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A Comparative Architectural and Structural Analysis of Earthquake Resistant Design Principles Applied in Reinforced Concrete Buildings

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***Abstract*—Earthquake resistant structure should have all its resistant capacity to withstand during the ground shake. If not, the building will be on the edge of collapsing. The outcome of the synergy between structural and architectural designs, reduces the chances of failure and increases the seismic resistant capacity of any structure. The earthquake resistant architecture integrate a general theory that facilitate architect to design a building properly in seismic zones not only averting adverse situations but also building their earthquake resistant capacity optimal. Therefore this study deals with the comparative study on ductile detailing of seismic code and Indian Standard Code. Moreover, this paper also discuss some of the earthquake resistant design principles which must be followed during designing and at the time of construction.**

***Index Terms*—Earthquake, Seismic Zones of India, basic design principles.**

I. INTRODUCTION

Earthquake are one of the greatest hazards of our planet which took life of thousands of people and property since ancient times. Around the world, about hundreds of small earthquake occurs which cannot be feel by humans but can be recorded through instrument like seismograph and other sensitive machines. An earthquake is one of the most disastrous phenomenon. It is very difficult to accurately measure and prevent an earthquake but the loss to the property and life can be reduced by its proper design. Hence it is advisable to first do the seismic analysis and then design to prevent any structure from any calamities.

Earthquake: It is a rapid movement of the earth's crust. This happens when tectonic plates move and rub against each other, due to the sudden release of energy in the lithosphere which forms seismic waves. Waves spread from the epicenter, the point on the surface above the hypocenter.

Seismic Zones of India:

For identifying the seismic region, the Geological Survey of India (GSI) presented the seismic zoning of the country. This process is done on the basis of the damage suffered by the no. of region of India. The changing geology at different region in the country is different and tells us about the possibility of upcoming earthquake.

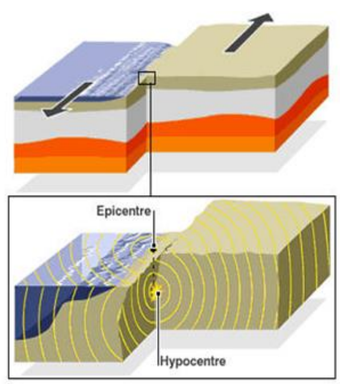

Fig. 1. Basic terminology

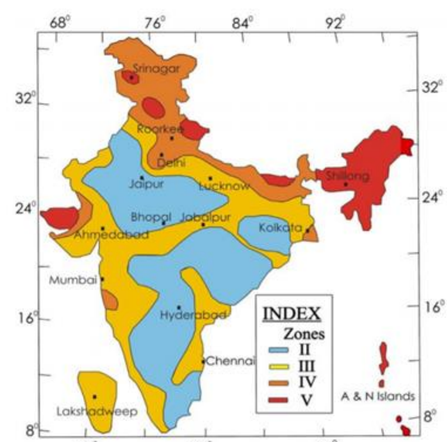

Fig. 2. Indian Seismic Zone as per IS: 1893(Part 1)-2002

Seismic Zonation in India (IS: 1962) Grouped the country into SEVEN ZONES i.e 0 (no damage) to VII (extensive damage).

Seismic Zonation in India (IS: 1970) the zonation map go through revision in 1970. It consist of five zone such as I, II, III, IV and V. The major change was the removal of the Zone 0 and merging of the Zone V and VI.

Seismic Zonation in India (IS: 1984) Again, in 1984 the map was revised in which regions of different seismogenic potential were analyzed.

Seismic Zonation in India (IS:2002) The map was modified again in 2002 in which zonation map is divided into FOUR ZONES - II, III, IV and V. Region lying under Zone -V(north-eastern part) is most seismically active and Zone-I and II were combined.

II. General Design and Planning Principles

A. Plan of Building

1) Symmetry

About both the axes, the building or its blocks should be designed symmetrical, if not the building will go through torsion during earthquakes. Symmetry also includes placing and sizing of openings, as much as possible.

