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CANADIAN CODE IMPLEMENTATION IN[1]
ADAPT SOFTWARE

This Technical Note details the implementation of the Canadian Code (CSA A23.3-04) in the Builder Platform programs.

The implementation follows the Canadian 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 Canadian 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
    - 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. CSA A23.3-04

MATERIAL AND MATERIAL FACTORS

Concrete[2]
- Cylinder strength at 28 days, as specified by the user
  f_{ck} = characteristic compressive cylinder strength at 28 days;

- Bilinear stress/strain curve with the horizontal branch at $0.9f'_c$ and maximum strain at 0.0035.Strain at limit of proportionality is not defined.

[1] Copyright 2006
[2] CSA A23.3-03 Section 10.1.3 & 10.1.6

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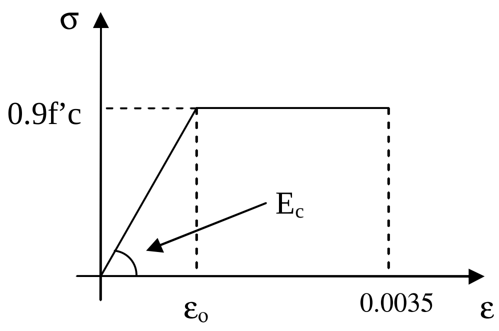


- Modulus of elasticity of concrete is automatically calculated and displayed by the program using f'_c, γc, and the following relationship[3] of the code. User is given the option to override the code value and specify a user defined substitute.

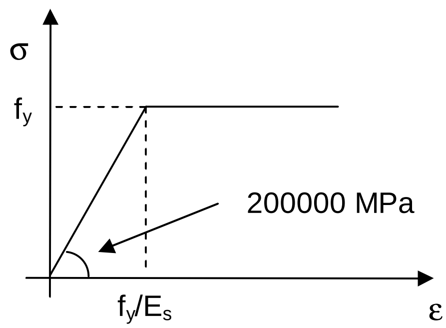
$$E_c = \left(3300\sqrt{f'_c} + 6900\right)\left(\frac{\gamma_c}{2300}\right)^{1.5}$$

where,

E_c	=	modulus of elasticity at 28 days
f'_c	=	characteristic cylinder strength at 28 days
γ_c	=	density of concrete [2400 kg/m^3]

Nonprestressed Steel[4]

- Bilinear stress/strain diagram with the horizontal branch at f_y
- Modulus of elasticity(E_s) is user defined [200000 MPa]
- No limit has been set for the ultimate strain of the mild steel in the code.



Prestressing Steel

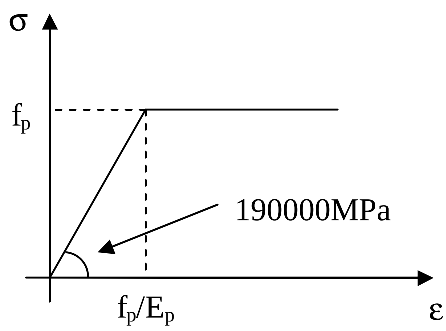
- A bilinear stress-strain curve is assumed.
- Modulus of elasticity is user defined [190000 MPa]

Material Factors

- Concrete $\Phi_c = 0.65$
- Nonprestressed steel $\Phi_s = 0.85$
- Prestressing steel $\Phi_p = 0.90$

[3] CSA A23.3-03 Section 8.6.2.2

[4] CSA A23.3-03 Section 8.5.3.2



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**[5]

  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 tensile zone exposed to corrosive environment : $0.25\lambda\sqrt{f'c}$
      For others : $0.5\lambda\sqrt{f'c}$

    ADAPT uses $0.50\lambda\sqrt{f'c}$ as its default value.

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

[5] CSA A23.3-94 Section 18.3.2

"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:

    For tensile zone exposed to corrosive environment : $0.25\lambda\sqrt{f'c}$
    For others : $0.50\lambda\sqrt{f'c}$

  ADAPT uses $0.50\lambda\sqrt{f'c}$ as its default value.

