improved. Stone or block should be well set in mortar. A plaster of mortar on the wall will increase the strength.
e) All the resisting elements should be well connected with each other to produce an integrated structure.
f) The weight of the heavy earth roof should be reduced and its connections with the supporting walls should be done carefully.
g) The quality of construction should be improved and emphasized.

Suggestions to improve the structural performance
In the light of the above general suggestions, the following simple modifications are suggested for different types of construction to improve earthquake resistance.

Stone Adobe Houses
a) To increase the shear strength of the stone walls, a better mortar than mud should be used.
b) Quarry stones should be preferred over round field or river bed stones.
c) Bond stones should be provided wherever required.

Clay Adobe Houses
a) Dried grass, rice husk and other similar locally available materials should be added in the clay to improve the strength.
b) Corners and junctions of the walls should be strengthened by providing wood planks, steel bars, wire mesh, etc.
c) Continuous timber lintel with enough embedment should be provided around the openings.

Clay-Block Adobe Houses
The behavior of clay-block adobe structure is found to be better than clay or stone adobe structures. This may be due to the better quality and geometry of the materia1.
a) Reinforcing bars should be provided at the corners and the junctions of the walls.
b) Connection between wall and roof should be made carefully.
c) Better quality mortar should be used.

PROPOSAIS TO MITIGATIE EARTHQUAKE LOSSES

The northern part of Pakistan is highly vulnerable to seismic activities. This is not the first calamity of its kind in Pakistan and there is no way of knowing when and where some disaster may strike again. There should be effective disaster mitigation settings to cope with such emergencies. It is necessary to tackle the problem by upgrading existing structures, introducing effective programs for preparedness among the general public and improving the existing communication system.

Structural Aspect
In order to reduce human and property losses in the future, serious efforts are required to improve the earthquake resistance of Kucha construction. To upgrade the existing structure, the following

recommendations are proposed:

a) The development of a serious program of research for improving the seismic behavior of locally available materials.
b) The formulation and implementation of a feasible program for upgrading and strengthening existing structures to withstand moderate earthquakes.
c) The dissemination of a set of simplified guidelines and rules for better design and detailing.

The first two tasks are not easy and require substantial funds but are essential to avoid heavy human loss in future major earthquakes. The third task is relatively easy and can be achieved by educating the people what to do and how to do it. It should be noted that the earthquake resistant solutions suggested above are not very expensive as compared to the present usual construction. Providing the additional corner reinforcement, tie beams, etc are very effective and not so expensive.
Thus, builders should be educated about these effective measures.

Preparedness Program
In view of the uncertainty about when the next earthquake will occur, necessary supplies like food, medicines, tents, etc. should be maintained as a permanent stock. Sound structures of the area should be designated as emergency centers. Considering the difficult accessibility, local residents should be trained as rescue workers and paramedics to cope with immediate post-earthquake situation.

Communication System
Earthquake-prone areas should be well connected with the provindal center, Peshawar. Telecommunication network should be expanded and round the year operation should be highly emphasized. Accessibility to far flung areas should be improved. Existing roadways should be expanded and upgraded to all weather roads.

