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# Ductile Detailing For Low-Cost Structures

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***Abstract:*** Ductile Design is one of the most important aspects of RCC design in modern days. Earthquake can cause huge damage to life and property. Several attempts are made nowadays to increase the resistance of structures against earthquake forces (also termed as Seismic Forces). Ductile Design is one such design concept which if properly maintained on any structure can make the structure seismic resistant. More over ductile design also increases the strength and load carrying capacity of the structure.

Ductile Design is done as per the guidelines and provisions provided in IS 13920 but at times for small buildings and structures, cost becomes an issue for constructing the building by following all the provisions provided in IS 13920 along with IS 456. This paper mainly provides a set of standard guidelines collected from various sources; which if maintained during the construction work, then the structure can also become earthquake resistant to some extent without any significant increase in the total cost of construction.

**Key Words: Ductile Design, Seismic Force, Joints**

## I. INTRODUCTION

Ductility is the property of any material by virtue of which the material (or structure) can undergo large deformations without failure. In context of earthquake engineering, it designates how well a structure can endure large lateral displacements imposed by ground shaking (earthquake) without any significant failure. Another important term in context of earthquake engineering is Stiffness; which is also the property of any material which measures the capacity or force of the structure to resists unit deformation.

Generally designing an earthquake proof building is not possible and understanding the exact intensity of earthquake is a very difficult work as it is a natural phenomenon. Hence, we engineer tends to use various approaches and techniques to make structures earthquake or seismic resistant. Ductile Design is a concept of design to increase the ductility of the structure so that it can be made a seismic resistant one. Concrete without reinforcement is basically brittle in nature. Reinforcement imparts the ductility property in the concrete. Hence in ductile design, more emphasis has been given on the usage, arrangements and amount of reinforcements to be used. Another portion is the Ductile Detailing. It means the process and the manner in which reinforcements are laid and provided so that it can sustain earthquake without any major failure. In India; IS 13920 gives the detail provisions and guidelines of Ductile Design. Hence for design on any building IS 13920 should be used along with IS 456:2000, IS 875 (all it parts) and IS 1893 if the location of the structure is coming in seismic zone III, IV and V.

Earlier IS 13920 was not given much importance in India and most of the small and medium buildings were designed and constructed without even considering the seismic effect. But nowadays the concepts have changed and IS 13920 is given more importance. But often for smaller structures where cost is a major issue, builders and contractors tends to construct buildings by just following IS 456:2000. In recent times, India has faced earthquakes time and again causing loss of life and property. But because of the cost issues, still in many interior places, IS 13920 is not at all followed despite the places may be falling under Seismic Zone-III, IV and V. In this paper, an approach has been made to summarize different set of guidelines collected from various sources; which if considered during the construction, the buildings will behave better against earthquake and the damages can be curtailed down without significant increase in the cost.

## I. IMPORTANCE

Structures are often design based on the design loads in accordance with the provisions of IS Codes. But many engineer's and researchers in various research works has claimed that this design loads are much less than the actual loads and generally this design load does not include the seismic load. If the structures are designed with actual seismic loads, then the cost will be very high especially for small structures as a matter of which some other ways and means are introduced in the structure to make them save from complete collapse during earthquake. Ductility is one of such means. A ductile structure will keep deforming in case of overloading due to earthquake i.e. will undergo large deformation (visible cracks will appear on the surface of the structure) before reaching its ultimate failure or collapse; hence occupants will get enough time for taking any preventive measures to avoid loss of life and property.

Below figure shows a comparison between a Brittle and Ductile structure from deformation point of view. If same intensity of force is applied on both the structures, both structures starts to deform and after some time the Brittle Structure indicated with dash line stops deforming and falls down. But the ductile structure continues to deform long.

