Chapter (6): Loads on Structures

6.1 Live Load Reduction:

6.1.1 Floors:

- For some types of buildings having very large floor areas, many codes will allow a reduction in the uniform live load for a floor.
- The reason is that it is unlikely to that the prescribed live load will occur simultaneously throughout the entire structure at any one time.
- ASCE7-02 allows a reduction of live load on a member having an influence area (K_{LL} A_T) of 400 ft² (37.2 m²) or more.

$$L = L_\circ \left(0.25 + \frac{4.57}{\sqrt{K_{LL} A_T}} \right) \quad \text{(SI)} \qquad (6\text{-}1)$$

$$L = L_\circ \left(0.25 + \frac{15}{\sqrt{K_{LL} A_T}} \right) \quad \text{(USCU)} \qquad (6\text{-}2)$$

Where,

L = reduced design live load per square foot or square meter of area supported by the member, > 0.5 Lo for 1 floor, > 0.4 Lo for 2 floors or more.

L_o = unreduced design live load per square foot or square meter of area supported by the member.

K_{LL}= live load element factor.

A_T = Tributary area in square meters or feet.

NOTE:

Case	Exception
Heavy Live Loads: Live loads that exceed 4.79kN/m² (100 lb/ft²) shall not be reduced	Live loads for members supporting two or more floors shall be permitted to be reduced by 20 percent.
Passenger Vehicle Garages: The live loads shall not be reduced in passenger vehicle garages.	Live loads for members supporting two or more floors shall be permitted to be reduced by 20 percent.
Assembly Uses: Live loads shall not be reduced in assembly uses.	-

Element	K_{LL}
Interior columns	4
Exterior columns without cantilever slabs	4
Edge columns with cantilever slabs	3
Corner columns with cantilever slab	2
Edge beams without cantilever slabs	2
Interior beams	2
All other members not identified, including:	1
Edge beams with cantilever slabs	
Cantilever beams	
One-way slabs	
Two-way slabs	
Members without provisions for continuous shear transfer normal to their span	

Illustrating some of the elements in the table above, and referring to the plan in Figure 6-1 :

Element	Example
Slabs	
One-way slab	S2
Two-way slab	S3
Columns	
Interior columns	C4
Exterior columns without cantilever slabs	C5
Edge columns with cantilever slabs	B3
Corner columns with cantilever slab	B2
Beams	
Interior beams	C2 – C5
Cantilever beams	D1 – D2
Edge beams without cantilever slabs	B5 – C5
Edge beams with cantilever slabs	B3 – B4

