Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VIII)

SL-6

REPAIR AND STRENGTHENING OF DAMAGED STONE HOUSES AFTER DHAMAR EARTHQUAKE OF DEC. 1982

Anand S. ARYA[1]

[1]Department of Earthquake Engineering, University of Roorkee, Roorkee, India

SUMMARY

The paper presents a scheme of repair and seismic strengthening, as recommended by the author, for about 13500 stone buildings damaged during Dec. 1982 earthquake in Dhamar Province of Yemen Arab Republic. The main causes of damage are outlined and the essential elements necessary for earthquake resistance are explained with practical details. The cost of total repairs was estimated less than 20% of reconstruction cost. One post office building was strengthened as field illustration.

INTRODUCTION

This brief paper is concerned with the repair and strengthening of those stone masonry buildings in Dhamar Province of Yemen Arab Republic which were damaged by varying degrees during the Dhamar Earthquake of Dec. 13, 1982. Although this earthquake had a moderate magnitude of 5.8 to 6.0 on Richter scale, the damaging effect on the stone buildings was rather destructive due to shallow focus of the earthquake assessed as 10 km and the peculiar site and construction features of the masonry houses. According to the survey carried out by Y.A.R. Government, 1176 settlements in Dhamar Province representing 82.2% of total were affected, 25045 houses (46.1% of total) were destroyed and 18458 homes (33.9% of total) were cracked. Besides, 19 Government buildings, 79 schools and 651 mosques were also destroyed. As a result about 1600 lives were lost inspite of the fact that the earthquake accurred at noon (12.13 PM local time). Had the earthquake occurred at night, the loss of life would have been dreadfully large.

The total rehabilitation programe of the large population rendered homeless (265300 persons or 58.5% of total population of the province) prepared by the Y.A.R. Government with the bilateral and international assistance consists of construction of about 15000 new houses through contractors, 10000 new houses through self-help and repairing of about 13500 cracked homes. Actually the earlier repairable estimate of about 18000 has later shown that about 25 percent of these houses will infact be unfit for repairing and may have to be demolished.

Thus a total of 13500 houses varying from one to three storeys and having different plans built according to the likes of generations of the population need to be repaired as well as strengthened to meet the future earthquake demands. A general scheme of repairing and seismic strengthening is worked out in this paper which can generally be applied to the masonry houses of one and two storey in height. It is hoped that after the proposed repair and strengthening measures are applied to the damaged buildings, they would be upgraded to an extent that they will be able to sustain without collapse, an earthquake of the type which accurred in Dhamar Province on Dec. 13,1982.

It will be advisable to reduce the number of storeys to two by removing the upper storeys.

TYPICAL HOMES IN STONE MASONRY CONSTRUCTION

The stone masonry has two general variations. In the rural areas the most common construction is in random rubble field stone, locally called as 'Goum', set in mud mortar and chip filling. Some times the stones are dry packed. The less common and more costly variation is the use of half-cut one-face-dressed stones on the outer face and random rubble on the inside face of the outer walls of the houses; the outside face left unplastered, the inside walls plastered with mud or gypsum. Gypsum pointing is used on the outside face in some cases in the courses of the half cut stones. Fig. 1 shows a typical Yemeni home. Fig. 2 shows a typical cross-section.

The stone wall thickness usually varies from 50 to 75cm, but may even be 90cm. Larger stones, from 20 to 30cm in width and height are provided to make the outer and inner wythes of a wall, and the space in between is filled with loosely broken stone chips along with clay mud. In some old homes the mud is washed out by rain.

The roofs in Yemen are invariably of flat type since rainfall is scanty. The traditional roof consists of wooden beams in round, half round or rectangular shapes, placed parallel to each other at a spacing of 50 to 60cm. The clear span of the joists would usually be 2.0 to 3.0m and the bearing length will seldom exceed 20cm. Thus the room widths are limited by the span of the joist. But the length of rooms used as Diwan can be as long as the width or length of the building, say 10 to 12m. Resting on the wooden beams, there are laid thin tree branches, or bushes to from a deck for receiving the clay topping. The clay roofing thickness usually varies from 15 to 30cm and could even be thicker upto half a metre. So also the thickness of the floors is quite massive with some times a concrete screed. In newer constructions ply wood sheets 1.2x2.44m in plan and about 12mm thick are used to form the deck. The climate of the region is dry with scanty rain-fall and large diurnal temperature variations. The winters are cold at the prevailing elevations of 2400m above mean sea level. These factors must have led to thick walls with small openings and flat heavy roofs.

