11 WCEE

Paper No. 1726. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

SEISMIC RETROFITTING OF STONE HOUSES IN MARATHWARA AREA, INDIA

ANAND S. ARYA

Professor Emeritus, University of Roorkee
Roorkee, INDIA

ABSTRACT

Based on the stone house types destroyed by the thousands in M = 6.4 earthquake on September 1993 in Marathawara Area, India, a seismic retrofitting methodology was designed, pilotted and experimentally tested in the field by the author by which about 180,000 standing houses in the area could be strengthened. It consists of , (i) reducing the roof earth fill to 200 mm from more than 500 mm to reduce the seismic force, (ii) installing R.C. 'through' headers across more than 600 mm thick stone walls at about 1.2 m apart for preventing delamination of the stone wythes, (iii) providing ferro-cement seismic belt all round with appropriate cross-ties to integrate walls into rigid box by preventing separation of walls at corners, and (iv) knee-bracing of internal wooden frames, where they exist, so as to increase their lateral strength and stability. Half scale model houses tested on a shake-table built in the field, showed that whereas the unretrofitted one was destroyed at base acceleration of 0.47 g, the retrofitted one could sustain even 1.6 g with only small cracks. The methodology could be adopted with minor modifications to various stone building types around the world at a cost of 15-20% of the replacement cost of the buildings.

KEYWORDS

Seismic retrofitting, stone houses, Indian earthquakes, Killari earthquake, low-cost technology.

INTRODUCTION

An earthquake of M = 6.4 (Richter scale) occurred at 03h 55m 47.53 s in the early morning of September 30, 1993 in the Marathawara Area of Maharashtra State, India (Mohan and Rao, 1994). Inspite the moderate magnitude, it caused widespread damage in some 80 villages of 13 Districts including Latur and Osmanabad, the main damage area lying between latitude 17°45' to 18°15'N and longitude 76°15' to 76°45'E. The devastation included complete collapse or destruction of 28771 buildings resulting into death of about 9800 persons and minor to heavy damage in 169,841 buildings (Nikolic-Brzev and Anicic, 1994). These buildings were mainly field-stone in clay mud type. The Maharashtra State Government developed a carefully considered rehabilitation programme which included major rescue and relief operations, reconstruction of housing and infrastructure, economic and social rehabilitation and other related activities. The housing involved the following elements (Pawar, 1994) :

(i) relocation of 49 villages at new serviced sites with 23000 core houses of three categories viz. A type, covering floor areas of 70 m^2 , 37 m^2 for B type and 23.2 m^2 for C type of which 5500 were offered to be built by donors,
(ii) reconstruction in-situ of 29600 houses in about 2500 villages in Latur, Osmanabad and 11 other districts,
(iii) repair and seismic retrofitting of about 180,000 houses in the thirteen districts abutting and around the main damaged area,
(iv) a pilot program of seismic strengthening of 5000 vulnerable houses of various types, and construction of 500 model houses to demonstrated low-cost earthquake resistant building techniques, and
(v) reconstruction of civic amenities in resettlement villages including offices, schools, health and work centres, centres for children and women etc.

The repair and seismic retrofitting became a very major component of the program because the population living in stone houses in the 13 districts was and is still so afraid that they do not want to sleep in the house at night. The number of such houses is 1.4 million. Hence an effective technology for seismic protection which should be easy to implement and very economical in cost was the need of the hour. The author worked out this methodology, demonstrated its execution on two sample houses and proved its effectiveness by shake-table testing to destruction of two half-scale similar one rooms, one kept unretrofitted and the other retrofitted. The paper describes the causes of large scale damage to the stone houses, the seismic retrofitting technology and the shake-table test results.

TYPICAL HOUSE CONSTRUCTION IN THE AREA

The predominant traditional houses (80 percent of total housing stock) are generally single storeyed and have the following features (See Fig. 1, Arya, 1994)

Roof : Wood beams, wood plank deck, earthfill on top 450 to 900 mm in thickness
Walls : Random rubble laid in clay mud, facia stones semi-dressed, walls generally thick 600 mm to 1100 mm, built in two wythes with hearting filled with small stones and clay mud.

