LONG-SPAN STRUCTURES

Chapter 6

Introduction

- Long-span structures are structural systems designed to bridge or cover large distances (Typically > 20 -30 m) without intermediate supports.

- Applications of Long Span Structures
  - Sports Arenas
  - Exhibition Halls
  - Convention Centers
  - Airports
  - Bridges
  - Industrial Buildings

Spectacular long span structures in late 20th century
- Largest covered stadium: 210 m span
- Largest exhibition hall: 216 m span
- Largest hangar: 75-80 m span

Types of Long Span Structures

- Trusses (2D and 3D systems) : Lightweight, triangular frameworks.
- Arches: Curved structures distributing load to supports.
- Shell Structures: Thin, curved surfaces like domes.
- Suspension Systems: Cables supporting the load.
- Cable-Stayed Structures: Cables connected to towers.
- Others…

- Portal frames, folded plates, prestressed beams and space frames are also used in the construction of long-span structures.
- The above mentioned systems can be used to construct simple and conventional structures

Key Characteristics

The structural system of a long-span structure is a critical design consideration and should possess the following characteristics:

- **Efficiency**: The system should be designed to minimize material usage while maximizing structural performance.
- **Lightweight**: Using lightweight materials for the structural components is preferable to achieve longer spans with reduced load.
- **Structural Integrity**: The system must be capable of withstanding various types of loads, including wind, seismic forces, and other environmental stresses.

Challenges

Challenges of Long Span Structures include:

- Complex Engineering: Designing and constructing long-span structures often requires significant design expertise, advanced computational analysis, and specialized experience. The construction process typically involves the use of sophisticated methods and equipment.
- Cost: Long-span structures tend to be more expensive than conventional structures due to the use of high-performance materials, complex design requirements, and specialized construction techniques.
- Vibrations and Deflection: Long-span structures are prone to frequent vibrations and large deformations. Specialized techniques are needed to manage these movements and ensure the structure’s stability and comfort for occupants.

TRUSSES

Chapter 6.1

Introduction

The use of trusses started in Roman architecture where they were the most efficient means to build long-span structures

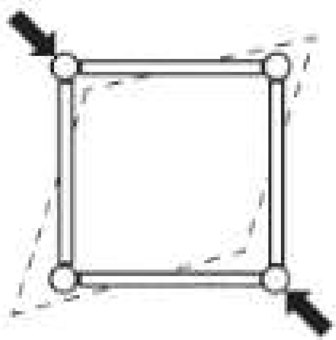
Introduction

In the modern world, trusses are everywhere, from machines and infrastructure to buildings.

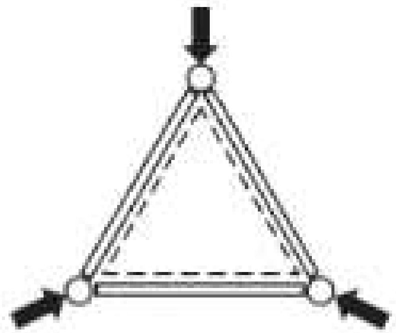
Introduction

- A truss is an assembly of individual linear elements arranged in a triangle or a combination of triangles to form a rigid framework that cannot be deformed by the application of external forces without the deformation of one or more of its members.
- The individual elements are typically assumed to be joined at their intersections with pinned connections.
- Members are customarily arranged so that all loads and reactions occur only at these intersections.
- The external force causes forces to be developed in members of the stable triangulated structure. These forces are either purely tensile or purely compressive. Bending is not present, nor can it be developed, as long as external loads are applied at nodal points.

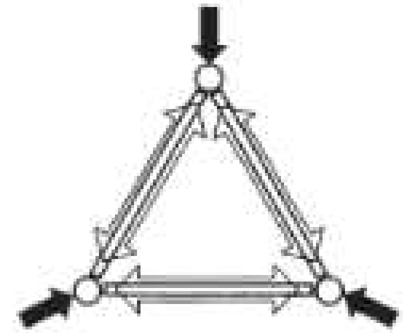
Introduction



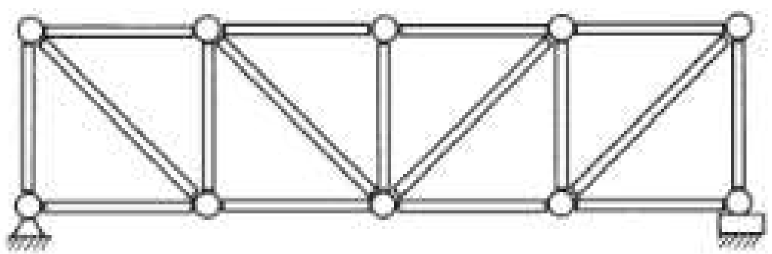
(b) Unstable configuration



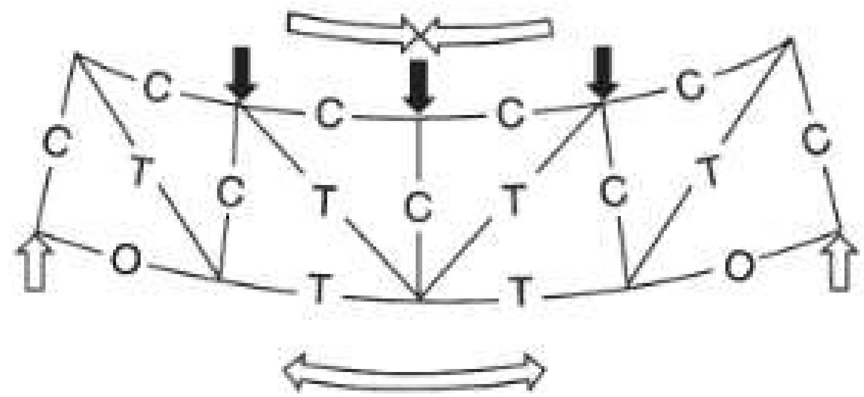
(c) Stable configuration



(d) Member forces



(e) Rigid triangulated configuration



(f) Only tension or compression forces are developed in pin-connected truss members if loads are applied only at panel (or connection) points.

Truss Analysis

- **Stability and determinacy**.

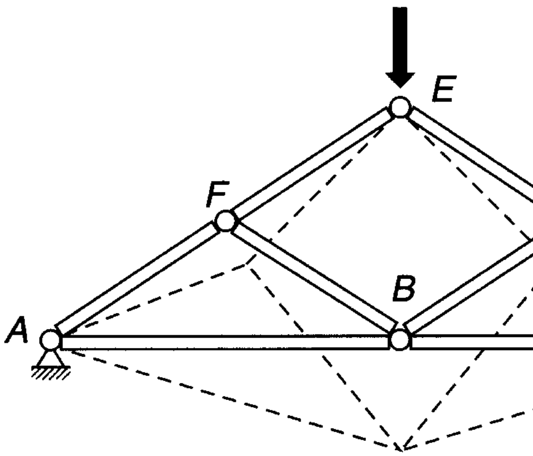
- It is usually possible to tell by inspection whether a truss is stable under external loads by considering each joint, in turn, to determine whether the joint will maintain a fixed relation to other joints under any loading condition applied to the truss. In general, any truss composed of an aggregation of basic triangular shapes will be a stable structure. Nontriangular shapes in a bar pattern are an obvious sign that the truss should be carefully inspected.

- The stability and determinacy can be checked by the following formula - for a stable and determinate truss $m = 2j - 3$ where m = the number of members and j = the number of joints, given that reactions are not parallel or intersect at the same point.

