INDIAN CODE IMPLEMENTATION IN ADAPT SOFTWARE

This Technical Note details the implementation of the Indian Code (IS 456:2000 & IS 1343:1980, including the latest amendments) in the Builder Platform programs.

The implementation follows the IS Code 's procedure of calculating a "Demand," referred to as "design value" for each design section, and a "Resistance," for the same section, referred to as "design capacity." "Design value" and "design capacity" are generic terms that apply to displacements as well as actions. For each loading condition, or instance defined in IS Code, the design is achieved by making the "resistance" exceed the associated demand "Design Value". Where necessary, reinforcement is added to meet this condition.

The implementation is broken down into the following steps:

- Serviceability limit state
  - Check for cracking
  - Deflection check

- Strength limit state
- Initial condition (transfer of prestressing)
- Reinforcement requirement and placing

In each instance, the design consists of one or more of the following checks:

- Bending of section
  - With or without prestressing
- Punching shear (two-way shear)
- Beam shear (one-way shear)
- Minimum reinforcement

In the following, the values in square brackets "[ ]" are defaults of the program. They can be changed by the user.

REFERENCES

1. IS 456:2000
2. IS 1343:1980

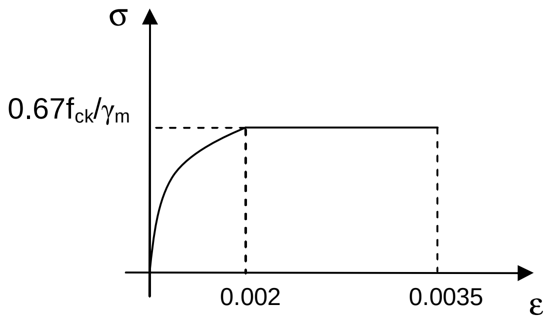
MATERIAL AND MATERIAL FACTORS[1]

Concrete

- Cube strength at 28 days, as specified by the user
  f_{ck} = characteristic compressive cube strength at 28 days;

[1] IS 456:2000 Section 38.1

- Parabolic stress/strain curve with the horizontal branch at $0.67f_{ck}/\gamma_m$; maximum strain at 0.0035; strain at limit of proportionality 0.002



- Modulus of elasticity of concrete is automatically calculated and displayed by the program using f_{ck}, and the relationship[2] of the code. User is given the option to override the code value and specify a user defined substitute.

$$E_c = 5000\sqrt{f_{ck}}$$

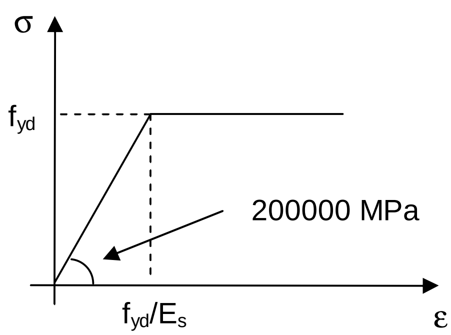
where,

E_c = modulus of elasticity at 28 days

f_{ck} = characteristic cube strength at 28 days

Nonprestressed Steel

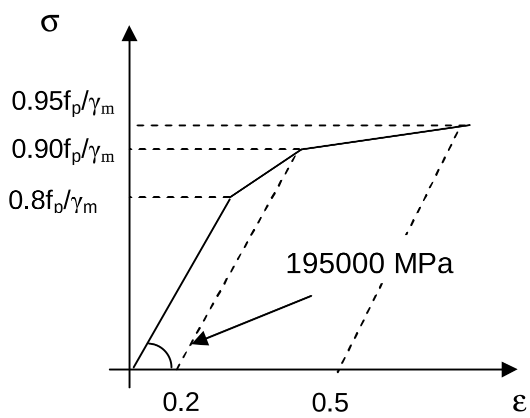
- Bilinear stress/strain diagram with the horizontal branch at $f_{yd}=f_y/\gamma_m$
- Modulus of elasticity(E_s) is user defined [200000 MPa]
- Maximum tensile strain in the steel is $\dfrac{f_y}{1.15E_s} + 0.002$



Prestressing Steel

- A tri-linear stress-strain curve is assumed.
- Modulus of elasticity is user defined [195000 MPa]

[2] IS 456:2000 Section 6.2.3.1



Material Factors

- Concrete $\gamma_m = 1.50$
- Nonprestressed steel $\gamma_m = 1.15$
- Prestressing steel $\gamma_m = 1.15$

LOADING

Self-weight determined based on geometry and unit weight of concrete. Other loads are user defined.

