EARTHQUAKE RESISTANT BUILDING CONSTRUCTION

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ABSTRACT

Earthquakes constitute one of the greatest hazards of life and property on the earth. Due to suddenness of their occurrence, they are least understood and most dreaded. The earthquake resistant construction is considered to be very important to mitigate their effects. This paper presents the brief essentials of earthquake resistant construction and a few techniques to improve the resistance of building and building materials to earthquake forces, economically.

I. INTRODUCTION

An earthquake is the vibration, sometimes violent to the earth's surface that follows a release of energy in the earth's crust. This energy can be generated by a sudden dislocation of segments of the crust, by a volcanic eruption or even by a manmade explosion. The dislocation of the crust causes most destructive earthquakes. The crust may first bend and then the stresses exceed the strength of rocks, they break. In the process of breaking, vibrations called seismic waves are generated. These waves travel outward from the source of the earthquake along the surface and through the earth at varying speeds depending on the material through which they move. These waves can cause disasters on the earth's surface.

No structure on the planet can be constructed 100% earthquake proof; only its resistance to earthquake can be increased. Treatment is required to be given depending on the zone in which the particular site is located. Earthquake occurred in the recent past have raised various issues and have forced us to think about the disaster management. It has become essential to think right from planning stage to completion stage of a structure to avoid failure or to minimize the loss of property. Not only this, once the earthquake has occurred and disaster has taken place; how to use the debris to construct economical houses using this waste material without affecting their structural stability.

II. HOW EARTHQUAKE RESISTANT CONSTRUCTION IS DIFFERENT?

Since the magnitude of a future earthquake and shaking intensity expected at a particular site cannot be estimated with a reasonable accuracy, the seismic forces are difficult to quantify for the purposes of design. Further, the actual forces that can be generated in the structure during an earthquake are very large and designing the structure to respond elastically against these forces make it too expensive.

Therefore, in the earthquake resistant design post yield inelastic behavior is usually relied upon to dissipate the input seismic energy. Thus the design forces of earthquakes may be only a fraction of maximum (probable) forces generated if the structure is to remain elastic during the earthquake. For instance, the design seismic for buildings may at times be as low as one tenths of the maximum elastic seismic force. Thus, the earthquake resistant construction and design does not aim to achieve a structure that will not get damaged in a strong earthquake having low probability of occurrence; it aims to have a structure that will perform appropriately and without collapse in the event of such a shaking.

Ductility is the capacity of the structure to undergo deformation beyond yield without loosing much of its load carrying capacity. Higher is the ductility of the structure; more is the reduction possible in its design seismic force over what one gets for linear elastic response. Ensuring ductility in a structure is a major concern in a seismic construction.

III. EFFECT OF EARTHQUAKE ON REINFORCED CONCRETE BUILDINGS

In recent times, reinforced concrete buildings have become common in India. A typical RC building is made of horizontal members (beams and slabs) and vertical members (columns and walls) and supported by foundations that rest on the ground. The system consisting of RC columns and connecting beams is called a RC frame.

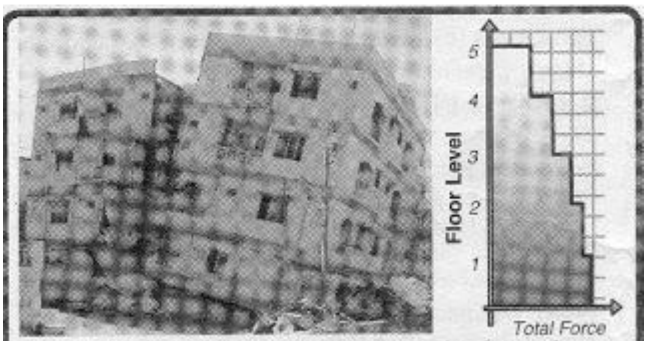


Figure 1: Total horizontal earthquake force in a building increases downwards along its height.

