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DAMAGES DURING DHAMAR EARTHQUAKE OF DECEMBER 13, 1982 IN YEMEN ARAB REPUBLIC

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SYNOPSIS

The Dhamar province of Yemen Arab Republic was shaken on December 13, 1982 by a moderate earthquake. The earthquake caused considerable loss of life and different degrees of damage to the traditional houses in the area. The most prevalent form of construction consisting of stone masonry and adobe suffered very extensive damage. The destruction of houses was mainly due to failure of superstructure and none due to movement of foundations. Ground ruptures, failure of dry packed stone retaining walls, rock fall and rupture of stone on hill sides were also observed. An above ground reinforced concrete water tank also collapsed. An isoscismal map of the earthquake damaged area has also been presented.

INTRODUCTION

Large area of Dhamar province of Yemen Arab Republic (YAR shown in Fig. 1) was rocked by a moderate earthquake which occurred around noon time on December 13, 1982. The main shock was felt over a large area including Sana'a the capital of Y.A.R. Rambling sounds accompanying the earthquake, were reported from several villages with a foreshock immediately preceeding the main shock. The heavily damaged area measures approximately 5000 sq. km and damage affected area approximately 20,000 sq. km. About 1600–3000 lives were lost, with number of injured persons running to more than 4000. More than 70,000 dwelling have been damaged affecting 500,000 people.

The Yemen Arab Republic covering an area of approximately 190,000 sq. km., is located in the south-eastern corner of the Arabian Peninsula on the shore of the Red Sea. It is bordered by Saudi Arabia on the north, the people's Democratic Republic of Yemen to the South, the Red Sea to the west and the great Arabian Desert called the Empety Quarter (Rubal Khali) to the east. The greater part of Yemen is high rugged and mountaineous, with valleys and Plateaus rising to 1500 to 2500 metres or even higher. The only flat coastal strip about 20–40 km wide known as the Tihama is hot, sandy and semi desert, in sharp contrast to the mountaineous interior. A range of high mountains called the Yemen High lands, runs north-south through the central part of the

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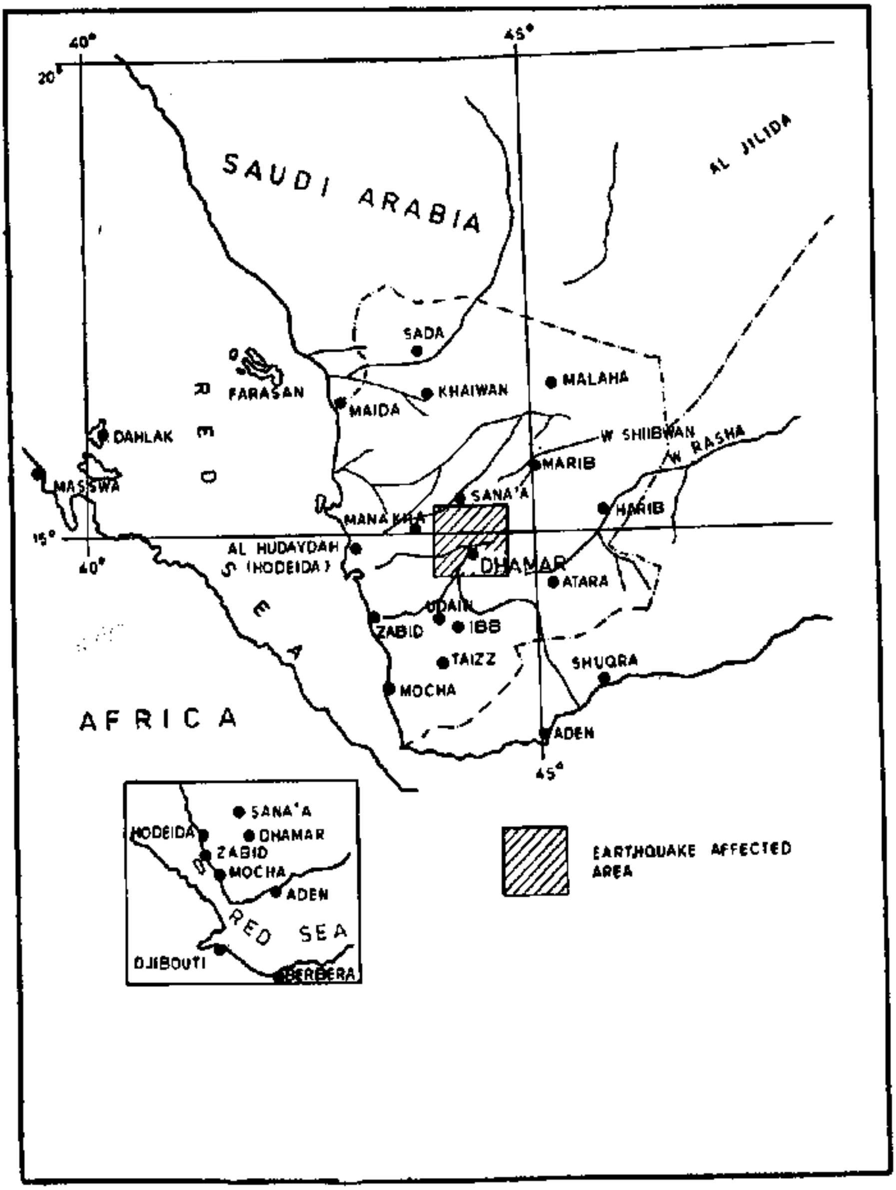

Fig. 1. Key plan and earthquake affected area around Dhamar Province Y.A.R.

country, with peaks rising to 4000 metres. The damaged area is also undulating and has high plateau. Many of the villages which were severely damaged had been situated on the ridges or side slopes.

DHAMAR EARTHQUAKE

Seismotectonic Setup of the Region

Recent studies of Satellite imageries of YAR indicate presence of an intensively active N20°W–S20°E trending tectonic belt with Recent faults and volcanism within several thousand years. This belt extending from Dhamar-Rada quarternary volcanic massif in the south, continue towards Sa'dah in the north and is intersected by a major northeast-southwest trending active belt with Recent faults extending from Mareb-Sirwah volcanic massif in the north-east and extending towards south-east in central mountaineous region. The December 13, 1982 Dhamar earthquake occurred in the zone of inter-section of the two belts. The ground breaks (fractures) with N10°W to N20°W trend follow the tectonic lineaments (Recent faults) parallel to Dhamar-Sa'dah belt,

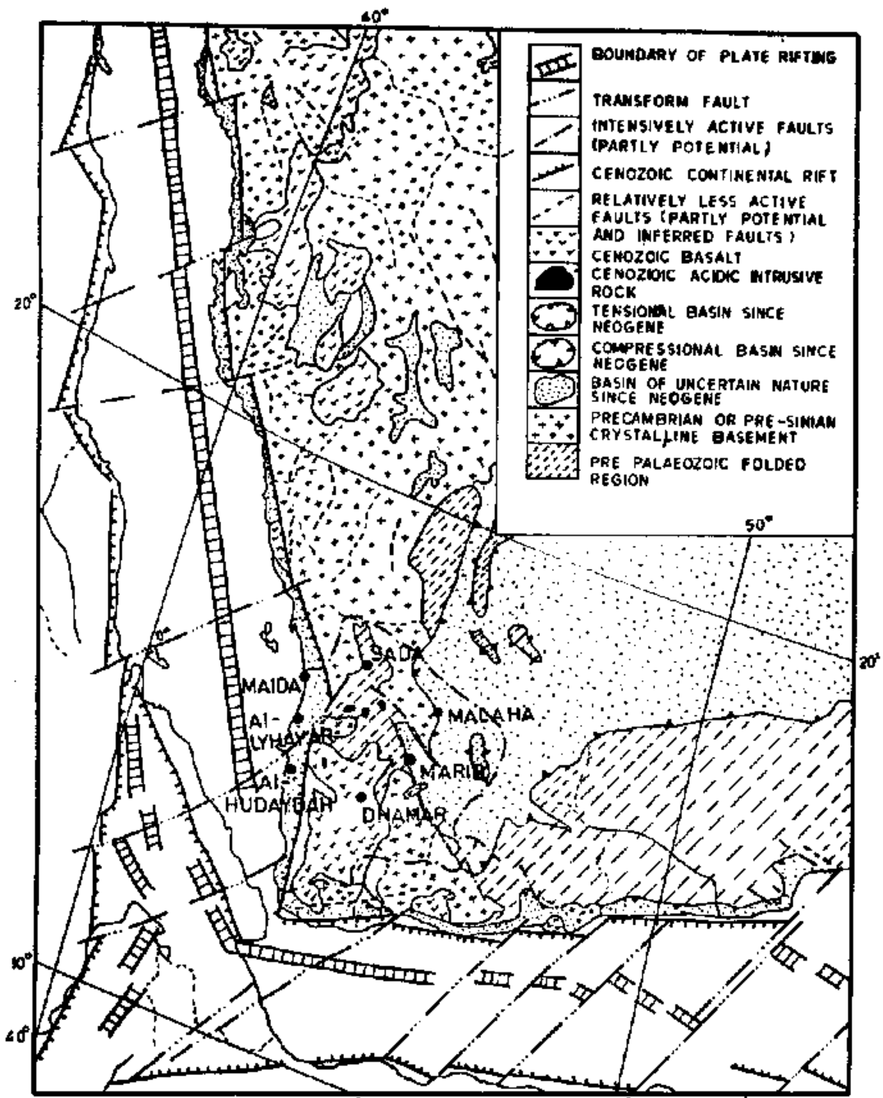

Fig. 2. Seismo tectonic map of area around North Yemen.

and are noted to occur at various locations along a length of about 15 km. with the western side moving up by few mm. to about 1.5 cm. with respect to eastern side. This is indicative of thurst fault mechanism with the western region overthrusting the eastern side. However such a mechanism of fault rupture is a tentative observation, which requires confirmation from fault plane solution study from seismic records of event from various parts of the world. Seismotectonic set up of the area around North Yemen is shown in Figure 2.

The Earthquake Occurrence

Yemen Arab Republic has been affected from time to time by earthquakes along the Red Sea and its coastal tract as well as inland. However systematic historical records of these events are not readily available. The oldest available information of destruction in Y. A. R. resulting from an earthquake is the destruction of Sabean dam of Sadd Mareb.

Shallow focus earthquake occurrence in various parts of Y.A.R. affected local regions and in many cases due to sparse population their occurrence has not been documented. Smaller shocks during present times remain undetected due to absence of network of seismic stations to record their occurrence. In the later part of this century, Mr. Patrice de Saint Ours (Report on "Seismic and Volcanic Risk in the Yemen Arab Republic, UNDRO/19/77, GE 77-11130, 1977) has reported, three earthquakes which have occurred inland as below.

Date	Epicentre Lat.	Location Long.	Magnitude (Mb)	Dept (km)
Oct. 17, 1955	17.16°N	43.65°E	—	—
Aug. 16, 1959	14.52°N	43.31°E	—	—
Oct. 17, 1965	17.2°N	43.7°E	*d*	*n*

d: magnitude between 5.3 and 5.8.

n: normal, depth undetermined, but focus less than 70 km.

The 1959 earthquake event was felt strongly in Mokha-Taiz and Ibb region. The 1955 and 1965 earthquakes were felt strongly in Sa'dah with possible damage. De Saint Ours has also described that in 1973 "the village of Al-Amar, near As-Safra and Al-Ouddat in Sa'dah Province, was destroyed by an earthquake, and towards the end of 1975 two other earthquakes were reported; the first in October 1975, occurred in the Azal Al-Radma region, part of the Ibb Province, where 38 houses in the village of Beit Badr had to be evacuated and 13 other dwelling became inhabitable in Khawlan village; the second occurred in December of the same year when people were awakened by tremors lasting more than ten minutes at Hodeidah, Salif and Al-Juhayaj, but causing only minor damage".

December 13, 1982 Dhamar earthquake which struck the region in the middle of the day is reported to have been preceded by minor foreshock within seconds of the main shock. The earthquake which caused great damage in Dhamar Province and adjoining areas was reported to have been felt all over Y.A.R. and was recorded at teleseismic stations all over the world. As per the preliminary information available from various observatories it is indicated that the earthquake had its epicentre at Lat. 14.6°N and Longitude 44.2°E and magnitude 5.9 (Ms). In the analysis of the available worldwide data for determination of epicentre, the depth was held fixed at 10 km. After-shocks have continued to occur in the region, and have been felt in various parts of the region. The biggest after-shock occurred on December 29, 1982 with origin time 23 hr 53 m. 16.75 UTM epicentre at Lat. 19.76°N: Long. 44.35°E, magnitude 5.1 (Ms) and depth 'held fixed at 10 km' (National Earthquake Information Service, Golden Colorado) which was felt in Sa'dah.

Ground Fractures

Figure 3 shows the location of ground fractures developed at various locatian in the region. Individual ground fractures, with opening from few mm to about 10 cm extend over 50 to 100 m distance. The width of the fracture zones consisting of two to three fractures varies from 0.5 m to 2 m. No strike slip movements or offsets could be observed along the ground fractures. However at many location the western sides of the fractures were noted to have moved up by few mm to about 15 mm in relation to the eastern side.

Intensity of Earthquake and Ground Motion

The Dhamar Earthquake caused extensive damage around Dhamar-Ma'bar region, The maximum Modified Mercally Intensity (MMI) in the area was estimated as MM VIII, which occurred in east-west trending elongated area about 45 km in length and 35 km in width. Random rubble stone masonry and mud bricks houses were subjected to severe damage resulting in partial and complete collapse responsible for considerable loss of life and injury to the people in the region. Dressed stone masonry and concrete blocks masonry single storeyed construction in gypsum and cement mortar developed cracks without endangering the safety of the houses. The data on earthquake damage observed in the area include the integrated effect of the main shock and the after-shocks. Thus many buildings damaged by the main shock suffered partial or complete collapse during after shocks.

