SITE INVESTIGATION AFTER HINDUKUSH EARTHQUAKE ON FEBRUARY 1, 1991 AND ITS EVALUTION TO EARTHQUAKE RESISTANT STRUCTURES

by:

Maliha Fatima*, Fumio Yamazaki and Kazuo Konagai****

SUMMARY

Pakistan lies in a seismically active zone with most of Baluchistan, the northern parts of the country and the Hunza area of Gilgit Agency being potentially hazardous. In this century, there have been several earthquake disasters in Pakistan. Unfortunately, they have not been properly documented and studied for damage of buildings and other civil engineering structures. On February 1, 1991, an earthquake of severe intensity struck Afghanistan and the northern parts of Pakistan. The epicenter was located in the Hindukush range which is one of the world's most active seismic region. The shocks were felt in parts of Russian Turkistan, north of Iran and northern India up to New Delhi. Due to the civil war in Afghanistan, exact statistics of damage in this area are not available. The areas in Pakistan close to the Afghanistan border received severe damage. Three months after the event, a three-member team from the University of Tokyo went to Pakistan to survey the areas affected by the earthquake and to document the damage of civil structures.

In the region, most of the building structures are the so-called adobe. Damage to these structures resulted in the loss of many human lives and property. Failure mechanism and earthquake resistant behavior of the damaged and the non-damaged structures was observed during the survey. A set of practical suggestions has been proposed for the new construction of different type of adobes. It is hoped that by adopting such inexpensive earthquake resistant measures, the structures will lead to satisfactory performance during moderate earthquakes.

INTRODUCTION

On February 1, 1991, an earthquake with magnitude 6.8 on the Richter scale hit the northern parts of Pakistan. The epicenter was

* Graduate Student, Institute of Industrial Science, The University of Tokyo, 7-22-1 Roppongi, Minato-ku, Tokyo 106, Japan.

** Associate Professor, ditto

Fig. 1 Epicenter and the surrounding areas

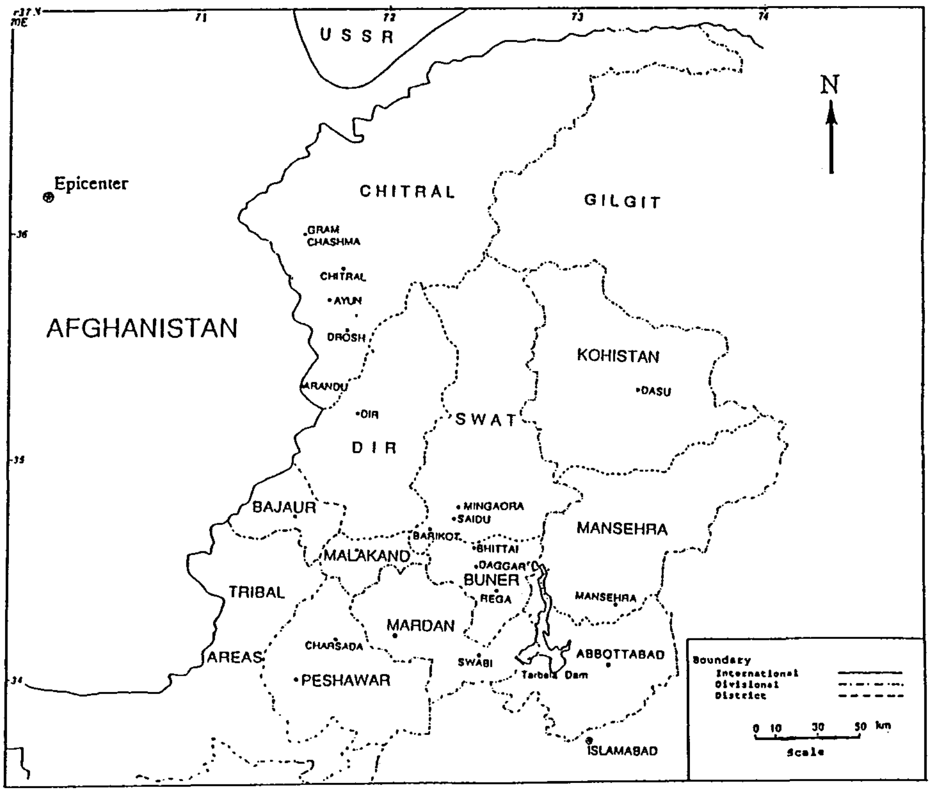

Fig. 2 Damaged areas in Pakistan including surveyed places

located in the Hindukush range at 36.2° N and 70.2° E with a focal depth of 125 km. It was severely felt in the North-west Frontier Province (NWFP) of Pakistan, Afghanistan and Soviet Central Asia. It also shook northern Iran, central Pakistan and northern India (Fig. 1).

The earthquake shocks came before dawn at 4:03 PST (January 31, 23:04 GMT). People were still asleep at the time inside their houses. Hence they became easy victims when their adobe structures collapsed due to severe jolts. At least 181 persons were killed and 741 injured. 5,187 houses were completely destroyed and 79,990 units received non-trivial damage. 5,302 cattle heads were perished. In the districts of Dir and Kohistan, major landslides have been reported. The Karakorum Highway was blocked for about two weeks.

Pakistan has an area of more than 800,000 km^2 and a population of more than 100 million. Administerially, the country is divided into four provinces, namely: Baluchistan, Sind, Punjab and NWFP. For this event, NWFP, Punjab and parts of Baluchistan experienced severe jolting. NWFP was the worst affected area in Pakistan and 90% of the entire damage was concentrated in its Malakand Division. Malakand Division is further divided into Chitral, Swat, Buner, Malakand, Dir and Bajaur Districts (Fig. 2).

Just after the earthquake, the Afghanistan Government issued a press release reporting an unconfirmed figure of 1000 casualties. Afterwards, there was no press coverage of the event so it is difficult to estimate the total damage that occurred in Afghanistan. To observe the adobe structures' behavior and damage, a three-member team from the University of Tokyo left for Pakistan at the end of April 1991. The damage is spread over the Malakand Division. However, severe damage occurred in the remote and barely accessible regions of Chitral and Dir Districts. Due to limited time and difficult accessibility, only three districts, namely: Chitral, Swat and Buner were visited by the survey team [1].

