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REPAIR AND STRENGTHENING OF EARTHQUAKE DAMAGED HOUSES IN MAHARASHTRA

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ABSTRACT

In the earthquake of 30th September 1993, with its epicentre near village Killari in Latur District of Maharashtra, thousands of houses collapsed and about 1.8 lakh houses were damaged. Before taking up the gigantic task of repair/strengthening/reconstruction of these houses, Govt. of Maharashtra requested the Central Building Research Institute (CBRI), Roorkee to take up a pilot project on damage survey, categorisation, repair/strengthening of 500 houses each in Districts of Latur, Osmanabad and Solapur and to train their engineers in rehabilitation work. The paper is based on the work carried out by CBRI under the pilot project.

INTRODUCTION

An earthquake of magnitude 6.4 on the Richter scale struck parts of Maharashtra and Karnataka on 30th September 1993, with its epicentre near village Killari in Latur District of Maharashtra. It took many seismologists and earthquake engineers by surprise, as peninsular India was so far considered a geologically stable region and major earthquakes had rarely occurred in this area. Construction practices prevalent in the area were least suited to resist earthquake forces. To have thermal comfort in the extreme hot climate of the region, the traditional practice had been to construct very thick walls and roofs. The walls were constructed predominantly using locally available irregular/round shaped stones bonded with mud mortar. Roofs were made of timber planks resting on timber beams or wooden twigs supported on timber logs and covered with a very thick layer of mud. Timber posts provided support to the roof in many cases. Though the magnitude of the earthquake was not very high, due to the heaviness of roofs and walls and the poor construction practice, thousands of houses collapsed and about 1.8 lakh houses either developed cracks or suffered partial collapse. About 8000 people are reported to have lost their lives and over 15,000 injured in the districts of Latur and Osmanabad alone. Before taking up the gigantic task of repair/strengthening/reconstruction of earthquake damaged houses, Govt. of Maharashtra requested the Central Building Research Institute (CBRI), Roorkee to take up a pilot project on damage survey, categorisation, repair/strengthening of 500 houses each in Districts of Latur, Osmanabad and Solapur and to train their engineers in rehabilitation work. This paper is based on the work carried out by CBRI under the pilot project in the three districts of Maharashtra during April to September 1994.

SURVEY AND COLLECTION OF DATA

A survey was conducted in a few selected villages of the area to assess the type of construction and damages to them during earthquake. The details are given in Table-1. The damage categorisation was based on the norms of International Association of Earthquake Engineering (ISET-1981).

Table 1 - House Damage Survey

DISTRICT	VILLAGE	HOUSES SURVEYED	HOUSES REPAIRABLE	HOUSES IN DAMAGE CATEGORY					
				0	I	II	III	IV	V
Latur	Nagarsoga	187	35	1	-	10	24	122	27
Latur	Belkund	150	6	-	-	-	6	147	3
Latur	Wanwade	165	8	-	-	-	8	130	27
Osmanabad	Balsur	533	110	-	1	8	101	273	150
Solapur	Bhandarkawathe	434	44	6	13	20	5	360	29
Solapur	Kini	41	1	-	1	-	-	36	4
Solapur	Kurnur	27	2	-	-	-	2	22	3

PLANNING OF HOUSES

Most of the houses were single storeyed with a large front room and a small rear room. When number of rooms were more they were built one after the other in a row. Houses were built back to back and on both sides with common walls between them on 2 or 3 sides. The houses had only one main entry door in the front. The planning of the houses resulted in poor lighting and ventilation. Some of the houses had a central open courtyard facilitating better lighting and ventilation. With very thick walls and roofs with 40 to 75cm overlay of earth, the buildings were thermally comfortable even in the extremely hot summer.

A typical plan of a common house with two rooms is shown in Fig.1. The plinth of the house is about 45cm high. The entrance and right side of the front room are at plinth level, while the rest of the area of the house was raised to a height of about 90cm above plinth. An incremental concept of housing had been adopted, with addition of rooms in stages, as per owner's requirement.

CONSTRUCTION OF HOUSES

Foundation and Walls

Some of the walls were fully load bearing while others were partially load bearing with part of the roof load carried by vertical timber members provided adjacent to the wall. Cross section of the load bearing walls used in most of the common houses is shown in Fig.2. The walls were 60 to 100cm thick made of irregular/round shaped stones in mud mortar. In a few of the houses, walls upto 160cm wide were seen. In some houses, flat flaky stones were also used for constructing walls. The walls were made of an outer and an inner wythe and the inner core was packed with small size stones and mud mortar. In some villages in Solapur District, locally available soil containing silt, sand and pebbles and lacking in clay content, had been used for mortar and filling the

