Dr. Khalil M. Qatu

Introduction to Structural Analysis

BIRZEIT UNIVERSITY

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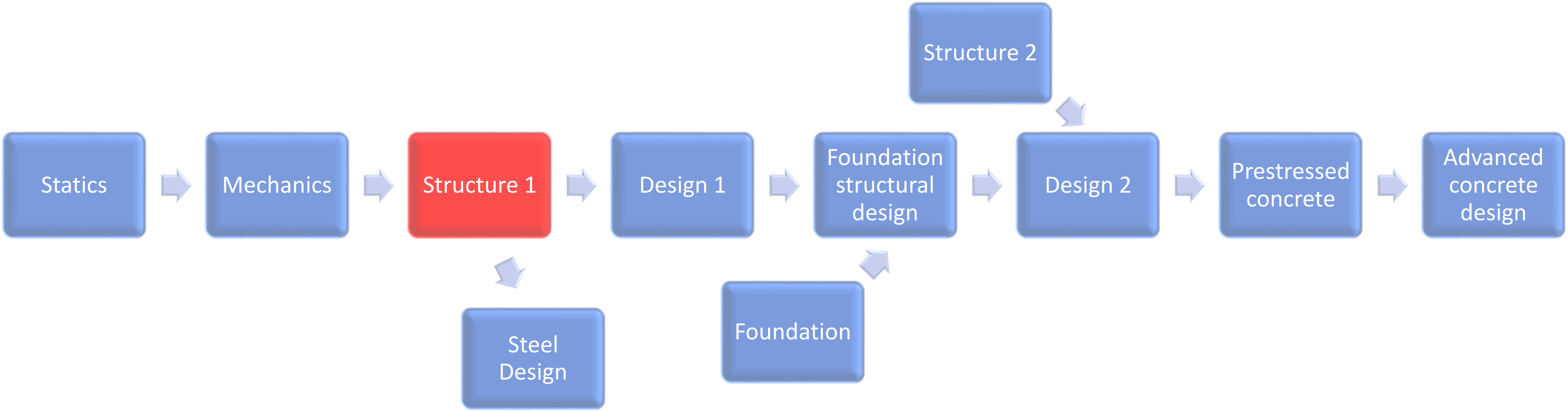

Structure 2
Statics
Mechanics
Structure 1
Design 1
Foundation structural design
Design 2
Prestressed concrete
Advanced concrete design
Steel Design
Foundation

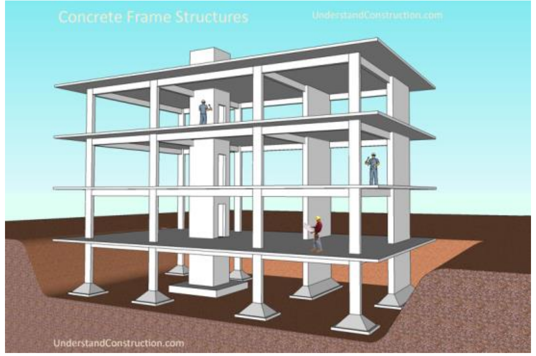
Revision **HW**

- What did we learn in
  - Statics
  - Mechanics of materials

Introduction

- A **<u>structure</u>** may be defined as a system of connected parts used to support a load

- For a structure to be designed properly, the designer should carefully consider the following:
  - Safety
  - Serviceability
  - Economy
  - Esthetics
  - Environment.



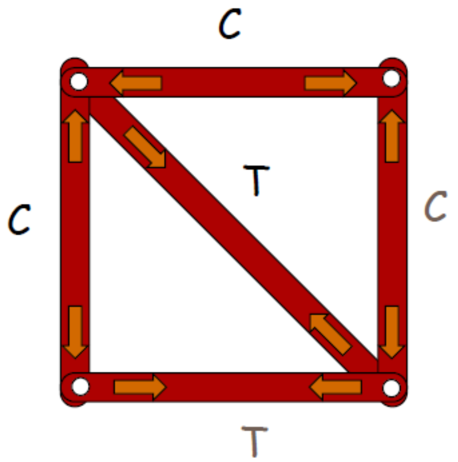
- The structural engineer must carefully study the following:
  - The structural loads that the structure would be exposed to.
  - Material properties used in the structure (stress strain diagram which shows how a material responds to load).
  - And type of structural system to be used (truss, frame, arch … etc.)

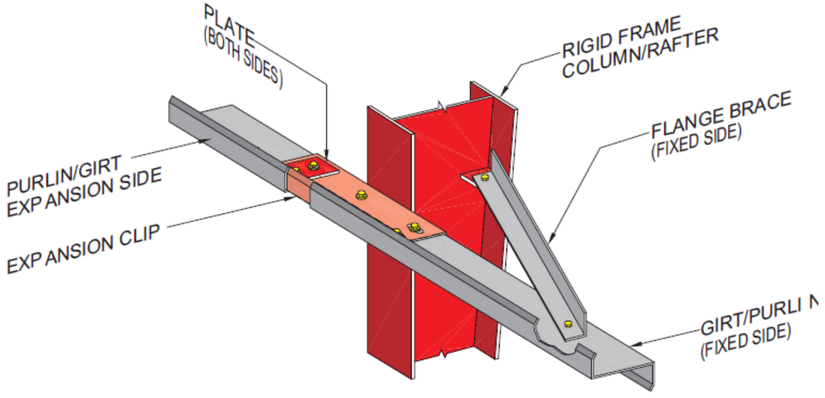
Types of structural elements

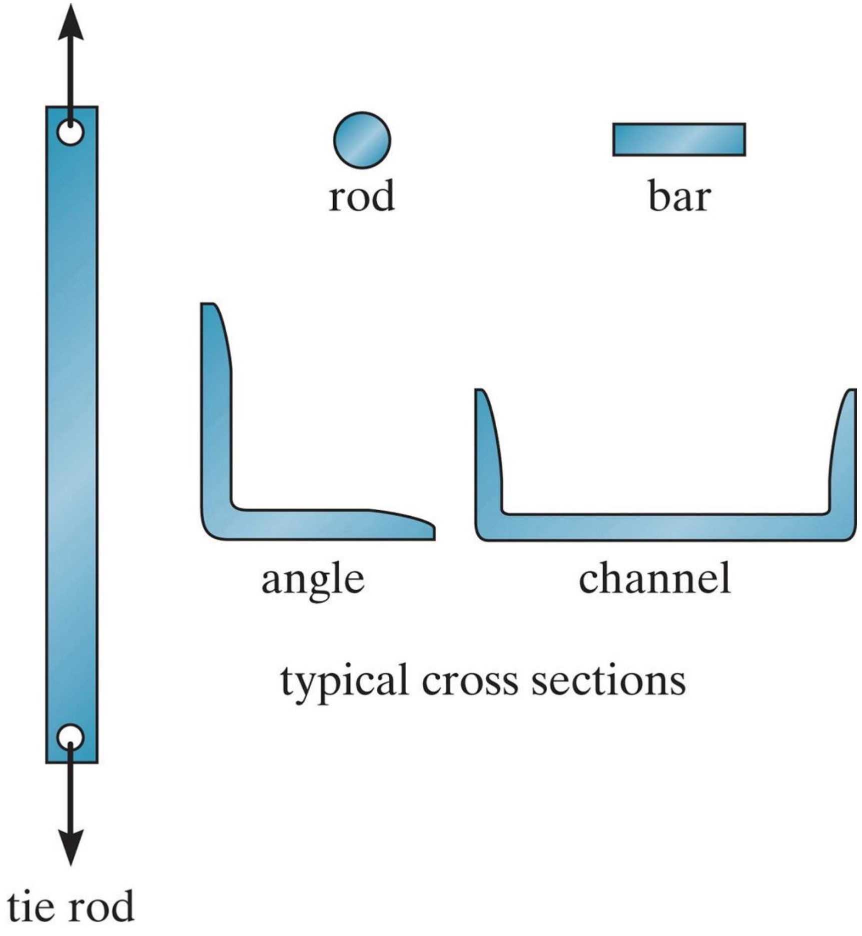
- Bar elements:

  Structural members subjected to only axial force, either compression or tension force.

