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RAWALPINDI EARTHQUAKE FEBRUARY 14,1977

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ABSTRACT

On 14th February 1977 a strong earthquake of magnitude 5.8 (Richter Scale) shook the twin cities of Islamabad-Rawalpindi. This earthquake had its epicenter only about 9 miles east of Rawalpindi. Extensive damage was caused to the villages near the epicentral area. A survey of the area was undertaken to study the distribution of damage for preparing an intensity map. The seismic data obtained from the seismic network of PAEC has been used to carry out the fault analysis. A geologic map of the area has also been prepared from aerial photographs and published maps. Some of the suspected areas were visited in the field with a view to locate any surface faulting which may have taken place as a result of this earthquake. The surface faulting was, however, not observed.

Rock motions have been computed from certain emperical relationships which do not show agreement with the recorded acceleration.

The recorded ground acceleration in the meisoseismal area of 0.2g far exceeds the 0.05-0.1g value recommended for this area in the seismic zoning map of Pakistan. The authors are of the view that the seismic zoning of Islamabad area needs to be revised.

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1.0 REGIONAL AND LOCAL SEISMICITY OF NORTH P A K I S T A N

The region north of Jhelum experienced several destructive earthquakes in historical past as recorded by historians of Allexandar's reign.

The district of Hazara is also known to be partially destroyed in first century. A.D. Ruins of seismic origin are seen in some of the ancient castles in Rawalpindi-Peshawar area (3). There is strong archaeological evidence that the city of Taxila was ruined during Gondophare's region (25-50 A.D.). At the tempel of Jandial, the heavy stone plinths of the pillars and plasters were split through. At Sirkap, one of the ancient dwellings of Taxila, most of the buildings were reduced to ruins, a heavy stupa was thrown off its base and laid on its side.

From historical records it is difficult to ascertain how large this particular earthquake would have been. The fact that the coinage of Azes II were practically reduced to non-existence, suggests that the earthquake destroyed not only the mints, but also the ingravers of Azes territory which extended from Attock to Pir Panjal Ranges in the east.

This destructive earthquake led to basic changes in the architecture of the new city. The Parthias rebuilt the city with houses of deeper foundations and reduced heights.

The sudden changes in the construction techniques of Taxila suggest that this region must have been safe from earthquake for a long period. The example of Taxila and certain other regions of the world obviously demonstrate that the conclusions about present day seismicity cannot be based on short period observations.

The occurrence of earthquake from time to time indicates that the neighbourhoods of Rawalpindi, Attock and Peshawar are very unstable, without having suffered to any great extent in recent past. At Attock during an earthquake on June 23, 1669 a fissure 50 yards long was formed in the ground (10). In 1831, Peshawar and the valley of Indus upto D.G.Khan were hit by a severe earthquake. Rocks falls were observed at many places and water was forced from crevices in the plains (10). Peshawar and Kabul were severely rocked on February 19,1842. At Peshawar, shock was very destructive and many people were killed (10).Official records show that due to earthquakes in August 1868 and in April 1869 portions of fort at Peshawar were shaken down (10). Rawalpindi and adjoining areas experienced a long duration shock on December 20,1869 (10). At Rawalpindi it cracked walls and caused people to run out of houses. The shock was strongly felt at Attock and Campbellpur where it caused damage to buildings. Minor shocks are commonly recorded in this region but a few tremors having magnitudes between 4 and 6 on Richter scale have also been recorded since 1905.

2.0 TOPOGRAPHIC SETTING

The area affected by the earthquake of February 14,1977 lies at the junction of the lower Himalayas with the Potwar plateau (9). Bordered on the north and northwest by the hill ranges and the river Soan on the south and south-east, the area gradually slopes down from an elevation of 2,000 ft. near Pind Begwal to elevation 1,650 ft. near Tarlai Kalan. It is mostly covered with aeolian and fluviatile deposits with scattered outcrops of Murree Formation. There are also two linear spurs extending from the main hill ranges into the area. One of the spur is on the northwest of Kuri-Pind Begwal which attains elevation upto 2,550 ft and extends upto Rawal Dam and the other is on the south-east of Nilore extending upto Pindi Daia near Shahrah-e-Islamabad. The area in-between these spurs is deeply incised by the nalas originating from the adjoining hill ranges. The main nala in the damaged area is Gumreh Kas which is aligned nearly parallel to epicentral tract just north west of Kuri and Pind Begwal.

3.0 SEISMOTECTONIC SETTING

The epicentral region and area of Rawalpindi-Islamabad forms the north-eastern extremity of Potwar

Plateau which separates the Salt Range from the Lower Himalayas. The epicentral region is underlain by Miocene rocks of Murree Formation which are mostly covered with varying thickness of alluvium. The Margala hill ranges north of Rawalpindi, between Islamabad and Abbotabad, are traversed by a system of nearly parallel northeast-south-west trending thrust faults, known as Upper Punjab and Hazara thrust system (Fig. 1). These faults join the Himalayan thrust along a syntaxial bend towards north east and to Kirthar-Sulaiman fault zone towards south-west. The fault nearest to Rawalpindi-Islamabad area is the thrust just north of Islamabad bordering the Margala hill, between Murree Formation and older rocks. Ganssar (5) shows that this fault continues only upto Muzaffarabad and does not join the Himalayan thrust while the Geological Map of Pakistan published by Geological Survey of Pakistan (GSP) shows this thrust as persisting throughout towards north-east, continuing around the syntaxial bend of Himalayas and into India as central faults of the Himalayan System (2). The above fault is most critical for evaluation of seismic risk for Rawalpindi-Islamabad area. No detailed studies are available about any evidence of Quaternary activity along this fault to ascertain whether it is active or inactive, its relationship with the Himalayan thrust has also not been established. There are also some faults on south-east of Rawalpindi near Kahuta, one of which has its nearest trace 12 miles from Rawalpindi. Further south there are a few thrust faults near Mangla and a large postulated fault along the whole front of Salt Range starting from the Jhelum in the east upto Kalabagh in the west. The lower Himalayan thrust also passes at a distance of 45 miles east of Rawalpindi. This thrust, which is mostly at the contact of Siwaliks and Murree Formations, continues for several hundred miles towards south-east and joins the central Himalayan thrust near Kangra.