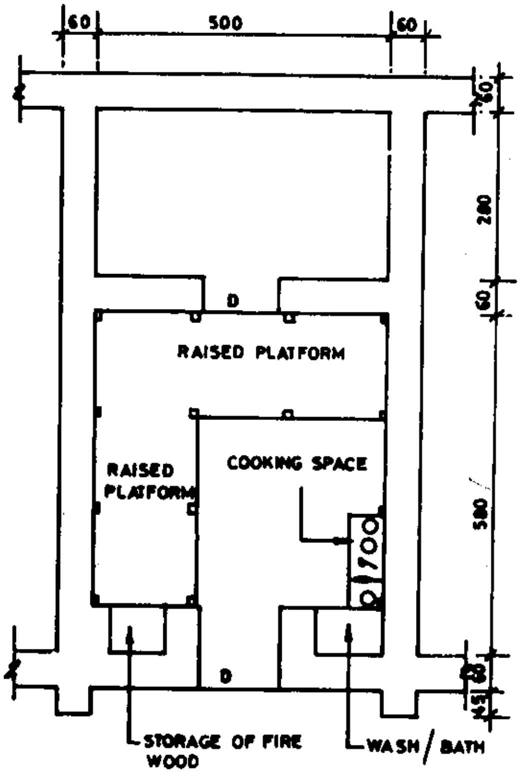


Fig.1 TYPICAL PLAN OF A HOUSE IN LATUR DISTRICT

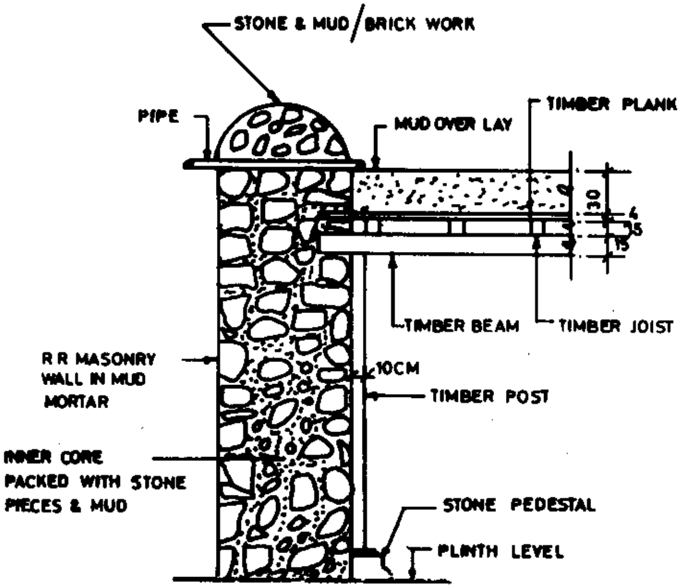


Fig.2 SECTION OF WALL AND ROOF

inner core. Its binding property was very poor and cannot be categorised as mud mortar as it lacked in clay content. No through stones were provided to tie the inner and outer wythes of the wall together. Thus, the quality of construction of the walls was extremely poor. Many of the walls were built out of plumb.

The plinth and foundation were also built similar to the cross section of wall shown in Fig.2. The thickness of foundation was equal or 20 to 30cm more than that of wall and in areas having shallow depths of black cotton soil, the foundation was taken to hard strata below the black cotton soil. In areas having deep deposits of black cotton soil, the foundation was taken upto 3.6 to 4.5m depth.

Timber Posts

The roof was supported partly on RR masonry walls and partly on timber posts. The main wooden posts, away from the wall were of cross section 15X15cm to 20X20cm and were usually made of good quality timber such as 'Neem'. Normally such posts were provided in the front room, while the rear room did not have any posts. The posts adjacent to the wall were of cross section about 15X7.5cm to 20X10cm. The wooden beams usually made of 'Neem' were resting directly over the posts without adequate tying between them. The posts were resting on stone pedestals of size 23X23cm to 30X30cm at bottom tapering towards top and had a height of about 23cm to 30cm. There was a 4X4X4cm nitche at the top of the stone pedestal into which a projection from the bottom of post was fixed. The stone pedestals were resting freely over the floor.

Roofs

The roofs (Fig.2) of some bigger houses usually owned by the higher income group of the villagers consisted of wooden beams of size about 15X20cm laid at a spacing of 1.2 to 1.3m c/c with wooden joists of 7.5X10cm section provided over the beams at a spacing of 20 to 30cm c/c. Planks of Mango or inferior quality timbers about 4cm thick were laid over the joists. An overlay of earth about 40 to 75cm thick was placed over the timber planks. Parapets upto 60cm high were made alround some of the houses in RR masonry in mud mortar. But in many cases, no parapets were provided, but the top of wall was rounded off with a layer of soil and pebbles, with provision of drain pipe as shown in Fig.2.