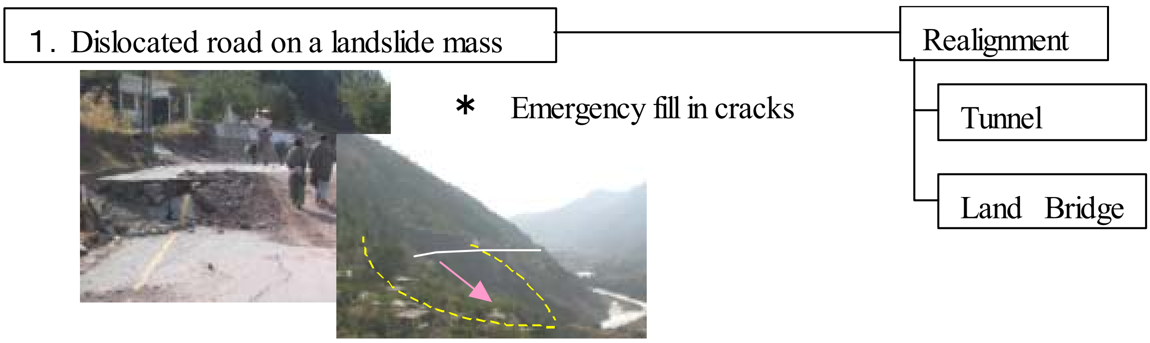
Roads and transportations

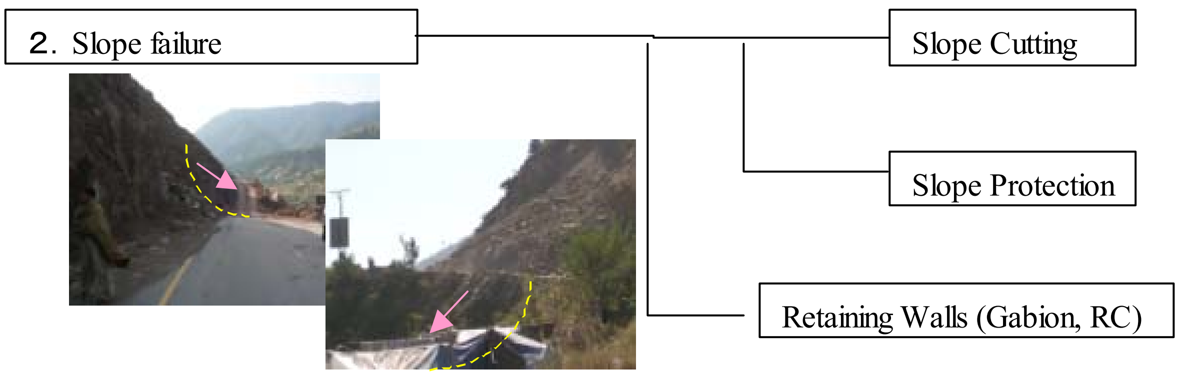
Short-term measures

1. Satellite and/or aerial photographs will provide useful information about geotechnical hazards along major roads. Extracting high-risk points, quick and thorough investigations are to be conducted at these high-risk points.
2. Unstable soil/rock masses remaining above the road are to be removed. If impossible, a possible distal end of landslide mass/debris is to be estimated. Existing debris deposits will give an important hint.
3. If road is to be constructed over debris deposits and/or landside masses, stabilize them. When a meandering river erodes the toe of the landslide mass, the toe must be protected by putting gabions etc.

Long-term measures

Long-term measures will be expensive, but surely reduce the maintenance costs. Here follows some illustrations of some measures considered to be feasible.