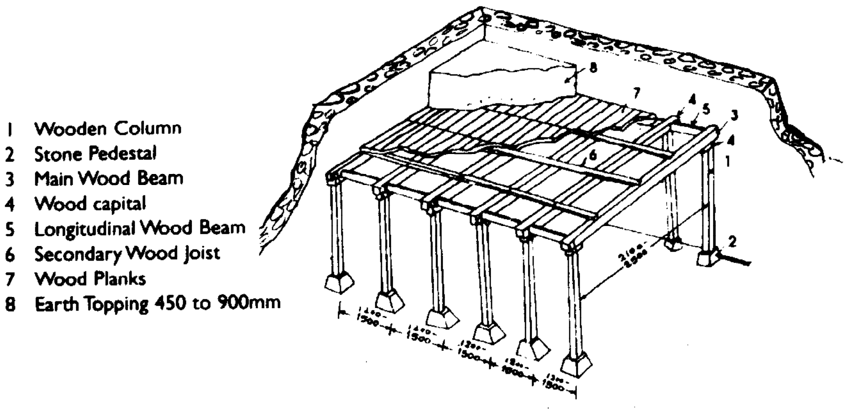

Fig. 1 Typical House Details (Arya, 1994)

Wood posts : Local wood 150 mm x 150 mm in cross-section, spaced about 1.2 m apart abutting the long stone walls, supporting the main beams of the roof. They rest on stone pedestals at base and connected to beams with mortise-tenon joints.

Foundation: The foundation footings and low height plinth are constructed using large stones laid in clay. Foundations of usually 900 mm to 1 m width go either to rock if shallow or 1.2 to 1.5 m deep in 'black cotton' soil, the local name for expansive clays. This soil is quite unsuitable for construction of modern rigid foundations and walls such as in fired bricks in cement mortar due to cracking occurring on account of volume changes in the soil during monsoon rains and hot summers. But the stone construction in mud mortar does provide the flexibility to absorb such movements.

Typical width of a room is 2.1 m to 2.5 m only depending on the wooden beam spanning between the wooden posts, but the length could be 3 to 6 times the 1.2 m module (called 'Khan'), that is 4.2 m to 7.2 m. The wooden post-beam construction looks like 'frame' but is infact unstable laterally, the posts being almost hinged at top and bottom. The frame is strong for carrying vertical load of roof but depends on the stone walls for its own lateral stability instead of providing support to the walls. This behaviour became evident during earthquake shaking as well as while constructing the half-scale specimens.

TYPICAL DAMAGE AND ITS CAUSES

The overall behaviour of the stone buildings during the September, 1993 earthquake showed that the most critical and weak element was the stone wall. The foundations nowhere showed settlement or slumping although they must have been saturated after the monsoon rains during June to September. Roofs fall down only when the walls collapsed and the wood 'frames' also tumbled along with. Lives were lost in such collapses only. But wherever, the wood frames kept on standing, though in tilted condition, roofs remained intact and people came out alive moving over fallen stone debris. Observations on houses which did not collaps but had moderate to heavy damage lead to the following mechanism of damage :

1) Large seismic force created in the building due to its closeness to the earthquake epicentre, very heavy roof mass and that of the walls themselves, caused excessive shaking of the walls along with the wooden frames. The strength of the clay mortar being low to nil, and due to the absence of 'through' or bond stones in the walls to provide connection between the outer and

Fig. 2. Delaminated wall (Arya 1995)

inner wythes of stones, the walls split or delaminated through the hearting and crumbled into heaps of rubble (See Fig. 2 which shows a damaged wall by delamination).

2) Where delamination did not occur, the perpendicular walls separated at the corners and junctions. As the walls separated, the integral box action of the enclosure got destroyed leaving the walls to fend for themselves individually and they overturned as a whole or in part.