The RC frame participates in resisting earthquake forces. Earthquake shaking generates inertia forces in the building, which are proportional to the building mass. Since most of the building mass is present at the floor levels, earthquake induced inertia forces primarily develop at the floor levels. These forces travel downward through slabs to beams, beams to columns and walls and then to foundations from where they are dispersed to the ground. As the inertia forces accumulate downward from the top of the building (as shown in fig3.1) , the columns and walls at the lower storey experience higher earthquake induced forces and are therefore designed to be stronger than the storey above.

Roles of floor slabs and masonry walls:

Floor slabs are horizontal like elements, which facilitates functional use of buildings. Usually, beams and slabs at one storey level are cast together. In residential multistoried buildings, the thickness of slab is only about 110mm-150mm. when beams bend in vertical direction during earthquakes, these thin slabs bend along with them. When beams move in horizontal direction, the slab usually forces the beams to move together with it.

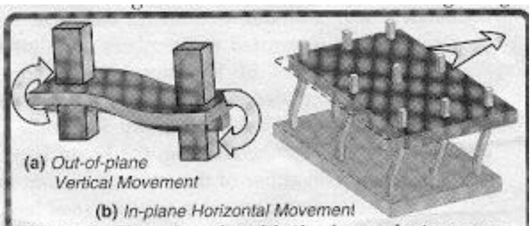


Figure 2: Floor bends with the beam but moves all columns at that level together.

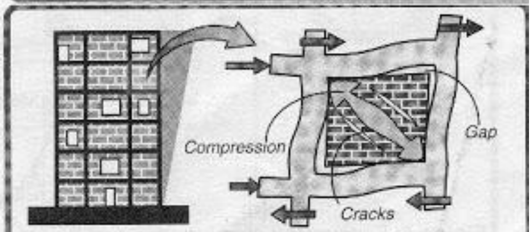


Figure 3: Infill walls move together with the columns under earthquake shaking.

In most of the buildings, the geometric distortion of the slab is negligible in the horizontal plane; the behavior is known as rigid diaphragm action. After columns and floors in a RC building are cast and the concrete hardens, vertical spaces between columns and floors are usually filled in with masonry walls to demarcate a floor area into functional spaces. Normally, these masonry walls are called infill walls, are not connected to surrounding RC beams and columns. When the columns receive horizontal forces at floor levels, they try to move in the horizontal direction, but masonry wall tend
to resist this movement.

Due to their heavy weight and thickness, these walls develop cracks once their ability to carry horizontal load is exceeded. Thus, infill walls act like sacrificial fuses in the buildings, they develop crack under severe ground shaking but help share the load the load of beams and columns until cracking.

Strength hierarchy:

For a building to remain safe during earthquake shaking columns (which receive forces from beams) should be stronger than beams and foundations (which receive forces from columns) should be stronger than columns. Further the connections between beams and columns, columns and foundations should not fail so that beams can safely transfer forces to columns and columns to foundations.

When this strategy is adopted in the design, damage is likely to occur first in beams. When beams are detailed properly to have large ductility, the building as a whole can deform by large amounts despite progressive damage caused due to consequent yielding of beams.

If columns are made weaker, localized damage can lead to the collapse of building, although columns at storey above remain almost undamaged.

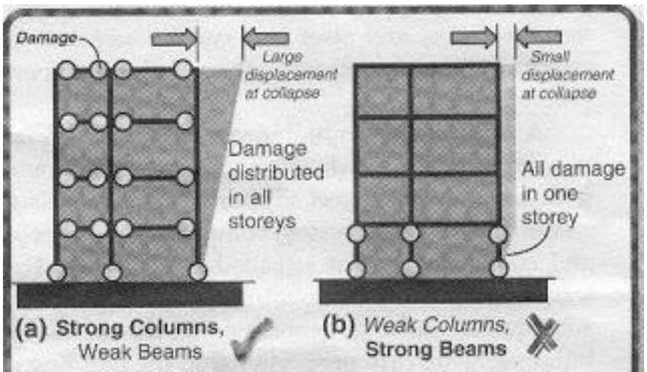


Figure 5: Two distinct designs of buildings that result in different earthquake performances – *columns should be stronger than beams.*