REGIONAL TECTONIC FEATURES

General Features

In the framework of the modern concept of plate tectonics, the geological setting of Pakistan is unique in the sense that active plate boundaries of different types are exceptionally well exposed (Fig. 3) [2]. In the northeast, there is an active continent-island arc-continent collision boundary, the west end of the Himalayan orogen. In the southwest, there is an active boundary of oceanic lithosphere subducting beneath arc-trench gap sediments and continental sediments, the oceanic part of the Arabic plate passing under the Makran arc-trench gap and the Afghan microplate. These two convergent boundaries are connected by very large displacement, the north-south left lateral strike-slip faults of the Chaman transform zone. The intersection of the fault systems and the fold belts has imparted a scalloped outline to the tectonic pattern which is a distinctive feature of the geology of Pakistan.

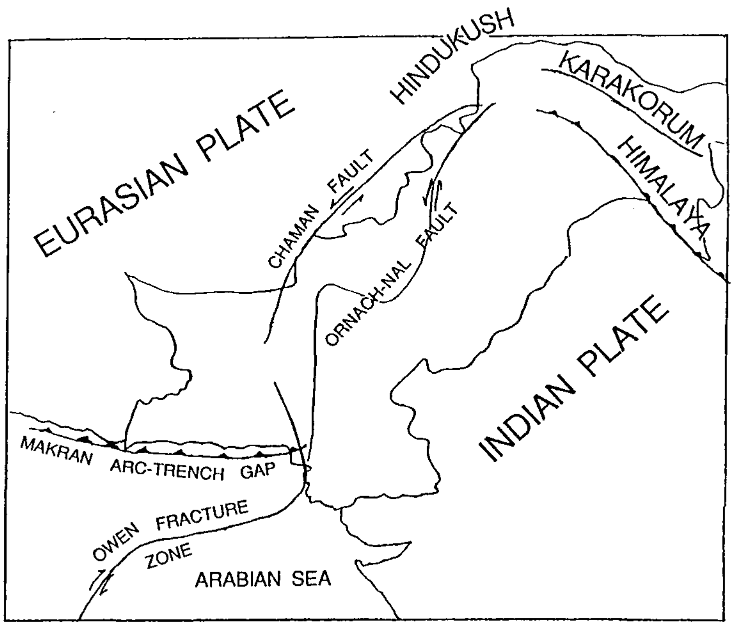

Fig. 3 Tectonics of Pakistan and surroundings [2]

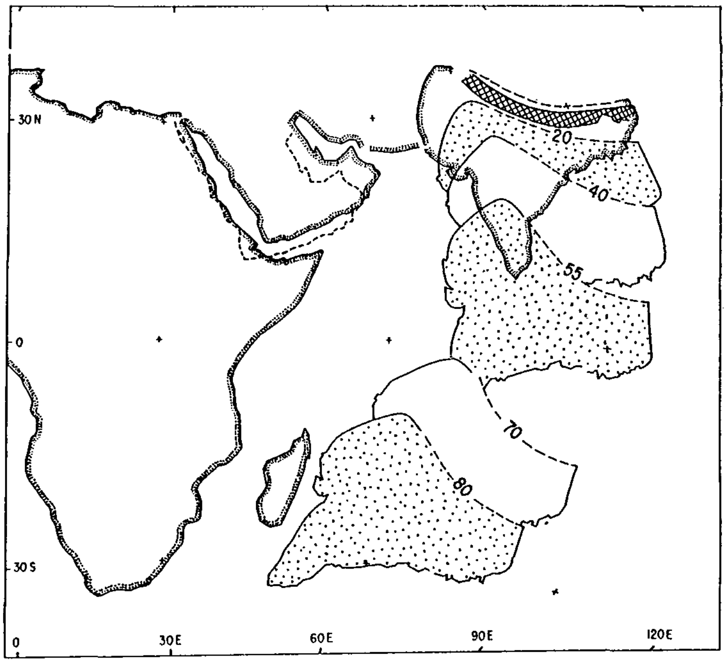

Fig. 4 The position of Indian sub-continent relative to Africa and Madagascar fixed in their present positions since 80 million years [3]

The Hindukush Zone

The Hindukush mountain zone, which fans out in NE-SW orientation from the Pamir Knot, is one of the interesting seismic zones of the world. It is considered as the final stage of subduction along the collisional boundary between the Eurasian and the Indian plates (Fig. 4) [3]. The earthquakes in this zone are enormous with most of them occurring at deep to intermediate depths. The deep earthquakes occur in a narrow zone around 36.58°N and 71.0°E while the intermediate activities are distributed over a wide area (Fig. 5). Most of the active area lies beyond the north-west boundary of Pakistan. But many deep earthquakes of the zone have been felt throughout the country and caused severe damage in the NWFP. For the instrumentally recorded earthquakes, the highest magnitude is 8.1 which was recorded on July 7, 1909.