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

STRENGTH

- **Load combinations**[6]

  - 1. 4 D + 1.0 Hyp
  - (1.25 D or 0.9 D)+1.5 L + (0.5 S or 0.4 W)+1.0 Hyp
  - (1.25 D or 0.9 D)+1.5 S + (0.5 L or 0.4 W)+1.0 Hyp
  - (1.25 D or 0.9 D)+1.4 W + (0.5 L or 0.5 S)+1.0 Hyp
  - 1.0 D+1.0 E + 0.5 L+ 0.25 S +1.0 Hyp

- **Check for bending**[7]

  - 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 "c"[8] is determined based on yield strength of the steel f_y.

    $$c/d \leq \frac{700}{700 + f_y}$$

    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 based on stress-strain relationship assumed
  - Stress in prestressing steel is calculated as:
    - For bonded tendon, stress is calculated from stress-strain compatibility of the section
    - For unbonded tendon[9]:

6 CSA A23.3-94 Annex C, Table C.1
7 CSA A23.3-94 Section 10.1
8 CSA A23.3-94 Section 10.5.2
9 CSA A23.3-94 Section 18.6.2

$$f_p = f_{pe} + \frac{8000}{l_0} \sum_n (d_p - c_y) \leq f_{py}$$

Where,

f_p = characteristic strength of tendon;

f_{pe} = effective prestress after all losses;

d_p = distance from extreme compression fiber to centroid of the tendon;

c_y = distance from extreme compression fiber to neutral axis calculated using factored material strengths and assuming a tendon force of $\Phi_p A_p f_{py}$;

$\sum_n (d_p - c_y)$ = sum of the distance $d_p - c_y$ for each of the plastic hinges in the span under consideration.

- Rectangular concrete stress block with maximum stress equal to $\alpha_1 \Phi_c f'_c$ and the depth of stress block from the extreme compression fiber, a, equal to $\beta_1 c$ is used.
  where,

  α_1 = 0.85-0.0015f'_c ≥ 0.67

  β_1 = 0.97-0.0025f'_c ≥ 0.67

- 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 member, except post-tensioned two-way floor systems, the following will be satisfied[10]:

  $M_r \geq 1.2 M_{cr}$

  Where,

  $$M_{cr} = \frac{I}{y_t}(f_{ce} + f_r)$$

  f_{ce} = compression stress in the concrete due to effective prestress at the extreme fiber of a section where tensile stresses are caused by applied loads

  fr = $0.6\lambda\sqrt{f'_c}$

- **One-way shear**[11]

The design is based on the following:

$V_r \geq V_f$

$V_r = V_c + V_s + V_p \leq v_{r,max}$

$v_{r,max} = 0.25\phi_c f'_c b_w d_v + V_p$

[10] CSA A23.3-94 Section 18.7

[11] CSA A23.3-94 Section 11.3

where,

V_r = factored shear resistance;
V_f = factored shear force due to design loads;
V_c = shear resistance attributed to the concrete factored by Φ_c;
V_s = shear resistance provided by shear reinforcement factored by Φ_s;
V_p = component of the effective prestressing force in the direction of the applied shear factored by Φ_p. ADAPT conservatively assumes it as zero;
b_w = width of the web;
d_v = effective shear depth= max {0.9d, 0.72h}

Design shear strength of concrete, V_c:

- For beams and one-way slabs:

$$V_c = \phi_c \lambda \beta \sqrt{f'_c} b_w d_v$$

Where,
β = factor accounting for shear resistance of cracked concrete
= 0.18, if the section contains at least the minimum transverse reinforcement
$= \frac{230}{(1000 + d_v)}$, if the section contains no transverse reinforcement
$\sqrt{f'_c} \leq 8$ MPa

- In the vicinity of corner columns in two-way slabs without beams[12]:

Shear is checked along a critical section located at d/2 from the column face.

$$v_c = \phi_c \lambda \beta \sqrt{f'_c}$$

Shear reinforcement, A_v:

§ If $V_f > V_c + V_p$ or h >750 mm $\qquad A_v = \frac{V_s s}{\phi_s f_y d_v \cot\theta} \geq A_{v\,min}$[13]

$$A_{v\,min} = 0.06 \sqrt{f'_c} \frac{b_w s}{f_y}$$

Where,
V_s = V_f - (V_c+V_p)
s = longitudinal spacing of vertical stirrups.
f_y = characteristic strength of the stirrup ≤ 400 MPa
θ = angle of inclination of diagonal compressive stresses to the longitudinal axis of the member =35^0

Maximum spacing of the links, s_{vmax}[14] :

[12] CSA A23.3-04 Section 13.3.6
[13] CSA A23.3-04 Section 11.2.8.2
[14] CSA A23.3-04 Section 11.3.8

s_{vmax} = min { 0.70d_v, 600 mm} if $\left(V_f - \phi_p V_p\right) < 0.125\lambda\phi_c f'_c b_w d_v$

s_{vmax} = min { 0.35d_v, 300 mm} if $\left(V_f - \phi_p V_p\right) \geq 0.125\lambda\phi_c f'_c b_w d_v$

- **Two-way shear**

  - **Categorization of columns**

No criterion is mentioned in CSA 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

In cases 2, 3 and 4, if the slab cantilevers beyond the exterior face of the support, based on the code[15], critical section may be assumed to extend into the cantilevered portion of the slab for a distance not exceeding d. But the program conservatively assumes that the columns are at the slab edge. Hence, the overhang of the slab beyond the face of the column is not included in the calculations.