IV. SEISMIC DESIGN PHILOSOPHY

Severity of ground shaking at a given location during earthquake can be minor, moderate and strong. Relatively speaking, minor shaking occurs frequently; moderate shaking occasionally and strong shaking rarely. For instance, on average annually about 800 earthquakes of magnitude 5.0-5.9 occurs in the world, while the number is only 18 for the magnitude ranges 7.0-7.9. Since it costs money to provide additional earthquake safety in buildings, a conflict arises 'should we do away with the design of buildings for earthquake effects? Or should we design the building to be earthquake proof wherein there is no damage during strong but rare earthquake shaking. Clearly the formal approach can lead to a major disaster and second approach is too expensive. Hence the design philosophy should lie somewhere in between two extremes.

Earthquake resistant building:

The engineers do not attempt to make earthquake proof buildings that will not get damaged even during the rare but strong earthquake; such buildings will be too robust and also too expensive. Instead, engineering intention is to make buildings earthquake resistant, such building resists the effects of ground shaking, although they may get damaged severely but would not collapse during the strong earthquake. Thus, safety of peoples and contents is assured in earthquake resistant buildings and thereby, a disaster is avoided. This is a major objective of seismic design codes through the world.

Earthquake design philosophy:

The earthquake design philosophy may be summarized as follows:

- Under minor, but frequent shaking, the main members of the building that carry vertical and horizontal forces should not be damaged; however the building parts that do not carry load may sustain repairable damage.
- Under moderate but occasional shaking, the main member may sustain repairable damage, but the other parts of the building may be damaged such that they may even have to be replaced after the earthquake.
- Under strong but rare shaking, may sustain severe (even irreparable) damage, but the building should not collapse.

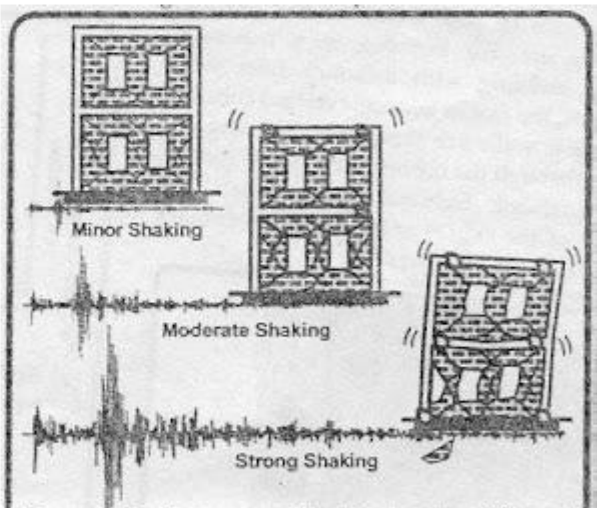


Figure 2: Performance objectives under different intensities of earthquake shaking – *seeking low repairable damage under minor shaking and collapse-prevention under strong shaking.*

Thus after minor shaking, the building will be operational within a short time and repair cost will be small and after moderate shaking, the building will be operational once the repair and strengthening of the damaged main members is completed. But, after a strong earthquake, the building may become disfunctional for further use, but will stand so that people can be evacuated and property recovered.

The consequences of damage have to be kept in view in the design philosophy. For example, important buildings like hospitals and fire stations play a critical role in post earthquake activities and must remain functional immediately after earthquake. These structures must sustain very little damage and should be designed for a higher level of earthquake protection. Collapse of dams during earthquake can cause flooding in the downstream reaches, which itself can be a secondary disaster. Therefore, dams and nuclear power plants should be designed for still higher level of earthquake motion.

V. REMEDIAL MEASURES TO MINIMISE THE LOSSES DUE TO EARTHQUAKES

Whenever a building project is prepared and designed, the first and the most important aspect of design is to know the zone to which this structure is likely to rest. Depending upon these, precautionary measures in structural design calculation are considered and structure can be constructed with sufficient amount of resistance to earthquake forces. Various measures to be adopted are explained pointwise, giving emphasis to increase earthquake resistance of buildings.

