DUCTILITY AND ITS IMPORTANCE

➢ Ductility

Ductility can be defined as the "ability of material to undergo large deformations without rupture before failure".

Ductility in concrete is defined by the percentage of steel reinforcement with in it. Mild steel is an example of a ductile material that can be bent and twisted without rupture.

Member or structural ductility is also defined as the ratio of absolute maximum deformation to the corresponding yield. This can be defined with respect to strains, rotations, curvature or deflections. Strain based ductility definition depends almost on the material, while rotation or curvature based ductility definition also includes the effect of shape and size of the cross-sections.

Each design code recognizes the importance of ductility in design because if a structure is ductile it ability to absorb energy without critical failure increases. Ductility behavior allows a structure to undergo large plastic deformations with little decrease in strength.

In general the ductility is increased by,

- An increase in compression steel content.
- An increase in concrete compressive strength.
- An increase in ultimate concrete strain.

And is decreased by,

- An increase in tension steel content.
- An increase in steel yield strength.
- An increase in axial load.

➢ SIGNIFICANCE OF DUCTILITY

- If ductile members are used to form a structure, the structure can undergo large deformations before failure. This is beneficial to the users of the structures, as in case of overloading, if the structure is to collapse, it will undergo large deformations before failure and thus provides warning to the occupants. This gives a notice to the occupants and provides sufficient time for taking preventive measures. This will reduce loss of life.
- Structures are subjected to unexpected overloads, load reversals, impact and structural movements due to foundation settlement and volume changes. These items are generally ignored in the analysis and design. If a structure is ductile than taken care by the presence of some ductility in the structure.
- The limit state design procedure assumes that all the critical sections in the structure will reach their maximum capacities at design load for the structure. For this to occur, all joints and splices must be able to withstand forces and deformations corresponding to yielding of the reinforcement.

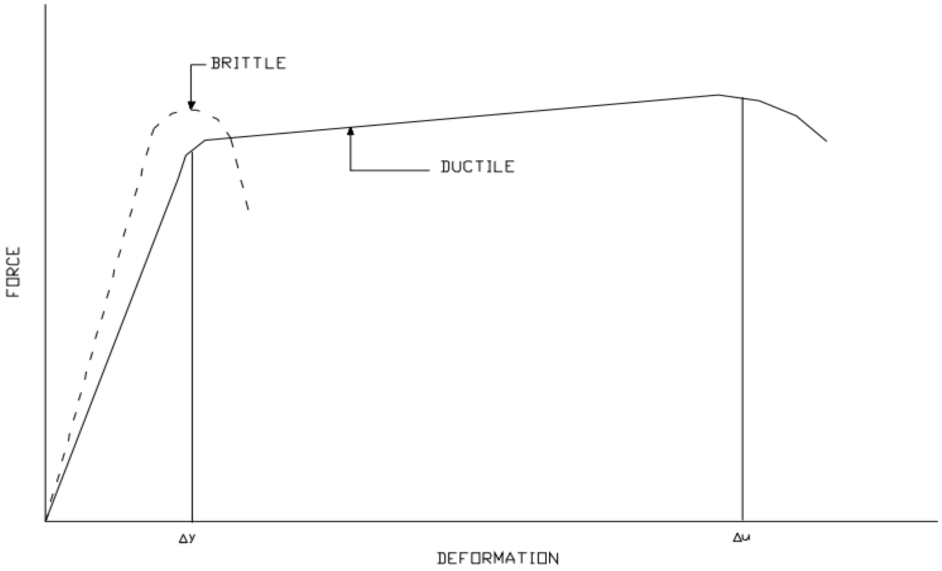
➢ COMPARISON WITH BRITTLE MATERIAL

Brittleness is a property of material that will fail suddenly without undergoing noticeable deformations. Brittle structures do not give notice before failure and may collapse and the occupants may not have time to take measures to prevent collapse.

Concrete is an example of brittle material. To avoid failure of structure the structural engineer must take all provisions to increase the ductility of structure. The structural engineer should design a structure functioning as a ductile one. By suitably anchoring the reinforcement, the ductility of a structure can be increased to a greater extent with little increase in cost.

Reinforced concrete structures, unlike steel structures, tend to fracture or fail in a relatively brittle fashion as the ductility or deformation capacity of conventional concrete is limited. In such structures the brittle failure as result of inelastic deformation can be avoided only if the concrete is made to behave in a ductile manner so that the member can absorb and dissipate large amount of energy.

Hence in the case of reinforced concrete members subjected to inelastic deformation, not only strength but also ductility plays vital role in the design. A ductile material is the one that can undergo large strains while resisting loads. Graph shown below also show comparison between brittle and ductile material regarding to deformation.