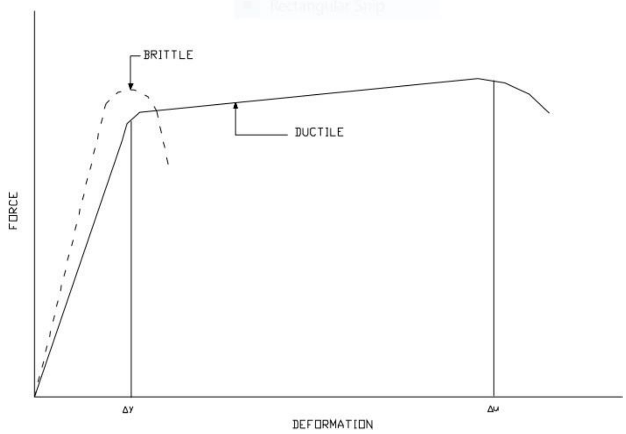


**Fig- 1:** Brittle and Ductile Force-Deformation Graph

## II. CODAL PROVISIONS

Below are some of the codal provisions of IS 13920:2016 is provided which are to be considered during ductile design of any structure:

1. Selection of Grade of Concrete and Grade of Steel: (Clause 5.2 and 5.3)
2. Detailing of Beam: (Clause 6)
    a) Longitudinal reinforcement in beam: (Clause 6.2)
    b) Lap slices in longitudinal steel in beam: (Clause 6.2.6.1)
    c) Transverse reinforcement in beam: (Clause 6.3)
3. Detailing of Colum: (Clause 7)
    a) Longitudinal reinforcement: (Clause 7.3)
4. Transverse Reinforcement: (Clause 7.4)
5. Special Shear Wall: (Clause 10)

## III. GENERAL CONSIDERATIONS TO INCREASE THE SEISMIC RESISTANCE OF THE STRUCTURE

1) Foundations of the buildings should be made on hard bedrock and never on loose or fractured rocks as loose ground easily settles down due to earth vibrations.

2) For shallow foundations, preference should be given on Strap Footing in place of isolated column footing. If structures are having high load ad soil condition are also not good always opt for Raft Footing in case of shallow foundation and Pile Foundation in case of Deep Foundation.

3) Buildings with irregular shapes, cantilever portions, porches, short columns and floating columns should be avoided.

4) Avoid Soft Storey floors and open ground floor parking as much as possible.

5) All the columns should be tied with the beam compactly and should be confined so that the entire structure behaves as a single unit to vibrations caused during earthquake.

6) Sufficient gap should be kept between two buildings so that one building doesn’t falls on another.

7) Weight of the building should be kept as less as possible because more the weight of the building, more adverse effect will come on the building during earthquake.

8) Buildings should have RCC roof and the roofs should be designed by the engineers in such a way that it should not yield to lateral stress.

9) Continuity should be maintained during entire construction work. If the work is suddenly stopped in some stage, and then again construction work starts after long period of time, then those junction points up to which work was previously stopped becomes week points of the building.

# IV. DUCTILE DETAILING

Following detailing if maintained during construction, the structures resistance against minor earthquake can be increased to a certain level without doing proper Ductile Design and the cost will also not be significantly high hence it will be suitable for small and medium structures where cost is one of the main constraints. All the detailing parameters have been collected from different research papers and IS 13920:2016.

# V. DETAILING TO BE MAINTAINED DURING CONSTRUCTION OF ANY FLEXURE MEMBER (OR BEAM): -

1) Strong Column Weak Beam concept should be followed i.e. the beam should be deliberately made weaker so that the failure can be confined to beam only and not to columns.

2) Minimum grade of structural concrete should be M20 and M25 for buildings of height more than 15m is Seismic Zone III, IV and V.

3) Steel reinforcements of grade Fe 415 or less shall be used. However, high strength deformed steel bars, produced by the thermo-mechanical treatment process, of grades Fe 500 and Fe 550, having elongation more than 14.5 percent and conforming to other requirements of IS 1786: 1985 may also be used for the reinforcement.

4) For Flexure members (beams); width to depth ratio should be more than 0.3.

5) Width of the beam should not be less than 200mm.

6) Overall Depth of the beam should not be more than 1/4th of the clear span.

7) At least two longitudinal bars throughout the member length at both top and bottom should be provided for beams.