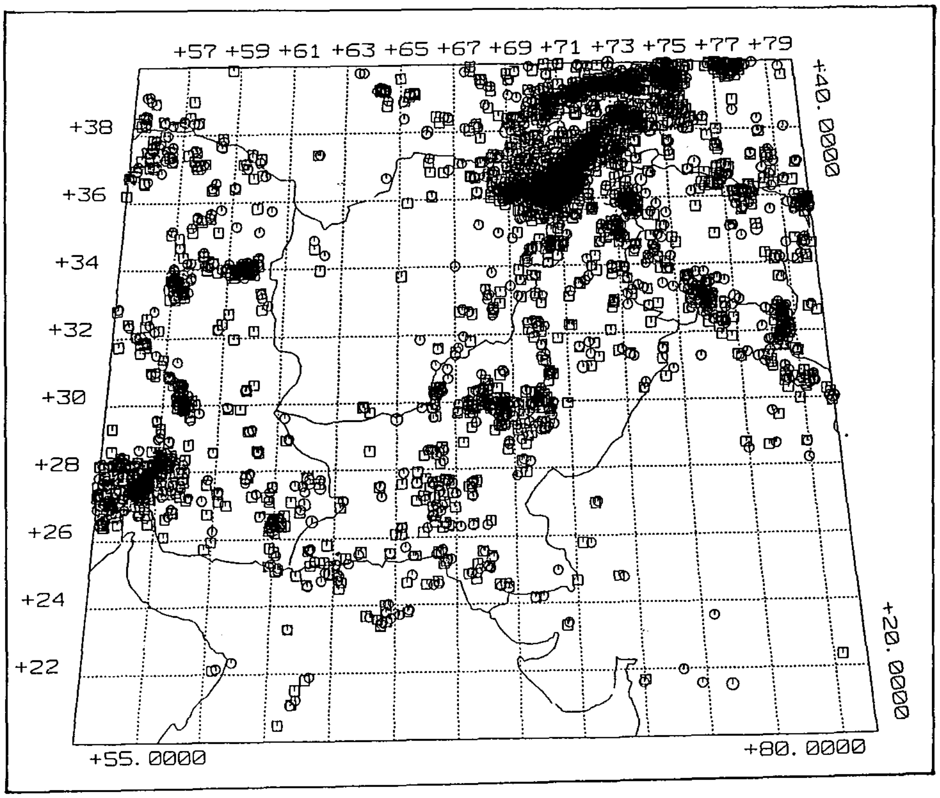

Fig. 5 Hindukush seismic zone activities

A list of historical major earthquakes originating from the Hindukush seismic zone is shown in Table 1 [4]. A few other important events are also included in the list.

Table 1. Major Historical Earthquakes recorded in Hindukush Zone

Time & Location	Details
25 A.D. (33.7°N 72.9°E)	Taxila, ruined the main center of Buddhist civilization of that period for the second time. MM Intensity X*.
893 A.D. (24.8°N 67.8°E)	Daibal, about 180,000 people died. MM Intensity X.
July 6, 1505 (34.6°N 68.9°E)	Hindukush, extensive damage was reported. MM Intensity IX.
Sep. 24, 1827 (31.6°N 74.4°E)	Lahore, about 1,000 people died. Excessive landslides were reported. MM Intensity IX.
Jan. 22, 1832 (36.9°N 70.8°E)	Hindukush, extensive damage, MM Intensity IX. Another earthquake of same intensity originated from the same seismic zone on Feb. 21.
Feb. 19, 1842 (34.3°N 70.3°E)	Hindukush, widespread damage was reported. Peshawar was heavily damaged. MM Intensity IX.
May 30, 1885 (34.1°N 74.8°E)	Kashmir, more than 3,000 people died. Many villages were destroyed completely. MM Intensity X.
April 4, 1905 (33.0°N 76.0°E)	Kangra (Mag. 8.0**). 20,000 people died. Extensive damage was reported, all buildings in Lahore were damaged.
May 31, 1935 (29.5°N 66.8°E)	Quetta (Mag. 7.5). 35,000 casualties, many cities, including Quetta, were completely destroyed.
Nov. 28, 1945 (24.5°N 63.0°E)	Makran (Mag. 8.6). Tsunami of over 15m height was produced, heavy loss of life and property.
Feb. 7, 1966 (29.8°N 69.7°E)	Barkhan (Mag. 6.0). 12 or 13 villages were razed to the ground. 5,000 buildings were damaged. 30,000 people were affected.
Sep. 3, 1972 (35.9°N 73.3°E)	Gilgit (Mag. 6.2). several villages were destroyed.
Dec. 28, 1974 (35.1°N 72.9°E)	Pattan (Mag. 6.0). 5,300 persons died and 17,000 were seriously injured. Thousands of houses collapsed. Excessive landslides were observed.
Sep. 12, 1981 (35.7°N 73.6°E)	Gilgit (Mag. 6.1). 200 people died and 2,000 were injured. Hundreds of houses collapsed.
Dec. 30, 1983 (36.4°N 70.7°E)	Hindukush (Mag. 6.6). considerable damage, 14 people died and hundreds were injured, felt up to N.W.India.
Dec. 17, 1985 (24.9°N 67.4°E)	Karachi (Mag. 6.1). slight damage to Steel mills and Port Qasim, cracks in tall buildings.
Feb. 1, 1991 (36.2°N 70.2°E)	Hindukush (Mag. 6.8). Discuss in detail.

* For earthquakes which occurred before 1900 A.D., the intensities in Modified Mercalli scale were estimated from historical documents.
** For recorded earthquakes, magnitudes (Mag.) are in the Richter scale.

SEISMIC OBSERVATION RECORDING

In Pakistan, strong motion accelerograms are installed only at Terbela Dam. Terbela Dam is the world's largest earthen gravity dam. The height of the embankment is 141.6m with a length of 2.75 km. The reservoir capacity is about $1.5*10^{10}$ m^3. It provides more than half of the irrigation water in Pakistan and generates more than half of its electrical energy. Photo 1 shows a general view of the dam.

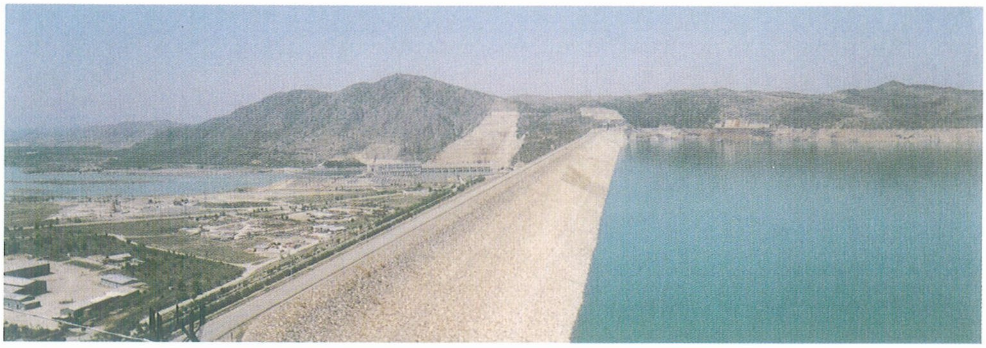

Photo 1 Terbela Dam, one of the world's largest dam

For the event of February 1, 1991, the epicentral distance is more than 330 km. Out of eleven accelerograms, six were triggered. The ground motions recorded vary from 0.08g on the rock to 0.10g at the crest of the dam. An acceleration of 0.11g was recorded at an instrument house located on the downstream slope about 46m above the toe of the embankment. Photo 2 shows the system of recording at Terbela Dam seismic observatory. Yellow drills were initiated due to this event. However, no damage was reported afterwards.