MAIN CAUSES OF DAMAGE AND COLLAPSE

The stone masonry houses suffer from the following inherent weaknesses and construction defects during earthquakes :

(a) Their rigidity is high leading to high acceleration resonse to earthquake motion. The amplification of ground acceleration could be 3-4 times. Moreover the large mass of walls as well as roofs will create large inertia forces.

(b) The tensile and shearing strength is very small, almost zero for masonry in mud mortar, thus incapable of resisting such imposed stresses during earthquakes. Also no 'through' or 'bond' stones are used in the walls which could have provided interconnection of the outer and inner wythes. Thus they are free to separate out during shaking. This may be called 'delamination' of the wythes (see Fig.3). The half cut stones generally become pyramidal in space, their stability under the vertical load depending on the filler stone pieces used to keep their outer face vertical and once they become loose during shaking, the stability of the outer wythe gets disturbed. The vertical load then tends to buckle the outer wythe outwards.

(c) Due to absence of bonding between perpendicular walls, they are quite free to separate from each other at the junctions, resulting in loss of rigid box-like action of the enclosures leaving each wall to resist the inertia forces on its own mass and the roof by itself, unaided by the shear-wall action of perpendicular walls.

(d) The roofs have no diaphragm action to be able to distribute the inertia force to all four walls or transfer it to the two end walls which would act as shear walls.

As a result, damage of varying degrees occurred. The damage to most repairable houses may be classified as follows :

(a) Vertical or slightly inclined cracks near outer corners indicating separation between the perpendicular walls, usually wider at top and finer towards base.

(b) Bulging of outer wythe of masonry in walls indicating its delamination and falling away of outer wythe stones in certain parts of the walls.

(c) Random cracks near the corners of openings, and disturbed parapet stones.

REPAIR, RESTORATION AND STRENGTHENING

By superficial repairs, like replastering and painting, neither the building is restored to its original strength nor will it be made strong for future earthquakes. Such a 'repaired' building will be very illusive, since all the structural weaknesses will be hidden and if it was shaken again it will be damaged more seriously. 'Restoration' involves repairs to the building structure so that at least the original strength of the building is restored. It involves removal of portions of cracked masonry and rebuilding it or injecting grout into the cracks. In the present context of damaged stone buildings, it will be necessary to carry out strengthening measures also besides restoration since even the original strength of these buildings was very inadequate for resisting earthquakes of MSK intensity VIII, and simple measures of repair and restoration will be grossly insufficient for their safety in future ground motions. Now it is neither structurally possible nor economically feasible to improve all the weaknesses of stone houses. However it is fairly possible at a reasonable cost, to remove many of the constructional defects and introduce enough strength to meet the future earthquake resistance requirements. The measures are described below :

(a) Grouting in cracks : The cracks in the masonry must be filled with gypsum or neat cement grout if they are fine or with cement-sand mortar if they are wide. Epoxy materials which can generate high tensile strength will be too expensive and unnecessary in stone walls in mud mortar, hence ruled out.

(b) Stitching of stones-wythes : It will be necessary to install 'through' bonding elements in the stone walls, particularly the outer perimeter wall in all storeys. If certain parts of outer wythes have fallen, these will have to be rebuilt using cement mortar and installing steel bar elements in the masonry itself.

(c) Treating Bulged Walls : Bulging of walls will indicate hollowness between the inner and outer stone wythes. This should be filled with cement-sand mortar after stitching of the two wythes is completed, otherwise the hydrostatic pressure of mortar may cause bursting of the walls. Treatment of 'seriously' bulged walls may require dismantling the bulged portion and rebuilding it. This operation may require shoring the adjoining walls or the roof and must be taken up carefully.