Although no attempt has been made for a systematic study of activity along the faults, however, there are many evidence of Quaternary activity in this region. Near Rawalpindi, tilted nearly vertical, Pleistocene conglomerates at Golra are folded into a syncline (12). Along the northern rim of the Soan Syncline, vertically folded Lower to Middle Pleistocene conglomerates extend for many miles and contain vertebrate fossils, teeth and bones of camelus, Equns, Bos and Conis (14). Post-Siwalik thrusts abound in the Hoshiarpur and Ambala regions of the Sub-Himalayan Punjab. In one case, the upper Siwaliks north of the Sutlej are seen pushed over the horizontal older alluvium of the Indo-Gangetic plain (7,8). Near Mangla, the Mangla thrust fault has displaced Siwaliks of the Pinjor Stage (Lower Pleistocene) by atleast 800 metres. The activity along the fault continued during Late Quaternary times and displaced alluvium with a throw of about 6 metres (1). Some recent studies by the authors have indicated ample evidence of recent tectonic activity associated with faulting in the western region of Salt Range.

4.0 THE EARTHQUAKE OF 14TH FEBRUARY, 1977

At about 0525 PST on Monday the 14th February 1977, an earthquake of moderate intensity was felt in Islamabad-Rawalpindi area. The earthquake caused damage in the villages east of Rawalpindi. The epicentral area, as reported by Geophysical Institute Quetta, was near Baramula in occupied Kashmir. However, the Lamont-Doherty seismological observatory at Tarbela and PAEC observatory at Nilour reported the epicentre to be in the vicinity of Nilour. This was supported by the macroseismic evidences in the epicentral area reported by the latter observatories.

The earthquake was recorded by all the eight seismic stations of Nilour Network operated by PAEC and also recorded by the 11 seismic stations at Tarbela. The parameters of the earthquake available from PAEC Nilour observatory are as follows:

Origin Time	.. 0022 hrs. 37.13 sec. GMT
Epicentre	.. 33^{o} 37.49 North 73^{o} 12.50 East
Depth	.. 14.46 Km
Error in Location	0.4 Km
Error in Depth	.. 0.2 Km
Magnitude	.. 5.8
Acceleration	.. 0.2_{g} at NILOUR

The earthquake was preceded by two foreshocks, the largest of which with magnitude 4.5 was felt one week before the main shock. About 57 after-shocks were recorded within 32 days of the main shock.

The event occurred before the morning prayers, when most village folks awake up and start preparing for the days errands. As stated by the local people, a few moments before the earthquake occurred the domestic animals like horses, cattle, fowls and birds panicked and a wild commotion was set up. This was followed by a thundrous creaking sound similar to that of a moonsoon thunderstorm, and the area was severely jolted. People ran out in the open as walls cracked and collapsed and small objects were thrown off the shelves. As reported by the elders of the village, such a destructive earthquake had not been felt in that area during the past century.

5. DAMAGE DISTRIBUTION

To ascertain the damage distribution,traverses were undertaken around the epicentral region covering an area of about 100 sq. miles. About 20 villages were visited between Pindi-Murree and Sihala-Kahuta road. The damage to the construction was physically observed and informations about the shock were gathered from the local inhabitants. The maximum damage is between village Kuri and Pind Begwal north-west of Nilour. As we move away from Kuri-Pind Begwal axis the intensity of damage gradually diminishes. The damage area does not extend beyond Bharakoa near Pindi-Murree road on the north-west and beyond village Ladiot near Sihala-Kahuta road on the south-east (see Fig. 2). The description of damage observed at specific localities is as follows:

The earthquake was felt strongly at RAWALPINDI but caused no damage except the collapse of the walls of two old houses, as reported in the press. The local intensity probably did not exceed IV + (MM). Also at BHARAKAO on Pindi-Murree Road, the earthquake was strongly felt but caused no damage.

East of Bhaṙakao the damage increased rapidly. At ATHAL, there is evidence of severe shaking. The ground motions were strong enough to throw-off the objects from the shelves. Here most of the houses are built with stones and mud mortar but there are also some houses built using cement as mortar or plastered with cement.Almost every house has developed cracks. Complete or partial collapse of walls and roofs has also occurred in houses built with stones and mud mortar (Plates 1). Cracks upto 3" width have been opened up at some places. The intensity of shaking in this village appears to be in the range of VI + (MM).

At PIND BEGWAL, the ground motions were so strong that it was difficult to stand on foot. The houses which are mostly built with stone and mud mortar have been badly damaged (Plate 2). Two persons were killed due to house collapse. The newly built CDA rest house near village Begwal suffered damage. The rest house is built of dressed blocks of sandstone and sand-cement mortar. The walls of the rest house have developed extensive cracks (plates 3,4). Most of these cracks are along the fillings of cement mortar between the rock blocks but at few places rock blocks have also sheared. The columns of the verandah have been sheared. Slumping of alluvial deposits on the steep walls of nala near the rest house was also observed. The intensity of shaking at Pind Begwal as inferred from the damage must have reached VII (MM).

At MALOT, east of Pind Begwal on the other side of Gumreh Kas, the intensity of shock was equivalent to that at Begwal. Here one person was killed due to collapse of roof.

KURI, where the damage was heaviest, has a population of about 5,000. Most of the houses are built of gravels and boulders with mud mortar and walls plastered with mud (Plate 5). There has been hardly any house which has not been damaged. Out of a total of 1,200 houses about 50% were so badly damaged that the houses required to be demolished before rebuilding. An old school building built of rock blocks with sand-cement mortar suffered extensive damage. Cracks were seen on the walls, and keystones of the arches have been displaced (Plates 7 & 8). The thick alluvial deposit, on which most of the Kuri village is situated, is cut by nalas towards north, east and south sides forming nearly vertical walls upto 60 ft. depth. Slumping on these steep walls of nalas was observed (Plate 9). It was also noticed that the houses built at lower level in the valley of the nalas suffered considerably less damage than the houses built on higher level on thick alluvium. Considering the amount of damage it was surprising that there was no loss of life in this village, this was mainly due to the fact that most of the village folk leave their houses early in the morning.The local intensity exceeded VII (MM).

At CHATTAH BAKHTAWAR, along National Park Road, the damage was slightly less than that at Kuri. Most of the houses, built with stones and mud mortar, developed cracks. The minartes of some mosques also fell down. Slumping on nala walls was also observed. The intensity of shaking was VI.

