

ACI-318-08 CODE REQUIREMENTS FOR DESIGN OF CONCRETE FLOOR SYSTEMS¹

This Technical Note details the requirements of ACI318 -08 for design of concrete floor systems, with emphasis on post-tensioning and their implementation in the ADAPT Builder Platform programs.

The implementation follows the ACI 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 ACI 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
- Strength limit state
- Initial condition (transfer of prestressing)
- Reinforcement requirement and detailing

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

- Bending of section
- 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. ACI-318R-08
2. ACI-318M-08

MATERIAL AND MATERIAL FACTORS

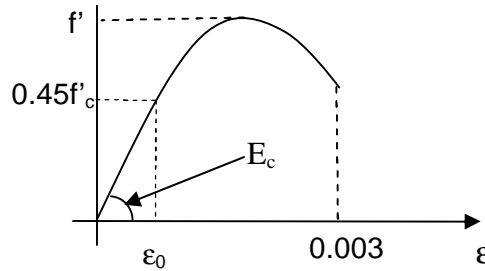
Concrete²

- Cylinder strength at 28 days, as specified by the user
 f'_c = characteristic compressive cylinder strength at 28 days [psi, MPa];

¹ Copyright ADAPT Corporation 2009

² ACI-318-08, Section 10.2.6

- Parabolic stress/strain curve with the maximum stress at f'_c and maximum strain at 0.003. Strain at limit of proportionality is not defined.



- Modulus of elasticity of concrete is automatically calculated and displayed by the program using f'_c , w_c , and the following relationship³ of the code. User is given the option to override the code value and specify a user defined substitute.

$$E_c = w_c^{1.5} \times 33 \sqrt{f'_c} \quad \text{US}$$

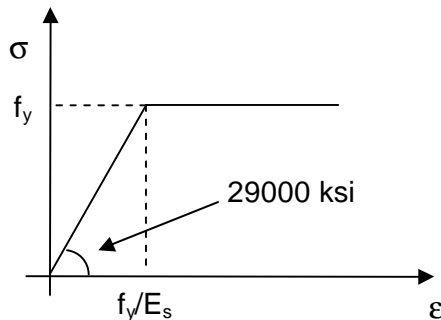
$$E_c = w_c^{1.5} \times 0.043 \sqrt{f'_c} \quad \text{SI}$$

Where,

- E_c = modulus of elasticity at 28 days [psi, MPa]
- f'_c = characteristic cylinder strength at 28 days
- w_c = density of concrete [150 lb/ft³, 2400 kg/m³]

Nonprestressed Steel⁴

- Bilinear stress/strain diagram with the horizontal branch at f_y
- Modulus of elasticity (E_s) is user defined [29000 ksi, 200,000 MPa]
- No limit has been set for the ultimate strain of the mild steel in the code.



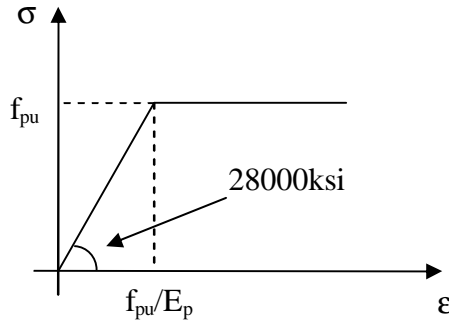
Prestressing Steel

- A bilinear stress-strain curve is assumed.

³ ACI-318-08, Section 8.5.1

⁴ ACI-318-08, Section 10.2.4

- Modulus of elasticity is user defined [28000 ksi, 190,000 MPa]



LOADING

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

SERVICEABILITY

- **Load combinations**

Total load combinations:

- 1.0 DL+1.0 LL+1.0 PT

Sustained load combinations

- 1.0 DL+0.3 LL+1.0 PT

The above combinations are the default settings of the program. User has the option to change them.

- **Stress checks**

Code stipulated stress limitations are used as default. However, user can edit the default values.