Figs. 12 and 13. Basic measures for slope failures

Fig. 14. Image of land bridge and tunneling

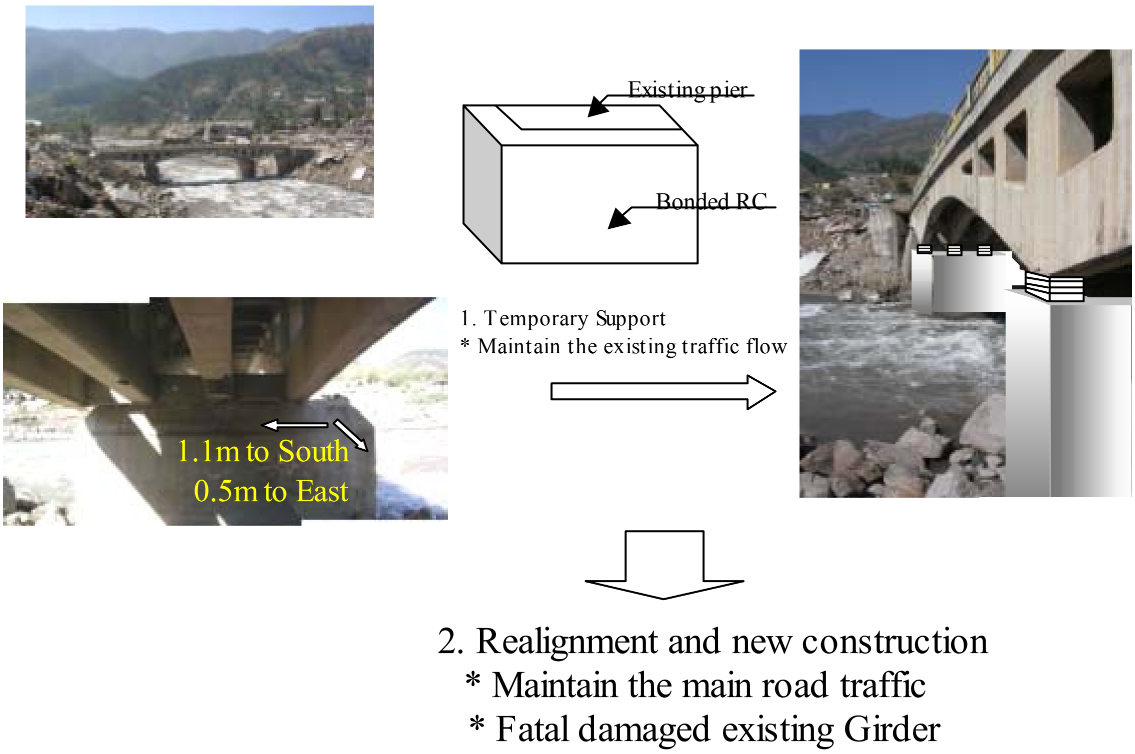


Fig. 15. Rehabilitation of Balakot bridge

Connecting existing roads point-wise by constructing new bridges etc, a cost-effective bypass can be constructed allowing bi-directional traffic to be realized. One of candidate sites for Balakot can be approx. 4km south of the city. Realizing a smooth traffic would make people to migrate easily, and new colonies will be formed.

* Avoid landslide/rockfall zones

Fig. 16. Enhancing redundancy by constructing bypass

Hierarchical operation for on-demand delivery

Here follows a proposal for hierarchical operation for on-demand delivery.

General rules

a) Urgent relief goods should be delivered within 24 hours
b) Operation center of the relief goods is to be set up. --- Big city without severe damage (can be far away from the damaged site)
c) Information sharing will be realized using wireless communication tools.
d) Relief goods without absolute urgency should be kept in satellite cities with slight damage and systematically delivered to the damaged area. (Spontaneous delivery is the worst.)

Typical procedure

1) ---(Operation Center)--- Roughly estimate the total amount of the urgent relief goods (drinking water, snacks, etc.) based on number of people in the severely damaged area.
2) ---(Operation Center→Damaged Area)--- Deliver urgent relief goods within 24 hours.
3) ---(Operation Center)--- All relief goods should be sent to the operation center first and the database of these goods should be built up.
4) ---(Damaged Area)--- When urgent relief goods are distributed, a database of people who came up to receive the goods should be built up. (photographs, names, number of people in a family, injury, etc.)
5) Establish communication: (damaged area) ⇔ (satellite cities) ⇔ (operation center) using i) mobile phones, ii)communication satellites, iii) ad-hoc wireless communications.
6) ---(Damaged Area)--- Collect information of needs of refugees and reflect it on the database
7) ---(Operation Center)--- Distribute relief goods to the satellite cities (using vehicles with large capacity) based on the needs on the database
8) ---(Satellite Cities→Damaged Area)--- Relief goods are sent systematically and regularly (using vehicles with small capacity and/or helicopters)

Background information

The reconnaissance team from JSCE observed refugees in Balakot and Muzaffarabad making long lines for rations by the army, volunteers and/or NPO. At the same time, unnecessary goods are thrown away (see pictures below).

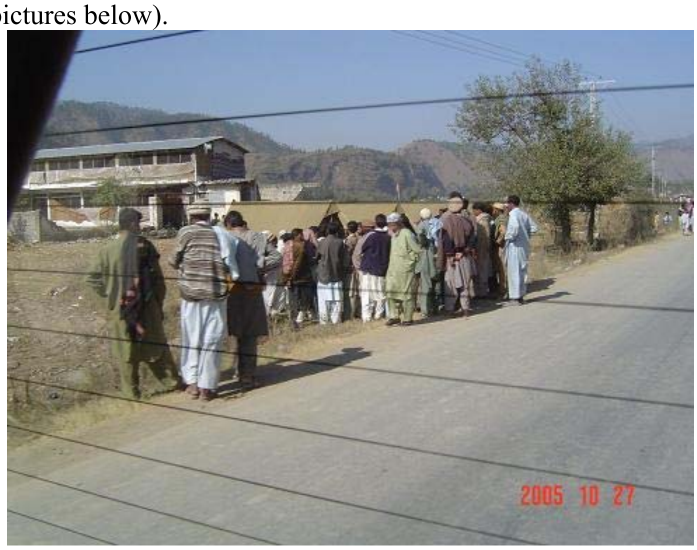


Fig. 17. Refugees gathering for ration

Fig. 18.   Cloths thrown away

This shows the mismatch between supplies and demands on the rescue goods. Also, the spontaneous delivery of the rescue goods makes people stand in the line and waste time for the goods, which are possibly of no use.

Relief goods have been dispatched from Islamabad to the damaged area mainly by small trucks. This results in a severe traffic jam. (On October 11, it took about 5hours from Mansehra to Muzaffarabad.)

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Geological map of Garhi Habibullah Area, District of Muzaffarabad, Geological Survey of Pakistan, April, 2004.

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