ASTOR VALLEY EARTHQUAKE, NORTHERN AREAS PAKISTAN
A FIELD ASSESSMENT, 1 APRIL 2003

Richard Hughes, Consultant, Aga Khan Cultural Services.

Introduction

On the 20th November 2002 a moderate sized earthquake struck the west flank of the great Nanga Parbat mountain, Northern Areas, Pakistan. This was the first disastrous event in the general area since the Darel Earthquake of 1981. The earthquake struck the junction of the Astor and Indus Valleys and several traditional villages with old buildings constructed in stone rubble were slightly to severely damaged. The Astor jeep road totally failed and in April 2003 was still in a precarious condition.

Minor ground shaking, with just very slight effects to existing building defects, were noticed throughout the region including at Astor, Chilas, Gilgit, and Karimabad. There appears to have been no significant damage to the terraced fields and to new buildings constructed with dressed stone masonry and in reinforced concrete. However, the important Astor Road and infrastructure facilities along it were substantially destroyed.

Twenty-five people were killed, many who were sleeping where walls collapsed inwards. Also, some penned-up farm animals died. The number of major injuries was not ascertained. Only six villages were significantly damaged and no more than ten sustained slight damage, as most of the affected area was a barren mountainous terrain.

The earthquake is notable for the considerable number of ‘fore’ and ‘after’ shocks, and perhaps the triggering, a long way off, of a vast glacial avalanche, at Karimabad, and creating at Atobad the location of a potential enormous landslide.

Aga Khan Cultural Services, Pakistan (AKCSP) and EEFIT visited the affected area on 1st April 2003 where the roads and electricity systems were seen to still be in the early days of being reconstructed. The inhabitants of the worst affected village are now living in government provided tents sited in the main Indus Valley. Elsewhere, for fear of future collapse, many people have moved out of damaged building to nearby land. Here, farming continues but people have not started repairing or building new houses. The team ‘s observations presented in this paper relate to a traverse made from the fringe to epicentral region.

The main reason of the AKCSP team visit was to see how the structure and materials of traditional buildings performed in an earthquake and this has important lessons for better conserve historic monuments and their components that provide earthquake resistance.

Seismology

The earthquake occurred on 20th November 2002, at 2132hrs. From the most affected villages the epicentral location was at Doian and Tato just off the Indus Valley at the confluence with the River Astor. The NEIC earthquake register indicates a magnitude of Mag 6.5 with a focal depth of under 50km (33km given in the register), centred at N35.41 E74.22. The epicentral intensity is estimated from the field observations to be no greater than VIII MSK.

The local inhabitants said that the main shock was no more than 15 seconds long and was a rapid/jerky lateral shaking, with no vertical component, and accompanied by ‘deep’ rumbling noises. Further away, the shaking was progressively less strong and the motion was attenuated to a reported gentle lateral motion of 30 seconds duration. Aftershocks are still being experienced, for example, at 3pm on 1st April 2003 people reported two small and one large ground motions that woke them up, with some people moving out of their damaged houses. No additional effects to the houses occurred.

The NEIC register shows that the main shock was preceded by 20 days of significant numbers of foreshocks ranging from magnitudes Mag 3.3 to 5.5. There was a particularly intensive phase of seismic activity 2nd to 8th November when 53 events were documented. These shocks with a couple of exceptions were all shallow, less than 50km. The foci of the earthquakes were widely spread but with a NNE –SSW trend covering 60km along the Indus Valley from Chilas to Doyan and below the 25km wide west flank of the Nanga Parbat mountain range. The patterns of earthquakes perhaps indicate 'structural' readjustment throughout an extensive region and not movement on a single fault plane.

Topography and Geology of the Setting

Topography

The topography in the affected area is dominated by magnificent and gigantic (or horrendous!) landforms. Immediately to the south the rock faces on the east side of the Indus Valley shoot up and become Nanga Parbat (8125m), eighth highest mountain in the world and with the biggest slopes anywhere - from bottom to top rising more than 5500m in one go. The Indus River flows in a gorge, often more than 1000m deep. The river gouges its way between vertical banks, sometime rock cataracts and sometime soil moraines or outwash scree fans issuing from side valleys and the latter being more than 2km long along their frontal edge.