8) Minimum 12mm diameter reinforcement should be used in beams.

9) Maximum steel ratio on any face at any section of beam shall not exceed $\rho max = 0.025$.

10) Tension steel ratio on any face at any section of beam, shall not be less than $\rho min = 0.24 \sqrt{fck}/fy$.

11) Longitudinal steel on bottom face of a beam framing in to a column (at the beam column junctions) shall be at least half the steel of its top face at the same section.

12) For an exterior joint the top and bottom bars of the beam shall be provided with anchorage length beyond the inner face of the column should be equal to development length of the bars in tension plus 10times the bar diameter minus the allowance for 900 bend.

13) For narrow columns, the anchorage length in the column beam junction should be approximately 50times the diameter of the bar.

14) For an internal joint, the reinforcements of the bar should be taken straight continuously through the column and the beam bars should not be bent or joggled to insert within the column.

15) For splicing in the longitudinal bars of beams, the lap length shall not be less than the development bar in tension.

16) Lap splices shall not be provided with in a joint and within a distance of 2d from the joint face where d is the effective depth of beam.

17) Not more than 50 percent of the bars shall be spliced at one section of the beam.

18) Links shall be provided over the entire splice length, at a spacing not more than 150 mm.

19) Lapping should be avoided in regions where longitudinal bars can yield in tension in a beam section (mainly near the beam-column junction).

20) Stirrups (U shaped) should be provided as web reinforcements with the ends bent at $135^0$.

21) Minimum bar diameter for stirrups shall be 6 mm for Beam Spans ≤ 5 m and 8 mm for Spans > 5 m.

22) First stirrup shall not be less than 50 mm from the column face.

23) Spacing of stirrups shall not be more than d/4 and 8times the bar diameter for a length of 2d from the face of the column. And for the rest portion of the beam span, the spacing should not be more than d/2, where d is the effective depth of the beam.

24) Minimum spacing of the stirrups should be 100mm.

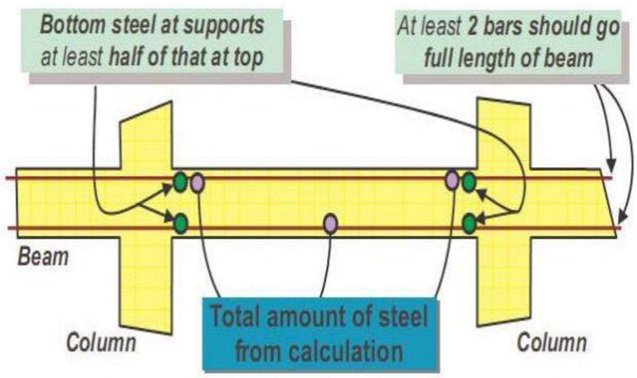


**Fig- 2** Location and amount of longitudinal steel bars in beams.

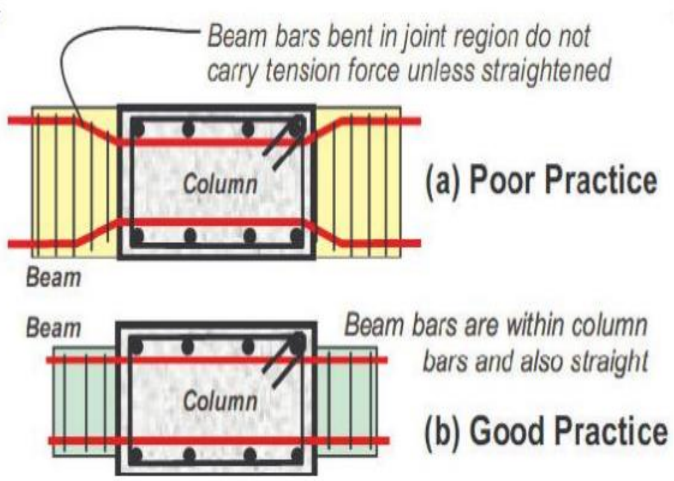


**Fig- 3** Anchorage of beam bars in a joint

## VI. Detailing to be Maintained During Construction of any Compression Member (Or Column): -

1) In general, the minimum dimension should not be less than 200mm.

