Design Loads and Methodology

Notation:

A = name for area
$ASCE$ = American Society of Civil Engineers
ASD = allowable stress design
D = dead load symbol
E = earthquake load symbol
F = hydraulic loads from fluids symbol
H = hydraulic loads from soil symbol
L = live load symbol
L_r = live roof load symbol
$LRFD$ = load and resistance factor design
R = rainwater load or ice water load symbol
S = snow load symbol
t = name for thickness
T = effect of material & temperature symbol
V = name for volume
w = name for distributed load
W = wind load symbol
= force due to a weight
= name for total force due to distributed load
γ = density or unit weight

Design Codes in General

Design codes are issued by a professional organization interested in insuring safety and standards. They are legally backed by the engineering profession. Different design methods are used, but they typically defined the *load cases or combination*, stress or strength limits, and deflection limits.

Load Types

Loads used in design load equations are given letters by *type:*

D = dead load
L = live load
L_r = live roof load
W = wind load
S = snow load
E = earthquake load
R = rainwater load or ice water load
T = effect of material & temperature
H = hydraulic loads from soil
F = hydraulic loads from fluids

Determining Dead Load from Material Weights

Material density is a measure of how much mass in a unit volume causes a force due to gravity. The common symbol for density is γ. When volume, V, is multiplied by density, a force value results:

$$W = \gamma \cdot V$$

Materials "weight" can also be presented as a weight per unit area. This takes into account that the volume is a constant thickness times an area: $V = t\cdot A$; so the calculation becomes:

$$W = (weight/unit\ area)\cdot A$$

Allowable Stress Design (ASD)

Combinations of service (also referred to as *working)* loads are evaluated for maximum stresses and compared to allowable stresses. When wind loads are involved, the allowable stresses are typically allowed to increase by 1/3. The allowed stresses are some fraction of limit stresses.

ASCE-7 (2010) combinations of loads:

1. D
2. $D + L$
3. $D + 0.75(L_r \text{ or } S \text{ or } R)$
4. $D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$
5. $D + (0.6W \text{ or } 0.7E)$

6a. $D + 0.75L + 0.75(0.6W) + 0.75(L_r \text{ or } S \text{ or } R)$

6b. $D + 0.75L + 0.75(0.7E) + 0.75S$

7. $0.6D + 0.6W$
8. $0.6D + 0.7E$

When F loads are present, they shall be included with the same load factor as dead load D in 1 through 6 and 8.

When H loads are present, they shall have a load factor of 1.0 when adding to load effect, or 0.6 when resisting the load when permanent.

Load and Resistance Factor Design – LRFD

Combinations of loads that have been *factored* are evaluated for maximum loads, moments or stresses. These factors take into consideration how likely the load is to happen and how often. This "imaginary" worse case load, moment or stress is compared to a limit value that has been modified by a *resistance* factor. The resistance factor is a function of how "comfortable" the design community is with the type of limit, ie. yielding or rupture...

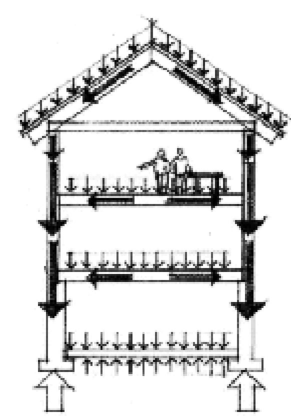
ASCE-7 (2010) combinations of factored nominal loads:

1. $1.4D$
2. $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
4. $1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $1.2D + 1.0E + L + 0.2S$
6. $0.9D + 1.0W$
7. $0.9D + 1.0E$

When F loads are present, they shall be included with the same load factor as dead load D in 1 through 5 and 7.

When H loads are present, they shall have a load factor of 1.6 when adding to load effect, or 0.9 when resisting the load when permanent.

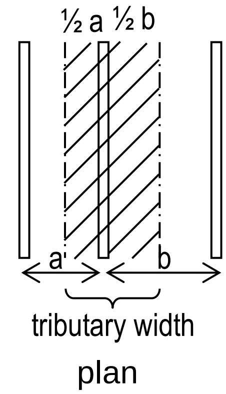
Load Tracing



- LOAD TRACING is the term used to describe how the loads on and in the structure are transferred through the members (*load paths)* to the foundation, and ultimately supported by the ground.

- It is a sequence of **actions**, NOT reactions. Reactions in statically determinate members (using FBD's) can be solved for to determine the actions on the next member in the hierarchy.

- The *tributary area* is a loaded area that contributes to the load on the member supporting that area, *ex*. the area from the center between two beams to the center of the next two beams for the full span is the load on the center beam. It can also be called the *load periphery*.



- The *tributary load* on the member is found by **concentrating (or consolidating)** the load into the center.