“Total load” condition:

- Concrete

§ Maximum compressive stress $0.60 f'_c$. If calculated stress at any location exceeds the allowable, the program identifies the location graphically on the screen and notes it in its tabular reports.

§ The maximum allowable hypothetical tensile stress for one-way slabs and beams depends on the selection of design in one of the three classes of uncracked (U), transition (T) or cracked (C):

Class U : $f_t \leq 7.5\sqrt{f'_c}$ ($0.62\sqrt{f'_c}$)

Class T : $7.5\sqrt{f'_c} < f_t \leq 12\sqrt{f'_c}$ ($1\sqrt{f'_c}$)

Class C : $f_t > 12\sqrt{f'_c}$

§ For two-way slabs design only Class U (uncracked) is permitted,:

Class U with $f_t \leq 6\sqrt{f'_c}$ ($0.5\sqrt{f'_c}$).

- Nonprestressed Reinforcement
 - § None specified
- Prestressing steel
 - § None specified

“Sustained load” condition:

- Concrete
 - § Maximum compressive stress $0.45 f'_c$. 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 the text output.
 - § The maximum allowable hypothetical tensile stress:
 - Class U : $f_t \leq 7.5\sqrt{f'_c}$ ($0.62\sqrt{f'_c}$)
 - Class T : $7.5\sqrt{f'_c} < f_t \leq 12\sqrt{f'_c}$ ($1\sqrt{f'_c}$)
 - Class C : $f_t > 12\sqrt{f'_c}$

Two- way slab systems: Class U with $f_t \leq 6\sqrt{f'_c}$ ($0.5\sqrt{f'_c}$).

Program does not handle Class C type.

ADAPT uses $6\sqrt{f'_c}$ ($0.5\sqrt{f'_c}$) as its default value for two-way systems and $7.5\sqrt{f'_c}$ ($0.62\sqrt{f'_c}$) as default for one- way systems .

- Nonprestressed Reinforcement
 - § None specified – no check made
- Prestressing steel
 - § None specified - no check made

STRENGTH

- **Load combinations⁵**

The following are the load combinations for gravity design of floor systems:

- 1.4 D +1.0 Hyp
- 1.2 D + 1.6 L + 1.0 Hyp

- **Check for bending⁶**

- Plane sections remain plane. Strain compatibility is used to determine the forces on a section.
- Maximum concrete strain in compression is limited to 0.003.
- Tensile capacity of the concrete is neglected.
- For ductility of members designed in bending the maximum depth of the neutral axis “c” is limited to :

⁵ ACI-318-08, Section 9.2.1

⁶ ACI-318-08, Section 10.2

$$c / d_t \leq 0.375$$

Where, d_t is the distance from compression fiber to the farthest reinforcement. 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.
- Rectangular concrete stress block with maximum stress equal to $0.85f'_c$ and the depth of stress block from the extreme compression fiber, a , equal to $\beta_1 c$ is used.

where,

$$\begin{aligned} \beta_1 &= 0.85 - 0.05(f'_c - 4000)/1000 \geq 0.65 && \text{US} \\ \beta_1 &= 0.85 - 0.05(f'_c - 28)/7 \geq 0.65 && \text{SI} \end{aligned}$$

- 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.
- At every section of a flexural post-tensioned member with bonded tendons, the following will be satisfied⁷:

$$M_n \geq 1.2M_{cr}$$

Where,

$$\begin{aligned} M_{cr} &= \text{cracking moment} = S^*(f_p + f_t) \\ S &= \text{section modulus} \\ f_p &= \text{stress due to post-tensioning} \\ f_t &= \text{tensile strength of the concrete} \end{aligned}$$

