INTRODUCTION TO STRUCTURAL SYSTEMS

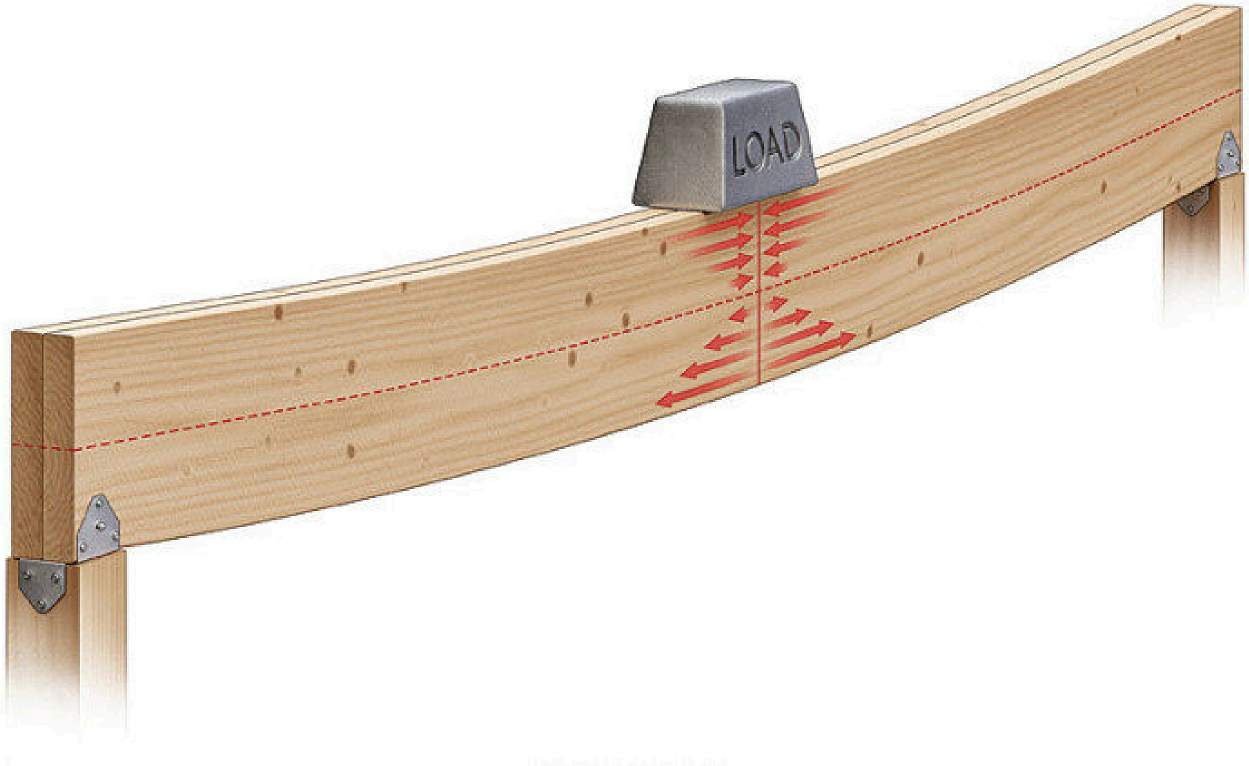
Chapter 2

Structures and structural engineering

Section 2.1

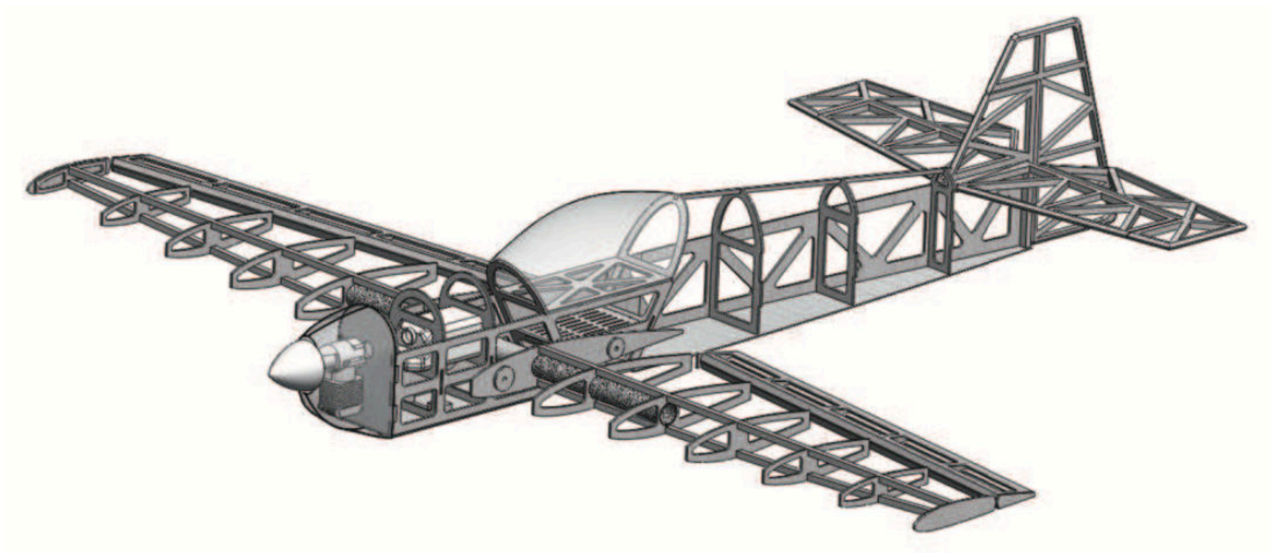
Structural Element

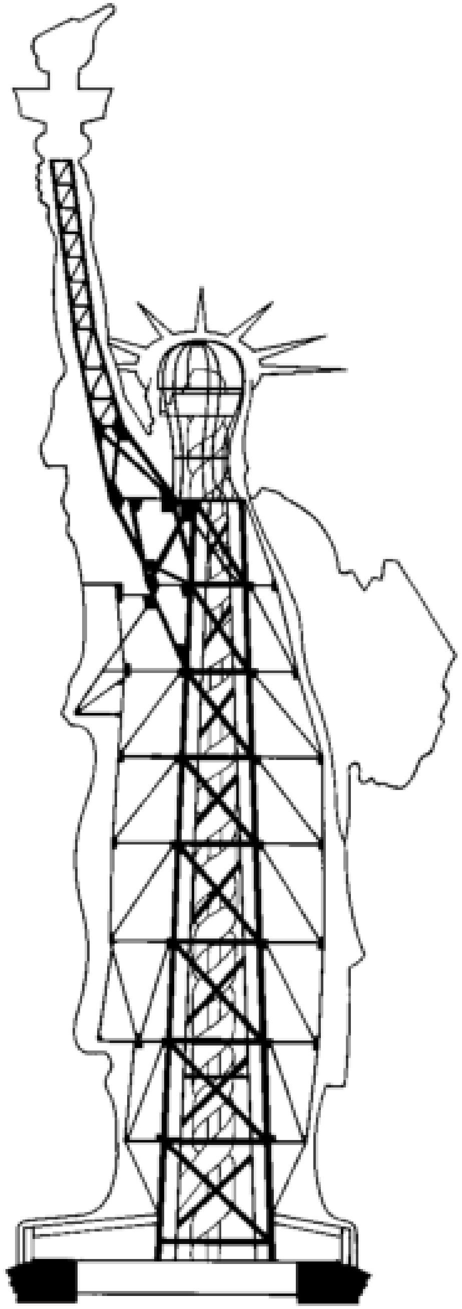
The structure element is an element that bears loads other than its self-weight, like those from occupancy, wind or snow.



Structural System

- **In General, a Structural system is** the sum of all elements constitutive of the assembly.
- More accurately, the load-carrying elements in everything have a shape, size, and function that shall be maintained.

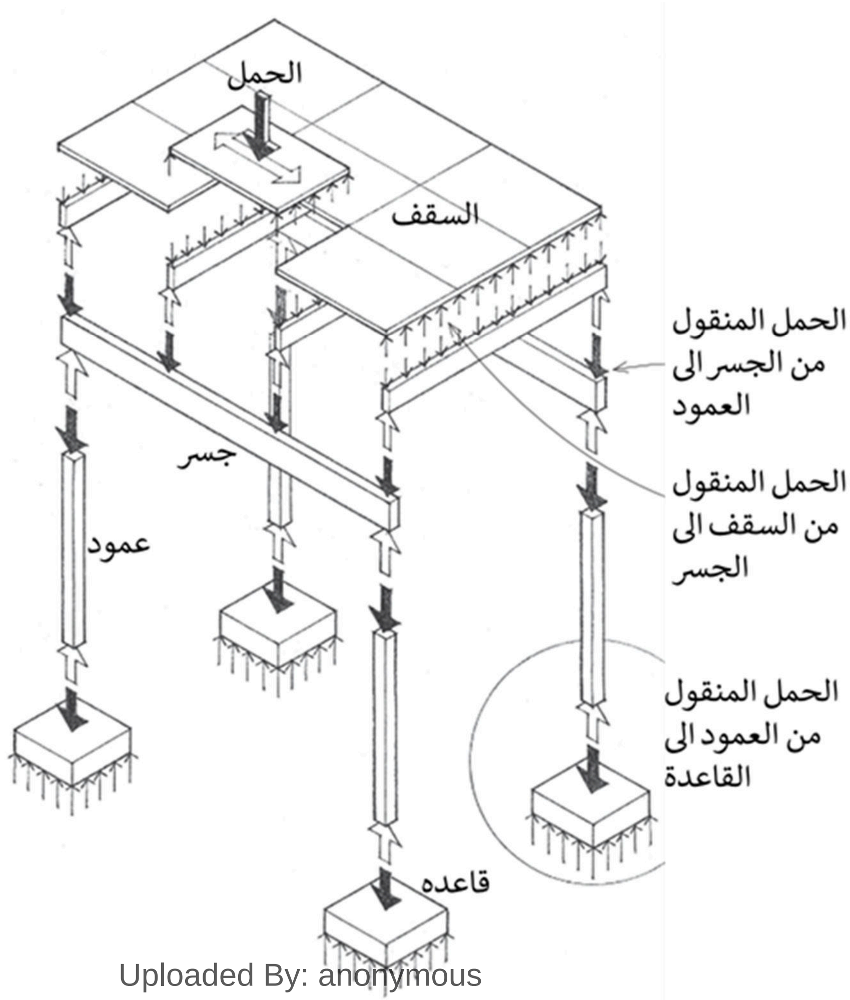




Building Structural System

- **The building's structural system** is the sum of all connected elements that carry and conduct the building's loads to the ground, where they can be finally resisted.

