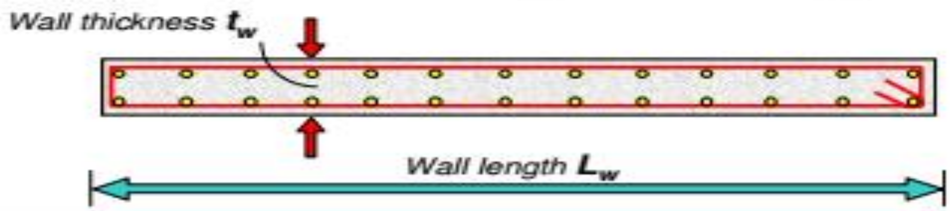
GENERAL REQUIREMENTS

General Requirements

The requirements of this section apply to the shear walls, which are part of the lateral force resisting system of the structure.

The thickness of any part of the wall shall preferably, not be less than 150 mm.

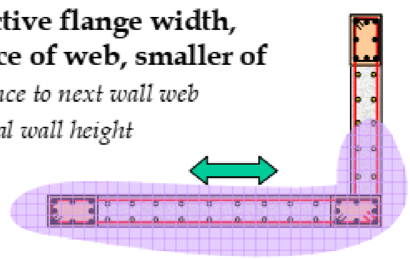
- **Thickness ≥ 150 mm** *(preferably)*
  - *Thinner walls have a tendency to buckle out of plane*



GENERAL PROVISIONS...

The effective flange width, to be used in the design of flanged wall sections, shall be assumed to extend beyond the face of the web for a distance which shall be the smaller of (a) half the distance to an adjacent shear wall web, and (b) 1/10 th of the total wall height.

- **Effective flange width, beyond face of web, smaller of**
  - *Half distance to next wall web*
  - *1/10 of total wall height*



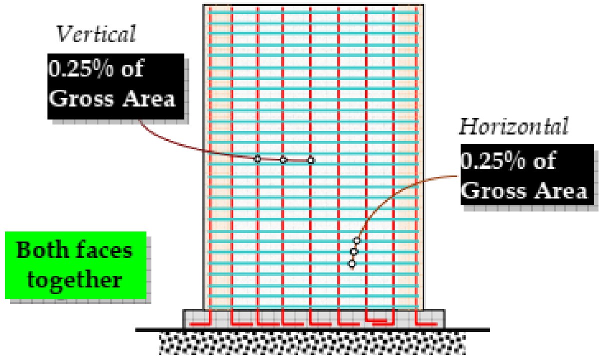
GENERAL PROVISIONS...

Shear walls shall be provided with reinforcement in the longitudinal and transverse directions in the plane of the wall. The minimum reinforcement ratio shall be 0·002 5 of the gross area in each direction. This reinforcement shall be distributed uniformly across the cross section of the wall.

- **Minimum reinforcement in walls**
  - *Vertical and horizontal direction 0.25% of gross area*

GENERAL PROVISIONS...

- **Minimum reinforcement in walls...**



GENERAL PROVISIONS...

If the factored shear stress in the wall exceeds $0{\cdot}25\sqrt{f_{ck}}$ or if the wall thickness exceeds 200 mm, reinforcement shall be provided in two curtains, each having bars running in the longitudinal and transverse directions in the plane of the wall.

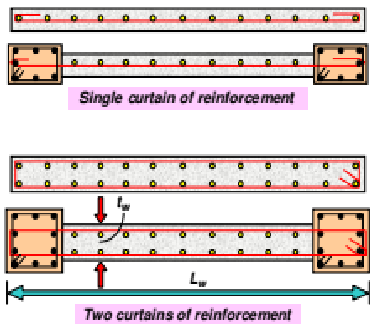
- **Two curtains of reinforcement, if**
  - *Factored shear stress* $> 0.25\sqrt{f_{ck}}$; *or*
  - *Wall thickness > 200 mm*
    - Two curtains reduce fragmentation and early deterioration of concrete under cyclic response.

GENERAL PROVISIONS...

- Two curtains of reinforcement...

$\tau_v > 0.25\sqrt{f_{ck}}$, or

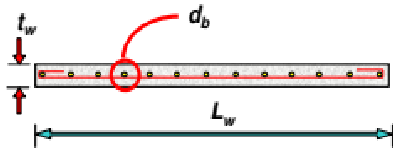
$t_w > 200mm$



GENERAL PROVISIONS...

The diameter of the bars to be used in any part of the wall shall not exceed 1/10th of the thickness of that part.