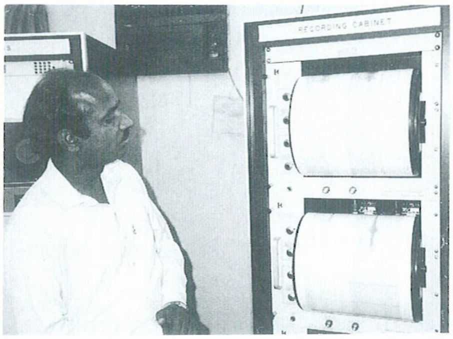

Photo 2 Seismic observatory, Terbela Dam

GENERAL DESCRIPTION OF CONSTRUCTION

The terrain is mountainous with dwellings scattered over the area. In some places, the houses are constructed by levelling the hillside. The houses are mainly constructed from locally available materials. The construction method varies from place to place depending on the availability of materials, the topography and the economic condition of the area. The building structures can be broadly classified into two categories, i.e., Pucca buildings and Kucha buildings.

Pucca building construction includes conventional reinforced concrete and load bearing structures. In this area, Pucca construction is mostly done by load bearing walls. These walls may be built from stone blocks or klin-burnt bricks set in cement mortar with cement-sand plaster (Photos 3, 4). The thickness of walls varies from 400 to 500mm. They are built with some engineering judgments and are of good standard of construction. Usually, such buildings house government offices, essential facilities and some private residents.

Kucha buildings constitute the major private housing in the area. These are made from various locally available materials like wood, sun-baked clay blocks reinforced with straw, in-place erected clay walls, walls erected by slate like stones without any mortar, round stone walls with or without mortar, block or irregularly shaped stones embedded in clay mortar without any plaster, walls constructed partially from stones and partially from clay (Photos 5, 6, 7, 8), etc. The thickness of the walls varies from 400 to 600mm. When the survey was conducted, most of the damaged houses were already reconstructed or repaired. However, damaged structures can still be well speculated.

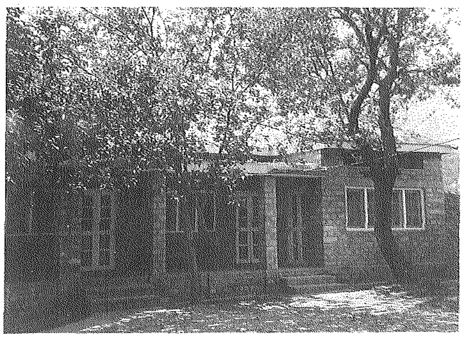

Photo 3 Stone-block load bearing structure

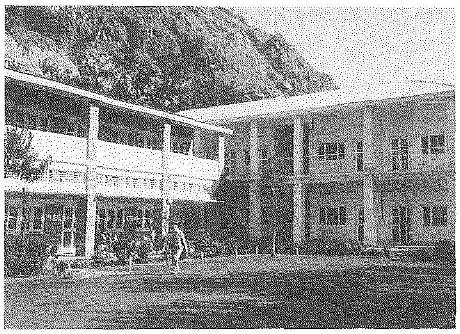

Photo 4 Stone masonry engineered structure

Photo 5 In-place erected clay adobe structure

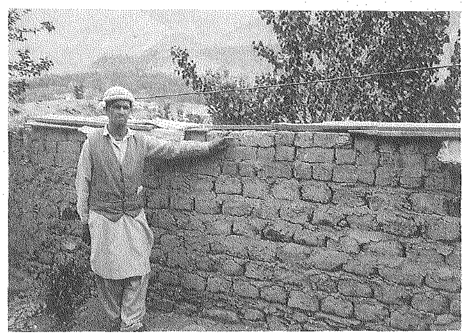

Photo 6 Sun-baked clay block adobe structure

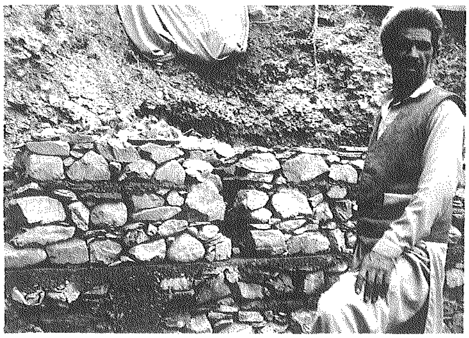

Photo 7 Irregular stones, embedded in mud mortar

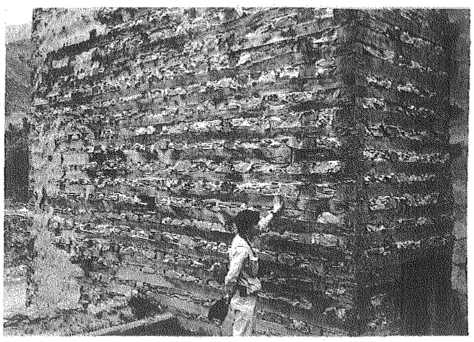

Photo 8 Stone reinforced by wood planks

Characteristic of Damage

The Pucca buildings resisted the earthquake in a better way. Except for some old ones, no major damage had been reported for these buildings. The damage included wide cracks (Photo 9), spalling of plaster, partial damage of internal walls, collapse of boundary walls, etc.

The Kucha type of construction sustained more damage which ranged from complete collapse to minor damage. In most cases, the houses collapsed when the earthquake struck. In some cases, they received major damage and came down afterwards when the rains started. The main factors which contributed to the damage of these structures were their heavy weight, brittle behavior with low tensile and shearing stresses, lack of adequate structural connection between walls and between roof and wall, poor quality of construction and deterioration of strength with time.

Stone Adobe

Usually, mud mortar is used to bind the stones. If the stones are not quarried but collected from fields and river beds, they will be covered with

