COURSE TOPICS:

- *Introduction of Types of Structures and Loads*
- *Concepts of Determinacy and Stability of Structures*
- *Analysis of Statically Determinate Shear and Moment Diagrams for a Frame*
- *Analysis of Statically Determinate Trusses*
- *Classification of Coplanar Trusses*
- *Influence Lines for Statically Determinate Beams and Trusses*
- *Maximum Influence at a Point due to a Series of Concentrated Loads*
- *Absolute Maximum Shear and Moment*
- *Deflections: The Double Integration Method*
- *Deflections : Conjugate-Beam Method*
- *Deflections Using Energy Methods*

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1 INTRODUCTION OF TYPES OF STRUCTURES AND LOADS

1.1 Introduction:

A *structure* refers to a system of connected parts used to support a load. Important examples related to civil engineering include buildings, bridges, and towers; and in other branches of engineering, ship and aircraft frames, tanks, pressure vessels, mechanical systems, and electrical supporting structures are important.

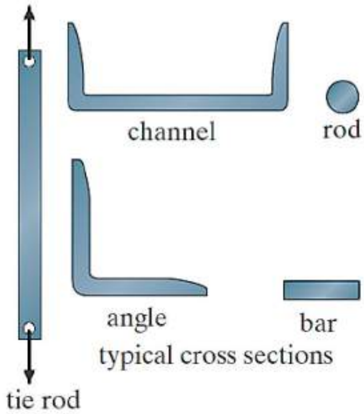
When designing a structure to serve a specified function for public use, the engineer must account for its safety, esthetics, and serviceability, while taking into consideration economic and environmental constraints.

1.2 Classification of Structures

It is important for a structural engineer to recognize the various types of elements composing a structure and to be able to classify structures as to their form and function.

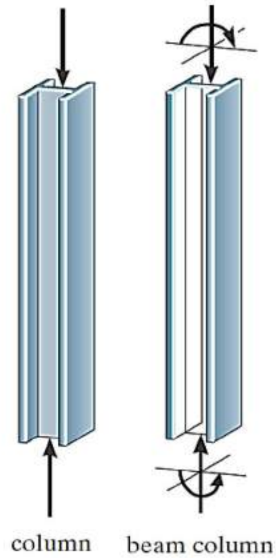
1.2.1 Structural Elements.

Some of the more common elements from which structures are composed are as follows.



Tie Rods.

- ✓Structural members subjected to a *tensile force* are often referred to as *tie rods* or *bracing struts.*
- ✓Due to the nature of this load, these members are rather slender, and are often chosen from rods, bars, angles, or channels.



Columns.

- ✓Members that are generally vertical and resist axial compressive loads are referred to as *columns*.
- ✓Tubes and wide-flange cross sections are often used for metal columns
- ✓Circular and square cross sections with reinforcing rods are used for those made of concrete.
- ✓Occasionally, columns are subjected to both an axial load and a bending moment as shown in the figure. These members are referred to as *beam columns.*

Beams.

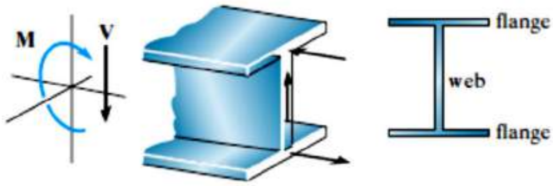
- ✓ Beams are usually straight horizontal members used primarily to carry vertical loads.
- ✓ Often they are classified according to the way they are supported
- ✓ When the cross section varies the beam is referred to as tapered or haunched. Beam cross sections may also be "built up" by adding plates to their top and bottom.
- ✓ Beams are primarily designed to resist *bending moment*; however, if they are short and carry large loads, the internal shear force may become quite large and this force may govern their design.
- ✓ When the material used for a beam is a metal such as steel or aluminum, the cross section is most efficient.
- ✓ The forces developed in the top and bottom *flanges* of the beam form the necessarycouple used to resist the applied moment ***M***, whereas the *web* is effective in resisting the applied shear ***V***.
- ✓ The cross section is commonly referred to as a "*wide flange*", and it is normally formed as a single unit in a rolling mill in lengths up to **75 ft (23 m**).
- ✓ 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.* This member is fabricated by using a large plate for the web and welding or bolting plates to its ends for flanges.
- ✓ The girder is often transported to the field in segments, and the segments are designed to be spliced or joined together at points where the girder carries a small internal moment.
- ✓ Concrete beams generally have rectangular cross sections, since it is easy to construct this form directly in the field.
- ✓ Because concrete is rather weak in resisting tension, steel "*reinforcing rods*" are cast into the beam within regions of the cross section subjected to tension.

simply supported beam

cantilevered beam

fixed–supported beam

continuous beam



The prestressed concrete girders are simply supported

Typical splice plate joints used to connect the steel girders of a highway bridge.

