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NON-ENGINEERED CONSTRUCTION IN DEVELOPING COUNTRIES -AN APPROACH TOWARD EARTHQUAKE RISK PREDUCTION

Anand S ARYA[1]

SUMMARY

The paper first discusses some issues in regard to earthquake risk reduction of Non-engineered buildings, such as : Earthquake risk in developing countries and its management, the IDNDR – Yokoyama message emphasising on pre-disaster mitigation and preparedness, earthquake damage reduction initiatives taken such as preparation of building codes and guidelines and disaster mitigation for sustainable development. Then, the major causes of severe damage observed in non-engineered buildings in the past earthquakes are presently briefly and critical elements to be incorporated in new constructions are highlighted. Methodology for seismic retrofitting of stone houses developed, implemented and verified by the author in the field is introduced. Next, costs and benefits of earthquake prevention measures are indicated. Finally a practically feasible and economically viable scheme of earthquake resistant new building construction and seismic-retrofitting of existing unsafe buildings is outlined.

INTRODUCTION

The non-engineered buildings considered in this paper are those which are spontaneously and informally constructed in various countries in the traditional manner without any or little intervention by qualified architects and engineers in their design. Such buildings involve field stone, fired brick, concrete blocks, adobe or rammed earth, wood or a combination of these traditional locally available materials in the wall construction. Cement, lime or clay mud are used for the mortars. Reinforced concrete lintels and floor and roof slabs and beams are also used. In some cases, use of reinforced concrete or steel columns and beams is also made particularly for shopping centres and school buildings, but here also a post-beam type simple concept is frequently adopted in a non-engineered manner without consideration of the stability of the system under horizontal seismic forces.

The safety of the non-engineered buildings from the fury of earthquakes is a subject of highest priority in view of the fact that in the moderate to severe seismic zones of the developing world more than 90 percent of the population is still living and working in such buildings, and that most losses of lives during earthquakes have occurred due to their collapse. The risk to life is further increasing due to rising population density in these countries, poverty of the people, scarcity of modern building materials, lack of awareness and necessary skills for improved construction. The present disaster management policies of the governments in the developing countries do not address the issue of preventive actions for the safety of such buildings toward seismic risk reduction; the development plans *do not require* consideration for safety from hazards as an essential component of the projects; the settlement planning and development legislations have no provision to attend to hazard safety concerns, and the building by-laws of municipalities and corporations are silent about earthquake resistance in buildings. The Codes and Guidelines developed through the standard making bodies remain *recommendatory documents of* good engineering practices, and their implementation depends upon the decision of the Heads of Agencies, Departs, Organisations, Institutions owning the buildings and structures in the public and private sectors. Private individuals have by and large remained uninformed.

The paper aims at highlighting the simple and very economical measures for achieving non-collapse seismic safety of various non-engineered buildings, and issues concerning national policies toward earthquake risk reduction including suggestions for an action plan to achieve the results in short and long range.

[1] *Professor Emeritus in Earthquake Engineering, University of Roorkee, Roorkee India, Fax:91(1332) 73560*

EARTHQUAKE RISK IN DEVELOPING COUNTRIES

Among the various natural disasters, namely earthquakes (including tsunamis), volcanic eruptions, floods, tropical cyclones, tornadoes, and land slides etc., that have occurred around the world between 1900-1976, the number of persons killed has been the maximum due to earthquakes (more than 2.66 million), the number two killer being flood (1.29 million) and the third was cyclone (0.43 million) [Crozier, 1986]. Earthquake disasters also rendered 28.9 million homeless during this period. Another survey [Shah, 1983] for the period 1947-80 brings out the facts that 180 earthquake events including seven tsunamis killed 358,980 in Asia, 38,837 in South America, 30,613 in the Caribbean and Central America, 18,232 in Africa, 7,750 in Europe and 137 in North America. So many earthquakes that have occurred since after 1980 in Mexico, Armenia, Iran, India, Philippines, and Japan have shown the fragility of the Non-Engineered buildings under earthquake intensities VII and larger with high potential of causing large loss of life and property. These surveys do highlight that among the various natural disasters, earthquake has been the worst killer and that the developing countries of Asia, South and Central America, and Africa, taken in that order, are the worst hit. The reasons are obvious. Asia is the most populated of the continents with the largest number of poor and illiterate people and a huge stock of unsafe non-engineered buildings. Also the major Himalayan – Alpide seismic belt runs across the Asian continent whereas the other major seismic belt at the rim of the Pacific Ocean forms its eastern boundary. The eastern Pacific coast is also as highly seismic affecting the North, Central and South American countries in equal measure. But Canada and the United States, being highly developed, have been able to achieve relatively good quality earthquake resistant buildings ensuring safety of their population to a great extent but the other countries are still highly vulnerable.

EARTHQUAKE RISK MANAGEMENT IN DEVELOPING COUNTRIES

So far as management of earthquake risk is concerned, the task is indeed difficult. In his famous address given in the Eighth World Conference on Earthquake Engineering held in San Francisco in 1984, Dr. Frank Press had generalised: "The class of hazards characterized by low probability of occurrence and high consequences, presents a difficult public policy problem; how to sustain public interest and involvement; how to attract adequate government resources for mitigation programs." It is, therefore, understable that most governments at national, provincial or state levels, have focussed, in their disaster management policies, on post-disaster response involving rescue, relief and rehabilitation of the affected communities. The agencies or departments looking after the emergencies are named variously in different countries, such as Emergency Management, Calamity Relief, Civil Defence, Crisis Management, etc. and may be under different ministries too, such as Ministry of Interior or Home, Revenue, Agriculture, etc., but the functions are mostly similar, that is, "post disaster response." Since earthquakes occur suddenly without prior indication and their destructive action is done in a few seconds or at most minutes, the disaster managers are usually taken by surprize and found unprepared for the tasks they are called upon to perform. Then it takes time to organize rescue and relief teams with the necessary tools and plants, transporting vehicles, and the supplies of emergency items.

For an alternative approach, it was quite apt for Dr. Press to suggest "Earthquakes are a special category of hazard in that most human losses are due to failure of human-made structures – buildings, dams, lifelines, and so on. Therefore, in principle, with sufficient resources for research, development, education, followed by necessary investments in hazard reduction, earthquakes are a hazard that are within our power to respond to. We can reduce their threat over time as much as we want to. We can learn where not to build and how to build so that failure of structures will not occur." That is, adopt 'prevention' in place of 'response'.

The IDNDR Conference of Members of the United Nations and other States in partnership with non-governmental organisations, with the participation of international organisations, the scientific community, business, industry and the media, held in Yokohama, Japan, in May 1994, gave the following important message to the disaster prone countries for consideration and action:

"The impact of natural disasters in terms of human and economic losses has risen in recent years, and society in general has become more vulnerable to natural disasters. Those usually most affected by natural and other disasters are the poor and socially disadvantaged groups in developing countries as they are least equipped to cope with them." Further,

"Disaster prevention, mitigation and preparedness are better than disaster response in achieving the goals and objectives of the Decade. Disaster response alone is not sufficient, as it yields only temporary results at a very high cost. We have followed this limited approach for too long. Prevention contributes to lasting improvement in safety and is essential to integrated disaster management."

SOME EARTHQUAKE DAMAGE REDUCTION INITIATIVES

Large earthquake occurrences in India namely Kangra (M8.0), in 1905 [GSI Officers, 1910]; Bihar-Nepal (M8.4) in 1934 [GSI Officers, 1939]; and Quetta (now in Pakistan M7.5) in 1935, in which many thousands of persons were killed and hundreds of thousands were rendered homeless due to large scale destruction of dwellings, had lead to development of some guidelines for new constructions for earthquake safety. The most important contributions could be cited as follows:

i) Wood frame construction with diagonal braces and brick nogging was adopted and propagated in the Kangra region after the 1905 quake. Many hundreds of such buildings still exist which have performed meritoriously during later earthquakes wherein the more recent brick and stone bearing wall buildings were destroyed.

ii) Heavy reinforced concrete or steel beams were suggested as 'bands' to be provided at plinth, door lintel and ceiling levels of bearing wall masonry buildings after the 1935 Quetta earthquake.

These formed the starting points of research and development work in University of Roorkee in the sixties on the safety of non-engineered buildings and the first Indian Standard Code [IS: 4326, 1967] was brought out in 1967 later revised in 1976. Experience of buildings, built by some Central and State Government Departments according to this Code, during the earthquakes in 1991 in Uttarkashi, 1993 in Latur, 1997 in Jabalpur, and 1999 in Chamoli which caused intensities of MSK VIII & IX in core damage areas, showed full efficacy of the Codal provisions in not only preventing collapse or severe damage but also restricting the damage to minor cracking only. Similar initiatives for safety of non-engineered buildings were also taken in other countries notably Peru, Mexico, Italy, the erst while Yugoslavia, and China.

Initiative by IAEE.

At the meeting of the Board of Directors of IAEE held at New Delhi in January 1977, it was decided that a Monograph be prepared to cover "Basic Concepts of Seismic Codes" and divided the work into three parts dealing with (I) Seismic Zoning, (ii) Non-Engineered Construction, and (iii) Engineered Construction. The first two parts were published in 1980 and part (iii) in 1982 [IAEE 1980, 1982]. National Committees were permitted to reprint or adopt them freely. Considering the wide utility of the Part on Non-Engineered Construction, IAEE Board of Directors' meeting in San Francisco decided to reprint it as separate Guidelines in revised and expanded form. Thus "Guidelines for Earthquake Resistant Non-Engineered Construction" was published [IAEE, 1986][1]. The Indian Society of Earthquake Technology reprinted it in throusands and distributed at cost price. It has now been translated into Spanish for use in the Spanish speaking countries [CISMID, 1993]. This IAEE publication has been most salutory initiative taken by IAEE toward earthquake damage reduction in the non-engineered buildings in developing countries. The engineering aspects of the non-engineered buildings are discussed in the following paragraphs including causes of catastrophic behaviour, critical remedial measures to be adopted in new construction and those for upgrading the seismic resistance of existing unsafe buildings. Cost-benefit aspects of the prevention methodology are also presented.