• **One-way shear**⁸

The design is based on the following:

$$\Phi V_n \geq V_u$$

$$V_n = V_c + V_s \leq V_{n,max}^9$$

$$V_{n,max} = 8\sqrt{f'_c} b_w d \quad \text{US}$$

$$V_{n,max} = 0.66\sqrt{f'_c} b_w d \quad \text{SI}$$

where,

$$\begin{aligned} V_n &= \text{factored shear resistance;} \\ V_u &= \text{factored shear force due to design loads;} \\ V_c &= \text{shear resistance attributed to the concrete;} \\ V_s &= \text{shear resistance provided by shear reinforcement;} \\ b_w &= \text{width of the web [in];} \\ d &= \text{effective shear depth [in]} \\ \sqrt{f'_c} &\leq 100 \text{ psi, } 8.3 \text{ MPa} \end{aligned}$$

⁷ ACI-318-08, Section 18.8.1

⁸ ACI-318-08, Section 11.1

⁹ ACI-318-08, Section 11.4.7.9

Design shear strength of concrete, V_c ¹⁰:

- Non-prestressed members

§ For members subject to shear and flexure only:

$$V_c = 2\lambda\sqrt{f'_c}b_wd \quad \text{US}$$

$$V_c = 0.17\lambda\sqrt{f'_c}b_wd \quad \text{SI}$$

Where,

- λ - a modification factor for concrete strength.
 - 1 for normal weight concrete
 - 0.85 for sand light-weight concrete
 - 0.75 for all-light-weight concrete

§ For members subject to axial compression:

$$V_c = 2\left(1 + \frac{N_u}{2000A_g}\right)\lambda\sqrt{f'_c}b_wd \quad \text{US}$$

$$V_c = 0.17\left(1 + \frac{N_u}{14A_g}\right)\lambda\sqrt{f'_c}b_wd \quad \text{SI}$$

Where N_u/A_g is in psi, MPa

- Prestressed members

$$V_c = \left(0.6\lambda\sqrt{f'_c} + 700\frac{V_u d_p}{M_u}\right)b_wd \geq V_{c \min} = 2\lambda\sqrt{f'_c}b_wd$$

$$\leq V_{c \max} = 5\lambda\sqrt{f'_c}b_wd$$

Where,

$$V_u d_p / M_u \leq 1$$

Shear reinforcement, A_v ¹¹:

§ If $V_u - \Phi V_c > V_{n, \max}$

shear is excessive, revise the section or increase the concrete strength

§ If $V_u < 0.5\Phi V_c$

no shear reinforcement is required

§ If $0.5\Phi V_c < V_u < \Phi V_c$

$$A_v = A_{v \min}^{12},$$

§ If $V_u > \Phi V_c$

$$A_v = \frac{(V_u - \Phi V_c) s}{\phi f_y t d}^{13} \geq A_{v \min}$$

Where $A_{v \min}$,

Nonprestressed members:

¹⁰ ACI-318-08, Section 11.2

¹¹ ACI-318-08, Section 11.4

¹² ACI-318-08, Section 11.4.6.3 & 11.4.6.4

¹³ ACI-318-08, Section R11.4.7

$$A_{v \min} = 0.75\sqrt{f'_c} \frac{b_w s}{f_{yt}} \geq \frac{50b_w s}{f_{yt}} \quad \text{US}$$

$$A_{v \min} = 0.062\sqrt{f'_c} \frac{b_w s}{f_{yt}} \geq \frac{0.35b_w s}{f_{yt}} \quad \text{SI}$$

Prestressed members:

$$A_{v \min} = \text{smaller of } \left\{ 0.75\sqrt{f'_c} \frac{b_w s}{f_{yt}}, \frac{50b_w s}{f_{yt}}, \frac{A_{ps} f_{pu} s}{80f_{yt} d} \sqrt{\frac{d}{b_w}} \right\} \quad \text{US}$$

$$A_{v \min} = \text{smaller of } \left\{ 0.062\sqrt{f'_c} \frac{b_w s}{f_{yt}}, \frac{0.35b_w s}{f_{yt}}, \frac{A_{ps} f_{pu} s}{80f_{yt} d} \sqrt{\frac{d}{b_w}} \right\} \quad \text{SI}$$