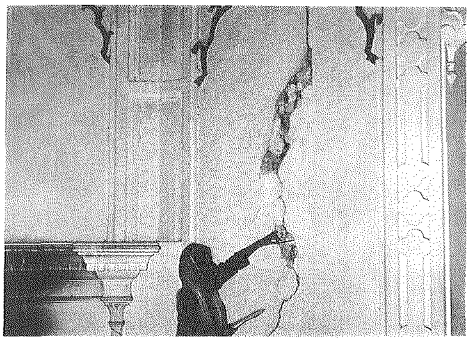

Photo 9 Damage to engineered structure

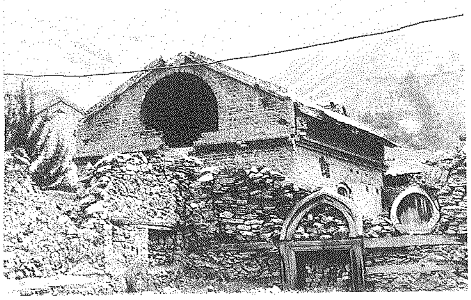

Photo 10 Failure of stone adobe, brick masonry (background) behaved well

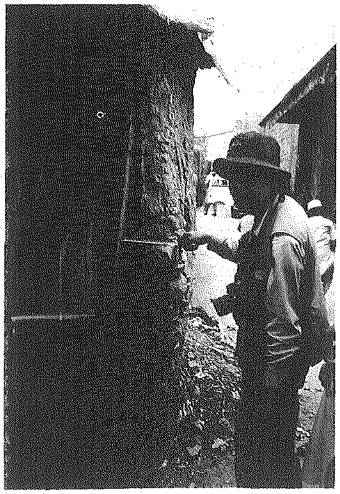

Photo 11 Adobe wall failure

Photo 12 Arch failure, Old Fort, Chitral

moss and dirt and will be round in shape. The mud mortar loses strength with time. When the strength is lost, no bond remains between the stones. During an earthquake, no shearing strength is left except the dry friction between the stones (Photo 10).

Clay Adobe

Damage patterns of adobe houses are observed as: pull apart of the longitudinal wall from the transverse wall, propagation of vertical cracks and outward inclination of the wall (Photo 11). Damage is caused by insufficient tension.

Clay-Block Adobe

In this case, the damage is characterized by the off-plane bending failure. Horizontal cracks on the tension side and partial crushing on the compression side of the wall were observed. Arches across the opening were badly damaged due to the loss of their end thrust under inplane shaking of walls (Photo 12).

SURVEY OF DAMAGED PLACES

The survey was focused on the worst affected region in Pakistan, the Malakand Division. It has an area of about 30,000 km^2 and a population is estimated around 3.1 million including 0.4 million Afghan refugees. Due to limited time and inaccessibility of some areas, only three districts (Chitral, Swat and Buner) were visited. Most of the journey was done on good-weather jeepable mountainous tracks. Interviews with the administrative officials in each district about the structural damage and the relief activities were conducted . Damage data were collected by visiting the relief commissioner office, Peshawar (Table 2). The damage

Table 2 Damage Statistics in Pakistan for February 1, 1991 Earthquake

No	Name of District	Casualties		Houses Damaged		Cattle perished
		Dead	Injured	Completely	Partially	
1	Swat	10	86	632	8498	359
2	Malakand	15	27	234	7352	70
3	Dir	26	164	901	9432	945
4	Chitral	24	155	1103	18035	2537
5	Bajaur	38	120	491	12076	363
6	Buner	36	108	833	9695	593
7	Mansehra	23	69	633	3088	159
8	Abbotabad	-	-	206	2432	34
9	Kohistan	2	5	117	362	136
10	Mardan	5	-	17	6708	72
11	Swabi	1	5	-	1881	34
12	Others	1	2	20	431	-
	TOTAL	181	741	5187	79990	5302

statistics do not include the damage to Afghan Refugee as their affairs are looked after by international agencies.

Chitral District

Chitral, which runs along the Pakistan-Afghanistan border, is areawise the biggest district in the Malakand Division. It has an area of 14,750 km^2 and a population of 277,000. The district can be divided into main, lower and upper Chitral. Its altitude ranges from 500m to 7,692m which is the peak of Trich Mir. From Peshawar, it is about an hour flight between the mountains of over 3,000m. Chitral District had suffered the maximum damage from the earthquake.

Chitral and Surroundings

Chitral City is the districtquarters of Chitral District. It lies at an altitude of 1,500m. The epicentral distance was 145 to 150 km. The intensity was estimated at X in Modified Mercalli (MM) scale [5]. The city's airport, which is the only one for the area, operates in good weather only. At the time of the earthquake, the city and the surroundings were covered by 0.3 to 0.4m thick snow. The water channel serving to the hydro-power station was hit by rolling boulders. It was able to supply water and power normally after two months when the repair work was finished. The telephone lines performed well.

The standard of construction around the city is comparatively good with 30% by Pucca. About 20% of the Pucca buildings received non-structural damage like wide diagonal cracks in the masonry (Photo 13), falling down of parapet wall, spalling of plaster, damage to roof chimneys, collapse of boundary walls, etc. One of the minarets of a city mosque, about 18m high, fell down (Photo 14). Some of the old constructed houses were rather severely damaged.

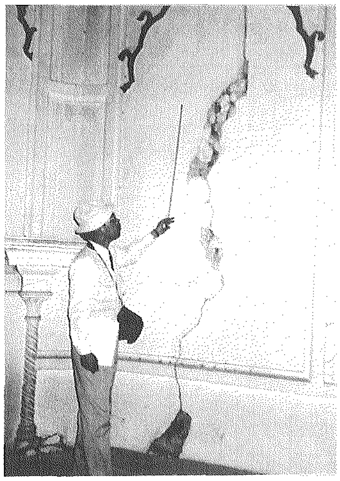

Photo 13 Cracked masonry wall, Chitral

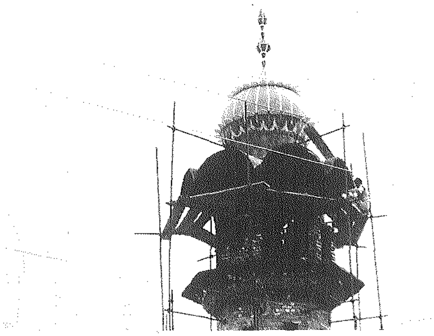

Photo 14 This minaret fell down, City mosque, Chitral

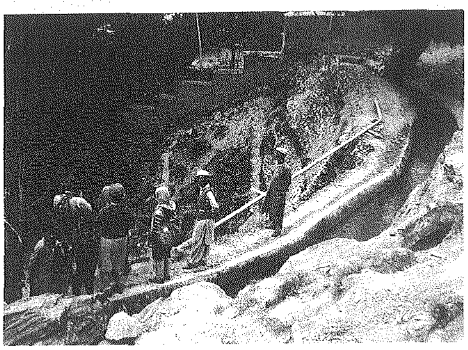

Photo 15 Village built on hillside

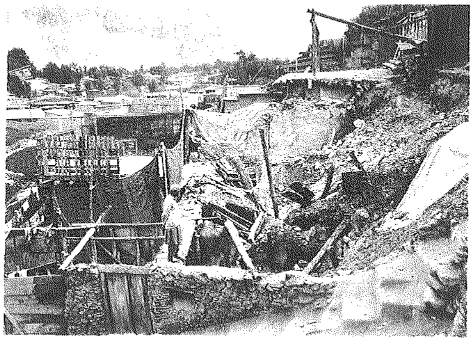

Photo 16 26 houses collapsed in this village

The Kucha buildings in this vicinity are made mainly from clay blocks or stones embedded in mud mortar with horizontal timber reinforcement at regular intervals. About 90% of such buildings received damage, 20% of which collapsed totally. In a village near the city area, houses are built on a man-made terrace. Out of 260 dwellings, 26 were completely destroyed and 160 received major damage (Photos 15, 16).