3) As the walls were destroyed in any of the two modes, the frames moved laterally, became unstable and fell down as a mechanism bringing down the roof along with, crushing every thing underneath. The fall of the pile of earth created huge amount of dust which suffocated those who escaped the crushing, before they could to get out. But if the frames were held up even by the fallen debris of the walls, the roof did not collapse and lives were saved.

The reasons for having fat walls and roof ascertained from the people are: safety against thefts, sign of prosperity, protection against monsoon rain water leaking through roofs and comfort during hot summers when temperature soars to 43^0 C week after week. Incidentally, they did not need to use electric fans since the inside of the house remained quite comfortable.

SEISMIC RETROFITTING SCHEME

The seismic retrofitting of such stone houses appeared unrealistic and impractical to most building experts who visited the area who would express the opinion that these should be dismantled and rebuilt using modern materials. Little they realised how costly it will be and what logistic problems concerning availability of materials and skilled labour would it pose. Even the reconstruction of resettlement villages with only 23000 core houses is giving nightmares due to these logistic problems, funds having been made available through the Donors and the World Bank loan. The reconstructed houses are costing per sq.m of plinth area as much as Rs.2700/- without equivalent thermal comfort whereas the suggested retrofitting scheme with adequette seismic improvement is costing only Rs. 270 to 380 per sq.m, that is 10 to 15% of the reconstruction cost.

The seismic retrofitting scheme consists of essentially five elements as follows (Arya, 1994):

1) *Reducing Roof Weight.* The roof thickness has to be reduced to 200 mm only so that the weight is less yet it remains sufficient for thermal comfort. To make it leak proof either heavy gauge black polythene membrane has to be used at mid-thickness of the clay-fill or the clay fill of about 150 mm has to be made of stabilized nature using straw and cowdung mix (called Mud-Phaska) and finished at top with locally available Shahbad stone slabs with joints pointed using cement-lime-sand 1:1:6 mix mortar.

2) *Installing 'Through' or Bond Elements in Walls.* Such elements are to be constructed in-situ at vertical and horizontal spacing of about 1 to 1.2 m. Through hole has to be made in the wall by gently removing one stone from outside, then the hearting material, finally the opposite stone from inside. The hole is to be filled with cement concrete with a reinforcing bar link of 8 mm dia (See Fig.3). These bonding elements of reinforced concrete will prevent the delamination of wythes in any future shaking.

3) *Installing Knee Braces in Wooden Frames.* To fully utilize the wooden frame, they are to be made strong against lateral forces caused by the seismic inertia of the roof and the upper half of the walls. It was found by calculations that the desired strength will be achieved by installing knee braces in each frame along both axes of the rooms(Fig.4). The knee braces could be of standard length and sizes (750 mm inclined length, 30x30x5 mm MS angle iron or 20 mm internal dia)

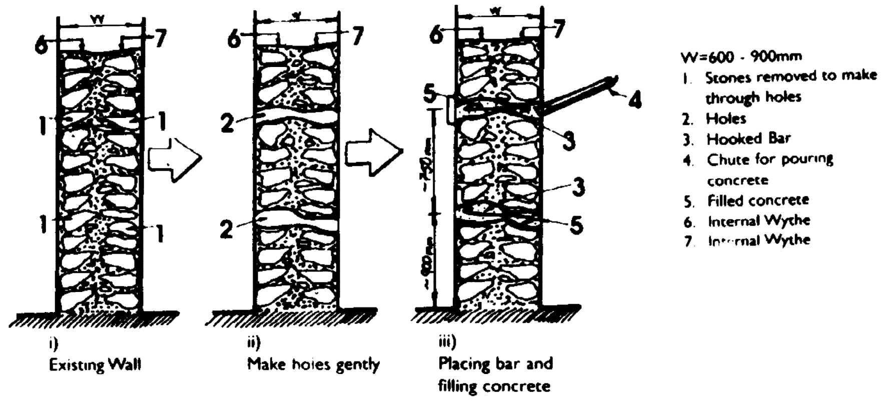

Fig. 3 Installing R.C.C. `through' elements (Arya, 1994)

black iron pipe, with welded end plates nailed to posts and beams by 100 mm long wire nails, 4 at each connection). Cross-bracings were also investigated but found to be unsuitable due to higher cost, requiring special site measurements and much higher skill for installation, difficult to get in the rural areas.