- Diameter of bars ≤ 1/10th wall thickness



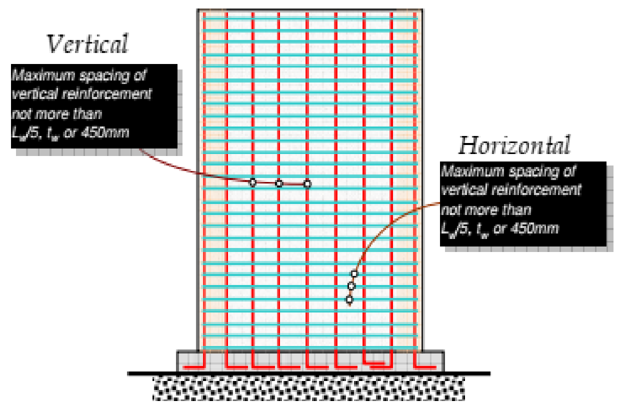
GENERAL PROVISIONS...

The maximum spacing of reinforcement in either direction shall not exceed the smaller of $l_w/5$, 3 t_w, and 450 mm; where l_w is the horizontal length of the wall, and t_w is the thickness of the wall web.

- Maximum reinforcement spacing ≤
  - $l_w/5$
  - $3t_w$
  - 450 mm

GENERAL PROVISIONS...

- Maximum reinforcement spacing...



SHEAR STRENGTH

The nominal shear stress, τ_v, shall be calculated as:

$$\tau_v = \frac{V_u}{t_w\, d_w}$$

where

V_u = factored shear force,

t_w = thickness of the web, and

d_w = effective depth of wall section. This may by taken as 0·8 l_w for rectangular sections.

The design shear strength of concrete, τ_c, shall be calculated as per Table 13 of IS 456 : 1978.

SHEAR STRENGTH...

The nominal shear stress in the wall, τ_v, shall not exceed $\tau_{c,\,max}$, as per Table 14 of IS 456 : 1978.

When τ_v is less than τ_c shear reinforcement shall be provided in accordance

When τ_v is greater than τ_c, the area of horizontal shear reinforcement, A_h, to be provided within a vertical spacing, S_v, is given by

$$V_{us} = \frac{0{\cdot}87\, f_y\, A_h\, d_w}{S_v}$$

where $V_{us} = (V_u - \tau_c\, t_w\, d_w)$, is the shear force to be resisted by the horizontal reinforcement. However, the amount of horizontal reinforcement provided shall not be less than the minimum

SHEAR STRENGTH…

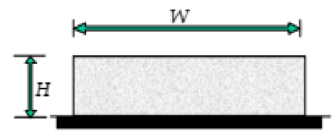
- provide same shear design provisions as in IS:456-2000 for beams

$\tau_v < \tau_c$	Minimum Reinforcement
$\tau_c < \tau_v < \tau_{c,\max}$	Design Reinforcement
$\tau_{c,\max} < \tau_v$	Redesign Section

SHEAR STRENGTH…

The vertical reinforcement, that is uniformly distributed in the wall, shall not be less than the horizontal reinforcement calculated

- Uniformly distributed vertical reinforcement ≥ Horizontal reinforcement calculated for shear
  - *Particularly important for walls with height-to-width ratio of 1.0 or less*



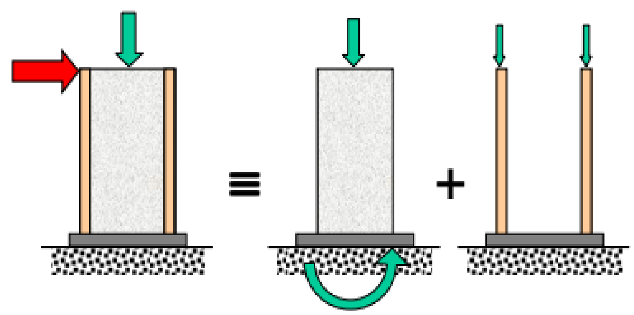
FLEXURAL STRENGTH

The moment of resistance, M_{uv}, of the wall section may be calculated as for columns subjected to combined bending and axial load as per IS 456 : 1978. The moment of resistance of slender rectangular shear wall section with uniformly distributed vertical reinforcement is given in Annex A.

- Flexural strength similarly calculated as for columns under axial loads (IS:456).
  - Can use Annex A equations for assessing flexural strength under uniform distribution of reinforcement

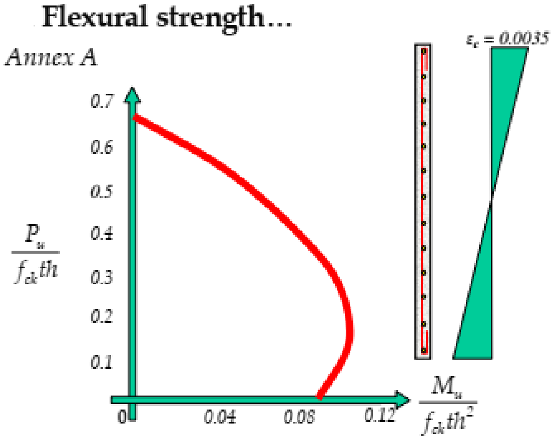
FLEXURAL STRENGTH…

- Flexural strength…



FLEXURAL STRENGTH…

- Flexural strength…
  - *Annex A*



FLEXURAL STRENGTH…

The cracked flexural strength of the wall section should be greater than its uncracked flexural strength.