DAMAGE RISK OF NON-ENGINEERED BUILDINGS

Earthquake Intensity and Building Damage

The destructive energy released during an earthquake is expressed by its Magnitude on Richter's open ended scale. The relationship between the Magnitude and energy is logarithmic such that a higher Magnitude by 1.0 has the energy about 31.5 times that of the lower Magnitude.

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[1] *IAEE Committee: Anand S. Arya India, Chairman), Teddy Boen (Indonesia) Yuji Ishiyama (Japan), A.I. Marteminatov (USSR), Roberto Meli (Mexico) Charles Scawthorn (USA), Vargas Julio N. (Peru) and Ye Yaoxian (China).*

The effects of an earthquake on ground (soils, rocks, hills and plains) as well as on man-made buildings, structures, infrastructure and services vary greatly in the overall impacted area. The parameters are very many which influence the effect on and the performance of any given building or structure. Therefore quite a non-uniform damage pattern is often seen. The main parameters are:

(i) distance from the causative fault:- usually the more the distance the less the damage, except where local soil effects change the pattern by amplifying the ground motion;

(ii) the inherent strength or vulnerability of the building or structure; the stronger the building the less the damage, the weaker the building the more the damage;

(iii) the local soil on which the structure is founded: usually the softer the soil the more the damage, except where the frequency content in the earthquake accelerations will be prejudicial to the buildings on harder strata.

For generalised assessment of the earthquake intensity in the affected area, the Modified Mercalli Intensity scale of 12 steps is utilized extensively. Recently, the more detailed International M.S.K. Intensity scale (1964) is coming into greater use in view of better quantitative description of terms like *Most* (about 75%), *Many* (about 50%), *Few* (about 15%) and *Single* (about 5%) and the description of grades of damage as *Total* (G5), *Destruction* (G4), *Heavy* (G3), *Moderate* (G2) and *Minor* (G1). The information extracted from the MSK Intensity scale for buildings, both engineered and non-engineered is presented in Table 1. This tabular presentation will permit its easy use for vulnerability analysis and assessment of risk in a given earthquake.

Table - 1 Seismic Intensity and Maximum Damage to Buildings*

Building Type	Intensity VII	Intensity VIII	Intensity IX
A) Mud and Adobe houses, random-stone constructions	Most have large deep cracks Few suffer partial Collapse	Most suffer partial collapse Few suffer complete collapse	Most suffer complete collapse
B) Ordinary brick buildings, building of large blocks and prefab type, poor half timbered houses	Many have small cracks in walls	Most have large and deep cracks Few partial collapses	Many show partial collapse Few completely collapse Few minor cracks
C) Reinforced buildings, well built wooden buildings	Many have fine plaster cracks	Most have small cracks in walls. Few may have Large deep cracks	Many have large and deep cracks Few may have partial collapse.

**Most = about 75%, Many = about 50%, Few = about 15%* *Source: A.S. Arya*

From Table 1, it is clearly seen that the non-engineered traditional buildings particularly Type A consisting of field stone or Adobe or clay walls are particularly liable to heavy damage, destruction and total loss (collapse) even in moderate MSK Intensities VII and VIII. Such Intensities are likely to occur in the epicentral areas of 6.0 to 6.5 Magnitude shallow focus earthquakes. In the higher Intensity of IX which will be likely in 6.6 to 7.2 Magnitudes, Type A buildings will rarely survive and even Type B buildings consisting of unreinforced ordinary brick walls, concrete block constructions, and better quality stone structures will be destroyed on a large scale, and only the buildings of Type C namely reinforced buildings and well built wooden buildings will have chance to survive.

Performance of Non-Engineered Buildings During Earthquakes

Earthen Houses

The performance of earthen houses during earthquakes of MSK VIII or more has been generally very poor consisting of wide cracks in walls and the separation of walls at corners, and the complete collapse of walls, roofs and floors leading to death and injury to the residents. Due to heavy mass of debris, rescue work of buried people also has been found to be difficult and time consuming; even more so if the streets get blocked by fallen debris. Single storeyed adobe and rammed earth houses with flat heavy roofs have shown fair behaviour during Dhamar (Yemen) earthquake of Dec. 1982 even in MM VIII area in that they did not collapse and cracking damage was minimal, but most of two and three storey houses collapsed completely [Arya, 1988].

Masonry Buildings

From the seismic observations all over the world on masonry buildings consisting of walls made from fired bricks, random-rubble or field stone or a combination thereof, the following types of damage become evident:

1) The masonry, being weak in tension as well as in shear, when shaken horizontally during an earthquake, cracks very easily in various ways such as vertical bending cracks near vertical edges, horizontal bending cracks below the roof and floor and above the plinth. Diagonal tension cracks starting from corners of openings as well as in star pattern in the vertical piers between openings and in the spandrel beams of shear walls are important since they adversely affect the structural strength.

2) In case of flexible roofs and floors (such as trussed roofs, pitched roof, wooden floors, floors consisting of precase RC joists with flexible covering), the perpendicular walls tend to fully separate from each other. In the absence of diaphragm action of roof and floors, the integral box - like action of walls is lost completely and the walls subjected to inertia force normal to their plane tend to fail by overturning mechanism. This leads to partial or total collapse of the house.

3) Parapets, and chimneys projecting above the roof are subjected to greatly amplified motion and easily fail by bending and overturning. When falling outside, they crush the people and parked or moving cars, hence dangerous elements. These should either be eliminated or properly reinforced and tied to the lower structure.

4) Gable ends of buildings with trussed roofs are unstable triangular vertical cantilevers which collapse laterally very easily. Four sloped (hipped) roofs are therefore superior in the seismic behaviour of the building. Gable masonry should therefore be replaced by a truss with a light sheet covering or the masonry should be properly reinforced and tied to the wall below and those at right angles.

5) Random rubble masonry (field-stone) walls, particularly those built with lime or clay mud mortar, are very weak in compression also. Strength further reduces if walls get wet during rains. On seismic shaking, they lose their cohesion and shatter completely, being converted into heap of rubble and clay. Two storeyed buildings have shown very bad performance by complete collapse even in moderate earthquakes (M.S.K. intensity VII to VIII). Hence their height must be restricted to one storey only, unless good cement mortar is used and reinforced at critical sections. .

Random rubble and half-dressed stone walls also suffer from the problem of delamination from the middle, the two wythes collapsing separately inward and outward causing total collapse of the house (Fig. 1).

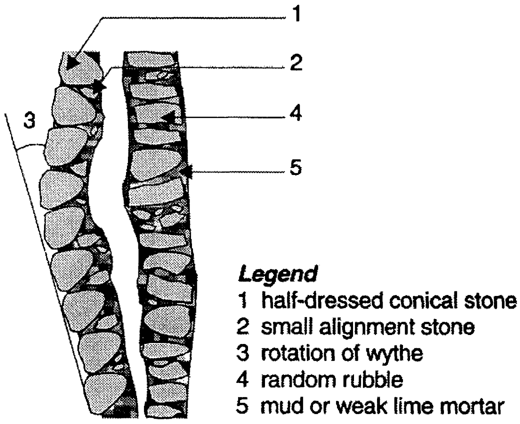


Figure 1: Delamination of stone walls

6) The wooden joists or round logs used as roof or floor beams in many countries frequently have a small length of bearing on the walls and are not fully held at the ends. Thus during shaking they become loose, the walls move out freely, and the roof or floor collapses.

7) Sometimes buildings have unduly long rooms, their long walls do not get adequate lateral support from the cross walls. Such walls are very dangerous due to out of plane bending and overturning collapse.

8) Location and relative size of the window and door openings to the size of the walls are seen to have a pronounced effect on the strength of the wall. Corner windows or those close to the edge of the wall are

found dangerous. Large openings and too many openings in a wall reduce its strength for vertical as well as lateral loads acting in either plane. This situation frequently happens in apartment houses where cross-walls remain solid and most openings are located in longitudinal walls. Such buildings collapse longitudinally during earthquakes.

9) Many modern masonry buildings, such as those used for schools, hospitals, etc. are sometimes made unsymmetrical in plan (C,U, E or Z shape) as well as in elevation, with several projecting wings and blocks. These suffer due to severe torsional effects caused by the eccentricity of earthquake force about the centre of rigidity of the building.

10) Heavy flexible roofs with no diaphragm action are dangerous. On the other hand light flexible roofs with no-binding effect on heavy masonry walls, will also be unsuitable since the absence of integrating/binding diaphragm effect on top of walls will lead to their separation and disintegration during earthquake shaking.

11) Quality of construction is seen to affect the seismic performance critically: good quality construction can survive in an earthquake which will destroy a similar house of poor construction quality. Some commonly seen construction defects are the following:
   a) Lack of bond between building units.
   b) Unfilled vertical joints between the units.
   c) Walls not plumb in vertical plane.
   d) Vertical planes of weakness due to adoption of toothed joints between perpendicular brick or block walls.
   e) Absence of 'through' or 'bond' stones in field-stone and half-dressed stone construction and, unstable configuration of stones in such constructions.
   f) Use of dry bricks, unsoaked in water, before laying, resulting in dried-up cement-or lime-sand mortars producing very weak masonry.

12) Finally well maintained buildings show better performance than neglected or poorly maintained buildings.

Wooden Houses

The earthquake performance of wooden houses has generally been good, particularly that of the wooden frame, and also where the cladding consists of sheeting, boarding, ikra walling, bamboo matting, etc. But the brick or stone infills have frequently shown movement out of the plane of the frames. The most dangerous aspect of wooden buildings has been their biodegradation and poor fire resistance. The danger of fire during earthquakes is real due to kitchen fires, as well as due to short circuiting of electric wiring.