- ✓ Precast concrete beams or girders are fabricated at a shop or yard in the same manner and then transported to the job site.
- ✓ Beams made from timber may be sawn from a solid piece of wood or laminated. *Laminated* beams are constructed from solid sections of wood, which are fastened together using high-strength glues.

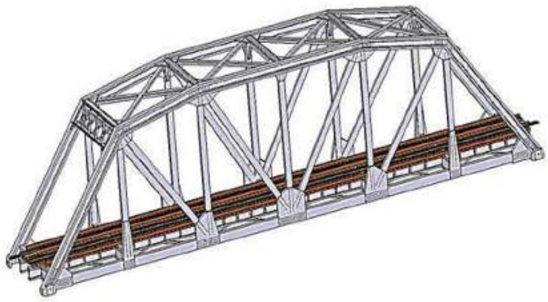
Beams made from timber

1.2.2 Types of Structures.

The combination of structural elements and the materials from which they are composed is referred to as a *structural system.*

Trusses.

- ✓ When the span of a structure is required to be large and its depth is not an important criterion for design, a truss may be selected. *Trusses* consist of slender elements, usually arranged in triangular fashion.
- ✓ *Planar trusses* are composed of members that lie in the same plane and are frequently used for bridge and roof support.
- ✓ Whereas *space trusses* have members extending in three dimensions and are suitable for derricks and towers.
- ✓ Due to the geometric arrangement of its members, loads that cause the entire truss to bend are converted into tensile or compressive forces in the members.
- ✓ One of the primary advantages of a truss, compared to a beam, is that it uses less material to support a given load.
- ✓ Also, a truss is constructed from *long and slender elements,* which can be arranged in various ways to support a load.
- ✓ Most often it is economically feasible to use a truss to cover sp*+ans ranging from **30 ft (9 m)** to **400 ft (122 m)**, although trusses have been used on occasion for spans of greater lengths.



Cables and Arches.

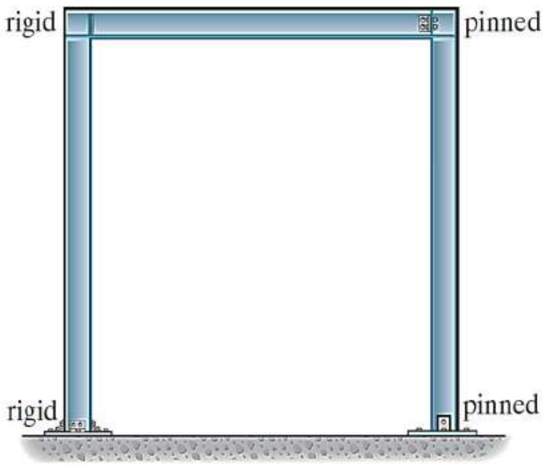
- ✓ Two other forms of structures used to span long distances are the cable and the arch.
- ✓ *Cables* are usually flexible and carry their loads in tension.
- ✓ They are commonly used to support bridges, and building roofs.
- ✓ The cable has an advantage over the beam and the truss, especially for spans that are greater than **150 ft (46 m)**. Because they are always in tension, cables will not become unstable and suddenly collapse, as may happen with beams or trusses.
- ✓ Furthermore, the truss will require added costs for construction and increased depth as the span increases.
- ✓ Use of cables, on the other hand, is limited only by their sag, weight, and methods of anchorage.
- ✓ The *arch* achieves its strength in compression, since it has a reverse curvature to that of the cable.
- ✓ The arch must be rigid, however, in order to maintain its shape, and this results in secondary loadings involving shear and moment, which must be considered in its design.
- ✓ Arches are frequently used in bridge structures, dome roofs, and for openings in masonry walls.