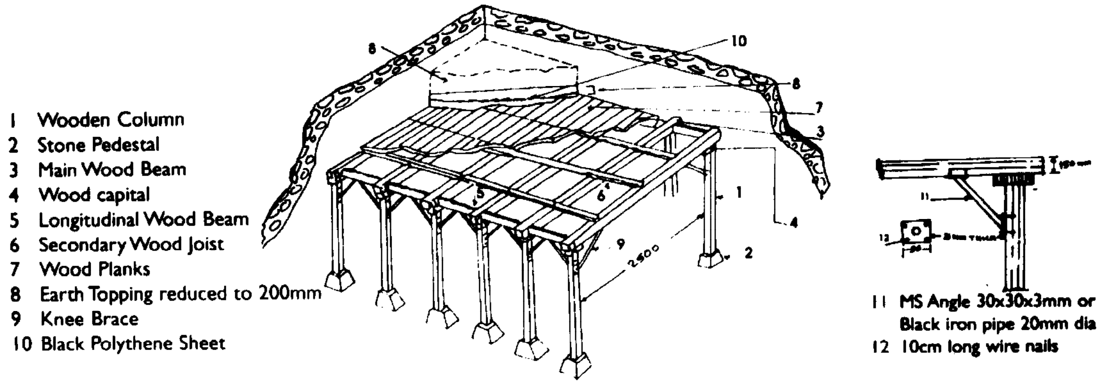

Fig. 4 Intalling knee-braces in wooden frames (Arya, 1994)

4) *Seismic Belt Around the Rooms.* In order to integrate the walls to ensure 'box action' under horizontal earthquake forces, a seismic belt of ferro-cement is to be provided just above the door lintel level upto the ceiling level all round each of the rooms. Where cross walls exist or in long rooms at about 4 m apart, cross-ties are to be installed connected to the seismic belt going round the whole house(Fig.5). For installation of the belt, the joints between the stones are to be raked out to a depth of 20 to 25 mm and the whole surface cleaned by wire-brush and all dust removed. Welded wire fabric is next nailed to the wall through 150 mm to 200 mm long nails to hold it in position. The mesh is then covered with 1:3 cement-coarse sand mortar in two coats of 15 to 20 mm each making a total thickness of 35 mm. The mortar bonds the weld-mesh to the stones and shear keys are formed by the mortar entering the raked joints.

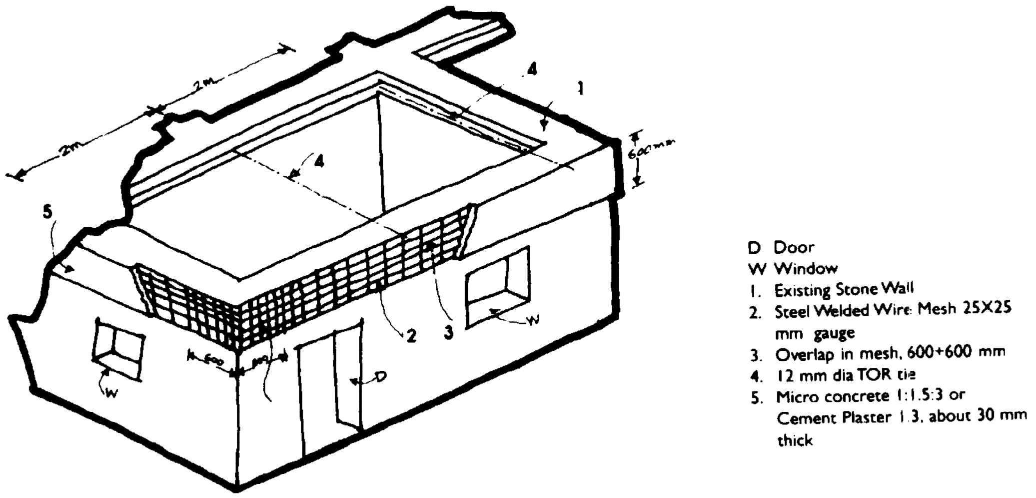

Fig. 5 Seismic belt and cross ties (Arya, 1994)