SERVICEABILITY

- **Load combinations**

  Total load combinations[3]:
    - 1.0 DL+1.0 LL+1.0 PT
    - 1.0 DL+1.0 WL(EL) +1.0 PT
    - 1.0 DL+0.8 LL+0.8 WL(EL) + 1.0 PT

  Sustained load combinations[4]
    - 1.0 DL+0.3 LL+1.0 PT

- **Stress checks**

  - Concrete

    Stress limitations for compression[5] are as follows:

    i. Stress in flexure:
       - Zone 1 (Sustained load)

         For Grade M 30, $0.41f_{ck}$

         For Grade M 60, $0.35f_{ck}$

       Intermediate values are obtained by linear interpolation.

[3] IS 1343:1980 Table 5

[4] IS code does not specify this combination, ACI 318 is recommendation, and EC2 factors are used.

[5] IS 456:2000 Section 22.8.1.1

§ Zone 2 (Total Load)

For Grade M 30, $0.34f_{ck}$

For Grade M 60, $0.27f_{ck}$

Intermediate values are obtained by linear interpolation.

ii. Stress in average precompression:
0.8 times the maximum allowable compressive stress in compression given in (i).

If stress at any location exceeds, the program displays that location with a change in color (or broken lines for black and white display), along with a note on program's text report.

Stress limitations for hypothetical tensile stress[6] for the three design options are as follows:

i. Type 1: No tensile stress
ii. Type 2:
Total load combination 4.5 MPa
Sustained load combination 3.0 MPa

iii. Type 3: Design based on cracked section. The design values are taken from Table 8[7] based on the concrete grade, modified by coefficients given in Fig.6, based on the depth of the member.

By defining the limits of the tensile stresses, the user specifies the design Type. Should stresses exceed the threshold of the design Type specified by user, the program automatically applies the restrictions applicable to the next design Type. More reinforcement is added, where needed. Computed crack widths are limited to those specified in the code.

- Nonprestressed Reinforcement
  - § No stress limits for service condition are specified – no check made
- Prestressing steel
  - § No stress limits for service condition are specified - no check made

- **Crack control**
  The program calculates the design crack width (w_{cr}) based on Annex F[8] for non-prestressed members for each design section. If the calculated value of a section exceeds the allowable, reinforcement is added to that section, in order to reduce the crack width to within the allowable limit. The allowable crack width depends on the exposure condition.

  - Crack width limitation for nonprestressed[9]concrete:

For aggressive environment	- 0.1 mm
For members where cracking is not harmful	- 0.3 mm
For all other	- 0.2 mm

[6] IS 456:2000 Section 22.8.1.1
[7] IS 1343:1980 Section 22.7.1
[8] IS 456:2000
[9] IS 456:2000 Section 35.3.2

ADAPT uses 0.2mm as its default value.

- Crack width limitation for prestressed[10] concrete:

Type1 and Type2 members	- no cracking
Type 3 members	
For aggressive environment	- 0.1 mm
For all other	- 0.2 mm

- For Type 3 members, if the tensile stress exceeds the threshold, program adds rebar to limit the cracking based on the prestressing system as follows[11]:
  - For grouted post-tensioned and pre-tensioned members, $0.0025A_t$ rebar in tension zone is added for every 1MPa of stress above the allowable up to the stress of $0.25f_{ck}$.
  - For other members, $0.0033A_t$ rebar in tension zone is added for every 1MPa of stress above the allowable up to the stress of $0.25f_{ck}$.

The addition of the above rebar for excess stress satisfies the limitations on crack width.

STRENGTH

- **Load combinations**
  - 1.5 DL+1.5 LL+ 1.0 Hyp
  - 1.5 DL+1.5 WL(EL) + 1.0 Hyp
  - 1.2 DL+1.2 LL+1.2 WL(EL) + 1.0 Hyp

- **Check for bending[12]**
  - Plane sections remain plane. Strain compatibility is used to determine the forces on a section.
  - Maximum concrete strain in compression is limited to 0.0035 .
  - Tensile capacity of the concrete is neglected.
  - Maximum allowable value for the neutral axis "x_u" is determined based on yield strength of the steel f_y .
    - For f_y = 250 MPa $x_u /d <= 0.53$
    - For f_y = 415 MPa $x_u /d <= 0.48$
    - For f_y = 500 MPa $x_u /d <= 0.46$

    Where necessary, compression reinforcement is added to enforce the above requirement.