At TARLAI KALAN, most of the houses including those built of stones with sand cement mortar developed severe cracks. A few walls and roofs collapsed partially and three persons were injured. The minarets of three mosques have fallen down (Plate 10). The intensity of ground shaking was VI (MM). South-west of Tarlai Kalan, at KHANNA DAK only cracks were developed in walls (Plate 11) and no collapse of walls or roof was noticed.

At NILOUR certain well constructed buildings also suffered some damage. A building with a frame structure has pier foundations placed on bedrock of Murree Formations, the outer walls of the main block of this building has glass panels. Cracks were developed between the columns and the partition walls and were mainly confined to the east-west facing walls. The cardboard packing of construction joints in the roof had fallen down in some blocks. The glass panels (5 mm to 12 mm thick) particularly along the east-west aligned walls had been extensively damaged. False ceiling in some of the rooms had also been displaced. The intensity of shaking at Nilour was estimated to be about VI on MM scale.

At CHERAH and MURI south-east of Nilour, the houses have only developed cracks and collapse of any roof or wall was not noticed. Here the houses are mostly built with gravels and boulders using mud mortar but at some places sand-cement was also used as mortar. A mosque built on bedrock with rock blocks using cement as mortar, suffered no damage. People report that the objects were thrown out of shelves during the shock.

GURA MAST, a village on the other side of the hill range south of Nilour, also suffered damage. The cracks were developed in the houses built with stones and mud mortar. Due to collapse of a house few domestic animals were killed. Small objects overturned. The intensity of earthquake was about V + on MM Scale.

At BAN, the intensity of shock was equally severe as that at Gura Must. However, damage to the houses was less due to comparatively better construction and only a few houses developed cracks (Plate 12).

Towards South at PIND MALKAN slight damage to construction was noticed and only few walls developed cracks. Similarly the damage was slight at LADIOT although the shock was quite severe. The intensity at Pind Malkan and Ladiot was about V + (MM).

Further south, on the left bank of Soan River near Sihala-Kahuta Road, the shock was strongly felt at NARA SAIYIDAN and CHAK KAMDAR, but it caused no damage. The local intensity probably did not reach V (MM).

6.0 FAULT ANALYSIS

Fifty-seven aftershocks were recorded within 63 days of the main shock. The data of 57 aftershocks with their epicentral location, depth of focus and origin time is listed in table 1. The epicentres of aftershocks with their order of occurrence are also plotted in Fig.3 alongwith epicentre of main shock. In order to understand the fault mechanism and source dimensions along which these events occurred, the hypocentres of aftershocks and main shock were plotted along three cross-sectional views

AA, BB and CC (Fig. 4). Spatial distribution of hypocentres along cross sections BB and CC clearly define the zone of activity. Most of the aftershocks are located within a zone 10 to 17 Km depth, however, three aftershocks lie between 18 and 22 Km depth. The mean line drawn for the zone of activity indicates that the fault plane dip at an angle of about 50^{o} towards south-east. Cross section AA drawn perpendicular to the section BB i.e. approximately parallel to the strike of the fault plane shows that the width of the zone of activity is 3.6 Km. Therefore, the fault rupture area defined by sections BB and AA measures 3.6x9 Kms. It may be mentioned that the strike of the fault plane is parallel to the regional structural features of this area which are also aligned in northeast-southwest direction. The projected trace of the fault lies in the vicinity of village Bharakao.The isoseismal lines drawn on the basis of damage observed (Fig. 2) are also aligned in northeast-southwest direction. The ranges surrounding the earthquake region extending from the Margala hills to the Soan river was mapped from aerial photographs (Fig. 6) to study the geology of the area and to look for any possible evidence of recent activity. Some of the suspected areas were visited in field. However, so far it has not been possible to link the Rawalpindi Earthquake of 14th February with any surface faulting.

The magnitude of earthquake against the length of surface rupture of 3.6 Kms. (2.1 miles) from Bonilla's relationship (13) between earthquake magnitude and length of surface rupture also comes out to be 5.8, which is equal to the computed magnitude.

7.0 GROUND MOTIONS

The acceleration of the main event could not be properly recorded by the strong-motion instrument at Nilour. However, as worked out from the maximum recorded acceleration due to a strong aftershock the acceleration of main shock at Nilour comes out to be 0.2_g. The acceleration of main shock at epicentre and its attenuation with distance was also computed from empirical relationships developed by Orphal and Lahoud (11) and Donovan (4).

The relationship developed by Orphal and Lahoud is

$$a = 6.6x10^{-2} x10^{0.4xM} xR^{-1.39} \quad ....Eq. \quad 1$$

where 'a' is acceleration in g, M is magnitude of earthquake and R is the hypocentral distance in Km.

Donovan has developed the following relationship:

$$a = 1080 \ x \ e^{0.5 \ x \ M} \ x(R+25)^{-1.32} \quad ....Eq. \quad 2$$

where 'a' is acceleration in gals, M is earthquake magnitude and R is the hypocentral distance in Km.

The epicentral accelerations computed from above equations. 1 and 2 comes out to be 0.33 g and 0.15g respectively. The acceleration values due to attenuation with distance from epicentre were also calculated from both these relationships and are given hereunder and also shown on Fig. 5.

	Distance from epicentre (Km)	Acceleration 'g'
Orphal & Lahoud	0	0.33
	5.4	0.30
	10.6	0.25
	15.1	0.20
	21.4	0.15
	31.4	0.10
Donovan	0	0.15
	15.2	0.125
	25.7	0.10
	40.3	0.075
	65.6	0.05

The acceleration values determined by above empirical relationships are not in good agreement with the actual recorded acceleration. The accelerations at Nilour computed from these relationship are 0.30g and 0.14g while the actual recorded acceleration at Nilour is 0.2g. The attenuation of accelerations calculated from empirical relationships as shown on Fig. 5 are also not compatible to the actual intensities determined from observed damages (Fig. 2) which diminish very rapidly away from the epicentre. It may be noted that the area of maximum damage is about 6 Kms. northeast of epicentre but parallel to the strike of the hypothesized fault, this is most probably due to the fact that the fault plane along which the movement took place or the source of energy comes nearer to ground surface near Kuri-Pind Begwal area, due to dip of fault towards southeast . On the basis of verbal reporting by local people the direction of motion of shock was east-west.