The poor experience of wooden building called Zigali in Manjil, Iran earthquake of 1990 [Moinfar & Naderzadeh, 1990] was due to severe deficiency of connections between the main members. The disastrous performance of two storey wooden houses in 1995 Kobe earthquake was mainly due to biodegradation of columns near their base, heavy weight of roof, lack of bracings and occurrence of fire [Doi, Kitamoto & Jian, 1996; Tomioka et al., 1996].

EARTHQUAKE PROTECTION MESURES

These can be divided into three parts (i) Architectural design, (ii) Structural counter measures, and (iii) Construction and maintenance quality. In most cases parts (i) and (iii) require little additional cost inputs, but if carried out according to earthquake resistance principles, they improve the seismic performance of the building quite appreciably at practically `no' cost. Structural countermeasures do require additional cost inputs whose relative cost varies with the basic building materials used and the level of reinforcing provided. The major seismic protection measures in non-engineered buildings are briefly highlighted here.

Architectural Design Features

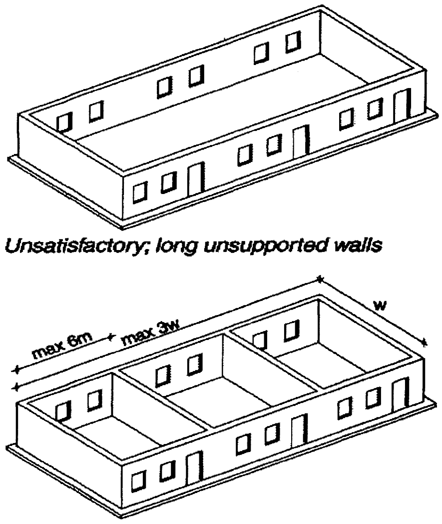
The following features are desirable for better seismic performance of buildings:

i) *Simplicity and symmetry in plan and elevations*: It will be preferable to build separate blocks for different functions based on their post-earthquake importance.

ii) *Enclosed space.* Within a building, smaller rooms with properly bonded long and short walls forming a crate like enclosure, are seismically stronger than rooms with long uninterrupted masonry walls (Fig. 2). The spacing of cross walls will depend on the mortar used.

iii) *Opening in Walls.* Window, ventilator and door openings reduce the shear and bending strength of walls, and their size as wall as location are both significant in this respect. For better seismic behaviour openings should be as small and centrally located as functionally feasible.

iv) *Building Height.* Restriction of height of load bearing wall buildings is necessary for better seismic safety. The guide lines are suggested as shown in Table 2, provided of course that reinforcing methods suitable for seismic intensities probable in the area will also be adopted in construction.



Unsatisfactory; long unsupported walls

Satisfactory; cellular enclosures

Figure 2: Nature of enclosures

Table –2 : Suggested Height Restrictions on Building in Moderate and Severe Seismic Zones

Building type	Suggested Height
1. Adoble house	One storey or one storey + Attic
2. Field Stone (Random Rubble masonry) in clay mud mortar	One storey or one storey + Attic
3. Dressed stone masonry in Cement mortar	Two storeys, or two storeys + Attic
4. Brick masonry in mud with critical sections in cement mortar	Two storeys, or two storeys + Attic
5. Brick or cement block masonry in good cement motar	Three storeys or three storeys + Attic
6. Reinforced masonry	As per design by a qualified engineer.
7. Wood frame	Two storeys, or two storeys + Attic

v) *Roofs.* Type of roof plays an important role in the seismic behaviour of the house. Lighter roofs are preferable to heavy roofs. Sheeted roofs are better than tiled roofs. All elements of a roof should be so integrated that it may have the capability of acting as one stiff unit in plan for holding the walls together. In this respect four-slope hipped roofs are better than trussed roofs, trussed roofs are better than lean-to roofs, and complete trusses are preferable to rafters with collar-ties. Trussed roofs require diagonal x-bracing elements in the sloping planes of the roof as well as at tie level so that the roof provides the diaphragm action for transferring the inertia load horizontally to the shear walls.

vi) *Floors.* Similar to the roofs, those floors which are rigid in the horizontal direction such as reinforced concrete slabs are much superior in their diaphragm action to wood-joist floors and jack arch or flat arch floors. For holding the walls together, the floor elements should have full bearing on the walls. This will help in restraining the floors against falling down during severe shaking of walls. Also the flexible wood-joist floors should be formed into grillages through diagonal bracing in plan and prefabricated flooring elements should be well connected together through a R.C. sceed so as to achieve horizontal rigidity of the floors.

vii) *Gables.* Gable tops of walls, whether external or internal, constitute the most unstable part of the walls and should be avoided by trussing and covering with light sheeting, boarding, etc. External gables can be avoided by using hipped roofs, and internal gables can be left open if a false ceiling is used in the building. Otherwise gable masonry should be bounded by reinforced concrete bands connected with the long walls.

Quality of Construction and Maintenance

In Adobe, Stone, Brick or Block masonry of any type, the following factors will constitute good quality of construction and need to be monitored and controlled:

i) Good quality of building materials - mortar and building units of good strength.
ii) Proper bond so as to break vertical joints in walls.
iii) Construction of walls truly vertical.
iv) Proper continuity at corners and wall junctions.
v) Integrity of stone walls by use of `through' stones or `bond' elements at the rate of one element in every 1.2 m x 0.6 m of wall area (Fig. 3), and use of long stones at corners to achieve bonding between perpendicular walls.

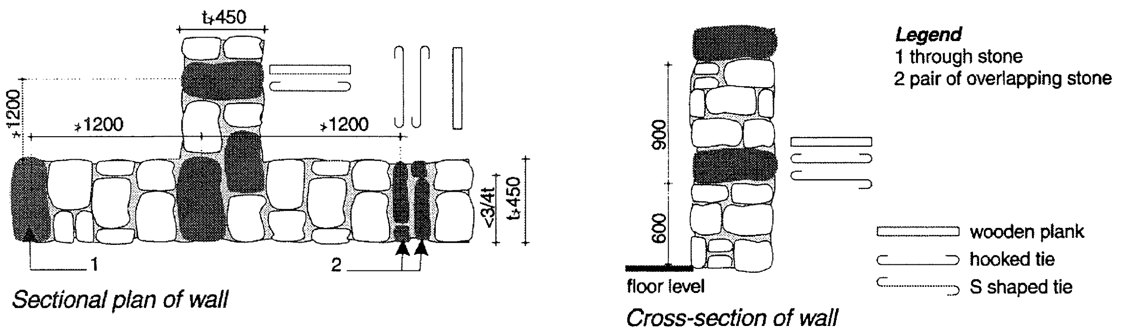


Figure 3: 'Through' stones or Headers for integrity of stone walls

vi) Full filling of mortar in vertical joints between the units - bricks, blocks etc.
vii) Soaking of bricks before laying in cement-sand mortar, moistening of Adobe, before laying in mud mortar.

Besides, buildings of stone or bricks laid in mud mortar and also earthen buildings need yearly maintenance for rain water-proofing so as to maintain dry strength of the clay which when wet could lose even 85 per cent of its strength. As per the Chinese saying, clay houses need `*hat and boot*' for safety against rain and flood waters.

Structural Strengthening of Low-Rise Masonry Houses

The adoption of the architectural planning principles as above is the first step toward improving the seismic behaviour of the buildings. Severe damage will still be likely in areas of Intensity VII or higher. Hence reinforcing of masonry walls will be necessary for seismic protection. The extent of reinforcing will depend on the level of safety desired.

While theoretically, if appropriate resources and building materials are made available, it may be possible to construct buildings which can withstand the effects of earthquake with damage restricted to G1 or Minor grade. Since it will require fully reinforced masonry walls in 1:3 cement sand mortar or grouted reinforced masonry walls, it will not be feasible to do so due to the very high costs involved.

In fact, from the view point of prevailing conditions the non-engineered buildings suffer from the following constraints:

(i) revolutionary change in the construction pattern is not feasible, hence not practical;
(ii) the use of local materials will continue with marginal increase in use of cement, steel and other modern materials, and
(iii) very simple modification in the traditional building systems need to be incorporated for earthquake resistance which could easily be understood and adopted by the local artisans, and socially accepted by the people.

From the safety view point, the safety of human lives and belongings is the primary concern. The functioning of the buildings has lower priority except those required for community activities such as schools, assembly halls, places of worship, and cinema halls, etc., and those required for the emergency, such as, buildings for hospital, operation theatre, telephone and telegraph, fire fighting and the like. The safety aims would therefore be met, if an ordinary building is designed and constructed in such a way that even in the event of the probable maximum seismic Intensity in the region,

i) it should not suffer total or partial collapse; and

ii) it should not suffer Destruction (G4) damage which would require demolishing and rebuilding. The damage shall be restricted within repairable limit, that is, grades G1 to G3 only.

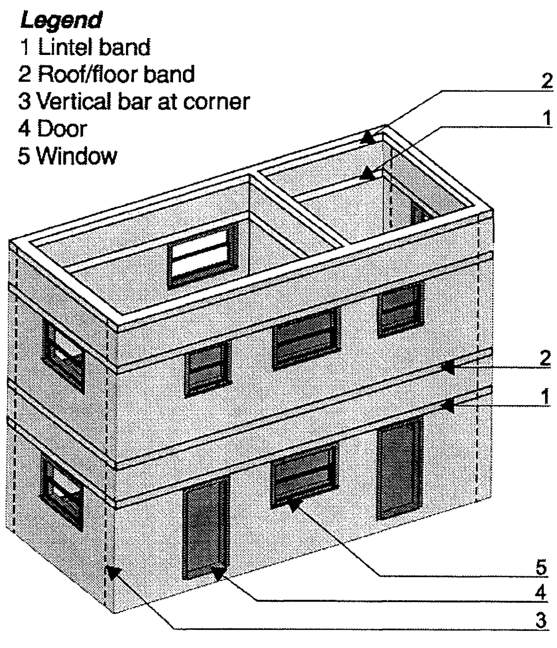
The level of safety of an important building should be such that the functioning of the activities during the post-emergency period may continue unhampered and the community buildings may be used as temporary shelters for the adversely affected people. This is, the maximum damage should be up to G2 grade only.