Figure 3 shows the isoseismal map of the region demarcating zones of

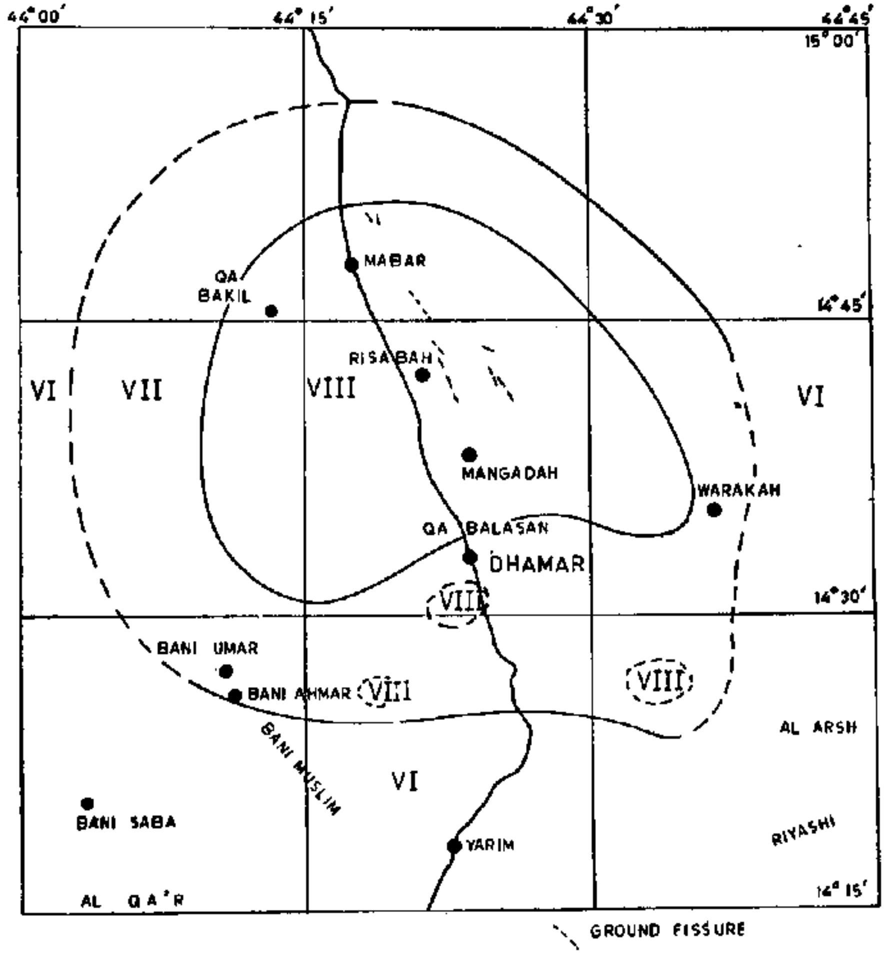

Fig. 3. Isoseismal map for December 13, 1982 Dhamar Earthquake Y.A.R.

MMI VIII, VII and VI and represent the integrated effect of the main shock and after shocks. It is noted that masonry as well as mud buildings located on rock suffered more severe damage as compared to those situated over recent sedimentary deposits around Dhamar-Ma'bar area, which indicates rapid attenuation of intensity of short period vibrations over alluvial tracts. It is also observed that ground motion intensity decreases faster in the area east of the ground factures as compared to the hilly terrain on west which sufferred severe damage over a larger area. Severe shaking was felt by people in the area with rumbling sounds during the earthquake. No major land slides or rock falls were reported to have occurred in the region. However, isolated large rock boulders (upto 60 cm in diameter) got detached and rolled down on steep slopes and edge of terraced fields at many locations in isoseismal VIII. Slumping of dry packed stone retaining walls supporting the edges of terraced fields was also observed at several locations within isoseismal VIII.

Sliding and overturning of utencils, furnitures and other loose objects was reported in the region and at Dawran a 3 m × 3 m × 2.5 m iron sheet box grocery shop facing S60°W direction and supported on 30 cm long, 7.5 cm wide angle iron legs was overturned as its front legs were bent. A similar shop resting on rock boulder platform did not undergo any movement. Photo 1 shows rupture of stone on a hill and photo 2 shows rock fall on a mountain and dislodging of boulders.

EARTHQUAKE DAMAGE TO HOUSES AND BUILDINGS

Damaged Area

The damaged area under this earthquake bounded inside MM VII zone would measure approximately 65 km northsouth and 75 km eastwest. The more severely damaged area in MM VIII zone would cover about 1400 sq. km measuring 35 km northsouth and 50 km eastwest. The estimates of number of lives lost vary from 1600 to more than 3000 and those injured from 2000 to about 4000. Due to the difficulties of terrain and heavy heaps of stone rubble from collapsed masonry houses, there may still be some bodies buried under the debris. It is estimated that about 70000 houses have been damaged and about 500,000 people are living (January 1983) outside their houses.

Types of Houses

The house types commonly used in the whole of the damaged area except some variations in the more recent urban constructions in Dhamar and Ma'aber towns consist of the following:

(a) Stone masonry construction.

(b) Mud houses and Adobe block construction.

The stone masonry has two general variations—the most common being random rubble field stone masonry, locally called Ghoum stone masonry set in mud mortar and chip filling or simply dry packed along with stone chips, and the less common being the one using half-cut or one face dressed stones on the outer face and random rubble on the inside which is generally the plastered face. Gypsum pointing is used on the outside in some cases in the courses of the half-cut stones. Cement sand mortar is used only in public buildings like dispensaries and schools built by the Government.

Photo 8 and 17 shows houses in random stone masonry and half cut stone construction. Photo 13 and 15 shows dry packed stone on two faces of walls with stone chip fillings. Photo 16, 18 and 21 shows random rubble masonry construction, coursed stone construction and half cut stone constructions being used in the area. Photo 33 shows a building with gypsum pointing on exterior walls of dressed stone. Photo 34 shows inside plaster in walls of Dohran dispensary. The two types of construction are briefly described below.

(a) *Stone Masonry Walls*—The wall thickness of this construction as seen in photo 4 and 13 varies from 60 to 90 cm. Heavy stones are provided on outside and on the inside faces of the walls and any space or gap left in between the two leaf of stones are filled with loosely broken stone or simply mud, and it could be easily seen in Photo 13 that there is generally no inter-connection between these stone widths provided in the innerside and outerside of a wall.

The hammer dressed stone which is used for outside walls in village houses is also mostly decorative as shown in photo 19 and these stones are also not connected with the inside face stones as described above. There is no interlocking at the corners or at *T*-junctions of walls.

(b) *Foundation of Stone Masonry Walls*—Most old buildings are built on cliffs as shown in photo 21 and hill sides (photo 24) resting on exposed rock directly. Where they rest on soil, foundations are dug to shallow depths and packed with stones with or without mud.

(c) *Clay Mud Walls*—The walls are made up of clay lumps and are 50 to 60 cm thick. The wall construction starts right from ground level without foundation and goes up to two stories even. The openings for windows in the walls are usually of small size (say 60 cm $\times$ 70 cm). There is no interlocking or proper adhesion between the walls at corners or *T*-junctions.

(d) *Adobe Block Walls*—In adobe construction also there is usually no foundation provided and the wall making starts right from the ground level. Generally 37 cm $\times$ 25 cm $\times$ 11 cm size blocks of adobe (photo 25 and 26) are used which permit use of a good bond breaking the vertical joints. Site test indicated that this adobe can bear the weight of a person weighing about 75 kg on a clear span 25 cm, hence having good enough tensile and compressive strength. Three storied houses were seen to have been constructed using this type of adobe.

(e) *Roof and Intermediate Floors*—In almost all houses using stone masonry or adobe construction for walls, the roofs are flat type (photo 21). The traditional roof has wooden rounds, half rounds or roughly dressed joists or proper rectangular joists placed parallel to each other across spans of 3 to 3.5 m at a centre to centre spacing of about 45 cm. This limits the width of the rooms which may, however, be made to have long lengths, even as much as 12–15 m. Across the wooden beams and over them are laid thin wooden planks or bushes or weeds to form the deck for receiving clay topping. The clay topping thickness may vary from 15 cm to 25 cm. When used as floor, a concrete screed with plaster on top is some times used. The roof requires addition of clay layer before each rainfall season to stop the leaks which goes on adding to the weight of the roof.

The parapets constructed on the roofs are usually of low height and are plastered over with mud plaster consisting of good clay mixed with straw.

Types of Community Buildings

The main public buildings are dispensaries and schools. These built by the Government consist of half-cut coursed stone masonry walls in good cement mortar, with appropriate foundations and reinforced concrete slab roofs. These are single storeyed and well finished on outside as well as plastered with gypsum or cement mortar on the inside. The Dohran dispensary and Madarsa are shown in photo 33 and 35 respectively.

Other Types of House Construction

Very few new houses use solid or hollow concrete block walls of about 20 cm thickness, using gypsum or cement mortar. The quality of blocks as well as the mortar appears to be poor and the quality of construction and bonding at the corners and junctions of walls below the mark.

New buildings in towns like Dhamar and Maabar for apartments and shops are being constructed in reinforced concrete as shown in photo 36 using column-beam frames and concrete block filler walls. Sometimes fully dressed stone facia is provided outside the concrete frame without any mechanical attachment, simply relaying on the gypsum or cement mortar adhesion strength. In the present earthquake intensity at these towns of about MM VII no distress has been complained about in these buildings but there is a question mark about their complete safety in a more severe shock. This type of construction is not discussed here any further.

Mechanism of Failure of Stone Masonry House

The following are the main ways in which the masonry buildings have seen to be damaged during the Dhamar earthquake:

(i) Separation of walls at the corners and *T*-junctions is the first action that took place during the earthquake shaking. Even where no collapse took place, this separation was conspicuously seen in all buildings which remained standing (see photo 14 and 17) in the areas where collapses were common as well as in lighter intensity areas. This points out to the inherent weakness in the stone masonry construction used, namely, very weak mortar as well as lack of proper bond between any two walls at right angles to each other.

(ii) Bulging of the wall masonry outward or inward and falling away of half the wall-thickness eitherway as shown in photo 12 and 15 was also a common sight. The outer wythe consisting of stones with outer face roughly dressed separated from the hearting of the wall and fell out at innumerable places exposing the inner muck-filling of the wall. The exposed cross-sections of masonry walls clearly showed the separate building up of the two wythes of the wall with small stone and earth filling in between them, without practically any mechanical connection which could be achieved by the use of "through" stones. At many places this must have led to the complete shattering of the wall resulting in only a heap of rubble as shown in photo 3, 4, 5, 6, 7 and 9 and falling of the roof along with it as shown in photo 8. Another adverse effect seen in the old masonry walls was that of washing away of the mud mortar from the joints leaving gaps between the stones so that their relative movement became easier leading to destruction of the walls.

(iii) Overturning of the walls occurred due to severe shaking after the walls had separated from the cross-walls since the bending strength and stiffness of a plain cantilever wall is very very much smaller than when it forms a box-like section with the walls at right angles to it. The lateral load action was further accentuated on those walls which were carrying the roof load through the wooden beams and one or both of them collapsed along with the roof crashing down with them.

(iv) The roofs usually consisted of round or half round timbers laid on two opposite walls carrying heavy load of clay on top. During ground shaking, such wooden elements tend to vibrate separately both longitudinally and transversely. The action of the roof is to form a sort of portal with the walls on which the joists rest rather than a diaphragm action involving all the four walls in the lateral load resistance. Moreover under unfavourable conditions such as seepage of water, the ends of wooden beams embedded in the walls get subjected to the weathering action as well as insect attack, consequently they may become loose in their seats having little bonding left. This aggravates relative motion, of the roof with respect to the walls. No wonder that the old masonry constructions were generally subjected to much harsher treatment than the new masonry constructions.

Failure of Mud and Adobe Houses

This material of construction is not only weak in tension and shear as stone masonry but also in compressive strength. Thus the separation of walls at corners and junction takes place easily under ground shaking, the cracks passing through the blocks themselves. Afterwards the walls fails either due to bending or shearing combined with the compressive loads, the whole house crashing down. Adobe walls do not on the other hand, have the bulging tendency as in masonry walls since they have flat courses and bonding between outer and inner faces. The effect of roof and intermediate floors is similar to that stated above for masonry buildings. A number of single storeyed clay-block houses showed practically no damage at all in the same areas where collapse of two or three storey houses had occurred. Photo 27, 28 and 29 shows the damages to the adobe and mud houses.

Failure of Concrete Block Walls

The main reasons of their failure are poor quality of construction and lack of bond between the walls at their corners and *T*-junctions.

Failure of a Concrete Water Tank

A concrete water tank of rectangular section measuring $7.5 \text{ m} \times 6.5 \text{ m} \times 3.1 \text{ m}$ and supported by seven reinforced concrete columns 3 m tall and 25×30 cm in cross-section crashed to the ground due to the collapse of the columns. Calculations indicated that the columns were too weak to take the horizontal accelerations in MM VIII area since their ultimate moment capacity would be exhausted at only 6 percent of gravity acceleration and hence the failure of columns is not surprising. Photo 37 shows the water tank on the ground and photo 38 and 39 shows the column failure with exposed reinforcement. A serious weakness of the reinforced concrete columns was lack of lateral ties which are required at closer spacing of about 7.5 cm near the column ends so as to confine the concrete and impart ductility to the columns.

For safeguarding other tanks of similar types, it is recommended that stone block masonry or brick walls in 1 : 6 cement-sand mortar should be tightly infilled between the column on the periphery so as to increase the stiffness as well as the lateral strength of the supporting structure.

RECOMMENDED NEW BUILDING CONSTRUCTION

General

The new building construction in the present earthquake affected area as well as in other earthquake prone areas of Y.A.R. should be in accordance with the principles of earthquake resistant design.