Cables support their loads in tension.

Arches support their loads in compression

Frames.

- ✓ Frames are often used in buildings and are composed of beams and columns that are either pin or fixed connected. Like trusses, frames extend in two or three dimensions.
- ✓ The loading on a frame causes bending of its members, and if it has rigid joint connections, this structure is generally "indeterminate" from a standpoint of analysis.
- ✓ The strength of such a frame is derived from the moment interactions between the beams and the columns at the rigid joints.



Frame members are subjected to internal axial, shear, and moment loadings.

Surface Structures.

- ✓ A *surface structure* is made from a material having a very small thickness compared to its other dimensions.
- ✓ Sometimes this material is very flexible and can take the form of a tent or air-inflated structure.
- ✓ In both cases the material acts as a membrane that is subjected to pure tension.
- ✓ Surface structures may also be made of rigid material such as reinforced concrete. As such they may be shaped as folded plates, cylinders, or hyperbolic paraboloids, and are referred to as *thin plates* or *shells.*
- ✓ These structures act like cables or arches since they support loads primarily in tension or compression, with very little bending.

The roof of the "Georgia Dome" in Atlanta, Georgia can be considered as a thin membrane.

1.3 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.

In general, the structural engineer works with two types of codes***: general building codes*** and ***design codes***.

General building codes specify the requirements of governmental bodies for minimum design loads on structures and minimum standards for construction.

Design codes provide detailed technical standards and are used to establish the requirements for the actual structural design.

Table 1–1 lists some of the important codes used in practice. It should be realized, however, that codes provide only a general guide for design.

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)

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.
- ✓ In some cases, a structural dead load can be estimated satisfactorily from simple formulas based on the weights and sizes of similar structures.
- ✓ Through experience one can also derive a "feeling" for the magnitude of these loadings. For example, the average weight for timber buildings is **40 – 50 lb/ft^2 (1.9 – 2.4 Kn/m^2)**, for steel framed buildings it is **60 – 75 lb/ft^2 (2.9 – 3.6 kN/m^2),** and for reinforced concrete buildings it is **110 – 130 lb/ft^2 (5.3 – 6.2 kN/m^2)**.
- ✓ The densities of typical materials used in construction are listed in Table 1–2, and a portion of a table listing the weights of typical building components is given in Table 1–3.

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

*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 purchased from ASCE at www.pubs.asce.org.

TABLE 1–3 Minimum Design Dead Loads*

Walls	psf	kN/m^2
4-in. (102 mm) clay brick	39	1.87
8-in. (203 mm) clay brick	79	3.78
12-in. (305 mm) clay brick	115	5.51
Frame Partitions and Walls		
Exterior stud walls with brick veneer	48	2.30
Windows, glass, frame and sash	8	0.38
Wood studs 2 × 4 in., (51 × 102 mm) unplastered	4	0.19
Wood studs 2 × 4 in., (51 × 102 mm) plastered one side	12	0.57
Wood studs 2 × 4 in., (51 × 102 mm) plastered two sides	20	0.96
Floor Fill		
Cinder concrete, per inch (mm)	9	0.017
Lightweight concrete, plain, per inch (mm)	8	0.015
Stone concrete, per inch (mm)	12	0.023
Ceilings		
Acoustical fiberboard	1	0.05
Plaster on tile or concrete	5	0.24
Suspended metal lath and gypsum plaster	10	0.48
Asphalt shingles	2	0.10
Fiberboard, $\frac{1}{2}$-in. (13 mm)	0.75	0.04

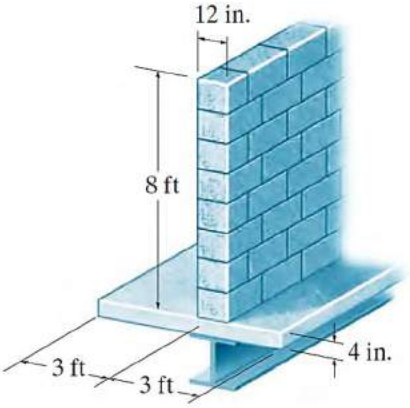
*Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures,* ASCE/SEI 7-10.