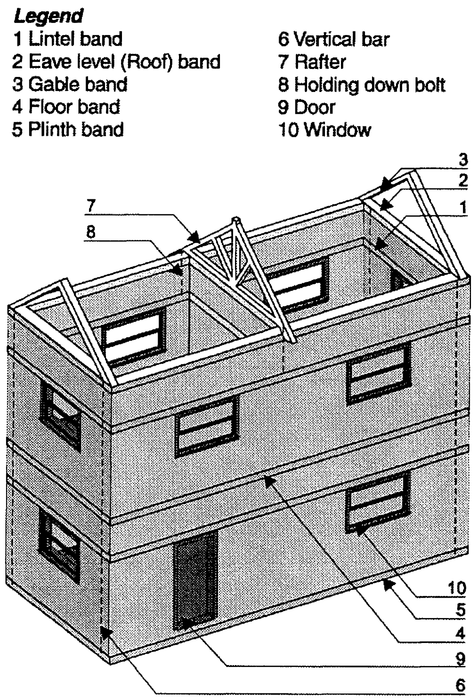
The present state of research indicates that fortunately the above structural safety can be achieved by providing reinforcement at only the critical sections of the walls.

The main component of structural strengthening will be as follows:

a) Mortar. Use of stronger mortar in masonry, at least cement-sand 1:6, preferably richer for important buildings , should be made where economically feasible.

b) Seismic Bands. The most important concept in strengthing of masonry building is the provision of horizontal seismic bands (variously called as seismic belts, collar beams, ring beams, etc.). A *seismic band* is a continuous runner of reinforced concrete or wood going into all external and internal walls with proper connections at the corners and T-junctions of walls. The *bands* are required at certain levels as stated below (Fig. 4, 5):





Overall arrangement of reinforcing masonry buildings (roof not shown)

Figure 4: Flat flexible roof case

Figure 5: Pitched roof case

Plinth Band should be provided in those cases where the soil is soft or uneven in its properties as usually happens in hill tracts. It will also serve as damp proof course. This band is not too critical.

Lintel Band is the most important band and will incorporate in itself all door and window lintels the reinforcement of which should be extra to the lintel band steel. It must be provided in all storeys in the building.

Eaves/Roof Band will be required at eaves level of trussed roofs or where flexible wood joist roof or precast roofing units are used.

Floor/Ceiling Band is needed in level with or just below such floors which consist of joists and loose covering material. These bands may be omitted where concrete slab having adequate bearing, minimum 200 mm, on all four walls is used for roof or floor.

Gable band is used to enclose the triangular part of masonry walls, the horizontal part will be continuous with the eave level band on longitudinal walls. *Ridge band* is used on top of masonry walls forming ridges running inside the building longitudinally from gable to gable.

The *bands*, particularly those at lintel, ceiling/roof and eaves levels perform the following important functions:

i) Ensuring box-like action of the individual room as well as that of the whole building by preventing the separation of perpendicular walls;
ii) providing out-of-plane bending resistance to the wall by forming a rigid horizontal frame with continuity at the corners;
iii) reducing the unsupported vertical height of the wall to that between the two consecutive bands, like *plinth* and *lintel*.

Use of steel mesh or wooden dowels at corners and T-junctions of walls for bonding and integrating the perpendicular walls is a poor alternative to the seismic bands stated above. But when used at intermediate levels in addition to the bands, this will enhance the damage resisting capability of the houses.

The reinforced concrete band details including the bending of the bars is shown in Fig. 6.

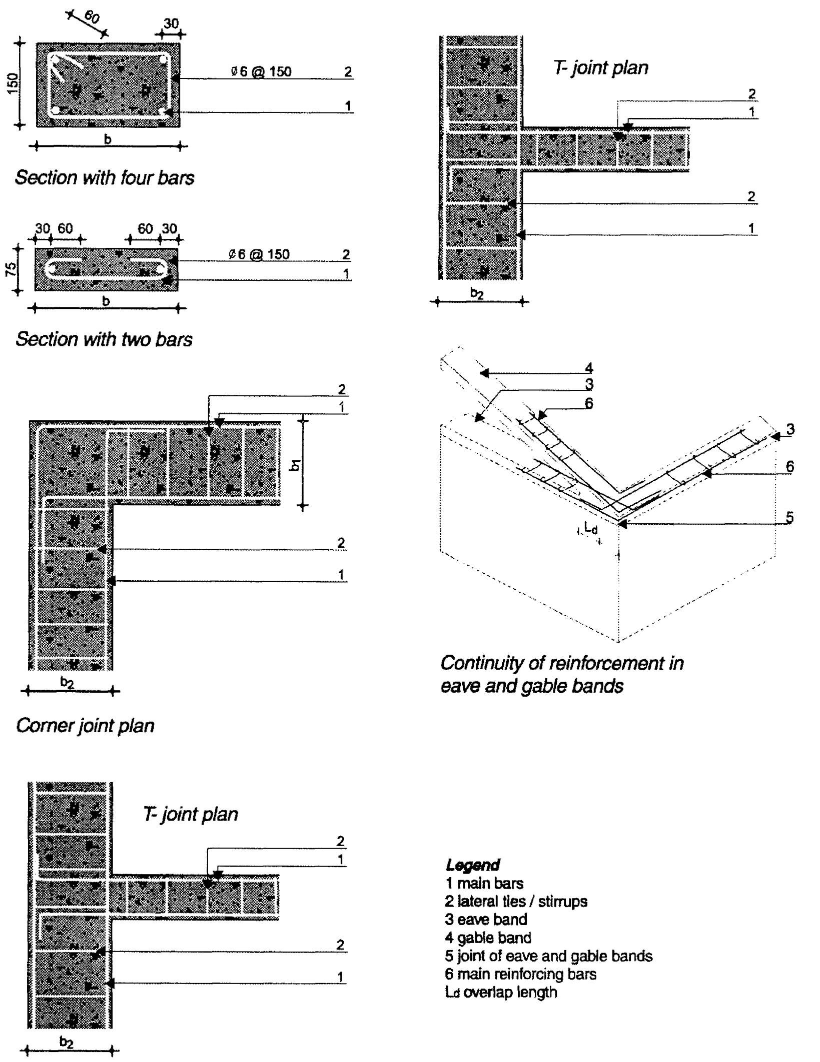


Figure 6: Reinforcement details in R.C. seismic bands

c) *Vertical Steel.* The next important strengthening provision is the installation of vertical reinforcing elements in the walls, using steel bars or bamboo or cane at the critical sections of the walls.

Analysis of the building for lateral seismic loads by *Pier Method* shows that as the Intensity (represented by the equivalent seismic coefficient) increases, the two ends of each pier, between the corner of the wall and the door/window opening or between two openings, are subjected to tension. The overturning effect of the lateral loads increases these tensions, particularly at the outer corners of the buildings. Thus, the critical section for vertical reinforcing are the corners of walls and the jambs of window and door openings.

Figures 4 and 5 show the general pattern of reinforcing of bearing wall buildings including horizontal *bands* and *vertical steel* at the corners. This pattern will mostly be adequate for the severe seismic zones in resisting the collapse of the building and reducing the extent of damage.

Sometimes small size vertical reinforced concrete columns are used in place of vertical steel bars embedded in the masonry. It may be emphasised, that they will not be as effective in aiding the shear wall action unless properly connected to the walls through shear keys (Fig.7). Here the wall is built first with the teeth projected out and the concrete is poured later. It should be ensured that the masonry is kept *wet* when the concrete is cast so that masonry does not soak away the water from the concrete.

Structural Strengthening of Wooden Houses

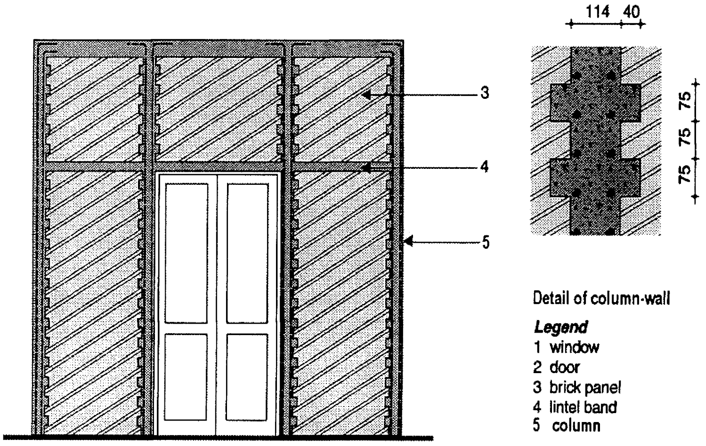


Figure 7: Vertical RC columns as part of masonry wall

The basic requirements of wooden buildings are regarding durability against weathering and insect attack by seasoning and preservative treatments. The joints between the members should be firm through the use of framing, nails, bolts or disc-dowels and kept tight by using steel straps.