In majority of cases, irregularly shaped trunks or large branches of trees were used in place of wooden beams and small branches of trees about 30 to 60mm dia, and twigs usually used as firewood, were placed across the main members, resting on walls. The trunks/large branches of trees were supported from bottom with wooden 'ballies' in cases, where there was sagging. Mud overlay about 40cm was provided over the twigs to complete the roof. Empty tins open at top and bottom or earthen pots with holes at bottom were embedded in the roof to provide light and ventilation and for escape of fumes. Such inferior type of roof construction was usually found in houses of poor people or in the rear rooms of houses of people of higher income group.

NATURE AND EXTENT OF DISTRESS OBSERVED

Nature and extent of distress observed in the houses surveyed in the three districts viz. Latur, Osmanabad and Solapur are as below:

* The most common distress observed was vertical cracks at the junctions of walls, specially at the corners of buildings. These cracks occur on the walls at a distance equal to the thickness of the wall, from outer edge of the corner.

* In houses having RR masonry pillasters, projecting out of wall, cracks occurred at the junction of pillaster and wall.

* Inclined cracks in walls over openings were noticed in some of the damaged houses.

* In severely damaged houses, in addition to development of cracks at corners, there was spalling of masonry (mainly outer wythe) at top of wall.

* Collapse of outer wythe to the full height of wall and for a distance equal to thickness of the perpendicular wall joining at the corner (Fig.3) was also observed.

Fig.3 COLLAPSE OF OUTER WYTHE OF WALL TO FULL HEIGHT

* Collapse of masonry in 'V' shape at corners of walls near the top was another distress commonly noticed in severely damaged houses.

* Further stage of damage was collapse of complete wall, which was more prevalent in the rear rooms of houses, where the roof was directly resting on walls, without the support of framework.

* Complete collapse of outer wythe of wall was another stage of damage (Fig.4). In most cases, walls had completely collapsed with part of roof still resting on timber framework, which had swayed in one direction or the other. (Fig.5)

Fig.4 COMPLETE COLLAPSE OF OUTER WYTHE OF WALL

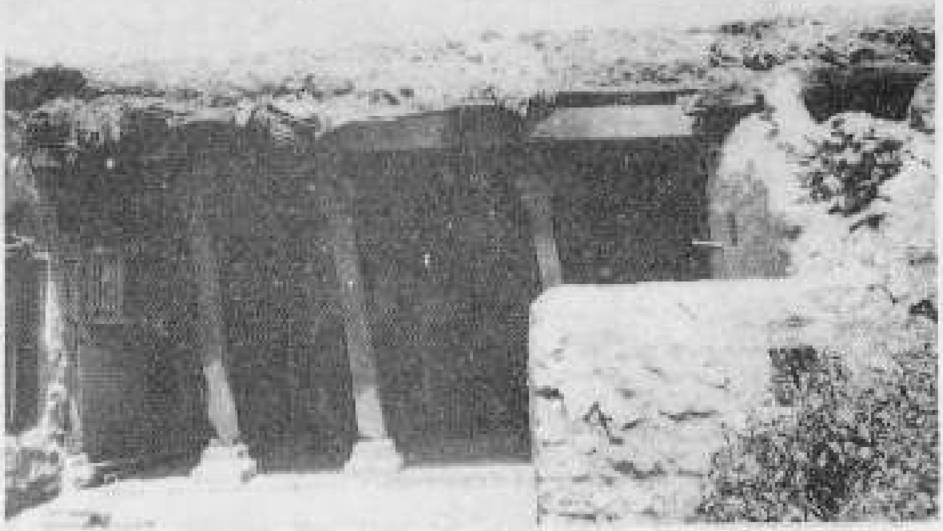


Fig.5 SWAY OF TIMBER FRAME WORK

* Complete collapse of the house including walls, roof and framework was also observed.

* Development of cracks and collapse of outer wythe of wall were more frequent than the collapse of inner wythe.

* In many houses, the door frames had distorted, making it impossible to open or close the shutters.

* In some of the houses, shear failure had occurred to the timber beams near their support.

* Only in rare cases, cracks or other signs of distress were observed in the plinth masonry and no signs of foundation failure were seen in the houses surveyed.

ANALYSIS OF STRUCTURAL WEAKNESS OF PREVALENT CONSTRUCTION AND RECOMMENDATIONS FOR IMPROVING STRUCTURAL SAFETY

The factors responsible for the collapse of houses or development of distress in them are listed and measures to enhance the structural safety of the buildings are discussed below.

* The traditional practice of constructing very thick walls and roofs resulted in developing high seismic forces during earthquakes.

  It is advisable to reduce thickness of walls to 20 or 23cm when using block/brick masonry or 40cm when using RR masonry in cement mortar and to have a 10/12cm thick RC slab roof with a roof treatment about 10 cm thick. Alternately, the walls and roofs could be constructed with GI sheets, RMP sheets, cement boards or other light materials.