$$w = (\frac{load}{area})x(tributary\ width)$$

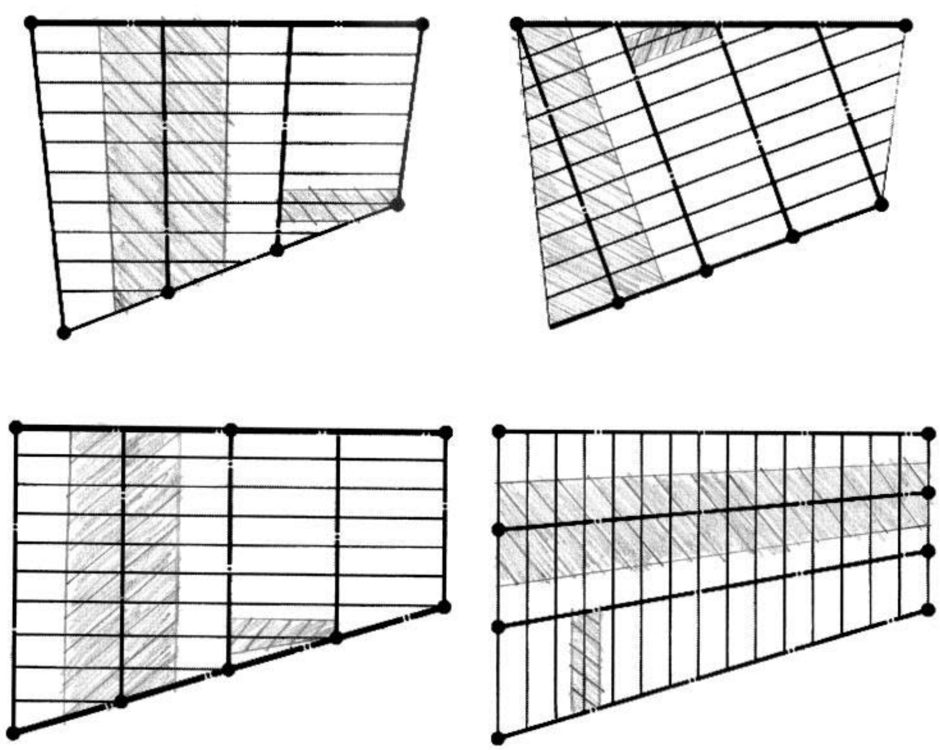
where:

w = distributed load in units of load/length

Distribution of Loads with Irregular Configurations

When a bay (defined by the area bounded by vertical supports) is not rectangular, it is commonly constructed with parallel or non-parallel spanning members of non-uniform lengths. With parallel spanning members, the tributary width is uniform. With non-parallel members, the tributary width at each end is different, but still defined as half the distance (each side) to the next member. The resulting distribution will be linear (and not uniform).

The most efficient one-way systems have regular, rectangular bays. Two way systems are most efficient when they are square. With irregular bays, attempts are made to get as many parallel members as possible with similar lengths, resulting in an economy of scale.



Distribution of Loads on Edge Supported Slabs

Distributed loads on two-way slabs (i.e. not one-way like beams) do not have obvious tributary “widths”. The distribution is modeled using a 45 degree tributary “boundary” in addition to the tributary boundary that is half way between supporting elements, in this case, edge beams.

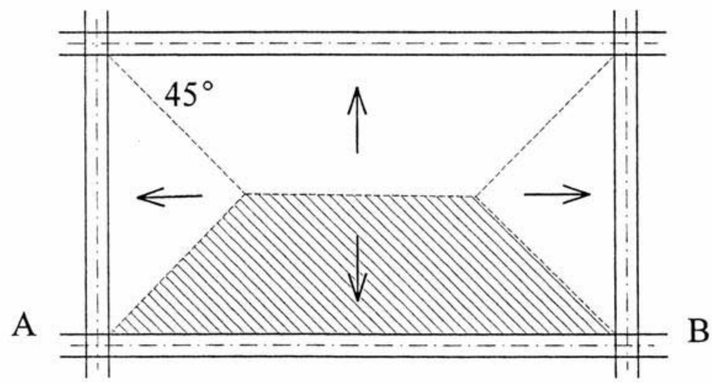


Figure 2-16: Supporting beams' contributing areas for reinforced concrete floor system.

The tributary distribution *from the area loads* result in a trapezoidal distribution. Self weight will be a uniform distributed load, and will also have to be included for design of beam AB.

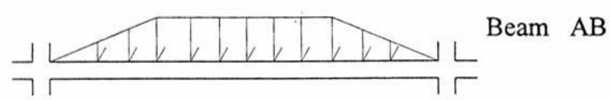


Figure 2-17: Trapezoidal distributed load for Beam AB of Fig. 2-16.

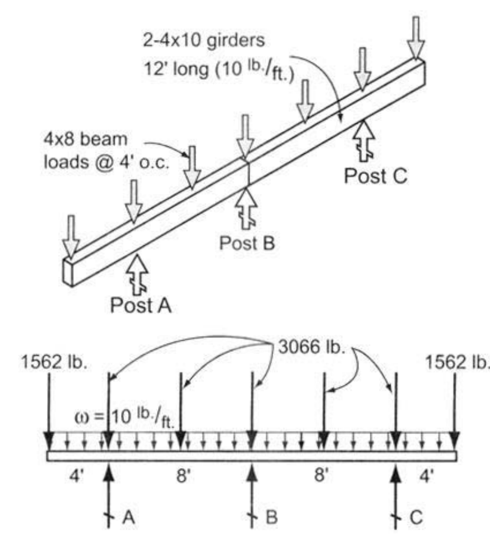
Openings in Floor/Roof Plans

Openings in a horizontal system usually are framed on all sides. This provides for stiffness and limiting the deflection. The edge beams may not be supporting the flooring, however, so care needs to be taken to determine if an opening edge beam must support tributary area, or just itself.

- *Any edge beam supporting a load has load* <u>*on only one side*</u> *to the next supporting element.*

Beams Supported by Other Beams

Joists are commenly supported by beams with beam hangers. The reaction at the support is transferred to the beam as a single force. A beam, in turn, can be supported by a larger beam or girder, and the reaction from this beam having a uniform distributed self weight, and the forces, will be an action on the girder.