- Cracked flexural strength > Uncracked flexural strength
  - *Avoid brittle behaviour*

FLEXURAL STRENGTH...

In walls that do not have boundary elements, vertical reieforcement shall be concentrated at the ends of the wall. Each concentration shall consist of a minimum of 4 bars of 12 mm diameter arranged in at least 2 layers.

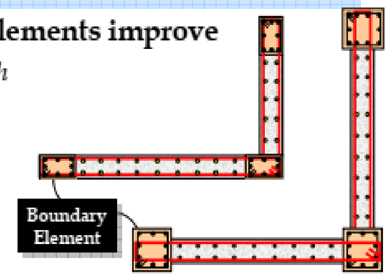
- **If no boundary elements**
  - *Provide 4 bars of 12 mm diameter*
  - *In two layers at either end*
    - **Good to have more reinforcement near wall ends**

BOUNDARY ELEMENTS

Boundary Elements

Boundary elements are portions along the wall edges that are strengthened by longitudinal and transverse reinforcement. Though they may have the same thickness as that of the wall web it is advantageous to provide them with greater thickness.

- **Boundary elements improve**
  - *Flexural strength*
  - *Shear strength*
  - *Ductility*

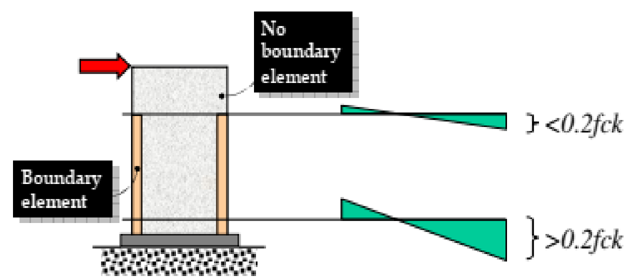


BOUNDARY ELEMENTS...

Where the extreme fibre compressive stress in the wall due to factored gravity loads plus factored earthquake force exceeds $0{\cdot}2f_{ck}$, boundaty elements shall be provided along the vertical boundaries of walls. The boundary elements may be discontinued where the calculated compressive stress becomes less than $0{\cdot}15f_{ck}$. The compressive stress shall be calculated using a linearly elastic model and gross section properties.

BOUNDARY ELEMENTS...

- **Boundary elements required**
  - *When extreme fiber compressive stress > $0.2f_{ck}$*
  - *May discontinue boundary element*
    - **When extreme fiber compressive stress < $0.2f_{ck}$**



BOUNDARY ELEMENTS...

A boundary element shall have adequate axial load carrying capacity, assuming short column action, so as to enable it to carry an axial compression equal to the sum of factored gravity load on it and the additional compressive load induced by the seismic force. The latter may be calculated as:

$$\frac{M_u - M_{uv}}{C_w}$$

where

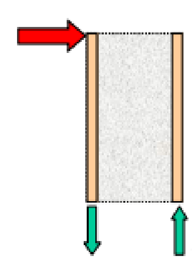
M_u = factored design moment on the entire wall section,

M_{uv} = moment of resistance provided by distributed vertical reinforcement across the wall section, and

C_w = center to center distance between the boundary elements along the two vertical edges of the wall.

BOUNDARY ELEMENTS...

- **Boundary element to carry axial**
  - *Gravity load P_w (its own share proportional to area)*
  - *Vertical load P_{eq} induced by EQ*
    - **Vertical force couple caused by EQ overturning moment**



BOUNDARY ELEMENTS…

- **Example**
  - *Given*

	Axial Load *P* on boundary element	Moment M_u on entire wall
Gravity	400 kN	-
Seismic	±50 kN	10,000 kNm

- *M_u resisted by web = 6,000 kNm*
- *M_{ub} resisted by boundary elements*

  = 10,000 - 6,000 = 4,000 kNm
- *C/c distance of boundary element = 5 m*
- *Axial force induced by 4,000 kNm moment =*

$$\pm\frac{4{,}000}{5} = \pm 800\ kN$$

BOUNDARY ELEMENTS…

If the gravity load adds to the strength of the wall, its load factor shall be taken as 0·8.

- **When gravity load adds to strength**
  - *Load factor is 0.8 (as against 1.2 or 1.5)*

    Example:
    - **Let load factor be 1.2 for gravity.**
    - **Design factored axial force**
      - ❑ *Compression: 1.2(400+50+800)=1,500kN*
      - ❑ *Tension: (0.8x400)-(1.2 x50)-(1.2 x800)=-700kN*

BOUNDARY ELEMENTS…

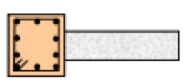
The percentage of vertical reinforcement in the boundary elements shall not be less than 0·8 percent, nor greater than 6 percent. In order to avoid congestion, the practical upper limit would be 4 percent.