* Use of irregular/round shaped stones, and small size stones bonded in mud mortar was another cause for failure of buildings. The walls were built in two leaves and the core area in between was filled up with small stones, pebbles and mortar. The size and shape of stones were such that they do not get sufficient bearing and overlap one over the other. As the mason's priority was to provide a plain face to the wall, the stones were laid in such a way that their flat surfaces were exposed and the curved/irregular face of stone was laid in the bedding plane, a position in which the stone was unstable. The mud mortar provides very poor bond. It shrinks on drying and cracks develop in the mortar. When it gets wet during rains, the mortar loses its strength considerably. Though the walls built in mud mortar have some compressive strength, they do not have adequate shear strength, to withstand seismic forces. Loose filling of core area with small stones, pebbles and mortar, without provision of any through stones to tie the two leaves of the walls together, further weakened the walls. Such poor quality of construction generally led to the collapse of walls during the earthquake.

  It is recommended that for construction of walls, the mortar should not be leaner than 1:6 cement:sand or equivalent composite mortar. Flat stones, rectangular in plan and of large size as laid down in PWD specifications should be used in the construction of RR masonry walls. Through stones should be provided at specified spacing. In case natural through stones are not available, precast RC through stones could be used. Alternately the walls could be built in block or brick masonry or coursed stone masonry in cement:sand mortar or composite mortar.

* Lack of proper bonding of stones at corners and junctions of walls was another weakness that led to development of vertical cracks at the junctions.

Construction of thinner walls with provision of proper bonding stones, can overcome this weakness.

* Many of the walls were constructed out of plumb, which induced out of plane destabilising forces in them.

The walls should be constructed to plumb.

* Where there were timber framework, the roof was supported on it with beams getting a short bearing on the inner wythe of wall. Where there were no frames, the roof was resting freely on the walls. As there was no connection between roof and walls and as the timber plank and mud roof was not stiff enough to transmit horizontal forces induced by earthquake, the roof did not act as a horizontal diaphragm to tie all the walls together and to give the desired box effect to the building. Hence, the walls acted independently and they were subjected to out of plane forces. As the walls had poor resistance against out of plane forces, collapse occured faster, in this mode.

For effective repair and strengthening of existing buildings, a RC band could be provided at roof level tying all the walls together. The adjacent long walls could be tied together at certain intervals with reinforcement bars, ends of which could be embedded in the RC band at the roof level. However, in case of new constructions, the RC roof band need not be provided where the roof consists of an RCC slab with full bearing on all the walls.

* In most of the houses, the floor was about 1.35m higher than the existing ground level and the ceiling was about 2.2m above the floor level. Thus while the height of inner wythe of the wall was only 2.2m, the height of outer wythe was 3.55m. The inner wythe of wall also had a support, to a limited extent from the roof members, which were partly resting on it. As the outer wythe of walls was less stiff, it collapsed first leading subsequently to failure of inner core of wall during earthquakes. It further resultd in failure of inner wythe.

A proper construction of a monolithic wall (without separate leaves) and provision of full bearing of roof over it, could have reduced the extent of such failures.

* In case of timber framework, the posts were resting freely on stone pedestals and beams at top were resting on the posts directly or through corbels, without much of fixity. These pin jointed connections resulted in sway of the frames during tremors in most cases and in collapse of frames and roofs in some cases.

To avoid sway of frames and their collapse, fixity should be provided to the joints between members of frames. Knee bracing at top of frame is one such measure.

* Even in houses, where framework was provided in every room, they acted independently, as they were not inter-connected through the walls.

  Interconnecting the frames of individual rooms would have increased the stability and earthquake resistance of the houses considerably.

* Some of the timber members of the frame had deteriorated due to aging or attack of white ants etc. Many of the half size timber posts, touching the walls were found to have deteriorated due to contact with moisture coming out of walls during rainy season and had also deformed. Ends of beams and joists inserted in the walls in old buildings had also damaged due to similar reason. The roofing planks, which were made of inferior quality of timber and were in contact with earth overlay also deteriorated quickly. These deteriorated members caused failure of the frames and roofs during earthquakes.

  The deteriorated/damaged members of timber need to be replaced with members of equivalent sections of good quality timber.

* Excessive thickness of mud overlay was another reason for damage/collapse of houses during earthquakes.

  The thickness of mud overlay should be reduced.

* Leakage of rainwater through the roof on to the walls led to weakening of the mud mortar and splitting of the wall in many cases.

  To avoid this, the roof should be made water tight, as far as possible.

* The practice of constructing houses with different plans and heights adjacent to each other was another cause for development of distress, as these long buildings were unsymmetrical in plan and section.

  In order to minimize torsion and stress concentration, it is preferable to separate out the buildings into simple symmetrical plans.

RECONSTRUCTION OF HOUSES ABOVE PLINTH LEVEL

In houses where walls and frames were severely damaged/deteriorated, it was recommended that the roof and frames and the walls upto plinth level be dismantled and new walls (Fig.6) and roofs constructed as follows.