- The function of a structural system in buildings is to supply the strength and rigidity which are required to prevent a building from collapsing.



Structural Engineering Processes

LOADS (INPUT) →  → **STRUCTURAL ANALYSIS**

STRUCTURE (SYSTEM)

↓

RESPONSE (OUTPUT)

Design Criteria →

- Strength
- Stability
- Serviceability
- Economy
- Aesthetics

↕

STRUCTURAL DESGN

Structural Analysis

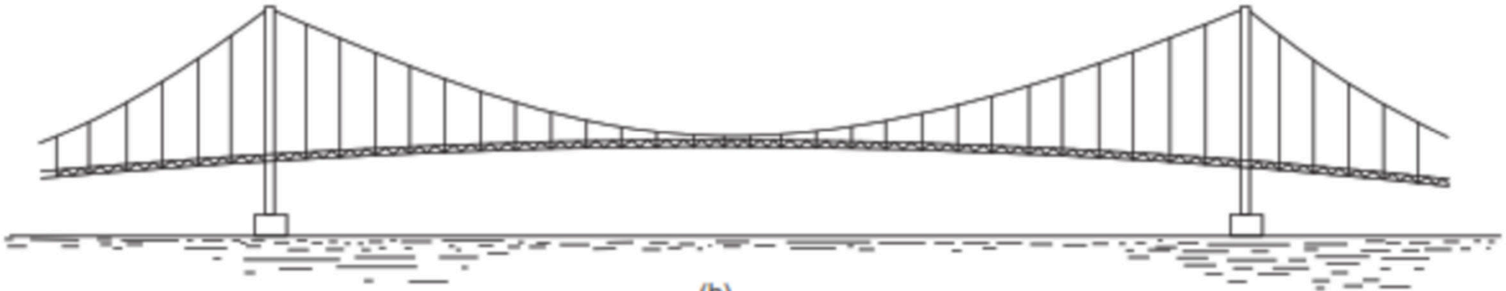
- ***Structural Analysis can be defined as the process whereby a particular structure with known loads is investigated to determine:***
    - The distribution of forces throughout the various members.
    - The distribution of stresses within individual members.
    - The calculation of deflections (i.e. how far the structure will move) under a particular set of loads.

Structural Design

In Structural engineering, the word 'design' can be used in two very different ways:

- Firstly it is used to describe the whole creative process of finding a safe and efficient solution to an engineering problem

(a)



(b)

Designing a bridge across a river. There is of course no 'correct' answer, but out of the infinite number of possible solutions, some are clearly much better than others

Structural Design

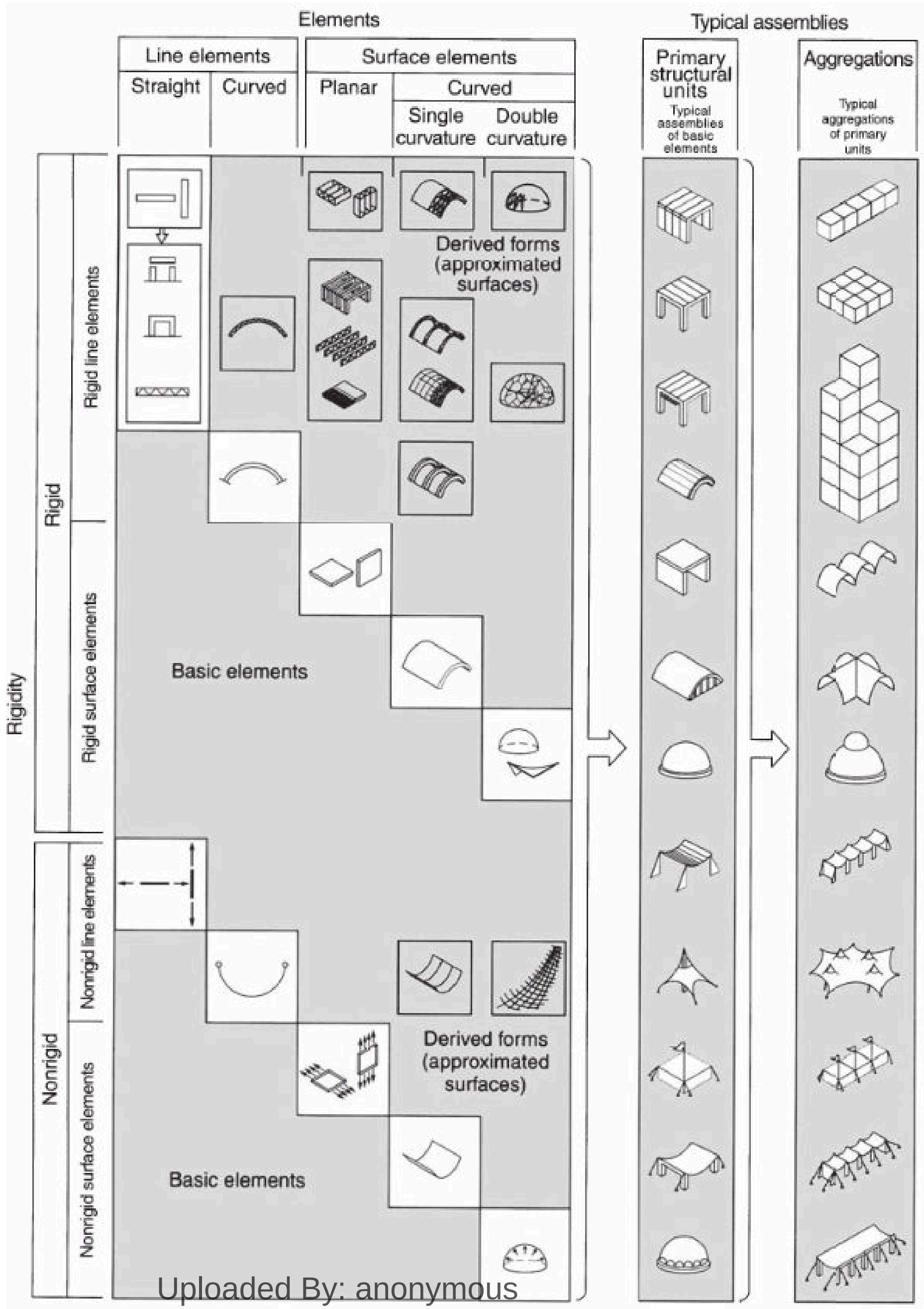
- Secondly, the activities which often come after the analysis stage, when the forces in each structural member are known including:
  - Determining the actual size of the structural member. This is referred to as element design.
  - Identifying the detailing of the structural members. This is called detail design.
- There may be several choices open to the designer, but element design and detail design are not as creative as the broader design process. They are, however, very important, and bad detail design is a major cause of structural failures.

Classifications of structures

Section 2.2

Classifications of structures

- One method for classifying structural elements and systems is the classification according to their
  - Geometry
  - Stiffens
  - Load transfer action
  - Construction material
  - Dominant stress state



Geometrical Classification

In terms of their basic geometries, the structural forms can be classified either as:

- ***line-forming elements*** (or composed of line-forming elements). Any long, slender element (such as a column whose cross-sectional dimensions are small with respect to its length). Line-forming elements can be further distinguished as straight or curved.

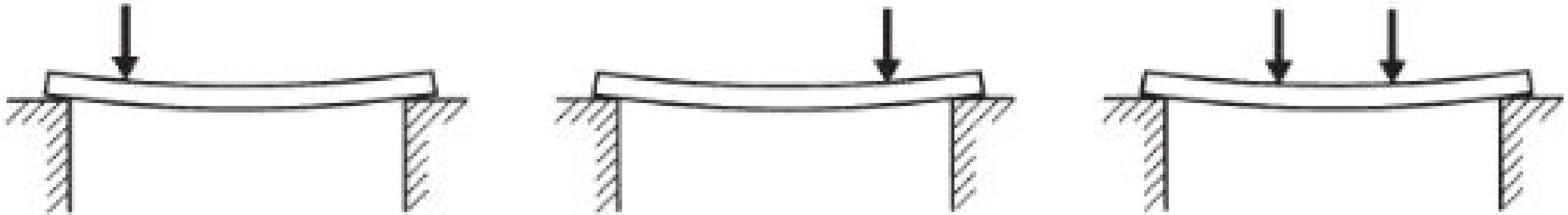
- ***Surface-forming elements.*** Any element whose thickness is small with respect to length dimensions. Can be either planar or curved. Curved-surface elements can be of either single or double curvature.

<u>Material. Steel and timber are mainly used in Line-forming elements.</u>
Concrete can be used equally for line and surface-forming elements.

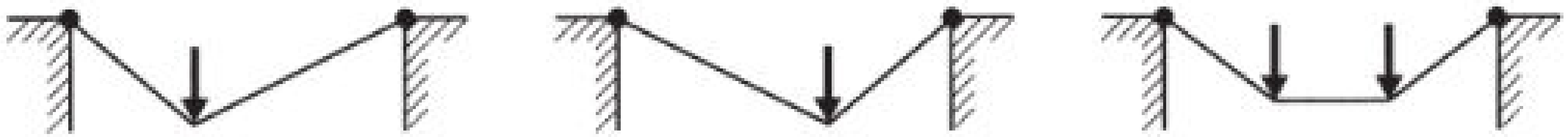
Stiffness Classification

- **Rigid elements**, such as typical beams, do not undergo appreciable changes in shape under the action of a load. However, they are usually bent to a small degree by the load's action.
- **Flexible elements**, such as cables, assume one shape under one loading condition and change shape drastically when the loading nature changes. Flexible structures maintain their physical integrity, however, no matter what shape they assume.
- Whether an element is rigid or flexible is often related to the construction material used. Many materials, such as timber, are inherently rigid; others, such as steel, can be used to make either rigid or flexible members.