  - Tie rods (tension)
  - Bracing struts (compression)
  - Truss members







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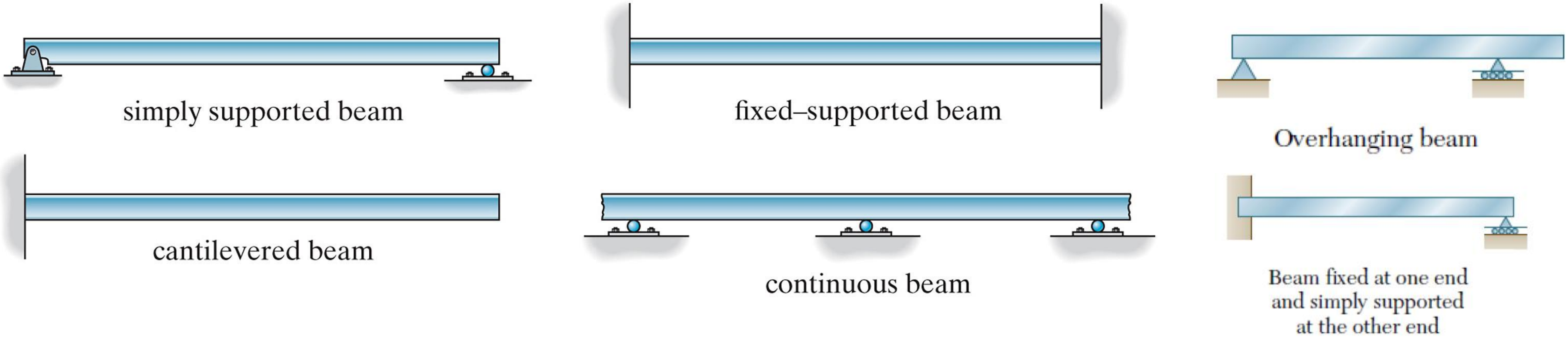
Types of structural elements

- Beam elements:

  Slender structural members that are used to support load that is applied perpendicular to their longitudinal axis.

  They are often classified according to the way they are supported



Types of structural elements

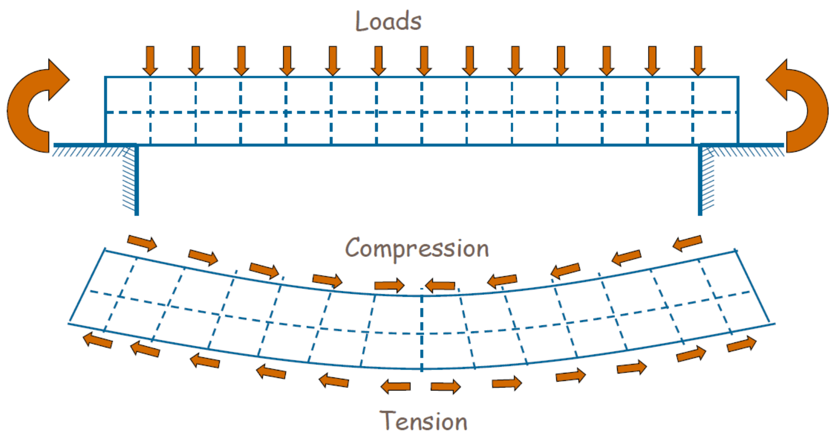
- Beam elements:

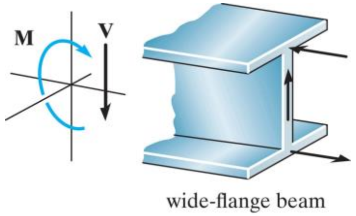
  Beams are used to support loads by bending (flexure).

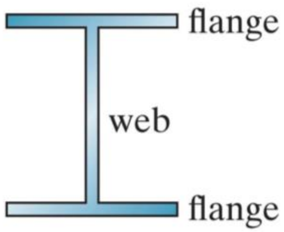
  The forces developed in the top and bottom flanges of the beam form the necessary couple used to resist the applied moment M.

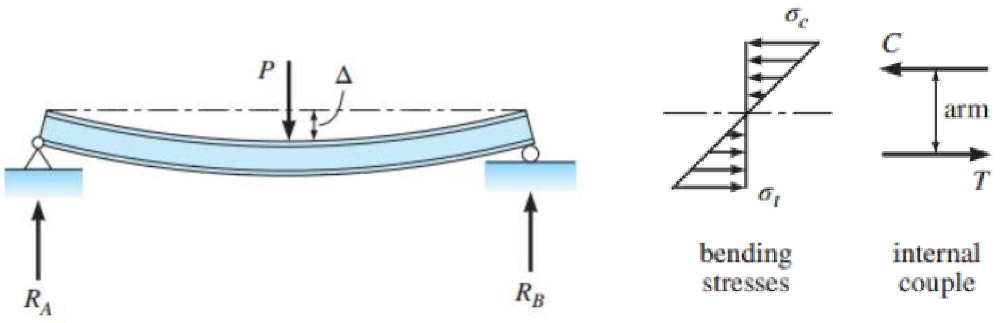
  The web is effective in resisting the applied shear V.

  When the beam is required to have a very large span and the loads applied are rather large, the cross section may take the form of a plate girder (built up section from steel plates).









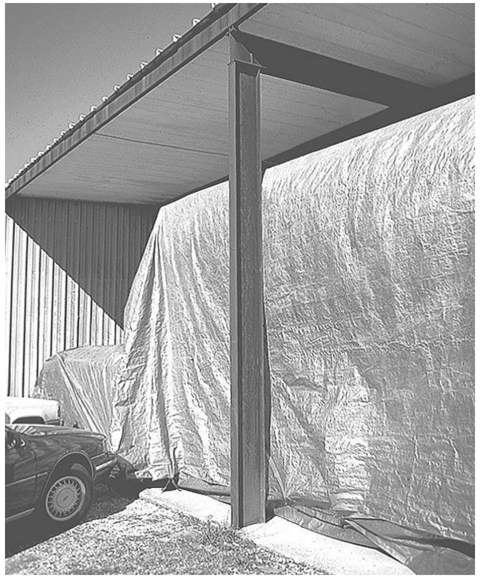
Types of structural elements

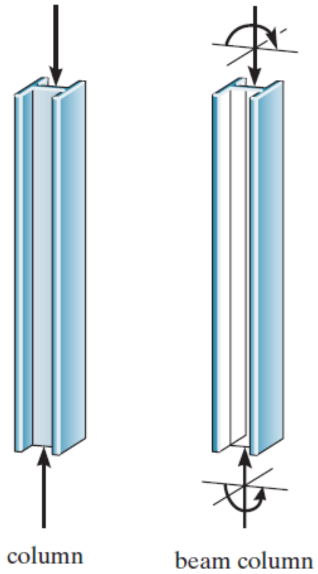
- Column elements:

  Members that are generally vertical and resist axial compressive loads.

  Columns are subjected to both anaxial load and bending moment as shown in the figure. These members are referred to as beam columns.

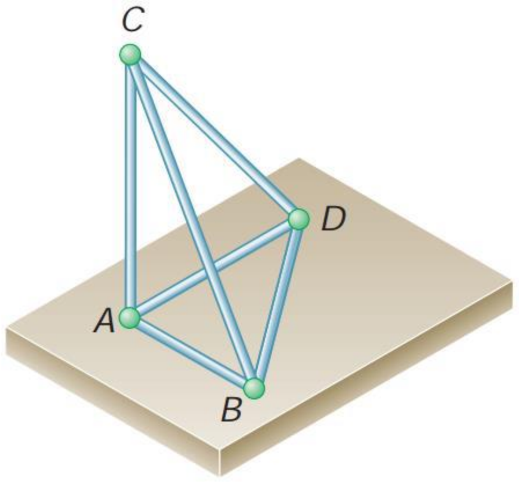
  Columns may fail in crushing ,yielding or buckling. The slenderness ratio L/r is important in compression members, where L is the length of the member and r is the radius of gyration.

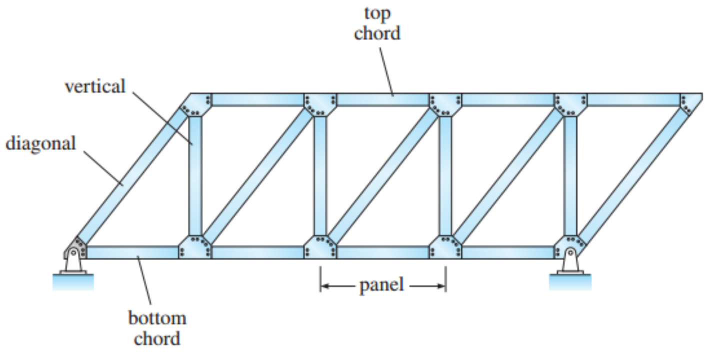




Types of structural Systems

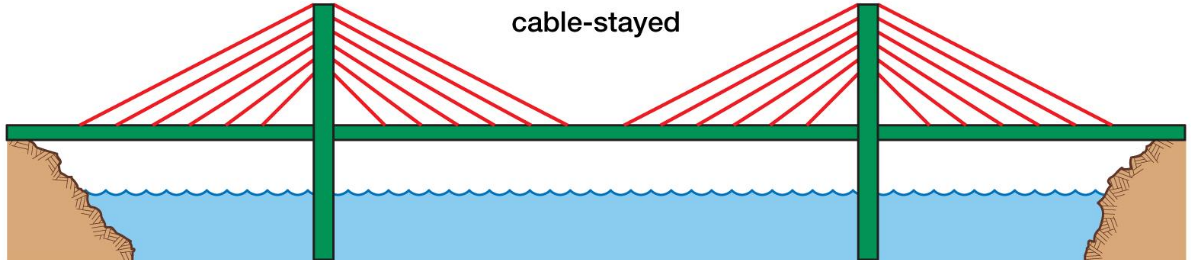
- Trusses
  - A truss is a structural system composed of slender bars whose ends are assumed to be connected by frictionless pin joints.
  - If pin-jointed trusses are loaded at the joints only, direct or axial stress develops in all bars.
  - Planar trusses are composed of members that lie in the same plane and are frequently used for bridges and roofs.
  - Space trusses have members extending in three dimensions and are suitable for towers.