  - If a section is made up of more than one concrete material, the entire section is designed using the concrete properties of lowest strength in that section.
  - Stress in nonprestressed steel is derived from representative stress-strain curve for the type of steel used.
  - Stress in prestressing steel is calculated as:
    - For bonded tendons, stress is calculated from stress-strain compatibility of the section.
    - For unbonded tendons, Indian code specifies rigorous analysis or tests. The stipulations of ACI-318-02 satisfy this requirement and are used. The following are the details.

[10] IS 1343:1980 Section 19.3.2(NOTE)
[11] IS 1343:1980 Section 22.7.1, Note
[12] IS 456:2000 Section 38 and IS 1343:1980 Section 22.1

For span-to-depth ratio of 35 or less

$$f_{pb} = f_{pe} + 70 + \frac{f'_c}{100\rho_p} \leq \min(f_{py}, f_{pe}+420)$$

For span-to-depth ratio greater than 35

$$f_{pb} = f_{pe} + 70 + \frac{f'_c}{300\rho_p} \leq \min(f_{py}, f_{pe}+210)$$

where,

f_p = tensile stress in the tendon;

f_{pe} = effective prestress after all losses;

f'_c = characteristic cylinder strength of concrete at 28 days = $0.8f_{ck}$.

- Compressive design force of concrete stress block is $0.36f_{ck}x_u$. The distance of center of compressive force from the extreme compression fiber is equal to $0.42x_u$.
- For flanged sections, the following procedure is adopted:
  - If x_u is within the flange, the section is treated as a rectangle
  - If x_u exceeds the flange thickness, uniform compression is assumed over the flange. The stem is treated as a rectangular section.

- **One-way shear**

  - **Non-prestressed members[13]:**

Nominal shear stress:

$$\tau_v = \frac{V_u}{bd}$$

where, V_u = shear force due to design loads;
b = width of the section. For flanged section, width of the web;
d = effective depth.

Design shear strength of concrete:

- For beams, shear strength of concrete, τ_c, is taken from Table 19[14].
- For solid slabs, shear strength of concrete is $k\tau_c$, where k[15] is a factor accounting the depth of the slab.
- For members under axial compression, shear strength of concrete is $\delta\tau_c$.

  where $\delta = 1 + \frac{3P_u}{A_g f_{ck}} \leq 1.5$

  P_u= axial compressive force in Newtons,
  A_g= gross area of concrete section in mm^2.

Shear reinforcement:

[13] IS 456:2000 Section 40
[14] IS 456:2000 Section 40.2.1
[15] IS 456:2000 Section 40.2.1.1

- If $\tau_v < \tau_c$, [16] $A_{sv} = \dfrac{0.4bs_v}{0.87f_y}$
- If $\tau_c < \tau_v < \tau_{cmax}$, [17] $A_{sv} = \dfrac{(\tau_v - \tau_c)bs_v}{0.87f_y}$

where,

τ_{cmax} = maximum allowable shear stress with shear reinforcement. For beams τ_{cmax} from Table 20 based on concrete grade is used and for solid slabs, half the appropriate values given in Table 20 is used.

s_v = longitudinal spacing of vertical stirrups.

f_y = characteristic strength of the stirrup ≤ 415 MPa

Maximum spacing of the links, s_{vmax} :

s_{vmax} = min{ $0.75d_t$, 300}

- **Prestressed structure[18]:**

  - $V < 0.5V_c$ No shear reinforcement is required.
  - $0.5V_c < V < V_c$ $A_{sv} = \dfrac{0.4bs_v}{0.87f_y}$
  - $V_c < V < V_{cmax}$ $A_{sv} = \dfrac{s_v(V-V_c)}{0.87f_y d_t}$

where d_t = maximum of distance from the extreme compression fiber to centroid of longitudinal bars or tendons.

V_{cmax} = Maximum allowable shear force with shear reinforcement .The values used are from Table 7 based on concrete grade multiplied by bd.