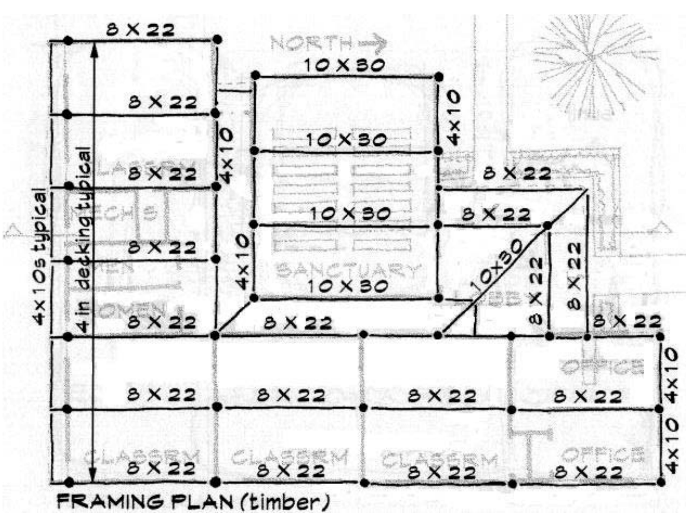
Framing Plans

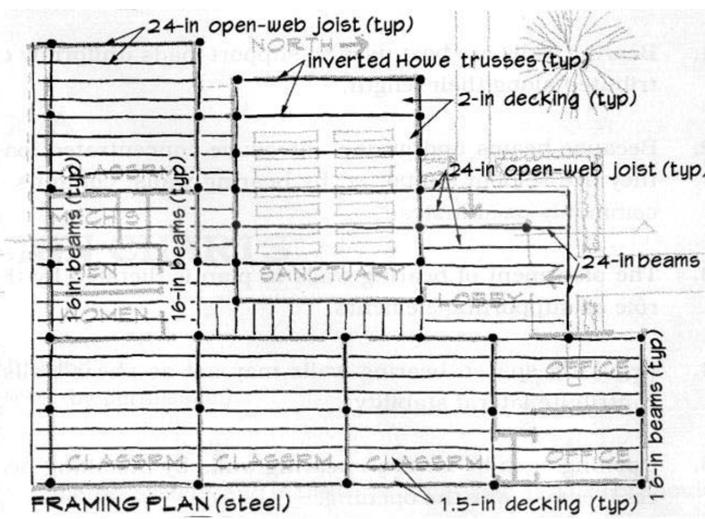
Framing plans are diagrams representing the placement and organization of structural members. Until the final architecture has been determined, framing plans are often drawn freehand with respect to the floor plans, and quite often use the formal conventions for structural construction drawings.

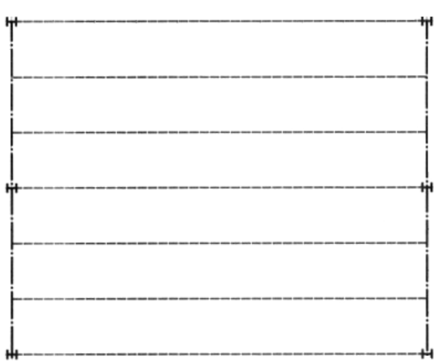
Parts of the building are identified by letter symbols:

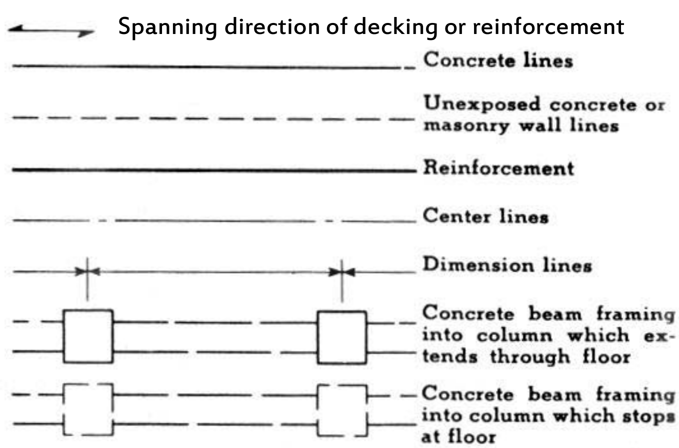
B – Beams	*F* – Footings	*L* – Lintels	*U* – Stirrups
C – Columns	*G* – Girders	*S* – Slabs	*W* – Walls
D – Dowels	*J* – Joists	*T* – Ties	

Other parts are represented with lines (beams and joists), dots, squares, rectangles or wide-flange shapes for columns. Column and footing locations in structural drawings are referred to by letters and numbers, with vertical lines at column centers given letters – *A, B, C,* etc., and horizontal lines at columns given numbers – *1, 2, 3,* etc. The designation *do* may be used to show like members (like *ditto*).