Truss Analysis

m= 8; j=6

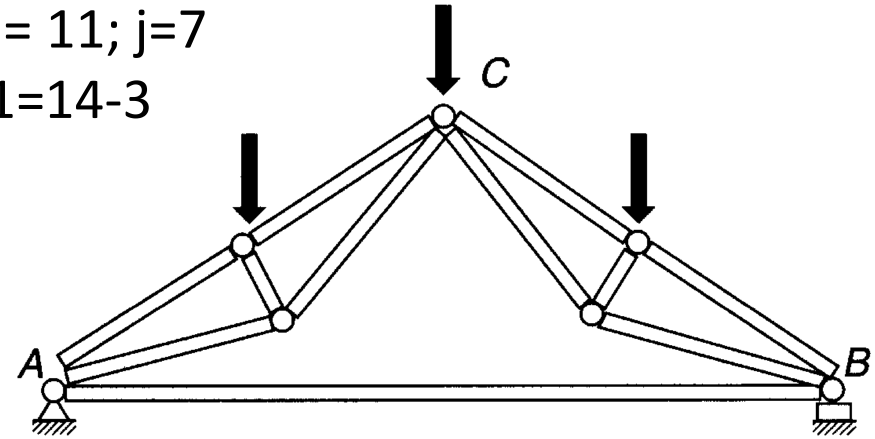
8<12-3



(a) Unstable truss: the nontriangulated central area of the truss will greatly distort under an applied loading, which will lead to a collapse of the entire truss.

m= 11; j=7

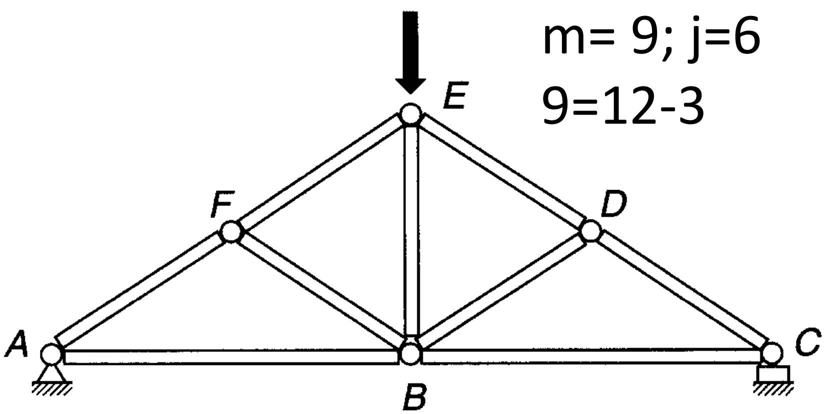
11=14-3



(c) Nontriangular bar pattern that is still stable.

m= 9; j=6

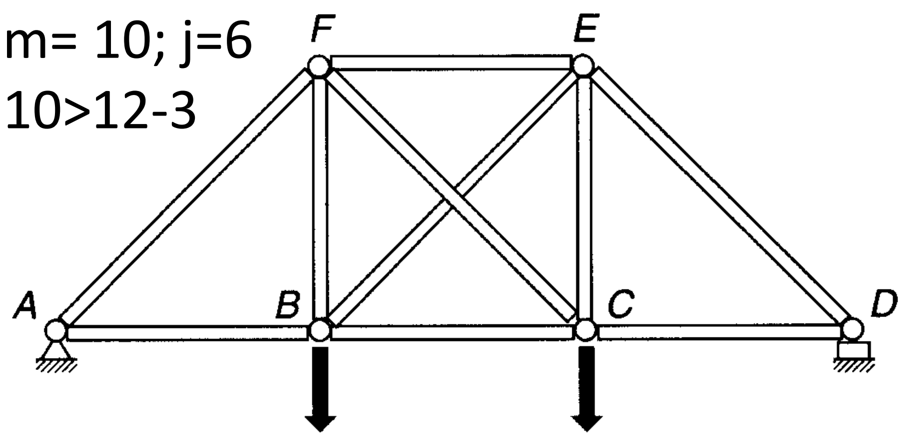
9=12-3



(b) Stable truss: the bar pattern is fully triangulated.

m= 10; j=6

10>12-3

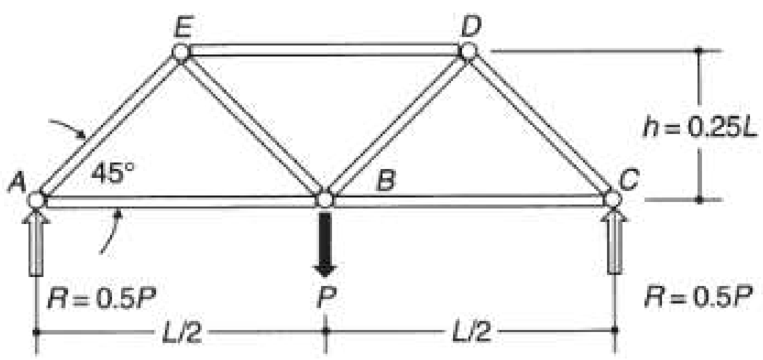


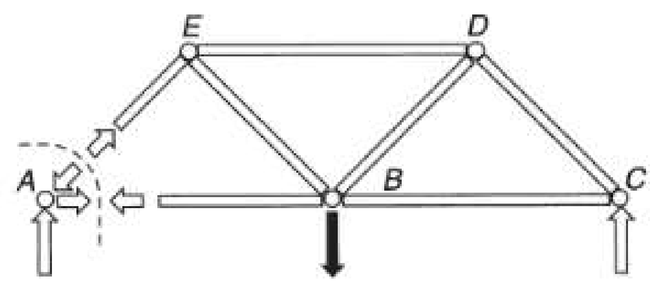
(d) Stable truss with more than the minimum number of bars necessary for stability.

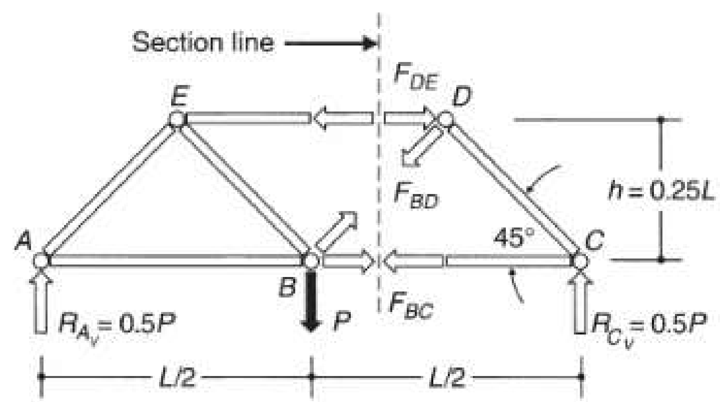
Truss Analysis

- **Member Forces.**

- Member forces and their sense (tension or compression) can be determined by the method of joints and the method sections. Indeterminate trusses can be analyzed using the stiffness or force methods.