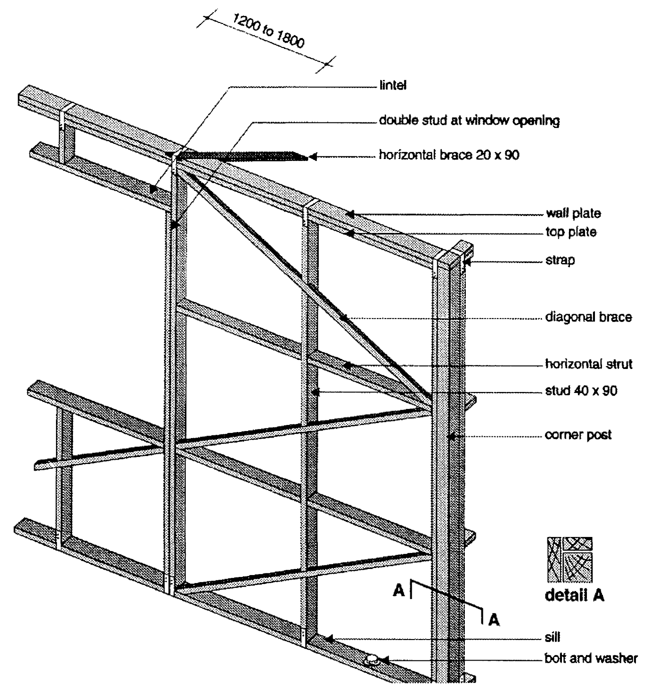


Figure 8: Bracings in wooden stud wall construction

In wooden buildings of stud-wall construction or the brick-nogged construction, the most important strengthening provision is that of diagonal bracing elements, both in the horizontal and vertical planes of the enclosure so that the house is restrained from twisting deformation in its plan and shearing deformation in the walls (Fig. 8).

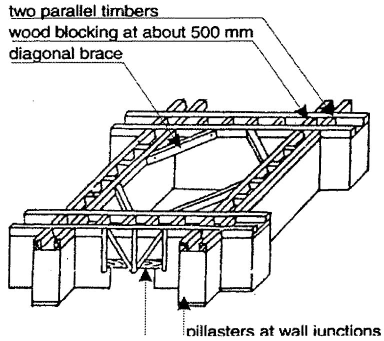
Fire resistance of wooden buildings must be given full consideration to avoid fire hazard initiated by earthquake damage to gas lines, electrical fittings or by burning of fallen objects on kitchen fires.

Strengthening Measures for Earthen Houses

Earthen houses can similarly be strengthened by using lintel band and roof bands made of wood. The roof rafters are to be held to the roof band through spikes or galvanized iron wires. Walls are made stronger by using buttresses or pillaster at the corners and wall junctions. These measures shown in Fig. 9 are enough for MSK VIII or lower zones. But in MSK IX, use of vertical canes or bamboos is found necessary (see Fig. 10).

Detailing of Non-Engineered R.C. Post-Beam Low Rise Buildings.

The main deficiencies in these buildings are (i) wider spacing of stirrups in beams and columns, (ii) absence of confining reinforcement in end lengths of columns, (iii) absence of stirrups within beam-column joints required for shear strength and confinement. Figure 11 shows typical reinforcing details which would remove most of these deficiencies.



a) With pillasters and wooden bands

b) with bamboo bands

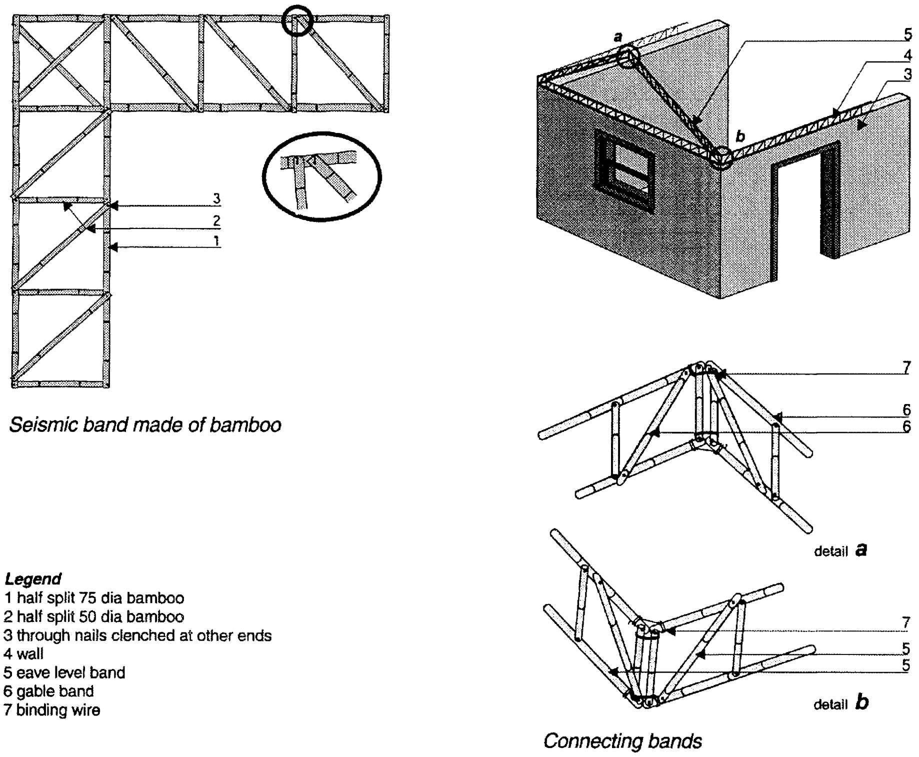


Figure 9: Strengthening earthen houses with seismic bands

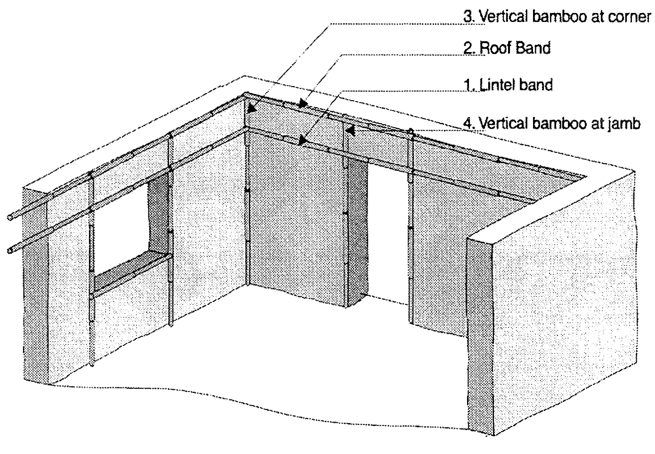


Figure 10: Strengthening earthen houses with bamboo verticals & bands

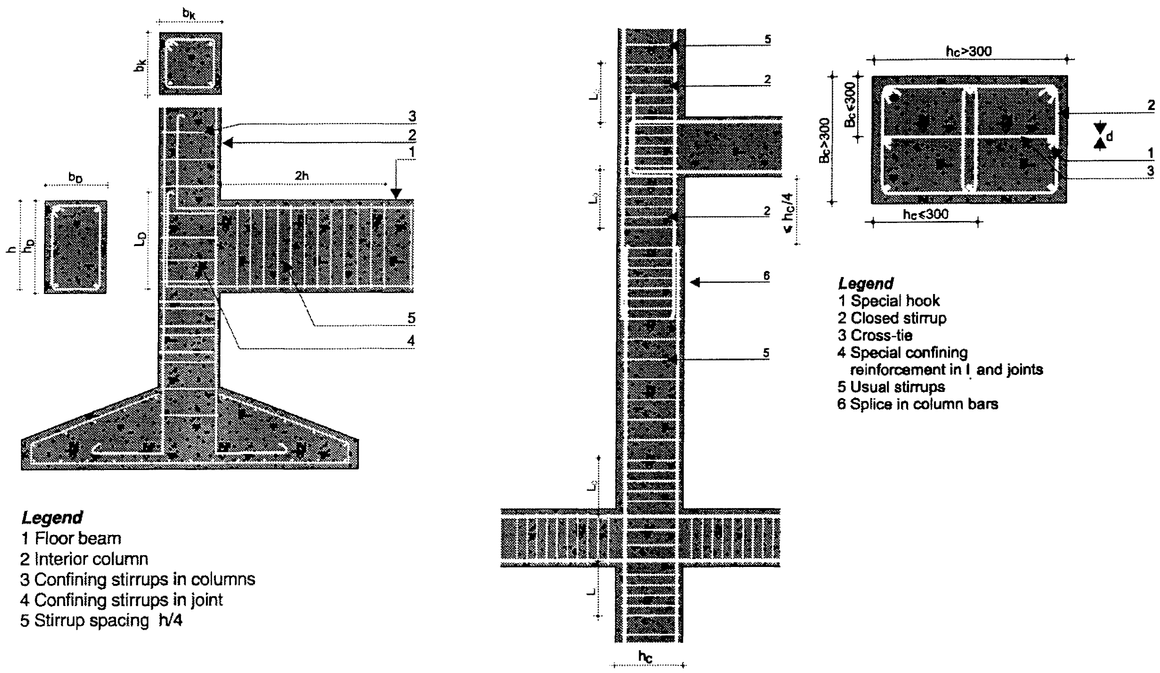


Figure 11: Typical reinforcing details for good seismic performance of RC post-beam construction

SEISMIC RETROFITTING OF EXISTING NON-ENGINEERED BUILDINGS

Besides the seismic protection of new construction, there is the problem of the huge stock of unsafe highly vulnerable non-engineered housing throughout the developing world. Even the developed countries suffer from this problem as seen in Whittier earthquake [..., 1988] and Kobe earthquake [Doi, Kitamoto & Jian, 1996]. The tragedy is that most new buildings in the rural and semi-urban areas of developing countries are still being constructed in the traditional way without taking advantage of the available know how of earthquake resisting methodologies, with the result that the numbers of unsafe buildings are increasing. Therefore, there is a crying need to devise and use appropriate seismic retrofitting measures to upgrade the seismic resistance of the existing buildings of various types. Research work is in progress in this direction in many countries. The IAEE guidelines [1986] have also covered this aspect of the problem. Recently, on similar lines, Bureau of Indian Standard have brought out standard guidelines, which basically deal with the non-engineered buildings [IS: 13935, 1993]. The main issues and methods of seismic retrofitting are highlighted here.