* Remove the mud overlay of roof first. If Shahbad stones or other reusable materials was used as flooring, the same should be removed. The outer walls could then be dismantled upto plinth level. This operation should be done from outside the house, taking appropriate measures for the safety of the workers involved in the job. Inner walls could then be dismantled, followed by the framework.

* Stones of proper size and shape, which can be used in reconstruction of walls, could be picked up from the debris and stacked near the house for reconstruction, while smaller size stones could be used for making aggregate. Timber components of frames and roof which are of good quality and are not damaged or deteriorated could be used for making doors/windows, cupboards etc.

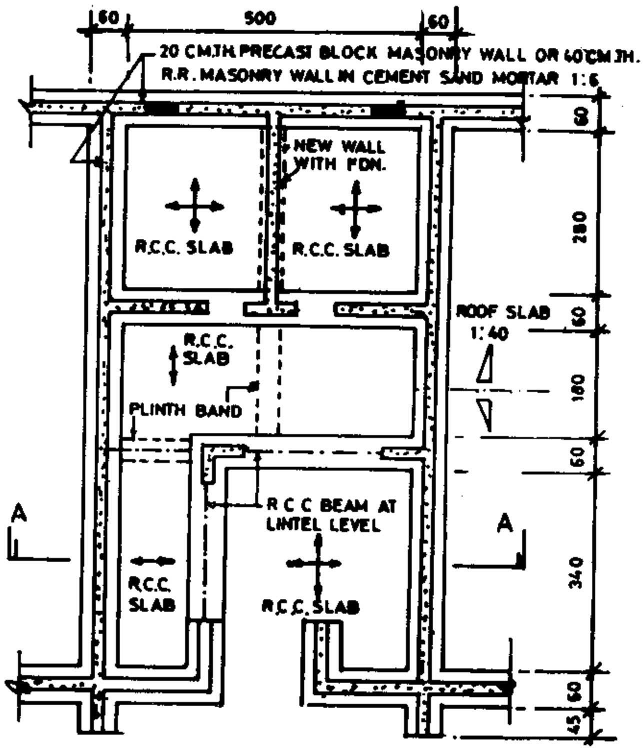
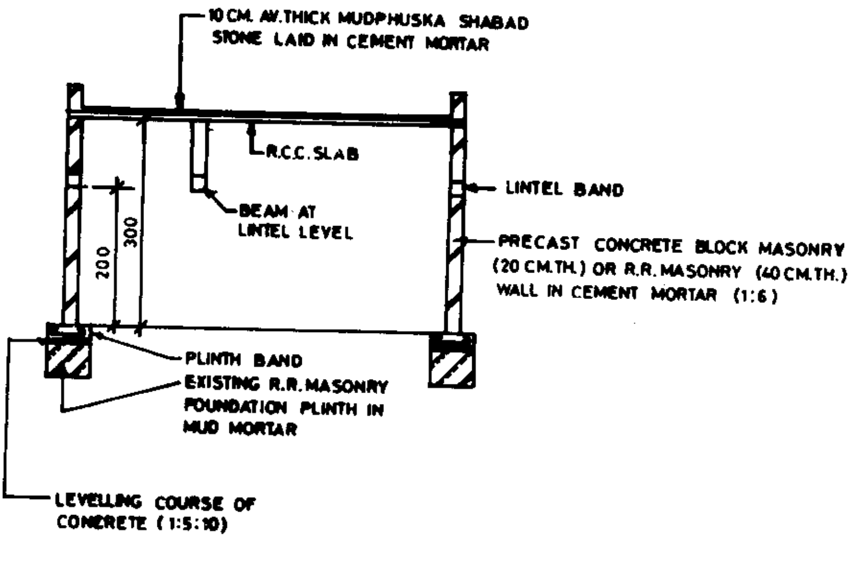


Fig.6 RECONSTRUCTION OF HOUSE ABOVE PLINTH LEVEL (PLAN)



SEC. AT A-A (REFER FIG. 6.)

Fig.7 RECONSTRUCTION OF HOUSE ABOVE PLINTH LEVEL

* After clearing the building off the debris, cracks, if any, in the plinth masonry should be repaired by 1:6 (cement:sand) mortar or 1:2:9 (cement:hydrated lime:sand) composite mortar. If necessary, stones on either side of cracks should be removed and relaid in 1:6 (cement:sand) mortar.

* The top of the walls should then be leveled at plinth level with a 5cm thick course of 1:5:10 cement concrete.

* If additional walls are to be constructed to partition any of the rooms/verandah, foundation and masonry for the same should also be constructed upto plinth level, first. To enhance earthquake resistance of houses, it is advisable to partition long rooms by constructing new intermediate walls.

* On top of the leveling course, a RC (1:2:4 concrete) band of thickness 10cm and to the full width of the existing plinth wall should be constructed, tying all the longitudinal and cross walls together. In case of long verandahs and rooms, additional plinth bands may also have to be provided as shown in Fig.6 for enhanced earthquake resistance. The bands should be reinforced with 2 Nos. 10mm dia. high strength deformed bars as longitudinal reinforcement and 6mm dia. MS bars @ 30cm c/c as ties.