Ayun and Vicinity

Ayun is a village located about 20 km southwest of Chitral City. The intensity was IX in MM scale, with 90% of the Kucha structures and 20% of the Pucca structures damaged. Excessive rockslides took place around Ayun and in the Kalash valley (Photos 17, 18). Afghan refugees' dwellings also received considerable damage.

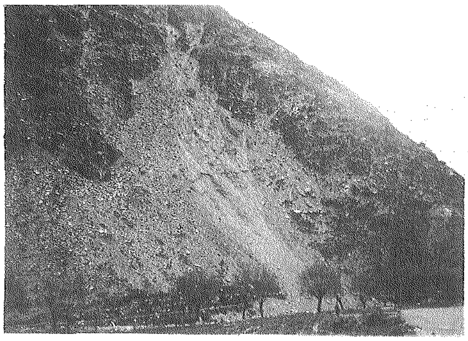

Photo 17 Rockslide near Ayun

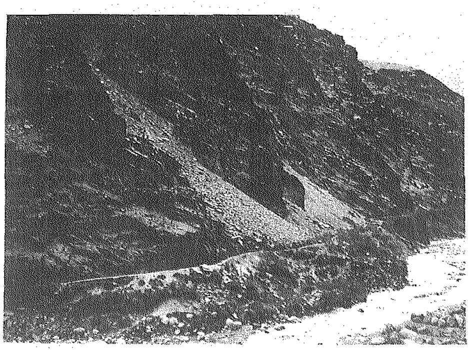

Photo 18 Rockslide in Kalash valley

Photo 19 Collapsed houses in Drosh

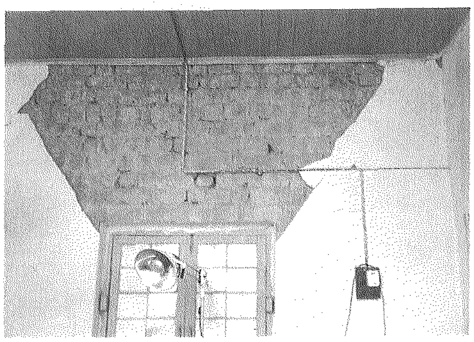

Photo 20 Non-structural damage to Pucca, Civil Hospital, Drosh

Drosh

Drosh is located 30 km south of Chitral City. The intensity was IX in MM scale. 90% of the Kucha buildings and 15% of the Pucca buildings were damaged. Most of the Kucha buildings are made from irregularly shaped stones with or without mortar (Photo 19). Among the Pucca buildings, the Meteorological observatory building was partly damaged with the retaining wall totally destroyed. The Civil hospital also received non-structural damages like spalling of plaster (Photo 20), wide cracks in the masonry and collapse of internal walls.

Arandu

Arandu is located at an altitude of 500m in lower Chitral valley. The distance from epicenter is about 155 to 160 km. It is situated 98 km southwest of main Chitral on the Pakistan-Afghanistan border. The intensity felt estimated as X in MM scale. All Kucha houses and 25% of the Pucca were damaged. For the Pucca, one of the reason of failure may be the poor connections between walls and wall and roof (Photo 21). Most of the Kucha structures either collapsed by ground shaking or demolished afterwards due to major damages. The police station building also collapsed (Photo 22). The boundary wall of a hospital, which was built

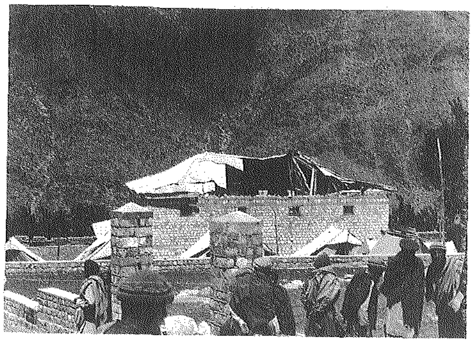

Photo 21 Damage to Pucca, Aradu

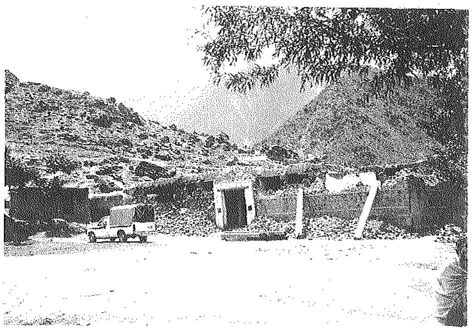

Photo 22 Damaged police station, Aradu

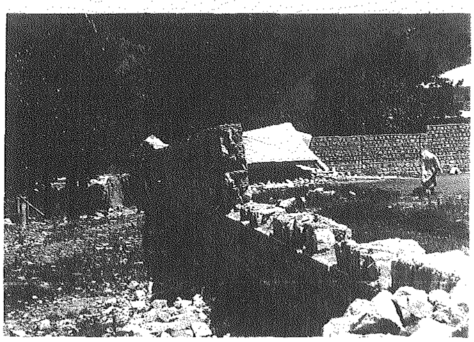

Photo 23 Blocked stone boundary wall, Arandu

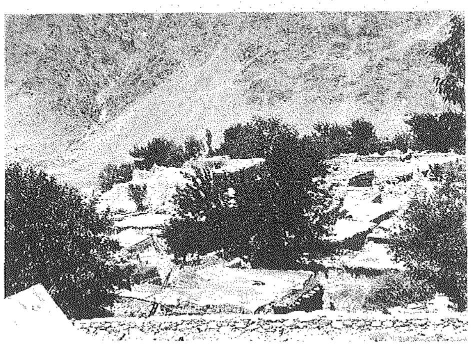

Photo 24 Reconstructed village in Arandu

Photo 25 Rockslide on way to Arandu

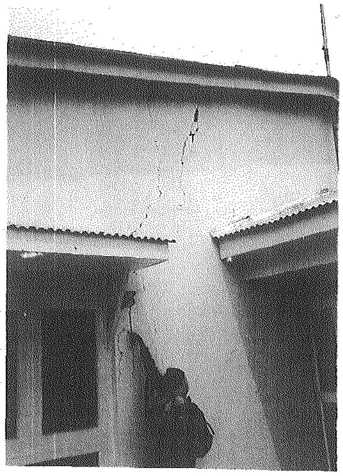

Photo 26 Governor House, Gram Chashma

from rectangular shaped stone blocks embedded in cement mortar, fell (Photo 23). A village having 300 dwellings was completely razed to the ground (Photo 24). A number of slides were found on the mountain trail leading to the place (Photo 25).