Cost of Seismic Protection in New construction and Retrofitting

Costwise, the building construction including the seismic resistance provisions in the first instance, works out the cheapest in terms of the safety of the building and that of the occupants. *Retrofitting* of an existing inadequate building may involve as much as 2 to 3 times the initial extra expenditure required on seismic resisting features. *Repair and seismic strengthening* costs of a damaged building may even be 4 to 8 times as expensive. It is therefore very much safer, as well as cost-effective, to construct earthquake resistant buildings at the initial stage itself according to the relevant seismic codes.

Retrofitting vs Reconstruction

Replacement of damaged buildings or existing unsafe buildings by reconstruction should generally be avoided due to a number of reasons, the main ones among them being:

a) higher cost of reconstruction than that of strengthening or retrofitting,
b) preservation of historical architecture, and
c) maintaining functional social and cultural environment.

In most instances, however, the relative cost of retrofitting to reconstruction cost determines the decision. As a rule of thumb, if the cost of repair and seismic strengthening is less than about 30 percent of the reconstruction cost, the retrofitting may be adopted. This will also require less working time and much less dislocation in the living style of the population. On the other hand reconstruction may offer the possibility of modernization of the habitat and may be preferred by well-to-do communities.

Non-Structural and Structural Repairs

The non-structural or architectural repairs like patching of cracks and plaster, repair of joinery or electrical, water supply and sewerage systems, repairing and replacing of roofing elements, replastering and painting are superficial in nature and neither restore the lost structural strength nor seismic resistance. If just done like that, they are illusory and dangerous in future earthquakes since the repaired building will infact be weaker than the original building before cracking occurred.

The structural repairs involve actions like rebuilding of cracked portions of the masonry in good mortar; stitching of wall across the cracks by using steel reinforcing on the wall faces nailed/bolted to the masonry, and covered by cement mortar, or grouting of cracks using cement or epoxy like adhesive materials which are stronger than the mortar used in the masonry. Such methods will restore the lost structural strength to the original level. The Structural repairing should therefore precede the architectural repairs.

Seismic Retrofitting

The main purpose of the seismic strengthening is to upgrade the seismic resistance of an existing unsafe building, or a damaged building while repairing so that it becomes safer under future earthquake occurences. This work may involve some of the following actions:

a) Giving unity to the structure, by providing a proper connection between its resisting elements, in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that have the ability to resist them. Typical important aspects are the bracing of roofs and floors to be able to act as horizontal diaphragms, and the connections between roofs or floors and walls, between intersecting walls and between walls and foundations.

b) Eliminating features that are sources of weakness or that produce concentration of stresses in some members. Asymmetrical plan distribution of resisting members, abrupt changes of stiffness from one floor to the other, concentration of large masses and large openings in walls without a proper peripheral reinforcement are examples of defects of this kind.

c) Increasing the lateral strength of walls and enclosures in one or both directions by increasing the wall areas, or by addition of ferrocement plates to the walls. The 'splint' and 'bandage' scheme of retrofitting consisting of external horizontal and vertical seismic belts of ferro-cement plates, or the Chinese system of external columns and beams and internal ties are very effective in improving seismic resistance of masonry buildings even for MSK IX areas.

d) Avoiding the possibility of brittle modes of failure by proper reinforcement and connection of resisting members.

Seismic Retrofitting of Stone Buildings

The stone buildings consisting of half dressed stone facia and random rubble wythes are most common in many countries. Such buildings have 450 to 900 mm thick walls constructed in mud mortar. The roofs of one storeyed houses, and roofs and floors in two to three storeyed houses consist of wooden logs or joists with wooden planks or reeds decking, topped with thick clay fill (fig.12). This fill may reach 500 to 750 mm in thickness in the roof with passage of time since to prevent leakage of rain water, people try to put more clayey soil on top. Such two and three storeyed houses in Dhamar Province of Yemen Arab Republic suffered catastrophic collapses in Dec. 1982 earthquake where the maximum intensity of MSK VIII was caused [Arya, 1988]. Similarly in Sept. 30, 1993 earthquake of M= 6.4 and maximum intensity MSK VIII in Latur and Osmanabad Districts of Maharashtra, India, even one storeyed buildings of similar wall and roof types suffered complete collapses killing more than nine thousand persons. Observations of house collapses during the earthquake showed that because of the absence of 'header' stones, the walls split through the middle and the inner and outer stone wythes collapsed, causing the fall of the roof as well. Whereas new buildings were required for replacing the collapsed and destroyed buildings, about 18 000 thousand buildings in Dhamar YAR, and more than two hundred thousand such houses needed seismic retrofitting in Maharashtra to provide the needed safety in future shocks and create the confidence among the inhabitants to live in them peacefully.

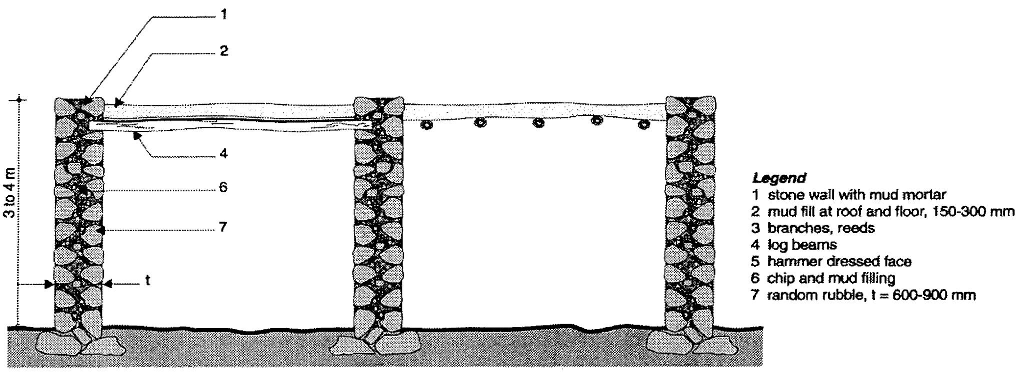


Figure 12: Section through typical rural stone house

The author has devised the scheme of retrofitting which consists of the following essential elements [Arya, 1996].

a) *For Walls*

1) Stitching the outer and inner wythes (stone layers) of the stone walls by the installation of reinforced concrete *headers* or 'bond' elements to serve as 'through' stones, so as to prevent *delamination (Fig. 15).*

2) Providing horizontal *seismic belts* around the houses (Fig. 13) for integrating the action of the walls together to resist the lateral seismic shaking effect on the house preventing the separation of the walls at the corners of the house, and installing cross ties across rooms connecting the seismic belts on the opposite walls. These ties acting in conjunction with the belt will hold the opposite walls together to improve the integrating action of the bands further.

3) Installing vertical seismic belts at the corners and wall junctions in Intensity IX area and in Important buildings in Intensity VIII area also (Fig. 13).

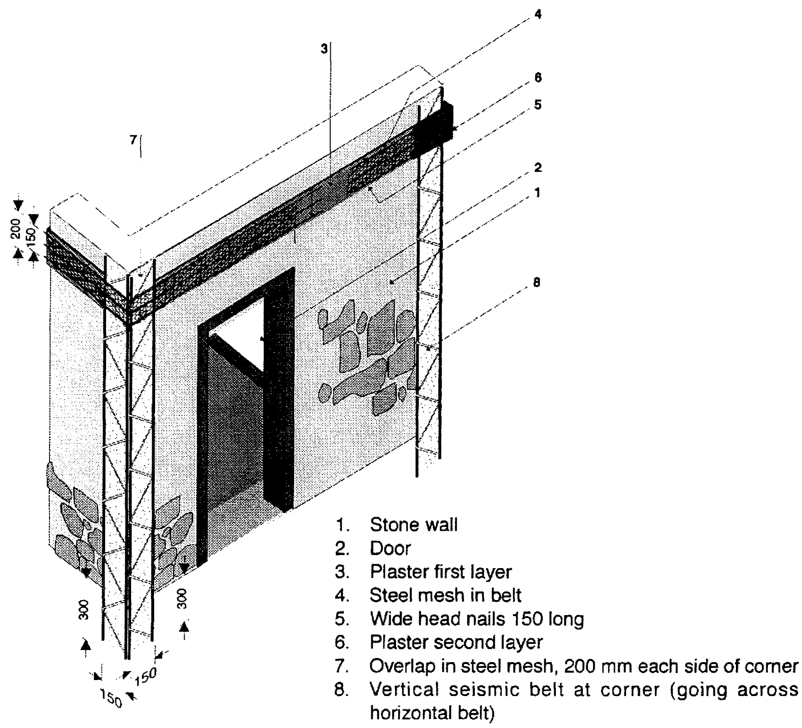


Figure 13: Installing horizontal and vertical seismic belts

b) *For heavy flat roofing*

1) Reducing the weight of the soil on the roof so as to reduce the earthquake force acting on the structure horizontally by using only 200 mm thickness of the earth as required to keep thermal comfort in the rooms during the hot summer season.

2) Laying black polythene sheet at mid-thickness of the 200 mm thick soil on roof for waterproofing.