- **Vertical reinforcement in boundary element**

  ≥0.8 % gross area of boundary element

  ≤6% (practically 4%)

  —Just like a column



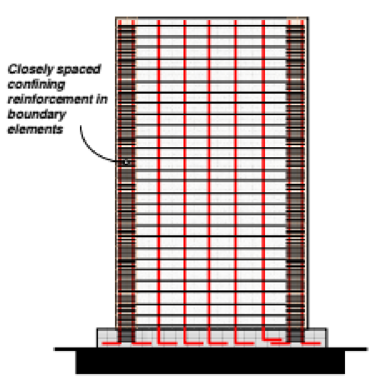
BOUNDARY ELEMENTS…

Boundary elements, where required, shall be provided throughout their height, with special confining reinforcement

- **Confinement reinforcement required throughout height of boundary element**

BOUNDARY ELEMENTS…

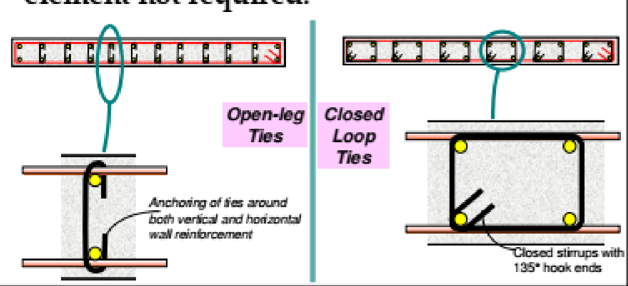
- **Confinement reinforcement…**



BOUNDARY ELEMENTS…

Boundary elements need not be provided, if the entire wall section is provided with special confining reinforcement, as per 7.4.

- **If entire wall is confined, boundary element not required.**



COUPLED SHEAR WALLS

Coupled shear walls shall be connected by ductile coupling beams. If the earthquake induced shear stress in the coupling beam exceeds

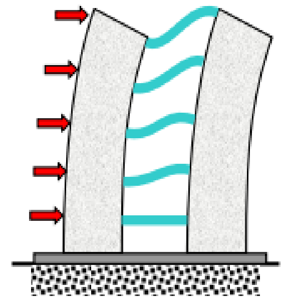
$$\frac{0{\cdot}1\, l_s \sqrt{f_{ck}}}{D}$$

where l_s is the clear span of the coupling beam and D is its overall depth, the entire earthquake induced shear and flexure shall, preferably, be resisted by diagonal reinforcement.

- **Coupling beams to be ductile**
  - *When shear stress in coupling beam exceeds given value, entire seismic shear and flexure to be taken by diagonal reinforcement (preferably).*

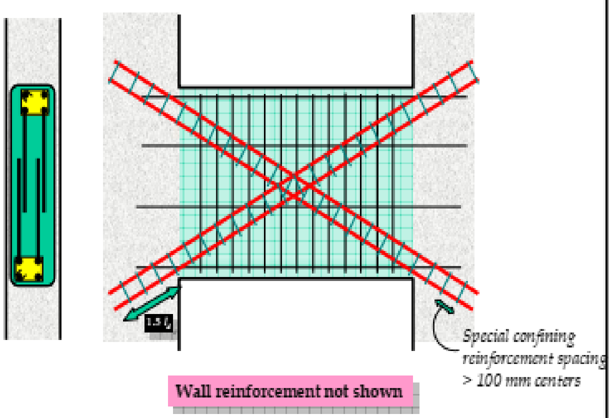
COUPLED SHEAR WALLS…

- **Coupling beams to be ductile…**



COUPLED SHEAR WALLS…

- **Coupling beams to be ductile…**



COUPLED SHEAR WALLS…

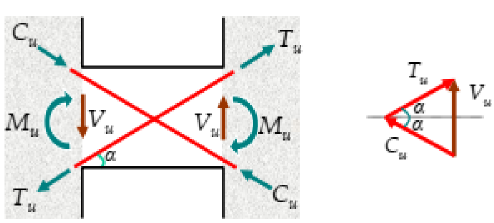
The area of reinforcement to be provided along each diagonal in a diagonally reinforced coupling beam shall be:

$$A_{sd} = \frac{V_u}{1{\cdot}74\, f_y \sin \alpha}$$

where V_u is the factored shear force, and α is the angle made by the diagonal reinforcement with the horizontal. At least 4 bars of 8 mm diameter shall be provided along each diagonal. The reinforcement along each diagonal shall be enclosed by special confining reinforcement, The pitch of spiral or spacing of ties shall not exceed 100 mm.