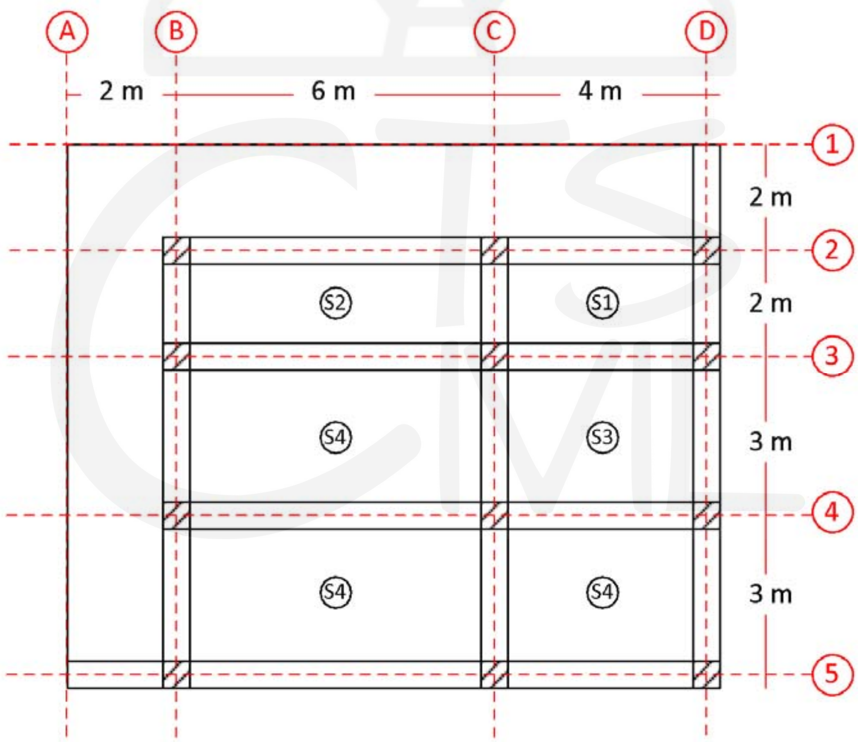


Figure 6-1: Floor plan

6.1.2 Roofs:

Ordinary flat, pitched, and curved roofs are permitted to be designed for a reduced roof live load in accordance with equation (4-2) from ASCE-7

$$L_r = L_o R_1 R_2 \tag{6-3}$$

Where

$$0.58 \le L_r \le 0.96 \quad (\text{SI}) \tag{6-4}$$

$$12 \le L_r \le 20 \quad (\text{USCU}) \tag{6-5}$$

L_r : reduced roof live load per ft^2 (m^2) of horizontal projection in pounds per ft^2 (kN/m^2)

The reduction factors R_1 and R_2 shall be determined as follows:

For R_1:

$$R_1 = \begin{cases} 1 & \text{for} \quad A_T \le 200\,\text{ft}^2 \\ 1.5 - 0.001A_T & \text{for} \quad 200\,\text{ft}^2 < A_T < 600\,\text{ft}^2 \\ 0.6 & \text{for} \quad A_T \ge 600\,\text{ft}^2 \end{cases} \quad (\text{USCU})$$

$$R_1 = \begin{cases} 1 & \text{for} \quad A_T \le 18.58\,\text{m}^2 \\ 1.2 - 0.011A_T & \text{for} \quad 18.58\,\text{m}^2 < A_T < 55.74\,\text{m}^2 \\ 0.6 & \text{for} \quad A_T \ge 55.74\,\text{m}^2 \end{cases} \quad (\text{SI})$$

And A_T = Tributary area supported by structural member in square meters or feet.

For R_2:

$$R_2 = \begin{cases} 1 & \text{for} \quad F \le 4 \\ 1.2 - 0.05F & \text{for} \quad 4 < F < 12 \quad (\text{USCU}) \\ 0.6 & \text{for} \quad F \ge 12 \end{cases}$$

where, for a pitched roof, F = number of inches of rise per foot (in SI: F = 0.12 x slope, with slope expressed in percentage points) and, for an arch or dome, F = rise-to-span ratio multiplied by 32.

6.2 Tributary Areas for beams and columns:

- Definition:
  - Beams: The area of slab that is supported by a particular beam is termed the beam's tributary area.
  - Columns: the area surrounding the column that is bounded by the panel centerlines
- Importance: to understand and determine the vertical loads transferred from slabs to beams and columns
- Notes:
  - Tributary area for interior columns is four time (4x) the tributary area typical corner column.

- Tributary area for beams surrounding a "square" slab share equal portion of the load applied to that slab.
- For rectangular slabs, the load shared by the beams in the short direction is triangular whereas the load shared by beams in the long direction is trapezoidal.