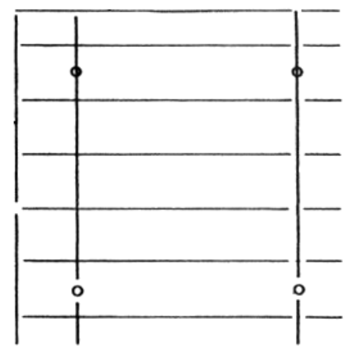




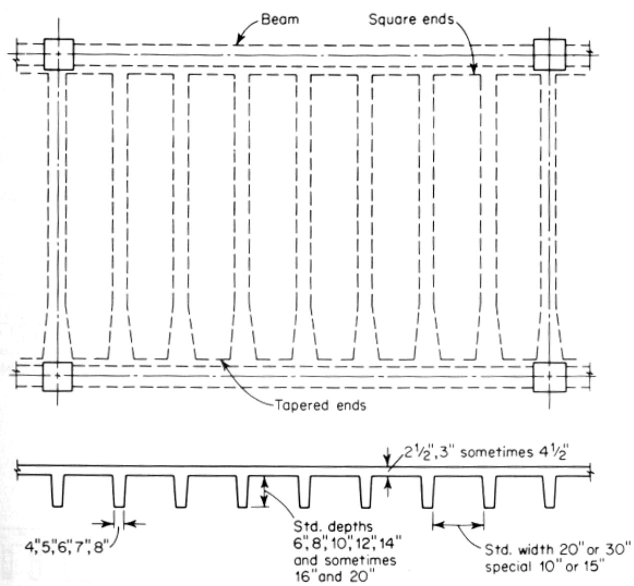


Breaks in the lines are commonly used to indicate the *end* of a beam that is supported by another member, such as a girder or column. Beams can span over a support (as a continuous beam) and therefore, there is no break shown at the column.

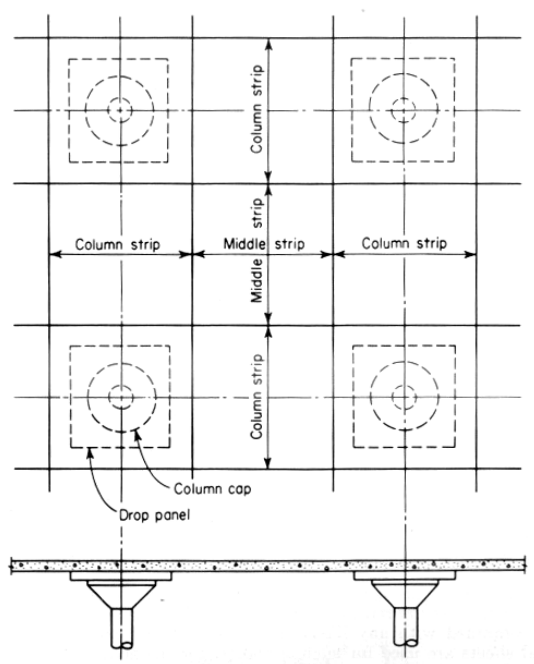
Joists can span over a supporting beam, and the lines will cross. (Looking for the ends of the crossing members give information about which is below and which is above.)



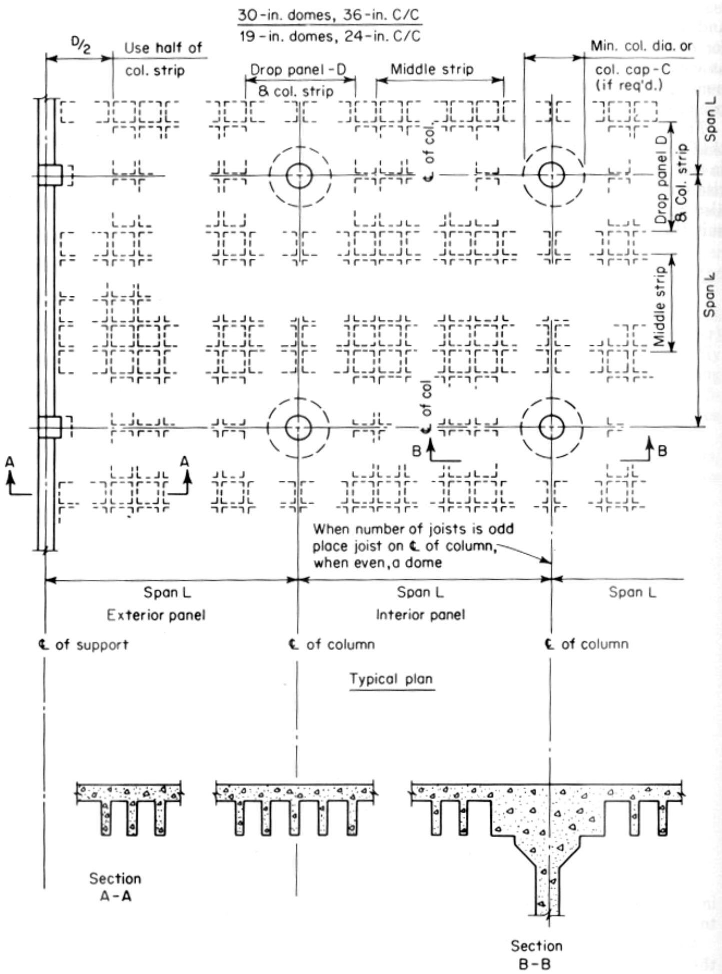
Concrete systems often have slabs, ribs or drop panels or strips, which aren't easily represented by centerlines, so hidden lines represent the edges. Commonly isolated "patches" of repeated geometry are used for brevity.