Building planning:

The records of various earthquake failures reveal that unsymmetrical structure performs poorly during earthquake. The unsymmetrical building usually develops torsion due to seismic forces, which causes development of crack leading to collapse of a structure. Building therefore should be constructed rectangular and symmetrical in plan. If a building has to be planned in irregular or unsymmetrical shape, it should be treated as the combination of a few rectangular blocks connected with passages. It will avoid torsion and will increase resistance of building to earthquake forces.

Foundation:

IS code recommends that as far as possible entire building should be founded on uniform soil strata. It is basically to avoid differential settlement. In case if loads transmitted on different column and column footing varies, foundation should be designed to have uniform settlement by changing foundation size as per code conditions to have a loading intensity for uniform settlement.

Raft foundation performs better for seismic forces. If piles are driven to some depth over which a raft is constructed (raft cum pile foundation), the behaviour of foundation under seismic load will be far better. Piles will take care of differential settlement with raft and resistance of structure to earthquake forces will be very large.

Provision of band:

IS code recommends construction of concrete band at lintel level to resist earthquake. The studies revealed that building with band at lintel level and one at plinth level improves load carrying of building to earthquake tremendously. It is suggested here that if bands are plinth level, sill level, lintel level and roof level in the case of masonry structure only, the resistance of building to earthquake will increase tremendously. Band at sill level should go with vertical band and door openings to meet at lintel level. Hold fast of doors can be fitted in their sill band. In case of earthquake of very high intensity or large duration only infill wall between walls will fail minimizing casualties and sudden collapse of structure. People will get sufficient time to escape because of these bands.

Arches and domes:

Behavior of arches has been found very unsatisfactory during earthquake. However domes perform very satisfactory due to symmetrical in nature. Arches during earthquake have tendency to separate out and collapse. Mild steel ties if provided at the ends, their resistance can be increased to a considerable extent.

Staircases:

These are the worst affected part of any building during earthquake. Studies reveal that this is mainly due to differential displacement of connected floors. This can be avoided by providing open joints at each floor at the stairway to eliminate bracing effect.

Beam column joints:

In framed structures the monolithic beam column connections are desirable so as to accommodate reversible deformations. The maximum moments occur at beam-column junction. Therefore most of the ductility requirements should be provided at the ends. Therefore spacing of ties in column is restricted to 100mm centre and in case of beam strips and rings should be closely spaced near the joints. The spacing should be restricted to 100mm centre to centre only near the supports. In case of columns, vertical ties are provided; performance of columns to earthquake forces can be increased to a considerable extent.

Steel columns for tall buildings ie buildings more than 8 storey height should be provided as their performance is better than concrete column due to ductility behavior of material.

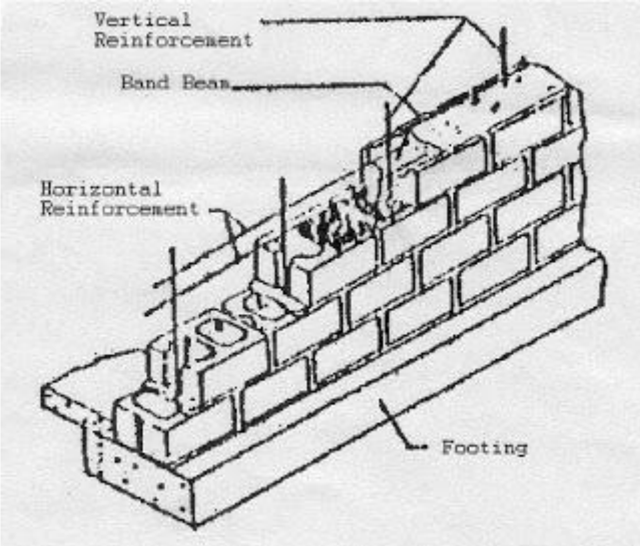
Masonry building:

Mortar plays an important role in masonry construction. Mortar possessing adequate strength should only be used. Studies reveal that a cement sand ratio of 1:5 or 1:6 is quite strong as well as economical also. If reinforcing bars are put after 8 to 10 bricklayers, their performance to earthquake is still better. Other studies have revealed that masonry infill should not be considered as non-structural element. It has been seen that in case of column bars are provided with joints at particular level about 600-700mm above floor level at all storey should be staggered. It may be working as a weak zone at complete floor level in that storey.