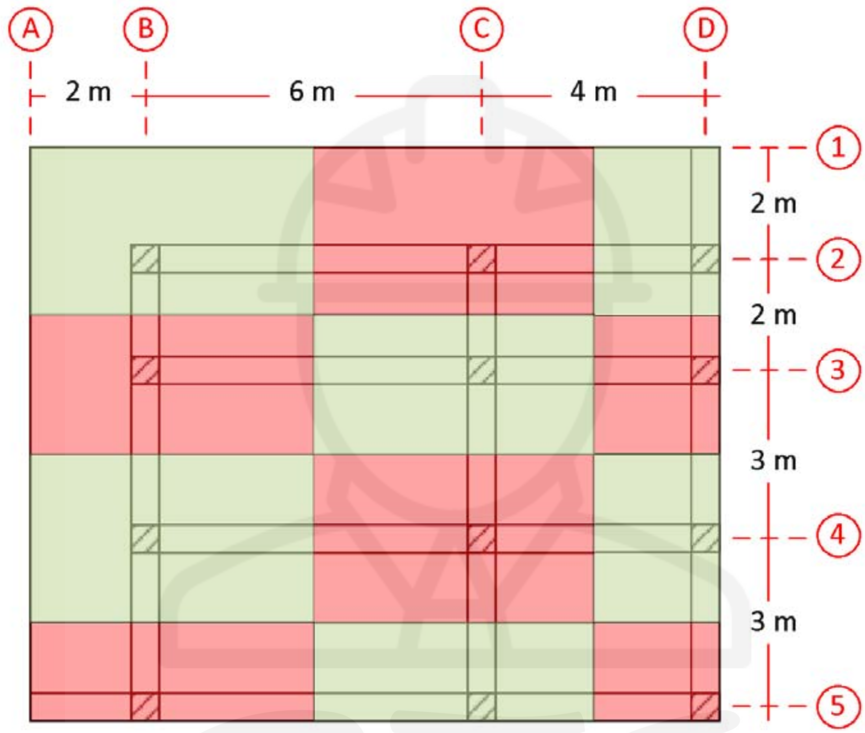


Figure 6-2: Tributary areas for different columns

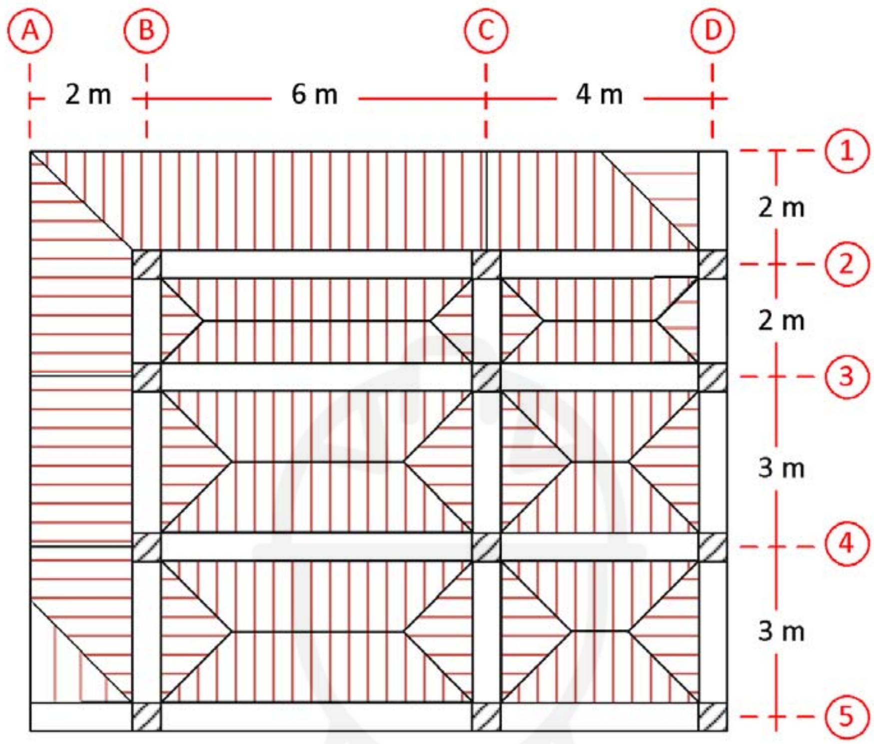


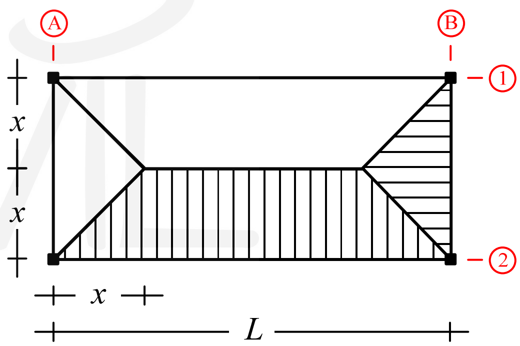
Figure 6-3: Tributary areas for different slabs

6.2.1 Approximate Methods:

Slab loads transmitted to beams can be calculated from the areas limited by lines bisecting the angles at the corners of any panel (tributary area). For convenience, these loads can be assumed as uniformly distributed over the beam span with some approximation techniques.