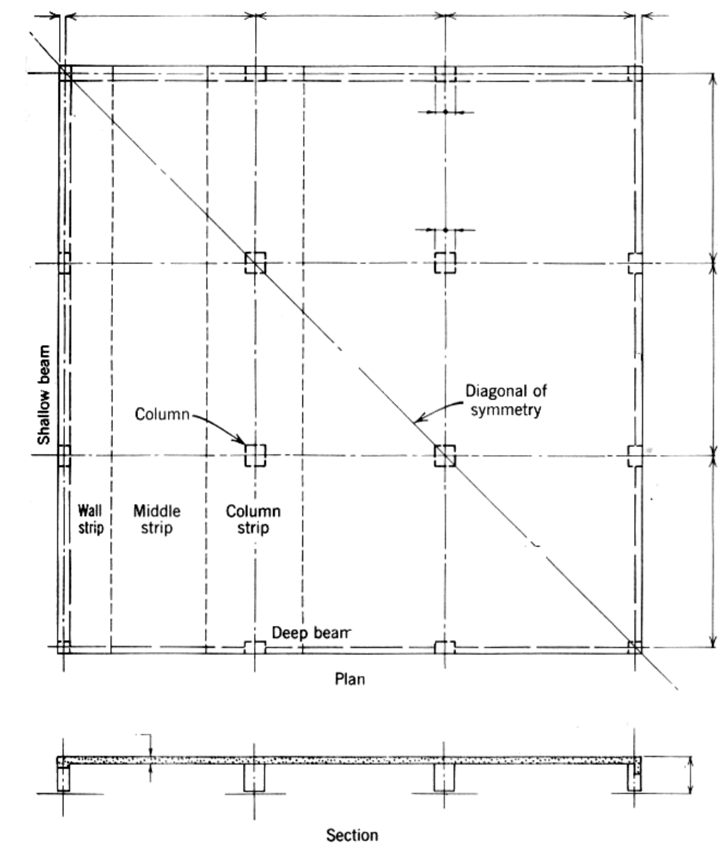
One-way concrete ribbed slab.



Two-way flat slab.



Two-way joist construction.

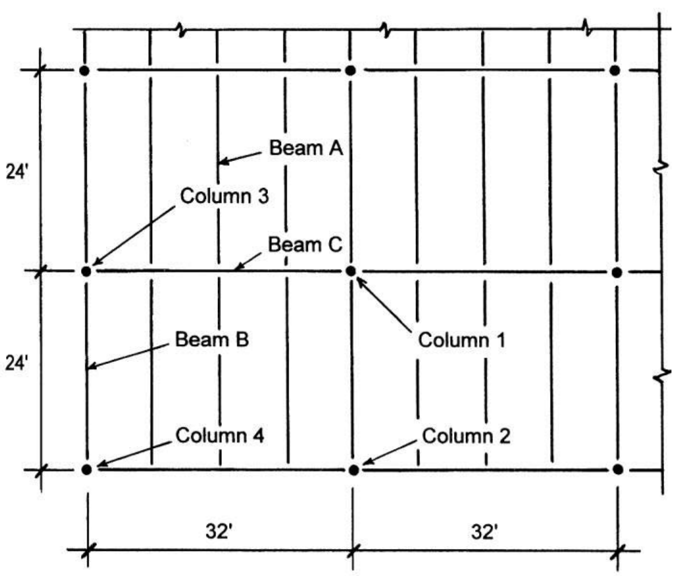


Layout of flat plate test structure.

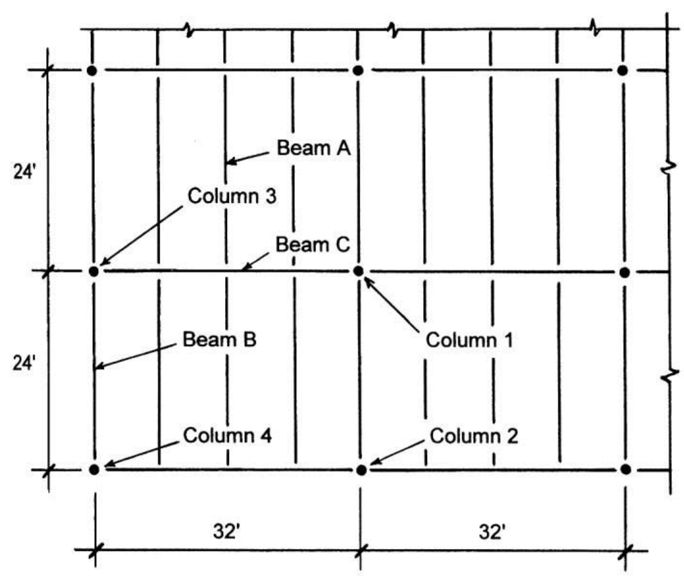
Example 1 (pg 50)

Identify the *tributary area* for beams A-C, and columns 1-4 for the plan shown (twice).

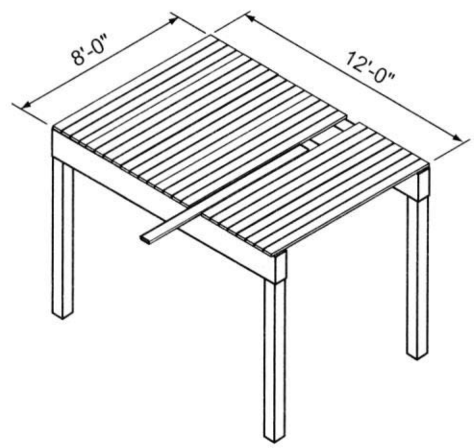
BEAMS:



COLUMNS:

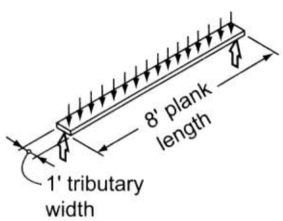


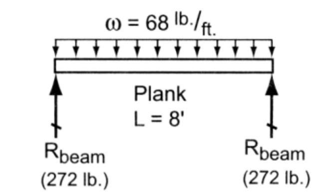
Example 2

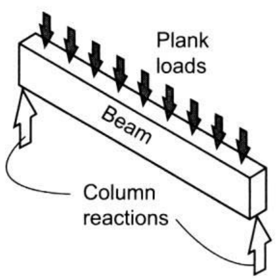


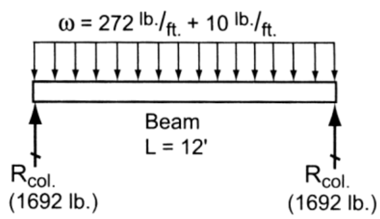
In the single-bay, post-and-beam deck illustrated, planks typically are available in nominal widths of 4" or 6", but for the purposes of analysis it is permissible to assume a unit width equal to one foot. Determine the plank, beam, and column reactions.