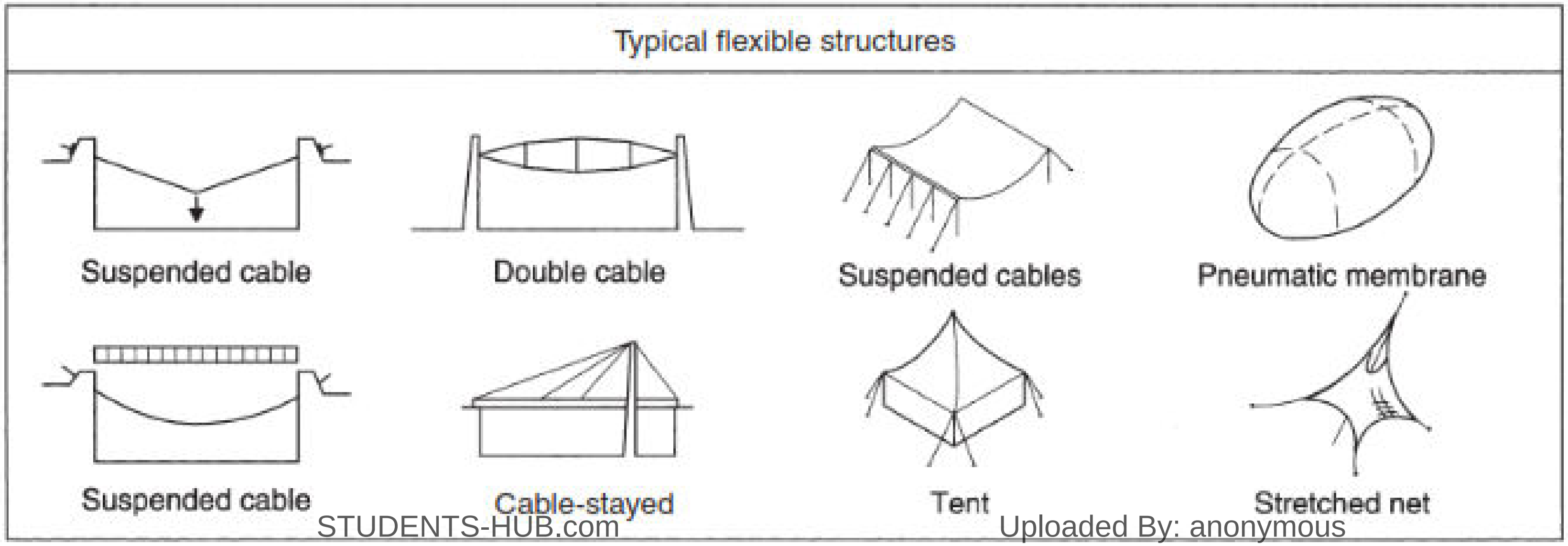
Stiffness Classification



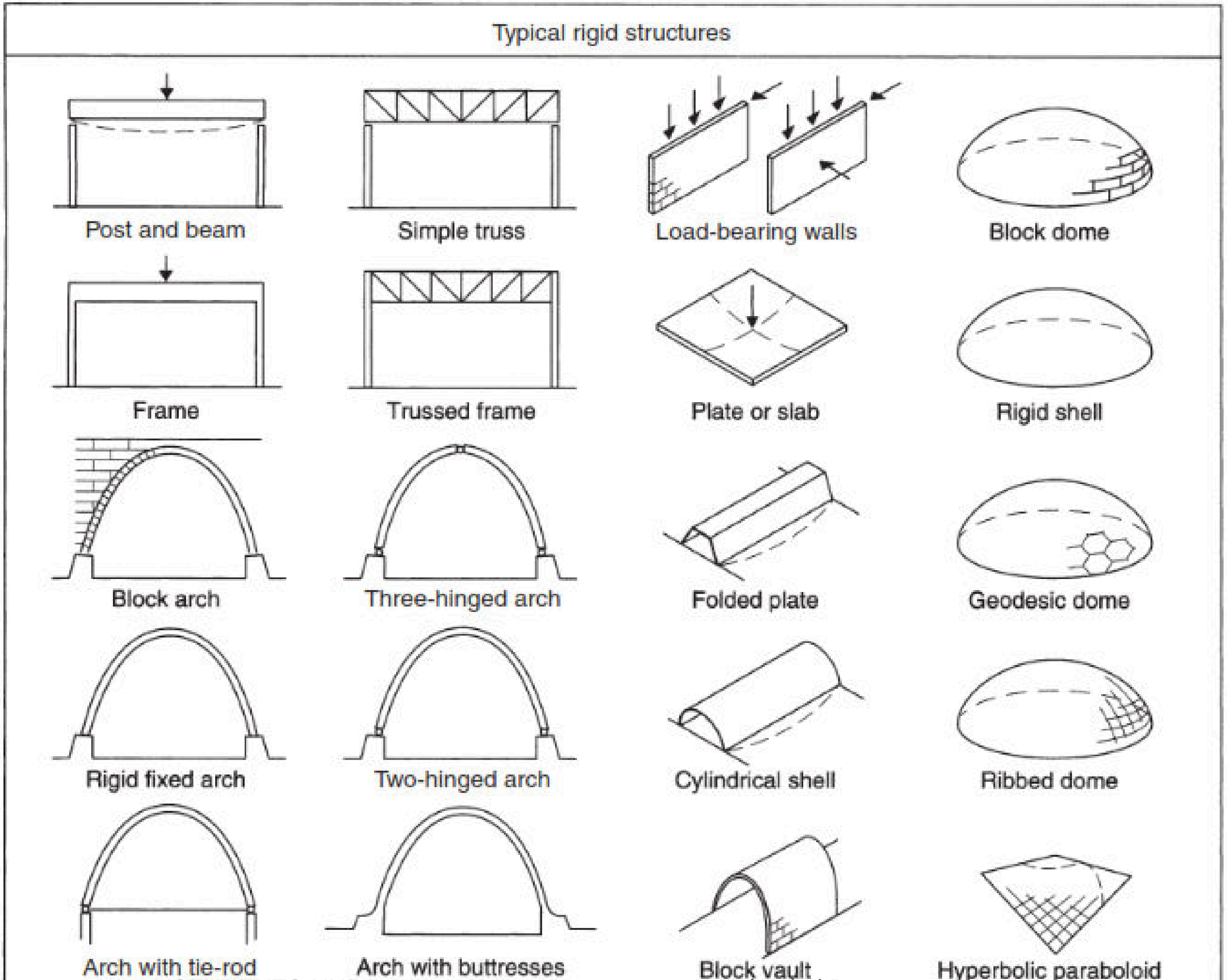
(a) Rigid structure (e.g., a beam). The structure is stiff and does not undergo appreciable changes in shape with changes in the loading condition.



(b) Nonrigid or flexible structure (e.g., a cable). The shape of the structure changes with changes in the loading condition.



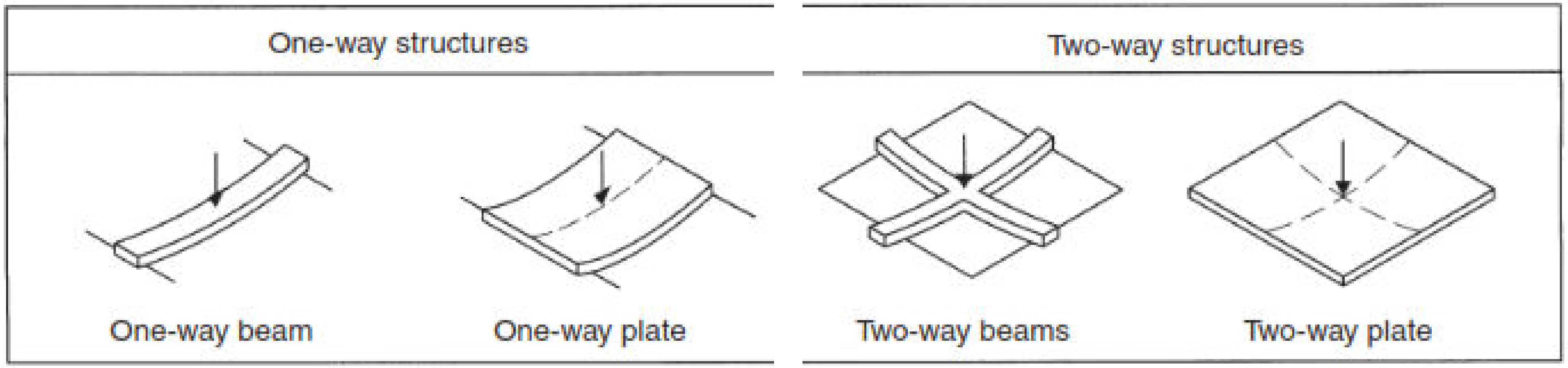
Stiffness Classification



Load Transfer Classification

One-Way and Two-Way systems

- In a one-way system, the structure's basic load-transfer mechanism for channeling external loads to the ground acts in one direction only.
- In a two-way system, the load-transfer mechanism's direction is more complex but involves at least two directions. A linear beam spanning two sup-



Materials Classification

A common classification approach to structures is by the type of material used (e.g., wood, steel, and reinforced concrete). A strict classification by materials, however, is somewhat misleading and is not adopted here because the



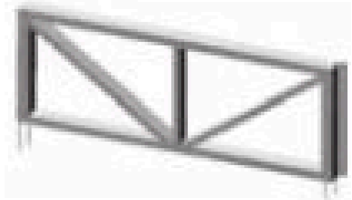
Dominant stress Classifications

Structural engineers classify structures based on the dominant stress into three basic types that are commonly used either individually or mixed.

- Tension and compression structures such as trusses, cables, arches, shells, and domes.
- Flexural structures such as beams, frames and slabs.