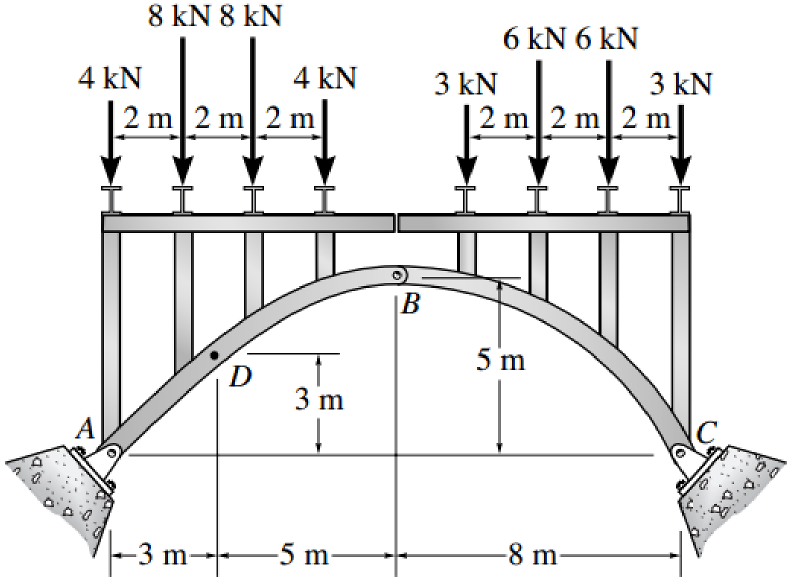
Types of structural Systems

- Cables
  - Usually flexible and carry their loads in tension. They are used to support bridges and building roofs.



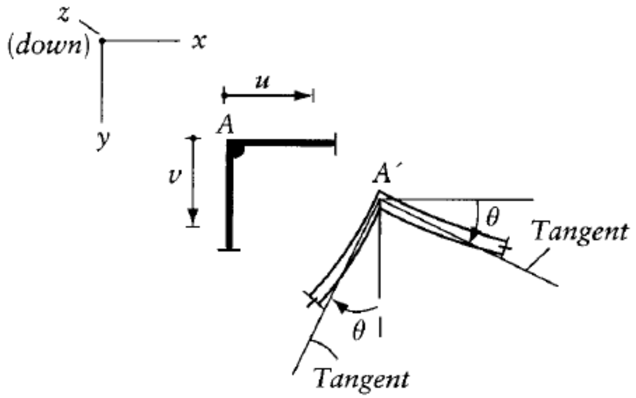
Types of structural Systems

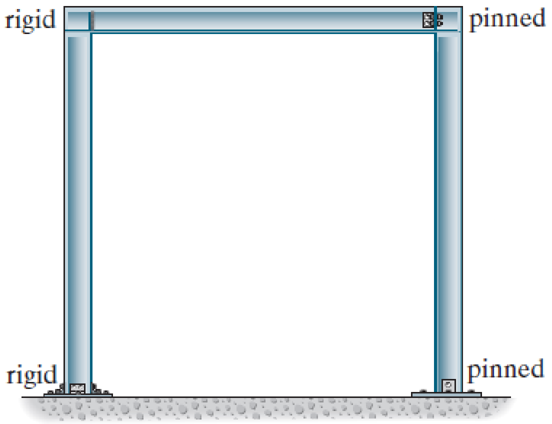
- Arches
  - The arch achieves its strength in compression, since it has a reverse curvature to that of the cable.
  - Due to arch rigidity, it may also resist some bending and shear depending upon how it is loaded and shaped (geometry).



Types of structural Systems

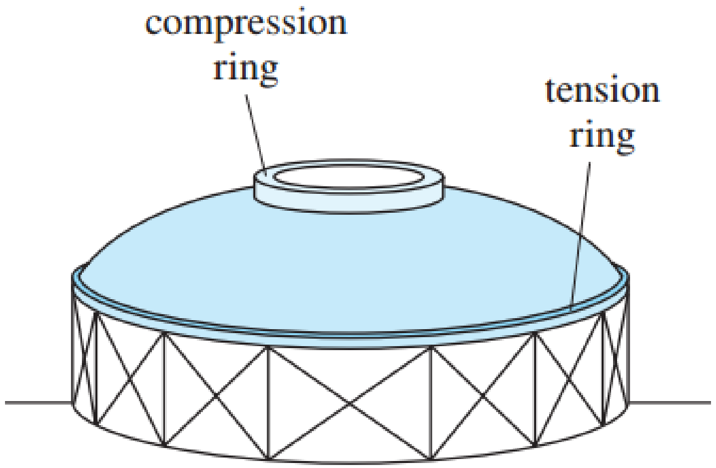
- Frames
  - Frames are composed of beams and columns that are either pin or fixed connected.
  - The loading on a frame (composed of slender elements) causes bending of its members
  - If it has continuous (rigid) joint connections, then the internal forces (axial, shear, and moment are transferred between frame elements)
  - For a joint to be continuous (rigid), the angle between the members must not change; the rotation of the beam's end is the same as the column's end at the connecting joint

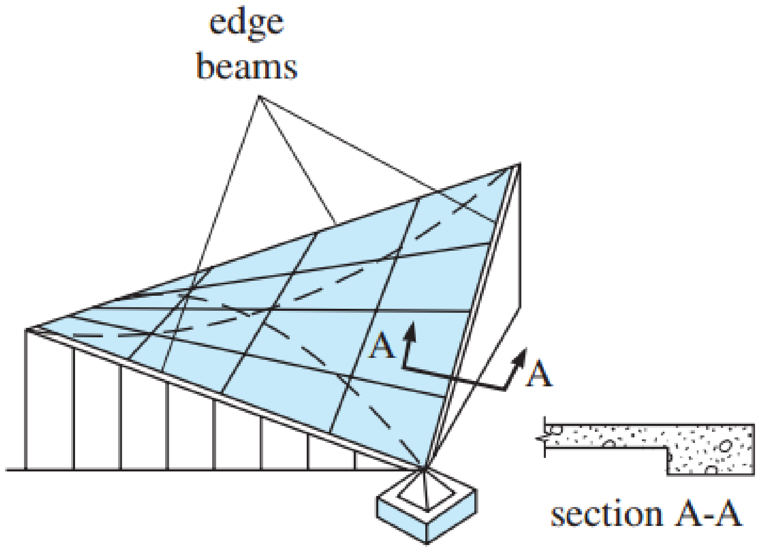


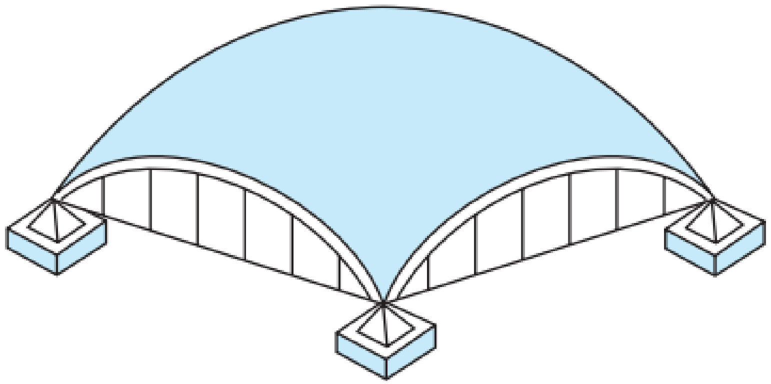


Types of structural Systems

- Surface Structures
  - A surface structure is made from a material having a very small thickness compared to its other dimensions. They are referred to as shells.
  - They can span large distances because of the inherent strength and stiffness of the curved shape.
  - The loading is resisted by the three-dimensional surface, often through tension or compression with very little bending







Loads

- In order to design a structure, it is therefore necessary to first specify the loads that act on it.
- The design loading for a structure is often specified in codes.
- The ultimate responsibility for the design lies with the structural engineer.