Even if the material is specified, the unit weights of elements reported in codes may vary from those given by manufacturers, and later use of the building may include some changes in dead loading. As a result, estimates of dead loadings can be in error by **15%** to **20%** or more.

Normally, the dead load is not large compared to the design load for simple structures such as a beam or a single-story frame; however, for multistory buildings it is important to have an accurate accounting of all the dead loads in order to properly design the columns, especially for the lower floors.

Example 1.3.1

The floor beam in the figure is used to support the **6-ft** width of a lightweight plain concrete slab having a thickness of **4 in**. The slab serves as a portion of the ceiling for the floor below, and therefore its bottom is coated with plaster. Furthermore, an **8-ft**-high, **12-in**.-thick lightweight solid concrete block wall is directly over the top flange of the beam. Determine the loading on the beam measured per foot of length of the beam.



Solution

Using the data in Tables 1–2 and 1–3, we have

Concrete slab: $[8\ \text{lb}/(\text{ft}^2.\text{in})](4\ \text{in})(6\ \text{ft}) = 192\ \text{lb/ft}$

Plaster ceiling: $(5\ \text{lb/ft}^2)(6\ \text{ft}) = 30\ \text{lb/ft}$

Block wall: $(105\ \text{lb/ft}^3)(8\ \text{ft})(1\ \text{ft}) = \underline{840\ \text{lb/ft}}$

Total load $1062\ \text{lb/ft} = 1.06\ \text{k/ft}$ *Ans.*

Live Loads.

- ✓ *Live Loads* can vary both in their magnitude and location. They may be caused by the weights of objects temporarily placed on a structure, moving vehicles, or natural forces. The minimum live loads specified in codes are determined from studying the history of their effects on existing structures.
- ✓ Usually, these loads include additional protection against excessive deflection or sudden overload.

TABLE 1–4 Minimum Live Loads*

Occupancy or Use	Live Load psf	Live Load kN/m^2
Assembly areas and theaters		
Fixed seats	60	2.87
Movable seats	100	4.79
Garages (passenger cars only)	50	2.40
Office buildings		
Lobbies	100	4.79
Offices	50	2.40
Storage warehouse		
Light	125	6.00
Heavy	250	11.97
Residential		
Dwellings (one- and two-family)	40	1.92
Hotels and multifamily houses		
Private rooms and corridors	40	1.92
Public rooms and corridors	100	4.79
Schools		
Classrooms	40	1.92
Corridors above first floor	80	3.83

*Reproduced with permission from *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10.

Building Loads.

- ✓ The floors of buildings are assumed to be subjected to *uniform live loads,* which depend on the purpose for which the building is designed.
- ✓ These loadings are generally tabulated in local, state, or national codes.
- ✓ A representative sample of such *minimum live loadings,* taken from the ASCE 7-10 Standard, is shown in Table 1–4.
- ✓ The values are determined from a history of loading various buildings.
- ✓ They include some protection against the possibility of overload due to emergency situations, construction loads, and serviceability requirements due to vibration.
- ✓ In addition to uniform loads, some codes specify *minimum concentrated live loads,* caused by hand carts, automobiles, etc., which must also be applied anywhere to the floor system.
- ✓ For example, both uniform and concentrated live loads must be considered in the design of an automobile parking deck.
- ✓ For some types of buildings having very large floor areas, many codes will allow a *reduction* in the uniform live load for a *floor,* since it is unlikely that the prescribed live load will occur simultaneously throughout the entire structure at any one time. For example, ASCE 7-10 allows a reduction of live load on a member having an *influence area* (K_{LL} A_T) of **400 ft^2 (37.2 m^2)** or more. This reduced live load is calculated using the following equation:

$$L = L_o\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right) \quad \text{(FPS units)}$$
$$L = L_o\left(0.25 + \frac{4.57}{\sqrt{K_{LL}A_T}}\right) \quad \text{(SI units)} \qquad \dots (1\text{-}1)$$

where

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

L_o = unreduced design live load per square foot or square meter of area supported by the member (see Table 1–4).

K_{LL} = live load element factor. For interior columns $K_{LL} = 4$

A_T = tributary area in square feet or square meters.

