1 Vertical Forces, Incidental Lateral Forces, and Other Variable Forces

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Nomenclature

- $a$: beam spacing  
- $A_T$: tributary area  
- $B_T$: tributary width  
- $l$: beam span  
- $V_{DB}$: beam dead load reaction  
- $V_{DC}$: total dead load applied to column  
- $V_{DG}$: girder dead load reaction  
- $w_B$: beam self-weight  
- $w_G$: girder self-weight  
- $w_L$: uniform line load  
- $w_{ij}$: member $ij$ uniform line load  
- $w_S$: slab weight plus superimposed dead load  
- $w_T$: total equivalent uniformly distributed dead load  
- $W_{DJ}$: total dead load on member $ij$  
- $W_{DB}$: total dead load on beam  
- $W_{DG}$: total dead load on girder

General Principles

A dead load is defined in the International Building Code\(^1\) (IBC) Sec. 202 and in Minimum Design Loads for Buildings and Other Structures\(^2\) ASCE/SEI7 Sec. 3.1.1 as the weight of construction materials and fixed service equipment incorporated into the building. These consist of permanent walls and partitions, floors, roofs, ceilings, stairways, finishes, cladding, architectural features, and fixed equipment such as cranes, HVAC (heating, ventilating, and air conditioning) systems, automatic sprinkler systems, and utility services.

To provide a uniform approach in design, a list of customary weights of building materials is given in ASCE/SEI7 Table C3-1, and a list of the customary densities of building materials is given in ASCE/SEI7 Table C3-2. In using these tables, however, allowance must be made for possible variations in the actual materials used. Allowance is also required for the possible future addition of permanent equipment loads and for additional wearing surfaces.

Over the life of a structure, partition walls not permanently attached may be rearranged many times in order to divide large floor areas into smaller offices and cubicles. IBC Sec. 1607.5 specifies a value of 15 lbf/ft\(^2\) for this partition load; moreover, because the load is not permanently fixed in position, it is considered a nonreducible live load. This partition load must be added to the specified floor live load whether or not partitions are shown on the construction documents; however, a partition load need not be applied when the floor live load exceeds 80 lbf/ft\(^2\).

Tributary Areas Exceeding Two

for a Slab with an Aspect Ratio

Figure 1.1 shows the floor layout of a reinforced concrete building. The floor slab is supported on beams, which run east-west and are supported by either columns or girders. Girders run north-south and are supported by columns. The aspect ratio of the slab panels exceeds two, and the slab is designed as a one-way slab spanning north-south between beams. Design of the slab may be by elastic analysis or by the approximate method given in the American Concrete Institute’s Building Code Requirements for Structural Concrete and Commentary\(^3\) ACI Sec. 8.3.3.

Dead loads are usually uniformly distributed, and the loading on a specific member of the structure may be determined using the tributary area principle. The tributary area for a specific member is the loaded area that is considered to directly load that member.
$A_e$ is the area of distribution reinforcement, and $A_g$ is the gross area of footing cross section. When concrete is cast against and exposed to earth (as is the case with the soffit of footings), ACI Table 20.6.1.3.1 specifies the minimum concrete cover provided for reinforcement to be 3 in. When concrete is exposed to earth or weather, ACI Table 20.6.1.3.1 specifies the minimum cover to be $1\frac{1}{2}$ in for no. 5 bars and smaller, and 2 in for no. 6 through no. 18 bars.

**Design for Punching Shear**

The critical perimeter for punching shear is specified in ACI Sec. 22.6.4.1 and illustrated in Fig. 3.3. For a concrete or masonry column, the critical section is a distance from the face of the column equal to one-half the effective depth. For a steel column with a base plate, the critical section is one-half the effective depth from a plane halfway between the face of the column and the edge of the base plate. The punching shear strength of the footing is determined as the smallest of the three values given by ACI Table 22.6.5.2.

\[
\phi V_e = 4\phi db_o\lambda\sqrt{E_c} \quad [a]
\]

\[
\phi V_e = \phi db_o\left(2 + \frac{4}{\beta}\right)\lambda\sqrt{E_c} \quad [b]
\]

\[
\phi V_e = \phi \left(\frac{\alpha_s d}{b_o} + 2\right)\lambda\sqrt{E_c}b_o d \quad [c]
\]

Where,

- $\alpha_s = 40$ for interior columns
- $\beta = 30$ for edge columns
- $\phi = 20$ for corner columns
- $\phi = 0.75$

For an interior column, Expression (a) governs for a square column, Expression (b) governs for a column when $\beta > 2$, and Expression (c) governs for a column when $b_o > 20d$.

When the column supports only an axial load, shear stress at the critical perimeter is uniformly distributed around the critical perimeter, and is

\[
v_u = \frac{V_u}{db_o}
\]

The factored shear force acting on the critical perimeter is

\[
V_u = P\left(1 - \frac{(c_1 + d)(c_2 + d)}{BL}\right)
\]

The depth of the footing is typically governed by the punching shear capacity.

When, in addition to the axial load, a bending moment, $M_o$, is applied to the column, an eccentric shear stress is introduced into the critical section with the maximum

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**Figure 3.3 Critical Perimeter for Punching Shear**

- Concrete column
- Masonry column
- Steel column
13. PRACTICE PROBLEMS

1. The select structural 3 × 10 Douglas fir-larch rafter shown is notched over a supporting 3 in wall. Based on the bearing stress in the rafter, what is most nearly the maximum available reaction at the support caused by snow loading? (ASD options are shown first. LRFD options are given in parentheses.)