2) In frames which have beams of span more than 5m, the minimum dimension should not be less than 300mm.

3) For Columns having unsupported length of more than 4m, the minimum dimension should not be less than 300mm.

4) The b / D ratio should be kept more than 0.4.

5) For a longitudinal reinforcement, lap splicing shall be provided only in the central half of the clear column height and not within a joint or within a distance of 2d from the face of the beam.

6) The lap length of the splicing shall not be less than the development length of the largest longitudinal reinforcement bar in the tension.

7) Lap splices shall not be used for bars of diameter larger than 32mm for which mechanical splicing shall be adopted.

8) At one section of the span, not more than 50% of area of steel bars shall be spliced.

9) Closed links or binders shall be provided over the entire length over which the longitudinal bars are spliced and spacing of these links should not be more than 100mm.

10) For Circular Column, Spiral or Circular links should be provided and for Rectangular Columns, Rectangular links should be provided.

11) Like Stirrups in beams, Links shall also be bent at $135^0$.

12) The minimum diameter of closed links or binders shall be 8mm, if the diameter of the longitudinal bars are equal to or less than 32mm, and if the longitudinal bars are more than 32mm, then diameter of the lateral ties should be 10mm.

13) The maximum spacing of the parallel legs of links shall be 300mm center to center.

14) If the length of any side of link exceeds 300mm, then cross-tie perpendicular to the link shall be provided.

15) The spacing of links shall not be more than half the least lateral dimension of the column except where special confinement reinforcement is provided.

16) If a larger amount of transverse reinforcement is required (Links or lateral ties) from shear strength consideration, then special confined reinforcement should be provided.

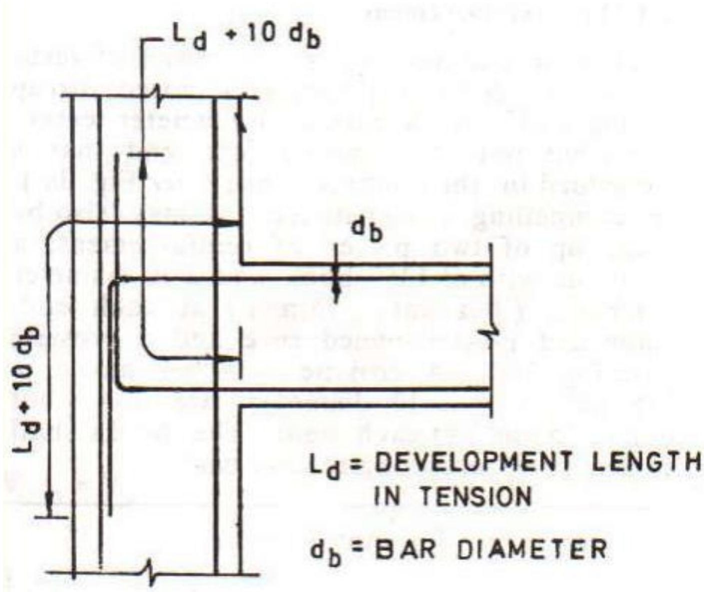


**Fig- 4** Anchorage of Longitudinal Beam Bars at Exterior Beam-Column Joint.

## VII. CONCLUSION

This paper aims to provide some readymade detailing parameters of beams and columns which if considered by the builders and the engineers during construction, the building can be made seismic resistant to some extent at least for minor earthquakes as all the parameters are collected from various research papers and IS codal provisions. But from engineers' point of view it is always suggested to go for proper dynamic analysis of seismic forces and perform Ductile Design or consider other constructional features like Shear Wall Construction, Diagonal Bracing Construction, Base Isolation Mechanism is foundations, etc. if cost is not a constraint. The above-mentioned parameters may not be a good option for severe earthquakes and heavy structures, but the parameters hold good for minor earthquakes and small building or structures.

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