Concrete Shear Resistance, V_c:

- For uncracked sections : $V_c = V_{co}$
- For cracked sections : V_c = lesser of V_{co} and V_{cr}

$$V_{co} = 0.67bh\sqrt{\left(f_t^2 + 0.8f_{cp}f_t\right)}$$

where f_t = maximum principal tensile stress $= 0.24\sqrt{f_{ck}}$

$$V_{cr} = \left(1 - 0.55\frac{f_{pe}}{f_p}\right)\zeta_c bd + M_0\frac{V}{M} \geq 0.1bd\sqrt{f_{ck}}$$

where

h = overall depth of the member,

f_{pe} = effective prestress after all losses < $0.6f_p$,

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[16] IS 456:2000 Section 26.5.1.6

[17] IS 456:2000 Section 40.4(a)

[18] IS 1343:1980 Section 22.4

f_{cp} = compressive stress at centroidal axis due to prestress taken as positive,

ζ_c = ultimate shear capacity of concrete obtained from Table 6 based on concrete grade,

d = distance from the extreme compression fiber to the centroid of the tendons at the section considered,

$M_0 = 0.8 f_{pbot} \times S_b$ - If applied moment due to DL & LL is positive

$M_0 = 0.8 f_{ptop} \times S_t$ - If applied moment due to DL & LL is negative

f_{ptop} and f_{pbot} - Stresses due to prestressing only
S_t and S_b - Top and bottom section moduli

Maximum spacing of the links, s_{vmax} :

- For $V < 1.8V_c$, s_{vmax} = min{ $0.75d_t$, $4b_w$ }
- For $V > 1.8V_c$, s_{vmax} = min{ $0.5d_t$, $4b_w$ }

Maximum lateral spacing of individual legs of the stirrups = $0.75d_t$

- **Two-way shear**[19]

    - **Categorization of columns**

No criterion is mentioned in IS code regarding categorizations of columns for punching shear check. The program uses ACI-318 criteria as detailed below.

Based on the geometry of the floor slab at the vicinity of a column, each column is categorized into to one of the following options:

1. Interior column
   Each face of the column is at least four times the slab thickness away from a slab edge

2. Edge column
   One side of the column normal to the axis of the moment is less than four times the slab thickness away from the slab edge

3. Corner column
   Two adjacent sides of the column are less than four times the slab thickness from slab edges parallel to each

4. End column
   One side of the column parallel to the axis of the moment is less than four times the slab thickness from a slab edge

[19] IS 456:2000 Section 31.6

In cases 2, 3 and 4, column is assumed to be at the edge of the slab. The overhang of the slab beyond the face of the column is not included in the calculations. Hence, the analysis performed is somewhat conservative.

- **Design Stress**

Stress is calculated for several critical perimeters around the columns based on the combination of the direct shear and moment:

$$\tau_v = \frac{V_u}{A} + \frac{\alpha_v \times M_u \times c}{J_c}$$

Where V_u is the absolute value of the direct shear and M_u is the absolute value of the unbalanced column moment about the center of geometry of the critical section. c is the distance of the point of interest to the center of the critical section, A is the area of the critical section, α_v is the ratio of the moment transferred by shear and J_c is the property of assumed critical section analogous to polar moment of inertia.

The implementation of the above in ADAPT is provided with the option of allowing the user to consider the contribution of the moments separately or combined. ACI 318 however recommends that due to the empirical nature of its formula, punching shear check should be performed independently for moments about each of the principal axis[20].

For a critical section with dimension of b_1, b_2 and column dimensions of c_1, c_2 and effective depth of d, A, J_c, c, α_v and M_u are:

1. Interior column:

$$A = 2(b_1 + b_2)d$$

$$c = \frac{b_1}{2}$$

$$J_c = \frac{b_1 d^3}{6} + \frac{d b_1^3}{6} + \frac{b_1^2 b_2 d}{2}$$

$$\alpha_v = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{b_1}{b_2}}}$$

$$M_u = abs\left[M_{u,direct}\right]$$

2. End column: (b_1 is perpendicular to the axis of moment)

$$A = (2b_1 + b_2)d$$

$$c = \frac{b_1^2 d}{2b_1 d + b_2 d}$$

$$J_c = \frac{b_1 d^3}{6} + \frac{d b_1^3}{6} + 2b_1 d\left(\frac{b_1}{2} - c\right)^2 + b_2 d c^2$$

[20] "Cocrete Q&A- Checking Punching Shear Strength by the ACI code," Concrete International, November 2005, pp 76.