5) *Water Proofing the Parapets.* In order to ensure safety of walls during monsoon rains, the parapets are to be covered with cement sand plaster of 1:6 mix embedding in it chicken wire mesh(Fig.6). It is not an essential requirement of seismic retrofitting but very helpful in maintaining the dry strength of mud mortar in the walls (saturated strength could become as low as 15-20% of the dry strength) and preventing the disintegration of parapet masonry during earthquake shaking and falling away.

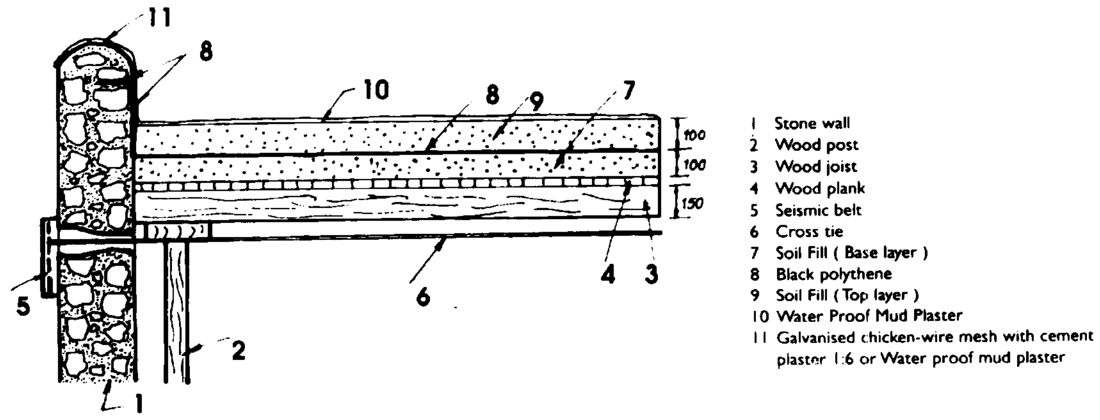

Fig. 6 Water proofing of roof and parapets (Arya, 1994)

TESTING OF EFFECTIVENESS OF RETROFITTING MEASURES

The above retrofitting scheme was approved and adopted by the Government of Maharashtra and the World Bank Experts for implementation in about 200,000 houses. However, due to the psychological impact on the population regarding stone houses collapsing in the earthquake and different, though casually expressed opinions by `experts' and non-experts which found easy access into the print media, fears continued lurching in the minds of the people. Only half-hearted adoption of the methodology occurred, more through the convincing efforts of a Non-Governmental Organisation than through the Government engineers. To fill the need of creating confidence, and sponsored by the Asian Development Bank through the Government of Maharashtra and DHV Consultants BV, the author conducted tests in the field as a confidence building measure. These are briefly described herebelow (Arya, 1995):

Tests on Model Walls

Twelve stone wall specimens of 0.6 scale with different construction details and seismic strengthening measures were first shaken out of plane by an eccentric-mass oscillator mounted on top till any cracking occurred, then tested to destruction by tilting upto overturning. The main result arrived at was that stone walls built as per rural construction without 'through' stones delaminated under vibration as well as tilting, while others which had such elements provided initially, or by retrofitting, did not delaminate and maintained their integrity until overturning.