COUPLED SHEAR WALLS…

- **C_u and T_u intersect at mid-span**
  - *Moment resisted at mid-span by diagonal bars is zero*

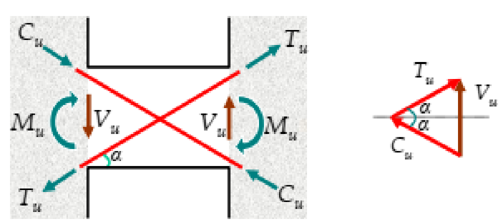


COUPLED SHEAR WALLS…

- …

$$V_u = 2T_u \sin\alpha \qquad \therefore V_u = 1.74 f_y A_{sd} \sin\alpha$$

$$T_u = 0.87 f_y A_{sd} \qquad A_{sd} = \frac{Vu}{1.74 f_y \sin\alpha}$$



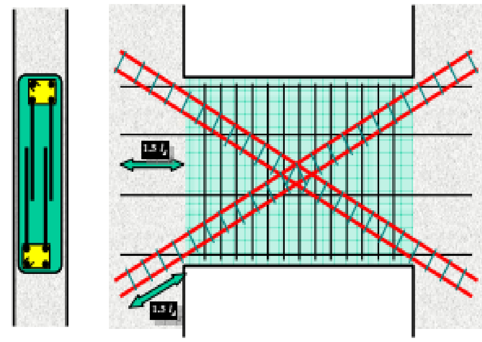
COUPLED SHEAR WALLS…

The diagonal or horizontal bars of a coupling beam shall be anchored in the adjacent walls with an anchorage length of 1·5 times the development length in tension.

- **Diagonal/horizontal bars**
  - *Anchored in wall by* $1.5L_{dt}$

COUPLED SHEAR WALLS…

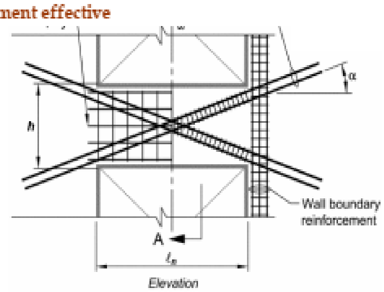
- **Diagonal/horizontal bars…**



COUPLED SHEAR WALLS…

- **ACI 318 – 11: Coupling Beams**
  - Diagonal reinforcement effective

$\frac{l_n}{h} < 4$



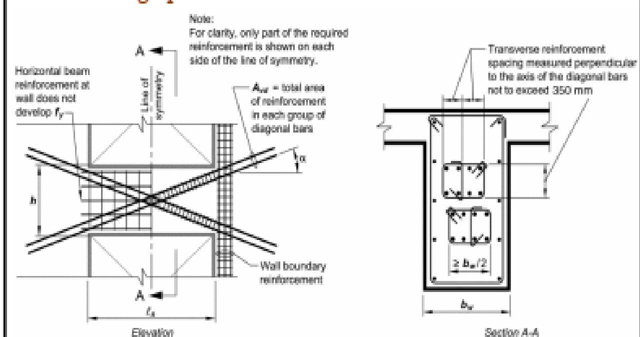
$for \quad \frac{l_n}{h} < 2$

- necessary to reinforced with two intersecting group of diagonally placed bars

COUPLED SHEAR WALLS…

- **ACI 318 – 11: Diagonal/horizontal bars**

Detailing option 1



Confinement of individual diagonals

COUPLED SHEAR WALLS…

- **ACI 318 – 11: Diagonal/horizontal bars**

Detailing option 1

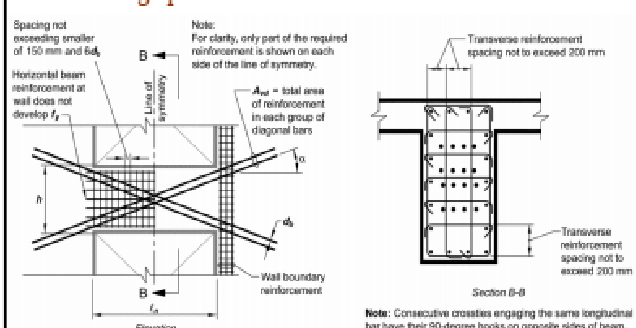
(c) Each group of diagonal bars shall be enclosed by transverse reinforcement having out-to-out dimensions not smaller than $b_w/2$ in the direction parallel to b_w and $b_w/5$ along the other sides, where b_w is the web width of the coupling beam. The transverse rein-

bars. Additional longitudinal and transverse reinforcement shall be distributed around the beam perimeter with total area in each direction not less than $0.002b_ws$ and spacing not exceeding 300 mm.

COUPLED SHEAR WALLS…

- **ACI 318 – 11: Diagonal/horizontal bars…**

Detailing option 2



Full confinement of diagonally reinforced beam section

COUPLED SHEAR WALLS...