* The superstructure could be constructed in RR or coursed stone masonry, solid concrete block (Chandra and Bhise, 1990), hollow concrete block or brick masonry in 1:6 (cement:sand) mortar or 1:2:9 composite mortar. The thickness of stone masonry walls should not exceed 40 cm while the thickness of concrete and brick walls should be kept as 20 and 23cm respectively. In all the cases, the construction should be done as per PWD specifications. In case of RR masonry, if natural through stones are not available, precast RC through stones 15x15cm in cross section and to the full width of wall could be used at a spacing, as laid down in the specifications.

* A RC band 7.5cm thick and to the full width of wall should be provided at lintel level connecting all walls together, as shown in Fig.7.

* The roof could be provided with RC solid plank and joist system (Sharma, Jindal and Chand, 1993) or Thin RC ribbed slab (Jaisigh, Chand and Jaisingh, 1985) or conventional RCC slab.

* The roof should be provided with mud phuska treatment of average thickness 10cm. Shahbad stones could be laid over the mud phuska with the joints between the stones pointed in 1:6 (cement:sand) mortar. Alternately nonerodable mud plaster (Malhotra, 1983) could be provided over the mud phuska.

RECONSTRUCTION OF HOUSES ABOVE SILL LEVEL WITH LIGHT WALLS AND ROOF

In houses, where the walls were severely damaged but the timber framework and roof members were in good condition, the walls could be dismantled upto sill level and light cladding provided with GI/RMP sheets or other light materials supported on a angle iron or tubular framework. The timber framework be strengthened and a sloping GI sheet roof provided over it, as discussed below:

* Remove the mud overlay of roof and dismantle walls upto sill level and clear

the building off the debris.

* Fix box sections posts made of 2 Ls 50x50x3mm welded together or 50mm nominal dia light gauge steel tubes by embedding the posts in pockets made in sill masonry with 1:2:4 cement concrete as shown in Fig.8. The spacing of the posts should be decided depending upon the sheeting material used for cladding and its thickness.

* Level top of sill masonry with 5cm thick layer of 1:5:10 cement concrete.

* Provide a RC band at sill level tying all walls together. The details of the band should be same as the plinth band discussed earlier.

* Verticality of existing timber posts should be checked in both the axes and the posts which are out of plumb should be refixed, keeping them vertical.

* Timber members of frame and roof which are damaged or deteriorated should be replaced.

* The junction of beams and posts at top should be strengthened by provision of knee bracing. If corbels have been provided at top of posts to support beams, they should be fixed to beams by nailing.

* As shown in Fig.8, short L iron/tubular/timber posts should be fixed on the existing beams at suitable spacing with L iron rafters fixed to them at top to support sloping roof made of GI sheets, RMP sheets, cement boards or other light materials. Wherever such roofs are provided, for thermal insulation, a layer of thatch may be fixed over it. Roofing sheets should be fixed to the rafters with J hooks, washers and nuts. At the junction of adjacent roofs, GI gutters should be provided to drain off rain water.

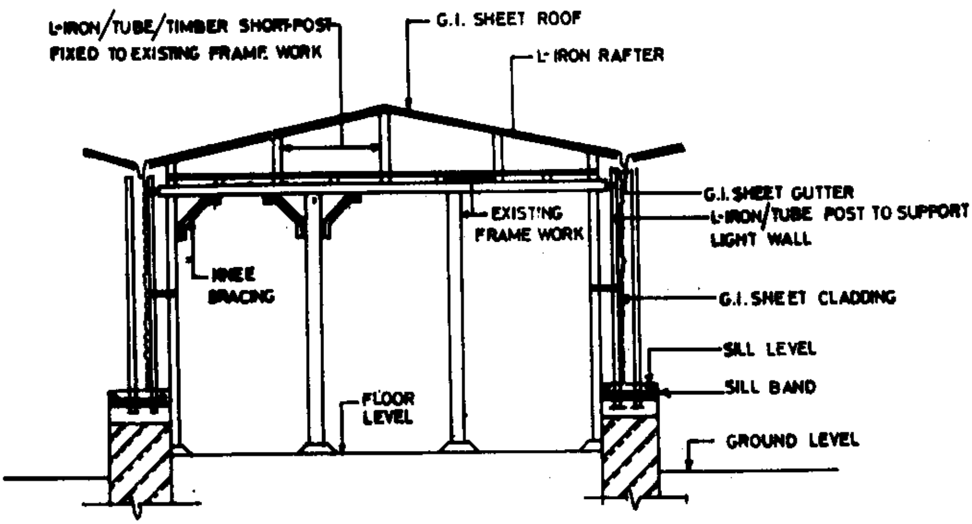


Fig.8 RECONSTRUCTION WITH LIGHT WALLS AND ROOFS

* GI sheet cladding should be fixed to the steel framework to form the outer face of external walls. On the inner face of external walls and inner walls, RMP sheets, cement boards or other suitable sheeting material could be fixed to form the walls.