(A) 5600 lbf (6800 lbf)
(B) 6300 lbf (7700 lbf)
(C) 6800 lbf (8300 lbf)
(D) 7500 lbf (9200 lbf)

2. The select structural 4 × 10 Douglas fir-larch ledger shown supports a dead plus floor live load of 225 lbf/ft (ASD) or 390 lbf/ft (LRFD). Based on the 1/4 in bolt design value in the ledger, what is most nearly the maximum allowable bolt spacing?

(A) 2.8 ft
(B) 3.2 ft
(C) 3.6 ft
(D) 4.0 ft

3. The floor system in an office building consists of select structural 2 × Douglas fir-larch joists at 16 in centers with $w_{pl}$ plywood sheathing. Each joist supports a dead load of $w_D = 33.33$ lbf/ft plus floor live load of $w_L = 66.67$ lbf/ft over a span of $L = 16$ ft. Acceptable deflection due to live load is $\Delta_{ST} = L/360$ and acceptable deflection due to total load is $\Delta_T = L/240$. The depth of joist necessary to give acceptable stresses and deflection is most nearly

(A) 8 in
(B) 10 in
(C) 12 in
(D) 14 in

4. A select structural 6 × 6 Douglas fir-larch column is subjected to axial load due to dead plus floor live load. The column is 10 ft high and may be considered pin ended. What is most nearly the maximum load that may be applied? (ASD options are shown first. LRFD options are given in parentheses.)

(A) 18,300 lbf (31,300 lbf)
(B) 19,300 lbf (32,300 lbf)
(C) 21,300 lbf (34,300 lbf)
(D) 22,300 lbf (35,300 lbf)
1. The reference design value for compressive bearing parallel to grain is tabulated in NDS Supp. Table 4A and is

\[ F_c = 1700 \text{ lbf/in}^2 \]

The applicable adjustment factors for compressive bearing parallel to grain are

\[ C_t = 1.0 \]
\[ C_M = 1.0 \]
\[ C_p = 1.0 \]
\[ C_i = 1.0 \]

The reference design value for compression perpendicular to grain is tabulated in NDS Supp. Table 4A and is

\[ F_{c\perp} = 625 \text{ lbf/in}^2 \]
\[ C_M = 1.0, \quad C_t = 1.0, \quad C_i = 1.0 \]

The bearing area factor for compression perpendicular to grain is specified in NDS Sec. 3.10.4 as

\[ C_b = \frac{l_b + 0.375}{l_b} = \frac{3 \text{ in} + 0.375}{3 \text{ in}} = 1.125 \]

ASD Method
From Table 6.5, the load duration factor for snow is

\[ C_D = 1.15 \]

The adjusted compressive bearing design value parallel to grain is

\[ F_c^* = F_c C_t C_M C_p C_i C_D = \left( 1700 \frac{\text{lbf}}{\text{in}^2} \right) (1.0)(1.0)(1.0)(1.0)(1.0)(1.15) = 1955 \text{ lbf/in}^2 \]

The adjusted compression design value perpendicular to grain is

\[ F_{c\perp}^* = F_{c\perp} C_b C_M C_p C_i = \left( 625 \frac{\text{lbf}}{\text{in}^2} \right) (1.125)(1.0)(1.0)(1.0) = 703 \text{ lbf/in}^2 \]

The allowable bearing design value at an angle \( \theta \) to the grain is given by NDS Sec. 3.10.3 as

\[
F'_{\theta} = \frac{F_c^* F'_{c\perp}}{F_c^* \sin^2 \theta + F_{c\perp} \cos^2 \theta} = \frac{1955 \text{ lbf/in}^2 (703 \text{ lbf/in}^2)}{1955 \text{ lbf/in}^2 (\sin^2 60^\circ) + 703 \text{ lbf/in}^2 (\cos^2 60^\circ)} = 837 \text{ lbf/in}^2
\]

The allowable reaction at the support is

\[
V = F'_{\theta} b_h = \left( 837 \frac{\text{lbf}}{\text{in}^2} \right) (2.5 \text{ in})(3 \text{ in}) = 6278 \text{ lbf} \quad (6300 \text{ lbf})
\]

The answer is (B).

LRFD Method
From Table 6.4, the time effect factor for snow load is

\[ \lambda = 0.8 \]

The format conversion factor given in Table 6.2 is

\[ K_F = 1.67 \quad \text{[for } F_{c\perp}] \]
\[ K_F = 2.40 \quad \text{[for } F_c] \]

The resistance factor given in Table 6.3 is

\[ \phi = 0.90 \quad \text{[for } F_{c\perp}] \]
\[ \phi = 0.90 \quad \text{[for } F_c] \]

The adjusted factored compressive bearing design value parallel to grain is

\[
F_c^* = F_c C_M C_p C_i K_F \phi = \left( 1700 \frac{\text{lbf}}{\text{in}^2} \right) (1.0)(1.0)(1.0)(1.0)(2.40)(0.8)(0.90) = 2938 \text{ lbf/in}^2
\]