As such if few measures are adopted during stages of design and construction of building their resistance to earthquake forces can be improved considerably. Though buildings cannot be made 100% earthquake proof but their resistance to seismic forces can be improved to minimize loss of property and human life during the tremors.

VI. EARTHQUAKE RESISTANT BUILDING CONSTRUCTION WITH REINFORCED HOLLOW CONCRETE BLOCK (RHCBM)

Reinforced hollow concrete blocks are designed both as load-bearing walls for gravity loads and also as shear walls for lateral seismic loads, to safely withstand the earthquakes. This structural system of construction is known as shear wall-diaphragm concept, which gives three-dimensional structural integrity for the buildings.



Structural features:

- Each masonry element is vertically reinforced with steel bars and concrete grouts fill, at regular intervals, through the continuous vertical cavities of hollow blocks.
- Similarly, each masonry element is horizontally reinforced with steel bars and concrete grout fills at plinth, sill, lintel and roof levels, as continuous RC bands using U-shaped concrete blocks in the masonry course, at repetitive levels.
- Grid of reinforcement can be built into each masonry element without the requirement of any extra shuttering and it reduces the scope of corrosion of the reinforcement.
- As the reinforcement bars in both vertical and horizontal directions can be continued into the roof slab and lateral walls respectively, the structural integrity in all three dimensions is achieved.

Structural advantages:

- In this construction system, structurally, each wall and slab behaves as a shear wall and a diaphragm respectively, reducing the vulnerability of disastrous damage to the structure during natural hazards.
- Due to the uniform distribution of reinforcement in both vertical and horizontal directions, through each masonry element, increased tensile resistance and ductile behavior of elements could be achieved. Hence the construction system can safely resist lateral or cyclic loading, when compared to other masonry construction systems. This construction system has also been proved to offer better resistance under dynamic loading, when compared to the other conventional systems of construction.

Constructional advantages:

- No additional formwork or any special construction machinery is required for reinforcing the hollow block masonry.
- Only semi-skilled labour is required for this type of construction.
- It is faster and easier construction system, when compared to the other conventional construction systems.
- It is also found to be cost-effective.

Architectural and other advantages:

- This constructional system provides better acoustic and thermal insulation for the building.
- This system is durable and maintenance free.

Studies on the comparative cost economics of RHCBM:

There is a general apprehension that the RHCBM would be a costlier system, as it advocates reinforcing and use of concrete grout in the hollow spaces within the masonry. To dispel the apprehension, the relative cost economics of RHCBM structures are worked out in comparison with conventional construction systems.

Structural scheme cost per sq.m in Rs.

Reinforced hollow concrete block masonry	Rs.1822
RC framed structure with brick masonry infill	Rs.1845
Load bearing masonry	Rs.1782

RHCBM has structural advantages of lighter dead weight and increased floor area. These advantages are quantitatively worked out from the fact that, RHCBM is built of 20cm thick hollow block wall, when compared to the 23cm thick one brick wall of RCC framed structure and 34cm thick one and half brick wall of load bearing structure.

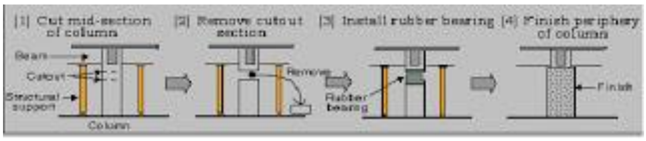
VII. MID-LEVEL ISOLATION

This includes mid-level isolation system installed while the buildings are still being used. This new method entails improving and classifying the columns on intermediate floors of an existing building into flexible columns that incorporate rubber bearings (base isolation systems) and rigid columns which have been wrapped in steel plates to add to their toughness. A combination of these two types of columns is then used to improve the earthquake-resistant performance of the building as a whole