Assuming that:

- *w:* Uniformly distributed load per unit area
- *L:* Span of beams
- *x:* Maximum distance of loading to the desired beam
- $\alpha\, w$: Equivalent load for bending moment calculations under the condition that the load is distributed over the total span of the beam with the maximum intensity at mid span.
- $\beta\, w$: Equivalent load for reaction and shear force and bending moment calculations for conditions not satisfied above.



where the values of α & β can be calculated from:

$$\alpha = 1 - \frac{1}{3}\left(\frac{2x}{L}\right)^2 \qquad (6\text{-}6)$$

$$\beta = 1 - \frac{x}{L} \quad (6\text{-}7)$$

The following table contains some tabulated values for α & β

Table 1: Some tabulated values for (α & β)

$L/2x$	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
α	0.667	0.725	0.769	0.803	0.830	0.853	0.870	0.885	0.897	0.908	0.917
β	0.5	0.544	0.582	0.615	0.642	0.667	0.688	0.706	0.722	0.737	0.75

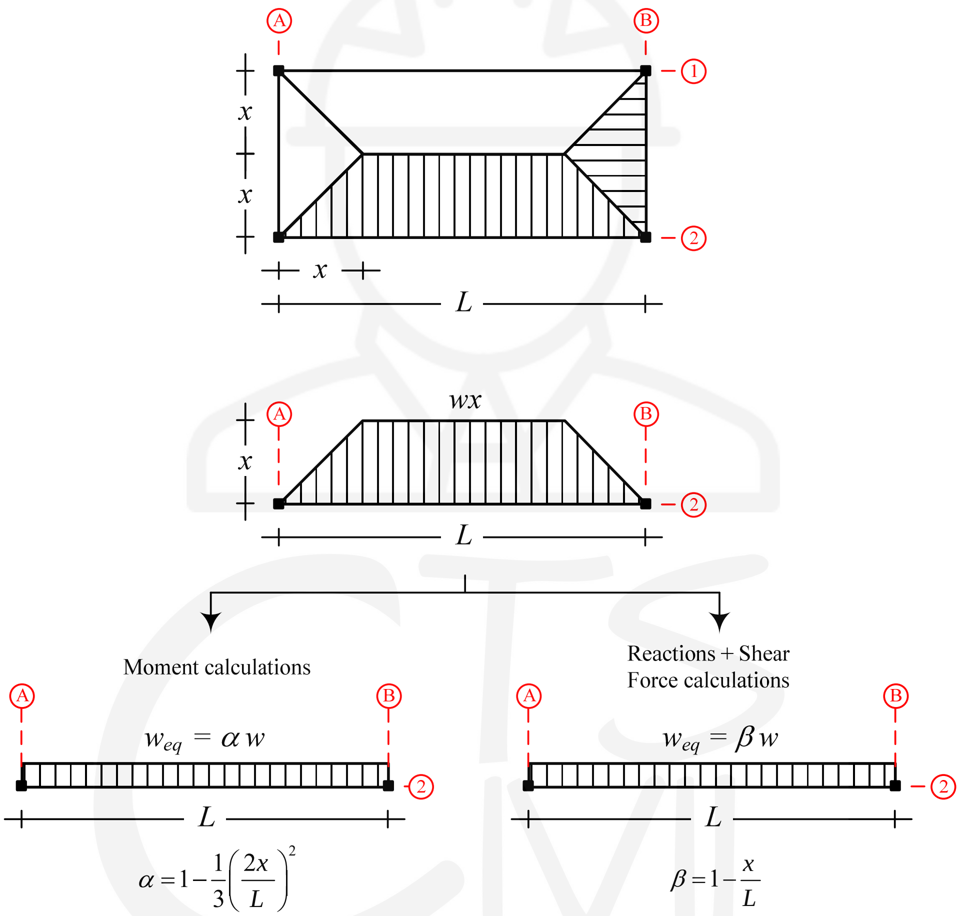


Figure 6-4: Steps in approximating trapezoidal load as a uniformly distributed load