Where,

s = longitudinal spacing of vertical stirrups [in,mm].
 f_{yt} = characteristic strength of the stirrup [psi, MPa]

Maximum spacing of the links, $s_{v \max}^{14}$:

- Nonprestressed members:

US:

$$s_{v \max} = d/2 \leq 24 \text{ in} \quad \text{if } (V_u - \phi V_c) < \phi 4\sqrt{f'_c} b_w d$$

$$s_{v \max} = d/4 \leq 12 \text{ in} \quad \text{if } \phi 4\sqrt{f'_c} b_w d < (V_u - \phi V_c) \leq \phi 8\sqrt{f'_c} b_w d$$

SI:

$$s_{v \max} = d/2 \leq 600 \text{ mm} \quad \text{if } (V_u - \phi V_c) < \phi 0.33\sqrt{f'_c} b_w d$$

$$s_{v \max} = d/4 \leq 300 \text{ mm} \quad \text{if } \phi 0.33\sqrt{f'_c} b_w d < (V_u - \phi V_c) \leq \phi 0.66\sqrt{f'_c} b_w d$$

- Prestressed members:

US:

$$s_{v \max} = 0.75h \leq 24 \text{ in} \quad \text{if } (V_u - \phi V_c) < \phi 4\sqrt{f'_c} b_w d$$

$$s_{v \max} = 0.375h \leq 12 \text{ in} \quad \text{if } \phi 4\sqrt{f'_c} b_w d < (V_u - \phi V_c) \leq \phi 8\sqrt{f'_c} b_w d$$

SI:

$$s_{v \max} = 0.75h \leq 600 \text{ mm} \quad \text{if } (V_u - \phi V_c) < \phi 0.33\sqrt{f'_c} b_w d$$

$$s_{v \max} = 0.375h \leq 300 \text{ mm} \quad \text{if } \phi 0.33\sqrt{f'_c} b_w d < (V_u - \phi V_c) \leq \phi 0.66\sqrt{f'_c} b_w d$$

- **Two-way shear**

- **Categorization of columns**

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

¹⁴ ACI-318-08, Section 11.4.5

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

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.

o **Stress calculation:**

The maximum factored shear stress is calculated for several critical perimeters around the columns based on the combination of the direct shear and moment¹⁵:

$$v_{u1} = \frac{V_u}{A} + \frac{\gamma \times M_u \times c}{J_c}$$

$$v_{u2} = \frac{V_u}{A} - \frac{\gamma \times M_u \times c'}{J_c}$$

Where,

- V_u - absolute value of the direct shear and
- M_u - absolute value of the unbalanced column moment about the center of geometry of the critical section
- c and c' - distances from centroidal axis of critical section to the perimeter of the critical section in the direction of the analysis
- A - area of concrete of assumed critical section,
- γ - ratio of the moment transferred by shear and
- J_c - moment of inertia of the critical section about the axis of moment.

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 axis¹⁶.

For a critical section with dimension of b_1 and b_2 and column dimensions of c_1 , c_2 and average depth of d , A_c , J_c , c , γ and M_u are:

1. Interior column:

¹⁵ ACI-318-08, Section R11.11.7.2

¹⁶ "Concrete Q&A- Checking Punching Shear Strength by the ACI code," Concrete International, November 2005, pp 76.