This is the first method of improving earthquake resistance in Japan that classifies the columns on the same floor as flexible columns and rigid columns, and it is the first case in west Japan (the Kansai region) of attaching rubber bearings by cutting columns on the intermediate floors an existing building. This method involves improving earthquake resistance while the buildings are still being used as normal operations. There are three types of base isolation systems, depending on the location where rubber bearings are incorporated:

- Pile head isolation
- Foundation isolation
- Mid-level isolation

By cutting horizontally all columns and walls on a specific intermediate floor and installing rubber bearings in the columns that have been cut, that floor becomes extremely flexible, and the building will sway horizontally with the large sway amplitude of 40-50 centimeters under maximum level earthquakes. It therefore becomes possible that the finishing materials, piping and existing elevators may not be able to keep pace with the deformations and break, perhaps resulting in their protruding from the site of the building. In the head office of Himeji Shinkin Bank, columns with rubber bearings incorporated in them to allow them to move flexibly and rigid columns which were made tougher by wrapping steel plate were placed effectively, thereby suppressing horizontal deformation and improving the earthquake resistance of the building as a whole. Vibration control units incorporating viscous materials with high energy absorption performance were installed in walls, to play the role of dampers. This reduced the swaying of the building. Mid-level isolation procedure is shown in the fig.



VIII. EARTHQUAKE RESISTANCE USING SLURRY INFILTRATED MAT CONCRETE (SIMCON)

Following the devastating earthquakes in Turkey this summer that killed as many as 20,000 people and injured another 27,000, images of survivors trapped beneath the rubble of collapsed buildings appeared daily in news reports worldwide. Now a North Carolina State University engineer is developing a new type of concrete to help prevent such scenes from happening again. Because it's reinforced with mats made of thousands of stainless steel fibers injected with special concrete slurry, the new material, called Slurry Infiltrated Mat Concrete (SIMCON), can sustain much higher stress loads and deformations than traditional concrete. Tests show that concrete buildings or bridges reinforced with SIMCON are far more earthquake-resistant and less likely to break apart in large chunks that fall off and cause injury to people below.

If extreme stresses cause SIMCON to fail, its mass of fibers and concrete doesn't collapse in the same way traditional concrete does. Instead of large chunks breaking and falling from a structure, the material crumbles into small, harmless flakes. This controlled form of failure is a key advantage of SIMCON. Because failure is inevitable in all structures, engineers must design buildings and bridges to fail in the safest way. In conventional concrete structures, this is achieved through the use of steel reinforcing bars -- rebars -- that give the concrete tensile strength it would otherwise lack. For safety and design reasons, the concrete is designed so that the rebars will fail before the concrete does. Unfortunately, many structures have not been designed to sustain the powerful stresses caused by earthquakes. When such extreme stresses occur, the concrete can crack, explode and break away from the rebars, causing the structure to collapse. By contrast, failure of SIMCON would present little danger to people or property below.

IX. TRADITIONAL EARTHQUAKE REISTANT HOUSING

Earthquakes are not common phenomena in most parts of the world. Hence, houses in most rural areas are not built to withstand seismic forces, resulting in heavy causalities even in moderate quakes. In some parts of the world, however, where earthquakes are common, people have incorporated the critical elements of quake-resistance in their traditional construction method. Traditional house building techniques have successfully demonstrated, during past earthquakes in the Himalayan region, that there is inherent after component associated with the constructional design. This was found during the 1905 Kangra earthquake, the traditional Kat-Ki Kunni houses in Kullu valley made up of timber remained unaffected. The Dhajji-Diwari buildings remained intact in the 1885 Srinagar earthquake. Similarly, in Uttarkashi the traditional 100 years old multistoried buildings called Pherols have incorporated basic features of earthquake resistance.

The Pherols of Uttarkashi:

Pherols are old traditionally built multistoried structures found in Uttarkashi district. The main materials of constructions are stone and wood with mud mortar. The construction is essentially coarse-rubble masonry type. The various earthquake resistant features in these types of houses are the use of wooden tie-bands as beams and vertical timber columns as pins to tie the inside and outside Wyeths of a wall. Long stones with flat surfaces are distributed in the walls to make the loads vertical in the wall units and minimize the tendency of the wall stones to push or run outward. Moreover, to distribute some of the seismic load vertically corner reinforcements are provided by the use of wooden blocks and long flat stones. Also, the height of the floor is kept low and there are minimum numbers of openings, for keeping the centre of gravity low and also for the insulation purposes.