Gram Chashma

Gram Chashma is located in upper Chitral valley at an altitude of about 3,000m. The epicentral distance is approximately 135 km. It is situated 47 km northwest of Chitral. Unusually heavy snowfall was reported last year. When the earthquake hit, the area was covered by about 1.5m thick snow. Due to the heavy snowfall, the telephone lines to Gram Chashma were already disconnected. The trail leading Gram Chashma was also inaccessible because of the heavy snow and the rolled down boulders and glaciers. The trail was opened to vehicular traffic in the last week of April. The upper areas were still inaccessible at the time of the survey.

In the Pucca masonry walls of the Governor's house, cracks developed with spalling of the plaster (Photo 26). Most of the damage in upper Chitral were due to rockfalls from the steep valley. In many instances, large boulders fell on the roofs of the houses which had suffered

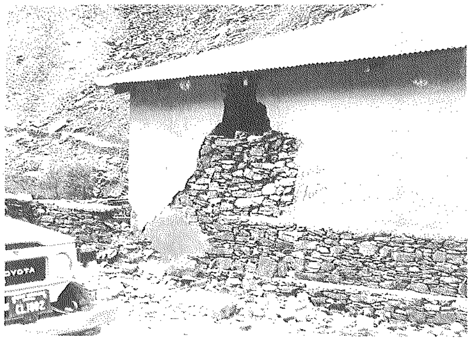

Photo 27 Wall breached by the boulder, which is still inside

Photo 28 Fallen pole, hit by rolling boulders

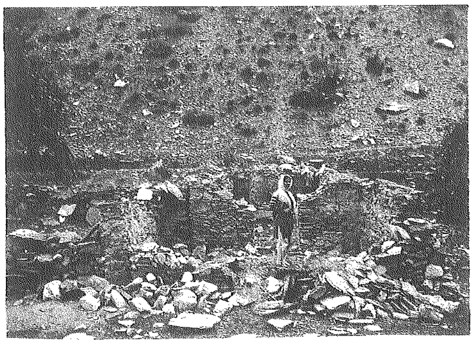

Photo 29 Collapsed dry masonry house, Gram Chashma

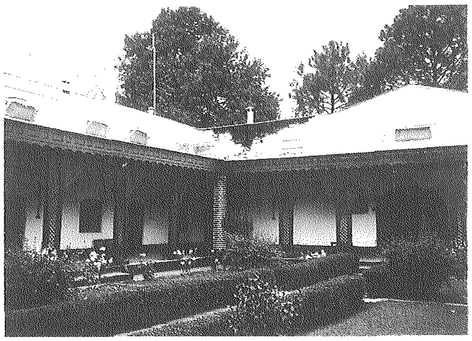

Photo 30 Damaged engineered structure, Swat

no structural damage from ground shaking (Photos 27, 28). The structures destroyed by shaking were mostly built of dry masonry with walls more than half meter thick, often made of balanced round stones. Such walls rarely fall sideway as a unit but collapsed due to crumbling (Photo 29).

Swat District

Swat District is the eastern part of the Malakand Division. Saidu, the divisional center is about 250 km from the epicenter. The construction quality is better as compared to other places. Mingaora is the worst affected place of the district with about 300 collapsed houses. In Saidu, most of the Pucca buildings suffered non-structural damage (Photo 30). In Nawagai village in Barikot, a place south of Swat, ground started to settle down after the earthquake. One month after the earthquake, rains started and triggered the ground settlement. The progressive settlement, which is still continuing, results in structural failures (Photos 31, 32). In upper Swat, some landslides which damaged the Karakorum Highway had been reported .

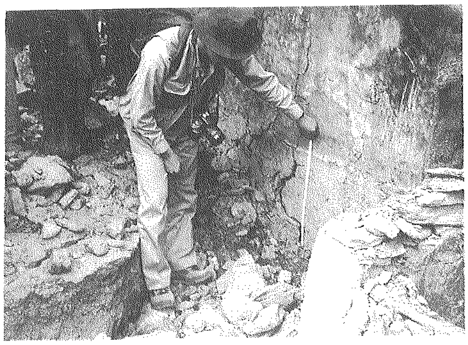

Photo 31 Uneven ground settlement, Barikot

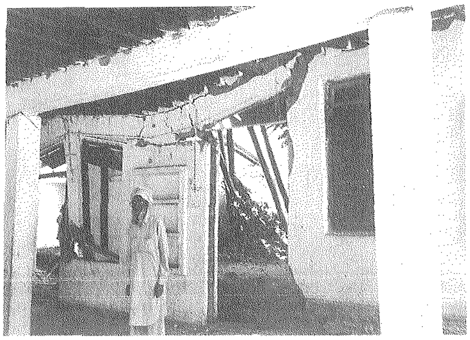

Photo 32 Structural damage due to ground settlement, Barikot

Photo 33 Damaged houses in Bhittai, Buner

Buner District

Buner District is situated south of Swat. Daggar, the districtquarters is located about 280 km from the epicenter. The shaking was severe throughout the district. However, the northern parts were more damaged by the ground shaking (Photo 33). Some of the damaged houses fell down after the earthquake because of the rains which started one month after the earthquake and continued for about two months. In the south of Buner, water came out from the ground which experienced excessive settlements. In places like Rega, Karappa and surrounding areas, collapse of houses and continous settlement of roads have been reported.