8.0 CONCLUSIONS

The Nilour earthquake of February 14,1977 was a comparatively large event as compared with other instrumentally recorded earthquakes since 1900 which had their epicentres near Rawalpindi-Islamabad area. It had a magnitude of about 5.8 and focal depth of about 14.4 Km. From the field observations it appears that the area of maximum damage is aligned between the Chatta-Bakhtawar and Pind Begwal area (see Fig 2). The damage has been observed in the 100 sq. miles area around the meisoseismal region. The concentration of damage in a small area also indicates that the earthquake was of shallow depth. From the amount of damage in the meisoseismal area and the verbal reporting of the inhabitants it is estimated that the earthquake was most probably of intensity VII on Modified Marcalli Intensity Scale.

In meisoseismal region damage has occurred in almost every building whether constructed with gravel and boulder using mud mortar or with dressed rock blocks using sand-cement mortar. However, the houses built using mud mortar suffered extensive cracks and at places partial or complete collapse of walls and roofs occurred, whereas the well constructed buildings (e.g. newly built CDA rest house near Pind-Begwal) only developed extensive cracks.

Three deaths have been reported in the area due to collapse of roofs. There are also few road bridges in the meisoseismal area which suffered no structural damage.

It has been noted that the damage to buildings in the area was more severe where houses were situated on thick alluvium with no lateral support. For example Kuri, where the damage was heaviest, is situated on a raised alluvial platform. The houses built in lower areas in the vicinity suffered comparatively less damage.

The fact that areas of raised alluvial platform have suffered comparatively more damage clearly indicates that the ground acceleration has been amplified owing to the less consolidated alluvial sediments.

The study of this earthquake also shows that the empirical relationships between magnitude, hypocentral depth and ground acceleration must be applied with caution. Unless there is close similarity in the tectonic setting of the areas, the relationship may show a wide variation. Another aspect which must be understood, and proved by this event is that it could be misleading to base the seismic hazard assessment of an area on a short period observation. The geologic criteria must essentially be taken into consideration while evaluating the seismic hazard of a region.

This earthquake has demonstrated that the possibility of a destructive earthquake occuring in one of our large cities cannot be entirely ruled out. Therefore, a comprehensive study of the seismotectonics of Pakistan is essential to evaluate the realistic seismic risk in various zones of the country. Cities are growing larger and larger in population. Industrialization, and building of expensive and vital structures is taking place at a fast rate. Huge amount of money is being invested in these undertakings. Loss and damage of cities and industrial plants would be catastrophic if a destructive earthquake does strike such areas.

RECOMMENDATIONS

For the re-evaluation of seismic risk in the different regions of Pakistan following recommendations are being made:

1. The seismic zoning map published by the Geophysical Institute Quetta has placed the areas near Rawalpindi-Islamabad in the range of 0.05 to 0.1 acceleration whereas the recent earthquake indicates that the acceleration in epicentral region may have reached upto 0.33 g. It is, therefore, recommended to adopt higher seismic factor than that has been indicated by the seismic zoning map of Pakistan, for future constructions in and around the capital area.

2. Seismic zoning of the whole of Pakistan should be revised by taking following steps:

   a) Installation of more seismographs to adequately cover the whole region alongwith some strong motion seismographs in areas of known activity. Faults associated with recent activity should be properly instrumented to monitor their behaviour.

   b) The epicentres of all the instrumentally recorded earthquakes should be relocated to relate them with the causative faults in order to make a meaningful interpretation.

   c) A comprehensive effort should be made to accumulate the historical earthquake data which should be properly analysed by experts.

   d) Detailed geological mapping of the existing faults should be carried out from ERTS imagery and aerial photographs and subsequent field studies with particular emphasis to quaternary activity along these faults to evaluate their capability.