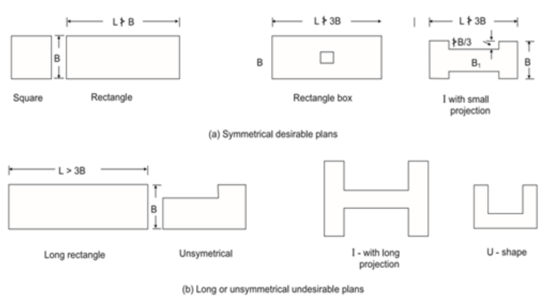

Fig. 3. Plan of building block

2) Regularity

It has been seen that simple rectangular shapes works better in an earthquake rather than shapes with a many projections. During an earthquake, torsion effects are distinct in a long narrow rectangular block. That is why it is advisable to divide "the long rectangular block into three times its width". There should be adequate space between the separations of blocks.

3) Simplicity

If we are talking about simplicity then there should be no place of large cornices, horizontal and vertical cantilever projections facia stones etc. "Simplicity is the best approach" i.e the structure must be reinforced with steel and properly tied with the main structure.

4) Enclosed area

From the structural point of view it is advisable to have multiple separate enclosures in a space compared to a single enclosures. Since, long walls derive earthquake resistance capacity from the transverse walls, thus, the earthquake strength decreases as their length increases. Therefore, a small building enclosure with interconnected walls will behave as a rigid box which is earthquake resistant.

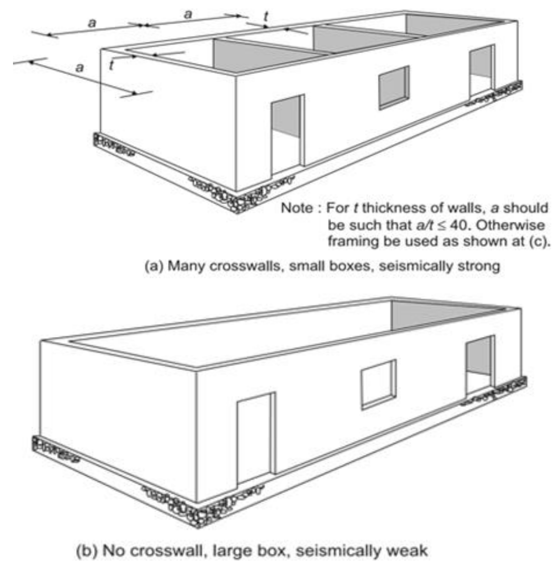

Fig. 4. Enclosed area forming box units

5) Separation of blocks

Separation of a large building into several blocks may be required so as to obtain symmetry and regularity of each block. To prevent damage to the structure due to hammering effect, it is advisable to provide a gap of 3 – 4 cm between the blocks through the height. But it is appropriate for only up to 3 storied building.

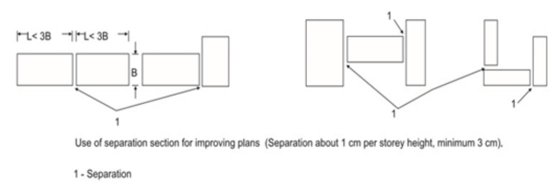

Fig. 5. Plan of building block

B. Fundamental Concepts in the Seismic Design of Structures

A structural system should content with the following three principles in order to obey the counter-earthquake design approach:

- Strength
- Ductility
- Stiffness

Strength the capacity of a structural component to withstand the internal forces created under diverse loading conditions. Structural components of a building should content with certain strength level in order to withstand the internal forces generated by an earthquake

Ductility is the most prudent character required for good earthquake performance. It is the ability of structural elements to make deformation without decrease in their load carrying capacity.

Stiffness can be explained as the opposition of the structural component versus displacement and torsion effects. Between two structural components uniform in size, the one that is less

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disfigured under the identical loading conditions and external effects has more stiffness than the other.