Reference in this regard may be made to the following:

IS: 1893—1975 Criteria for Earthquake Resistant Design of Structures and

IS: 4326—1976 Recommendations for Earthquake Resistant Building Constructions, published by Indian Standard Institution, Bahadur Shah Zafar Marg, New Delhi.

Considering the present situation of availability of building materials, technical personnel, economical condition, the general use of reinforced concrete, though most desirable, can not be feasible. As such a number of alternative construction techniques will have to be used in the reconstruction program permitting a choice to suite the site conditions.

The following types of building construction could be used in the region.

Reinforced Concrete Rigid Frame Construction

These will be suitable for more than three storey buildings used for public purposes and will have to be properly designed for earthquake forces to be specified for the region.

Reinforced Concrete Prefabricated or Cast-in-place Large Panel Construction

This will need imported technology with adequate earthquake resistant design of panels as well as their connections, and may be used in the capital towns of the Provinces near the metalled roads. Number of storeys may be limited to about four without provision of lifts. There are many such systems available on the market.

Solid Concrete Block Walls and Prefabricated Roofing Units with Caste-in-place Concrete on Top

This type of construction could be adopted in road side as well as distant villages since the transport of concrete blocks and light roofing elements should be feasible through small length lorries and pick-up trucks. The system will need structural designing of various elements and working out of suitable reinforcing pattern from earthquake resistant view point. Number of stories of these buildings should be restricted to three.

Hollow Concrete Block Walls and Prefabricated Roofing Units with Cast-in-place Concrefe Topping

Hollow concrete blocks permit the provision of vertical steel bars through the holes and walls can be structurally designed against earthquake forces using a pattern of vertical and horizontal steel bars. The system can be used as the solid block construction stated above. The mortar will be cement-sand mortar in both these cases.

Stone Masonry Construction

A number of alternatives seem possible with stone masonry wall construction, the variations being as follows:

(i) The type of stone masonry, viz. field stone or random rubble; half-cut stone masonry and full cut stone masonry.

(ii) The mortar type, viz. cement-sand, cement-lime-sand, gypsum, or mud.

(iii) The roof and floor type, e.g., reinforced concrete slab, traditional wood-beam, with clay covering. It may be stated that for various social requirements flat roof will be necessary and roof thickness will have to be sufficiently thick from insulation view point.

From the earthquake view point the following are indicated in the order of decreasing suitability:

Roof :	(i)	R.C. slab	(ii)	Wood-beam floor or roof
Masonry:	(i)	Full cut stone	(ii)	Half cut stone
	(iii)	Field stone		
Mortar :	(i)	Cement-sand	(ii)	Gypsum
	(iii)	Mud		

The solid or hollow concrete block and burned brick walls will be comparable with full cut stones from earthquake stability view point.

All cases of masonry wall construction need certain minimum reinforcing measures and limiting specifications to achieve non-collapse performance during earthquakes of Dhamar type. When constructed with these seismic measures these buildings may develop minor cracking but not likely to get any serious damage. Earthquake Resistance of Masonry and Adobe Buildings gives recommended details to be adopted for such buildings. Drawing No. 1 shows typical plans of 2 bedrooms, 3 bedrooms and 4 rooms single storied dwellings using locally available random stones for reconstruction. These plans have been prepared fulfilling the needs and requirements of local populations and provide an area of 96 sq. m., 103 sq. m. and 136 sq. m.

Drawing no. 1(E) shows roof plan for two units if constructed side by side.

Adobe Block Construction

Adobe block buildings fall in the category of unsuitable buildings in seismic areas particularly in zones of MM VIII or higher and should not be used. In lower seismicity zones, these may be used with certain limitations and strengthening measures, as outlined below for ready reference.

EARTHQUAKE RESISTANCE OF MASONRY AND ADOBE BUILDINGS

General

In order to prevent severe damage or collapse of the buildings to be constructed in the presently affected area as well as other areas of Y.A.R. lying in the probable earthquake occurrence zones, it will be necessary that appropriate seismic construction features be adopted in all new buildings of traditional types. Recommendations for earthquake resisting measures are included here below for the traditional constructions which could be immediately used with the available materials, financial resources and the rural technology of construction.

Roof and Floor

In view of the requirements of insulation from heat and cold and the social needs of the people to use the roof for sitting, storing fodder, dung cakes and firewood, etc., a flat roof must be used. Two alternatives are suggested as below:

(a) Reinforced Concrete Slab

R.C. slab is the best alternative for using as floor or roof since it is rigid in its own plane capable of acting as rigid diaphragm and also providing restraint against the separation of walls at the corners. If made continuous at the intermediate walls and covering the full width of external walls, a completely water proof roof will be obtained. For the usual spans of 3 to 4 m, used for rooms, a uniform slab thickness of about 10 to 12 cm will suffice. This has of course to be designed. For acheiving insulation from summer heat and winter cold, a layer of clay about 75 mm average thickness may be laid over the slab. Roof drainage slope may be achieved by varying the thickness of clay layer.

When R. C. slab is used as floor or roof, no separate roof band is required.

(b) Traditional Wood Beam Roof

The following modifications are suggested to the traditional wood beam roof and floor:

(i) Wooden runner may be provided on the walls alround below the level of the ends of the wooden beams to which the beams may be spiked. These runners must be made continuous by proper splicing at ends and connections at corners so that they may act as a roof level band tying the walls together.

(ii) Wooden planks may be nailed from above or from below in a diagonal direction to the wooden beams so as to provide diagonal bracing to the roof in plan.

(iii) The roof decking may preferably be made through thin wooden planks nailed to the wooden beam from above, instead of bushes, thatch etc.

(iv) The clay topping may be laid in two layers of about 75 mm thick each and polythene sheets may be laid in between them with at least 15 cm overlap between the sheets so as to provide barrier against leakage of water. The slope for drainage may be made properly in the lower layer and the overlap of the polythene made appropriately on the side of the parapet and pressed under clay plaster.

The plan and section showing the details of wood runner, wooden beams etc. are given in Drawing no. 4(A) and 4(B) respectively.

Stone Masonry Walls

The collapse of stone masonry walls has been the most serious problem and reconstruction of buildings using stone masonry walls will need positive aseismic measures, as recommended below:

(a) Choice of Mortar

The best mortar for stone masonry will be cement-sand mortar in the ratio 1 : 4 or cement-lime-sand mortar 1 : 1 : 6. However cement-sand mortar in the ratio 1 : 6 could also be used for achieving sufficiently good strength of stone masonry. Use of mud mortar should be avoided as far as possible but may have to permitted for economic or material availability constraints in remote villages. The following height limitations are recommended for stone-masonry construction of various types:

(b) Limitation of Height

It is strongly recommended that

(i) The height of random rubble masonry in any mortar and half cut stone masonry in mud mortar may be limited to one storey only.

(ii) The height of one-side dressed or half cut stone masonry in cement mortar or fully cut stone masonry in mud mortar may be limited to two storeys only.

(iii) The height of fully cut stone masonry in gypsum or cement mortar may be limited to three stories and in each case the following specifications must be used.

(c) Specifications

(i) The thickness of the wall should not exceed 40 cm with the stones of the outer and inner faces suitably interlocked to the possible extent and the extent of chip filling in the hearting should be reduced to the minimum possible.

(ii) 'Bond stones' or 'through elements' must be provided at regular intervals of not more than one metre apart horizontally and not more than 90 cm vertically. In case such stones of 40 to 50 cm length are not available, other elements may be used as indicated below:

— Mild steel bars 8 mm dia. hooked at both ends, or

— wooden pieces or tree branches of about 30 cm^2 in cross-section,

— welded wire fabric consisting of at least 4 wires of 2 mm dia in section across the length of wall. Besides the above special reinforcement may be provided in the walls as detailed in section entitled special reinforcement in masonry walls.

— Drawing no. 2(A) shows a random stone masonry wall construction in plan with the use of "Bond stone" with proper interlocking of random stones and drawing no. 2(B) and 2(C), the cross-section of wall and elevation of random stone wall respectively.

— Drawing no. 2(E) shows an isometric view of a dwelling with window openings, provision of continuous band and arch over window.

— Drawing no. 2(F) indicates a door and window opening in part of a dwelling with continuous band.

Concrete Block or Burnt Brick Walls

These walls may be constructed upto two storeys in height using cement mortar of 1 : 6 proportion. Proper bonding should be used to break the continuity of vertical joints. The wall thickness may be kept 20 cm or so. The special reinforcement as detailed below shall also be provided.

Special Reinforcement in Masonry Walls

For maintaining the integrity of the corners and *T*-junctions of walls during earthquake shaking, the following reinforcing is essential:

(a) A reinforced concrete band going over all external and internal walls should be cast at door lintel level in all storeys. All lintels of doors and windows should be kept at one level for this purpose and the band should go across any windows having semicircular ventilators above this level. The band should cover full width of the wall and have a height of 15 cm. The reinforcement may consist of 4 bars 10 mm dia going continuously over corners and junctions with overlaps provided for full tension. These bars should be tied within steel ties 6 mm dia @ 15 cm c/c. The concrete mix may be 1 : 2 : 4 nominal. The lintel band details are shown in drawing no. 3(A).

(b) Welded-wire-fabric consisting of 2 mm wires @ 25 mm c/c cut to cover the width of walls may be laid in a masonry course at about 0.9 m above the floor in each storey at corners and junctions of all walls for a length of about 60 cm going into each wall beyond the junction as shown in drawing no. 3(D).

Seismic Strengthening of Adobe Walls

The adobe size may be standardised as 38 cm × 25 cm × 11 cm as used generally. The dried adobe may be tested as a beam having a clear span of about 25 cm and should not break under the weight of a man of about 75 kg by weight standing on it on one foot. If it breaks more clay and straw may have to be added. The same mud used for making adobe may be used for building the wall.

The wall thickness may be kept 38 cm, all adobe units used in header bond so as to break the vertical joints. The height of adobe house may be limited to one storey only.

A continuous band of wood joists should be provided at door and window level going overall external and internal walls with continuity at all points. For achieving continuity, proper splicing by using steel cover plates should be used at intermediate points and the same method can be used at corners and junctions of walls if single timber is used. If two timbers are used, one on outer face and the other on inner face, which will be far superior to single timbers, they may be braced with cross-timbers and nailed to each other at intersections at corners and wall junctions.

The corners and junctions of walls should also be braced with timber dowels going into both walls at right angles to each other at about 90 cm above the ground floor. These details are shown in drawing no. 4(C) and (D).

Note: All the above recommendations for Masonry and Adobe have been illustrated in typical drawings No. 1, 2, 3 and 4 made in the Ministry of Public Works under the supervision of the Authors so that reconstruction could start immediately without any ambiguity.

Restoration of Damaged Masonry Buildings

There are many masonry buildings of even upto three storeys height which are still standing in damaged state with various degrees of damage. Most of these buildings are rectangular in plan and present separation of walls at their junctions in most cases. It appears that they can be restored by installation of horizontal steel ties running parallel to walls just below each floor and roof and anchored against steel plates, angles or channel sections through nuts. The fine cracks can be grouted with cement or lime and wide cracks filled with mortar. More details of restoration procedure that will be effective and economical will have to be worked out for each building depending on its damaged state and configuration.

FURTHER RECOMMENDATIONS

Seismic Code and Regulations

Present Status

A country which experiences earthquakes should have a code dealing with the criteria for earthquake resistant design of structures and it should be applicable to buildings, elevated structures, bridges, dams, embankments, retaining walls and other civil engineering structures. Yemen Arab Republic does not at present have such a code.

Seismic zoning

The preparation of a code describing the criteria for earthquake resistant design of structures suitable to Y.A.R. will naturally take lot of time and effort. Preparation of a seismic zoning map and basic design seismic forces appropriate for each zone must be taken in hand urgently which could be used along with a standard code of practice of some other country, like India, for determining design forces and construction features for various types of structures. IS: 1893–1975, Indian Standard Criteria for Earthquake Resistant Design of Structures and IS: 4326–1976, Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings, are available from India.

Education and Research

Training of Engineers and Architects

Since the engineers and architects practicing in Y.A.R. at present are not acquinted with earthquake resistant design principles and detailing techniques, it is recommended that a series of well planned short term courses of four to six weeks duration may be organised at Sana'a itself through foreign experts invited under UN agencies or bilateral collaborations. These courses may have emphasis on specific topics like building design, bridge design or dam design, etc. These short term courses should be very helpful in preparing a team of engineers, and architects who could design and detail earthquake resistant structures.

Review of Design of Structures

Rapid development is taking place in Y.A.R. with regards to housing and industries. There is an urgent need to review design of these structures which are under planning or design stage (such as buildings, bridges, industries, dams, power plants etc.) so as to incorporate earthquake resistance in them.

These structure which are under construction or completed and occupied, their design may also be reviewed in order to detect any critical weakness in them so as to undertake appropriate retrofitting or strengthening measures, if found necessary.

Demonstrative Constructions

Since majority of house reconstruction is likely to be carried out by the rural masses themselves in the traditional manner utilizing locally available materials and technology, it will be extremely useful if a number of demonstrative construction of dwellings are carried out in appropriate villages which could serve as models and village Artesans could see and copy their construction. The details of such construction which are earthquake resistant have been outlined earlier.

CONCLUSIONS

The main cause of failure of dwellings in this earthquake is the inherent weakness in dry packed stone masonry construction, lack of bond stones in the masonry and little or no connection between walls at right angles. This resulted in shattering of innner and outer wythes of walls and separation at corners and *T*-junctions. Dwellings located on hill slopes were invariably destroyed due to higher acceleration experienced by them. Traditional mode of construction needs improvement in their lateral load resisting capabilities by appropriate measure as given in Reference (2) and outlined in the paper.

ACKNOWLEDGEMENTS

This paper is extracted from the report of the Indian Earthquake Engineering Mission consisting of the authors to Yemen Arab Republic on Dhamar Earthquake of December 13, 1982 submitted to the Ministry of External Affairs, Government of India, New Delhi in March 1983. The support from Indian Society of Earthquake Technology, Government of India and Government of Yemen Arab Republic in carrying out this study is gratefully acknowledged.