Dominant stress states

Dominant stress states in common structural forms under primary loadings

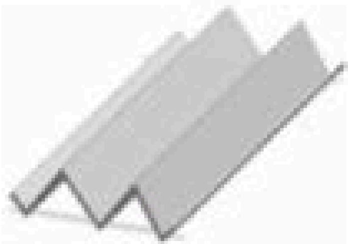


Beams and frames:
primarily in bending, with shear and axial forces

Trusses:
axial tension (T) and compression (C) in members

Arches:
compression (C) under primary loadings

Cables:
tension (T)



Folded plates:
beam-like action in bending, with shear

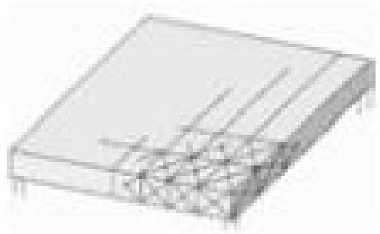
Pneumatic structures:
in-plane biaxial tension membrane stresses in surface

Membrane structures:
in-plane biaxial tension membrane stresses in surface, masts in compression, and tie-backs in tension

Dominant stress states

Dominant stress states bending, shear, and axial forces and stresses in common structural forms under primary loadings

Plates:
primarily biaxial bending, with shear



Space frames:
axial tension (T) and compression (C) in members

Shells:
in-plane membrane stresses in surface (T or C), minor bending at boundaries

Free-form rigid shapes: primarily in bending with some in-plane tension or compression

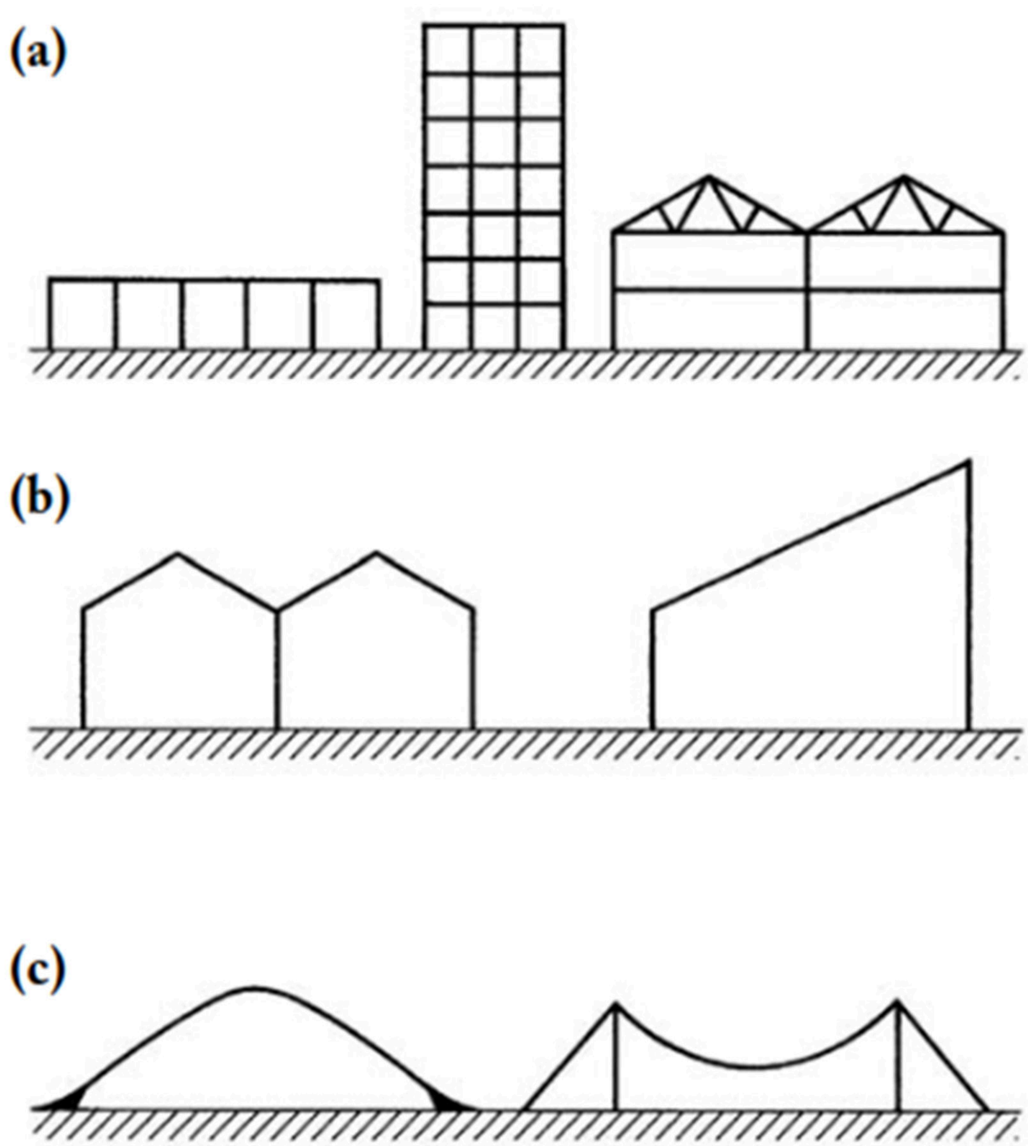
Architectural Classifications

- In the context of architecture, where gravitational loads normally predominate, there are three basic arrangements:

  a) Non-form active.

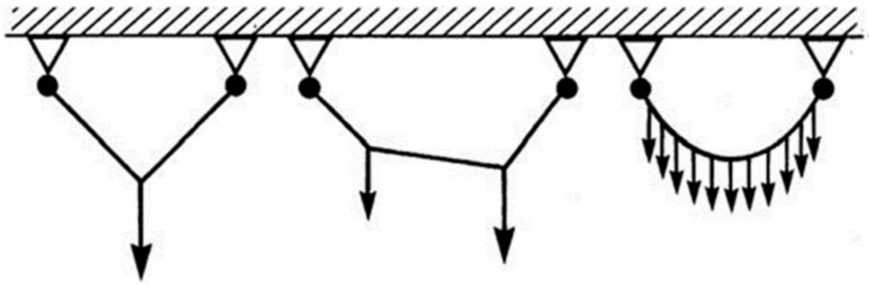
  b) Semi-form-active.

  c) Form-active or funicular structures.

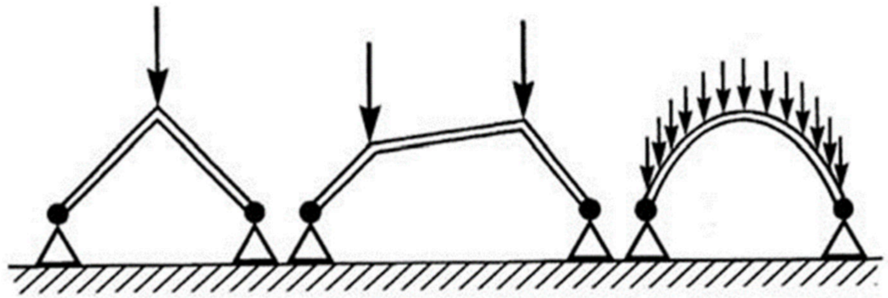


Form-active (Funicular) structures

- Form-active refers to a structure that, due to its overall form, is subjected to axial internal forces only (tensile and compressive).
- The easiest way to determine the funicular response for a particular loading condition is by identifying the exact shape to which a flexible string would deform under a load. Such a shape is called the tension funicular. Inverting this shape yields a compression funicular. A given loading condition has only one funicular shape.
- Funiculars need not be only two-dimensional structures; they also can be three-dimensional.