TABLE 1.1 Codes

General Building Codes
Minimum Design Loads for Buildings and Other Structures, ASCE/SEI 7-10, American Society of Civil Engineers
International Building Code
Design Codes
Building Code Requirements for Reinforced Concrete, Am. Conc. Inst. (ACI)
Manual of Steel Construction, American Institute of Steel Construction (AISC)
Standard Specifications for Highway Bridges, American Association of State Highway and Transportation Officials (AASHTO)
National Design Specification for Wood Construction, American Forest and Paper Association (AFPA)
Manual for Railway Engineering, American Railway Engineering Association (AREA)

Types of loads

- Dead loads
  - Dead loads consist of the weights of the various structural members and the weights of any objects that are permanently attached to the structure.
  - Hence, for a building, the dead loads include the weights of the columns, beams, shear walls, floor slabs, roofing, partitions, floor finishes, windows, plumbing, electrical fixtures, and other miscellaneous attachments.
  - Structural dead load is calculated using simple formulas based on the densities given by building standards or/and manufactures.

TABLE 1.2 Minimum Densities for Design Loads from Materials*

	lb/ft^3	kN/m^3
Aluminum	170	26.7
Concrete, plain cinder	108	17.0
Concrete, plain stone	144	22.6
Concrete, reinforced cinder	111	17.4
Concrete, reinforced stone	150	23.6
Clay, dry	63	9.9
Clay, damp	110	17.3
Sand and gravel, dry, loose	100	15.7
Sand and gravel, wet	120	18.9
Masonry, lightweight solid concrete	105	16.5
Masonry, normal weight	135	21.2
Plywood	36	5.7
Steel, cold-drawn	492	77.3
Wood, Douglas Fir	34	5.3
Wood, Southern Pine	37	5.8
Wood, spruce	29	4.5

*Minimum Densities for Design Loads from Materials, Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10. Copies of this standard may be purchaed from ASCE at www.pubs.asce.org, American Society of Civil Engineers.

Types of loads

- Live Loads
  - Live loads can vary both in their magnitude and location.
  - They may be caused by the weights of occupants using the structure, objects temporarily placed on a structure, moving vehicles, or natural forces.
  - The minimum live loads are specified in standards and categorized by the occupancy or usage of the structure.

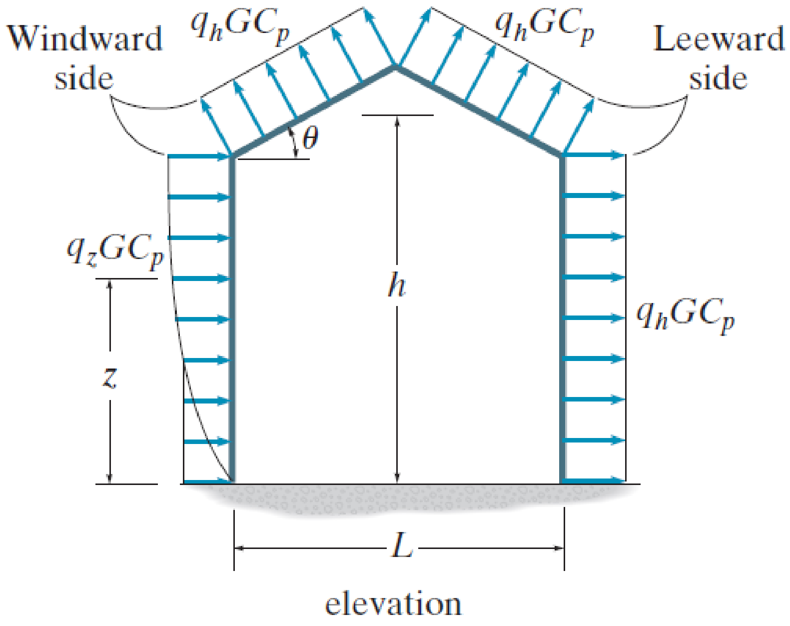
TABLE 1.4 Minimum Live Loads*

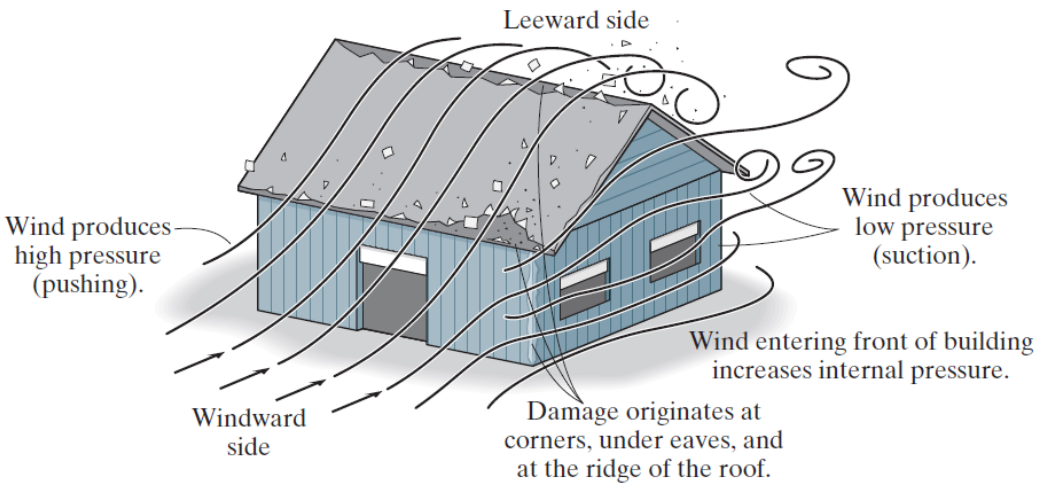
Occupancy or Use	Live Load psf	Live Load kN/m²	Occupancy or Use	Live Load psf	Live Load kN/m²
Assembly areas and theaters			Residential		
Fixed seats	60	2.87	Dwellings (one- and two-family)	40	1.92
Movable seats	100	4.79	Hotels and multifamily houses		
Garages (passenger cars only)	40	1.92	Private rooms and corridors	40	1.92
Office buildings			Public rooms and corridors	100	4.79
Lobbies	100	4.79	Schools		
Offices	50	2.40	Classrooms	40	1.92
Storage warehouse			First-floor corridors	100	4.79
Light	125	6.00	Corridors above first floor	80	3.83
Heavy	250	11.97			

*Minimum Live Loads, Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10, American Society of Civil Engineers.

Types of loads

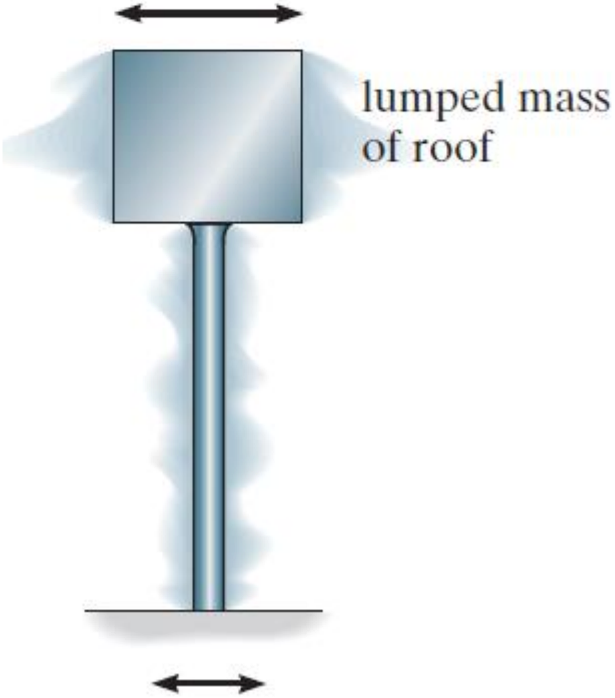
- Wind Loads
  - The pressure created by the wind is proportional to the square of the wind speed





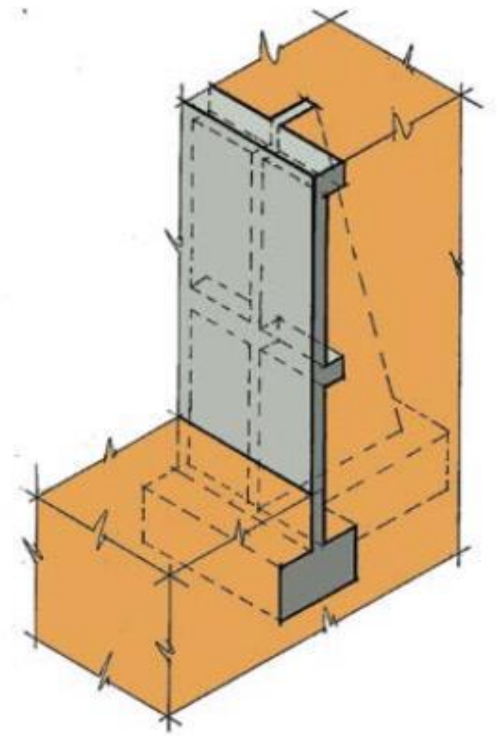
Types of loads

- Earthquake Loads
  - Earthquakes causes inertia forces at the floor levels (mass points) of the building
  - The magnitude of an earthquake loads (seismic loads) depends on the severity and probability of occurrence of earthquakes in the region, and the mass, stiffness and importance of the structure