BRITTLE AND DUCTILE FORCE-DEFORMATION BEHAVIOUR

➢ NECESSITY OF DUCTILE DETAILING

Ductile detailing is provided in structures so as to give them adequate toughness and ductility to resist severe earthquake shocks without collapse.

Ductile detailing is provided for the following structures.

- The structures is located in seismic zone IV and V.
- The structure is located in seismic zone III and has the important factor (I) greater than 1.
- The structure is located in seismic zone III and is an industrial structure.
- The structure is located in seismic zone III and is more than 5 storeys high.

➢ DUCTILITY CRITERIA FOR EARTHQUAKE RESISTANT STRUCTURES

The performance criteria in most earthquake code provisions require that a structure be able to :

- Resist earthquakes of minor intensity without damage. A structure would be expected to resist such frequent but minor shocks within its elastic range of stresses.
- Resist moderate earthquakes with minor structural and some non-structural damage. With proper design and construction, it is believed that structural damage due to the majority of earthquakes will be limited to repairable damage.
- Resist major catastrophic earthquake without collapse.

➢ VARIABLES AFFECTING DUCTILITY

- Tension steel ratio p_t

  The ductility of a beam cross-section increases as the steel ratio p or (p-p0) decreases. If excessive reinforcement is provided the concrete will crush before the steel yields, leading to brittle failure corresponding to μ0=1.0. In other words, a beam should be designed as under reinforced.

  The ductility is directly affected by the values ρa, σck, and δy. the ultimate strain εu is a function of a number of variables such as the characteristic strength of concrete, rate of loading and strengthening effect of stirrups. The code recommends a value of 0.0035 for εu. Ductility increases with the increase in characteristic strength of concrete and decrease with the characteristic strength of steel. In fact, ductility is inversely proportional to square of δy. It suggests that Fe 250 grade mild steel is more desirable from the ductility point of view as compared with the Fe 415 grade or Fe 500 grade high strength steels.

- Compression steel ratio p_c

  Compression steel ratio is an important parameter defining the ductility ratio. The ductility increases with the decrease in (p-p0) value, that is, ductility increases with increase in compression steel.

- Shape of cross-section

  The presence of an enlarged compression flange in a T-beam reduces the depth of the compression zone at collapse and thus increases the ductility.

- Lateral reinforcement

  Lateral reinforcement tends to improve ductility by preventing premature shear failures and by confining the compression zone, thus increasing deformation capability of a reinforced concrete beam.

Ductility can be increased by

- Decrease in the % tension steel (p_t).
- Increase in the % compression steel (p_c).
- Decrease in the tensile strength of steel.
- Increase in the compressive strength of concrete (But very high grades of concrete are undesirable).
- Increase in the compression flanges area in flanged beams.
- Increase in the transverse (shear) reinforcement.

➢ DESIGN FOR DUCTILITY

Following certain simple design details such as can ensure sufficient amount of ductility:

- The structural layout should be simple and regular avoiding offsets of beams to columns, or offsets of columns from floor to floor. Changes in stiffness should be gradual from floor to floor.
- The amount of tensile reinforcement in beam should be restricted and more compression reinforcement should be provided. The latter should be enclosed by stirrups to prevent it from buckling.
- Beams and columns in a reinforced concrete frame should be designed in such a manner that inelasticity is confined to beams only and the columns should be remain elastic. To ensure this, sum of the moment capacities of the columns for the design axial loads at a beam-column joint should be greater than the moment capacities of the beams along each principal plane.
- The shear reinforcement should be adequate to ensure that the strength in shear exceeds the strength in flexure and thus, prevent a non-ductile shear failure before the fully reversible flexure strength of a member has been developed.

- Closed stirrups or spirals should be used to confine the concrete at sections of maximum moment to increase the ductility of members. Such sections include upper and lower ends of columns and within beam-column joints, which do not have beams on all sides. If axial load exceed 0.4 times the balanced axial load, spiral column is preferred.
- Splices and bar anchorages must be adequate to prevent bond failures.
- The reversal of stresses in beams and columns due to reversal of direction of earthquake force must be taken into account in the design by appropriate reinforcement.
- Beam-column connections should be made monolithic.