1) Floor discontinuities

Through the floor slabs, lateral forces travels to the columns and shear-walls of the structure. Generally, it has been observed that there is infinite rigidity in the floor slab. But if the structure have large openings in slabs or slab contain severe changes, then there will be no variation in its slab rigidity. In the absence of rigid floor slab, uncertain and critical changes could be seen in the distribution of the lateral loads to the share walls and column. Also building's dynamic behavior affects negatively. If it is mandatory to provide discontinuities in floor slab, then it is advisable to increase the rigidity of beams and columns around the opening. Other than this, shear wall should be installed around the opening.

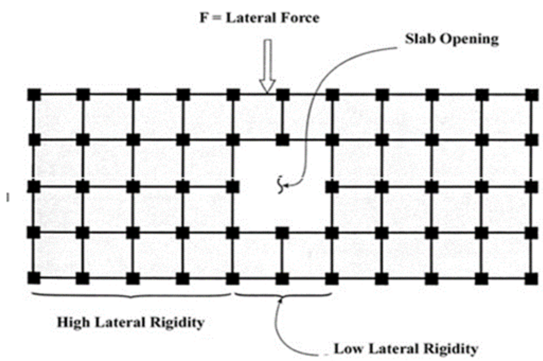

Fig. 6. Discontinuities in the floor slab

2) Projections in plan

Most of the reinforced concrete structures and mainly residential buildings have projections in plan due to architectural considerations or functional necessities. To the whole plan, the ratio of these projections is very essential in terms of seismic behavior of the building. When the projections are too large they will cause further stresses on the structure. Most critical moments and shear forces take place in the intersection line of the projection and the main body. If the projections are entirely necessary, it is advisable to provide additional reinforcement as per civil engineer. If there is a possibility, the structure should be split into different sections with structural joints.

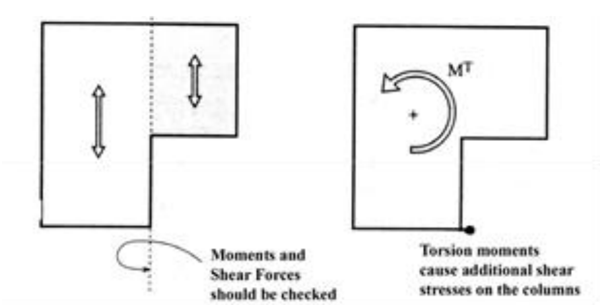

Fig. 7. Disadvantages of projections in plan

3) Non-continuous beams

It is advisable that architect should try to minimize the span of non-continuous beams. As the lateral forces will be distributed to the vertical elements like column and shear wall through thin floor slab, if non-continuous beam is designed. Therefore, designer should always take care of lateral displacement of the entire design.

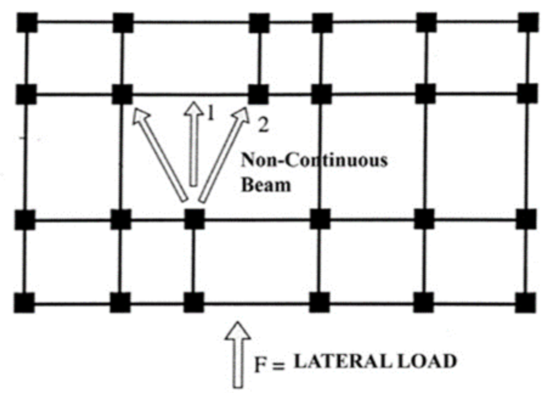

Fig. 8. Non-continuous beam

4) Beam-to-beam connection without vertical support

In architectural design projects, under beam-to-beam connections sometimes vertical bearing members are neglected due to spatial considerations. This kind of arrangements are very hazardous under lateral loading. Because of this reason, there will be a huge point load on the connection point and there will be the chance for large diversion and cracks on the beams. Extra reinforcements plus very large beam cross-sections will be required. This should always be kept in mind that stiffness is negatively proportional with the length of the element. When the span of the beam between the beam-to-beam connection joint and the column becomes very short, very critical torsion moments will occur both on the beams and the column.