- **ACI 318 – 11:** Diagonal/horizontal bars

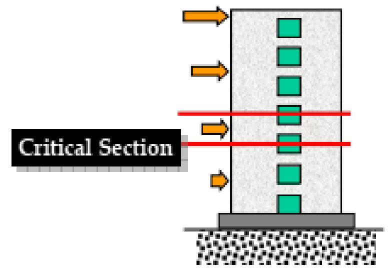
Detailing option 2

(d) Transverse reinforcement shall be provided for the entire beam cross section satisfying 21.6.4.2, 21.6.4.4, and 21.6.4.7, with longitudinal spacing not exceeding the smaller of 150 mm and six times the diameter of the diagonal bars, and with spacing of crossties or legs of hoops both vertically and horizontally in the plane of the beam cross section not exceeding 200 mm. Each crosstie and each hoop leg shall engage a longitudinal bar of equal or larger diameter. It shall be permitted to configure hoops as specified in 21.5.3.6.

OPENINGS IN WALLS

The shear strength of a wall with openings should be checked along critical planes that pass through openings.

- Shear strength to be checked along planes passing through openings



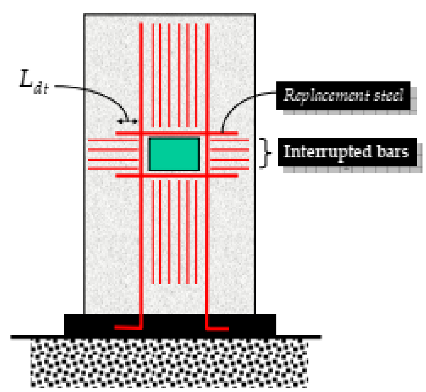
OPENINGS IN WALLS...

Reinforcement shall be provided along the edges of openings in walls. The area of the vertical and horizontal bars should be such as to equal that of the respective interrupted bars. The vertical bars should extend for the full storey height. The horizontal bars should be provided with development length in tension beyond the sides of the opening.

- Reinforcement interrupted by opening to be provided along edges
  - *Vertical edge reinforcement to extend full storey height*
  - *Horizontal edge reinforcement to have development length in tension*

OPENINGS IN WALLS...

- Reinforcement at openings...



DISCONTINUOUS WALLS

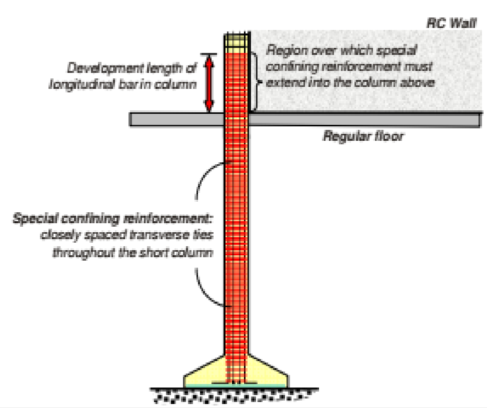
Discontinuous Walls

Columns supporting discontinuous walls shall be provided with special confining reinforcement

- Special confinement reinforcement required over full height of columns supporting walls

DISCONTINUOUS WALLS...

- Special confinement reinforcement...



CONSTRUCTION JOINTS

Construction Joints

The vertical reinforcement ratio across a horizontal construction joint shall not be less than:

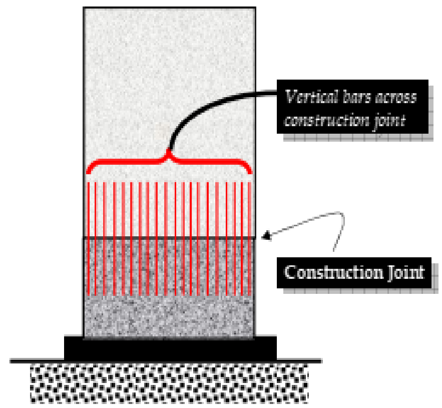
$$\frac{0.92}{f_y}\left(\tau_v - \frac{P_u}{A_g}\right)$$

where τ_v is the factored shear stress at the joint, P_u is the factored axial force (positive for compression), and A_g is the gross cross sectional area of the joint.

- Minimum vertical reinforcement across the construction joint

CONSTRUCTION JOINTS...

- Construction Joints...



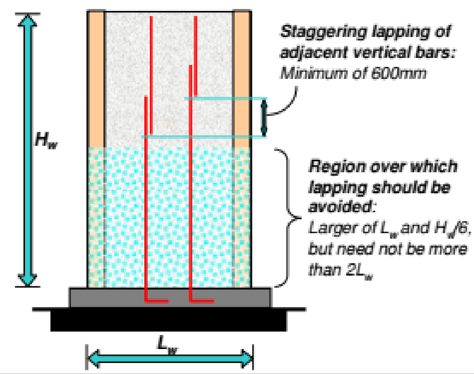
DEVELOPMENT, SPLICE & ANCHORAGE REQUIREMENT

Horizontal reinforcement shall be anchored near the edges of the wall or in the confined core of the boundary elements.