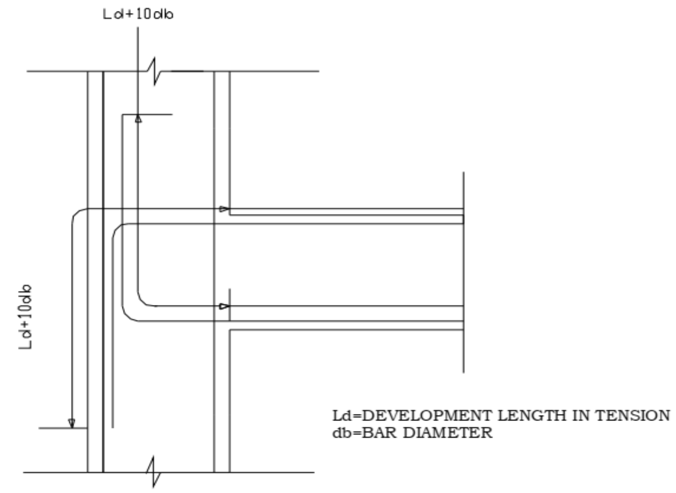
➢ DUCTILE DETAILING FOR FLEXURE MEMBER

- The factored axial stress on the member under earthquake loading shall not exceed $0.1f_{ck}$.
- The member shall have preferably had a width-to-depth ratio of more than 0.3.
- The width of the member shall not be less than 200 mm.
- The depth of the member shall preferably be not less than ¼ of the clear span.

LONGITUDINAL REINFORCEMENT

- The top as well as bottom reinforcement shall consist of at least two bars throughout the member length
- The tension steel ratio on any face, at any section, shall not be less than $\rho_{min}=0.24(f_{ck}/f_y)^{1/2}$.
- The maximum steel ratio on any face at any section, shall not exceed $\rho_{max}=0.025$.
- The positive steel at a joint face must be at least equal to half the negative steel at that face.

ANCHORAGE OF BEAM BARS IN AN EXTERNAL JOINT



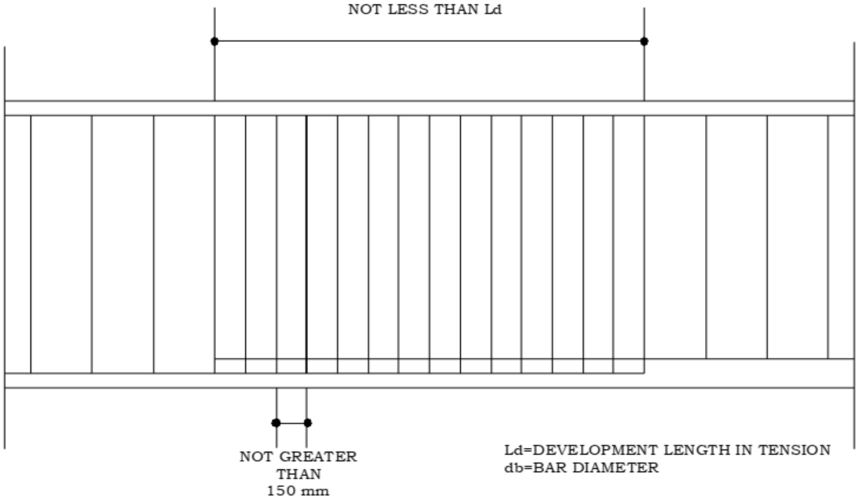
Ld=DEVELOPMENT LENGTH IN TENSION
db=BAR DIAMETER

- In an external joint, both the top and the bottom bars of the beam shall be provided with anchorage length, beyond the inner face of the column, equal to the development length in tension plus 10 times the bar diameter minus the allowance for 90 degree bend.
- In an internal joint, both face bars of the beam shall be taken continuously through the column.

PURPOSE

Flexure members of lateral force resisting ductile frames are assumed to yield at the design earthquake load. To ensure proper development of reversible plastic hinges near continuous supports (beam column connections) where they are usually develop in such members.

LAP, SPLICE IN BEAM



- The longitudinal bars shall be spliced, only if hoops are provided over the entire splice length, at spacing not exceeding 150 mm.

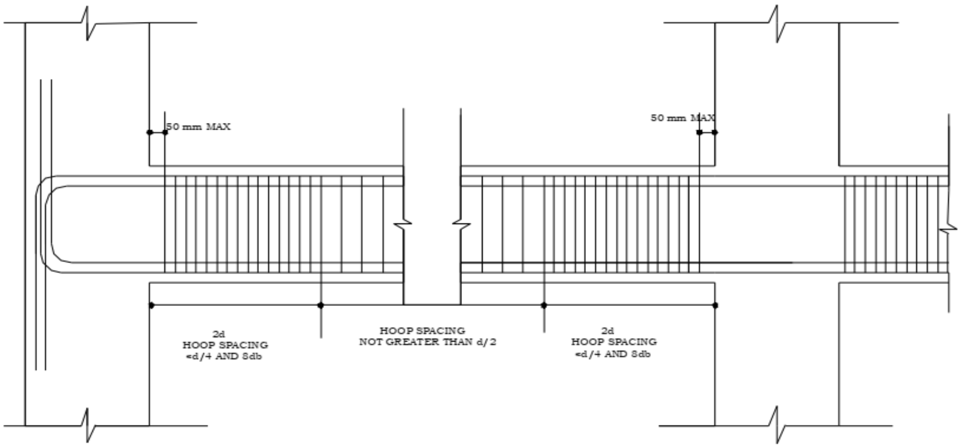
  PURPOSE

  For confining the concrete and to support longitudinal bars.
- The lap length shall not be less than the bar development length in tension.
- Lap splices shall not be provided
  - Within a joint
  - Within a distance of 2d from joint face
  - Within a quarter length of the member where flexural yielding may generally occur under the effect of earthquake forces.
- Not more than 50% of the bars shall be spliced at one section.