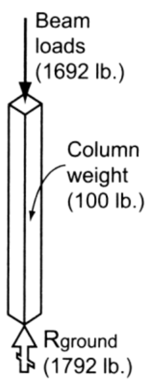
The loads are: 60 lb/ft^2 live load, 8 lb/ft^2 dead load, 10 lb/ft self weight of 12' beams, and 100 lb self weight of columns.











Example 3

EXAMPLE

Assume that the average dead plus live load on the structure shown in Figure 3.15 is 60 lbs/ft^2. **Determine** the reactions for Beam D. This is the same structure as shown in Figure 3.1.
^ E, B and A *Assuming all beams are weightless!*

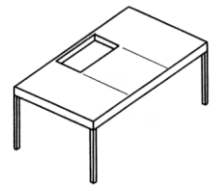
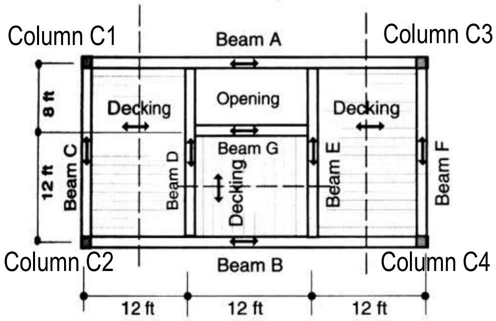


Figure 3.1

Solution:
Note carefully the directions of the decking span. Beam D carries floor loads from the decking to the left (see the contributory area and load strip), but not to the right, since the



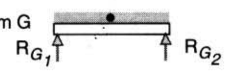
Live and dead load

Assume $w_{DL+LL} = 60$ lbs/ft^2

Beam G carries distributed loads only

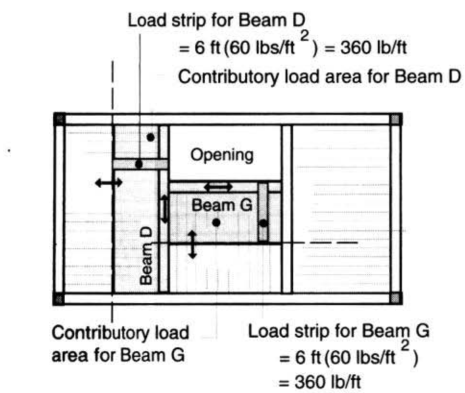
Find reactions for Beam G

$w = 6$ ft$(60$ lbs/ft$^2) = 360$ lb/ft

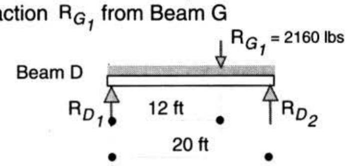


$R_{G_1} = wL/2 = (360$ lb/ft$)(12$ ft$)/2 = 2160$ lbs

$R_{G_2} = wL/2 = (360$ lb/ft$)(12$ ft$)/2 = 2160$ lbs



Beam D (and E) carries both distributed loads and the reaction R_{G_1} from Beam G



$\Sigma M_{D_1} = 0$

$-(12\text{ ft})(2160\text{ lb}) - (360\text{ lb/ft})(20\text{ ft})(20\text{ ft}/2) + 20R_{D_2} = 0$

$R_{D_2} = 4896$ lb $= R_{E2}$

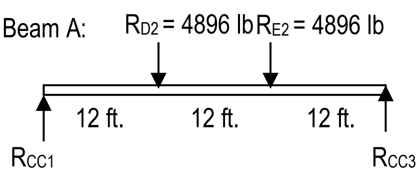
$\Sigma F_y = 0$

$R_{D_1} + R_{D_2} = (360\text{ lb/ft})(20\text{ ft}) + 2160$ lb

$R_{D_1} = 4464$ lb $= R_{E1}$

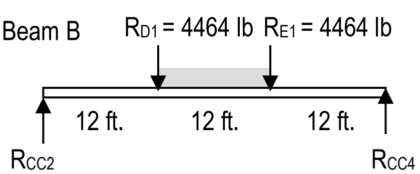
FIGURE 3.15 Load modeling and reaction determination.

Beam A:



By symmetry; $R_{CC1} = R_{CC3} = (4896\text{ lb} + 4896\text{ lb})/2 = 4896$ lb

Beam B



By symmetry; $R_{CC2} = R_{CC4} = (4464\text{ lb} + 4464\text{ lb})/2 + (6\text{ ft})(60\text{ lb/ft}^2)(12\text{ ft})/2 = 6624$ lb

Additional loads are transferred to the column from the reactions on Beams C and F:

$R_{C1} = R_{C2} = R_{F1} = R_{F2} = wL/2 = (6\text{ ft})(60\text{ lb/ft}^2)(20\text{ ft})/2 = 3600$ lb

center decking runs parallel to Beam D and is not carried by it. Beam D also picks up the end of Beam G and thus also "carries" the reactive force from Beam G. It is therefore necessary to analyze Beam G first to determine the magnitude of this force. The analysis appears in Figure 3.15. The reactive force from Beam G of 2160 lbs is then treated as a downward force acting on Beam D. The load model for Beam D thus consists of distributed forces from the decking plus the 2160-lb force. It is then analyzed by means of the equations of statics to obtain reactive forces of 4896 lbs and 4464 lbs at its ends.