Splicing of vertical flexural reinforcement should be avoided, as far as possible, in regions where yielding may take place. This zone of flexural yielding may be considered to extend for a distance of l_w above the base of the wall or one sixth of the wall height, whichever is more. However, this distance need not be greater than 2 l_w. Not more than one third of this vertical reinforcement shall be spliced at such a section. Splices in adjacent bars should be staggered by a minimum of 600 mm.

DEVELOPMENT, SPLICE & ANCHORAGE REQ....

- Splicing of vertical reinforcement to be avoided in critical regions



DEVELOPMENT, SPLICE & ANCHORAGE REQ....

Lateral ties shall be provided around lapped spliced bars that are larger than 16 mm in diameter. The diameter of the tie shall not be less than one fourth that of the spliced bar nor less than 6 mm. The spacing of ties shall not exceed 150 mm center to center.

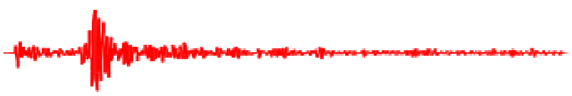
- Lateral tie requirements for lapped spliced bars

DEVELOPMENT, SPLICE & ANCHORAGE REQ....

Welded splices and mechanical connections shall confirm to 25.2.5.2 of IS 456 : 1978. However, not more than half the reinforcement shall be spliced at a section, where flexural yielding may take place.

- Welded splices and mechanical connections as per IS:456.

Example: RC Shear Wall Design



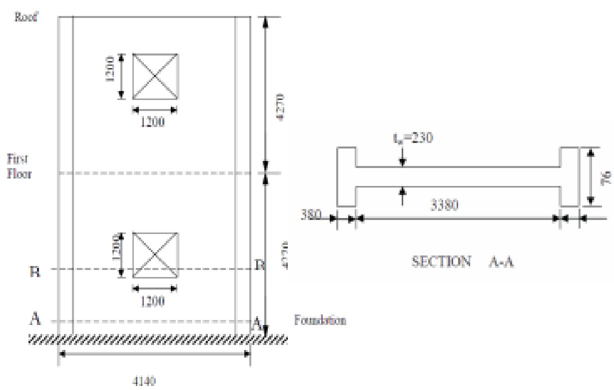
EXAMPLE

- Design a shear wall for a two-storey building as shown in Figure. The materials are M20 concrete and Fe415 steel. The example shows design for load combination 1.2(DL + LL +EL) only. In practice all other combinations should also be considered. The unfactored forces in the panel between the ground level and first floor are obtained by analysis as

S.No	Load Case	Bending Moment	Axial Force	Shear Force
1.	(DL+LL)	-577.5	1922.9	19.7
2.	Earthquake	4830.9	255.7	699.1

Explanatory Examples for Ductile Detailing of RC Buildings

EXAMPLE…



EXAMPLE…

- Factored bending moment on the section,
  - M_u = 1.2 × (577.5 + 4830.9) = **6490 kNm**
- The maximum factored shear force,
  - V_u =1.2 × (19.7 + 699.1) = **863 kN**
- Effective depth
  - d_e = 3380+(380/2)+(380/2) = 3760 mm
- Shear stress, $\tau_v = \dfrac{V_u}{d_e \times t_w} = 0.998$
- Let the minimum vertical reinforcement = 0.25% provided in the web

SHEAR DESIGN…

- As per Table 19 of IS: 456-2000, τ_c = 0.36 N/mm^2.
- Shear carried by concrete,

  $V_{uc} = \tau_c \times d_e \times t = 311$ kN
- Shear to be resisted by horizontal reinforcement,

  $V_{us} = V_u - V_{uc}$ = (863 – 311) = 552 kN

  $$V_{us} = \frac{0.87 f_y A_h d_e}{S_v} \qquad \Rightarrow \frac{A_h}{S_v} = 0.41$$
- Minimum horizontal reinforcement (0.25%) requires this ratio to be **0.575**
- For t_w **> 200 mm**, the reinforcement shall be in 2 layers
- Provide horizontal reinf. of *8mm dia. bars at 175 mm c/c in 2 layers*

SHEAR DESIGN AT OPENING…

- Effective depth of wall on each side of opening

  = (1090+380/2) = 1280 mm

  → **τ_v =1.47 N/mm^2**
- Shear to be resisted by reinforcement on each side of opening

  V_{us}= 326 kN.
- Provide 8 mm diameter 2-legged stirrups at 140 *mm* c/c on each side of opening

FLEXURAL STRENGTH OF WEB…

- Vertical reinf. in web is 0.25 percent
- L_w = 4140 mm and t_w = 230 mm
- Axial compression will increase moment capacity of wall
  - *Factored axial force*
    - P_u = 0.8 × 1922.9 +1.2 × 255.7 = **1845 kN**
  - *Assuming this axial load to be uniformly distributed, load on web* = 0.574 × 1845 = **1059 kN**
- The moment of resistance of a slender rectangular shear wall section with uniformly distributed vertical reinf. can be estimated as per IS 13920: 1993 **(Annex A)**