  PURPOSE

  To avoid the possibility of spalling of concrete cover under large reversed strains.

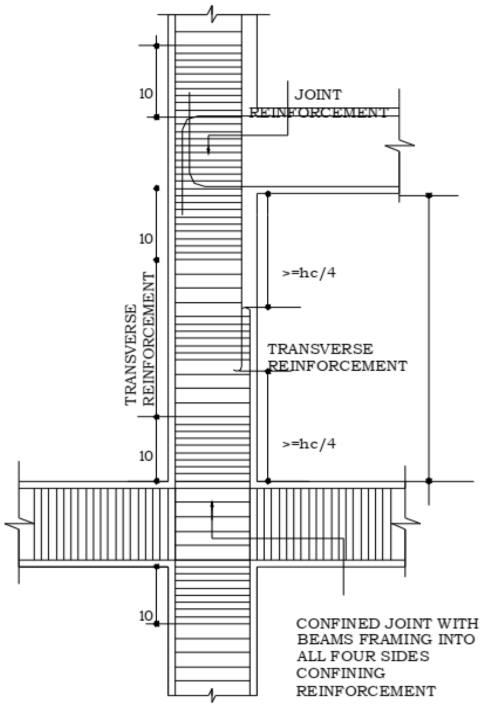
BEAM REINFORCEMENT



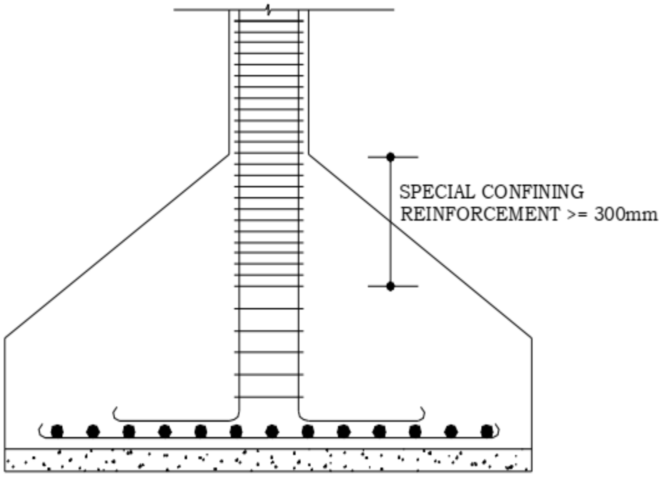
- The spacing of hoops over a length of 2d at either end of a beam shall not exceed
  - d/4
  - 8 times the diameter of the smallest longitudinal bar (it must not less than 100 mm).
- The first hoop shall be at a distance not exceeding 50 mm from the joint face.
- Vertical hoops at the same spacing shall also be provided over a length equal to 2d on either side of a section where flexural yielding may occur under the effect of earthquake forces.
- Elsewhere, the beam shall have vertical hoops at a spacing not exceeding d/2.

COLUMN AND JOINT DETAILING

- Lap splice shall be provided only in the central half of the member length. It should be proportioned as a tension splice. Hoops shall be provided over the entire splice length at spacing not exceeding 150mm center to center. Not more than 50% of the bars shall be spliced at one section.
- The spacing of the hoops shall not exceed half the least lateral dimension of the column, except where special confining reinforcement is provided.
- Special confining reinforcement shall be provided over a length l0 from each joint face, towards mid-span, and on either side of any section, where flexural yielding may occur under the effect of earthquake forces.
- The length l0 shall not be less than
  - Larger lateral dimension of the member at the section where yielding may occurs
  - 1/6 of the clear span of the member
  - 450mm.
- The special confining reinforcement as required at the end of column shall be provided through the joint.
- A joint, which has beams framing into all vertical faces of it and where each beam width is at least ¾ of the column width, may be provided with half the special confining reinforcement required at the end of the column. The spacing of the hoops shall not exceed 150 mm.



PROVISION OF SPECIAL CONFINING REINFORCEMENT IN FOOTING



PROVISION OF SPECIAL CONFINING
REINFORCEMENT IN FOOTINGS

- When a column terminates into a footing or mat, special confining reinforcement shall extend at least 300 mm into the footing or mat.