$$\alpha_v = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{b_1}{b_2}}}$$

$$M_u = abs\left[M_{u,direct} - V_u(b_1 - c - \frac{c_1}{2})\right]$$

3. Corner Column:

$$A = \left(b_1 + b_2\right)d$$

$$c = \frac{b_1^{\,2}}{2b_1 + 2b_2}$$

$$J_c = \frac{b_1 d^3}{12} + \frac{d b_1^{\,3}}{12} + b_1 d\left(\frac{b_1}{2} - c\right)^2 + b_2 d c^2$$

$$\alpha_v = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{b_1}{b_2}}}$$

$$M_u = abs\left[M_{u,direct} - V_u(b_1 - c - \frac{c_1}{2})\right]$$

4. Edge column: (b_1 is perpendicular to the axis of moment)

$$A = \left(b_1 + 2b_2\right)d$$

$$c = \frac{b_1}{2}$$

$$J_c = \frac{b_1 d^3}{12} + \frac{d b_1^{\,3}}{12} + 2b_2 d c^2$$

$$\alpha_v = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{b_1}{b_2}}}$$

$$M_u = abs\left[M_{u,direct}\right]$$

- **Allowable Stress**

For prestressed and non-prestressed members:

$\tau_{allow} = k_s\ \tau_c$

where,

$k_s = (0.5 + \beta_c) < 1$

β_c = ratio of short side to long side of column/capital

$\tau_c = 0.25\sqrt{f_{ck}}$

- **Critical sections**

The closest critical section to check the stresses is d/2 from the face of the column where d is the effective depth of the slab/drop cap. Subsequent sections are 0.5d away from the previous critical section.

If drop cap exists, stresses are also checked at 0.5d from the face of the drop cap in which d is the effective depth of the slab. Subsequent sections are 0.5d away from the previous critical section.

- **Stress check**

Calculated stresses are compared against the allowable stress:

If $\tau_v < \tau_{allow}$ no punching shear reinforcement is required
If $\tau_v > \tau_{max} = 1.5\,\tau_c$ punching stress is excessive; revise the section
If $\tau_{max} > \tau_v > \tau_{allow}$ provide punching shear reinforcement

For the option of considering moments separately, if stress is below the permissible value in both directions, then no shear reinforcement is needed otherwise if at least in one direction, stress exceeds the permissible value, shear reinforcement should be provided.

Stress check is performed until shear stress does not exceed $0.5\tau_c$[21]. Where drop caps exist, stresses are checked within the drop cap until the design stress is less than the permissible, then in a similar manner the stresses are checked outside the drop cap.

- **Shear reinforcement**

Where needed, shear reinforcement is provided according to the following:

$$A_s = \frac{(\tau_v - 0.5\tau_c)\ b_0 s}{0.87 f_y}$$

Where τ_v is the maximum shear stress calculated based on the direct shear and moments using the equations shown earlier.

b_0= periphery of the critical section ,
s = spacing between the critical sections [d/2].

- **Arrangement of shear reinforcements**[22]

Shear reinforcement can be in the form of shear studs or shear stirrups (links). In case of shear links, the number of shear links (N_{shear_links}) in a critical section and distance between the links ($Dist_{shear\_links}$) are given by:

[21] IS 456:2000 Section 31.6.3.2
[22] IS code does not specify the type of reinforcement, so reinforcement based on ACI-318 will be used.

$$N_{shear\_links} = \frac{A_s}{A_{shear\_link}}$$

$$Dist_{shear\_links} = \frac{b_0}{N_{shear\_links}}$$

If shear studs are used, the number of shear studs per rail (N_{shear_studs}) and the distance between the studs ($Dist_{shear\_studs}$) are given by:

$$N_{shear\_studs} = \frac{A_s}{A_{shear\_stud} \times N_{rails}}$$

$$Dist_{shear\_studs} = \frac{d_{slab}}{N_{shear\_studs}}$$

INITIAL CONDITION

- **Load combinations**[23]

  1.0 DL +1.15 PT

- **Allowable stresses**

  i. Tension[24]:

  $0.22\sqrt{f_{ci}}$

  Compression stresses are as follows:

  i. Stress in flexure:

  § Post-Tensioned member:

  For Grade M 30, $0.54f_{ci}$

  For Grade M 60, $0.37f_{ci}$

  § Pre-Tensioned member:

  For Grade M 30, $0.51f_{ci}$

  For Grade M 60, $0.44f_{ci}$

  where,

  f_{ci} = Cube strength of concrete at transfer

  iii. Stress in average precompression:

  0.8 times the maximum allowable compressive stress in compression given in (i).

DETAILING

- **Reinforcement requirement and placing**

  Non-prestressed member[25]

[23] IS code does not specify the load combination for initial condition. So ACI-318 will be used.