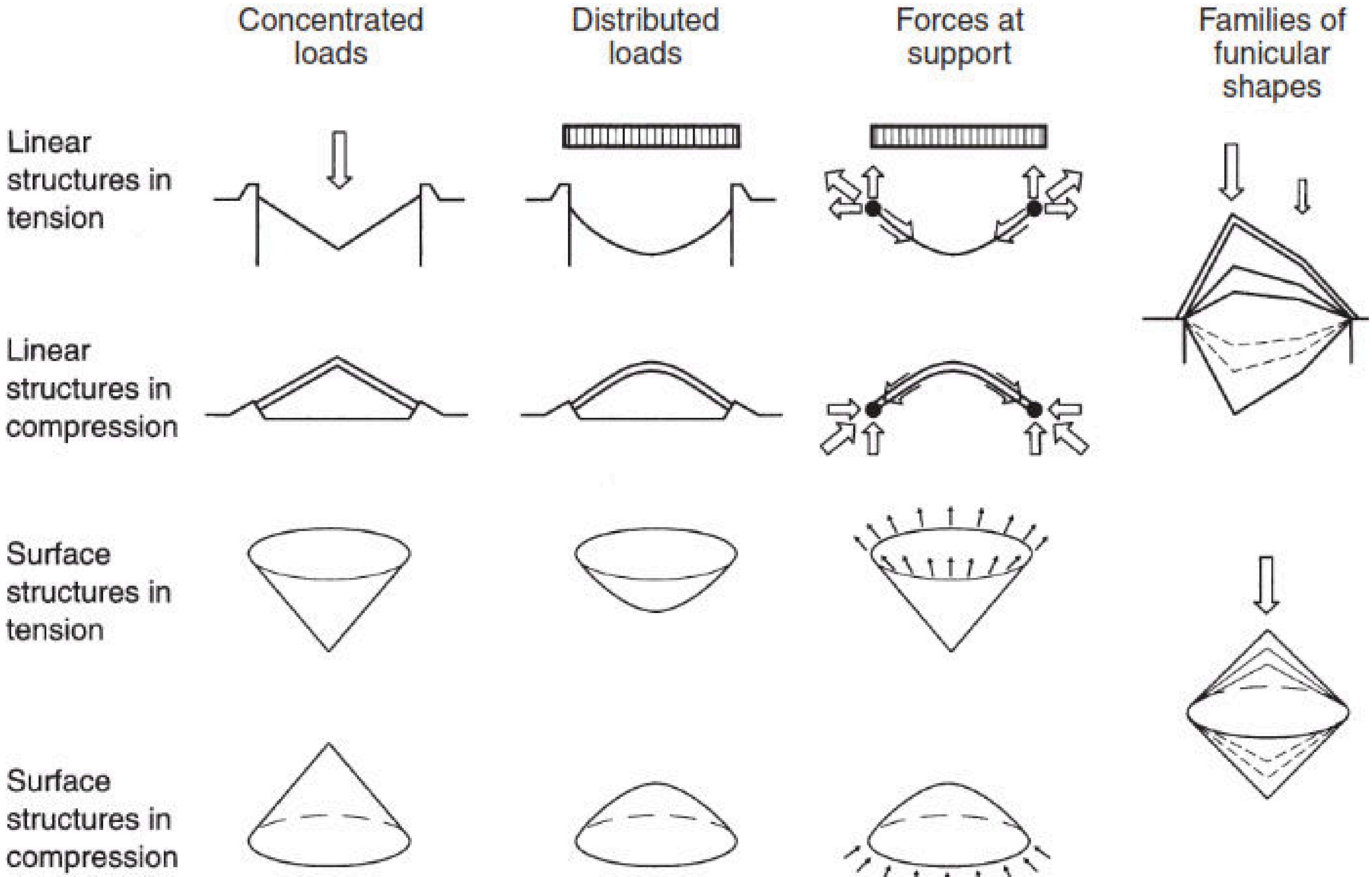


Tension funicular shapes



Compressive funicular shapes

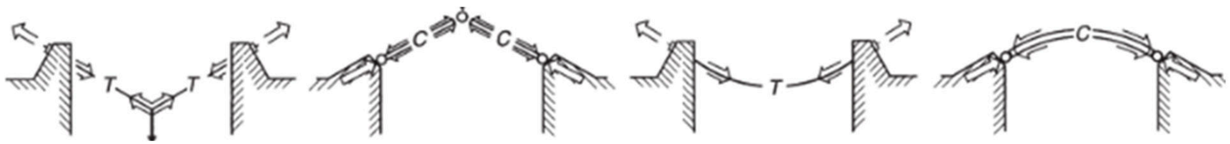
Form-active (Funicular) structures



Form-active (Funicular) structures

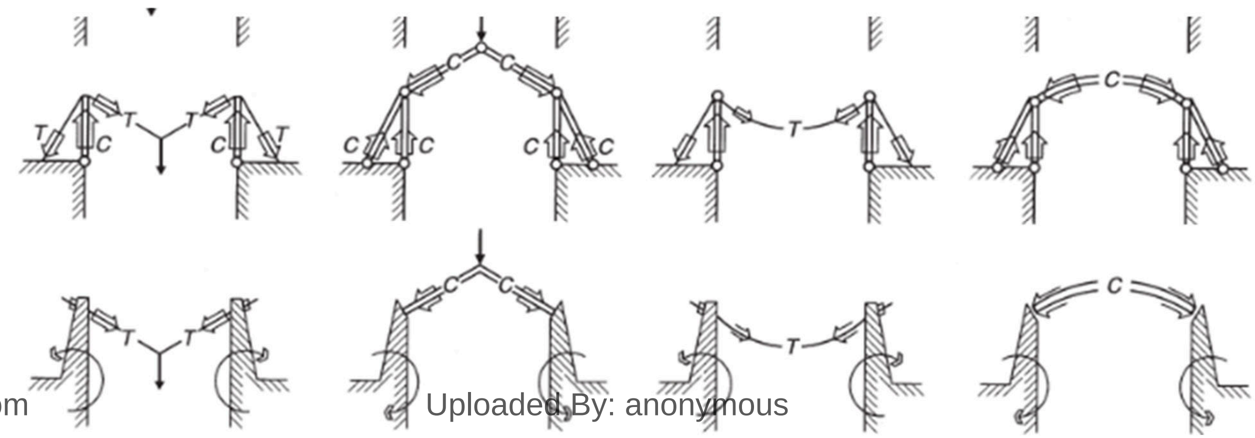
- Funicular structures produce horizontal thrust at their supports, therefore, their supports or foundations shall be capable to sustain these thrust forces. This can be done through

• Using built-in massive foundations



• Using struts or tie members.

• Using buttressing elements.



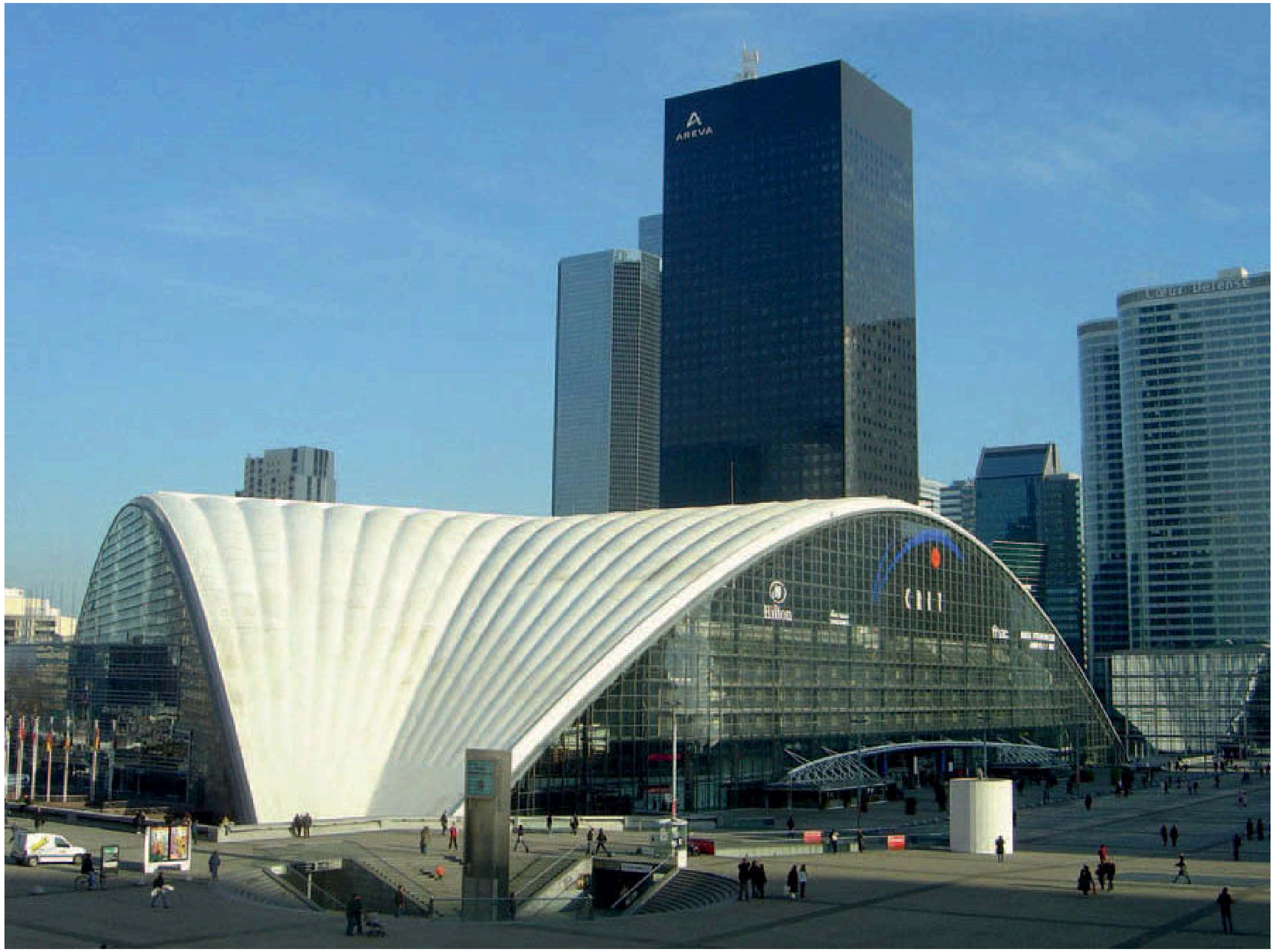
Examples of Form-active structure

The Charles Kuonen Suspension Bridge, Switzerland. The steel rope bridge illustrated in the figure achieves a span of 494 m with a very small amount of structural material. The steel ropes that support the footway are form-active structures.

Examples of Form-active structure

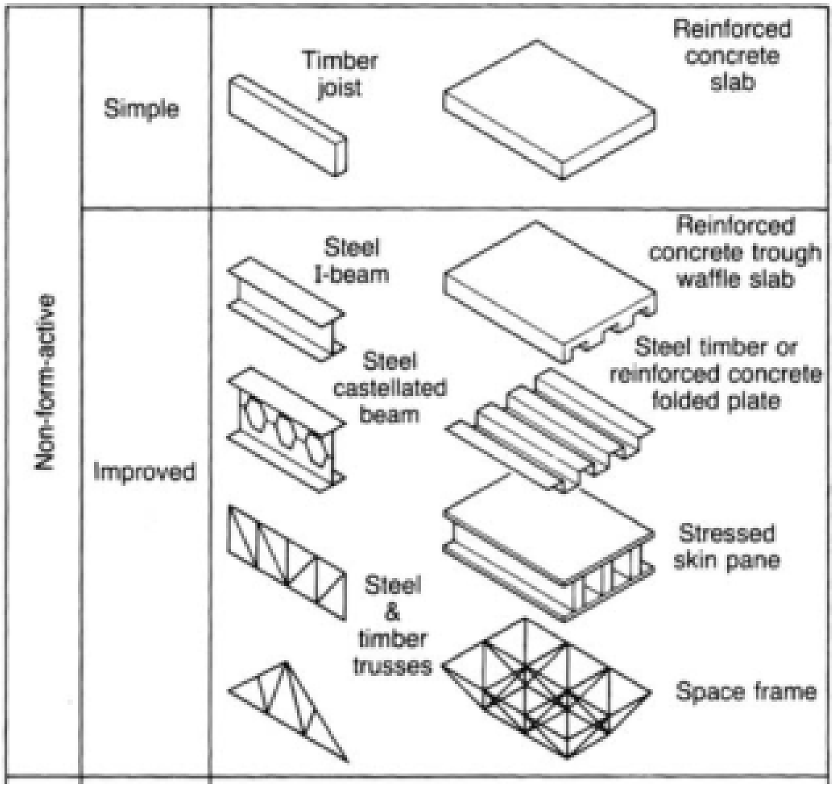
The reinforced concrete envelope of the CNIT enclosure in Paris achieves a span of 218 m with an overall shell thickness of 120 mm due to its having an overall shape that is form-active

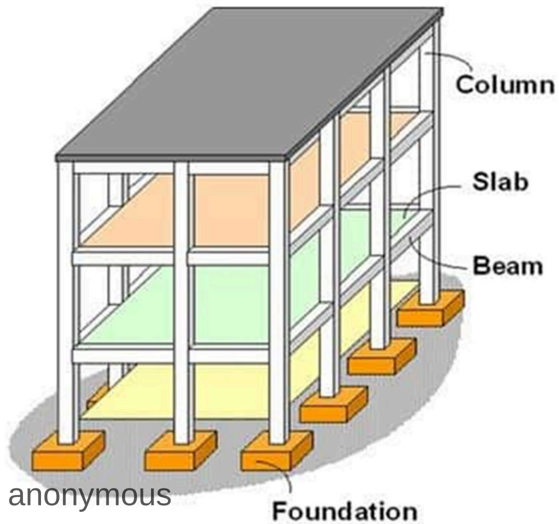
- In a non-form-active, post-and-beam configuration in reinforced concrete, a depth of around 500 mm would be required to achieve a span of as little as 10 m.



Non-form-active structure

- Structures built with vertical and horizontal elements loaded perpendicular to their axis.
- The dominant stress state in these elements/ structures is bending in addition to shear and axial stresses.
- Fairly wide variety of different structural arrangements, of both the continuous and the discontinuous types, is possible. A large range of spans is also possible depending on the types of elements that are used.