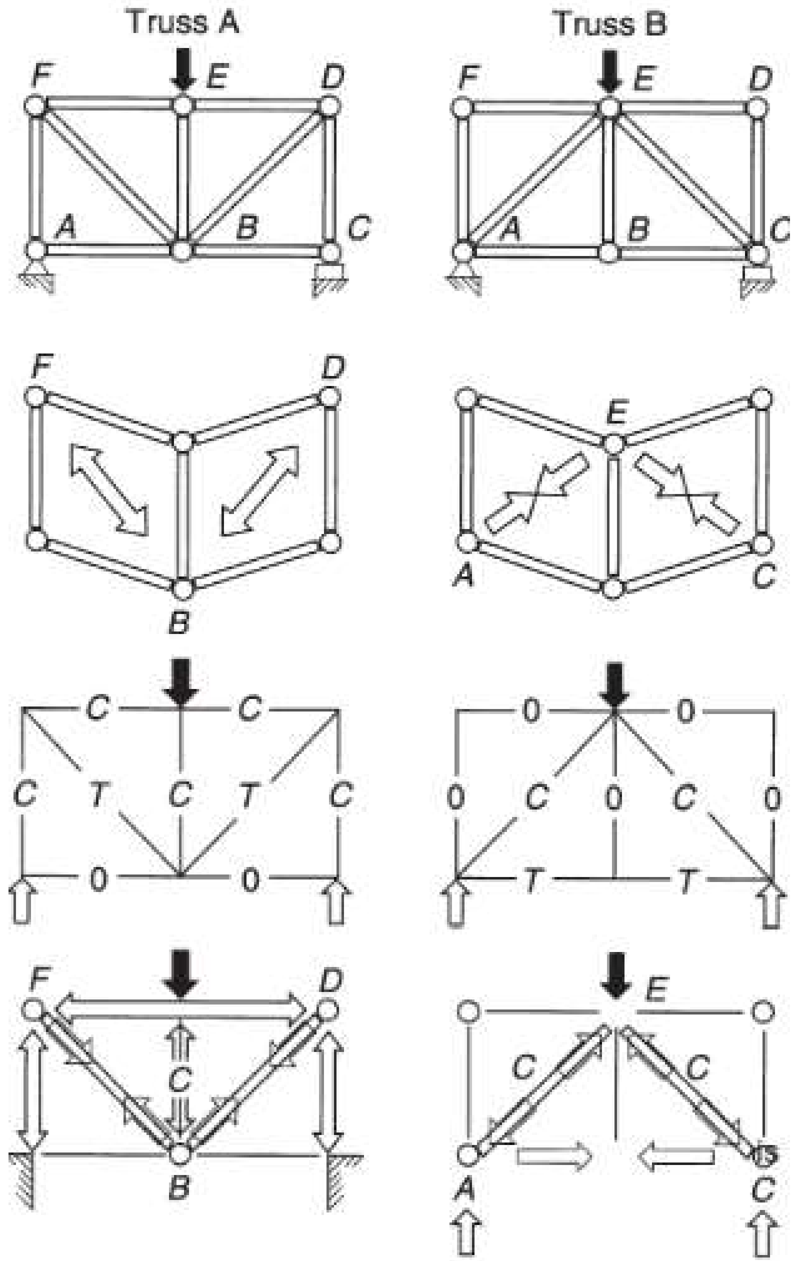




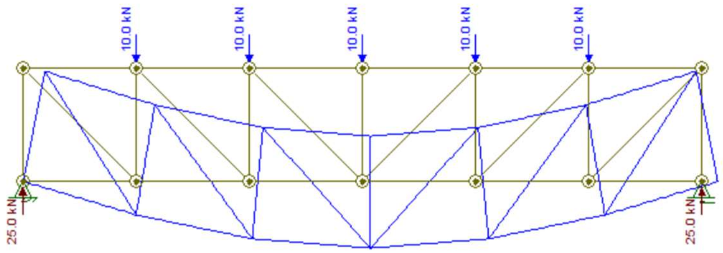
Member Forces: Qualitative analyses

For some simple truss configurations, the basic sense (tension, compression, zero) of the forces in many members can be determined by simple techniques that might help visualize how certain trusses carry external loads. The techniques that can be used include:

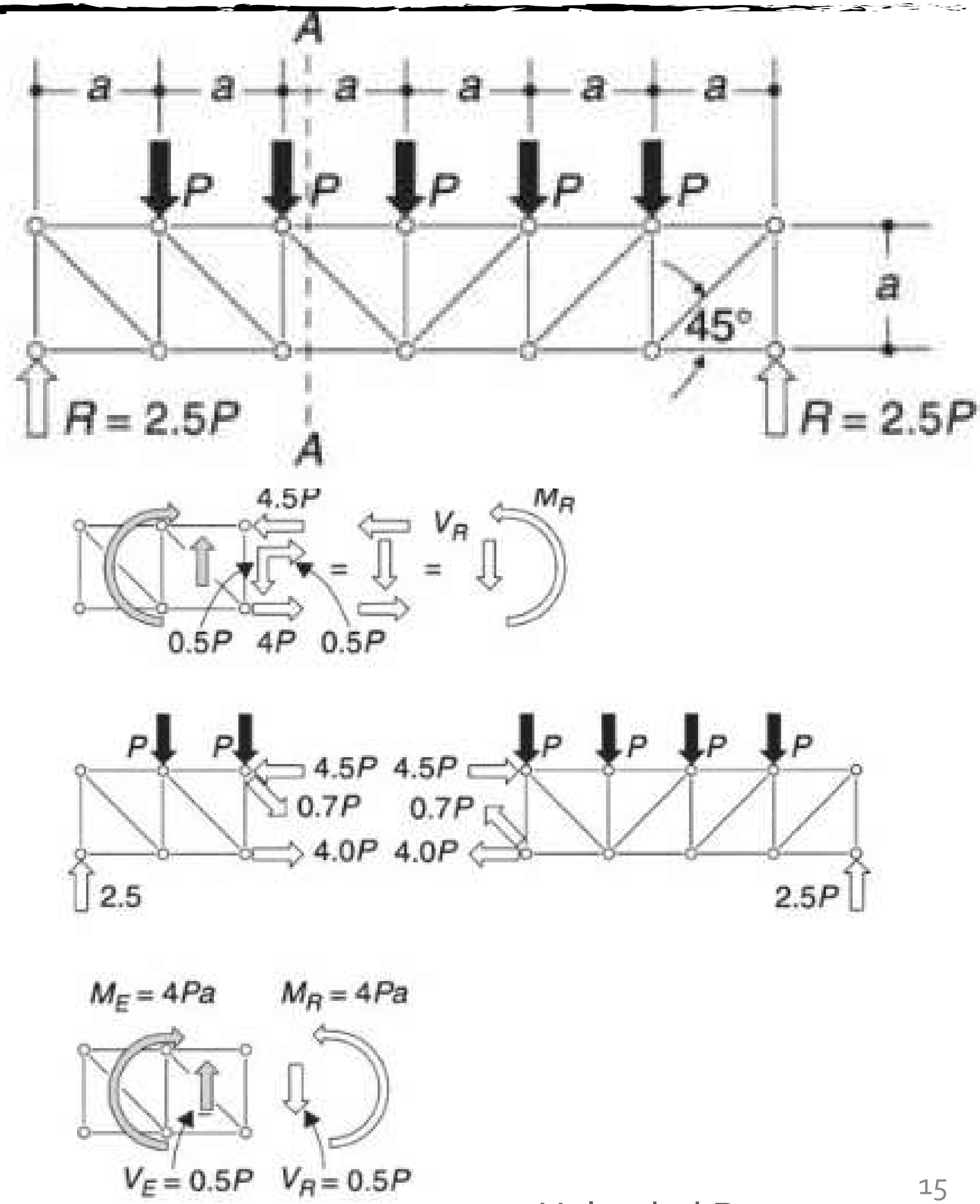
- Removing the member and observing the deflected shape,
- Using the arch-and-cable analogy.
- Using the method of joints/ section



Shears and Moments in trusses



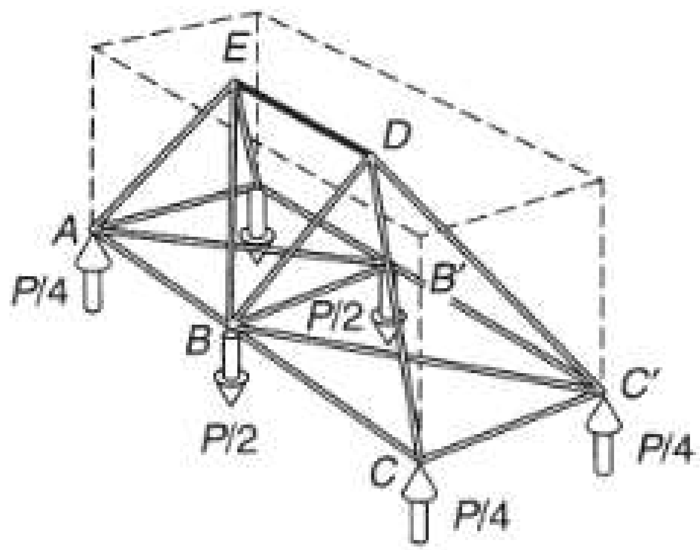
Deflected shape



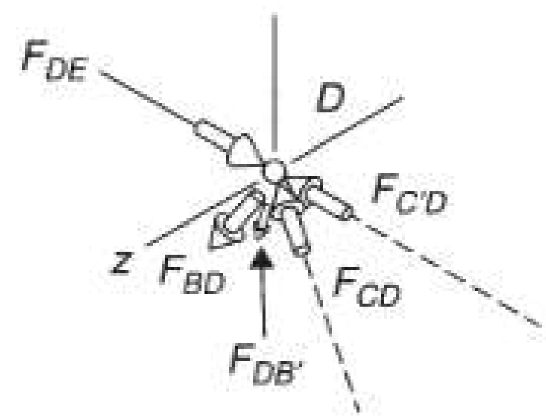
The exact way different structures respond to the same loading may vary, but each provides (and must provide) the same internal resisting shears and moments, no matter what truss configuration is used.