REPAIR AND STRENGTHENING OF WALLS AND FRAMES

Where the walls were only slightly damaged and the frames were in good condition, it is recommended that the walls be repaired and the frames be strengthened. Details of the repair and strengthening measures recommended are given below :

* Mud mortar should be raked out of cracks, if any, in the walls for a depth of at least 5cm for the full length of crack and the crack should be filled up with 1:6 (cement:sand) mortar or 1:2:9 (cement:hydrated lime:sand) composite mortar. Where necessary, stones on either side of crack should be removed and relaid in cement/composite mortar.

* The mud overlay on the roof should be removed.

* Damaged/deteriorated timber members of frame should be replaced with timber members of equivalent section and of good quality. Similarly, deteriorated timber planks of roof should be removed and good quality planks fixed in their place.

* The timber posts should be checked for plumb and where found necessary, they should be refixed keeping them vertical.

* The junction of timber posts and beams should be strengthened by fixing knee bracing using L iron or timber battens (Fig.9). If corbels have been provided over the posts, they should be fixed to the beams by nailing.

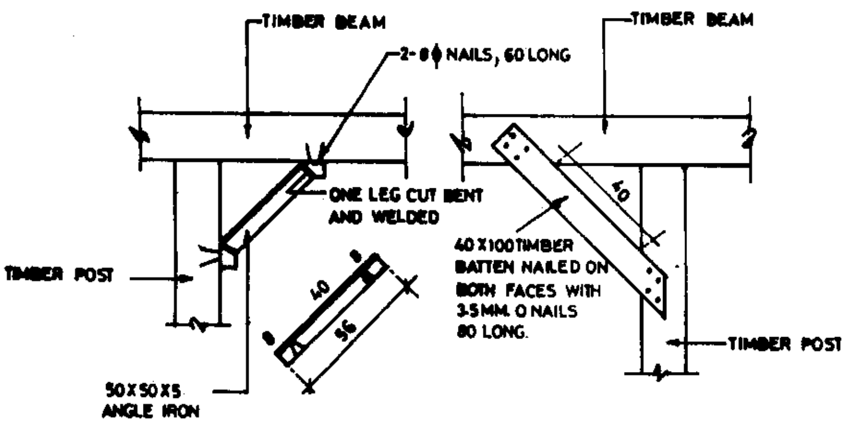


Fig.9 KNEE BRACING

* At lintel level, horizontal timber battens of 40x100mm section or MS Ls 40x40x5mm should be fixed between the timber posts, touching the walls, as shown in Fig.10. Diagonal cross bracing with MS flats 50x3mm should be fixed between vertical timber posts and horizontal tie members at lintel level and roof level. In case of internal walls, where there are timber posts on both faces of walls, the battens and L iron bracing should be fixed on both faces of wall.

Though the horizontal members and the cross bracing cannot resist full horizontal seismic forces likely to be exerted by the massive RR masonry walls during an earthquake of high magnitude, it will increase the seismic resistance of the wall and prevent falling of stones from the wall inside to a great extent. Thus, the suggested repair and strengthening measures will help making the houses safer in future earthquakes.

* Another alternative is to provide welded wire fabric from sill height to top of the wall, between the timber posts, touching the walls as shown in Fig.11 to prevent falling of stones inside. The weldmesh consisting of 3mm wires @ 100mm c/c bothways, could be fixed touching the wall by providing timber battens 40x100mm or L irons 50x50x5mm between the vertical posts. The timber battens or L irons could be fixed to the posts.

* Parapet wall if any and the top of RR masonry wall should be dismantled upto top of timber battens of the roof. The top of the wall should be levelled with a 5cm layer of 1:5:10 cement concrete.

* A RC band should be provided over the leveling course, connecting all the longitudinal and cross walls together. Details of the band are shown in