C1 = 4896 lb + 3600 lb = 8,496 lb

C2 = 6624 lb + 3600 lb = 10,224 lb

C3 = 4896 lb + 3600 lb = 8,496 lb

C4 = 6624 lb + 3600 lb = 10,224 lb

Example 4

A steel-framed floor for an office building, as shown in Figures 5.54 to 5.56, was designed to support a load condition as follows:

Loads:

Live load	= 50 psf
Dead loads:	
Concrete	= 150 #/ft.^{3}
Steel decking	= 5 psf
Mechanical equipment	= 10 psf
Suspended ceiling	= 5 psf
Steel beams	= 25 #/ft.
Steel girders	= 35 #/ft.

Using appropriate FBDs, determine the reaction forces for beams B-1, B-2, and B-3, and girder G-1.

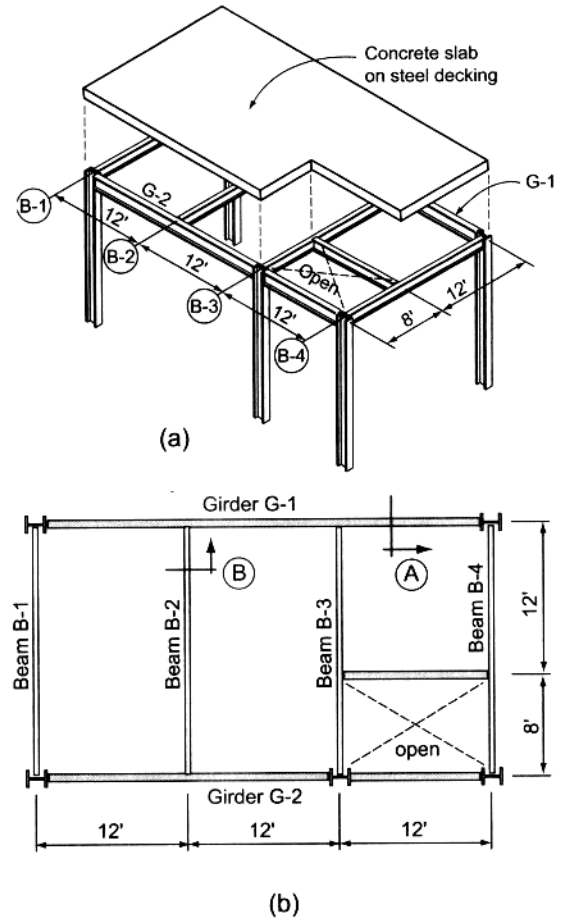


Figure 5.54 (a) Isometric view of partial steel framing arrangement. (b) Partial floor framing—office structure.

Solution:

Loads:

$$\text{Slab load} = \left(\frac{4\text{ in.}}{12\,{}^{\text{in.}}/_{\text{ft.}}}\right) \times \left(150\,{}^{\text{lb.}}/_{\text{ft.}^3}\right) = 50\,{}^{\text{lb.}}/_{\text{ft.}^2}$$

Dead loads:	= 50 psf (slab)
	+ 5 psf (decking)
	+ 10 psf (mech. equip.)
	+ 5 psf (ceiling)
Total DL	= 70 psf

Dead load + Live load = 70 psf + 50 psf = 120 psf

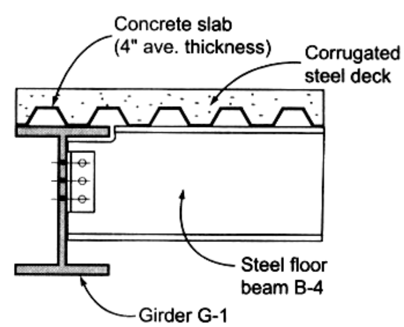


Figure 5.55 Section A at girder G-1.

Beam B-1 (Figures 5.57 and 5.58):

(Tributary width of load is 6')

$$\omega_1 = \left(120\,{}^{\text{lb.}}/_{\text{ft.}^2}\right) \times (6\text{ ft.}) + \underset{\text{(beam wt.)}}{25\,{}^{\text{lb.}}/_{\text{ft.}}} = 745\,{}^{\text{lb.}}/_{\text{ft.}}$$

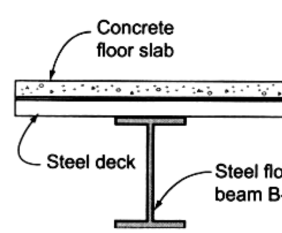


Figure 5.56 Section B at beam B-2.

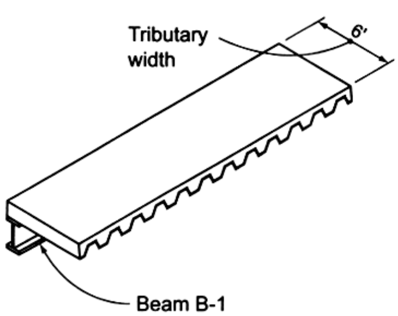


Figure 5.57 Tributary width for beam B-1.

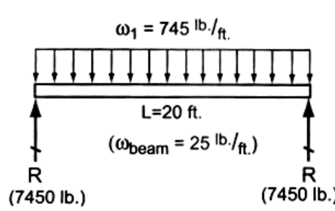
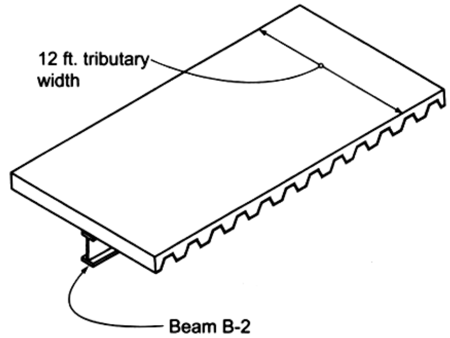


Figure 5.58 FBD of beam B-1.