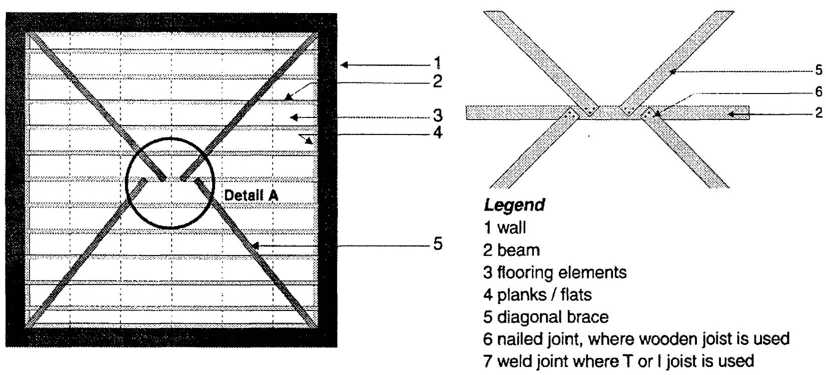


Figure 14: Imparting rigidity to flat flexible floor

3) Installing prependicular and diagonal bracing planks by nailing from underneath the floor/roof for imparting rigidity (Fig. 14)

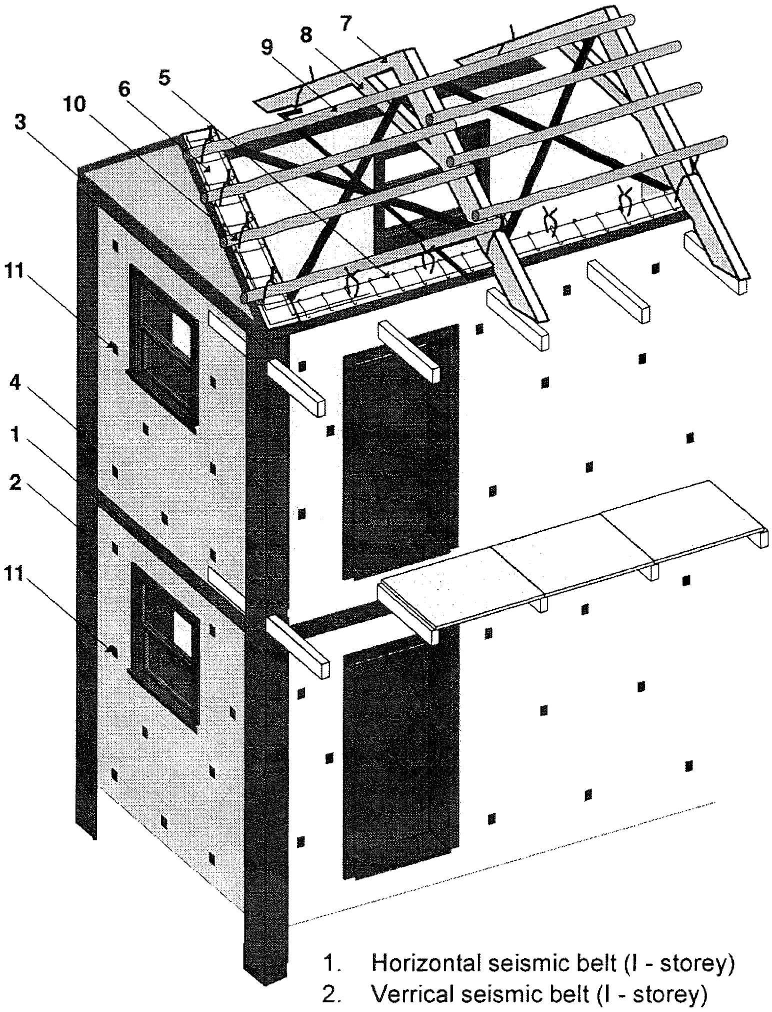
c) *For raftered sloping roofs*

1) Removing the roof, constructing eave and gable bands along with diagonal bracings.

2) Relaying the rafters, installing collar ties, holding down the rafters to the eave band through galvanized wires.

3) Completing the roof with purlins and sheeting or tiling.

The retrofitting details recommended for retrofitting two storeyed stone houses in Chamoli (1999) earthquake affected area (U.P. India) is shown in Fig. 15.



1. Horizontal seismic belt (I - storey)
2. Verrical seismic belt (I - storey)
3. Horizontal seismic belt (II - storey)
4. Vertical seismic belt (II - storey)
5. Eave level band
6. Gable top band
7. Principal rafter
8. Horizontal tie making A-frame
9. Purlin
10. Tying wire
11. Bond elements

Figure 15: Overall retrofitting arrangement for 2-storey stone houses

COST OF IMPROVING SEISMIC RESISTANCE OF BUILDINGS (INDIAN EXPERIENCE)

New Earthquake Resistance Constructions

India has a large part of its land area liable to wide range of probable maximum seismic intensities where about 1200 shallow earthquakes of magnitudes of 5.0 or more on Richter scale have been known to occur in the historical plast and those recorded in the last about 100 years. These include 8 of **M** $\geq$ 8.0, 43 of **M** = 7.0 to 7.9, 312 of **M** = 6.0 to 6.9 and the rest of **M** = 5.0 to 5.9. More than 55 percent of the land area of India is liable to seismic hazard damage (about 25% under MSK Intensity VII, 18% under VIII and 12% under IX and higher).

The housing situation in the country is shown in Table 3: It is seen that 50 percent of existing 195 million housing units consist of clay, adobe or stone walls and 35 percent have burnt brick walls. They are all highly vulnerable to sustain *heavy* to *total* damage under the above stated seismic Intensities, namely VII, VIII and IX. From these facts, the most appropriate method of reducing the disaster risk posed by future earthquakes will be to reduce the physical vulnerability of the built environment. This is the only measure where, given the combined will of the polity and the society, we can create the necessary awareness, provide professional guidance, develop the necessary human resource and exercise effective control, through empowerment of the local bodies' administration.

Table 3 - Various Building Types by Wall Materials in India*

Wall Type	Number	Percent of total	Damage Vulnerability MSKVII	MSKVIII	MSK IX
Earthen Walls (mud, unburnt brick/blocks)	74.7 million	38.3	M	H	VH
Stone walls	21.7 million	11.1	M	H	VH
Burned Brick walls	68.9 million	35.3	L	M	H
Concrete walls	3.96 million	2.0	VL	L	M
Wood & Ekra walls	3.12 million	1.6	VL	L	M
Gl and other metal sheets	1.02 million	0.5	VL	VL	L
Bamboo thatch, leaves, etc.	21.6 million	11.0	VL	VL	L

**Census of Housing 1991, total housing units = 195 million.*
VH = Very High, H = High, M = Moderate, L = Low, VL = Very Low

India has advanced considerably in developing the design criteria [IS: 1893, 1986], Codes of practice [IS:4326 and 13920, 1993], and Guidelines [IS: 13827, 13828 and 13935, 1993] for improving the earthquake resistance of various building types, the semi-engineered masonry buildings constructed in the formal sectors and also the non-engineered buildings of clay, brick, stone or wood built in the informal/traditional sector. The earthquake resisting features specified to be used while constructing any new building depend on *the seismic intensity zone in which the building is located, the base soil and the functional use of the building, whether considered important or ordinary*. The extra cost of these resisting features will vary accordingly. Now reasonably accurate information is available on percent extra cost in the case of masonry buildings built in cement mortar in various seismic zones of India and can be taken as follows for various building Categories given in Table 4 as per IS: 4326-1993:

Building Categories **A** and **B**	1.5 – 2%
Building Categories **C**	3 – 4%
Building Categories **D** and **E**	5 – 6%

Table – 4: Building Categories for Earthquake Resisting Features in Masonry and Earthen Buildings

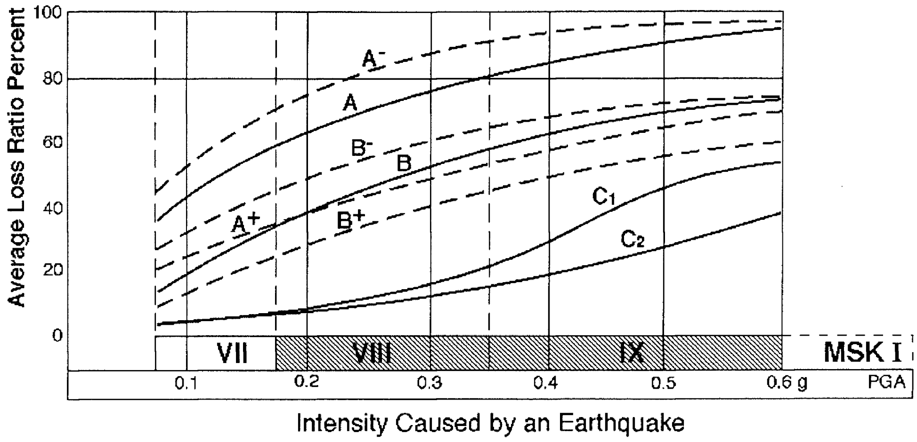
Range of Design Seismic Co-efficient a_h*	Building Category
Less than 0.05	**A**
0.05 to 0.06 (both inclusive)	**B**
More than 0.06 and less than 0.08	**C**
0.08 to less than 0.12	**D**
Equal to or more than 0.12	**E**

* IS: 1893- 1984 Cl. 3.4.2.3

The percent cost will be higher for the weaker informal brick builings using mud mortar or coursed rubble stone masonry for which the increase in cost may be assumed as additional 0.5 to 1.0 percent.

Damage Vulnerability of Buildings

The seismic vulnerability of masonry buildings under various earthquake Intensities has been studied reasonably well through observations under specific earthquake occurrences as well as through the average observations as brought out in the MSK Intensity scales (See Table 1), and Vulnerability functions have been developed such as shown in Fig. 16. From this figure, it is observed that



A = Buildings in Field Stone, Rural Buildings, Unburnt Brick Houses, Clay House (1 to 1 ½ storey)
B = Ordinary Brick Buildings, Buildings in Large Blocks, Half Timbered Buildings in Natural Dressed Stone (1 to 1 ½ storeys)
C1 = Buildings in strengthened masonry in cement (1 to 2 storeys)
C2 = Reinforced Concrete and Steel Buildings, Ell Built Wooden Buildings.
A- = A-Type, But Taller (2 or more storeys)
A+ = A-Type, with Earthquake Resistance Features
B- = B-Type, But Tallar (2 or more storeys)
B+ = B-Type with Earthquake Resistance Features

Figure 16: Vulnerability functions Based on MSK – Intensity Scales (Source : Dr. A.S. Arya)

i) the average loss ratio to the reconstruction cost, which is taken as 100 percent, increases for all building types as the earthquake Intensity increases, but the increase is non-linear;

ii) weaker the building like adobe or unreinforced masonry, higher the damage ratio for any Intensity level; and

iii) earthquake resisting features like *`bands'* and the *`vertical steel'* provision at the corners and junction of walls and jambs of openings as per IS: 4326-1993, Fig. 4 and 5, lower the damage ratio curves, hence reduce the vulnerability.