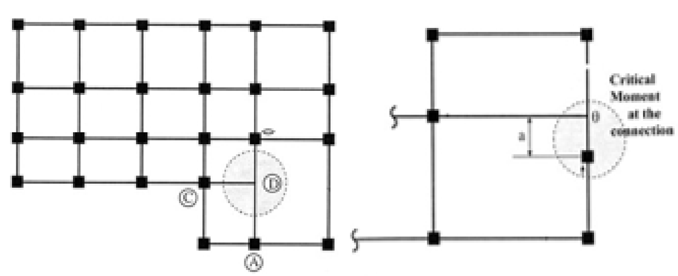

Fig. 9. Beams intersecting without vertical support

5) Cantilever slabs

There are basically open and closed cantilever projections which are commonly used to increase the rooms size and for making balconies in residential buildings. It should always be kept in mind that due to long cantilever slab there are chances of large deflection. During an earthquake, especially closed projections creates critical displacements, which results into partial collapse. If you are designing cantilever projections, continuous beam should be provided under the cantilever slab. Along the periphery of the projection, side beam should be designed. In this way the overall rigidity of the structure will be increased and all the separate frames will act systematically and uniformly under earthquake loads. In addition, the columns which are placed adjacent to the cantilever should also be connected to each other with a beam. Resulting “the lateral loads will be directly distributed to all the columns without being transferred to relatively less rigid floor slabs.”

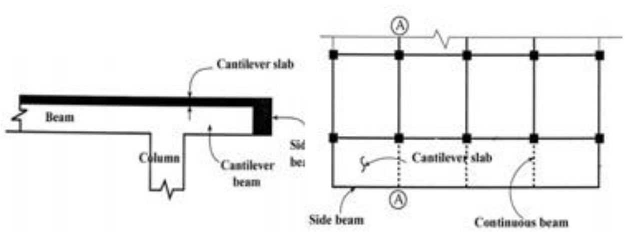

Fig. 10. Cantilever slabs

6) Column configuration

In case of irregular plan, establishing continuous frames is difficult. The fluctuating in lateral rigidity if the building will create critical torsion moments on the system. In such cases, very large and expansive element cross-section will be required to achieve earthquake resistant structure. However in a regular plan, columns are arranged according to an axial system leading to high lateral rigidity, reduced stresses and minimum displacement of the elements. Only disadvantages is, such a regular structural grid leads to constrains inn architectural design flexibility. So, the structural system must be designed somewhere in between the two examples to give freedom for design flexibility and at the same time keeping in mind the earthquake resistance principles of structural grid system.

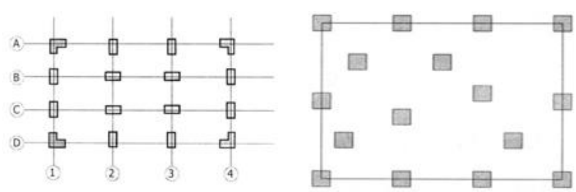

Fig. 11. Irregular vs. Regular configuration of columns

7) Location of shear-walls

Shear-walls are specially designed structural walls adapted in buildings to resist lateral forces from wind and earthquake. While designing it should be kept in mind that the shear wall should be near the centre of gravity and rigidity as much as possible. If the shear-walls is designed only on one side of the building, then there will be uneven displacements and extreme torsion eccentricities on the structure. Shear-walls should always be design centrally and symmetrically. Past earthquakes have proved that shear-walls are life-saviors during an earthquakes. Therefore, architects should have the proper knowledge to assimilate these structural elements in their designs.

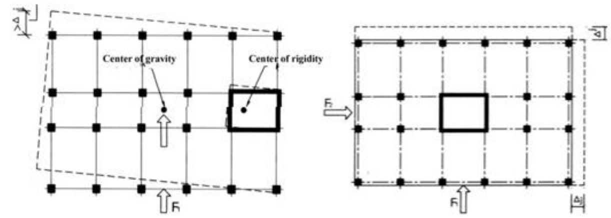

Fig. 12. Location of shear-walls

III. Objective

The main objective of the research work presents in this paper can be highlighted as follows:

1. To achieve the ability that architectural designs and building component will interact positively with each other during seismic shaking, thus promoting its seismo resistance.
2. To minimize the earthquake damage, decision of good practice should be followed at building planning stage to minimize the earthquake damage.
3. To establish the guidelines for structural forms of reinforced concrete building that would assure satisfactory behavior in earthquake.
4. To study about the selection of advisable design criteria which proofs to be useful to enhance the ductility of reinforced concrete structures for the prevention of excessive damage or collapse of building in an earthquake.
5. To study the ductile detailing of Indian Standard Code.
6. To study ductile detailing of Seismic Code.
7. Comparative study between Seismic Code and Indian Standard Code.