The epicentre lies to just to the south of the Astor Valley, one of the larger side tributaries of the Indus and generally traversing E-W across the Nanga Parbat Massif and the main route up to the Deosi Plateau that is set 4000m above sea level. At the Indus confluence this valley is a narrow 'slot', with a base at about 2000m, often more than 200m deep and the same width! This landscape picture shouts out as one of vast amounts of rapid river down-cutting accompanied by equal amount of mountain uplift.

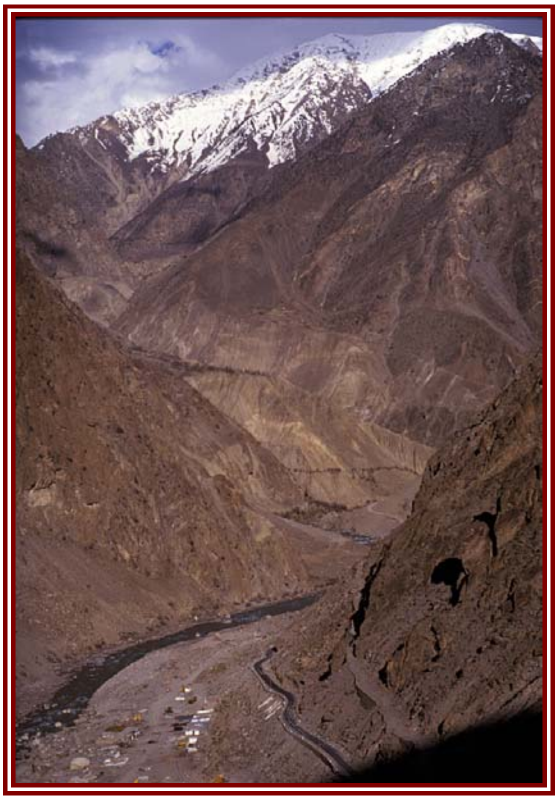

Figure 1: General view look east up the Astor Valley

The Astor road hugs the cliff face and at many locations there are soil slopes - rock scree and terminal moraines of glaciers descending off the north facing flanks of the great mountain. There are the odd house or small clusters of houses set in the gorges or at the foot of the precarious slopes and cliffs but the villages sit above the valley bottom, usually high up on raised terraces viewing down into the gorges and surrounded by small patches of terraced fields.

This is however a mountain desert environment. Without the occasional settlement the landscape would be devoid of all vegetation. The ground surface comprises loose stones and boulders and with a compacted soil crust, all tainted, to varying degrees, by coatings of desert varnish with brown-red-yellow hues. Throughout are pockets of blown sand, further south these becoming large-scale dunes.

Geology

The earthquake was located within the Nanga Parbat Massif, with the main shock being under it. This mountain is formed from a tight recumbent fold, a frontal lobe of the Indian Continental plate over-thrusting the Khoistan Island Ark structure of the Main Mantle Thrust.

Variously exposed are elements of the thrust structure including rare segments of the early ductile contact between the Kohistan Arc and Indian plate. However, the margin is typified by later structures associated with metamorphism and shallow-water formations. Throughout shearing, faulting, and uplift are outstandingly demonstrated. Astor valley, at the junction with the Indus illustrates, in a south -north orientation, the early ductile contact and later north-south faulting.

Within Astor Valley the cliffs on the road side (south) show consistent plunging of sheared, highly strained gniesses and schists with fine (cm wavelength) biotite foliations. Much of the loose rock scree formations, derived from elevated flanks of Nanga Parbat, are leucogranites and biotite microgranites. No meta-sedimentary formations of the India cover were obvious during the visit.