(d) Installing Reinforced Concrete 'Band' : This 'band' is variously called such as 'bond beam', 'perimeter beam' or 'chaining', etc. and may be installed in new constructions at various levels of a building such as plinth level, the lintel level and just below floor and roof levels within the wall thicknesses. In the old buildings the best location will be just below the roof and floor beams and it will have to be installed outside the wall thickness. It will serve two important functions : (i) To bind all the external walls together and prevent their separation at the corners. (ii) To act as horizontal bending beam for resisting the horizontal inertia force of roof or floor as well as that of the mass of the outer walls, and transfer these loads to the shear walls.

Ideally it will be desirable to run this 'band' on all internal and external walls as in new constructions. But the strengthening work of the existing house can be simplified by using cross-ties instead, running by the sides of the internal walls reaching to outside of the external walls to hold the opposite external walls together. The cross--ties will also reduce the horizontal span of the bands on the external walls, thus ensuring integral box like action of all the walls. Fig. 4 shows the proposal schemetically.

(e) In some old buildings there exist horizontal wood runners which have held the masonry walls together to the extent they could. But their utility was restricted because of rather weak joints in their lengths where separation occurred and masonry cracked. After grouting the wall cracks, the value of the wood runners will be enhanced by nailing or screwing steel straps to them across their joints. The straps should be strong enough to equal the full tensile strength of the wood members. In such house, the provision of reinforced concrete band may be omitted.

DETAILS OF REPAIR AND STRENGTHENING SCHEME

(a) Grouting in cracks : For fine cracks, the grout should be gypsum-water fluid like mixture or neat cement and water in the ratio about 1:1. For wide cracks, it may consist of cement and fine sand in the ratio of 1:1 or 1:2 depending upon the crack width and water added to obtain free flowing consistency. For grouting operation, a low pressure mobile grouting pump run on diesel will be suitable. But it could be carried out by using a container kept about 1.5 to 2m higher than the cracked area and grout allowed to flow freely through a plastic pipe into the cracks. The cracks to be grouted will be sealed with mortar first along their length leaving a few ports open to receive the nozzle of the grout pipe. The grouting is to be done starting with the lowest part and proceeding upwards after the lower part of the crack gets filled up, see Fig.5. It may be mentioned that it will be too expensive to fill the normal joints in dry masonry walls by this procedure, and should not be attempted.

(b) Stitching oof Stone wythes : For new constructions, the 'through' stones or 'bonding' elements are recommended to be provided at the rate of one per m^2 area of the wall. For restoration work, however, it is considered adequate that stitching elements may be provided at one level in each storey at about mid-height between the floor and the reinforced concrete band, that is, about 1.2m above the floor and a horizontal distance of not more than about 2m. For installing the bonding element, a hole will be made through the wall by removing one external stone and one opposite internal stone. After cleaning the hole, it is to be filled with concrete while embedding a 8mm dia bar hooked at both ends in it transverse to the wall length. The length of this bar will be kept 5cm less than the wall thickness (see Fig.3). These may be omitted where cross walls exist at right angles to the external walls.

(c) Treating Bulged Walls : The grouting of the hollow will be done after installation of bonding elements whose number could be increased locally if the bulge area is large. The grouting mortar could in this case be cement-fine sand in the ratio of 1:3. Fallen masonry should be reconstructed using 1:6 cement sand mortar and installing 'through' stones or bonding element, as the reconstruction proceeds. See Fig. 3.

(d) Installing Reinforced Concrete Band : This will involve the following steps (see Fig. 4 and 6).

(i)Making through hole in the walls, one stone in size, just below the roof or floor, one each at the ends of spans at a spacing not more than 5m, through which the cross-ties may be installed. Additional holes will be made at centre of these spans for providing additional shear-connection between outer and inner bands.

(ii)Installation of cross ties through the holes and filling all holes in internal walls with concrete 1:2:4. The cross ties are placed at two points in each direction dividing the length or width of the building in three parts, each less that about 5m in length. The ties consist of two high-strength-deformed bars 10mm dia.