FLEXURAL STRENGTH OF WEB…

(a) For $x_u/l_w < x_u^*/l_w$

$$\frac{M_{uv}}{f_{ck} t_w l_w^2} = \varphi\left[\left(1+\frac{\lambda}{\varphi}\right)\left(\frac{1}{2}-0.416\frac{x_u}{l_w}\right)-\left(\frac{x_u}{l_w}\right)^2\left(0.168+\frac{\beta^2}{3}\right)\right] \qquad (1)$$

where

$$\frac{x_u}{l_w} = \left(\frac{\varphi+\lambda}{2\varphi+0.36}\right) \qquad \frac{x_u^*}{l_w} = \left(\frac{0.0035}{0.0035+0.87 f_y/E_s}\right)$$

$$\lambda = \left(\frac{P_u}{f_{ck} t_w l_w}\right) \qquad \varphi = \left(\frac{0.87 f_y \rho}{f_{ck}}\right)$$

ρ = vertical reinforcement ratio = $A_{st}/(t_w l_w)$,
A_{st} = area of uniformly distributed vertical reinforcement,
β = $0.87 f_y/(0.003\,5\,E_s)$,
E_s = elastic modulus of steel, and
P_u = axial compression on wall.

FLEXURAL STRENGTH OF WEB…

(b) For $x_u^*/l_w < x_u/l_w < 1.0$

$$\frac{M_{uv}}{f_{ck} t_w l^2 w} = \alpha_1\left(\frac{x_u}{l_w}\right)-\alpha_2\left(\frac{x_u}{l_w}\right)^2-\alpha_3-\frac{\lambda}{2} \qquad (2)$$

where

$$\alpha_1 = \left[0.36+\varphi\left(1-\frac{\beta}{2}-\frac{1}{2\beta}\right)\right] \qquad \alpha_2 = \left[0.15+\frac{\varphi}{2}\left(1-\beta+\frac{\beta^2}{3}-\frac{1}{3\beta}\right)\right];\ \text{and}$$

$$\alpha_3 = \frac{\varphi}{6\beta}\left(\frac{1}{(x_u/l_w)}-3\right)$$

Value of x_u/l_w calculated from the quadratic equation

$$\alpha_1 = \left(\frac{x_u}{l_w}\right)^2 + \alpha_4\left(\frac{x_u}{l_w}\right) - \alpha_5 = 0;$$

where

$$\alpha_4 = \left(\frac{\varphi}{\beta}-\lambda\right);\ \text{and}\ \alpha_5 = \left(\frac{\varphi}{2\beta}\right).$$

FLEXURAL STRENGTH OF WEB…

- As $x_u/l_w < x_u^*/l_w$,
  - *we get the value as:*

    λ= 0.056, **φ** = 0.045, x_u/l_w = 0.233,

    x_u^*/l_w = 0.660, and **β** = 0.516
- Moment of resistance of the web
  - M_{uv} = **3296 kNm**
- Remaining moment will be resisted by reinf. in boundary elements
  - $(M_u - M_{uv})$ = (6490 - 3296) = **3194 kNm**

BOUNDARY ELEMENTS…

- Due to combined axial load and bending, axial compression at the extreme fibre = **6.81 N/mm²**
  - **> 0.2f_{ck}** → Boundary elements are mandatory
- Center to center dist. b/w the boundary elements, C_w = 3760 mm
- Axial force on the boundary element due to earthquake loading

  = $(M_u - M_{uv})/C_w$ = 3194/3.76 = **849 kN**
- Maximum factored compression on the boundary element [849 + 0.213 × 1.2 × (1922.9 + 255.7)] = **1406 kN**
- Factored tension on the boundary element,

  [0.213 × (0.8 × 1922.9 - 1.2 × 255.7) -849] = **-587 kN**

BOUNDARY ELEMENTS…

- Assuming short column action
  - the axial load capacity of the boundary element with min. reinf. of 0.8% = 2953 kN
- 12 bars of 16 mm diameter will be adequate to take the compression as well as tension
- Also, provide special confining reinf. as per **Cl. 9.4.5**

REINFORCEMENT AROUND OPENING…

- Opening size = 1200 mm by 1200 mm
- Area of vertical and horizontal reinforcement in the web (0.25%) that is interrupted by it is 690 mm^2
  - Provide area of bars equal to the respective interrupted bars
- Thus, one bar of 16 mm diameter should be provided per layer of reinforcement on each side of the opening
  - The vertical bar should extend for the full storey height
  - The horizontal bar should be provided with development length in tension beyond the sides of the opening

REINFORCEMENT DETAILS…