Observations Made Prior to the Inspection in the Epicentre Region

Karimabad and Atobad (100km to the north)

In Karimabad the earthquake was felt and people woke up but did not rush out of their houses. No new or reactivated old damage occurred to buildings. At Baltit Fort structural monitoring tell tales recorded 0.5mm of new movement but returnable swaying may have occurred unnoticed. Here on January 16th 2003 a gigantic avalanche occurred out off Mt. Ultar (7388m) and down through the nullah gorge. This spread up to 100mm of ice crystals across several square kilometres of Karimabad and on the Nagar side of the valley there was a white surface dusting. Such an event has not occurred in living memory and avalanches only occur here in spring and occasionally in autumn. Folk-tales report that once a man ploughing in Hunza was hit by an avalanche and found himself then working the fields in Nagar – this may now be not too far fetched a story! Fortunately for Baltit Fort and Karimabad, the Ultar nullah gorge is a zigzag and this would have disrupted the frontal pressure wave and velocity of the suspended ice load.

About 10km upstream of Karamabad another rare incident has occurred since the November earthquake. Sometime during the first week of February 2003 the inhabitants of Atabad, noticed a crack in the ground above their village. The crack can be traced uphill through steep scree slopes and rock debris flows and it progressively gets larger until reaching the mountain rock face where as a series of interlinked holes and cracks it is now 1.5m wide with a scarp face more than 0.6m high. It then swings back downhill until intersecting with the Hunza gorge cliff edge and where the crack also passes through some now abandoned houses.

Following inspection and then in discussion with the villagers the houses down slope of the cracked ground have been vacated. This feature has all the signs of being an incipient large landslide 300m from bottom to top and 600m across and perhaps triggered by the earthquake and topographic amplification effect – nothing like this has occurred in the area in historic times. The crack also crosses 30m deep stream channels and so in total more than 5.5Mm³ of scree could collapse off the mountainside, down 1000m, and across the Hunza Valley (click here for more information).

In Gilgit Jaglot and Chilas (20 to 50km distant)

In the towns and major settlements surrounding the epicentral region the earthquake was felt but with no damage. In all of these places people reported feeling just a main shock that was horizontal and a rapid but smooth motion. No damage was reported. No window glass was broken, nothing fell off shelves, and lights did not swing. There were no animal noises.

When passing the military cantonment at Jaglot the many well-built structures all appeared sound. It was not possible to closely inspect the outside or insides of these buildings

Effects Along the Karakoram Highway (KKH) Local to the Earthquake

Between Raicot and Gunar there were major landslides but at the usual places of slope instability. The failures were mainly boulder moraine cliffs where the road is cut back into the slope and through the hard surface crusts into loose soil powder and massive boulders. The KKH took several weeks to repair, which is not uncommon, and is functioning now in its normal bumpy way.

No damage occurred to modern bridges across the Indus or over lateral valleys.

Observation in the Epicentre of the Earthquake

The Astor Valley Road
From the Indus Valley to Astor, some 40km, 90% of the mountain road has failed. A lot of the significant collapses and burial points are in the usual places of cliff and soil moraine instability. At the

best of times, this road is a tortuous and precarious structure and is over short lengths continually being remade.

Figure 2: Clearing away rock falls along the main road into Astor Valley

- The rock cliffs appear to be mostly biotite mica schists and gneisses that have highly sheared and consistently dip to the gorge. These are interspersed with what appears to be micro granodirorites and these forming more the vertical cliffs. Fractures are epidemically open here and not just the result of blasting! Rock detritus looked very sandy and micaceous, with no evidence for strata of fine silts and clays – the absence is as one would expect from the hydrological/rock/glacier character.
- There appears to be no slope damage on the opposite (north) bank of Astor Valley – morphology looks to be naturally more stable here related to rock structure and aspect, with no instability resulting from road construction.
- The road to Harchi is mostly in a very narrow gorge and from Harchi to Astor is generally more open with the road near to river level and with it being more intact. Terraces fields and tree areas seem to have not to have been affected. Along the whole the road telegraph poles are down and short lengths near Mushkin are actively being replaced.
- The road up to Harchi is mostly a massively high and narrow gorge more vertical and soil strewn on the south (road) side. At regular intervals are side valleys. Settlements are located on the crest of the gorge and the odd building at the junction of gorge and side valleys.