(iii) Installation of band steel on outside and inside faces of the external walls. This will consist of two bars 10mm dia on each face which can be placed in position by driving concrete nails in the stones at about 0.9m apart at the correct level, supporting the bars on the nails and tying with them by wire.

(iv) Inserting U-shaped stirrups, 8mm dia, two from outside and two from inside in each hole so as to go round the 10mm dia longitudinal bars and be tied to them.

(v) Tying of galvaized wire mesh (wire 1mm dia, mesh 25mm x 25mm) to the main bars in between the holes.

(vi) Nailing of wooden strips 4cm thick and 7.5cm wide into the joints of the stone wall to form the edges of band-concrete so as to achieve 30cm wide band.

(vii) Filling of all holes in external walls with 1:2:4 concrete, and applying cement concrete 1:2:4, using aggregate passing 10mm size, by trowels like plaster to form the concrete plate. The mesh will hold the concrete and prevent its shrinkage cracking.

The longitudinal bars will have an overlap of 60cm wherever necessary and bend around external corners by at least 30cm each to give a total overlap of 60cm.

(e) Splicing existing wooden band beam : This may be done by nailing iron flats.

(f) Safeguarding parapets : Reduce the height of parapets to about 45 to 60cm and cast 40mm thick concrete reinforced with welded wire mesh throughout.

The total cost of repair and strengthening was estimated and came to less than 20% of the reconstruction cost of these stone buildings. The procedure was demonstrated in the field by carrying out the seismic strengthening of post office building at Dhamar.

CONCLUSION

The scheme of repair and seismic strengthening presented here-above would achieve stitching of inner and outer stone wythes in the walls to avoid their delamination during an earthquake, and will more than restore the lost strength by grouting the cracks and rebuilding fallen wythes. Provision of reinforced concrete bands in each storey just below the roof and floor and installation of steel cross-ties at the same level will effectively integrate all walls like a multicellular boxed unit with great resistance against horizontal inertia forces. Also walls will get horizontal bending strength to resist the horizontal inertia of roof and floor. Thus no-collapse seismic strengthening to about MSK VIII will be achieved.

ACKNOWLEDGEMENT

The discussion held with Mr. Jamal Mohammed Abdu, Dy Minister of Executive Office and Mr. Abdul Samad Sanabany, Director Repairs and Training, Y.A.R. helped a great deal in finalising the scheme. Their assistance is gratefully acknowledged.

REFERENCES

1. Arya A.S., L.S. Srivastava and S.P. Gupta, "Damages during Dhamar earthquake of Dec. 13, 1982 in Yemen Arab Republic", Bull ISET, Vol. 21,No.4, Dec. 1984, pp. 115-162.

2. Basic Concepts of Seismic Codes, Vol. I, Part II, Non-Engineered Construction, IAEE Committee (ii), IAEE, Tokyo, 1980, pp.33-76.