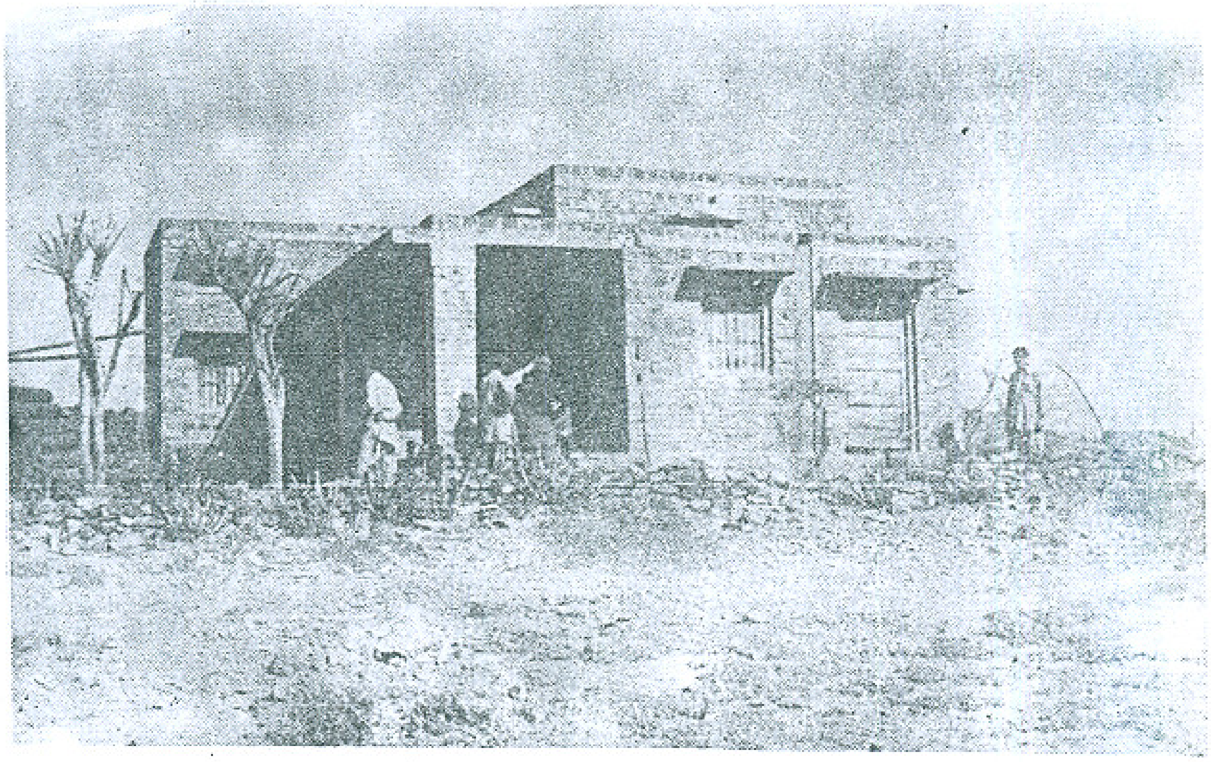


Plate No. 3 Cracks in CDA Rest House-Pind Begwal

Plate No. 4 Same as Plat-3
Close view of Cracks in Wall

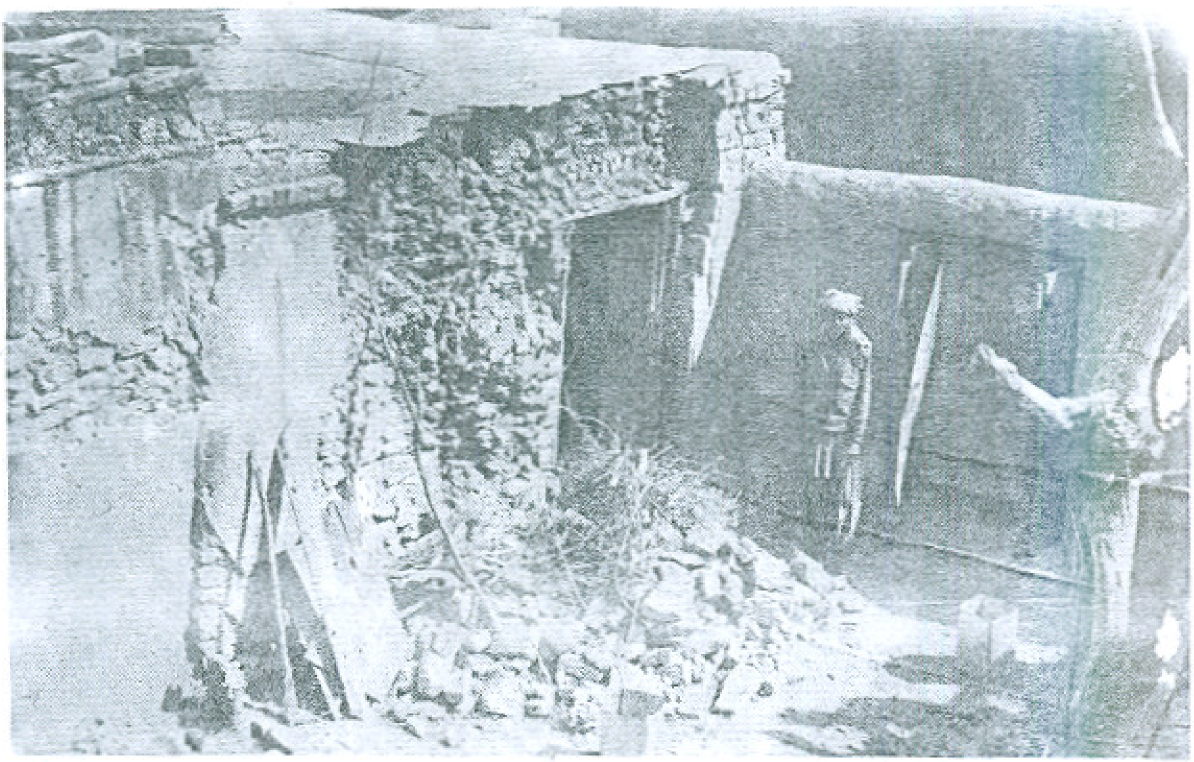
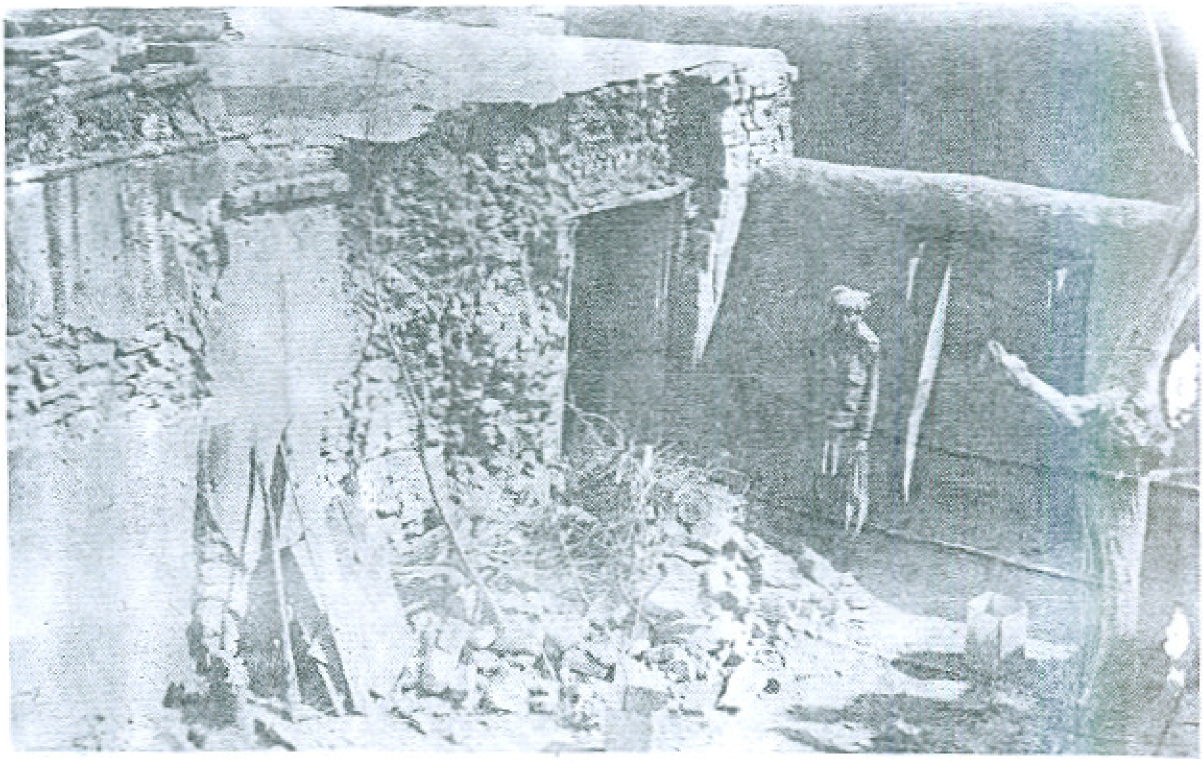