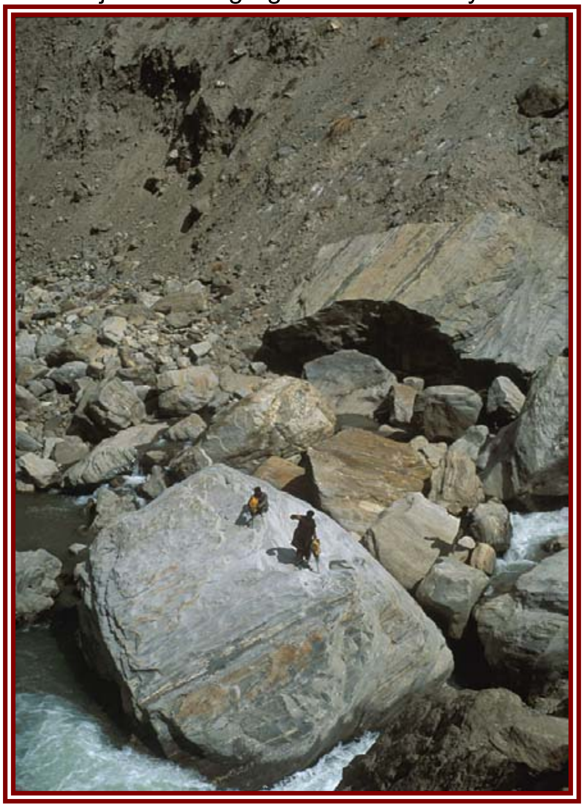

Figure 3: Breaking up a boulder that had fallen down the mountain side and forming a significant blockage in the river

- Downstream of Harchi, the moraines are wet with reports of changes to water routes and with increasing taste and smell of sulphur. At one location just down stream of Harchi several boulders in the river, the size of small houses, are being drilled and blasted to stop water flow towards the soil- rubble tip forming the road bank and which is some 50m high. Generally, the river is the recipient of spoil end tipped when forming and maintaining the road.
- Up stream of Harchi, seven small to medium ice avalanches crossed the road and three of which were sufficiently large to block it for vehicles and which now have been cut through.

Character of Buildings and Damage in the Astor Valley

The following observations were made during the traverse through the Astor Valley:

- Most villages are set above the gorge on narrow plateaux and most are near side valleys where water is easily obtained. The villages are surrounded by narrow terraced fields. The houses occur in clusters but many are isolated, set within their mountainside fields. The villages tend not to have definable centres and have no bazaars.
- Villages are either set on rock outcrops such as Doian or on moraines such as Harchu. The site aspect and agricultural potential are more important than the source of building materials and the building foundation situation. But, as a result, for example, Doian has more of a dry-stone walling technique and Harchu uses un-worked angular rock bedded with liberal amounts of weak sandy mortar.
- Houses are humble affairs reflecting on status of agriculture (here very poor and which can be compared with the rich soil terraces of Hunza and most consist of an agglomeration of small add on rooms. They are architecturally simple, very box-like, with no elaborate room arrangements and complex living spaces. There is very little ornamentation and woodcarving. Animal enclosures are abutted to the houses, as lean-too sheds. Rooms double up for storage and for animals in winter. House contents are simple; of a utilitarian character with much storage of old things, for a potential future use.
- Buildings are single storey structures sometimes staggering up the hillside with overlap for using roofs as terraces. They tend to be long and thin running along slope contours. End walls and partition walls are mostly load bearing with mid spans supported off a front to back load bearing beam. These central beams are sometimes supported with posts and occasionally these with simple capitols. Rear walls are often structurally crude, formed from *in situ* rocks and looses boulders stacked against the hillside cut. Windows and doors tend to be in the façade walls. Walls of all types generally have long quoins (good for earthquake resistance) but are made with two skins with random rubble cores and no through stones (bad for earthquake resistance). Given the traditions of Cators construction throughout Darel, Tangir, Hunza, and Baltistan, it is surprising that here there are no applications of ring beams wall plates and tying down of roof members with pegs.
- Windows and doors are full size with usual short lintels and cills.
- Roofs are all flat with beams bearing onto walls and generally with no wall plates. Beams support planks with the roof soil covering being 100 to 200mms thick. Houses do not have roof drainage and no parapet walls or end stopper planks were noted. Some roofs have sub round stone edging –probably to stop children falling over the edge and animals dislodging the soil where it is critically placed over the wall tops.
- In more recent dwellings, and in cases where there have been some improvements to old ones, there is a fashion to use corrugated galvanised iron sheet (and is probably responsible for unloading walls and removing useful compression forces). More important buildings have dressed masonry walls with raised cement mortar jointing.