Types of loads

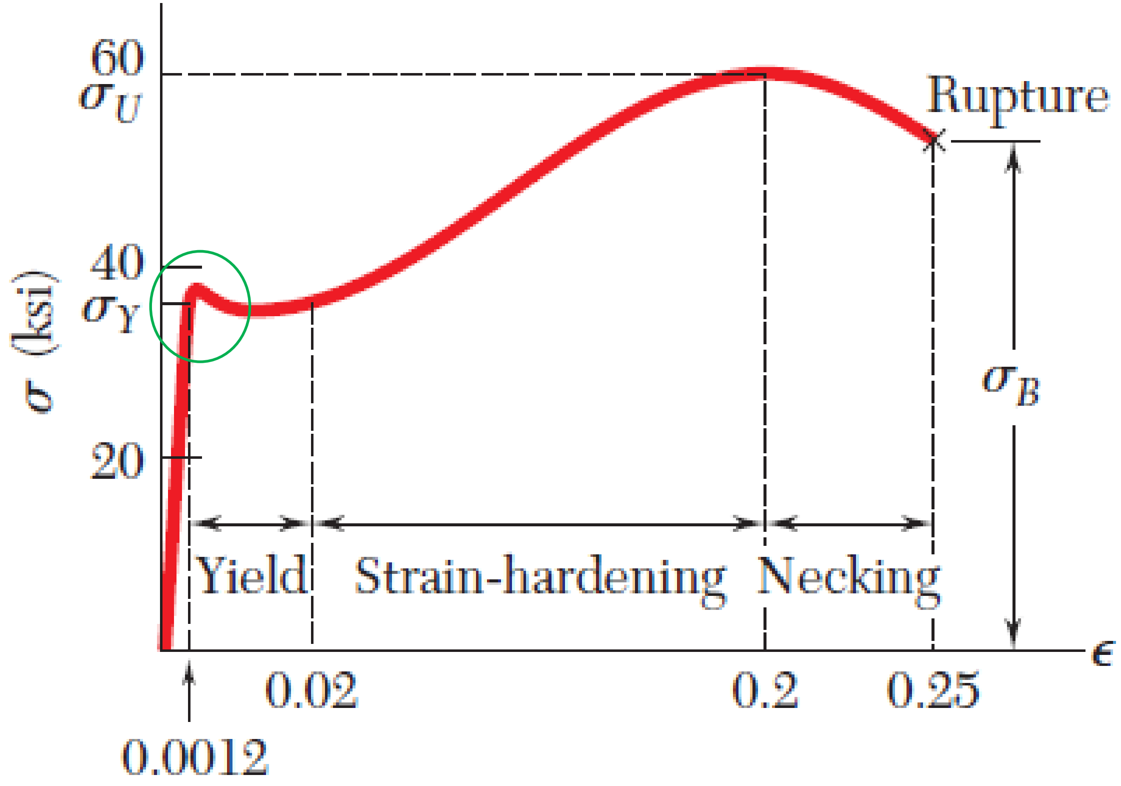
- Hydrostatic and Soil Pressure loads
  - When structures are used to retain water, soil, or granular materials, the pressure developed by these loadings becomes an important criterion for their design.



- **Other Natural Loads**: Several other types of live loads may also have to be considered in the design of a structure, depending on its location or use. These include the effect of **blast, temperature changes, and differential settlement of the foundation**.

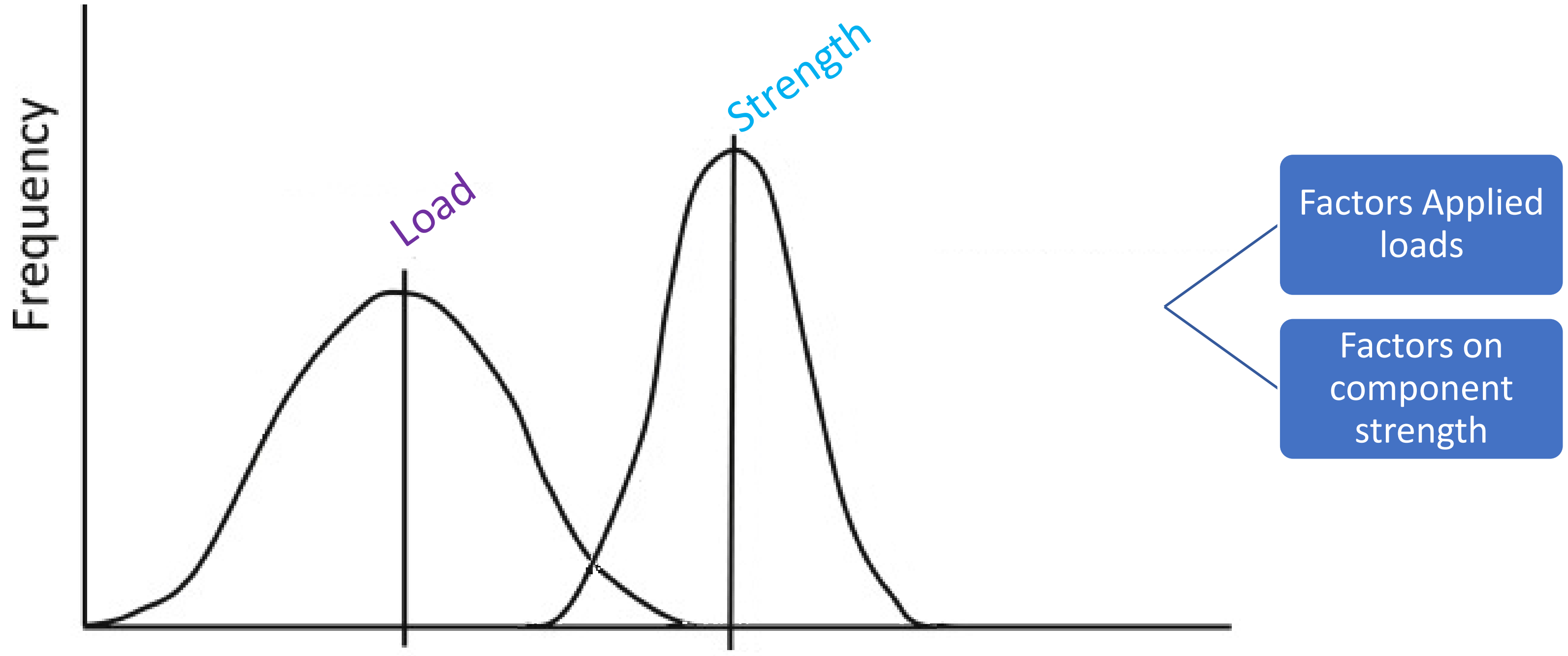
Structural Design

- Allowable stress design (ASD)



Structural Design

- Load and resistance factored design (LRFD)
  - This methods considers the variability in the applied loads (internal) and component strength



Structural Design

- Load and resistance factored design (LRFD)
  - Load Factors and load combinations

Table 5.3.1—Load combinations

Load combination	Equation	Primary load
$U = 1.4D$	(5.3.1a)	D
$U = 1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$	(5.3.1b)	L
$U = 1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (1.0L \text{ or } 0.5W)$	(5.3.1c)	L_r or S or R
$U = 1.2D + 1.0W + 1.0L + 0.5(L_r \text{ or } S \text{ or } R)$	(5.3.1d)	W
$U = 1.2D + 1.0E + 1.0L + 0.2S$	(5.3.1e)	E
$U = 0.9D + 1.0W$	(5.3.1f)	W
$U = 0.9D + 1.0E$	(5.3.1g)	E

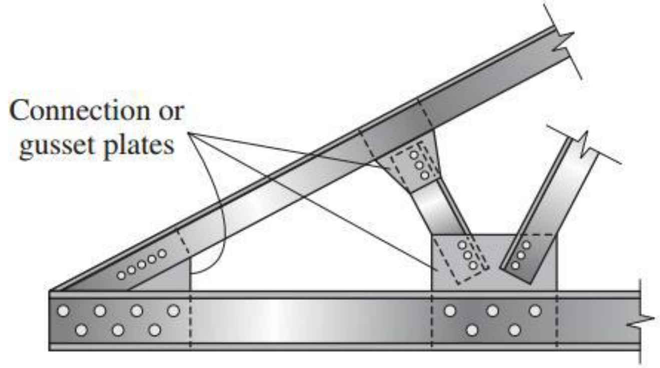
Note that factors are higher for loads with high variability