  - **Design Stress[16]**

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

$$v_f = \frac{V_f}{A} + \left(\frac{\gamma \times M_f \times e}{J}\right)_x + \left(\frac{\gamma \times M_f \times c}{J}\right)_y$$

Where V_f is the absolute value of the direct shear and M_f is the absolute value of the unbalanced column moment about the center of geometry of the critical section. e is the distance of the point of interest to the center of the critical section, A is the area of the

[15] CSA A23.3-04 Section 13.3.3

[16] CSA A23.3-04 Section 13.3.5

critical section, γ is the ratio of the moment transferred by shear and J is the property of assumed critical section analogous to polar moment of inertia.

The implementation of the above in ADAPT is extended with the option of allowing the user to consider the contribution of the moments separately.

For a critical section with dimension of b_1 and b_2 and effective depth of d, A, I, c, γ and M_f are:

1. Interior column:

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

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

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

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

$$M_f = abs\left[M_{f,direct}\right]$$

2. Edge column: (b_1 is parallel to the axis of moment)

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

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

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

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

$$M_f = abs\left[M_{f,direct} - V_f\left(\frac{b_1}{2} - c\right)\right]$$

3. Corner Column:

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

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

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

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

$$M_f = abs\left[M_{f,direct} - V_f(\frac{b_1}{2} - c)\right]$$

4. End column: (b_1 is parallel to the axis of moment)

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

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

$$I = \frac{b_1 d^3}{12} + \frac{d b_1^3}{12} + 2b_2 dc^2$$

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

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

- **Allowable Stress**

For non-prestressed member, and prestressed member where columns are less than $4h_s$ from a slab edge[17] :

$$v_c = \min\begin{cases} (\alpha_s \frac{d}{b_0} + 0.19)\lambda\phi_c\sqrt{f'_c} \\ (1 + \frac{2}{\beta_c})0.19\lambda\phi_c\sqrt{f'_c} \\ 0.38\lambda\phi_c\sqrt{f'_c} \end{cases}$$

where,
β_c = ratio of long side to short side of the column;
α_s = 4 for interior columns, 3 for edge columns, and 2 for corner columns.
$\sqrt{f'_c} \le 8$ MPa

If d> 300 mm, v_c will be multiplied by 1300/ (1300+d)

For prestressed member where columns are more than $4h_s$ from a slab edge[18]:

$$v_c = \beta_p\lambda\phi_c\sqrt{f'_c}\sqrt{1 + \frac{\phi_p f_{cp}}{0.33\lambda\phi_c\sqrt{f'_c}}} + \frac{v_p}{b_0 d}$$

where,

β_p = the smaller of 0.33 or $\left(\alpha_s d/b_0 + 0.15\right)$

α_s = 4 for interior columns, 3 for edge columns, and 2 for corner columns

b_0 = the perimeter of the critical section

f_{cp} = the average value of f_{cp} for the two directions ≤ 3.5 MPa

[17] CSA A23.3-04 Section 13.3.4

[18] CSA A23.3-04 Section 18.12.3.3

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

$f'_c \leq$ 35 MPa

- **Critical sections**[19]

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**

Stresses are calculated by combining the stresses in two directions and compared against the allowable stress. User has the option to consider the contribution of stress in each direction separately.

If $v_f < v_c$ no punching shear reinforcement is required
If $v_f > v_{max}$ punching stress is excessive; revise the section
If $v_{max} > v_f > v_c$ provide punching shear reinforcement

where,

v_{max} = maximum allowable shear stress for a critical section including the contribution of shear reinforcement

$= 0.75\lambda\phi_c\sqrt{f'_c}$ For headed shear reinforcement[20]

$= 0.55\lambda\phi_c\sqrt{f'_c}$ For stirrup reinforcement[21]

Stress check is performed until no shear reinforcement is needed. 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.