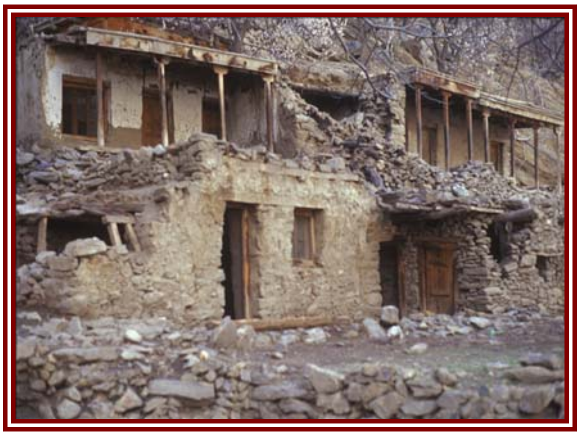

Figure 4: Major epicentral damage of the terraced mountain housing built with random rubble and mud mortars.

Figure 5: Internal damage to non-load bearing cross walls built in rubble masonry

General Discussions of the Observed Damage

The following observations were made during the traverse through the Astor Valley:

- The epicentre is at Doian, Mushkin, Dashkin and Toto where there was substantial damage. There was moderate damage in Harchu and very slight damage to pre existing defects at Astor Town. Overall the affected area was very small: a) to isolated villages in the epicentre; and b) the gorge structure along the main road.
- There appears to be no systematic damage within the settlements and the impression is that the older ones sustained most and recent ones less.
- Severe damage illustrates 'granular disintegration' of all walls and where it is not possible to see a sequence excepting collapse of the roof, from one load bearing side down onto the collapsed rubble.
- Moderately to severe damage shows corner wedge failure, outer or inner face skin (more on outside) splitting with collapse mostly mid wall, local failure under front beam, shattering of internal plaster.
- Light damage is typified by cracking at the ends of quoins, diagonal crack to top corners or away from them, occasional X pattern cracks between windows and doors.
- Quoin structures looked to have worked well.
- Dressed stone walls appeared to have survived better but the rubble internal faces of these tended to be shattered.