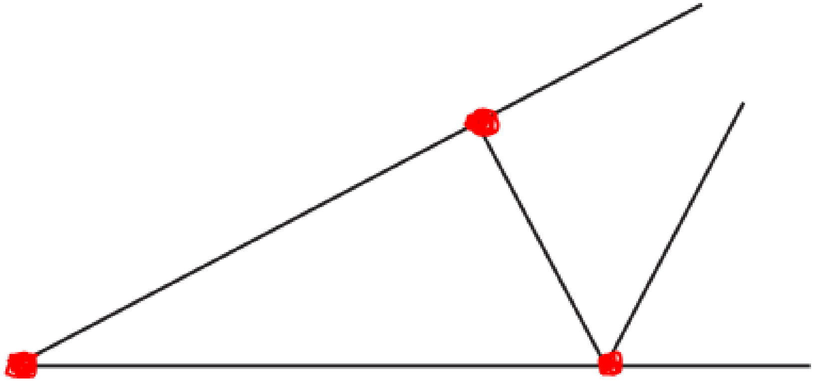
- After structural analysis we get ultimate internal forces in the member in consideration

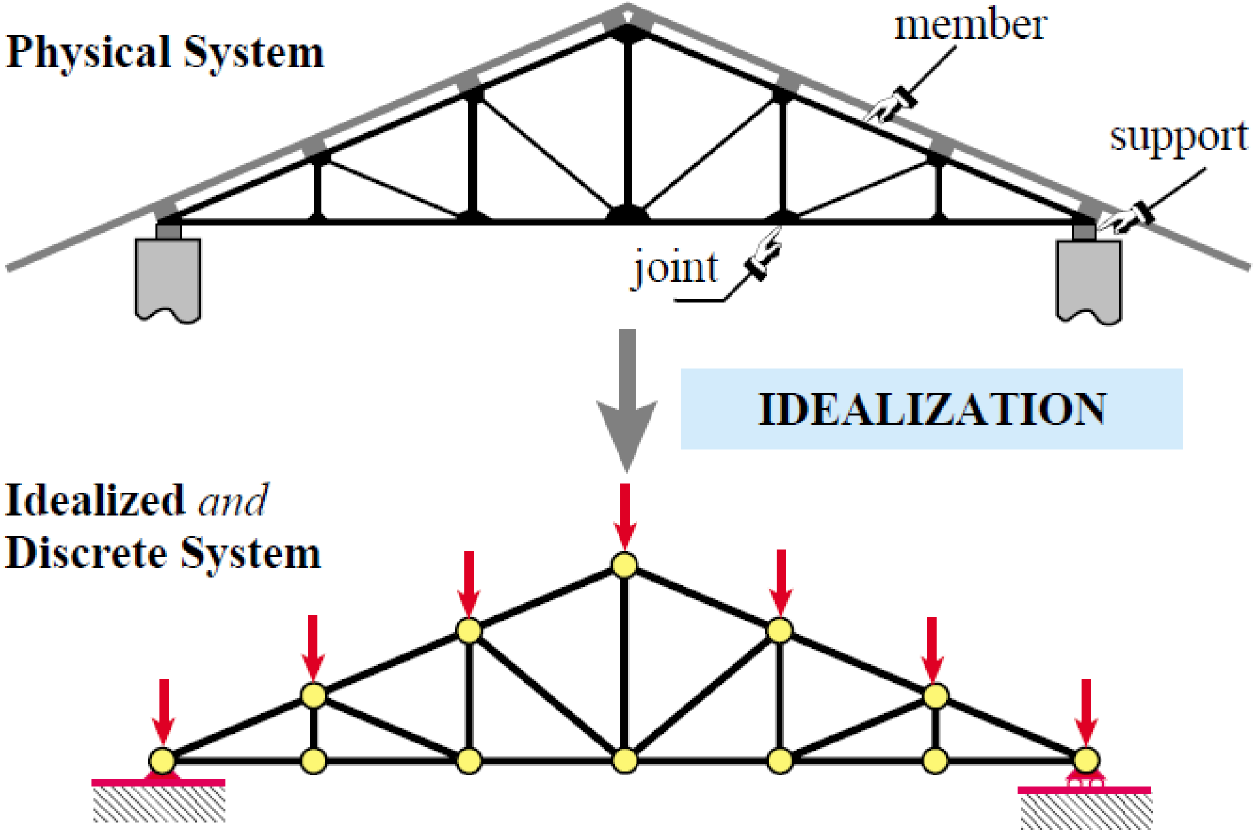
$$M_u \qquad V_u \qquad P_u$$

Idealization of structures

- The process of replacing an actual (physical) structure with a simple (mathematical) system conducive to analysis.

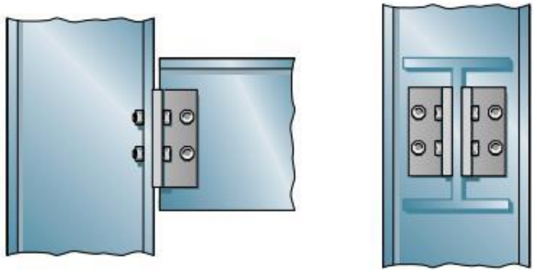




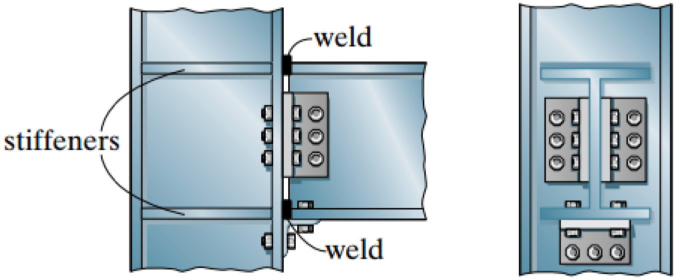


Idealization of structures

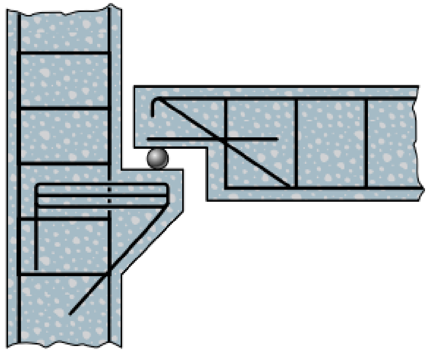
- An exact model of a structure can never be constructed!
- Connections to be modeled based on expected behavior:



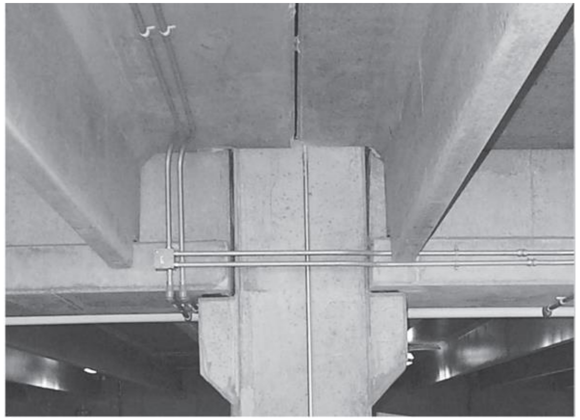
typical "pin-supported" connection (metal)

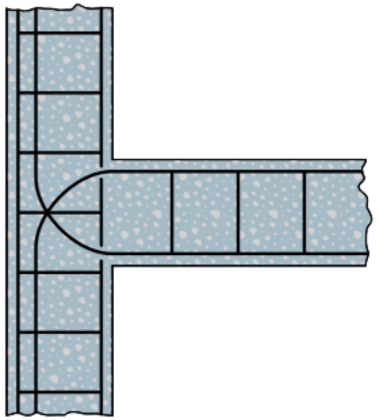


typical "fixed-supported" connection (metal)



typical "roller-supported" connection (concrete)





typical "fixed-supported" connection (concrete)

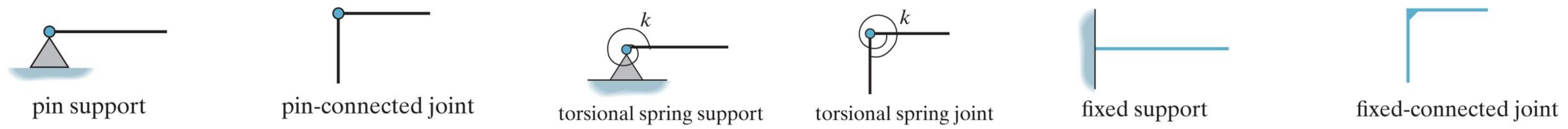
Idealization of structures

TABLE 2.1 Supports for Coplanar Structures

Type of Connection	Idealized Symbol	Reaction	Number of Unknowns
(1) light cable; weightless link		F, θ	One unknown. The reaction is a force that acts in the direction of the cable or link.
(2) rollers; rocker		F	One unknown. The reaction is a force that acts perpendicular to the surface at the point of contact.
(3) smooth contacting surface		F	One unknown. The reaction is a force that acts perpendicular to the surface at the point of contact.
(4) smooth pin-connected collar		F	One unknown. The reaction is a force that acts perpendicular to the surface at the point of contact.