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

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

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

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

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

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

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

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

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

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

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

3. Corner Column:

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

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

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

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

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

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

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

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

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

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

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

o **Allowable stress¹⁷:**

For nonprestressed member and prestressed member where columns are less than 4h_s from a slab edge:

$$v_c = \min \begin{cases} (2 + \frac{4}{\beta_c}) \lambda \sqrt{f'_c} \\ (2 + \alpha_s \frac{d}{u}) \lambda \sqrt{f'_c} \\ 4 \lambda \sqrt{f'_c} \end{cases} \quad \text{US}$$

$$v_c = \min \begin{cases} 0.17 (1 + \frac{2}{\beta_c}) \lambda \sqrt{f'_c} \\ 0.083 (2 + \alpha_s \frac{d}{u}) \lambda \sqrt{f'_c} \\ 0.33 \lambda \sqrt{f'_c} \end{cases} \quad \text{SI}$$

where β_c is the ratio of the larger to the smaller side of the critical section and f'_c is the strength of the concrete. α_s is 40 for interior columns, 30 for edge and end columns and 20 for corner columns. u is the perimeter of the critical section.

For prestressed member where columns are more than 4h_s from a slab edge:

$$v_c = (\beta_p \lambda \sqrt{f'_c} + 0.3 f_{pc}) + v_p$$

where,

β_p = the smaller of 3.5 and (α_sd/b₀ + 1.5) - US

= the smaller of 0.29 and 0.083* (α_sd/b₀ + 1.5) -SI

α_s = 40 for interior columns, 30 for edge columns, and 20 for corner columns

b₀ = the perimeter of the critical section

f_{pc} = the average value of f_{pc} for the two directions ≤ 500 psi(3.5 MPa), ≥ 125 psi(0.9 MPa)

V_p = the factored vertical component of all prestress forces crossing the critical section. ADAPT conservatively assumes it as zero.

¹⁷ ACI-318-08, Section 11.11.2.1& 11.11.12.2

$$\sqrt{f'_c} \leq 70 \text{ psi (0.5 MPa)}$$

○ **Critical sections¹⁸**

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 stress¹⁹:

If $V_u < \phi_v V_c$	no punching shear reinforcement is required
If $V_u > \phi_v V_{n,max}$	punching stress is excessive; revise the section
If $\phi_v V_{n,max} > V_u > \phi_v V_c$	provide punching shear reinforcement

For stirrups²⁰:

$\phi_v V_{n,max}$	=	$\phi_v * 6 \sqrt{f'_c}$	US
	=	$\phi_v * 0.5 \sqrt{f'_c}$	SI

For studs²¹:

$\phi_v V_{n,max}$	=	$\phi_v * 8 \sqrt{f'_c}$	US
	=	$\phi_v * 0.66 \sqrt{f'_c}$	SI

Where ϕ_v is the shear factor and $v_{n,max}$ is the maximum shear stress that can be carried out by the critical section including the stresses in shear reinforcement.

Stress check is performed until no shear reinforcement is needed anymore. In case of existence of a drop cap, stresses are checked within the drop cap until the stress is less than the permissible stress and then checked outside the drop cap region until the stress is less than the permissible value.

V_u shall not exceed $\phi_v * 2 * \lambda * \sqrt{f'_c}$ ²² [$\phi_v * 0.17 * \lambda * \sqrt{f'_c}$ in SI] at the critical section located $d/2$ outside the outermost line of shear reinforcement that surround the column.

○ **Shear reinforcement**

Where needed, shear reinforcement is provided according to the following:²³

¹⁸ ACI-318-08, Section 11.11.1.2

¹⁹ ACI-318-08, Section 11.11.7.2

²⁰ ACI-318-08, Section 11.11.3.2

²¹ ACI-318-08, Section 11.11.5.1

²² ACI-318-08, Section 11.11.5.4 for studs and 11.11.7.2 for stirrups

²³ ACI-318-08, Section 11.4.7

$$A_v = \frac{(v_u - \phi_v v_c) u s}{\phi_v f_y \sin(\alpha)}$$

For studs, $A_v \geq A_{vmin}^{24}$ where $A_{vmin} = \frac{2\sqrt{f'_c} u s}{f_y}$

Where,

$$v_c = \begin{matrix} = 2\lambda\sqrt{f'_c}^{25} & [0.17\lambda\sqrt{f'_c} \text{ in SI}] & \text{for stirrups} \\ = 3\lambda\sqrt{f'_c}^{26} & [0.25\lambda\sqrt{f'_c} \text{ in SI}] & \text{for studs} \end{matrix}$$

α is the angle of shear reinforcement with the plane of slab and u is the periphery of the critical section. s is the spacing between the critical sections [$d/2$].