Tests on Half Scale Room Models

Two half-scale room models were tested on a shake table specially designed and built in the field for the purpose, as shown in Fig.7. Both specimens were constructed in the rural style exactly in similar way, taking care that the normal stones were broken to half-scale (1/8 in volume) before use. The construction was done using external and internal wythes as normal in the villages. The wooden frame was also half-scale, so also the wall and roof thickness. Then one specimen was retrofitted using R.C. headers, knee bracing, seismic belt and reduced weight of roof clay reducing the height of parapets accordingly.

Fig.7 Half scale model rooms tested on shake table (Arya, 1995)

The testing of the two specimens was done *simultaneously* by giving repeated shocks by a tractor from each end of the shake table. A total of 12 shocks were given. Acceleration measurements were taken at the two ends of the table, at the top of the two specimens and at mid-height and end corners of the retrofitted model. The significant results are very briefly summarised below :

i) The base accelerations in the 12 shocks varied from 0.06 g to 1.60 g.

ii) The unretrofitted specimen developed serious cracks and delamination of walls at 0.47g base acceleration, falling of masonry and tilting of wooden frame continued in subsequent shocks. The pattern of damage resembled exactly what happened in the real earthquake.

iii) The retrofitted specimen developed only minor cracks at 0.47 g base acceleration and remained intact with increasing extent of cracks which did not become wide, even upto 1.6g base acceleration.

This showed that the retrofitting was fully effective in preventing (a) delamination of walls, (b) separation of walls at corners, and tiltingof the wooden frame. In fact complete collapse was still not in-sight. The tests on walls and the half-size specimens clearly demonstrated the effectiveness of the retrofitting measures. About 80 persons including the bureaucrats, high and low level engineers and public men witnessed the testing. The press reporting later on has created the necessary confidence in the retrofitting program.

CONCLUSIONS

There is a very large stock of vernacular stone houses in many earthquake prone countries of the world which are extremely dangerous in seismic intensity areas of MSK VII or more. Earthquakes in India, Iran, Turkey, Armenia, Yemen etc. testify this situation in clearest terms. The number of such houses in the world may run to more than a hundred-million. To save lives of human beings as well as cattle, sheep and fowl occupying them, the only economical and practical way will be to retrofit them before the next moderate or severe earthquake destroys them. Minimising weight of roof, providing 'through headers' in the walls and binding the homes with seismic belt and cross-ties are three common and essential elements to achieve collapse proof stone houses. In Maharashtra, knee-bracing of existing wooden frames is specific to the typical houses and water proofing of roof and parapets are for normal comfort and additional precaution.

ACKNOWLEDGEMENT

The studies reported in the paper have been possible with the financial assistance of Building Materials and Technology Promotion Council, Government of India and the Asian Development Bank through DHV Consultants BV and Government of Maharashtra (GoM.). The dynamic testing equipment and instrumentation was provided by IIT Bombay through Dr. Ravi Sinha and Dr. Alok Goyal who personally assisted in the testing along with other staff. The assistance received as above and from the engineering staff of GoM. is gratefully acknowledged.

REFERENCES

1. Arya, A.S. (1994). Retrofitting of Stone Houses in Marathwada Area of Maharashtra. *Booklet* published by Building Materials and Technology Promotion Council, Ministry of Urban Development, Government of India, March, pp. 1-12.
2. Arya, A.S. (1995). *Experimental Verification and Confidence Building, Report,* Asian Development Bank TA No.2066-IND, Technical Assistance for Earthquake Engineering Rehabilitation Management Project, DHV Consultants BV, Aug. pp.10-16.
3. Mohan I. and Rao M.N. (1994). A Field Study of Latur (India) Earthquake of 30th September, 1993. *Latur Earthquake,* Geological Survey of India, Bangalore, pp. 7-32.
4. Nikolic-Brzev S. and Anicic D. (1994). *Strategy for Reconstruction, Repair and Strengthen. ing,* Version 3, Government of Maharashtra, Bombay June, p.8.
5. Pawar S. (1994). *Earthquake Rehabilitation Policy of Government of Maharshtra,* Earthquake Rehabilitation Cell, Mantralaya, Bombay, March, pp. 0-7.