Plate No. 5 Partial collapse of walls of houses built with rubble using mud mortar - K u r i



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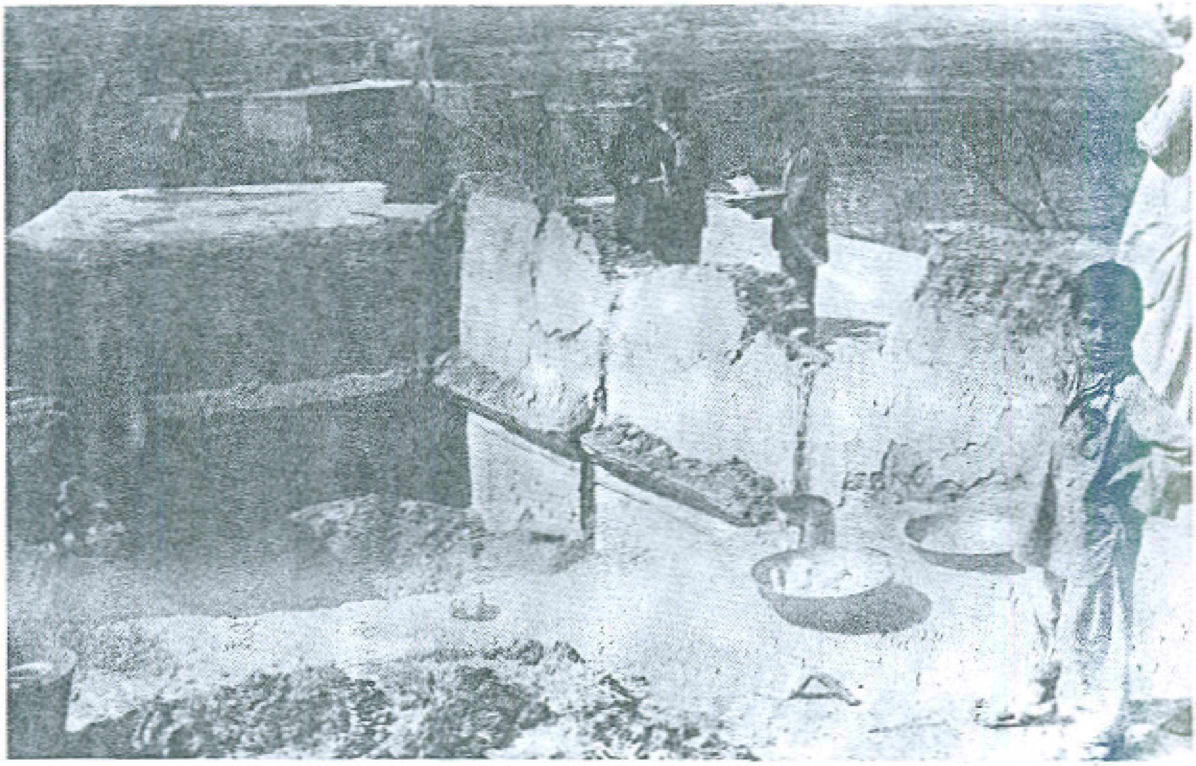

Plate No. 6 Roof collapse, Cracks in plaster and tilting in walls built with rubble using mud mortar-Kuri

Plate No. 7 Extensively damaged part of Kuri School being demolished.

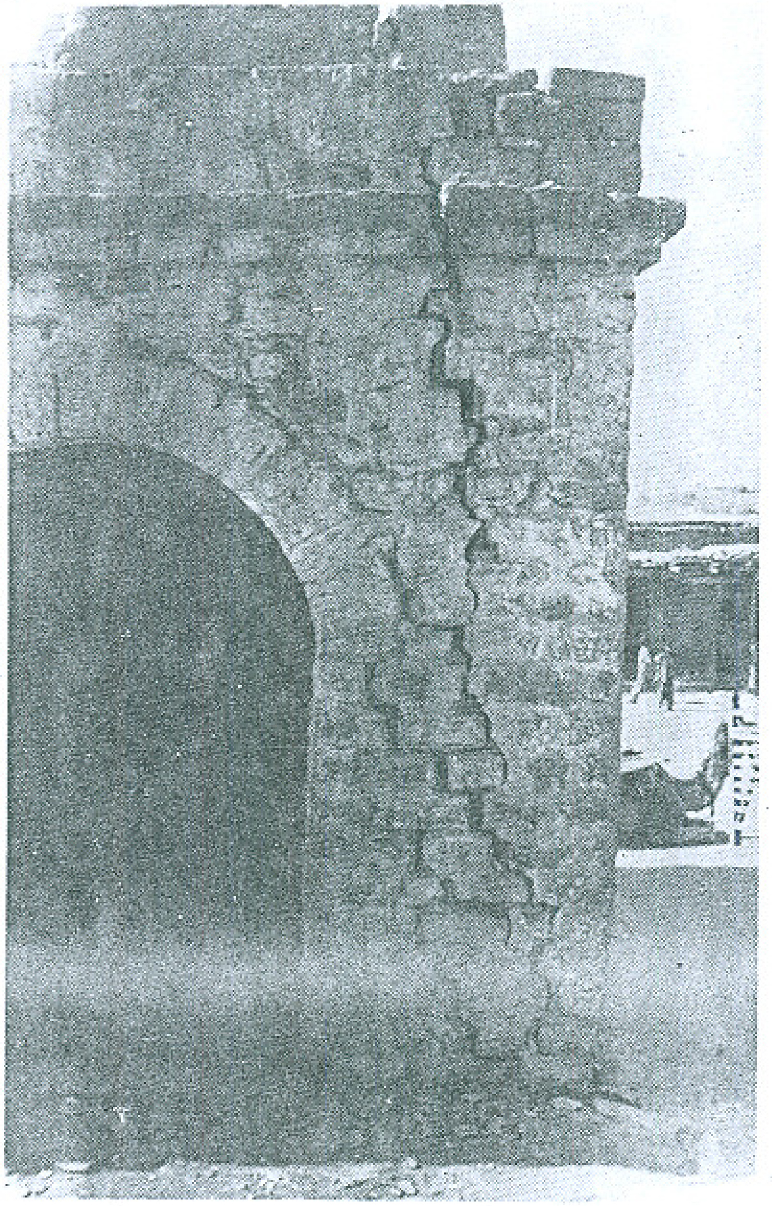

Plate No. 8 Cracks in wall built with dressed rock blocks using lime mortar -Kur School.