If required, shear reinforcement will be extended to the section where v_u is not greater than $\phi_v 2\lambda\sqrt{f'_c}$ [$\phi_v 0.17\lambda\sqrt{f'_c}$ in SI].

o **Arrangement of shear reinforcements:**

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:

$$N_{shear_links} = \frac{A_v}{A_{shear_link}}$$

$$Dist_{shear_links} = \frac{u}{N_{shear_links}}$$

The first layer of stirrups is provided at $d/2$ from the column face and the successive layers are at $d/2$ from the previous layer. The spacing between the adjacent stirrup legs in the first line of shear reinforcement shall not exceed $2d$ measured in a direction parallel to the column face²⁷.

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:

$$N_{shear_studs} = \frac{A_v}{A_{shear_stud} \times N_{rails}}$$

$$Dist_{shear_studs} = \frac{d/2_{slab}}{N_{shear_studs}}$$

The spacing between the column face and the first peripheral line of shear reinforcement shall not exceed $d/2$. The spacing between adjacent shear reinforcement elements,

²⁴ ACI-318-08, Section 11.11.5.1

²⁵ ACI-318-08, Section 11.11.3.1

²⁶ ACI-318-08, Section 11.11.5.1

²⁷ ACI-318-08, Section 11.11.3.3

measured on the perimeter of the first peripheral line of shear reinforcement, shall not exceed 2d. The spacing between peripheral lines of shear reinforcement, measured in a direction perpendicular to any face of the column, shall be constant²⁸.

INITIAL CONDITION

- **Load combinations**

ADAPT uses the following default values. User can modify these values.

1.0 SW +1.15 PT

- **Allowable stresses²⁹**

i. Tension:

At ends of simply supported members: $6\sqrt{f'_{ci}}$ ($0.5\lambda\sqrt{f'_{ci}}$)
 All others : $3\sqrt{f'_{ci}}$ ($0.25\lambda\sqrt{f'_{ci}}$)

The latter option is coded in ADAPT as default.

ii. Compression : $0.6f'_{ci}$

If the tensile stress exceeds the threshold, program adds rebar in the tensile zone.

- **Reinforcement**

Reinforcement will be provided for initial condition if tensile stress exceeds allowable stress. Rebar is provided based on ACI code and will be placed on tension side:

$$A_s = \frac{N_c}{0.5f_y}$$

Where:

A_s = Area of reinforcement
 N_c = tensile force in the concrete computed on the basis of uncracked section.
 f_y = Yield Stress of the steel but not more that 60 ksi

DETAILING

- **Reinforcement requirement and placing³⁰**

- Nonprestressed member:

Minimum tension rebar

§ Beam:

$$A_{s \min} = \frac{3\sqrt{f'_{ci}}b_wd}{f_y} \geq \frac{200b_wd}{f_y} \quad \text{US}$$

$$A_{s \min} = \frac{0.25\sqrt{f'_{ci}}b_wd}{f_y} \geq \frac{1.4b_wd}{f_y} \quad \text{SI}$$

²⁸ ACI-318-08, Section 11.11.5.3

²⁹ CSA A23.3-04 Section 18.3.1.1

³⁰ ACI-318-08, Section 10.5

where,

b_w = width of the web [in,mm]

For statically determinate members with flange in tension,

$$A_{s \min} = \frac{3\sqrt{f'c}bd}{f_y} \geq \frac{200bd}{f_y} \quad \text{US}$$

$$A_{s \min} = \frac{0.25\sqrt{f'c}b_wd}{f_y} \geq \frac{1.4b_wd}{f_y} \quad \text{SI}$$

where,

b = minimum of { $2b_w$, width of the flange } [in,mm]

Minimum rebar requirement will be waived if A_s provided is at least 1/3 greater than that required by Analysis.