Space Truss

The stability inherent in triangulated patterns of bars is also present when the structure is extended into the third dimension. Whereas the simple triangle is the basic repetitive element in planar trusses, the tetrahedron is the basic repetitive element in three-dimensional trusses.

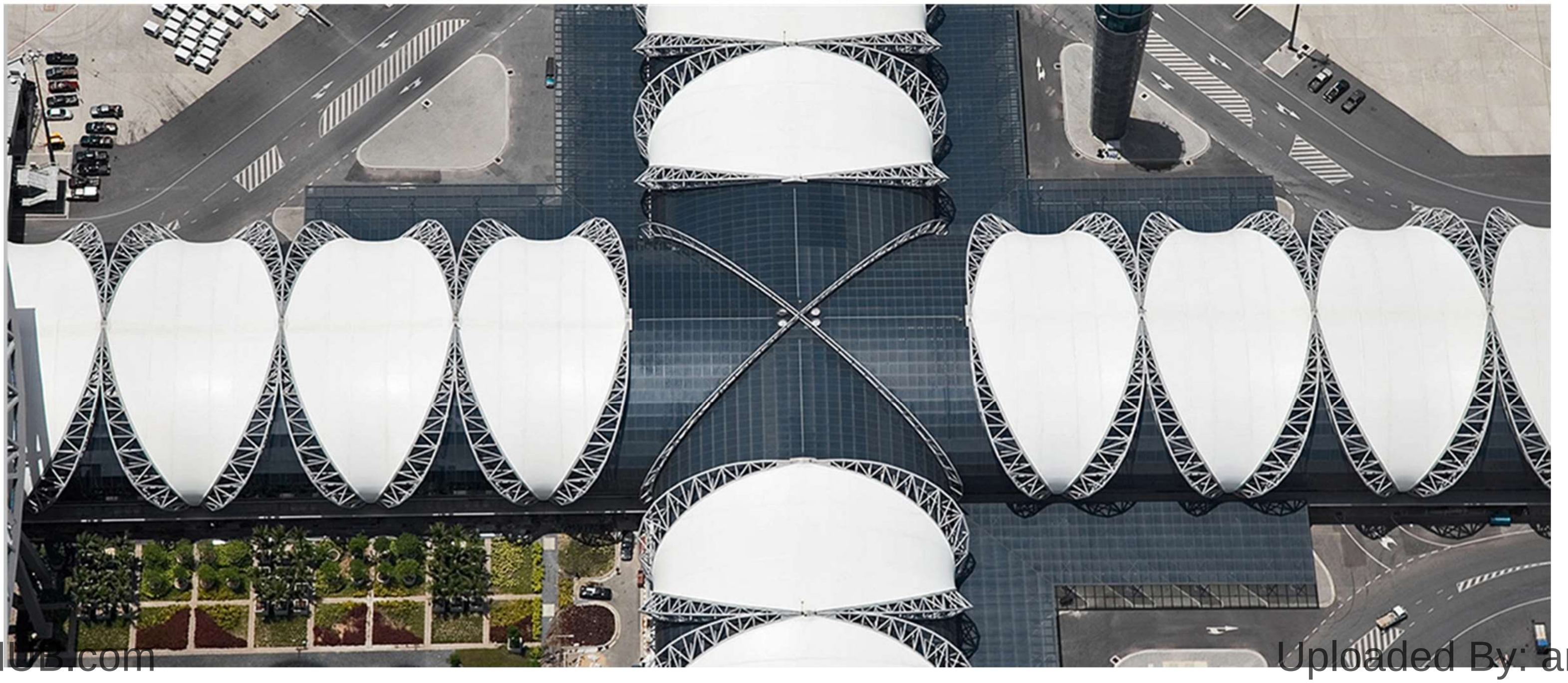


(a) Typical three-dimensional configuration

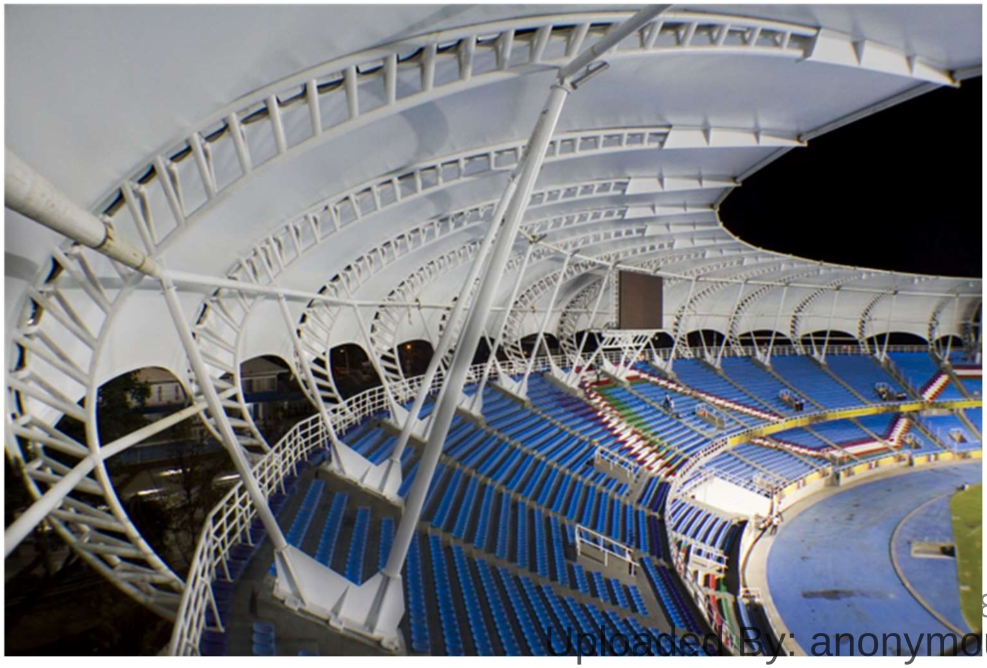


(b) Any joint must be in a state of translatory and rotational equilibrium. Thus, $\Sigma F_x = 0$, $\Sigma F_y = 0$, and $\Sigma F_z = 0$.