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1. Arya, A.S., Srivastava, L.S. and Gupta, Satyendra P., Report of The Indian Earthquake Engineering Mission to Yemen Arab Republic on Dhamar Earthquake of December 13, 1982, Indian Society of Earthquake Technology and Department of Earthquake Engineering, University of Roorkee, Roorkee, India, March 1983.

2. A Manual of Earthquake Resistant Non-Engineered Construction, published by Indian Society of Earthquake Technology, Roorkee, April 1981.

3. Our Saint de Patrice, Report on Seismic and Volcanic Risk the Yemen Arab Republic, UNDRO/19/77, GE 77-11130, 1977.

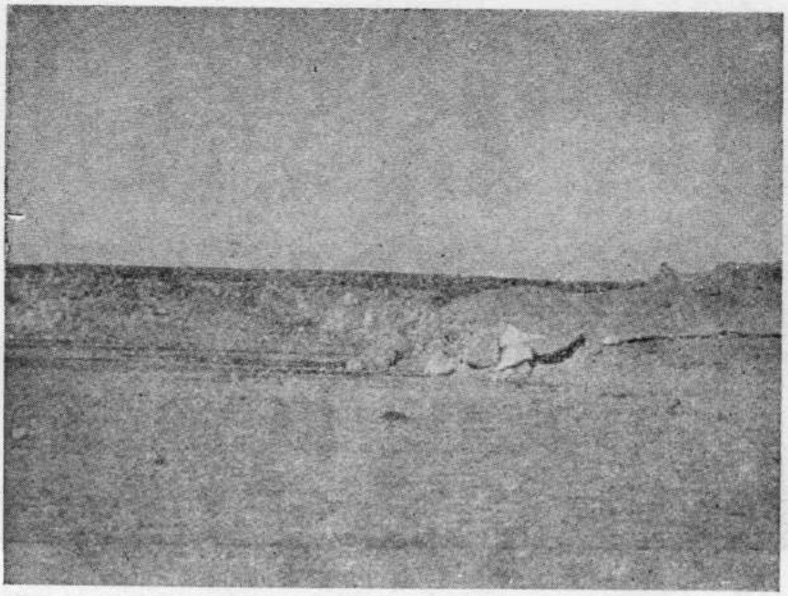


Photo 1. Rupture of stone on a hill due to force of Earthquake near village Qubatil.

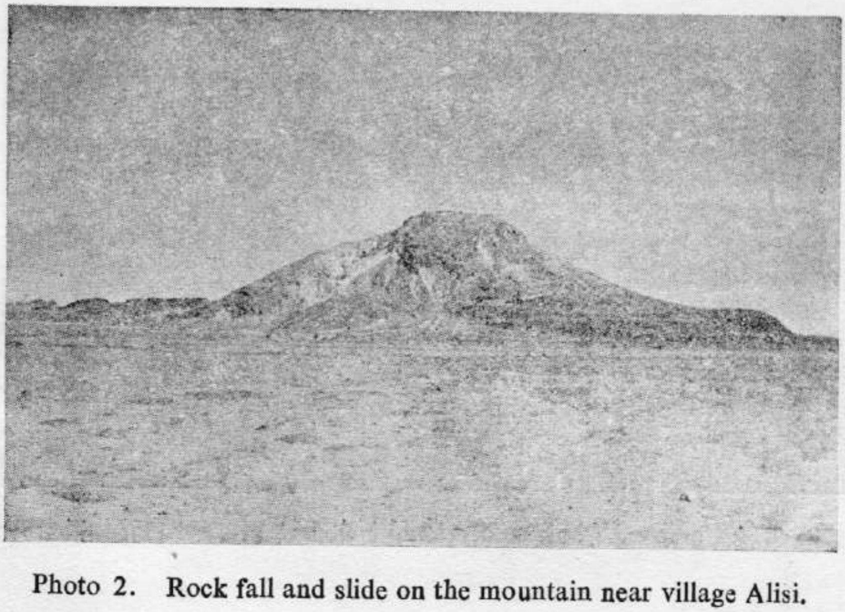


Photo 2. Rock fall and slide on the mountain near village Alisi.

Photo 3. Complete Collapse of a single storied dwelling of random stone construction near Dohran.

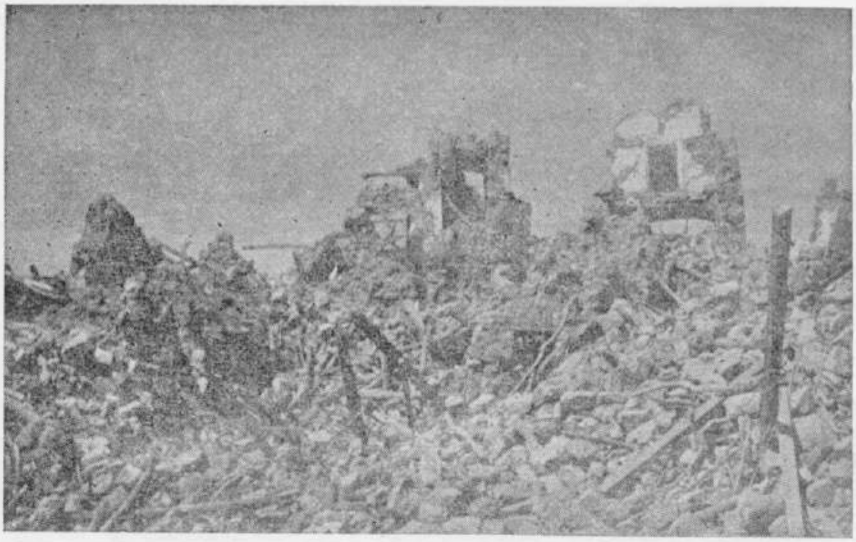


Photo 4. Complete Collapse of random stone house in village Dohran.

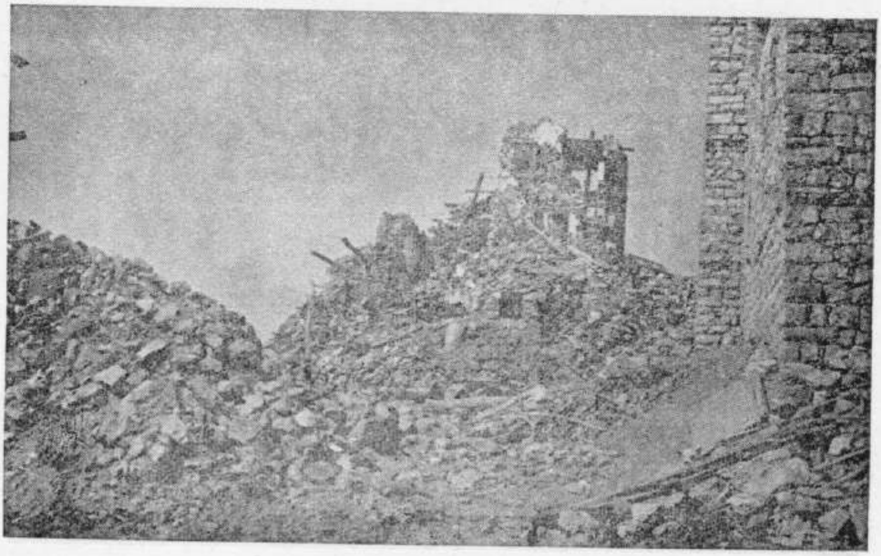


Photo 5. Collapse of houses built of random rubble stone in village Dohran.

Photo 6. Complete Collapse of a house of random stone construction with muck filling in the hearting of walls at village Dohran.

Photo 7. Collapse of stone built dwellings in village Dohran.

Photo 8. Collapse of third storey and cracks in lower storey walls, very heavy floors in houses seen in village Dohran.

Photo 9. Collapse of Dohran Madarsa-cum-Mosque, some Arches and posts still standing.

Photo 10. Undamaged portion of Dohran Madarsa-cum-Mosque, standing posts, arches and damage in the roof.

Photo 11. Damages to the Dohran Madarsa-cum-Mosque, fallen wood pieces from roof, cracked and peeled off plaster on walls and pillars.

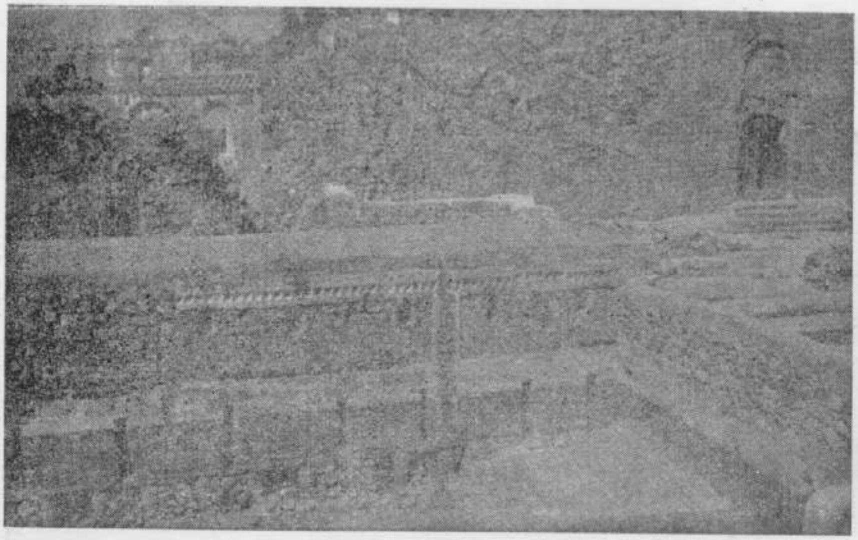


Photo 12. Back portion of Dohran Madarsa-cum-Mosque wall, one leaf of stone fallen, random combination of stone and brick wall construction may be seen in the foreground.

Photo 13. Random rubble stone wall, no interlocking between inner outer faces of stones at Village Hizrat Mangada.

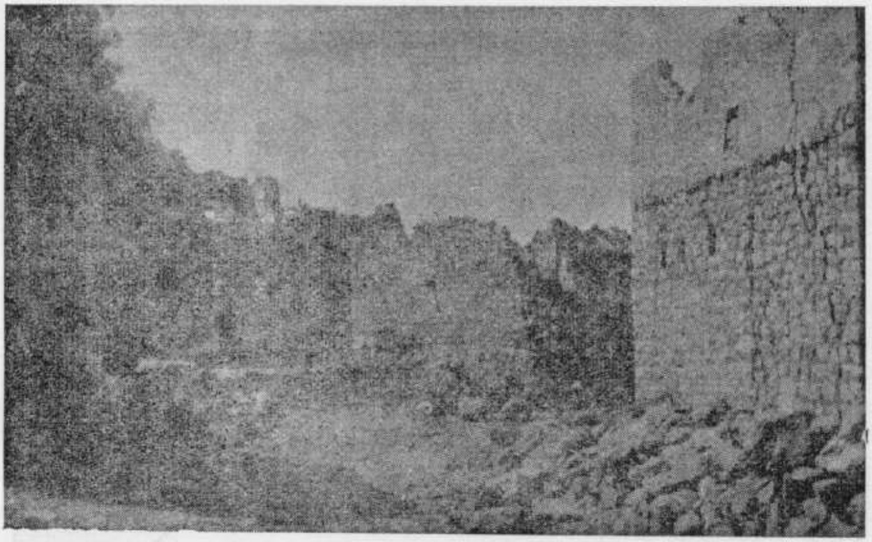


Photo 14. Construction using random stone in lower floor and adobe on upper floor in village Dohran, cracks and collapse of wall.

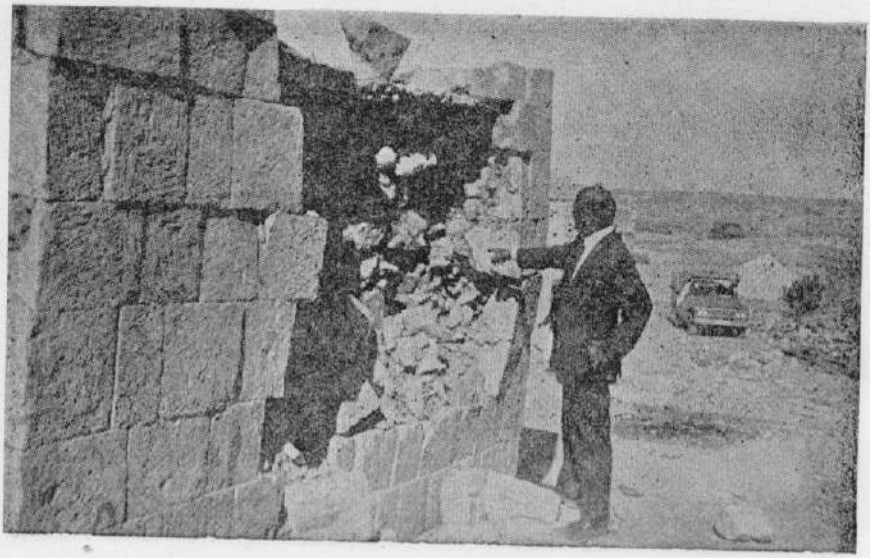


Photo 15. Outside dressed stone wall and inside small random stone and muck filling at Village Qubatil. Collapse of outer leaf of dressed stone.