The Dhajji-Diwari buildings of Kashmir:

The Dhajji-Diwari buildings were the one that survived when part of the palace and other massive old building collapsed in the Srinagar quake of 1885. The most significant aspect of the Dhajji-Diwari buildings is the combination of the building materials used. These materials are locally available and have been used for generations. The basic elements in these buildings are the load bearing masonry piers and infill walls. There are wooden tie-bands at each floor level. The foundation consists of rubble masonry with lime mortar whereas; mud mortar is used for the rest of the structure.

The infill materials are usually abode bricks bonded with mud mortar. The wooden bands tie the walls of the structure with the floors and also impart ductility to a structure that is otherwise brittle. The unreinforced masonry walls have stiffness but not strength. In the absence of strength, flexibility is essential for quake resistance. Here, the desired flexibility is provided by the combination of wood and unreinforced masonry laid in a wear mortar. The wooden beams tie the whole house together and ensure that the entire building sways together as one unit in an earthquake.

The Kat-Ki- Kunni Buildings of Kulu Valley:

Similar to the Pherols and the Dhajji-Diwari buildings, the Kat-Ki-Kunni or timber cornered buildings suffered minimal damage in the epicentral tract of Kulu Valley during the 1905 Kangra earthquake. This structure is almost identical to the Pherols of Uttarkashi. It combines the weight, solidity and coolness of a stone building with the flexibility and earthquake-resisting qualities of a wooden one. Here the wood bonding takes place at vertical intervals of three to five feet. Two parallel beams are laid along with layer of masonry, one on the inside and one on the outside. At the end of one wall the beams cross them on the walls at right angle, and the wooden pins hold the crossing together. Crossties of wood similarly hold the two parallel beams in position at intervals along their length.

Quincha earthquake resistant buildings:

Following a devastating earthquake in the Alto Mayo region of Peru in 1990 ITDG's Shelter Programme became involved in a major reconstruction project to build earthquake resistant housing using 'improved quincha' - a timber and lattice frame design with an earth infill - based on traditional technologies. Traditional quincha building technology results in a flexible structure with an inherent earthquake resistance. It has been used in parts of Peru for many centuries. Traditionally, a quincha house would have a round pole set directly in the ground; in filled with smaller wooden poles and interwoven to form a matrix, which is then plastered with one or more layers of earth. ITDG worked closely with builders, householders and community organisations in Alto Mayo to introduce improved, earthquake resistant building technology - quincha mejorada.

Improved quincha had the following characteristics over and above traditional quincha:

- Concrete foundations for greater stability.
- Wooden columns treated with tar or pitch to protect against humidity, concreted into the ground with nails embedded in the wood at the base to give extra anchorage.
- Using concrete wall bases to prevent humidity affecting the wood and the canes in the walls.
- Careful jointing between columns and beams to improve structural integrity.
- Canes woven in a vertical fashion to provide greater stability.
- Lightweight metal sheet roofing to reduce danger of falling tiles.
- Nailing roofing material to roof beams; tying of beams and columns with roof wires.
- Incorporating roof eaves of sufficient width to ensure protection of walls from heavy rains.

X. CONCLUSIONS

- There is a lack of awareness in the earthquake disaster mitigations. Avoiding non-engineered structures with unskilled labour even in unimportant temporary constructions can help a great way.
- Statewide awareness programmes have to be conducted by fully exploiting the advancement in the information technology.
- Urgent steps are required to be taken to make the codal provisions regarding earthquake resistant construction undebatable.

- The builders and constructors should adopt the codal provisions in all the future construction, as prevention is better than cure. On the light of avoiding the risk, this may not be an impossible task as earthquake resistant measures in building involves only 2%-6% additional cost depending on the type of building.

Using construction techniques like SIMCON and RHCBM can not only mitigate earthquake effects but also are cost effective.

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