[24] Not explicit in IS code, so ACI-318 will be used.

- Minimum and maximum tension rebar

  Beam:

  $$A_{s\,min} = \frac{0.85bd}{f_y}$$

  A_{smax}= 0.04bh

  Slab:

  A_{smin}= 0.0015A_c

  $\phi_{max} < h/8$

  where Φ = diameter of the bar

- Maximum compression rebar

  Beam - A_{smax}= 0.04bh

Prestressed member[26]

Minimum longitudinal reinforcement: 0.002 A_c

The requirement is satisfied by both prestressed and non-prestressed reinforcement, using the following relationship.

$$\frac{\left(A_p \times \frac{f_{py}}{f_y} + A_s\right)}{A_c} \geq 0.002$$

Minimum for cracking moment capacity:

The total reinforcement should provide a design capacity equal or larger than the cracking moment.

APPENDIX

This appendix includes additional information directly relevant to the design of concrete structures, but not of a type to be included in the program.

- **Effective width of the flange[27]**

  Effective flange width is not included in ADAPT Floor Pro, because it is implicit in the finite element analysis of Floor Pro. But this will be included in ADAPT_PT and will be calculated as follows:

  - For T-Beams

  $$b_f = \frac{l_o}{6} + b_w + 6h_f < b_w + \frac{(l_1 + l_2)}{2}$$

  - For L-Beams

  $$b_f = \frac{l_0}{12} + b_w + 3h_f < b_w + \frac{(l_1 + l_2)}{2}$$

  - For isolated beams

[25] IS 456:2000 Section 26.5

[26] IS 1343:1980 Section 18.6.3.1

[27] IS 456:2000 Section 23.1.2

T-Beams, $$b_f = \frac{l_0}{\left(\frac{l_0}{b}\right)+4} + b_w < b_w + \frac{(l_1 + l_2)}{2}$$

L-Beams, $$b_f = \frac{0.5 l_0}{\left(\frac{l_0}{b}\right)+4} + b_w < b_w + \frac{(l_1 + l_2)}{2}$$

where,

b_f = effective width of flange,
l_0 = distance between points of zero moments in the beam,
For continuous beams and frames, l_0 = 0.7*effective span
b_w = breadth of the web,
l_1, l_2 = clear span length of the adjacent spans,
h_f = thickness of flange, and
b = actual width of the flange.

- **ANALYSIS**
  - Skipping of Live Load[28]
    If the ratio of live over dead load exceeds 0.75, live load is skipped as in the following combination:
    - § Design dead load on all spans with full design imposed load on two adjacent spans; and
    - § Design load on all spans with full design imposed load on alternate spans.
  - Redistribution of moment[29]
    - § No redistribution is allowed if the ultimate moment of resistance at any section of a member is less than 70% of the factored moment at that section for non-prestressed and 80% of the factored moment at that section for prestressed structure;
    - § The percentage of moment redistribution should not be more than 30 for non-prestressed and 20 for prestressed structure;
    - § At sections where the moment capacity after redistribution is less than the elastic moment, the following relationship will be satisfied:

$$\frac{x_u}{d} + \frac{\delta M}{100} \le 0.6$$, 0.5 for prestressed structure

where,

x_u = depth of neutral axis,
d = effective depth, and
δM = percentage reduction in moment.

- **Deflection[30]**
  Long-Term deflection without super-imposed dead load - L/250
  Long-Term deflection including instantaneous deflection due to super-imposed dead load - min {L/350, 20mm}

[28] IS 456:2000 Section 22.4.1
[29] IS 456:2000 Section 37.1.1
[30] IS 456:2000 Section 23.2 and IS 1343:1980 Section 19.3.1

Camber - L/300

L- span length of the member

NOTATION

A_t = area of concrete in tension zone;

DL = dead Load;

EL = earthquake Load;

f_{ck} = characteristic compressive cube strength at 28 days;

f_p = characteristic tensile strength of prestressing steel [1860 MPa];

f_{py} = characteristic yield strength of prestressing steel [1700 MPa];

f_y = characteristic yield strength of steel, [460 MPa];

Hyp = hyperstatic(secondary);

h = overall depth of the beam/ slab;

LL = live load;

s_v = spacing of the stirrups;

τ_v = design shear stress;

τ_c = concrete shear strength;

x_u = depth of neutral axis;

w_{cr} = design (computed) crack width; and

WL = wind load.