6.3 Concepts in Structural Design:

- The design of any structure should account for safety, serviceability, and economy.
- Economy usually means less cost of construction materials resulting from smaller sections in general.
- This amount corresponds to the cross section with the smallest weight per unit length, which is the one with the smallest cross-sectional area.
- Other considerations, such as ease of construction, may ultimately affect the choice of member size.
- Having established this objective, the engineer must decide how to do it safely, which is where different approaches to design come into play.
- The fundamental requirement of structural design is that the required strength not exceed the available strength; that is,

$$\text{Required Strength} \leq \text{Available Strength}$$

6.3.1 LRFD:

- Load factors are applied to the service loads, and a member is selected that will have enough strength to resist the factored loads.
- In addition, the theoretical strength of the member is reduced by the application of a resistance factor.
- The criterion that must be satisfied in the selection of a member is

$$\text{Factored Load} \leq \text{Factored Strength}$$

- In this expression, the factored load is actually the sum of all service loads to be resisted by the member, each multiplied by its own load factor.
- The factored strength is the theoretical strength multiplied by a resistance factor. So,

$$\sum(\text{Load} \times \text{Load factor}) \leq \text{Resistance} \times \text{resistance factor}$$

- The factored load is a failure load greater than the total actual service load, so the load factors are usually greater than unity.
- However, the factored strength is a reduced, usable strength, and the resistance factor if usually less than unity.
- The factored loads are the loads that bring the structure or member to its limit.
- In terms of safety, this limit state can be fracture, yielding, or buckling, and the factored resistance is the useful strength of the member, reduced from the theoretical value by the resistance factor.
- The limit state can also be one of serviceability, such as a maximum acceptable deflection.

6.3.2 Load Combinations:

- We have seen that

$$\sum(\text{Load}\times\text{Load factor})\le\text{Resistance}\times\text{resistance factor}$$

- It can be written as

$$\sum \gamma_i Q_i \le \phi R_n \qquad (6\text{-}8)$$

Where:

γ_i : a load factor

Q_i : applied load

ϕ : resistance factor

R_n : the nominal resistance or strength

ϕR_n : the design strength

- The summation on the left side of the above expression is over the total number of load effects (including, but not limited to, dead load and live load), where each load effect can be associated with a different load factor.
- This can be obtained by what is known as "Load Combinations"
- Many structures will see most, if not all, the loads mentioned above sometime in their life.
- The next challenge becomes how to combine the loads reasonably.
- A direct combination of all the loads at their maximum is not considered to be probable.
- For example, it would not be reasonable to expect a full live load to occur simultaneously with a full snow load during a design level wind storm.
- The design of a structural member entails the selection of a cross section that will safely and economically resist the applied loads.

6.3.3 LRFD Load Combinations:

$$1.4(D+F) \quad (1)$$

$$1.2(D+F+T)+1.6(L+H)+0.5(L_r \text{ or } S \text{ or } R) \quad (2)$$

$$1.2D+1.6(L_r \text{ or } S \text{ or } R)+(L \text{ or } 0.5W) \quad (3)$$

$$1.2D+1.0W+1.0L+0.5(L_r \text{ or } S \text{ or } R) \quad (4)$$

$$1.2D+1.0E+1.0L+0.2S \quad (5)$$

$$0.9D+1.6W+1.6H \quad (6)$$

$$0.9D+1.0E+1.6H \quad (7)$$

Where:

D = Dead load

F = Fluid Load

T = Self straining load

L = Live load

L_r = Roof live load

H = Lateral earth pressure, ground water pressure

S = Snow load

R = Rain load

W = Wind load

E = Earthquake load

Note:

Wind and earthquake loads will have compression and tensile components. For tensile, use negative value and positive value for compression loads.