If the shear reinforcement is required, then the layer outside the last layer of reinforcement will be checked against $0.19\lambda\phi_c\sqrt{f'_c}$

- **Shear reinforcement**

Where needed, shear reinforcement is provided according to the following[22]:

$$A_{vs} = \frac{(v_f - v_c)b_0 s}{\phi_s f_y}$$

where,

$v_c = 0.28\lambda\phi_c\sqrt{f'_c}$ for headed shear reinforcement[23]

[19] CSA A23.3-04 Section 13.3.3.1
[20] CSA A23.3-04 Section 13.3.8.2
[21] CSA A23.3-04 Section 13.3.9.2
[22] CSA A23.3-04 Section 13.3.8.5

$$= 0.19\lambda\phi_c\sqrt{f'_c} \quad \text{for stirrup reinforcement}$$ [24]

Where v_f is the maximum shear stress calculated based on the direct shear and moments in both directions using the equations shown earlier.

If required, shear reinforcement will be extended to the section where v_f is not greater than $0.19\lambda*\Phi_c*\sqrt{f'c}$, but at least a distance 2d from the face of the column.

- **Arrangement of shear reinforcements**

Shear reinforcement can be in the form of shear studs (headed shear) 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:

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

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

The first layer of stirrups is provided at d/4 from the column face and the successive layers are at d/2 from the previous layer.

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:

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

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

INITIAL CONDITION

- **Load combinations**

CSA does not specify a load combination for the initial condition. ADAPT uses the following default values. User can modify these values.

1.0 DL +1.15 PT

- **Allowable stresses**[25]

i. Tension:

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

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[23] CSA A23.3-04 Section 13.3.8.3
[24] CSA A23.3-04 Section 13.3.9.3

[25] CSA A23.3-04 Section 18.3.1.1

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 based on the following relationship:

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

where,

N_c = tensile force in the concrete computed on the basis of uncracked section.

- **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:

As=T/(0.5Fy)
Where:
As: Area of reinforcement
T: total tensile force on tension block
Fy: Yield Stress of the steel but not more that 60 ksi

DETAILING

- **Reinforcement requirement and placing**

Non-prestressed member

Minimum tension rebar

Beam[26]:

$$A_{s\,min} = \frac{0.2\sqrt{f'_c}\, b_t h}{f_y}$$

where,

b_t = width of the tension zone of the section considered
For T-beam with flange in tension, $b_t \le 2.5 b_w$
For L-beam with flange in tension, $b_t \le 1.5 b_w$

For flanged beams where flanges are in tension, minimum reinforcement over an overhanging flange equals 0.004 times area of the overhanging flange.

Minimum rebar requirement will be waived if $M_r > M_f/3$

Slab[27]:

$A_{smin} = 0.002 A_g$
s_{max} = min (5h, 500mm)

Prestressed member[28]

[26] CSA A23.3-04 Section 10.5.1.2
[27] CSA A23.3-04 Section 7.8.1

Minimum reinforcement for beams and slabs with bonded and unbonded tendons are based on Table 18.1.

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 flange**[29]

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

  i. For T-Beams

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

     a. 1/5th of the span length for a simply supported beam;
     b. 1/10th of the span length for a continuous beam;
     c. 12 times the flange thickness;
     d. ½ of the clear distance to the next web.

  ii. For L-Beams

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

     a. 1/12th of the span length of the beam;
     b. 6 times the flange thickness;
     c. ½ of the clear distance to the next web.

- **ANALYSIS**
  - Arrangement of loads:

    Continuous beams and one-way slabs[30]:

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

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

    § factored dead and live load on all spans.

  Two-way slabs[31]:

  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 3/4th of the full factored live load on the panel and on alternate panels; and

    § factored dead load on all spans with 3/4th of the factored live load on adjacent panels only.

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[28] CSA A23.3-04 Section 18.8.2

[29] CSA A23.3-04 Section 10.3.3 & 10.3.4

[30] CSA A23.3-04 Section 9.2.3.1

[31] CSA A23.3-04 Section 13.8.4

- Redistribution of moment[32]

  Percentage of redistribution = (30-50c/d) % ≤ 20%

  where,
  - c = depth of neutral axis, and
  - d = effective depth

- **Deflection**

  Maximum permissible computed deflections are based on Table 9.3[33].

NOTATION

A_t = area of concrete in tension zone;

D = dead load;

E = earthquake load;

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

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

f_{cp} = average compressive stress in concrete due to effective prestress only;

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

h = overall depth of the beam/ slab;

I = moment of inertia of section about centroidal axis;

L = live load;

M_r = factored moment resistance;

S = snow load;

s_v = spacing of the stirrups;

v_f = design shear stress;

v_c = concrete shear strength;

W = wind load;

x_u = depth of neutral axis; and

[32] CSA A23.3-04 Section 9.2.4

[33] CSA A23.3-04 Section 9.8.5.3

λ = factor to account for low-density concrete; 1.0 for normal density; 0.85 for semi-low density; 0.75 for low-density