Space Truss



Space Truss



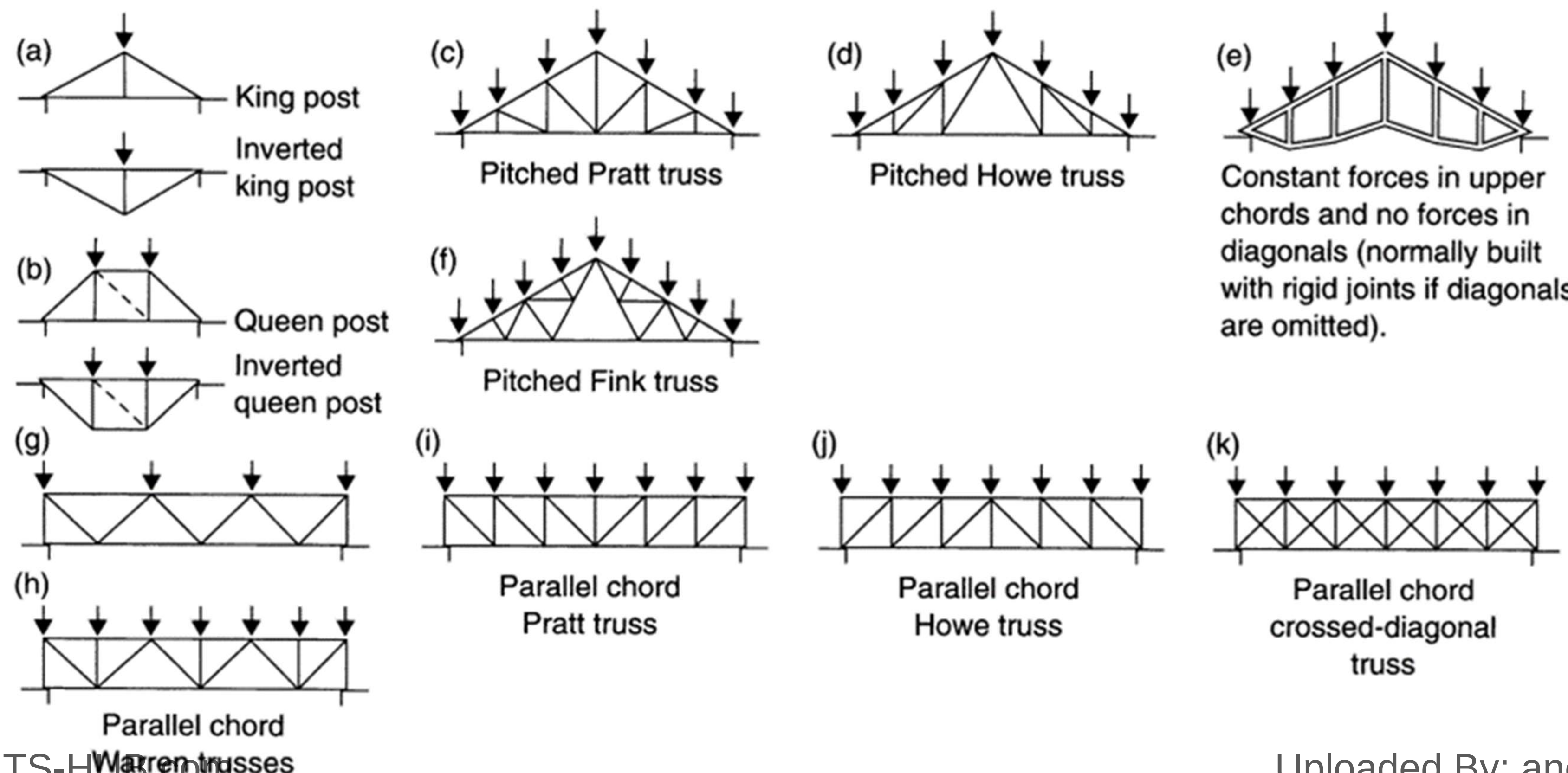
Truss design efficiency

- **Structural efficiency** - To minimize the total amount of material used in a truss in order to support a given loading over a given span while providing adequate safety and stiffness. For example, efficient patterns may be developed that minimize the length of long compression members and maximize the length of tension elements.

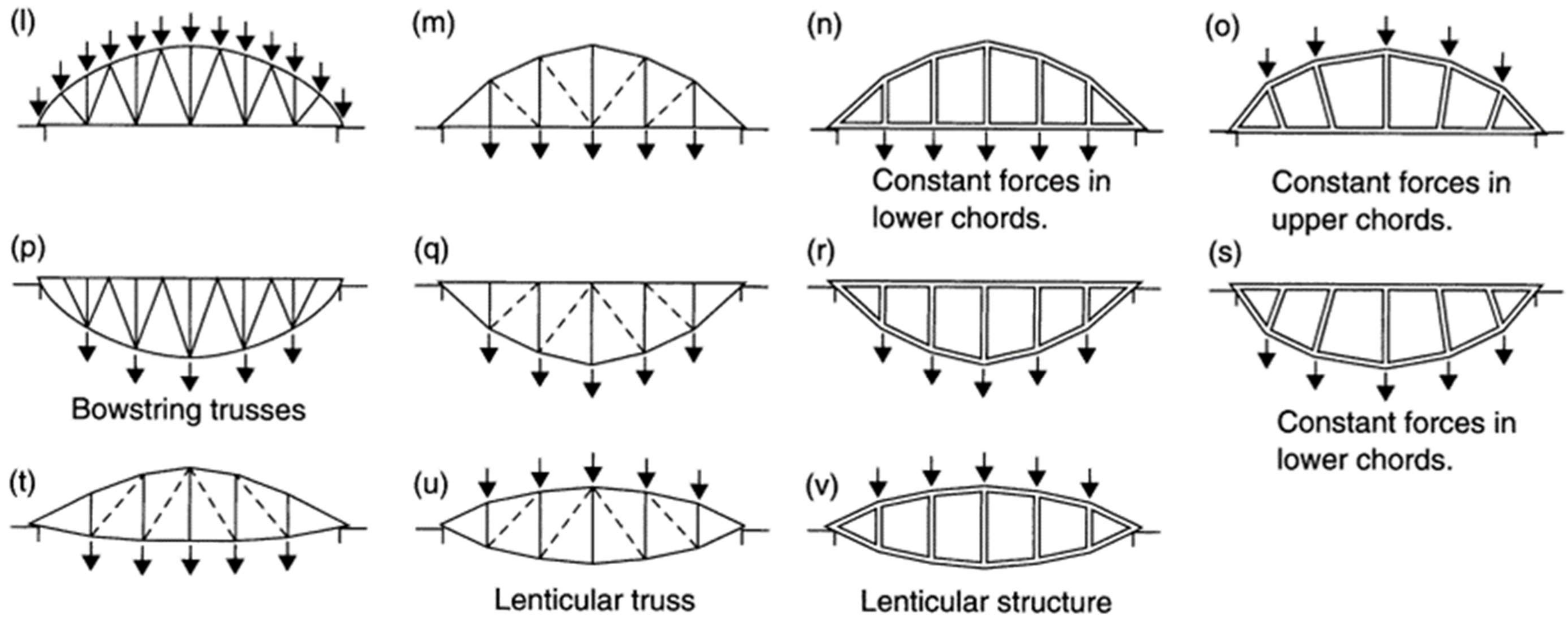
- **Construction efficiency** - considerations related to the fabrication and making of a truss. Responding to these objectives frequently leads to trusses with simple external configurations (often, parallel upper and lower chords or simple gabled forms). Equally simple internal triangulation patterns are used as well, with the objective of making all members the same length. Member design attitudes are also affected: Instead of making different truss members different sizes, one size may be selected

Design of Trusses

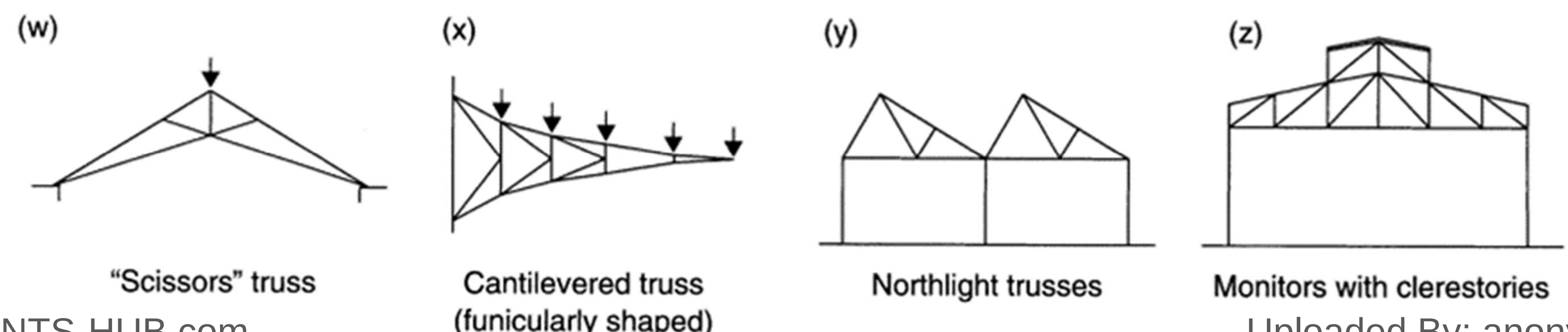
- There are many aspects of truss design. Broad issues include
  - The overall external configuration of a truss,
  - The pattern of its internal triangulation, and
  - The choice of materials and the design of members.