The reduced live load defined by these equation is limited to not less than **50%** of L_o for members supporting one floor, or not less than **40%** of L_o for members supporting more than one floor. No reduction is allowed for loads exceeding **100 lb/ft^2 (4.79 kN/m^2)**, or for structures used for public assembly, garages, or roofs.

Highway Bridge Loads.

- ✓ The primary live loads on bridge spans are those due to traffic, and the heaviest vehicle loading encountered is that caused by a series of trucks.
- ✓ Specifications for truck loadings on highway bridges are reported in the *LRFD* Bridge Design Specifications* of the American Association of State and Highway Transportation Officials (AASHTO).

* load-and-resistance factor design

Impact Loads.

- ✓ Moving vehicles may bounce or sidesway as they move over a bridge, and therefore they impart an impact to the deck.The percentage increase of the live loads due to impact is called the *impact factor*, ***I***. This factor is generally obtained from formulas developed from experimental evidence. For example, for highway bridges the AASHTO specifications require that

$$I = \frac{50}{L + 125} \quad \text{but not larger than } 0.3$$

where L is the length of the span in feet that is subjected to the live load.

- ✓ In some cases provisions for impact loading on the structure of a building must also be taken into account. For example, the ASCE 7-10 Standard requires the weight of elevator machinery to be increased by 100%, and the loads on any hangers used to support floors and balconies to be increased by 33%.

Wind Loads.

- ✓ When structures block the flow of wind, the wind's kinetic energy is converted into potential energy of pressure, which causes a wind loading.

- ✓ The effect of wind on a structure depends upon the density and velocity of the air, the angle of incidence of the wind, the shape and stiffness of the structure, and the roughness of its surface.
- ✓ For design purposes, wind loadings can be treated using either a static or a dynamic approach.
- ✓ For the static approach, the fluctuating pressure caused by a constantly blowing wind is approximated by a mean velocity pressure that acts on the structure. This pressure q is defined by its kinetic energy $q = 0.5\,\rho V^2$, where ρ is the density of the air and V is its velocity.
- ✓ According to the ASCE* 7-10 Standard, this equation is modified to account for the importance of the structure, its height, and the terrain in which it is located. It is represented as

$$q_z = 0.00256 K_z K_{zt} K_d V^2 \text{ (lb/ft}^2\text{)}$$
$$q_z = 0.613 K_z K_{zt} K_d V^2 \text{ (N/m}^2\text{)} \quad \ldots(1\text{-}2)$$

V = the velocity in mi/h (m/s) of a 3-second gust of wind measured 33 ft (10 m) above the ground. Specific values depend upon the "category" of the structure obtained from a wind map.

K_z = the velocity pressure exposure coefficient, which is a function of height and depends upon the ground terrain.
K_{zt} = a factor that accounts for wind speed increases due to hills and escarpments. For flat ground K_{zt} = 1.0.
K_d = a factor that accounts for the direction of the wind. It is used only when the structure is subjected to combinations of loads. For wind acting alone, K_d = 1.0.

*American Society of Civil Engineers

Snow Loads.

- ✓ Design loadings typically depend on the building's general shape and roof geometry, wind exposure, location, its importance, and whether or not it is heated.
- ✓ Like wind, snow loads in the ASCE 7-10 Standard are generally determined from a zone map reporting 50-year recurrence intervals of an extreme snow depth. For example, on the relatively flat elevation throughout the mid-section of Illinois and Indiana, the ground snow loading is 20 lb/ft^2 (0.96 kN/m^2).
- ✓ Specifications for snow loads are covered in the ASCE 7-10 Standard, although no single code can cover all the implications of this type of loading.

Earthquake Loads.

- ✓ Earthquakes produce loadings on a structure through its interaction with the ground and its response characteristics.
- ✓ These loadings result from the structure's distortion caused by the ground's motion and the lateral resistance of the structure.
- ✓ Their magnitude depends on the amount and type of ground accelerations and the

Hydrostatic and Soil Pressure.

- ✓ When structures are used to retain water, soil, or granular materials, the pressure developed by these loadings becomes an important criterion for their design. Examples of such types of structures include tanks, dams, ships, bulkheads, and retaining walls.
- ✓ The laws of hydrostatics and soil mechanics are applied to define the intensity of the loadings on the structure.mass and stiffness of the structure.

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.