IV. Methodology

In order to achieve the above objectives, the following methodology was adopted:

1. Study of various basic earthquake resistant design principles applied in reinforced concrete buildings.
2. Paper literature survey.
3. Detailed study of seismic code and Indian Standard Codes.
4. A comparative analysis of Seismic code and Indian Standard Code.

“The study is primarily based on secondary data. The secondary data has been collected from various sources like internet, books, e-procurement websites, Indian Standard Code, Seismic Code.”

V. Comparison

Difference between the ductile detailing of Seismic Code and Indian Standard Code:

A. According To Seismic Code

a) Dia. of a bar provided in over lapping: 4-10Ø
b) Spacing between the stirrups @ 210mm c/c
c) Anchorage length: L_d +10Ø

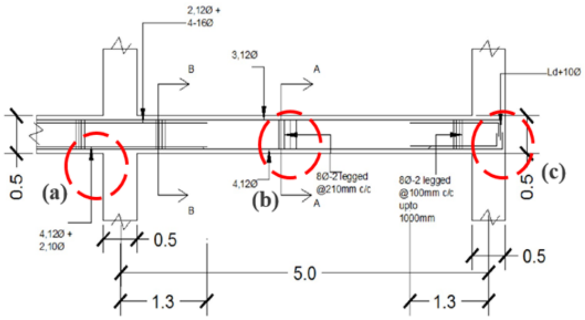

Fig. 13. Interior beam

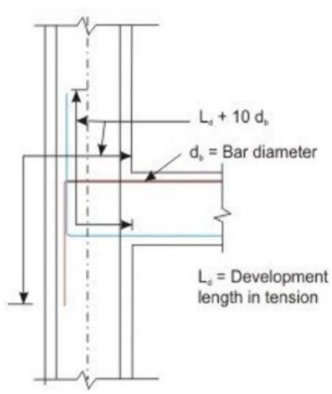

Fig. 14. Anchorage of beam bars in an external joint

Anchorage length for both the top and bottom bars of the beam = L_d + 10 dia. - allowance for 90 degree bends.

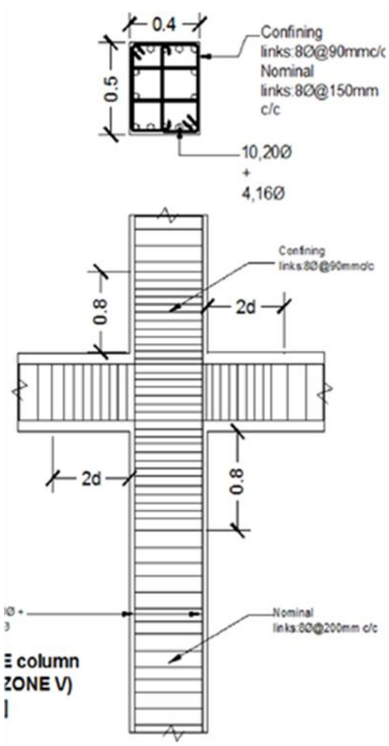

Fig. 15. Interior column

Nominal links: 8Ø 150 m c/c

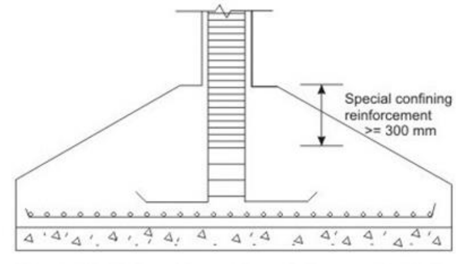

Fig. 16. Reinforcement in footing

When column terminate into the footing, the minimum depth of special confining reinforcement into the footing should be 300mm.