§ Slab³¹:

$$\begin{aligned} A_{s \min} &= 0.0018A_g \quad \text{for } f_y = 60 \text{ ksi} \\ &= 0.0020 A_g \quad \text{for } f_y = 40 \text{ or } 50 \text{ ksi} \\ &= 0.0018 \cdot (60/f_y) \cdot A_g \quad \text{for } f_y > 60 \text{ ksi, where } f_y \text{ in ksi} \end{aligned}$$

$$s_{\max} = \min(3h, 18\text{in}) \quad \text{US}$$

$$s_{\max} = \min(3h, 450\text{mm}) \quad \text{SI}$$

- Prestressed member:

§ One way system with unbonded tendon:

$$A_{s \min} = 0.004A_{ct}$$

Where,

A_{ct} = Area of that part of cross-section between the flexural tension face and center of gravity of cross-section

§ Two way system with unbonded tendon:

Positive moment areas if tensile stress exceeds $2\sqrt{f'c}$:

$$A_{s \min} = \frac{N_c}{0.5f_y}$$

Negative moment areas at column supports:

$$A_{s \min} = 0.00075A_{cf}$$

Where,

A_{cf} = larger gross cross-sectional area of the design strips in two orthogonal directions

³¹ ACI-318-08, Section 7.12.2.1

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 flange³²**

- i. For T-Beams

Effective flange width $\leq \frac{1}{4}$ of the span length and;

Effective overhanging flange width on each side is the smallest of:

- a. 8 times the flange thickness;
- b. $\frac{1}{2}$ of the clear distance to the next web.

- ii. For L-Beams

Effective overhanging flange width on each side is the smallest of:

- a. $\frac{1}{12}$ th of the span length of the beam;
- b. 6 times the flange thickness;
- c. $\frac{1}{2}$ of the clear distance to the next web.

- **Analysis**

- Arrangement of loads³³:

Continuous beams and one-way slabs:

§ factored dead load on all spans with full factored live load on two adjacent spans;

§ factored dead load on all spans with full factored live load on alternate spans; and

Two-way slabs³⁴:

If the ratio of live over dead load exceeds 0.75, live load is skipped as in the following combination:

§ factored dead load on all spans with $\frac{3}{4}$ th of the full factored live load on the panel and on alternate panels; and

§ factored dead load on all spans with $\frac{3}{4}$ th of the factored live load on adjacent panels only.

- **Redistribution of moment³⁵**

Redistribution is only permitted when the net tensile strain, ϵ_t , is not less than 0.0075.

Percentage of redistribution = $1000\epsilon_t\% \leq 20\%$

where,

ϵ_t = net tensile strain in extreme layer of longitudinal tension steel at nominal strength.

- **Deflection**

Maximum permissible computed deflections are based on Table 9.5(b)³⁶.

³² ACI-318-08, Section 8.12.2 & 8.12.3

³³ ACI-318-08, Section 8.11.2

³⁴ ACI-318-08, Section 13.7.6

³⁵ ACI-318-08, Section 8.4

³⁶ ACI-318-08, Section 9.5.2.6

NOTATION

- A_t = area of concrete in tension zone;
- C = depth of neutral axis; and
- D = dead load;
- f_c = characteristic compressive cylinder strength at 28 days;
- f_y = characteristic yield strength of steel, [60 psi, 420 MPa];
- h = overall depth of the beam/ slab;
- I = moment of inertia of section about centroidal axis;
- L = live load;
- ΦM_n = factored moment resistance;
- M_u = factored moment at section;
- s = spacing of the stirrups;
- v_u = design shear stress;
- v_c = concrete shear strength;
- λ = modification factor reflecting the mechanical properties of the concrete.