TABLE 2.1 Supports for Coplanar Structures

Type of Connection	Idealized Symbol	Reaction	Number of Unknowns
(4) smooth pin-connected collar		F	One unknown. The reaction is a force that acts perpendicular to the surface at the point of contact.
(5) smooth pin or hinge	θ	F_y, F_x	Two unknowns. The reactions are two force components.
(6) slider; fixed-connected collar		M, F	Two unknowns. The reactions are a force and a moment.
(7) fixed support		M, F_y, F_x	Three unknowns. The reactions are the moment and the two force components.



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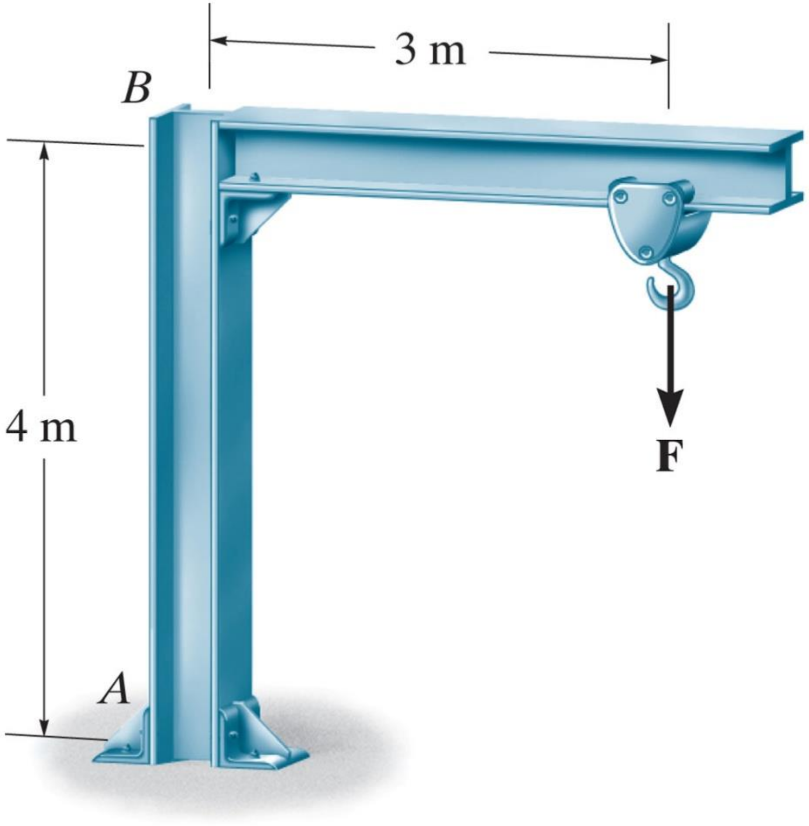
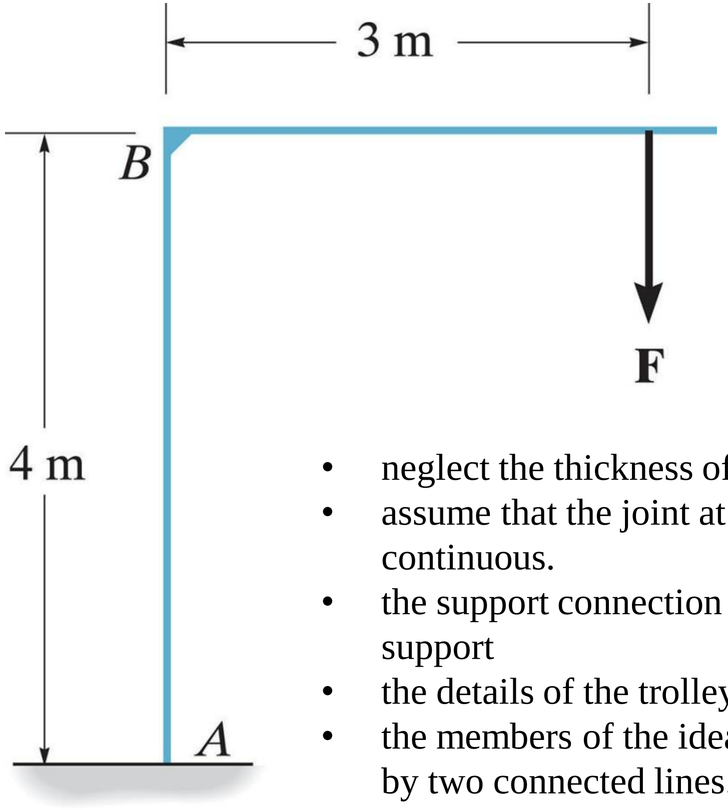
Idealization of structures

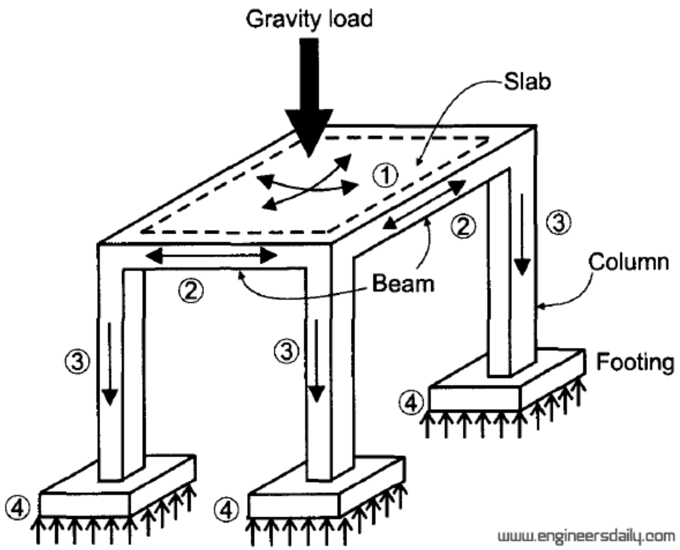


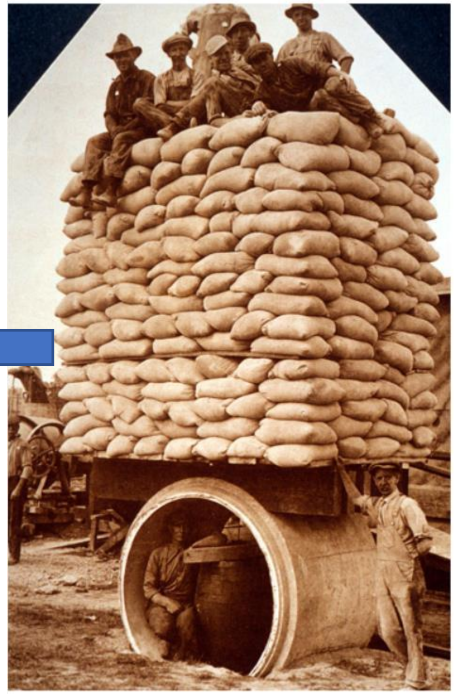


- neglect the thickness of the two main members
- assume that the joint at B is fabricated to be continuous.
- the support connection at A can be modeled as a fixed support
- the details of the trolley excluded.
- the members of the idealized structure are represented by two connected lines.
- the load on the hook is represented by a single concentrated force **F**

Load Path

- how the loads are transmitted through various structural members from point of application to the foundation!
- •Like a chain, which is "as strong as its weakest link", so a structure is only as strong as the weakest part along its load path