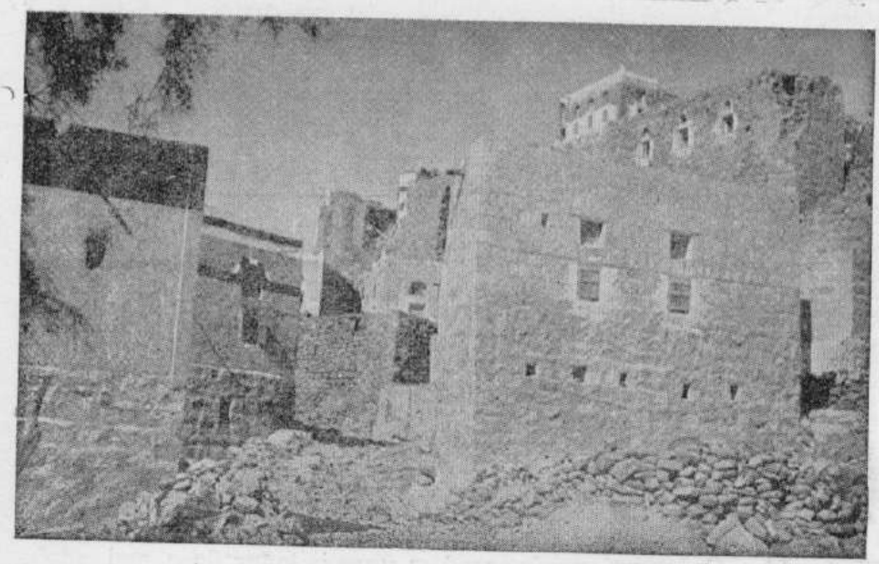


Photo 16. Damage to corners and walls in upper floors of dwellings, random provision of wood pieces over window in village Dhi-Hawlan.

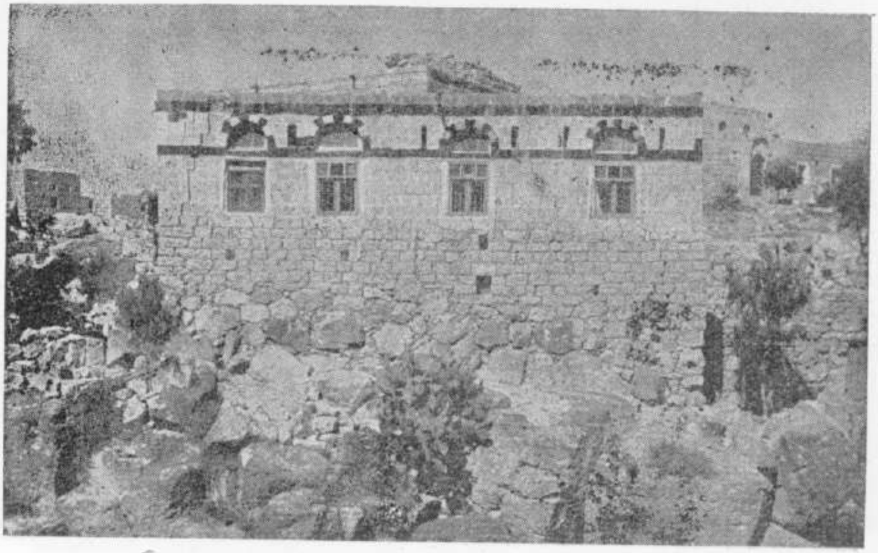


Photo 17. Random stone and coursed stone construction, cracks and separation at corner of wall at Village Hizrat Mangada.

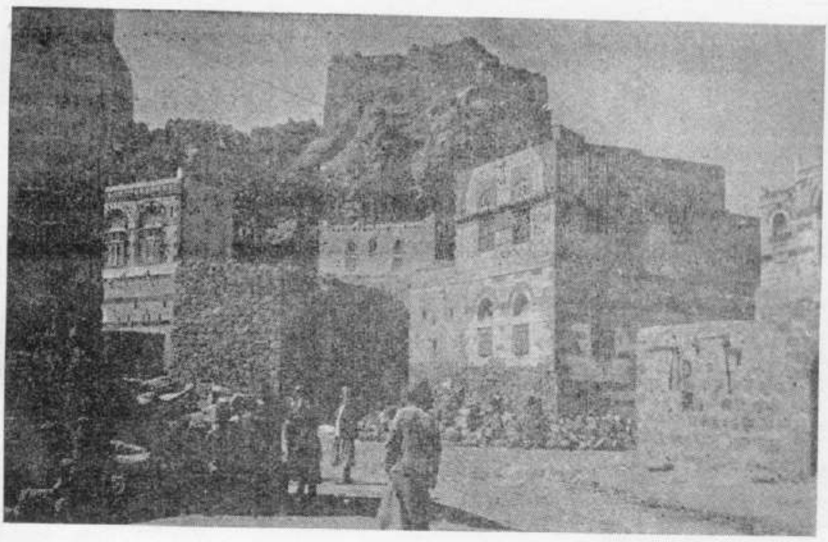


Photo 18. Collapse of upper floor of a house on hill top. Other houses cracked but not collapsed in village Warakah. Separation of walls seen at their intersections.

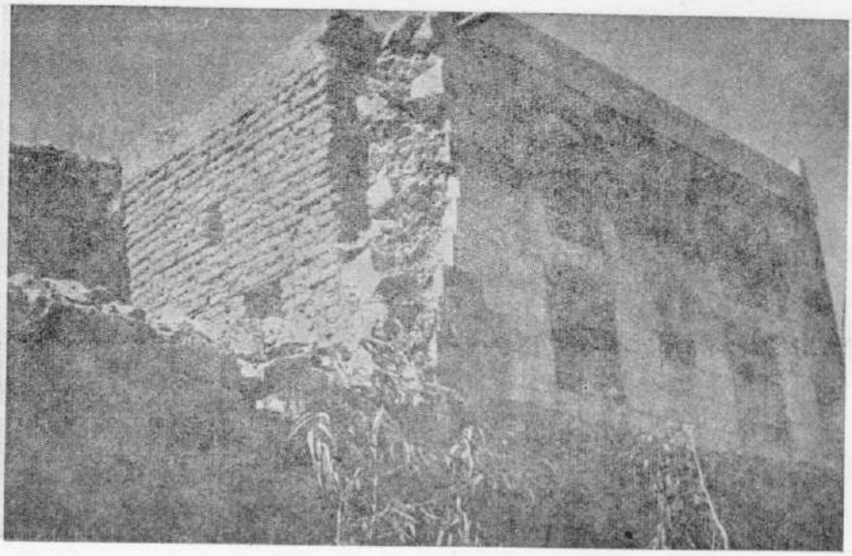


Photo 19. One face dressed coursed stone and another face random stone in front wall and adobe construction along side wall of a house, no interlocking at corner of wall and damage at corner in Village Warakah.

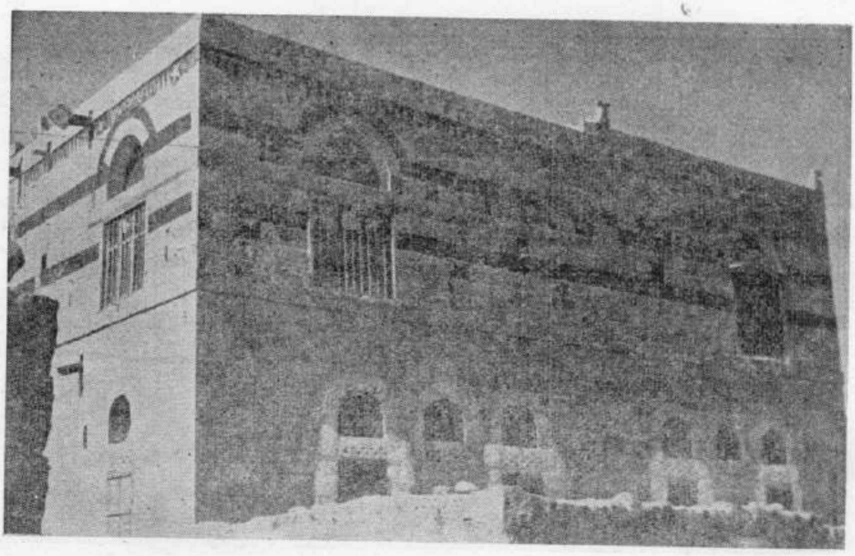


Photo 20. Dressed stone two storied house in village Dhi-Hawlan, use of wood piece at corner of walls and over window. Apparently no damage.

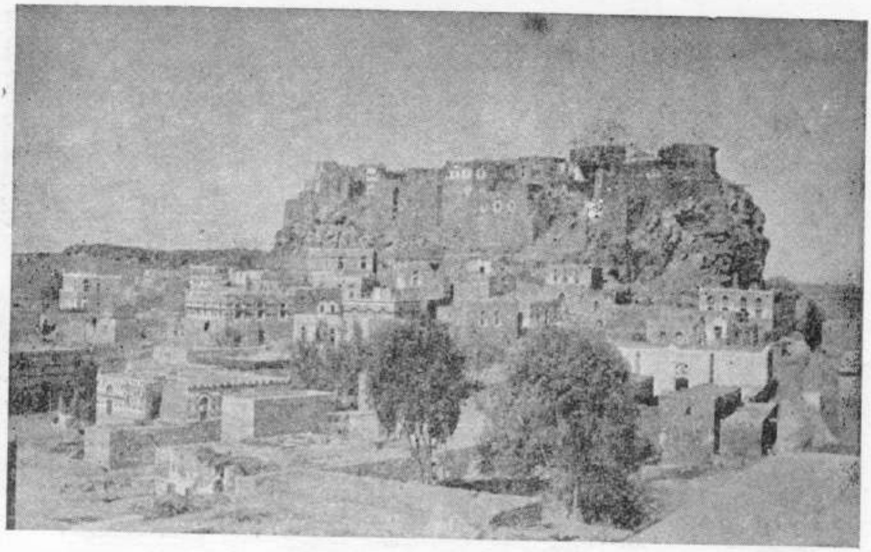


Photo 21. General view of random and coursed stone and adobe construction with houses on hill top at village Dhi-Hawlan.

Photo 22. Destruction of houses in village Dohran.

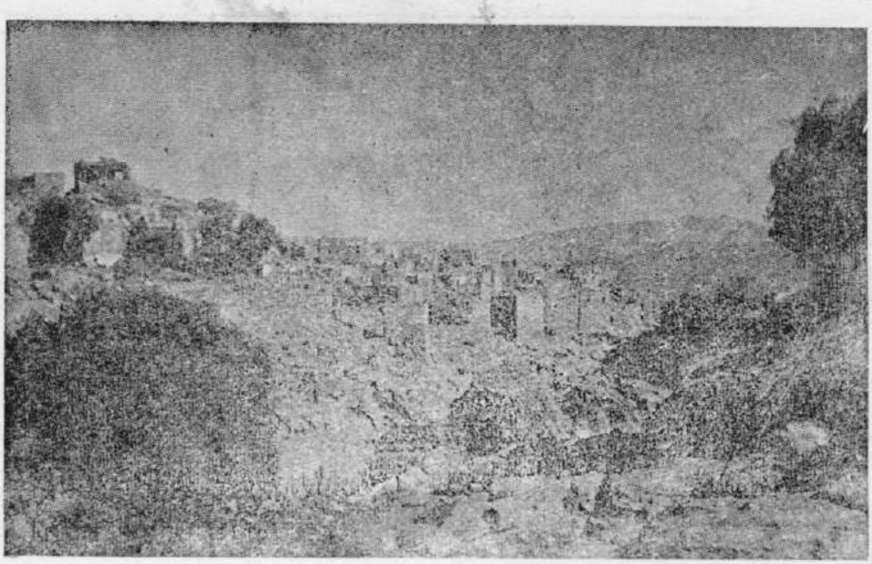


Photo 23. General view of severe damages of houses on a hill top near Hizarat Mangada.

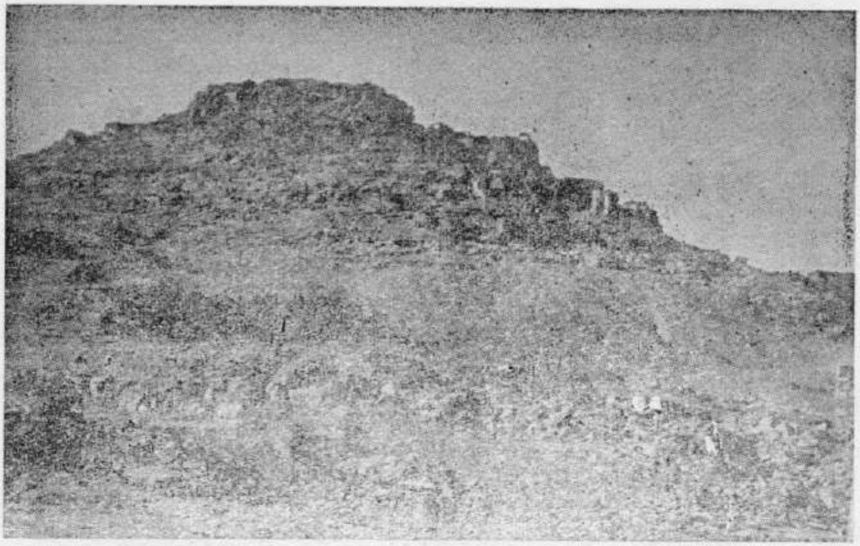


Photo 24. Complete destruction of all houses situated on hill top in Qubatil. The random stones littered all over the hill slopes.

Photo 25. Adobe making in progress in village Al-Olayb. Corner wall construction shown size of adobe is such that breaking of vertical joints in different courses is perfectly arranged.