OTHER AFFECTED AREAS

Due to limited time and difficult accessibility, only three districts were visited by the survey team. In Malakand division, Dir, Malakand and Bajaur Districts suffered considerable damage. In Bajaur, the intensity was IX in Modified Mercalli (MM) scale. About 80% of the houses were damaged. Three villages were completely razed to the ground due to severe jolting which lasted for about three minutes. In Dir, intensity was reported as IX in MM scale . Here excessive rockslides occurred. Most of the houses were damaged by rolling boulders. At the time of the survey, the road access to Dir was completely blocked due to rolling down glaciers and rockslides. The Malakand agency is situated about 240 km from the epicenter. About 50% of the Kucha houses collapsed.

In Hazara Division, three districts, namely: Kohistan, Mansehra and Abbottabad were affected. In Kohistan, the Karakorum Highway was blocked at various sections due to major landslides. It took about two weeks before the road opened. Mardan Division also suffered building damages. The intensity in these areas ranged from VII to VIII in MM scale. In Peshawar, Kohat and D.I.Khan Divisions, the intensity ranged from VI to VII in the MM scale. Some damage to structures, from minor to collapse, had been reported in these areas. In Terbela, the intensity was reported as VI in MM scale.

Besides the NWFP region, the earthquake was strongly felt in central Pakistan. In Islamabad, Lahore and vicinity areas, the intensity was estimated to be in the range of V to VI in MM scale. Some damage to old or poorly constructed houses had been reported in these areas. The earthquake intensity was IV in MM scale in Multan, a city about 700 km southeast of epicenter.

According to Press Trust of India, the tremors were felt in northern India including New Delhi, which lies 800 km away from the epicenter in the southeast direction. Panic was reported as hundreds of people rushed out of their houses when the shaking began. Details are not available for Afghanistan, Russian Turkistan or northern Iran.

RELIEF OPERATION ACTIVITIES

The stricken region is seismically active and is frequently jolted by earthquakes. No relief funds or goods were available with the local authorities to respond to such an emergency. The event took place in the early hours of Friday which is a weekend in Pakistan. Being a bank holiday, no governmental funds could be activated immediately for relief purposes. In the meantime, the local authorities at the division and district levels started their activities and tried to be in contact with each other. At that time, all the Malakand Division was covered with snow with no accessibility to upper Chitral, Dir and Kohistan areas. This situation created uncertainty and led to higher causalty estimates in the beginning.

The immediate rescue operation was done by the neighboring people. They pooled the money they had in their pockets, purchased blankets and edibles and distributed them among the homeless people. Shelters were opened in the schools which are Pucca buildings. The first relief items were received by the local welfare organization after 24 hours in Swat and Buner Districts only. Due to the weather conditions, the relief operation in far areas was delayed. Relief supplies were air dropped in some places. However, there were areas which have not yet received any aid at the time of this survey.

The prime minister, Mr. Nawaz Sharif, visited Arandu in Chitral District and Chauttera in Bajaur District on February 2 and shared the grief of the affected people. He announced cash compensation of Rs. 20,000 for a dead person, Rs. 4,000 for an injured person, Rs. 25,000 for a collapsed house, Rs. 2,000 for a partially damaged house and Rs. 600 for a perished cattle head. It is worth mentioning that the average monthly salary of a college or university graduate is about Rs. 2500.

An emergency cell was created in the provincial capital, Peshawar, to coordinate the division and district administrations so the relief and rescue operations and the distribution of essential goods among the victims can be expedited.

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 have 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 steel, lack 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) Continous 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 material.

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.

PROPOSALS TO MITIGATE 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 Aspects

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 provincial 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.

CONCLUDLING REMARKS

Areas affected by the earthquake were visited three months after the event. The damage was spread over a large area. Due to the short duration of the team's stay in Pakistan and difficult accessibility of many places, this survey does not represent a complete picture of the situation. Moreover, most of the structures were already either reconstructed or repaired at the time of survey. Hence, this report does not cover different aspects of the damage and failure mechanism of various type of adobes. Local construction practices and failure mechanism suggest that the people had not experienced any earthquake resulting in severe damage in the recent past. Therefore, they are generally ill-informed about earthquake resistant construction. It is not practically possible to replace the existing structures by well designed earthquake resistant ones. Comprehensive studies should be made to understand the behavior of local available materials during ground shaking and improve the performance of Kucha houses.

Considering the seismic activities in the northern parts of Pakistan and the intensity of the damage experienced from time to time, it is highly recommended to revise the existing seismic zoning map of Pakistan. This is also confirmed during this event that in Terbela (epicentral distance more than 350 kms) the maximum recorded ground motion was .11g while in the seismic zoning map this region is shown in .05g to .10g zone.

The authorities should plan effective mitigation programs for similar calamities in the future. Local residents should be educated how to face such emergencies. Necessary medicines and food should be keep in ready stocks. Existing road network should be improved by connecting remote areas to the local centers.

Interesting observations can be made by studying the seismic activities in the Hindukush seismic zone. A seismic observatory, equipped with the latest technology, should be set up in Chitral.

ACKNOWLEDGEMENT

It would be impossible to name all the persons who extended their help during this survey but to each and everyone, heartfelt thanks are extended. Special thanks are extended to Mr. Asif Ezdi, Minister of Embassy of Pakistan, Tokyo; Mr. Shakil Durrani, Commissioner Malakand Division; Mr. I. B. Khan, Relief Commissioner, Peshawar and Mr. Ujihara, Tobishima Corporation, Islamabad office for their valuable help during our survey. We would also like to thank the officials at the district levels, of the Terbela Dam and of the Meteorological Department for their cooperation and for providing us useful information.

REFERENCES

[1] Maliha, F., Yamazaki, F. and Konagai, K. (1991). Reconnaissance report of Pakistan-Afghanistan earthquake on February 1, 1991, International Symposium on Natural Disaster Reduction and Civil Engineering, JSCE.

[2] Farah, A. and DeJong, K.A. (1979). An introduction : Geodynamics of Pakistan, Geodynamics of Pakistan, Geological Survey of Pakistan.

[3] Powell, C. McA. (1979). A speculative tectonic history of Pakistan and surroundings, Geodynamics of Pakistan, Geological Survey of Pakistan.

[4] List of significant earthquakes in and around Pakistan, Geophysical Center, Pakistan Meteorological Department.

[5] Khan, M. (1991). Report on earthquake damage survey, Peshawar Center, Pakistan Meteorological Department.