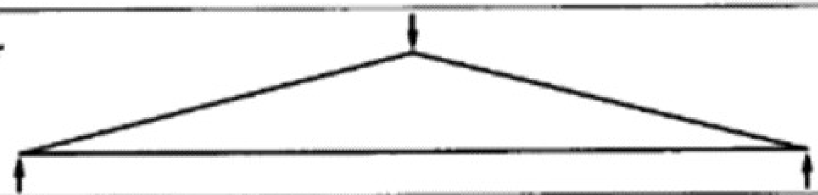
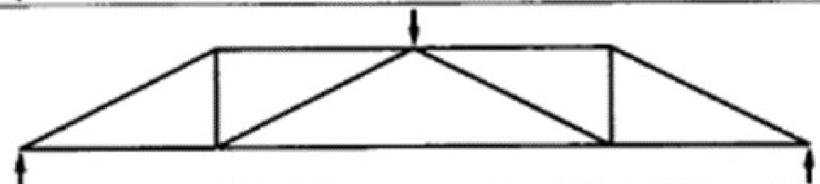
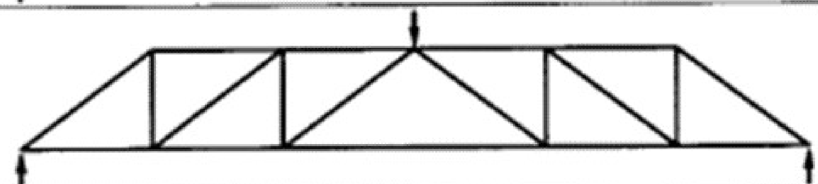
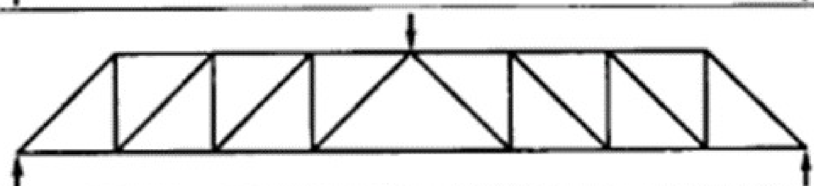
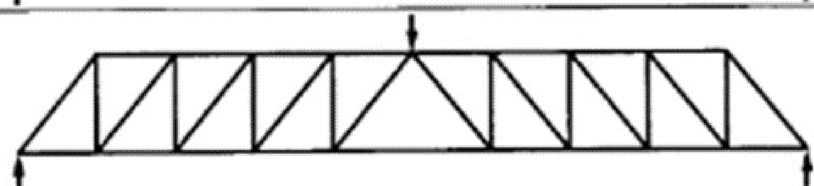
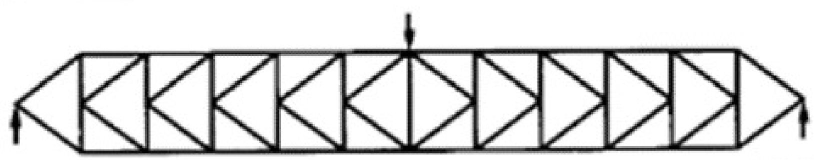
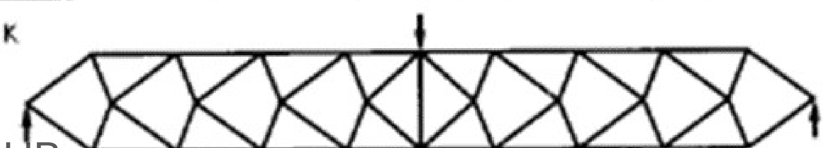
Design of Trusses



Funicularly shaped trusses: depths vary with bending moment (horizontal components of chord forces are equal and diagonals are zero-force members under design loadings).

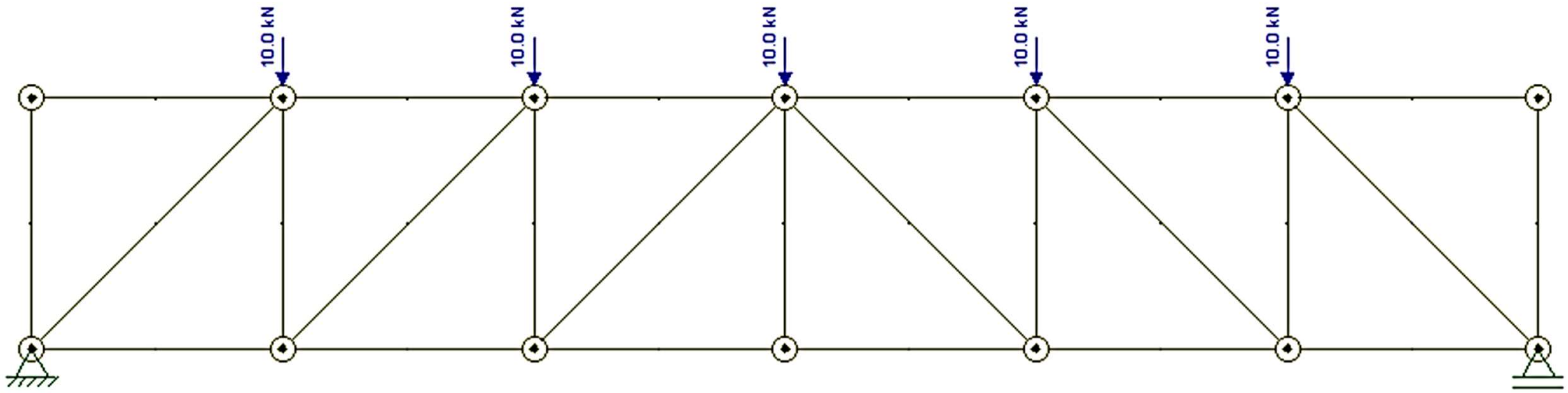


Configuration and efficiency

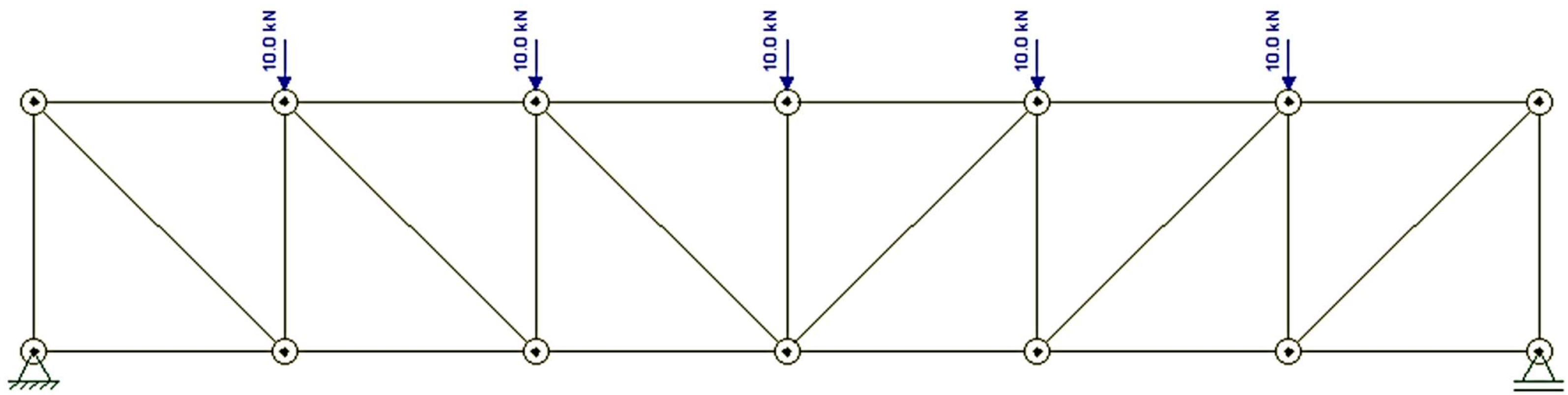
Configuration	Panels	Total length of members	Total volume of material
(a) Triangular 	1	2.031 L	4.125 PL
(b) Howe 	4	2.868 L	3.375 PL
(c) Howe 	6	3.417 L	3.292 PL
(d) Howe 	8	3.789 L	3.125 PL
(e) Howe 	10	4.800 L	3.525 PL
(f) K 	12	5.542 L	3.082 PL
(g) Modified K 	10	4.940 L	3.072 PL