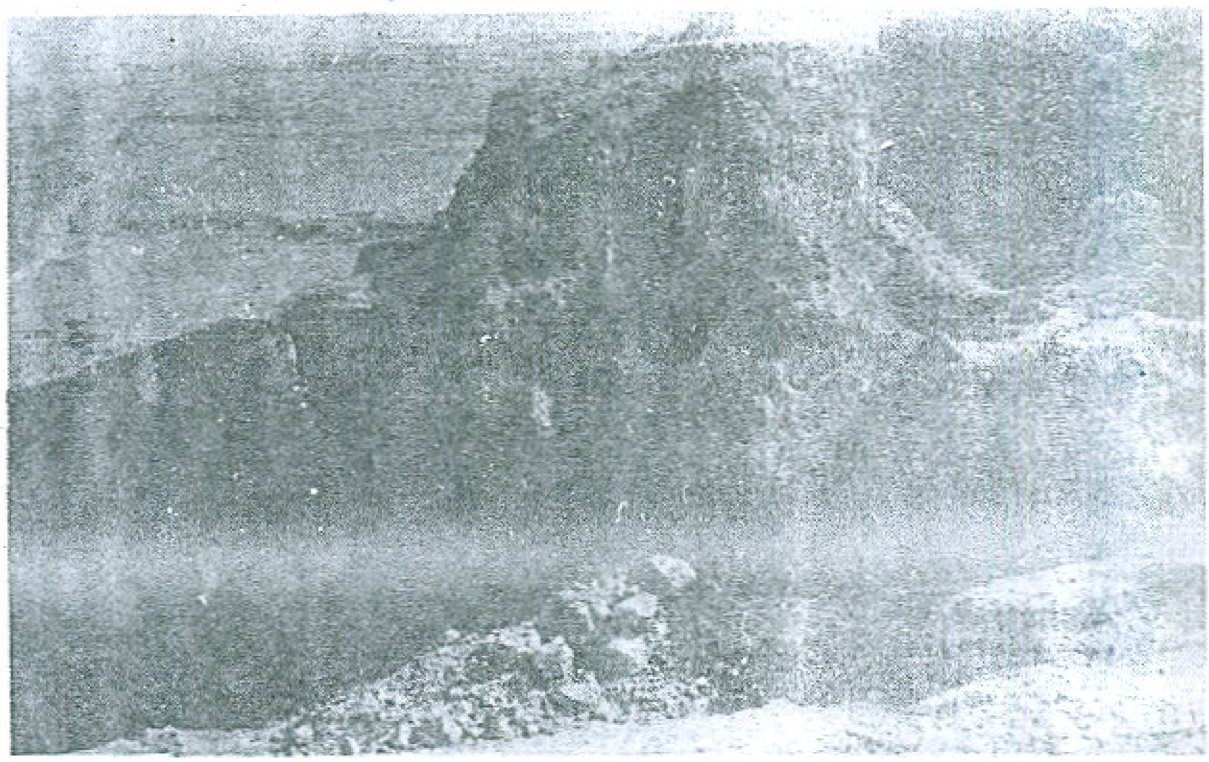

Plate No. 9 Slumping on nala wall-Kuri

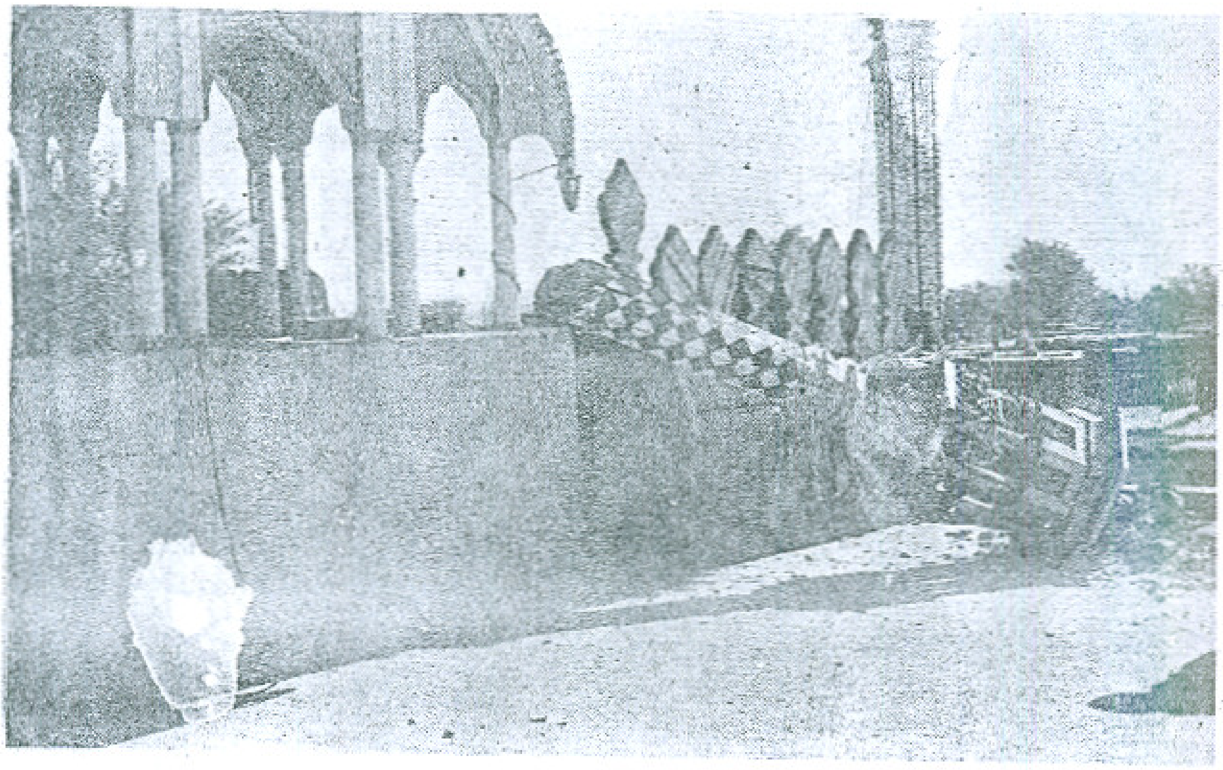

Plate No. [illegible] Fallen down minarte of a mosque-Tarlai Kalan