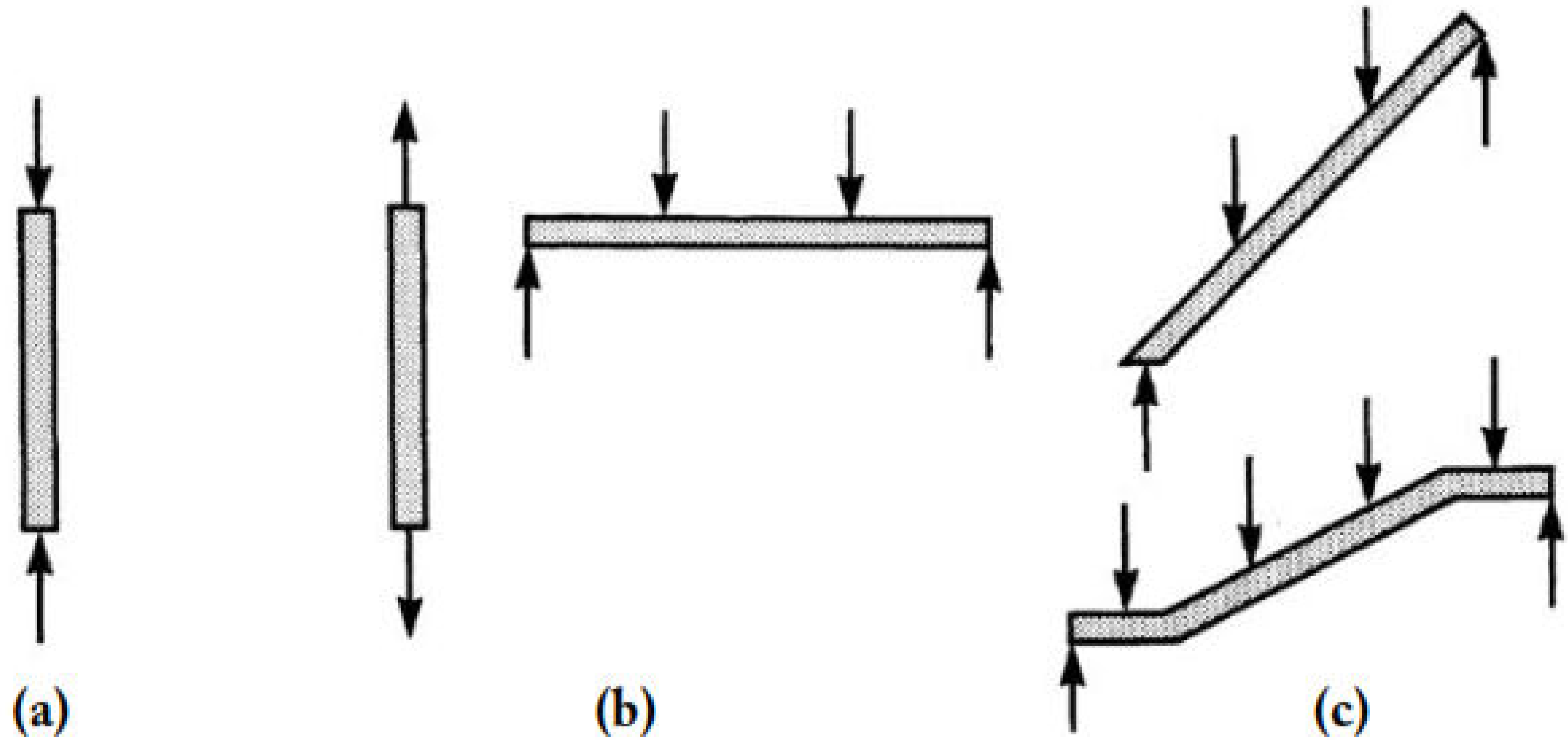
Structural Efficiency

Section 2.3

Introduction

- In structural engineering ***EFFICIENCY*** indicates the weight of the material that must be provided to carry a given amount of load. The efficiency of an element is regarded as high if the ratio of its strength to its weight is high.
- The direction of the applied loads relative to the structural elements axes determines the types and magnitudes of internal force that occur within the elements.
- The type and the magnitude of the internal force have a crucial effect on the level of structural efficiency that can be achieved because they determine the amount of material that must be provided to achieve particular levels of strength and rigidity.

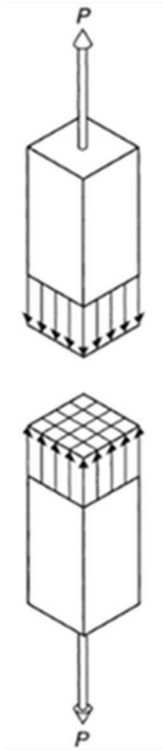
Loading pattern and internal stresses



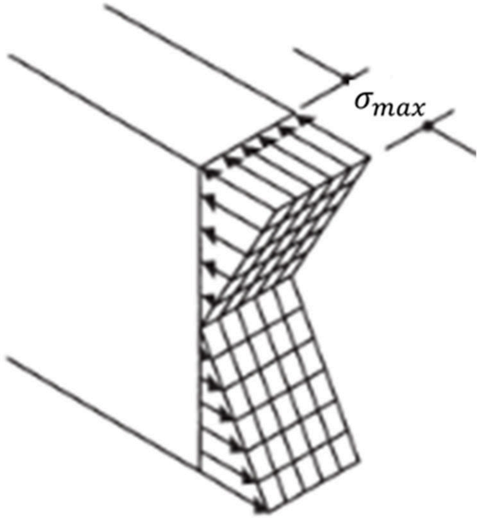
(a) Load coincident with principal axis: axial internal force. (b) Load perpendicular to the principal axis: bending-type internal force. (c) Load inclined to the principal axis: combined axial and bending-type internal force.

Stresses and structural efficiency

- A - axial stress – the stress intensity is constant across the cross-section.
- B – Bending stress – the stress intensity varies from a maximum at the edges to zero at the neutral axis.



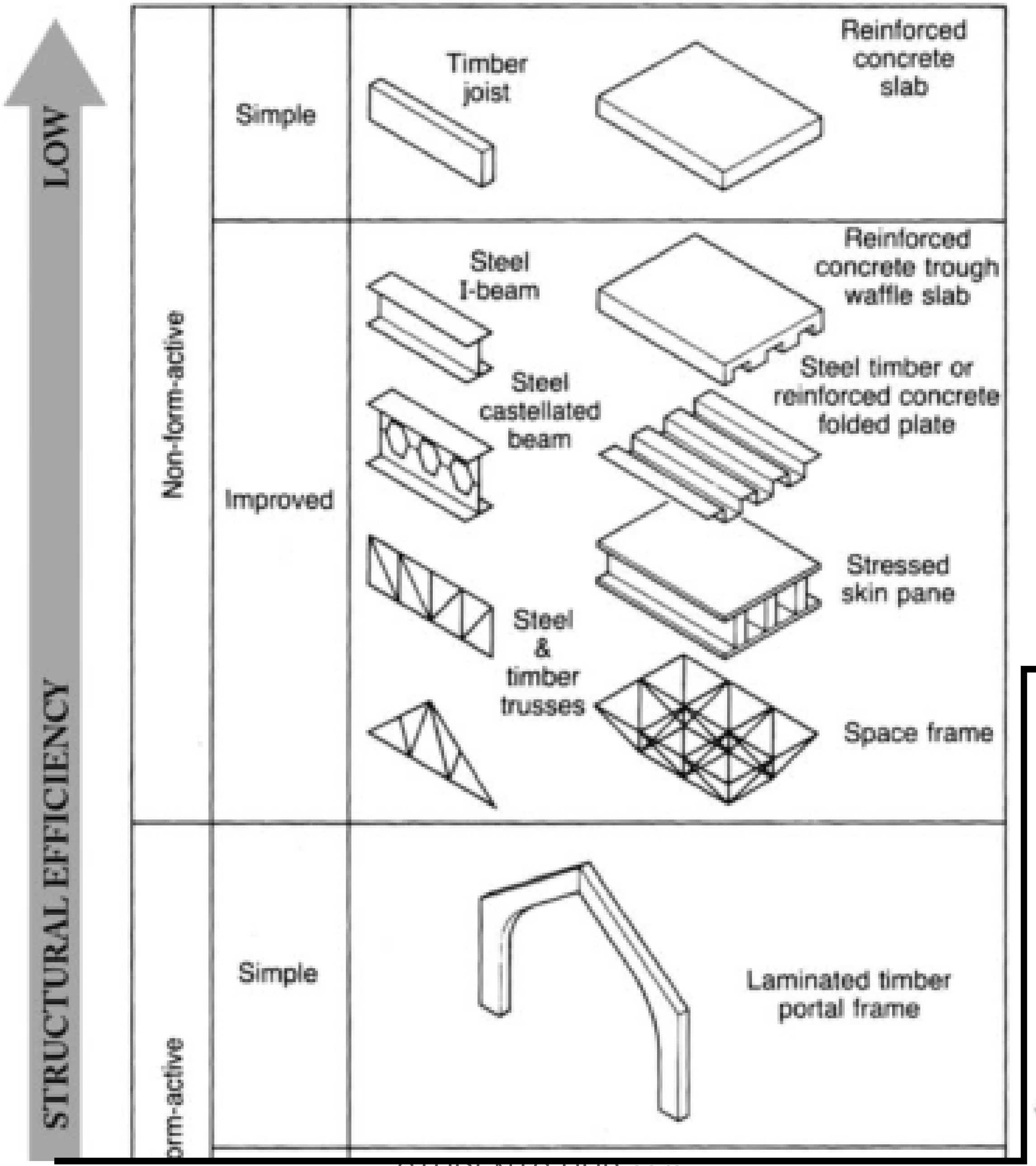
A



B

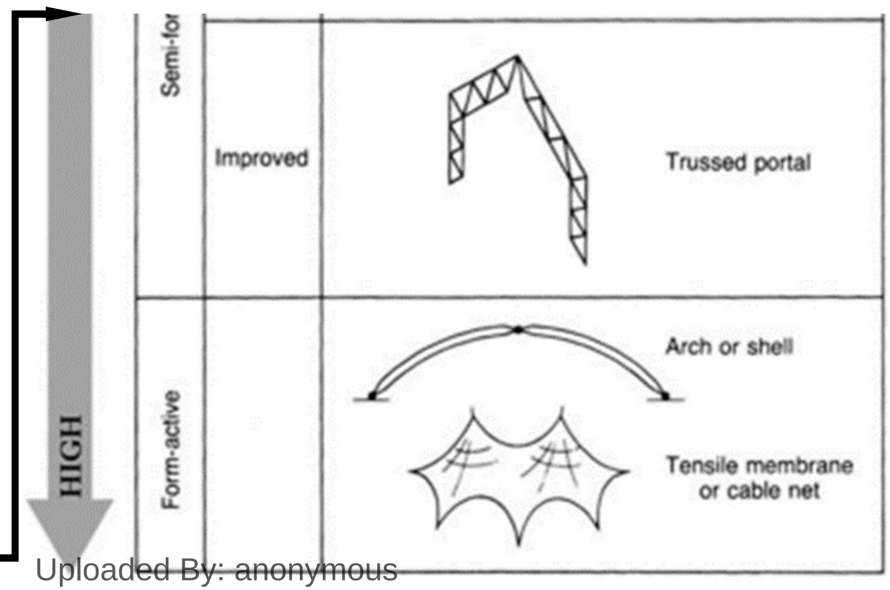
- Accordingly, Structural elements subjected to axial stress can be considered more efficient than that subjected to bending (flexure stress).