It may be mentioned that when the damage ratio reaches 60% or higher, the building approaches destruction and partial collapse and at about 75% total collapse situation develops. On the other hand, a damage ratio less than 50% will indicate heavy damage and at 30% as moderate damage. Therefore for saving lives, the aim of seismic strengthening will be to reduce the vulnerability level to well below 50%.

Case of Hypothetical Earthquake Recurrence in Himachal Pradesh

Hypothetical damage scenario of the State of the Himachal Pradesh was worked out as if it was subjected to 1905 Kangra type earthquake again in Census year 1991. The results are obtained as shown in Table 5 for two cases of all buildings being (i) *Without*, (ii) *With* earthquake resisting features. The following results are obtained.

(a) If all the 1 815 858 houses are without earthquake safety provisions, the direct losses will amount to INR 51.04 billion. Since about 65 000 lives may be lost and 399 695 houses will be ruined completely, the trauma will be too great and the cost of emergency relief will be exorbitant much beyond the capacity of the State and even the country as a whole.

(b) If all the houses were made earthquake resistant when built initially, the direct losses will amount only to INR 19.6b, giving a saving of INR 31.44b. The extra cost of earthquake safe buildings for all houses would have been INR 6.35 b, giving a net saving of INR 25.09 b. Besides, since the lives lost will only be 12 000 now, about 1/5 of (a) and totally ruined houses reduced to 103 295 (about ¼ of `a'), the trauma and relief costs will also be reduced to about one-fourth of case (a).

(c) Since presently the houses are NOT earthquake resistant, let us make them safe by seismic retrofitting. This will cost INR 15.25 b, but the loss scenario will be more or less similar to (b) above, giving a net saving of INR 16.19 b besides reduction in trauma and savings in relief costs to about ¼ of (a).

Table -5 : Losses in Magnitude 8.0 Hypothetical Earthquake if occurred again in Kangra, Himachal Pradesh in 1991

S. No.	Item	Scenario if all buildings are *without* earthquake resistance		Scenario if all buildings are *with* earthquake resistance	
		Physical Damage	Loss in INR* (million)	Physical Damage	Loss in INR (million)
1.	Loss of Lives	65 000	6 500	12 000	1 200
2.	Total collapse of buildings G5	136 339	9 540	8 298	580
3.	Destroyed buildings,G4	263 356	18 430	94 997	6 650
2+3	**Buildings to rebuild.**	**399 695**	**27 970**	**103 295**	**7 230**
4.	Heavily damaged buildings, G3 (to repair & retrofit.)	915 602	12 820	312 382	4 370
5.	Moderately damaged building. G2 (to repair & retrofit)	357 510	3 750	648 040	6 800
6.	**Total losses**		**51 040**		**19 600**

*INR = Indian Rupees, 1 US$ ~ INR 40.0 in 1997

It may therefore be concluded that earthquake resistant houses, whether so built initially or retrofitted later on will not only save the society from trauma and relief costs but result in much larger economic benefits as compared to the additional costs of earthquake resisting features.

DISASTER MITIGATION FOR SUSTAINABLE DEVELOPMENT

For a long time, the cause and effect relationship between disasters and socio-economic development has been ignored. Disasters were seen in the context of emergency response, not as a part of long-term development planning, except in the case of flood hazards, preventive actions have been taken for quite some time consisting of construction of storage dams for flood reduction, providing protective embankments and raising of villages, etc.. The growing body of knowledge on relationship between disasters and development indicates that disasters do have a serious impact on long-term economic development. Disaster even set back development programs by destroying years of initiatives.

Disaster mitigation should therefore, become a part of the national development process. Planning and preparing for them can significantly reduce their social and economic costs. On the lines of the IDNDR

Yokohama Strategy for Safer World, the objectives of the national policy for natural disaster reduction should be to reduce loss of lives, property damage and economic disruption. In order to move towards these objectives, certain goals need to be fixed, national and state/provincial strategies formulated and concerted action planned with adequate financial support. The following goals may be adopted in this regard:

1) *Creating Public Awareness about Safety from Disaster*: Awareness is to be created at all levels of the Society about the Science underlying the Hazards, value and feasibility of preparedness and preventive actions, and role to be played by various sectors of society toward disaster reduction, so that willing cooperation and participation of the people in natural disaster reduction could become a reality. A Vulnerability Atlas of the country would provide a most visible earthquake risk situation to the various Stake holders, from policy planners to the communities in earthquake prone areas.

2) *Amending/Enacting Legislation for Safety from Hazards*[2]: Appropriate legislation for land use zoning of development areas, building by-laws of local bodies, and empowerment for implementation are needed on urgent basis.

3) *Planning Development Areas with Safety from Hazards*: All urban and rural habitat development should be planned to be safe from the impact of the probable earthquake hazard.

4) *Protection of Existing Habitations from Adverse Hazard Impacts* : The existing towns and villages are to be protected from the ravages of natural hazards.

5) *Building New Structures with Safety from Earthquakes* : All buildings for various uses, bridges and services, in moderate to severe earthquake intensity zones, should be built according to earthquake resistant criteria and guidelines.

6) *Retrofitting Existing Construction for Improving Earthquake Resistance*: Important and critical buildings, selected on the basis of criteria of safety and importance to economy, should be upgraded by retrofitting procedures to meet earthquake resistant criteria and guidelines.

All these goals are long range and strategies should adopt timewise targets focussing on actions with higher benefit to cost ratios. It is believed that by organising the various activities on scientific basis with appropriate financial and institutional support, the preventive actions will begin showing resulting starting with the very first year of their implementation.

Items 5) and 6) above involve more direct involvement of earthquake engineers and are discussed in some detail in the following paras.

PREVENTIVE STRATEGY FOR NEW CONSTRUCTIONS

The strategy for prevention may be adopted sector wise as follows:

a) *Government Buildings.* It should be ensured that all new buildings and related infrastructure must be designed and constructed according to the Standard Codes and Guidelines for resistance against earthquake as required at the given location. The adoption of the building codes should be made mandatory in all government departments whether dealing with urban or the rural sector. The additional expenditure on this aspect will automatically form part of development plan expenditure and not part of Crisis Relief Expenditure.

b) *Public Sector and Private Undertakings.* Construction of official and industrial buildings as well as residential colonies of the public sector as well as private undertakings should also be obligated to follow the Codes & Guidelines for safety against earthquakes in the concerned localities.

c) *Private Buildings.* For private buildings in municipal areas, implementation of building by-laws containing disaster- safety requirements will be the appropriate method for ensuring safety. All extensions of the buildings should be similarly covered.

The rural areas and others lying outside the municipal limits will, however, pose a problem in enforcing/incorporating the earthquake resistance requirements. Here an awareness cum demonstrative approach may be used. All buildings in various Rural Development Plans may be provided extra funding for disaster resistance along with technology transfer as a package. All new official/institutional buildings like schools, health centres, clinics, etc. should be constructed using earthquake resistant design and construction details, and these should serve as demonstration buildings. For effectiveness, these buildings should preferably use the same local materials as used by the population for their housing.

[2] *See Paper No. 309/1/A, "Techno-Legal Regime for Earthquake Risk Reduction in India" by A.S. Arya and T.N. Gupta in the Poster Session of this Conference.*

STRENGTHENING OF EXISTING BUILDINGS

Post-construction strengthening of structures for upgrading seismic resistance is more involved and costlier than incorporating such resistances is new construction. The problem is also more wide spread due to large stock of unsafe buildings. Retrofitting all such units will be too huge and too costly to be undertaken. In view of the varying probable intensities in different areas and some buildings and structures having different levels of functional importance, it will be practical and economically feasible to priorities the buildings for retrofitting implementation in highest Intensity zones to start with. A priority list is suggested herebelow for the building stock:

(i) Instructional, laboratory and library buildings of educational institutions (schools, colleges, institutes, and universities).
(ii) Hospitals including wards, dispensaries, clinics, etc.
(iii) Telephone exchanges, fire stations, water supply pump houses
(iv) Congregation halls, cinemas, theatres, etc.
(v) Residences of disaster managers in the districts
(vi) Other to be identified.

The buildings and structures prioritised above should be taken for study of their deficiencies and retrofitting needs irrespective of their ownership. For that purpose the Governments should make it mandatory for all concerned to act in a given time frame.

Side by side the retrofitting work of priority buildings and structures, some typical houses should be taken up for demonstration of retrofitting methodologies, which should be propagated through media campaigns for encouraging the house owners to do it by themselves in their own safety interest. As an incentive, insurance premiums for buildings constructed with seismic resistant features or seismically retrofitted afterwards, should be reduced as compared to those not so strengthened.

CONCLUSION

From the brief presentation given in the text, it may be concluded: For saving the existing and future building works from the disastrous impact of probable earthquakes, a holistic approach is called for consisting of creation of public awareness, education and training, and research and development about the safety from earthquake hazard. The engineering, architecture and planning measures are needed which should cover land use zoning, planning of habitat, implementation of building codes in all new constructions, and seismic retrofitting of existing buildings and infrastructure for upgrading earthquake resistance. Appropriate policy, financial and institutional support at national and state levels needs to be provided for putting this strategy into a workable action plan.

Finally it is suggested that the experience gained from the performance of various building types during the earthquakes since after 1986 and the results of the efforts of UNESCO, DHA-IDNDR and WSSI may be pooled and analysed. So, IAEE may again establish an international Group to review the Guide [IAEE, 1986] and improve it by including relevant case studies of successes and failures, and benefits and costs. It was said, "Earthquakes don't kill people, buildings do." Let us say "We will save buildings, earthquake will kill no more."

ACKNOWLEDGEMENT

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