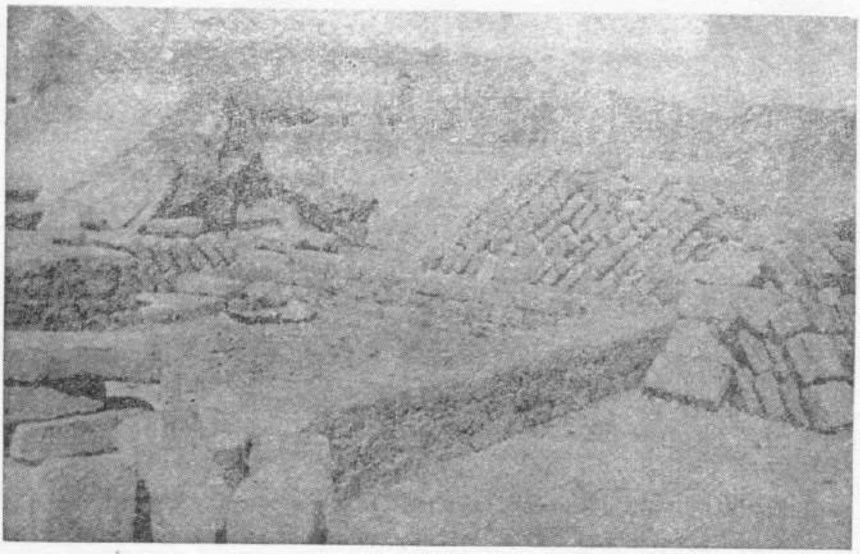


Photo 26. Adobe construction in progress in village Wasta.

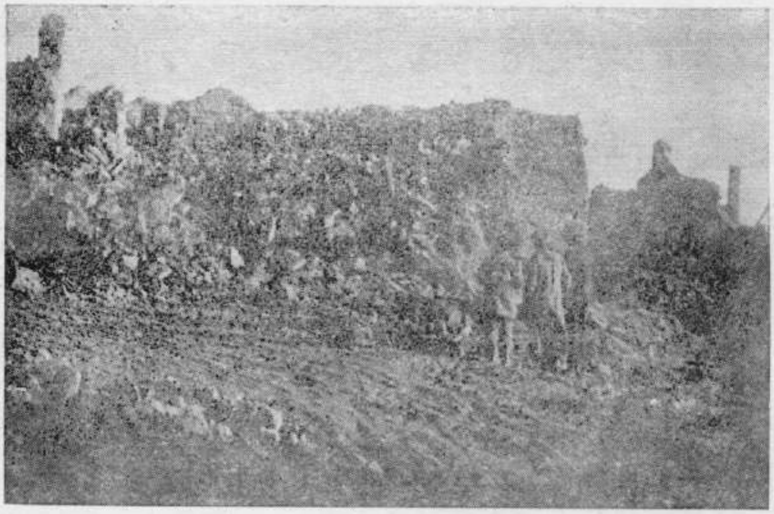


Photo 27. Destruction of adobe Houses at village Al-Olayb.

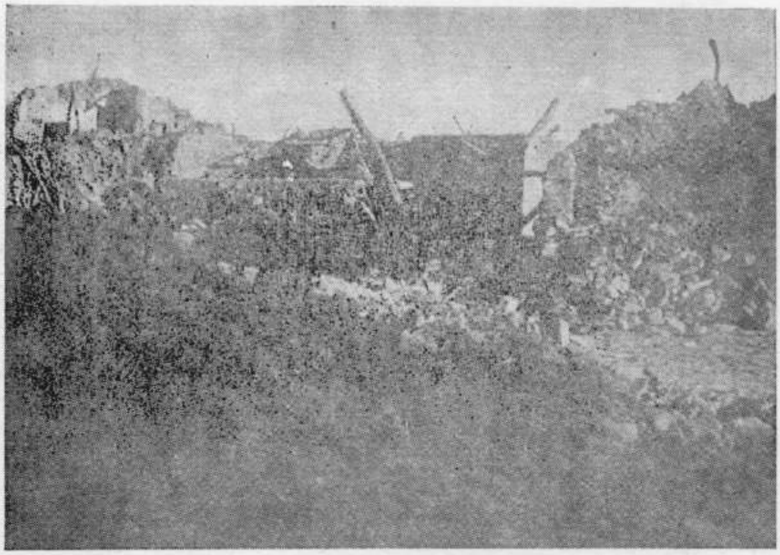


Photo 28. Destruction of adobe Houses in village Al-Olayb. See choking of streets.

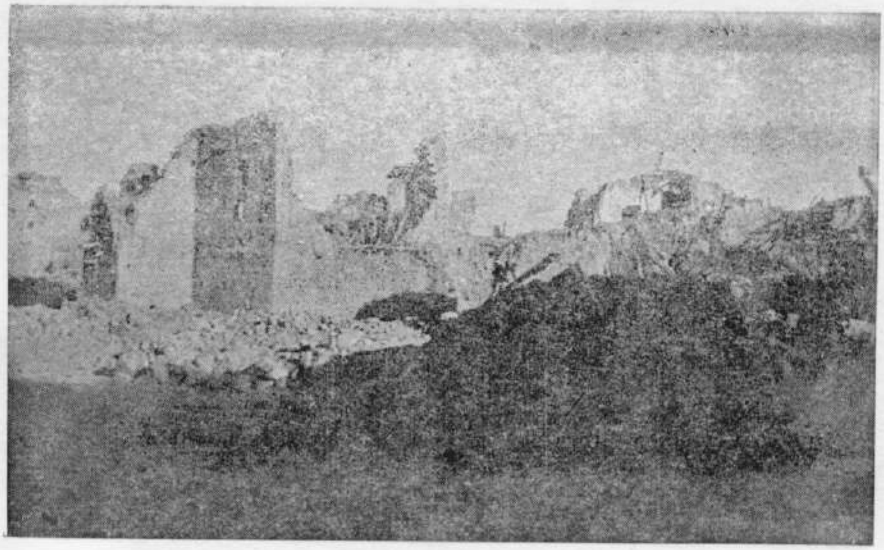


Photo 29. Damages to adobe construction in village Al-Olayb.

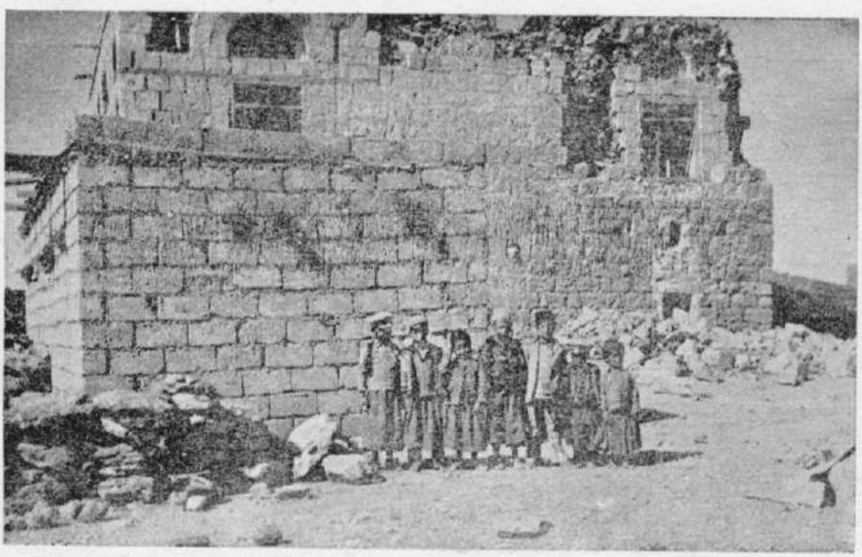


Photo 30. A single storeyed house built from solid concrete blocks in gypsum mortar remains undamaged and a two storeyed stone house badly damaged with collapse of corners in village Hizarat Mangada (See discontinuous use of wood pieces).

Photo 31. Electrical substation building, minor crack in wall in village Dohran (Dressed stone masonry in cement mortar).

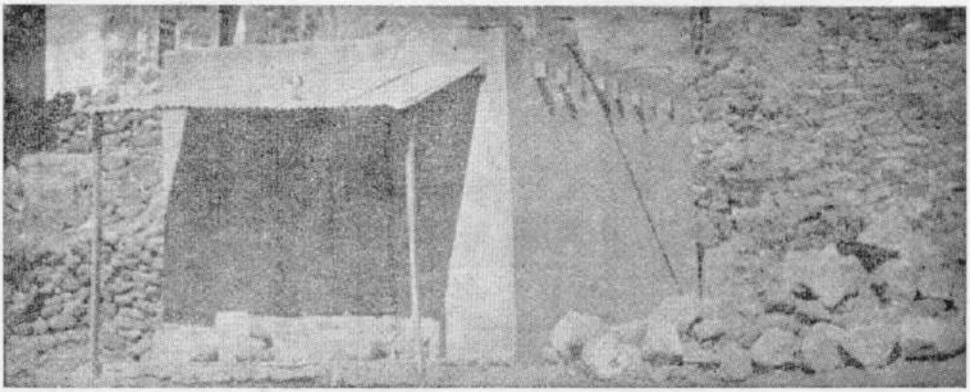


Photo 32. A single storied (apparently newly built) ration shop located at the foot of the hill was not damaged in village Dohran. See cement plaster outside the walls.

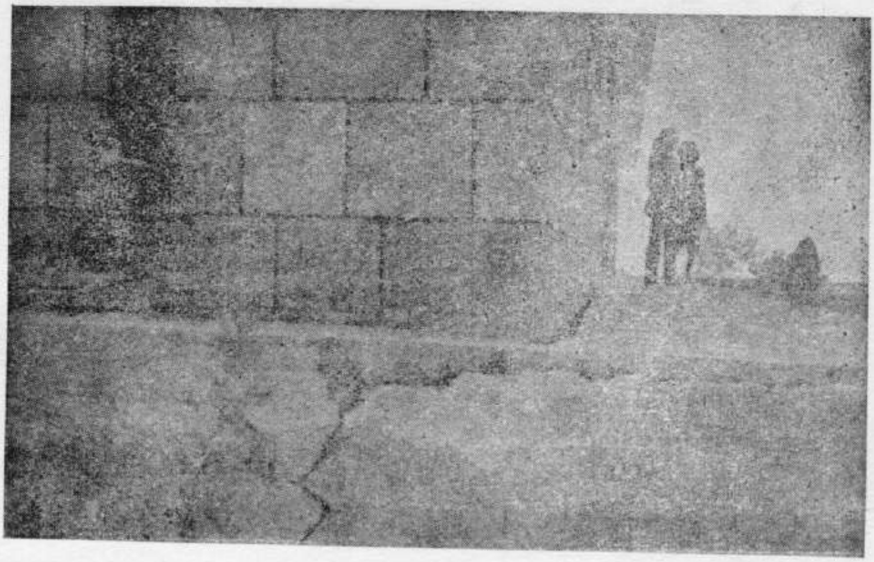


Photo 33. Cracks and separation on the North-East corner of the foundation and wall of the Dohran Dispensary. Sinking of outside passage.

Photo 34. Diagonal cracks in the wall (inside view) in a room of the Dohran Dispensary, stone masonry consisting of half-dressed stones built in gypsum mortar.

Photo 35. No damage, only minor cracks in the Dohran Madarsa (Masonry as in Dohran Dispensary.)

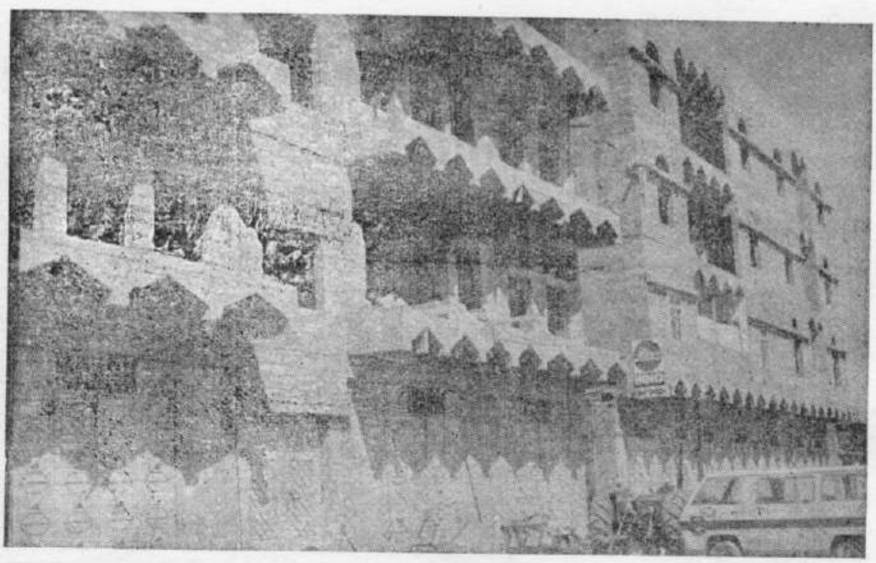


Photo 36. Reinforced concrete framed structures with concrete block wall filling in Dhamar, no damage reported. (Balcony wall filled with concrete block may fall in severe shaking, proper bonding and strength required.)

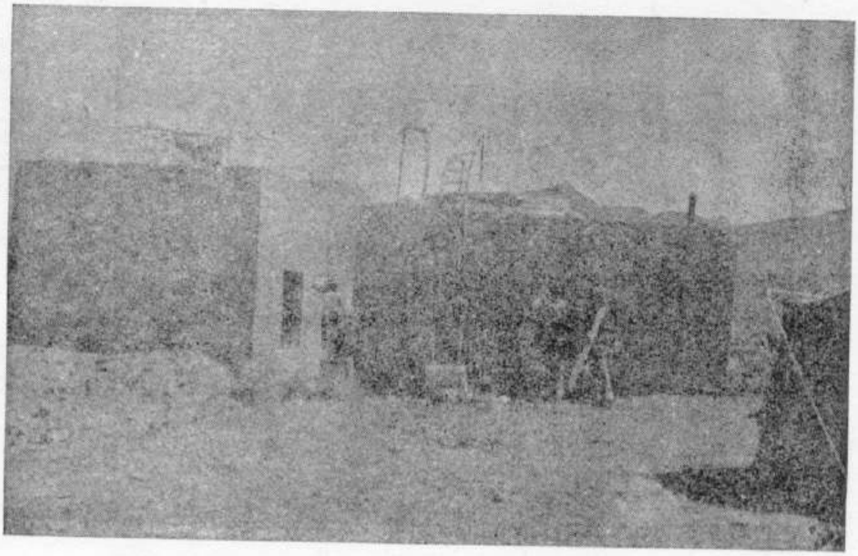


Photo 37. Collapse of a reinforced concrete water tank near village Dohran, the adjoining pump house suffered cracks in the walls.