Form and Efficiency



Structural efficiency is directly related to the structural form. The most efficient structures are respectively:

- Form-active
- Semi form-active
- Non-form-active



Improving structural efficiency

The element efficiency can be improved through

I. Improving the shape of the element sections – distributing the cross-section material based on the stress distribution, and improving the longitudinal section based on force intensity.

II. Arrange the elements so that they will be subjected to axial loads only. This can be achieved in funicular structures (Form – active), trusses, and some discontinuous structures.

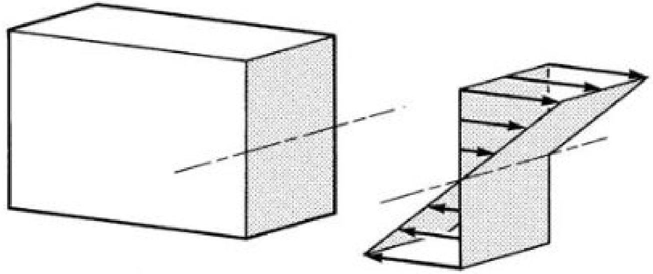
Cross-Section Improvement

1. Improving cross-section shape can improve the efficiency of elements that carry bending-type loads. For example:

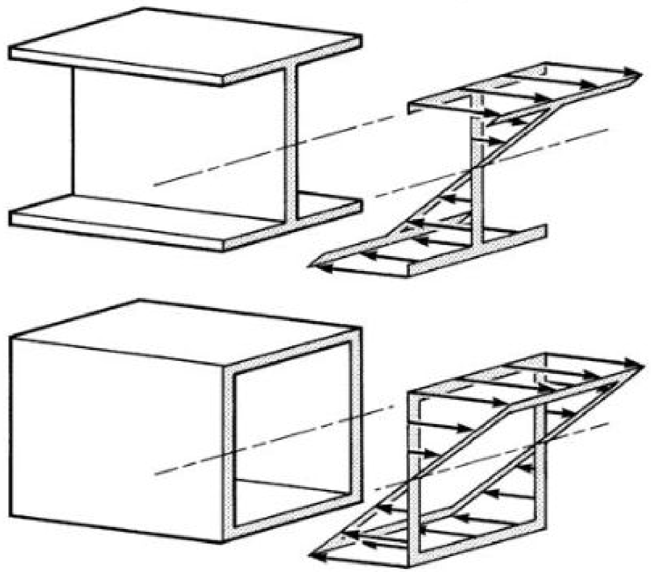
(a) Element with a rectangular cross-section – high bending stress occurs at the extreme fibers only. Most of the material carries low stress and is therefore inefficiently used.

(b) ‘Improved’ cross-sections, I or hollow box, efficiency is increased by the elimination of most of the under-stressed material adjacent to the center of the cross-section.

(a)

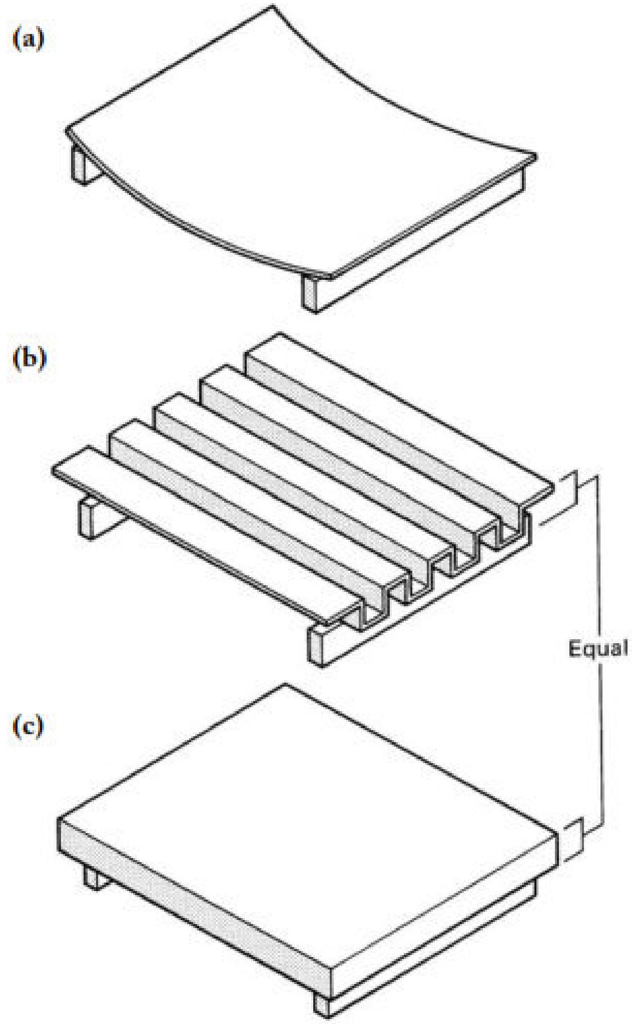


(b)



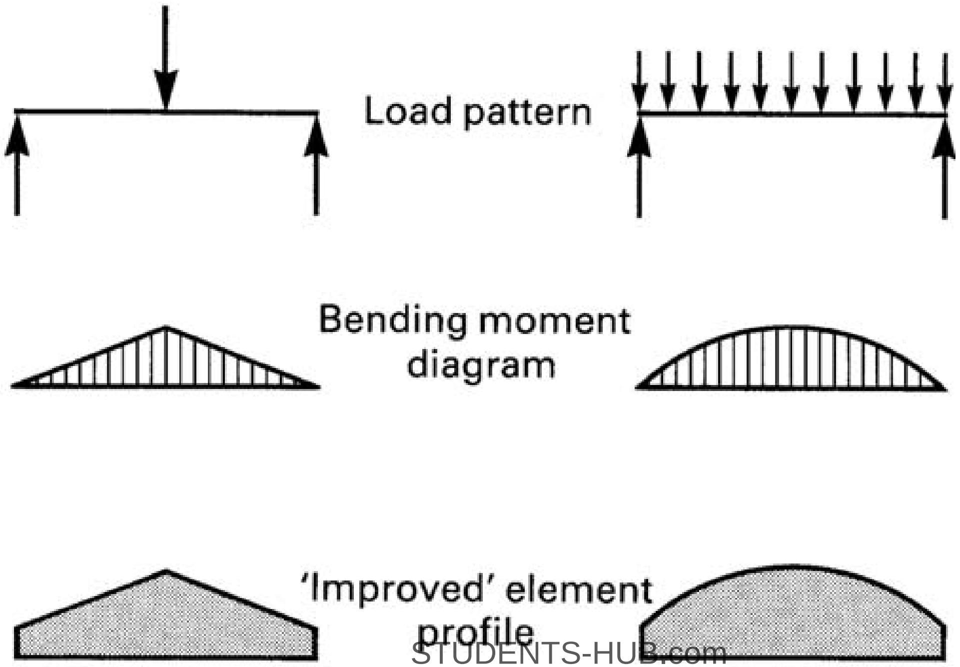
Cross-Section Improvement

- Section Folding. For example, the capacity and efficiency of a thin slab section can be significantly improved by folding because the section's moment of inertia will be increased.
- Voided slabs. Solid slabs are much less efficient in their use of material than those in which the material is removed from the interior.



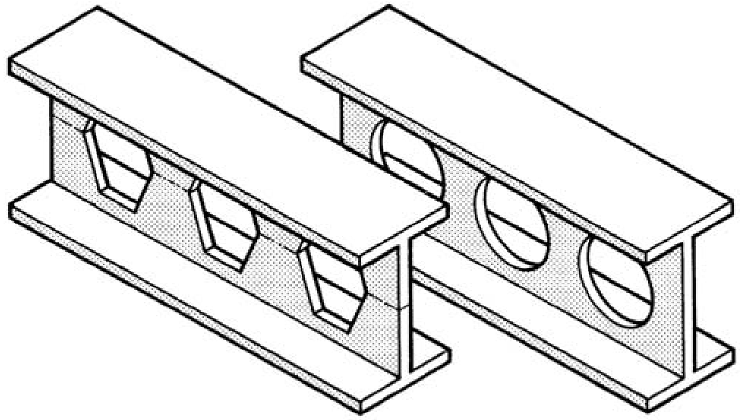
Longitudinal Section Improvement

- The efficiency of an element subjected to transverse loading can be improved by varying the cross-section depth along the span.
- The depth of the element is the dimension on which bending strength principally depends. If the depth is varied according to the intensity of bending forces, a more efficient use of the material will be achieved.



Longitudinal Section Improvement

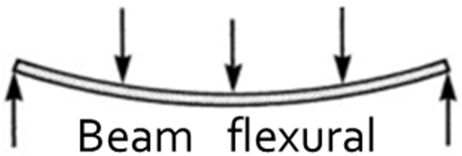
- Perforated beam concept: the element's efficiency can be improved by removing the under-stressed material from the interior of the element. The figures exhibits examples of elements in which under-stressed elements have been removed.



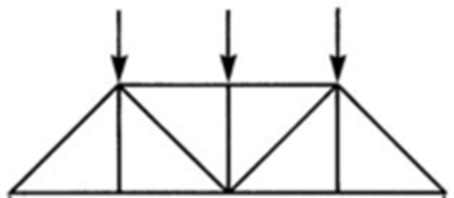
Elements arrangement

The structural efficiency can be improved by arranging the elements to carry axial loads only. For example

- A beam is less strong and rigid than a triangulated structure of the same weight.
- A Space-frame made of rigid linear member arranged in a triangular pattern is more efficient than rigid plate especially for long spans.