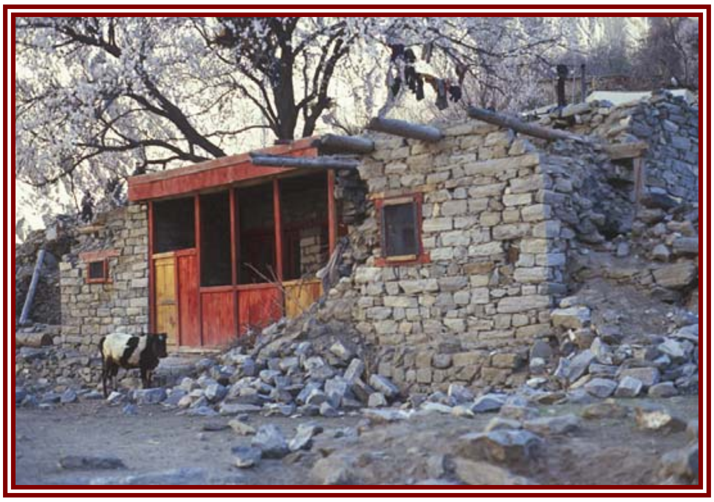

Figure 6: Load bearing facade survival in new dressed masonry

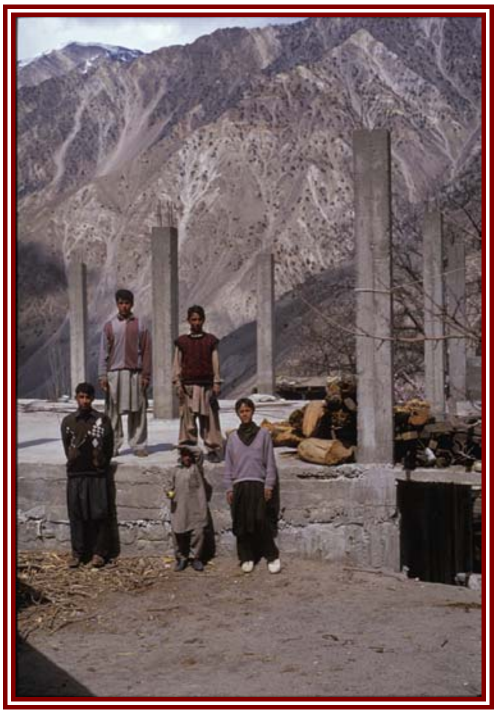

Figure 7: New 'ish' concrete columns with no damage -in epicentral region

- In light to moderately affected areas roofs appear to have generally remained intact supported of surviving load-bearing walls. Front façade walls appear to have rotated out from base having no top restraint and not being in compression.
- Cupboards set into walls often have provided structural support.
- In moderately damaged structures window glass not broken in surviving walls.
- Field terrace walls and stone steps and tracks appear not to have been damaged. There were no signs of fallen or tilting trees.
- Wall cores all seem very loose, set in sand mortar or was poor dry stone walling in some areas.
- In all cases beam-ends appear to contain decay and are loose within walls.
- No damage seen to RC column and beam structures. In Harchu, freestanding columns under construction were not damaged.
- Steep slope settings support good base drainage away from walls.
- No modern cast *in situ* RC bridges and abutments appear to have been damaged.
- Only one case was seen of a stone having descended onto and through a roof

Conclusions

The AKCSP/EEFIT visit to the Astor Valley Earthquake was rapid but where it was possible to assess damage in several villages and to the local landscape.

The earthquake was of moderate magnitude and the observed building damage is commensurate with this. Major damage occurred to the main Astor road and to the KKH, but mostly at places where scree slopes and cliffs regularly collapse and will do so in future. This will happen at the first sign of any dynamic situation including, for example, those caused by earthquake, rainfall, unusual temperatures, and glacier movements.

A major avalanche and creation of a potential large rotational landslide in central Hunza, both occurring a couple months after the main seismic shock, may illustrate trigger effects caused by topographic amplification of the earthquake ground motion.

The visit was extremely helpful to the AKCSP team in showing how important it is for historic monument conservation and old house upgrading: 1) to structural stabilise stone rubble wall materials particularly at exposed locations near their top; 2) for tying structural timbers together, especially in roof level ring beams; and, 3) to design-out places where wood decay can occur, especially in joints, beam-wall connections and base plates.

For the local people who are still living in tents, it is important that they wait until aftershocks further considerably reduce in magnitude and frequency before mending and moving back into their homes. It is clearly possible that dangerous secondary phase and knock-on damage will occur. The apparent absence of damage to fields and retaining walls is supportive of farming activities continuing. The summer months will allow for animals to be penned outdoors away from potentially dangerous walls and roofs.

It is recommended that FOCUS provides advice about emergency and disaster recovery procedures, and the consultant is very willing to give specialist advice about these activities.