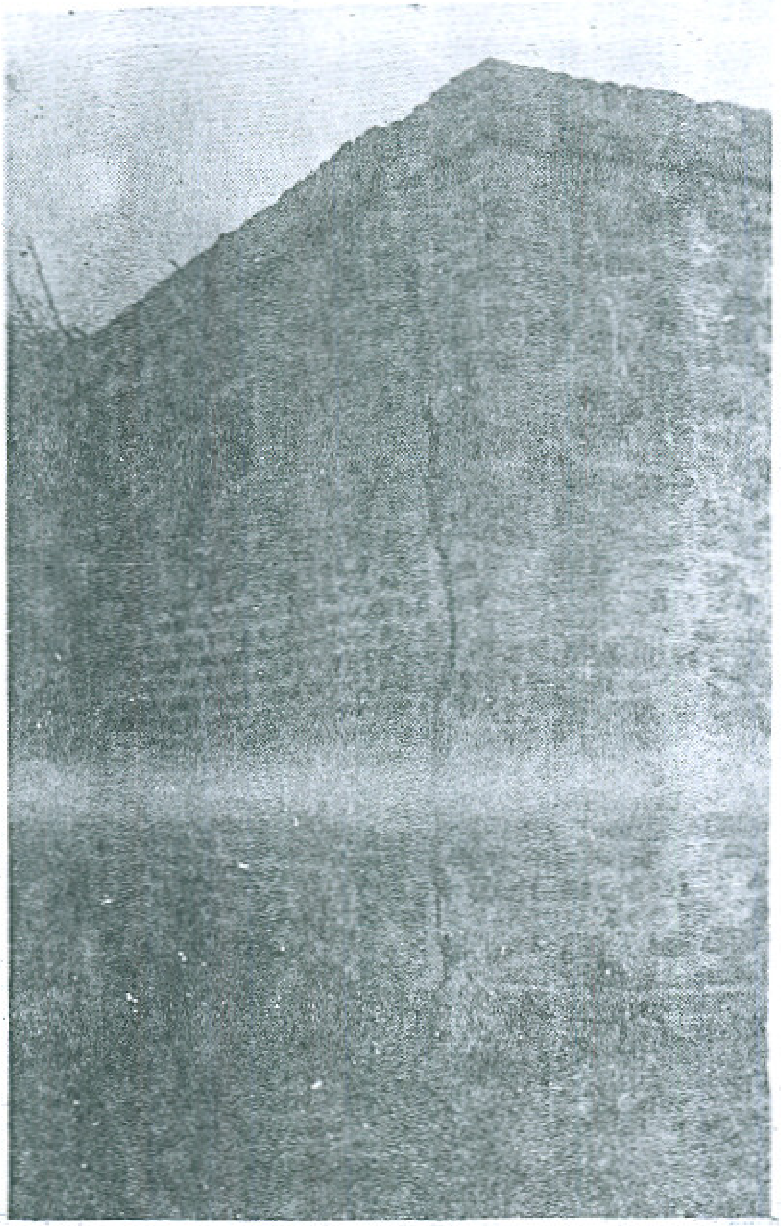

Plate No. 11 Open Cracks in wall built with brick using Sand-Cement mortar-Khanna Dak.

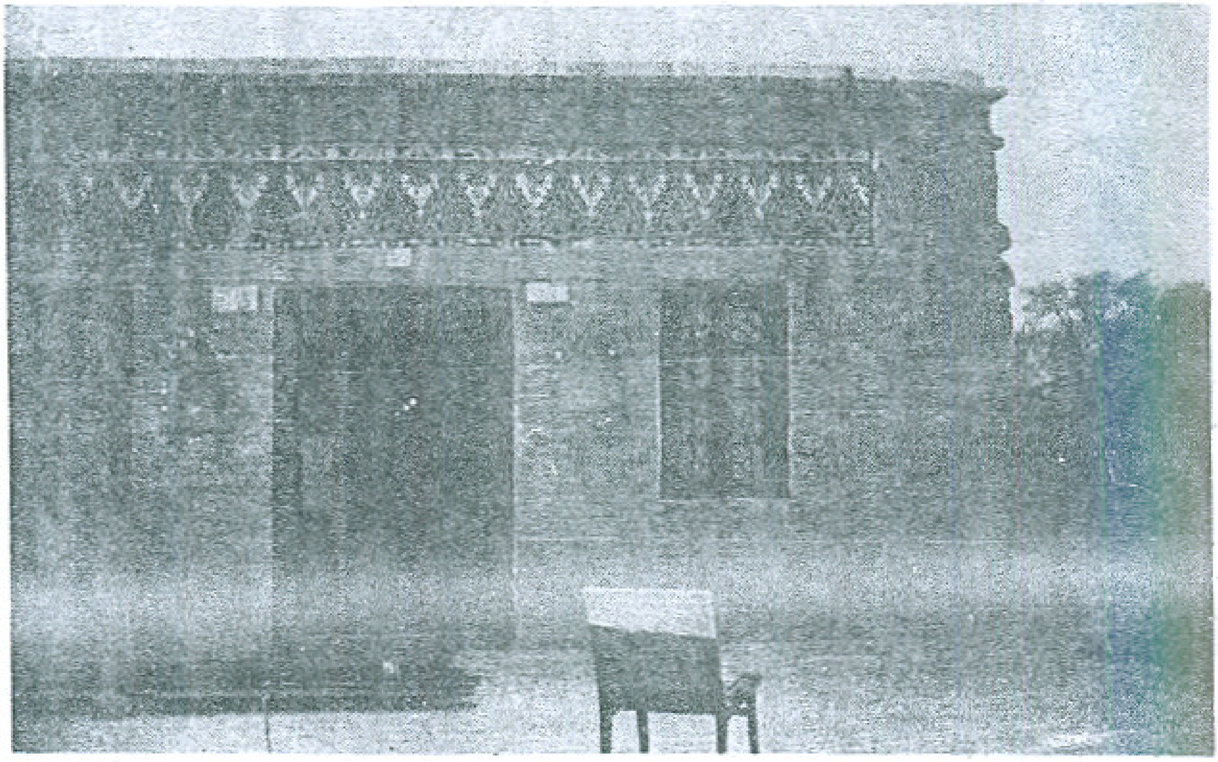

Plate No. 12 Cracks in Wall- Ban.