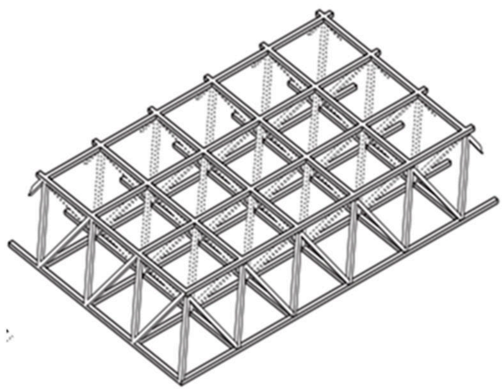


Beam flexural stress



Truss Axial stress

Solid plate
Biaxial bending & shear



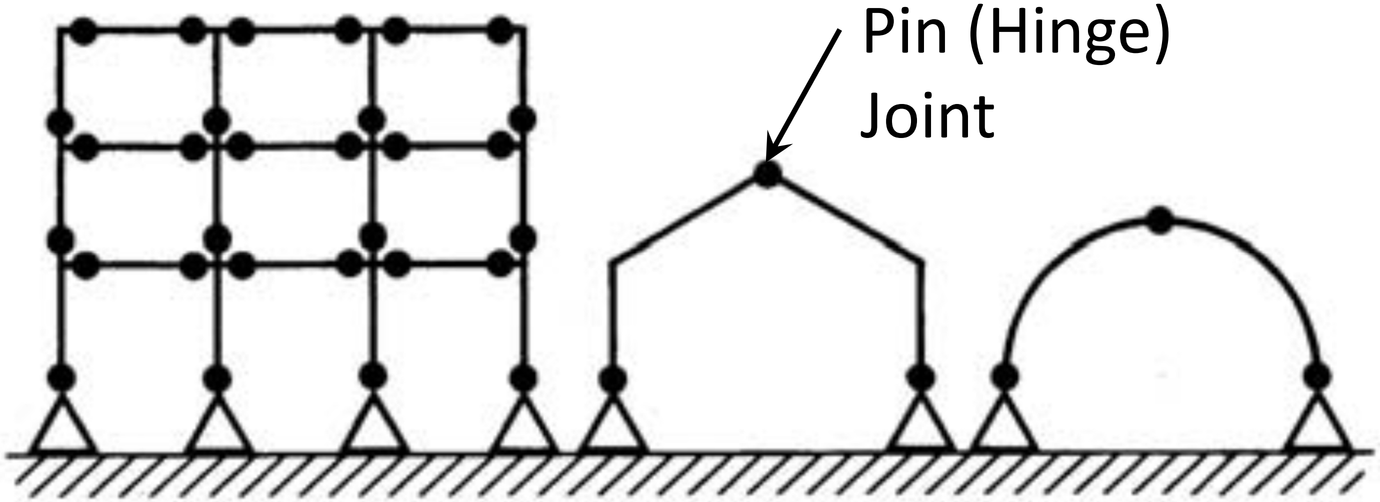
Space-frame
Tension & compression

Structural Continuity

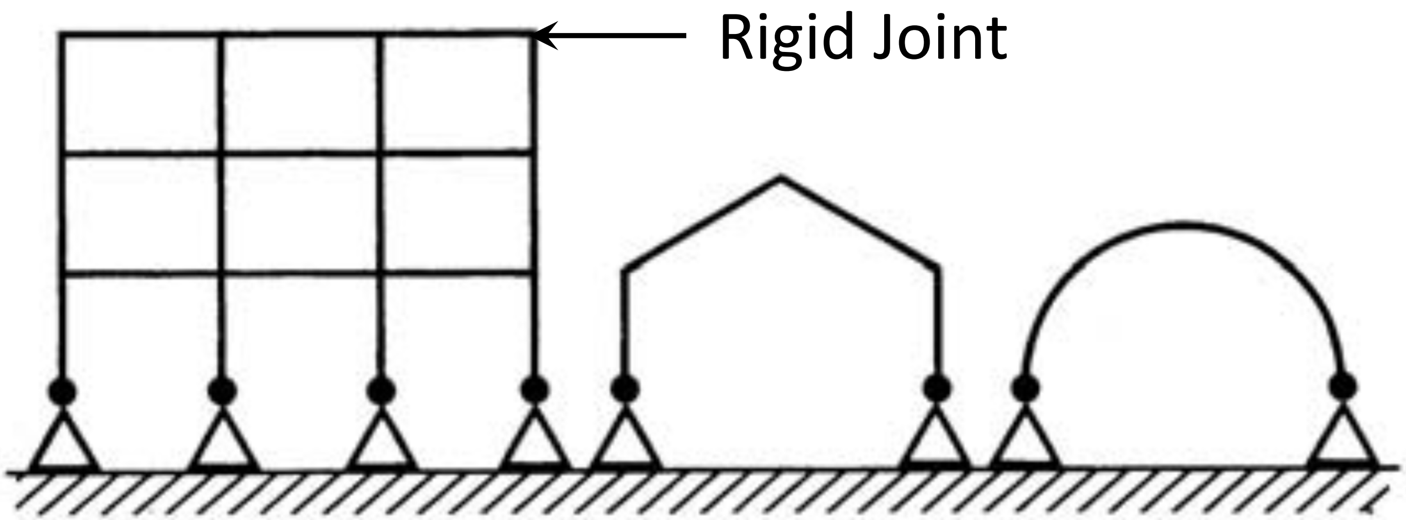
Continuous & Discontinuous Structures

- Continuous structures, the majority of which are also statically indeterminate, contain more than the minimum number of constraints required for stability.
- Discontinuous structures contain only sufficient constraints to render them stable; they are assemblies of elements connected by hinge-type joints, and most are also statically determinate.
- Most structural geometries can be made either continuous or discontinuous depending on the nature of the connections between the elements. If the joints are made rigid, continuity exists, otherwise, if pin or hinge joints are used the structure will be discontinuous.

Structural Continuity



Discontinuous Structures



Continuous Structures

Discontinuous structures

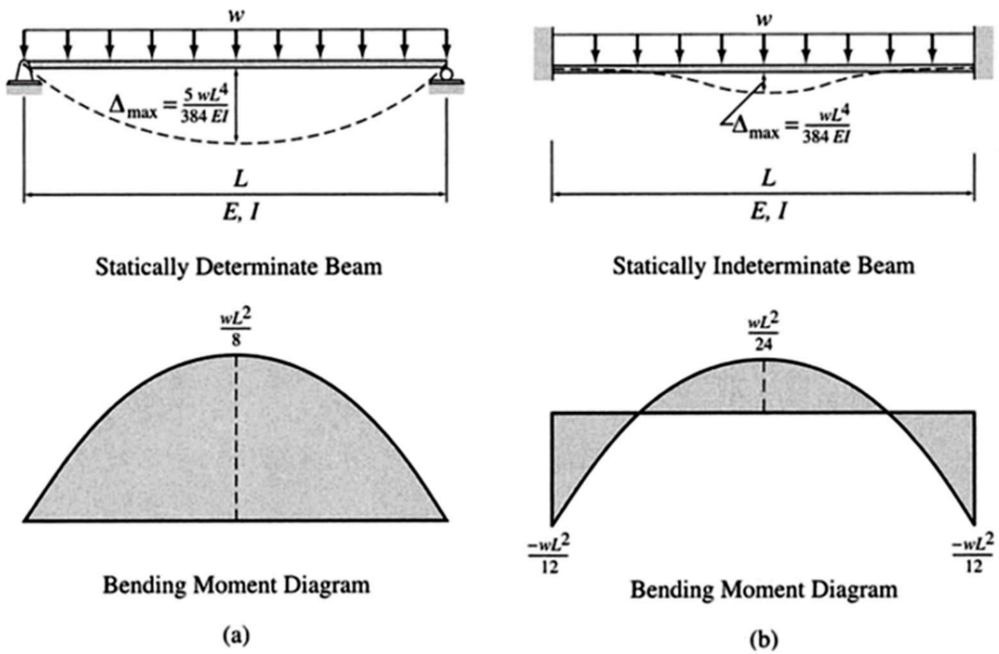
- **Advantages**
- It is simple, both to design and to construct.
- Its behavior in response to differential settlement of the foundations and to changes in the lengths of elements, such as occur when they expand or contract due to variations in temperature, does not give rise to additional stress.

- **Disadvantages**
- For a given application of load, it contains larger internal forces than a continuous structure with the same basic geometry: larger elements are required to achieve the same load-carrying capacity and it is, therefore, less efficient.
- It must normally be given a more regular geometry than an equivalent continuous structure in order that it can be geometrically stable.

Continuous structures

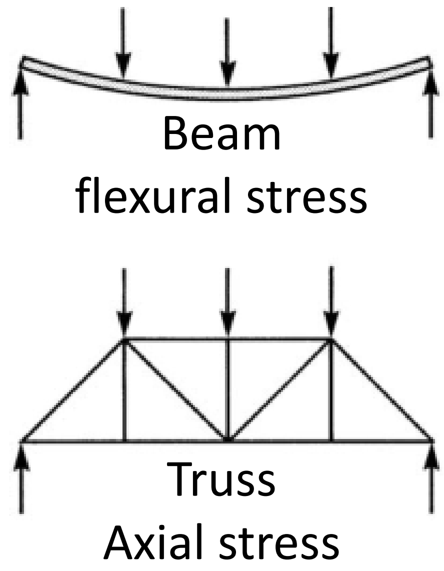
- **Advantages**
- Potentially more efficient than discontinuous structures.
- Have a greater degree of geometric stability.
- Have greater Stiffness (i.e., smaller deformations), than those of comparable determinate structures.

- **Disadvantages**
- They are more difficult both to design and construct.
- They are also unable to accommodate movements such as thermal expansion and foundation settlement without the creation of internal forces.



Elements arrangement

- **Trusses.** A triangular arrangement of straight elements structured and connected in a way such that they only incur axial force. The truss is an ancient structural concept; it was widely utilized in Roman architecture to construct long-span structures. A beam is less strong and rigid than a triangulated structure of the same weight.



- **Space-frame** structures are typically made of rigid linear members normally arranged in repeating geometric or modular units to form a thin, horizontally spanning structure. The dominant stress is axial.