Configuration and efficiency

A

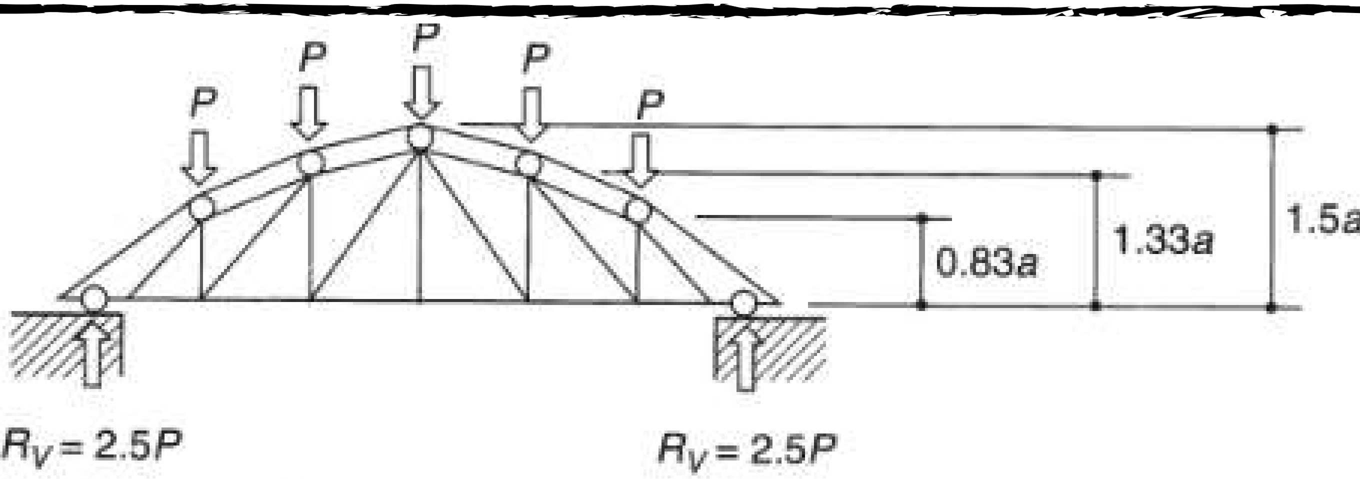


B

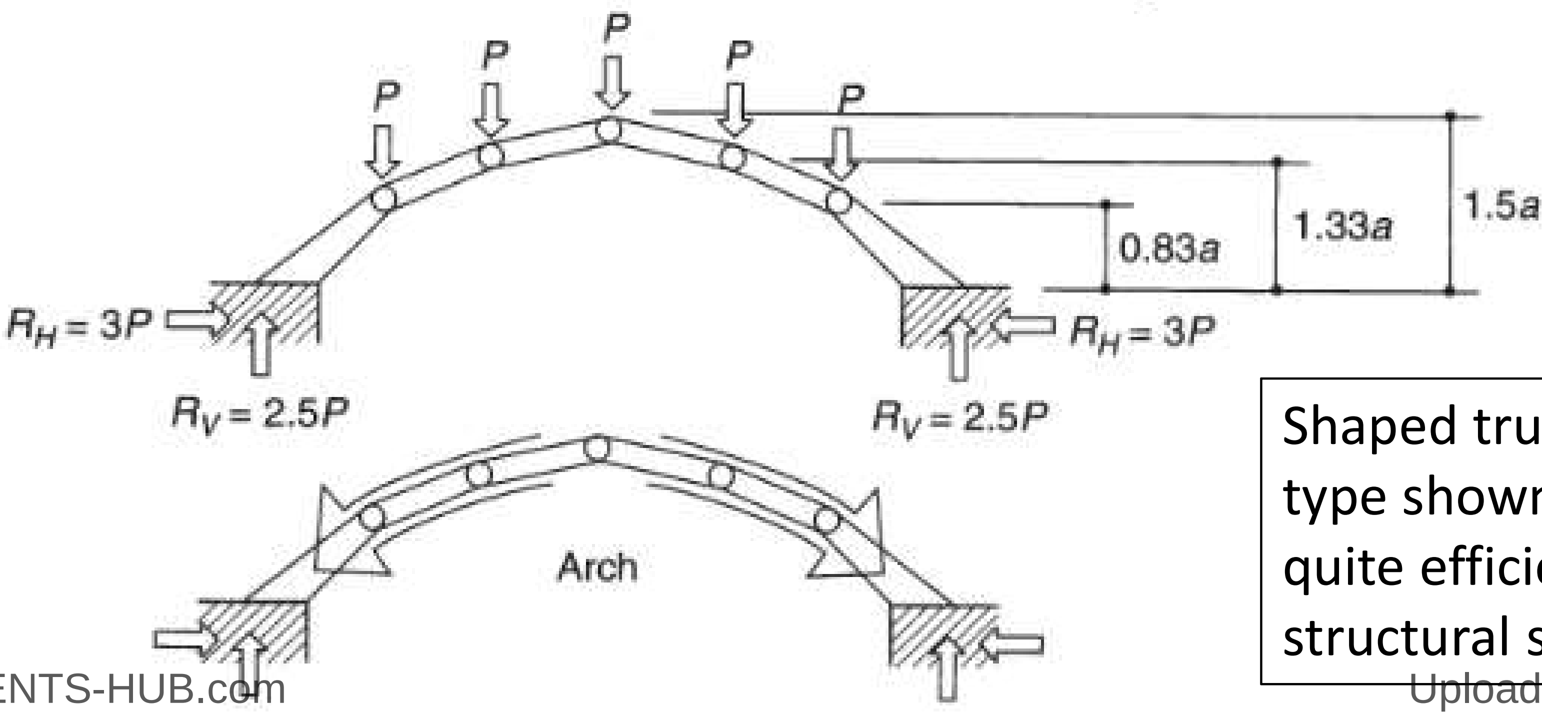


Compare configuration A with B

Funicular-shaped trusses.



(a) Funicularly shaped truss for a series of identical and equally spaced concentrated loads. Interstitial members are zero-force members under the primary loading condition shown but carry forces when the loading changes. This is a common bridge structure.

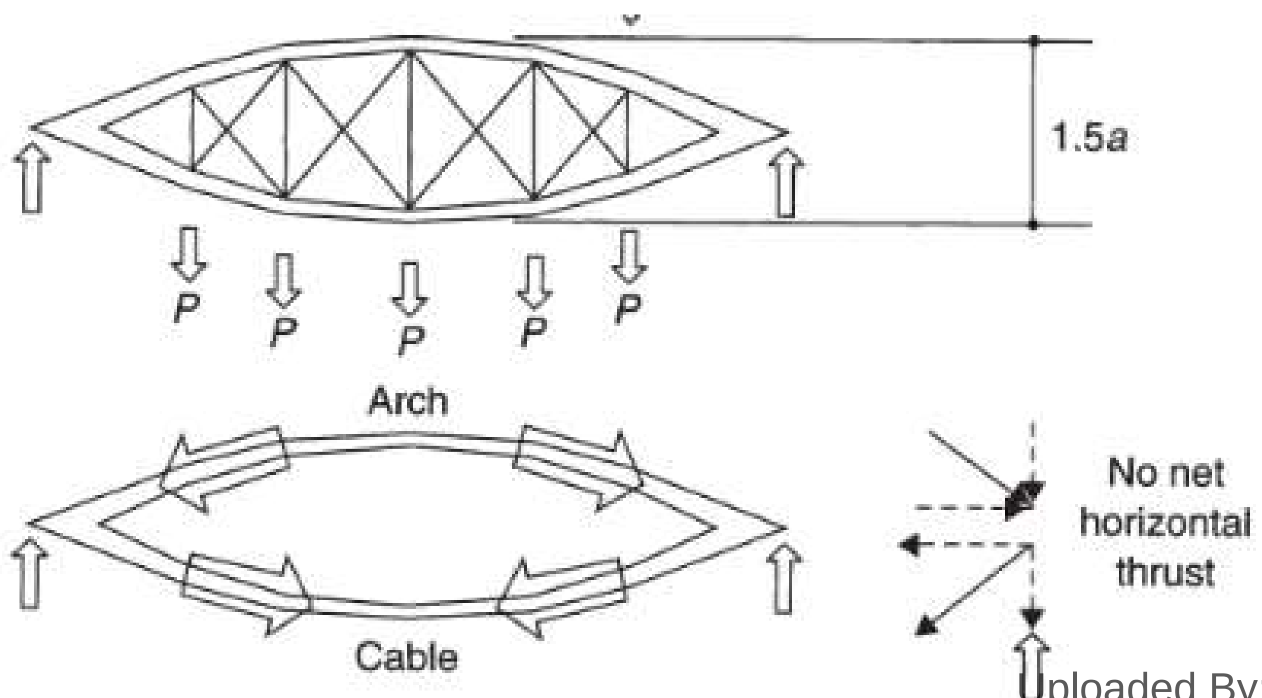


Shaped trusses of the type shown are often quite efficient in a structural sense.