Draw LOAD PATH & structural model of the system

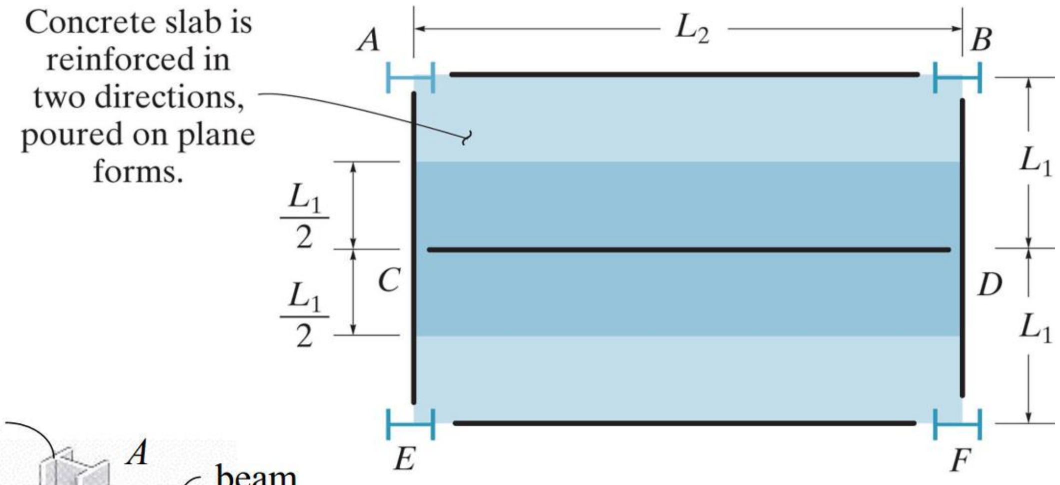
Load transfer & tributary loadings

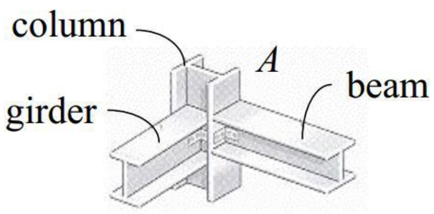
- Many floor systems consist of a reinforced concrete slab supported on a rectangular grid of beams.
- The supporting beams reduce the span of the slab and permit the designer to reduce the depth and weight of the floor system.
- The distribution of dead loads to a floor beam depends on the geometric configuration of the beams forming the grid.
- Determine how the load on these surfaces is transmitted to the various structural elements used for their support !!!
- There are generally two ways in which this can be done :
  - One Way system.
  - Two Way system.

An example of one-way slab construction of a steel frame building having a poured concrete floor on a corrugated metal deck. The load on the floor is considered to be transmitted to the beams, not the girders.

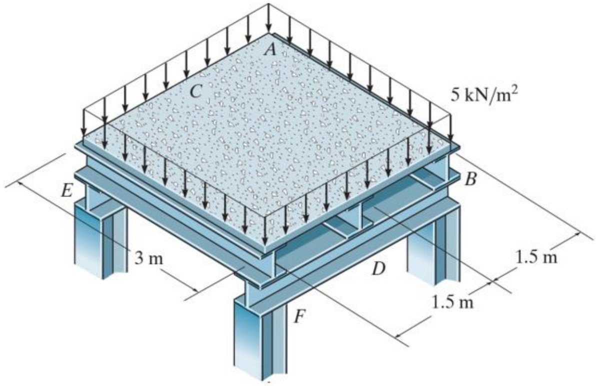
Load transfer & tributary loadings

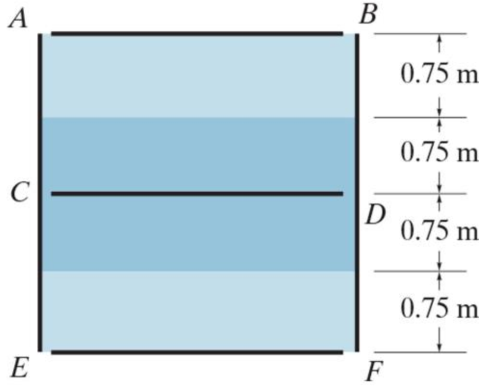
- One-way system
  - According to the ASCE-7, if $L_2 \geq L_1$ and the support ratio $(L2/L1) \geq 2$, then the load is assumed to be transferred to the supporting beams and girders in one direction.



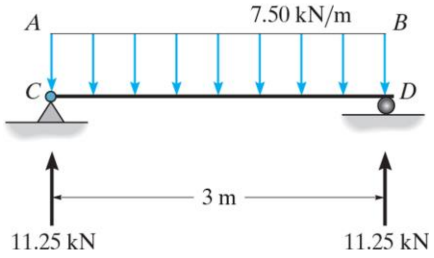


Idealized framing plan for one-way slab action requires $L_2/L_1 > 2$.

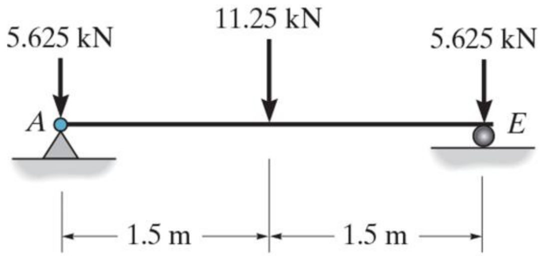




idealized framing plan



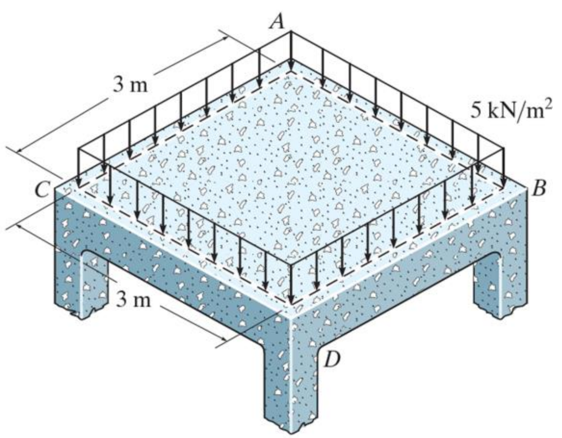
idealized beam

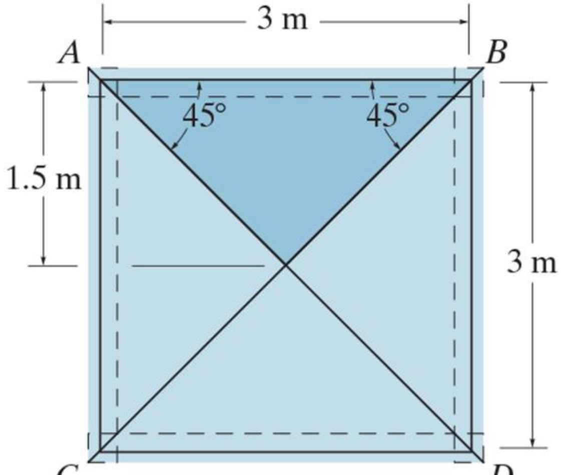


idealized girder

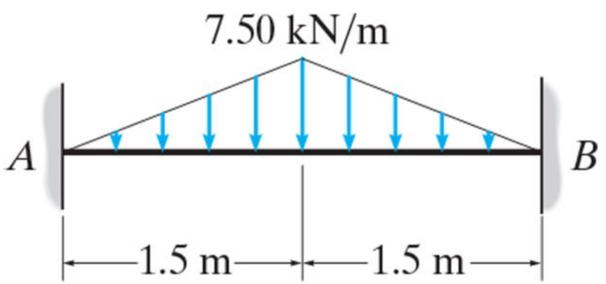
Load transfer & tributary loadings

- Two-way system

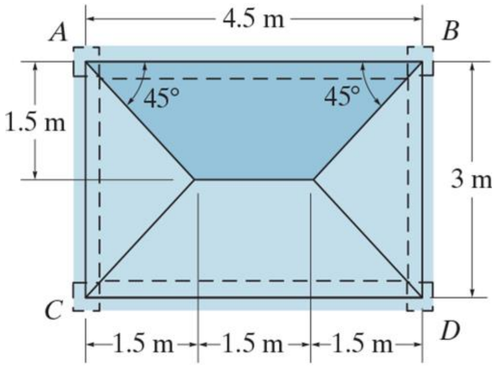




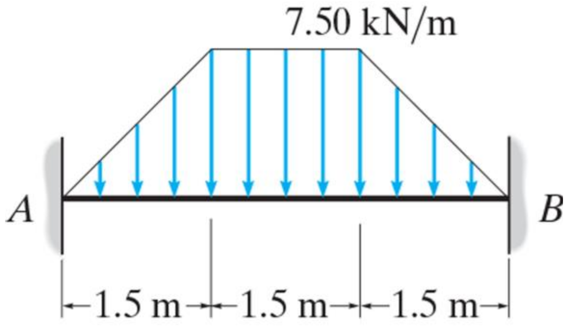
idealized framing plan



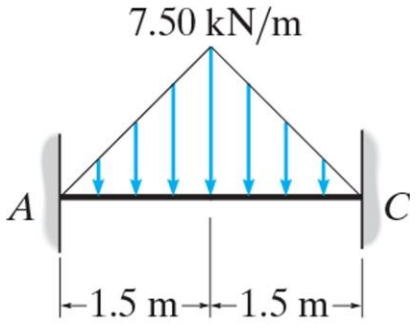
idealized beam



idealized framing plan



idealized beam



idealized beam

Dr. Khalil M. Qatu

Load transfer & tributary loadings

- Column Load
  - To determine the gravity loads transmitted into a column from a floor slab, the designer can either
    - Determine the reactions of the beams framing into the column
    - Multiply the tributary area of the floor surrounding the column by the magnitude of the load per unit area acting on the floor.
  - The tributary area of a column is defined as the area surrounding the column that is bounded by the panel centerlines.