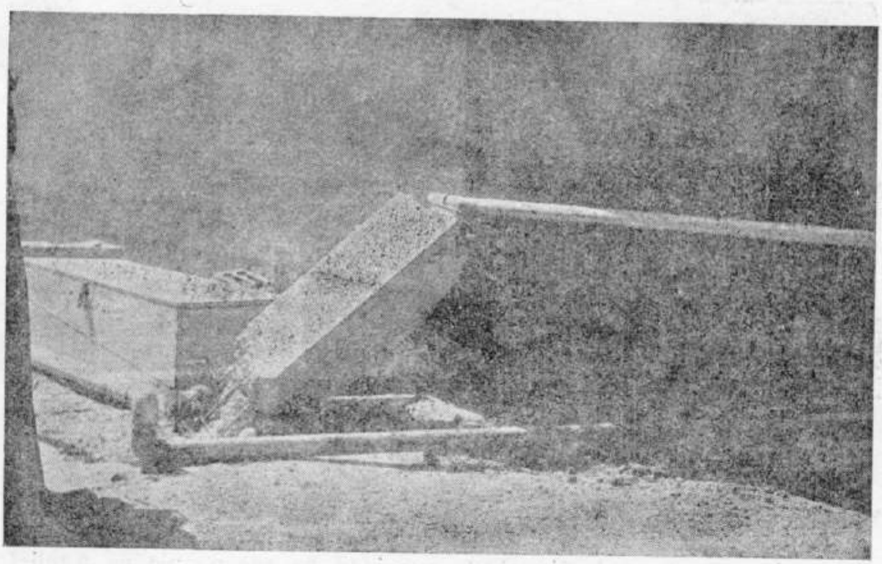


Photo 38. Damage to reinforced water tank columns, inadequate reinforcement and ties.

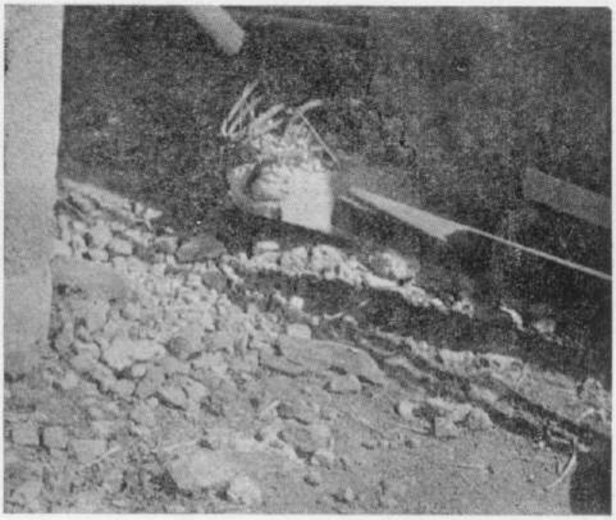


Photo 39. Buckling of reinforcements in the columns of water tank, badly mixed concrete and few reinforcements.

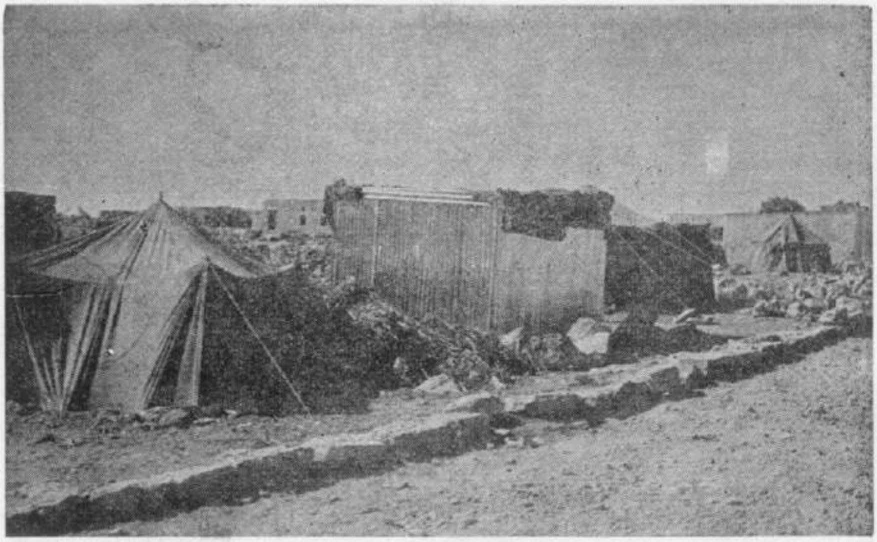
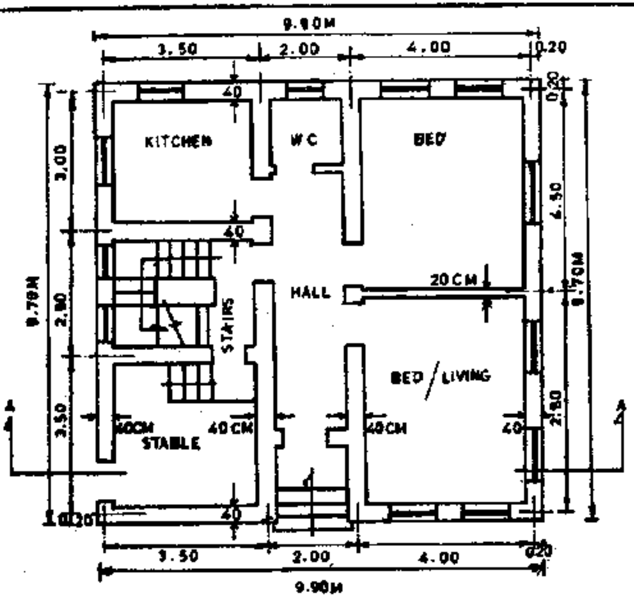
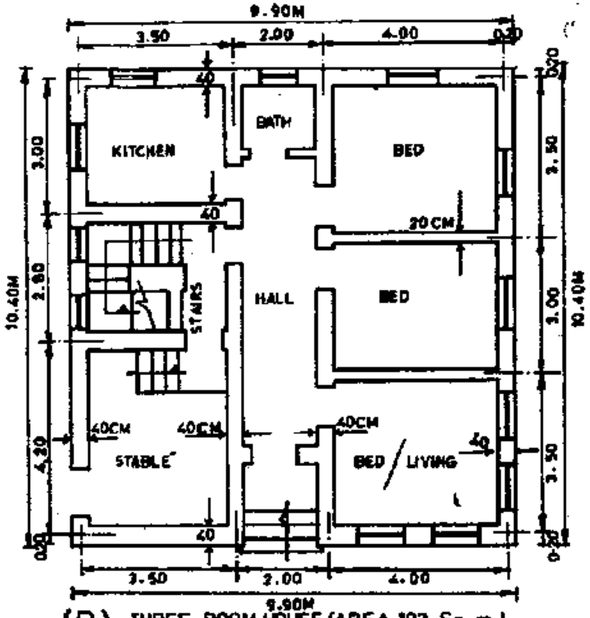


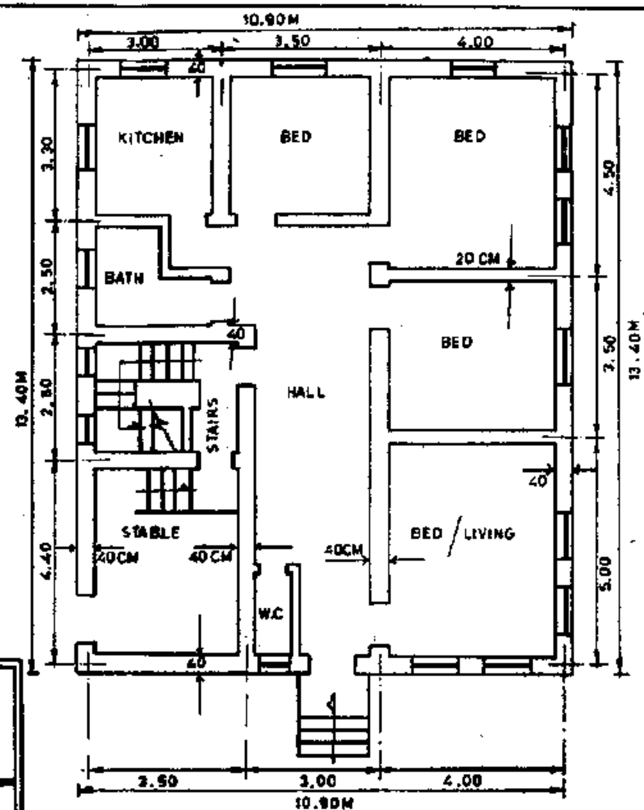
Photo 40. Tents and Tin sheds provided to the people as a relief measure at Village Hizrat Mangada.



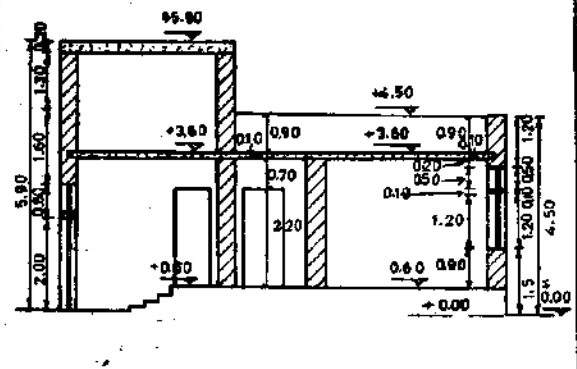
(A) - TWO ROOM HOUSE (AREA 96 Sq.m.)



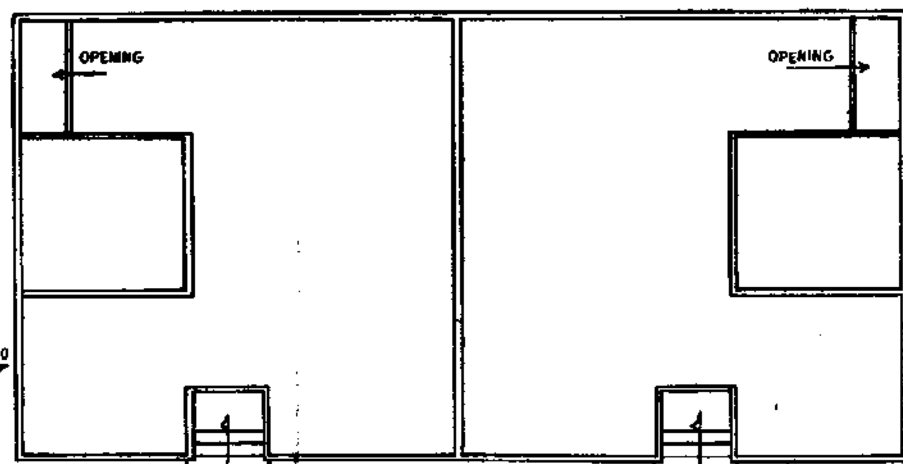
(B) - THREE ROOM HOUSE (AREA 103 Sq.m.)



(C) - FOUR ROOM HOUSE (AREA 136 Sq.m.)