Example 4 (continued)

Beam B-2 (Figures 5.59 and 5.60):
(Tributary width of load is 6' + 6' = 12')

$$\omega_2 = \left(120\,{}^{\text{lb.}}/_{\text{ft.}^2}\right) \times (12\text{ ft.}) + 25\,{}^{\text{lb.}}/_{\text{ft.}} = 1465\,{}^{\text{lb.}}/_{\text{ft.}}$$



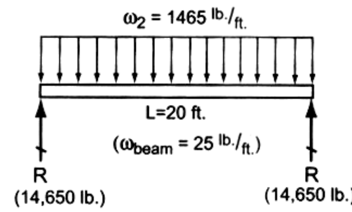


Figure 5.59 Tributary width for beam B-2. *Figure 5.60 FBD of beam B-2.*

Beam B-3 (Figures 5.61 to 5.62): This beam has two different load conditions due to the changing tributary width created by the opening.

For 12' of span:

$$\omega_3 = \left(120\,{}^{\text{lb.}}/_{\text{ft.}^2}\right) \times (12\text{ ft.}) + 25\,{}^{\text{lb.}}/_{\text{ft.}} = 1465\,{}^{\text{lb.}}/_{\text{ft.}}$$

For 6' of span:

$$\omega_4 = \left(120\,{}^{\text{lb.}}/_{\text{ft.}^2}\right) \times (6\text{ ft.}) + \underset{\text{(beam wt.)}}{25\,{}^{\text{lb.}}/_{\text{ft.}}} = 745\,{}^{\text{lb.}}/_{\text{ft.}}$$

$$\sum M_a = 0$$

$$-\left(745\,{}^{\text{lb.}}/_{\text{ft.}}\right)(8\text{ ft.})(4\text{ ft.}) - \left(1465\,{}^{\text{lb.}}/_{\text{ft.}}\right)(12\text{ ft.})(4\text{ ft.})$$

$$+ B_y(20\text{ ft.}) = 0$$

$$\therefore B_y = 13{,}498\text{ lb.}$$

$$\sum F_y = 0$$

$$-\left(745\,{}^{\text{lb.}}/_{\text{ft.}}\right)(8\text{ ft.}) - \left(1465\,{}^{\text{lb.}}/_{\text{ft.}}\right)(12\text{ ft.})$$

$$+ 13{,}498\text{ lb.} + A_y = 0$$

$$\therefore A_y = 10{,}042\text{ lb.}$$

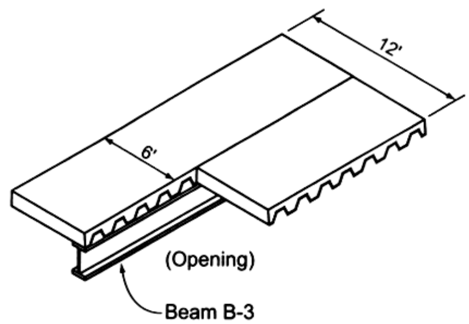


Figure 5.61 Tributary widths for beam B-3.

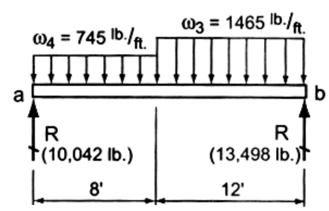


Figure 5.62 FBD of beam B-3.

Girder G-1 (Figures 5.63 and 5.64): Girder G-1 supports reactions from beams B-2 and B-3. Beam B-1 sends its reaction directly to the column and causes no load to appear in girder G-1.

$$\left[\sum M_a = 0\right]$$

$$-(14{,}650\text{ lb.})(12\text{ft.}) - (13{,}498\text{ lb.})(24\text{ ft.})$$

$$-\left(35\,{}^{\text{lb.}}/_{\text{ft.}}\right)(36\text{ ft.})(18\text{ ft.}) + B_y(36\text{ ft.}) = 0$$

$$\therefore B_y = 14{,}512\text{ lb.}$$

$$\left[\sum F_y = 0\right] - 14{,}650\text{ lb.} - 13{,}498\text{ lb.}$$

$$+ 14{,}512\text{ lb.} + A_y = 0$$

$$\therefore A_y = 14{,}896\text{ lb.}$$

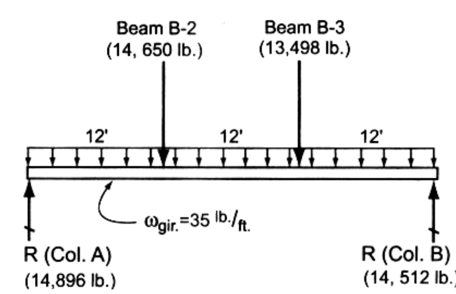


Figure 5.64 FBD of girder G-1.

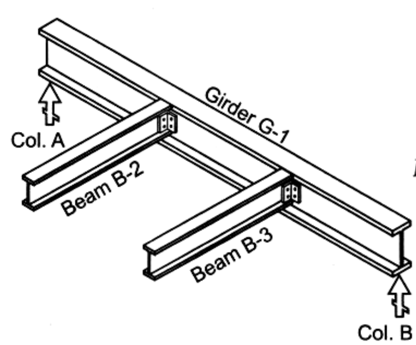


Figure 5.63 Girder G-1 (partial framing).