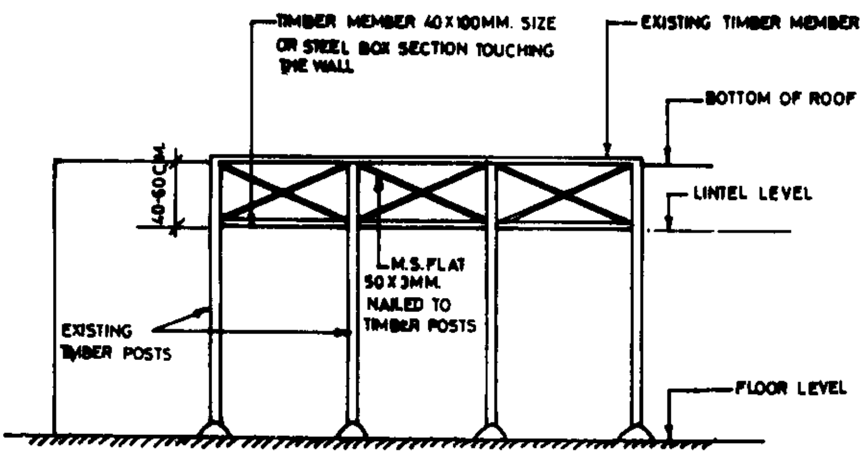


Fig.10 STRENGTHENING OF FRAME AND WALL WITH SPANDREL BRACING

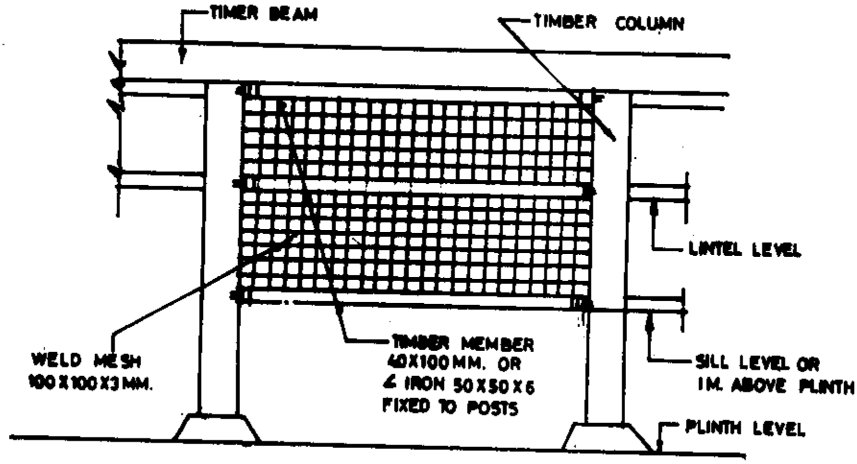


Fig.11 PROTECTING WALL WITH WIRE MESH

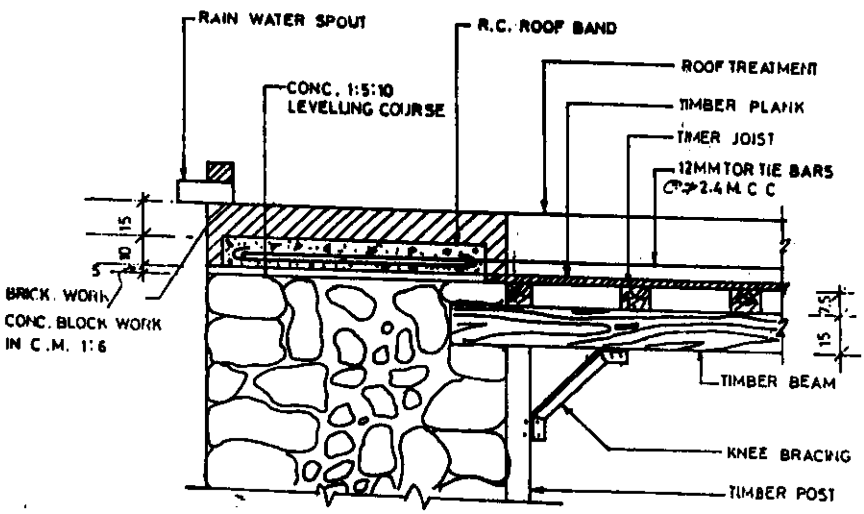


Fig.12 SECTION OF ROOF BAND

Fig.12. Brick work or concrete block work could be provided on either face of wall to act as lost shuttering for laying the concrete of roof band.

* 12mm dia high strength deformed bars should be provided at a maximum spacing of 2.4m c/c to tie the adjacent long walls together at roof level. These bars should be embedded in the RC band, while casting them, as shown in Fig.12. Part of the bars, which will be embedded in the mud phuska treatment should be given bitumen coating, to prevent rusting of the bars.

* Two layers of black polythene sheets of gauge 400μ should be laid over top of timber planks of roof. They should be taken up and glued on to the top of wall with bitumen.

* Mud phuska treatment of 10cm average thickness should be laid in slope over the polythene sheets. 5cm thick layer of waterproof nonerodable mud plaster (Malhotra, 1983) should be provided over the mudphuska.

* 15cm thick layer of brickwork in cement:sand mortar 1:6 could be provided over the roof band so that top of brickwork is flush with top of roof treatment. 11.5cm wide and 15cm high brick course should be provided over the wall at outer edge as shown in Fig.12. Rainwater spouts could be embedded in this masonry.

CONCLUSIONS

Training including practical demonstration was provided to 500 engineers and administrators of Govt. of Maharashtra on repair, strengthening and reconstruction of earthquake damaged houses as discussed in this paper. The work has now been taken up under the supervision of these trained engineers.

ACKNOWLEDGEMENT

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