(D) - CROSS SECTION A-A

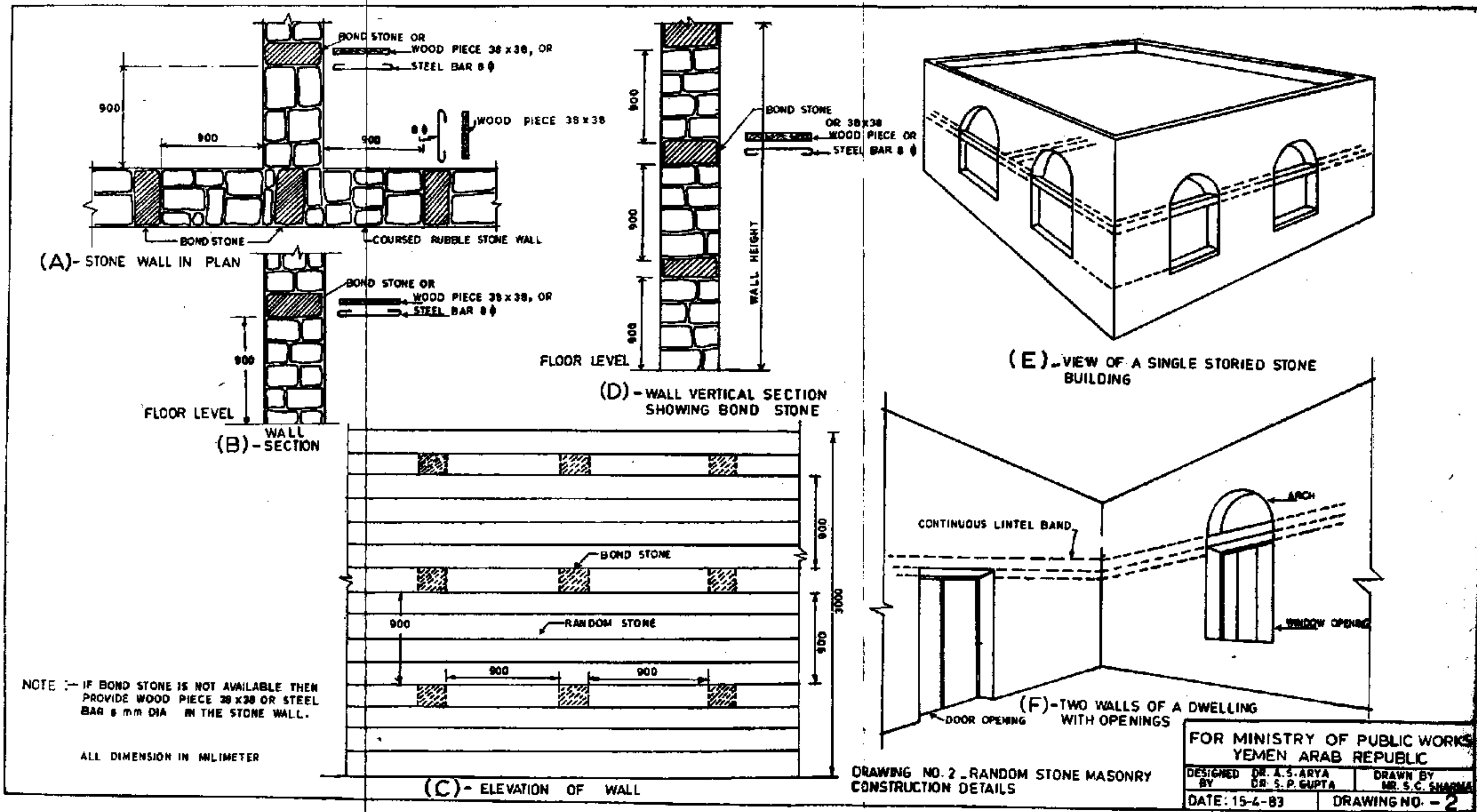


(E) - ROOF PLAN FOR TWO UNITS

DRAWING NO.1-TYPICAL PLANS OF TWO, THREE AND FOUR ROOM HOUSES

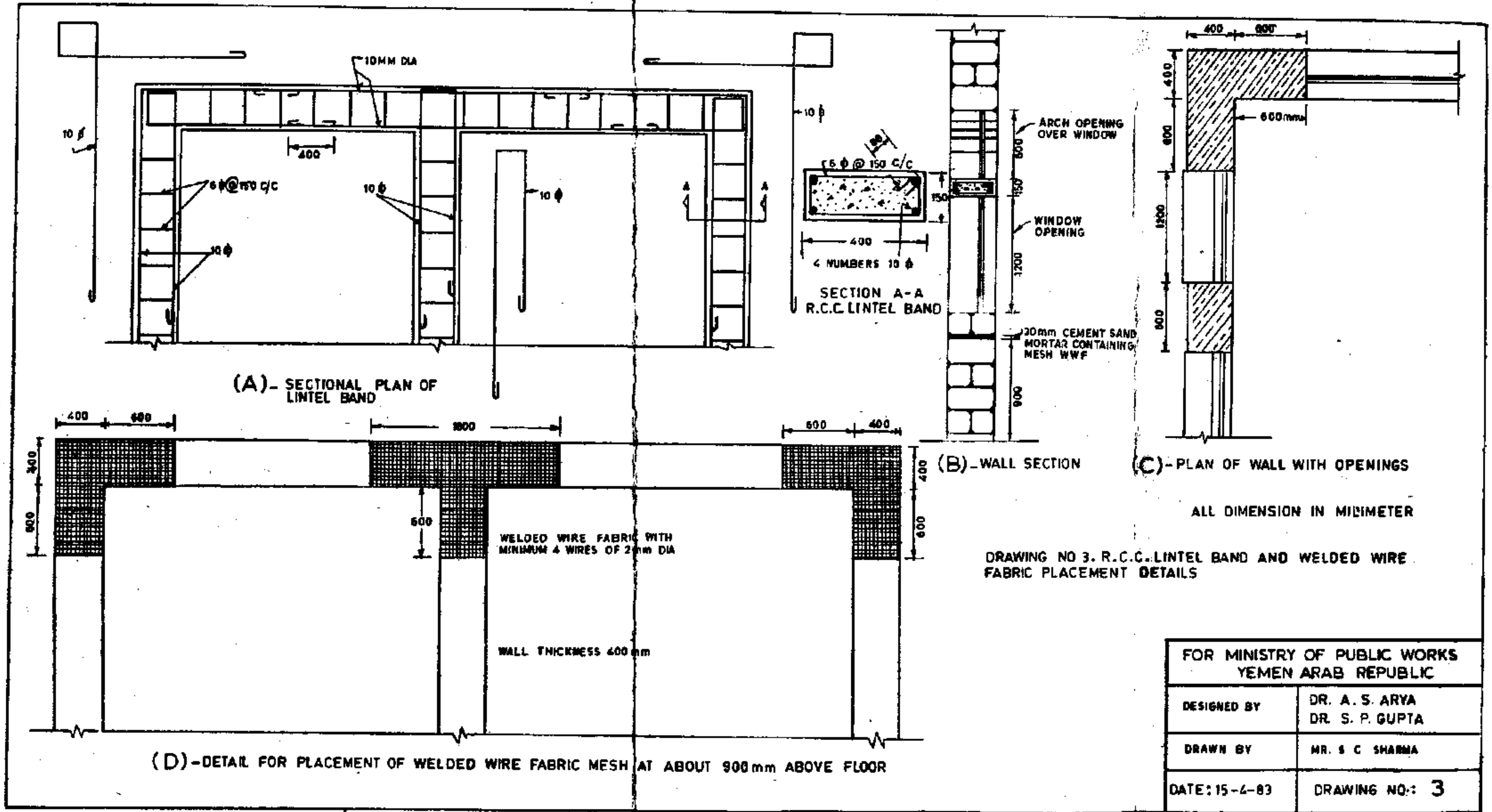
FOR MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC		
CHIEF ENGINEER	MR. ABDUL RAHMAN SHAMSAN	
ASST. OF CHIEF ENGINEER AND ARCHITECT	MR. HATIM AL-SABAHI	
INDIAN ENGINEERS	DR. A.S. ARYA DR. S.P. GUPTA	
INDIAN DRAFTSMAN	MR. S.C. SHARMA	
SCALE F:100	DATE 15-4-1983	DRAWING NO. - 1

Drawing No. 1

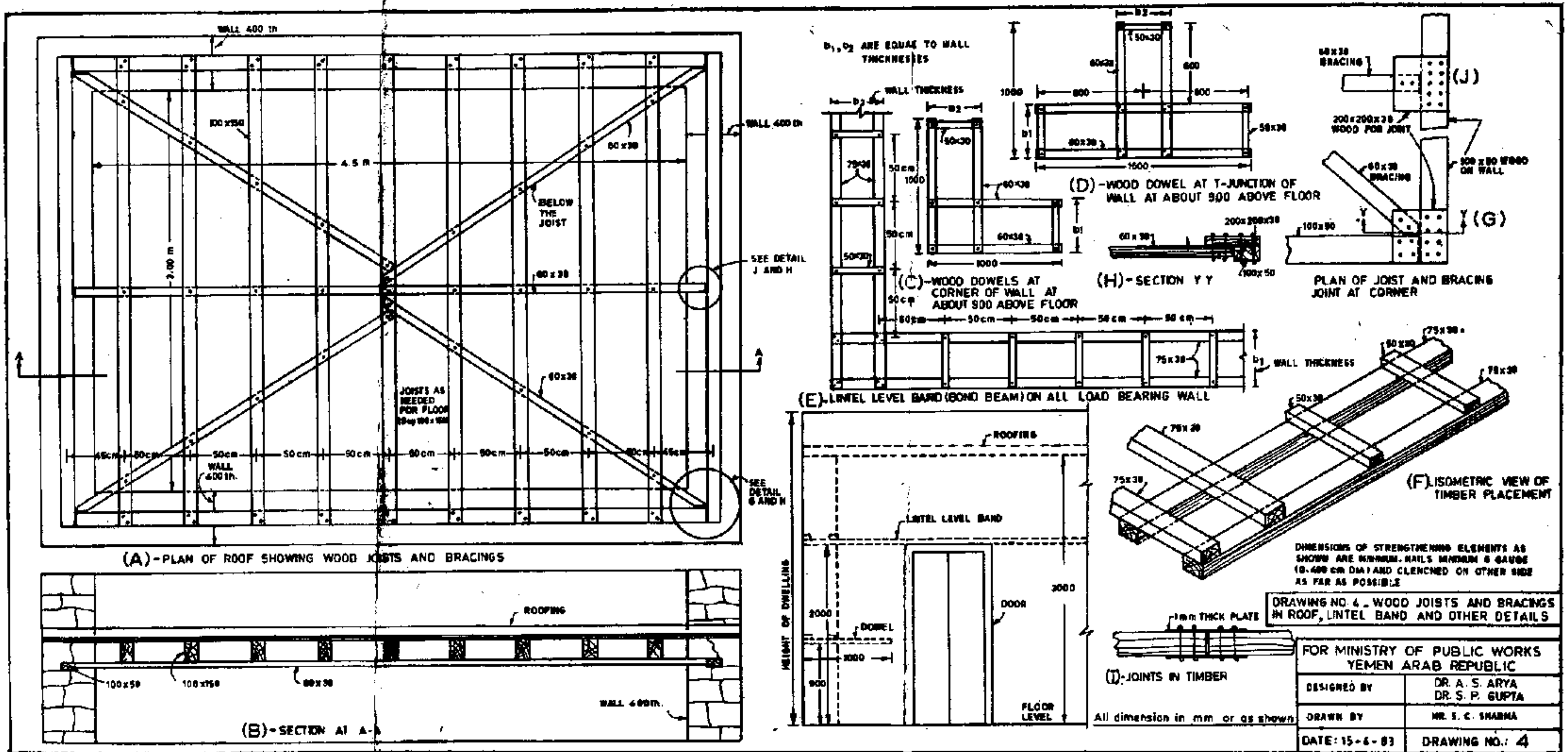


BOND STONE OR
WOOD PIECE 38 x 38, OR
STEEL BAR 8 ϕ
900
900
900
8 ϕ
WOOD PIECE 38 x 38
BOND STONE
COURSED RUBBLE STONE WALL
(A)- STONE WALL IN PLAN
BOND STONE OR
WOOD PIECE 38 x 38, OR
STEEL BAR 8 ϕ
900
FLOOR LEVEL
(B)- WALL SECTION
900
900
900
BOND STONE
OR 38 x 38
WOOD PIECE OR
STEEL BAR 8 ϕ
WALL HEIGHT
FLOOR LEVEL
(D) - WALL VERTICAL SECTION SHOWING BOND STONE
BOND STONE
RANDOM STONE
900
900
900
900
900
3000
(C) - ELEVATION OF WALL
NOTE :- IF BOND STONE IS NOT AVAILABLE THEN PROVIDE WOOD PIECE 38 x 38 OR STEEL BAR 8 mm DIA IN THE STONE WALL.
ALL DIMENSION IN MILIMETER
(E)-VIEW OF A SINGLE STORIED STONE BUILDING
CONTINUOUS LINTEL BAND
ARCH
WINDOW OPENING
DOOR OPENING
(F)-TWO WALLS OF A DWELLING WITH OPENINGS
DRAWING NO. 2 - RANDOM STONE MASONRY CONSTRUCTION DETAILS
FOR MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC
DESIGNED BY DR. A. S. ARYA DR. S. P. GUPTA
DRAWN BY MR. S. C. SHARMA
DATE: 15-4-83
DRAWING NO. - 2

Drawing No. 2


10MM DIA
10 ϕ
6 ϕ @ 150 C/C
400
10 ϕ
A
(A)- SECTIONAL PLAN OF LINTEL BAND
6 ϕ @ 150 C/C
150
400
4 NUMBERS 10 ϕ
SECTION A-A
R.C.C. LINTEL BAND
ARCH OPENING OVER WINDOW
WINDOW OPENING
30mm CEMENT SAND MORTAR CONTAINING MESH WWF
500
150
1200
900
(B)-WALL SECTION
400
600
600mm
1200
(C)-PLAN OF WALL WITH OPENINGS
ALL DIMENSION IN MILIMETER
DRAWING NO 3. R.C.C. LINTEL BAND AND WELDED WIRE FABRIC PLACEMENT DETAILS
1800
WELDED WIRE FABRIC WITH MINIMUM 4 WIRES OF 2mm DIA
WALL THICKNESS 400 mm
(D)-DETAIL FOR PLACEMENT OF WELDED WIRE FABRIC MESH AT ABOUT 900mm ABOVE FLOOR
FOR MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC
DESIGNED BY
DR. A. S. ARYA
DR. S. P. GUPTA
DRAWN BY
MR. S C SHARMA
DATE: 15-4-83
DRAWING NO.: 3

Drawing No. 3


(A) - PLAN OF ROOF SHOWING WOOD JOISTS AND BRACINGS
(B) - SECTION AT A-A
(C) - WOOD DOWELS AT CORNER OF WALL AT ABOUT 900 ABOVE FLOOR
(D) - WOOD DOWEL AT T-JUNCTION OF WALL AT ABOUT 900 ABOVE FLOOR
(E) - LINTEL LEVEL BAND (BOND BEAM) ON ALL LOAD BEARING WALL
(F) ISOMETRIC VIEW OF TIMBER PLACEMENT
(H) - SECTION Y Y
PLAN OF JOIST AND BRACING JOINT AT CORNER
(I) - JOINTS IN TIMBER
b1, b2 ARE EQUAL TO WALL THICKNESSES
SEE DETAIL J AND H
SEE DETAIL G AND H
JOISTS AS NEEDED FOR FLOOR
BELOW THE JOIST
LINTEL LEVEL BAND
ROOFING
DOOR
DOWEL
FLOOR LEVEL
HEIGHT OF DWELLING
1mm THICK PLATE
DIMENSIONS OF STRENGTHENING ELEMENTS AS SHOWN ARE MINIMUM. NAILS MINIMUM 6 GAUGE (0.400 cm DIA) AND CLENCHED ON OTHER SIDE AS FAR AS POSSIBLE
DRAWING NO. 4 - WOOD JOISTS AND BRACINGS IN ROOF, LINTEL BAND AND OTHER DETAILS
All dimension in mm or as shown
FOR MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC
DESIGNED BY DR. A. S. ARYA DR. S. P. GUPTA
DRAWN BY MR. S. C. SHARMA
DATE: 15-6-83
DRAWING NO.: 4

Drawing No. 4