Funicular-shaped trusses.

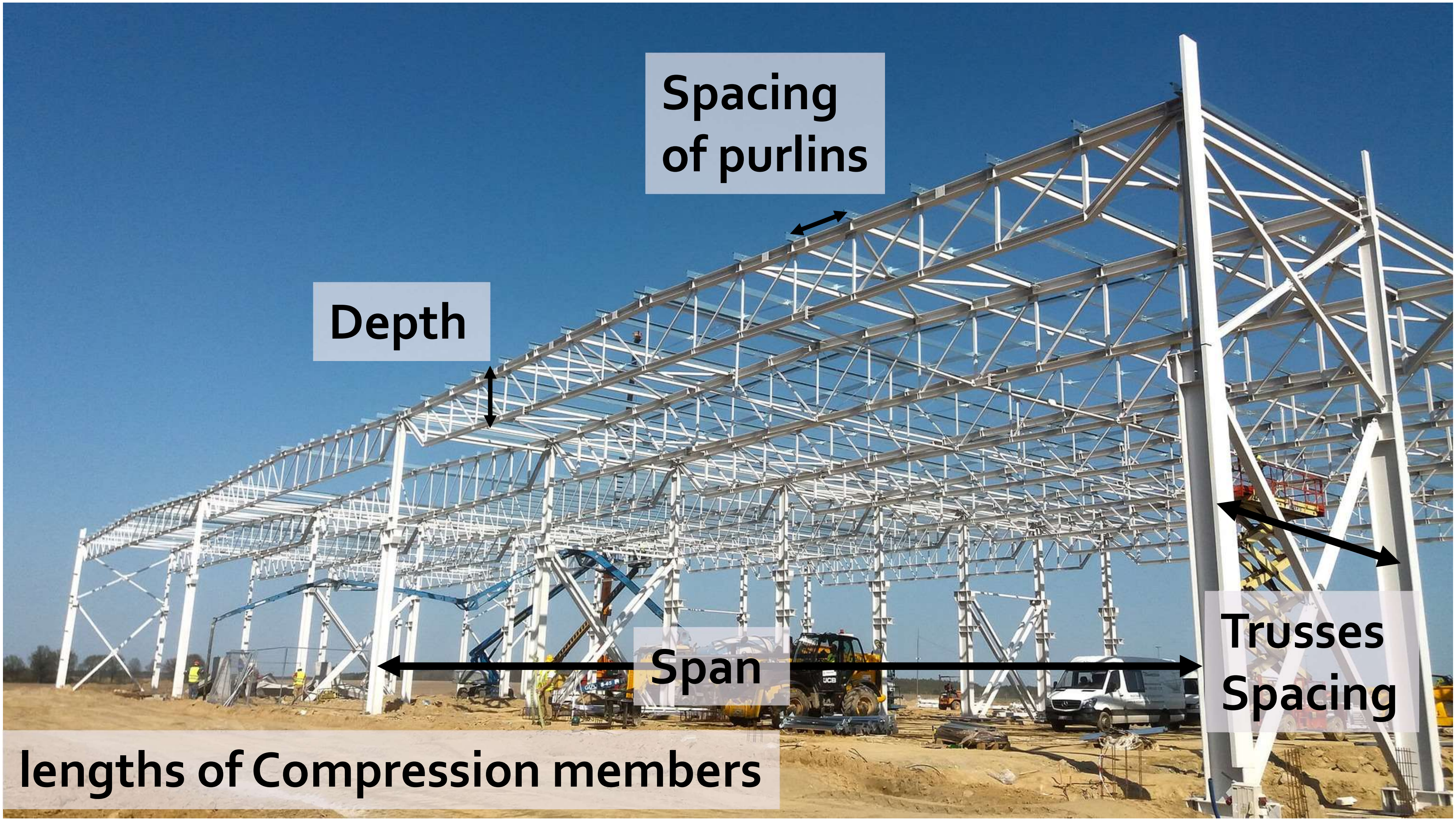
The lens-shaped Truss

An analysis of this truss would reveal that the interstitial diagonals are zero-force members and thus serve only the function of stabilizing the assembly under variant loading conditions. The verticals transfer loads such that the upper and lower chord members are similarly loaded (a condition that must be met for the similarity of shape to be correct).



Design of Trusses

- Important dimensional variables include

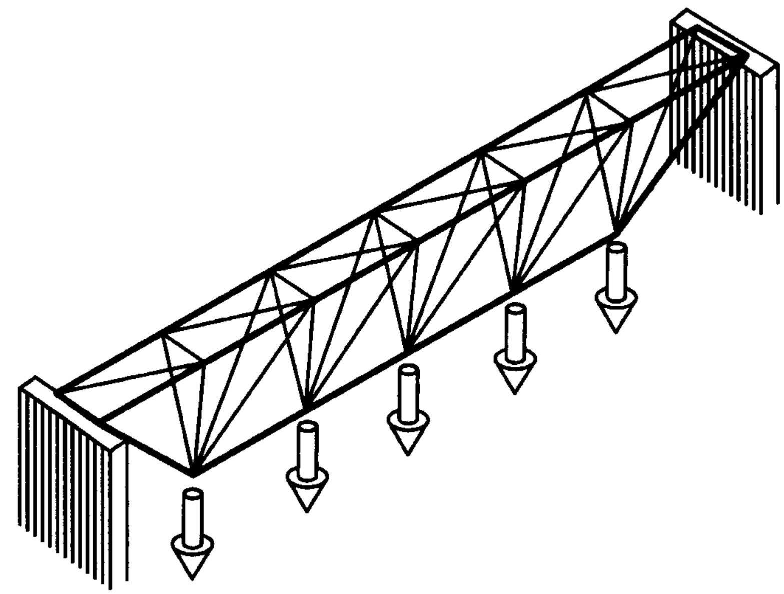


Depths of Trusses

- In general, trusses that are relatively deep in relation to their span are the most efficient, and shallow trusses are less so.
- Rules of thump
- Trusses that carry relatively light loads and are closely spaced: approximately 1/20 of their span
- Secondary collector trusses that carry reactions produced by load-transfer members: 1/10 of their span.
- Primary collector trusses, which support huge loads (e.g., a truss carrying the column loads from a multistory building over a clear span on the ground floor): 1/4 or 1/5 of the span

Planar Versus Space Trusses

- In one-way spanning elements, a planar truss usually requires less volume of truss material than does a space truss serving the same function, particularly when they are used on the interior of a building and lateral bracing is intrinsically provided by the roof framing system or some other element.
- Space trusses prove efficient when the trusses are used in a freestanding way (without transverse beams framing into their top chords). In these cases, the forms are inherently resistant to simple lateral overturning. Their compression zones are also naturally resistant to lateral buckling of whole bar assemblies.



(b) Three-dimensional truss: width of top plane provides resistance to lateral buckling.

Planar Versus Space Trusses

- On occasion a space truss may be chosen because of its inherent capability to resist torsional effects as may result from asymmetrical loadings.

Table 1 Approximate depths and span ranges for trusses of hot-rolled sections in single-storey steel frames

	Depth of main frame (mm)		
Span (m)	*Solid web*	*Plane truss*	*Space truss*
10	450	1000	1000
15	600	1200	1200
20	700	1400	1400
30	900	1800	1600
40	1200	2500	2200
50	–	3000	2800
60	–	4000	3800
70	–	5000	4800
80	–	6000	5500
100	–	8000	6000