B. According to Indian Standard Code

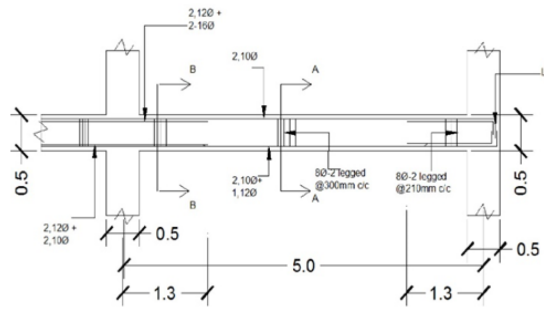

Fig. 17. Interior beam

a) Dia. of bar provided in over lapping: 2-12Ø
b) Spacing between the stirrups @ 300mm c/c
c) Anchorage length: Ld

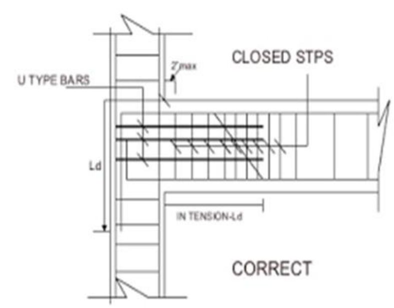

Fig. 18. Anchorage of beam bars in an external joint

Anchorage length for both the top and bottom bars of the beam = L_d- allowance for 90 degree bends.

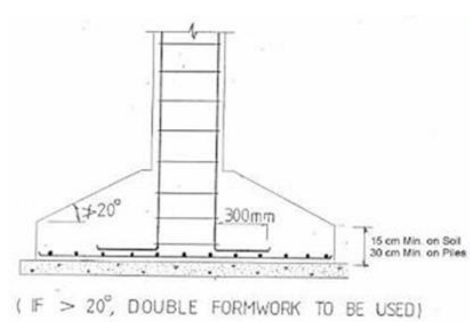

Fig. 19. Reinforcement in footing

When column terminate into the footing, the minimum depth of special confining reinforcement into the footing should not be 300mm.

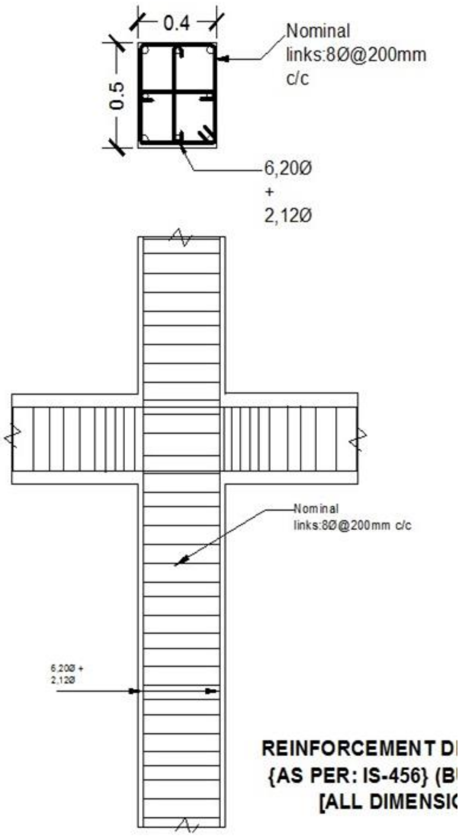

Fig. 20. Interior column

VI. Conclusion

The following conclusion may be drawn from the study:

1. Reinforcement should be done appropriately as per their respective Seismic Code.
2. It is advisable to use design principles for earthquake resistant buildings which should be compulsorily adopted while planning a building.
3. Strong elements beam, column should be arranged symmetrically which will increase the strength of structure and prevent it from collapsing.
4. It is advisable to use simple planning, do not use irregular shapes like L, T and H.
5. Building need to be proportioned reasonably to avoid unduly long, tall or wide dimensions which are known to result in poor seismic performance during an earthquake
6. Ductile detailing of a structure is essential, which reduces the possibility of displacement during an earthquake.

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