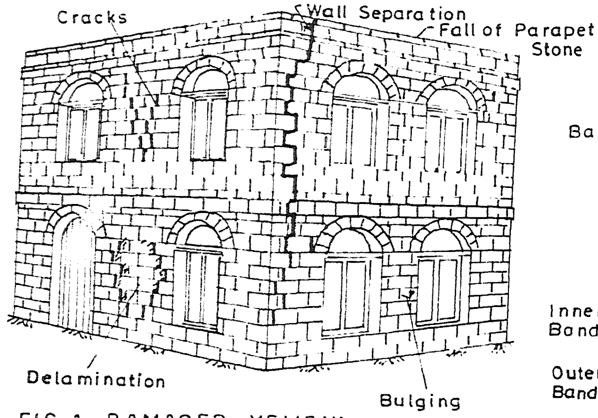

FIG.1_DAMAGED YEMENI HOME

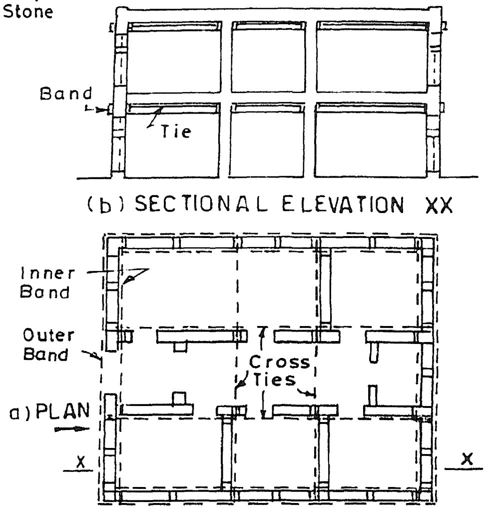

FIG.4_ BAND AND CROSS-TIES

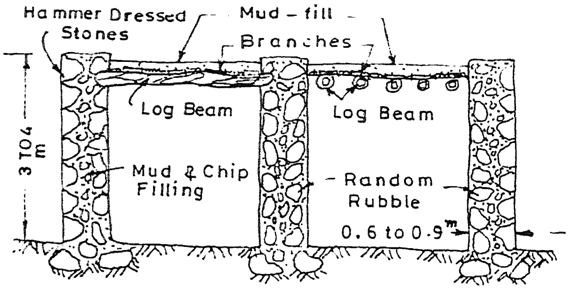

FIG. 2 . TYPICAL CROSS SECTION

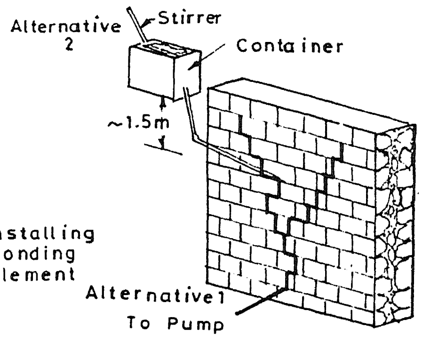

FIG. 5 _ GROUTING OF CRACKS

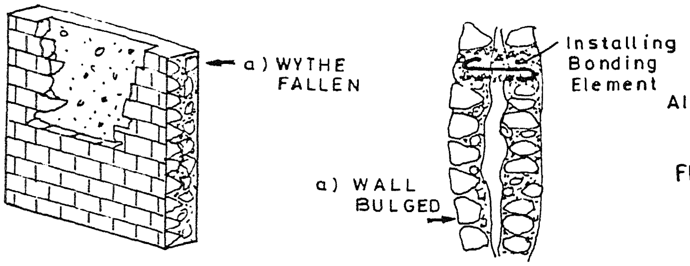

FIG. 3_ DELAMINATED WALLS

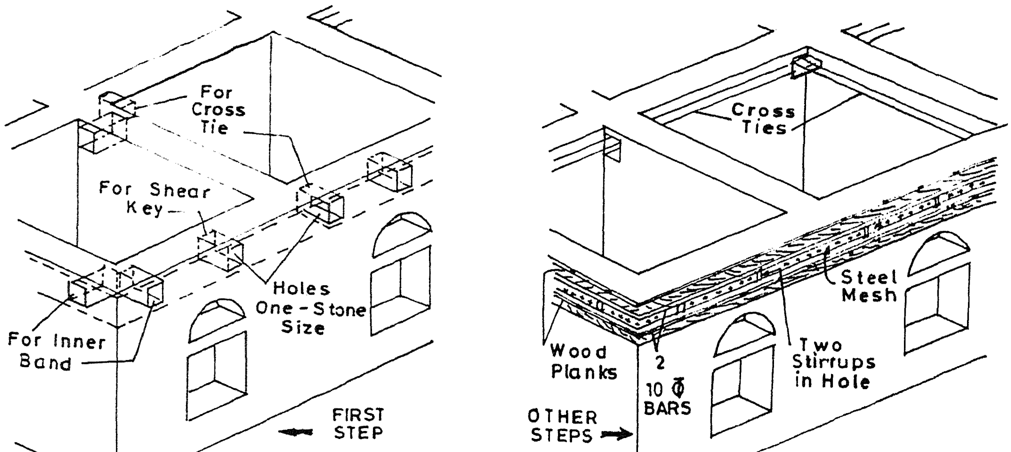

FIG. 6_ INSTALLING BANDS AND CROSS-TIES