EWCE-311

STRUCTURAL ANALYSIS AND DESIGN-I

Determinate Arches Analysis

Lecture 5

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Analysis of Arches



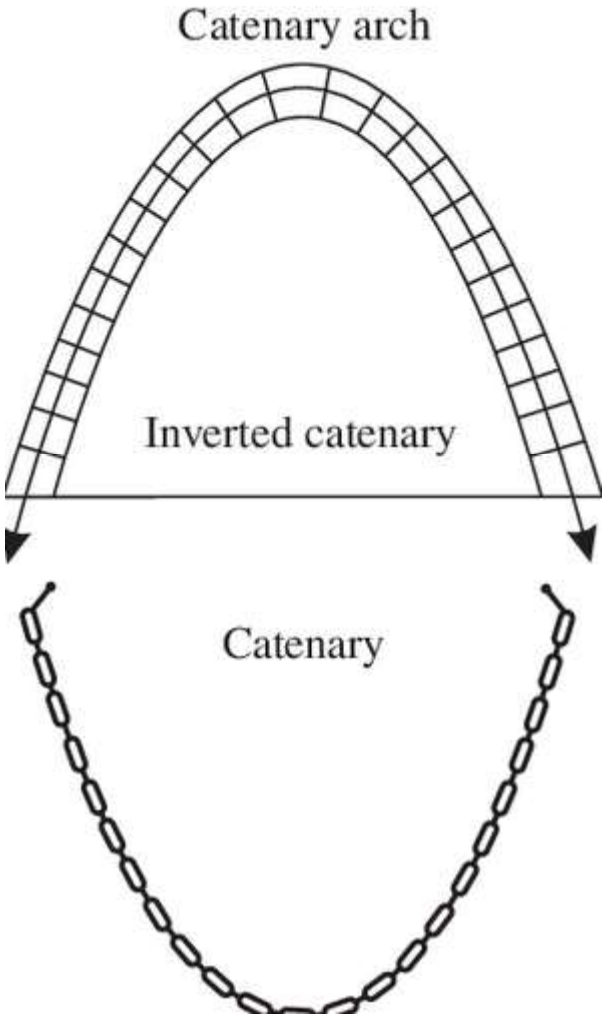


Analysis of Arches

- A curved structure designed to carry loads across a gap mainly by compression.
- The mechanical principle of the arch is precisely the same as that of the portal frame. The straight pieces of material joined by sharp bends are smoothened into a continuous curve. This increases the cost of construction but greatly reduces the stresses.
- The geometry of the curve further affects the cost and stresses. The circular arch is easiest to construct, the catenary arch is the most efficient.
- Arches can be three pinned, two pinned or rigid.

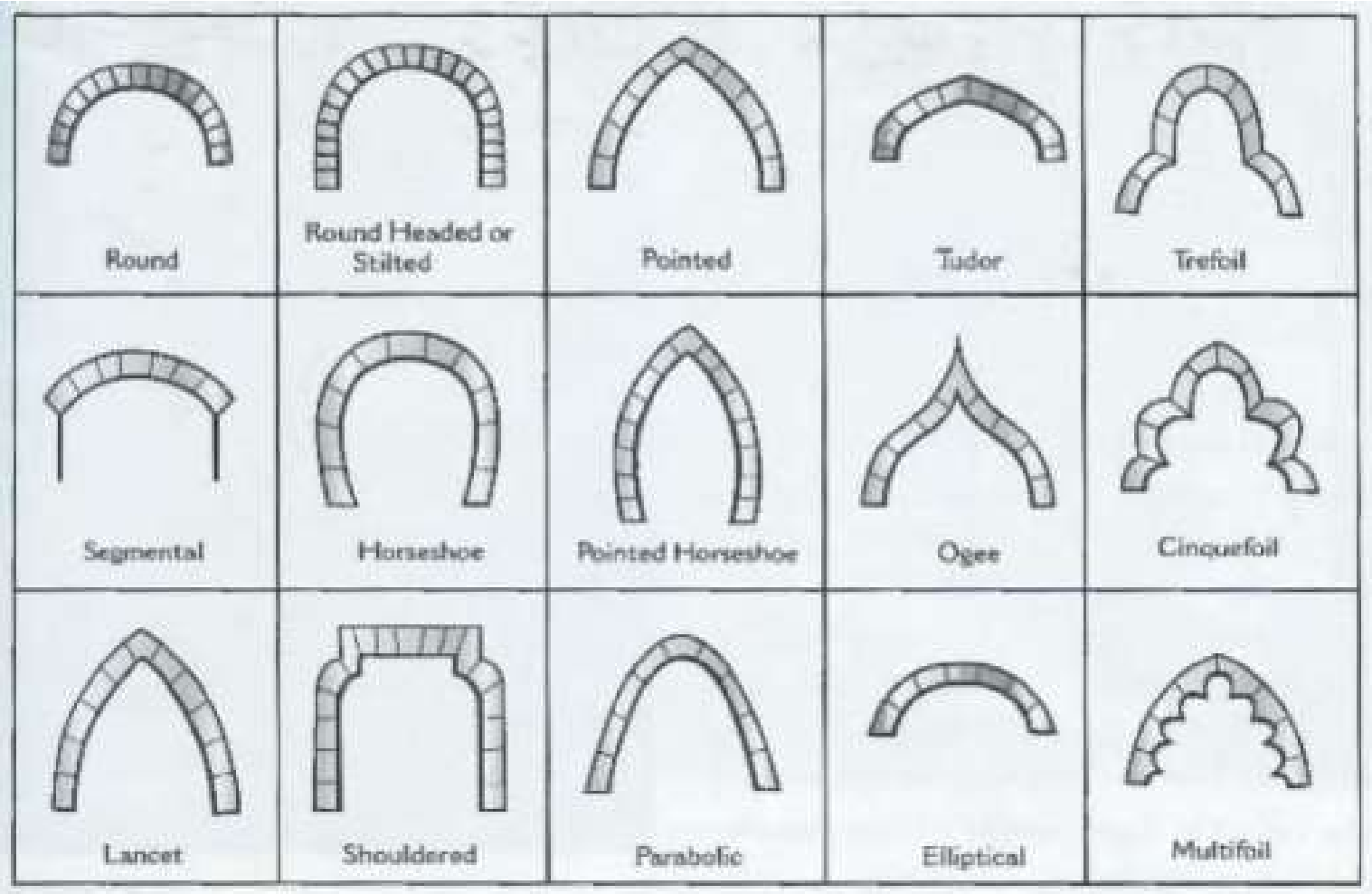


Analysis of Arches





Circular arch


Round
Round Headed or Stilted
Pointed
Tudor
Trefoil
Segmental
Horseshoe
Pointed Horseshoe
Ogee
Cinquefoil
Lancet
Shouldered
Parabolic
Elliptical
Multifoil

Arches and lintels:

Arch: Arch is one of the structure that consists of a curved top on two supports that holds the weight of something above it. (construction materials are wood, stone, steel, brick and concrete)

Lintel: lintel is also a structure which is horizontally made up from Timber stone concrete or steel across the top of a door or window

Function:

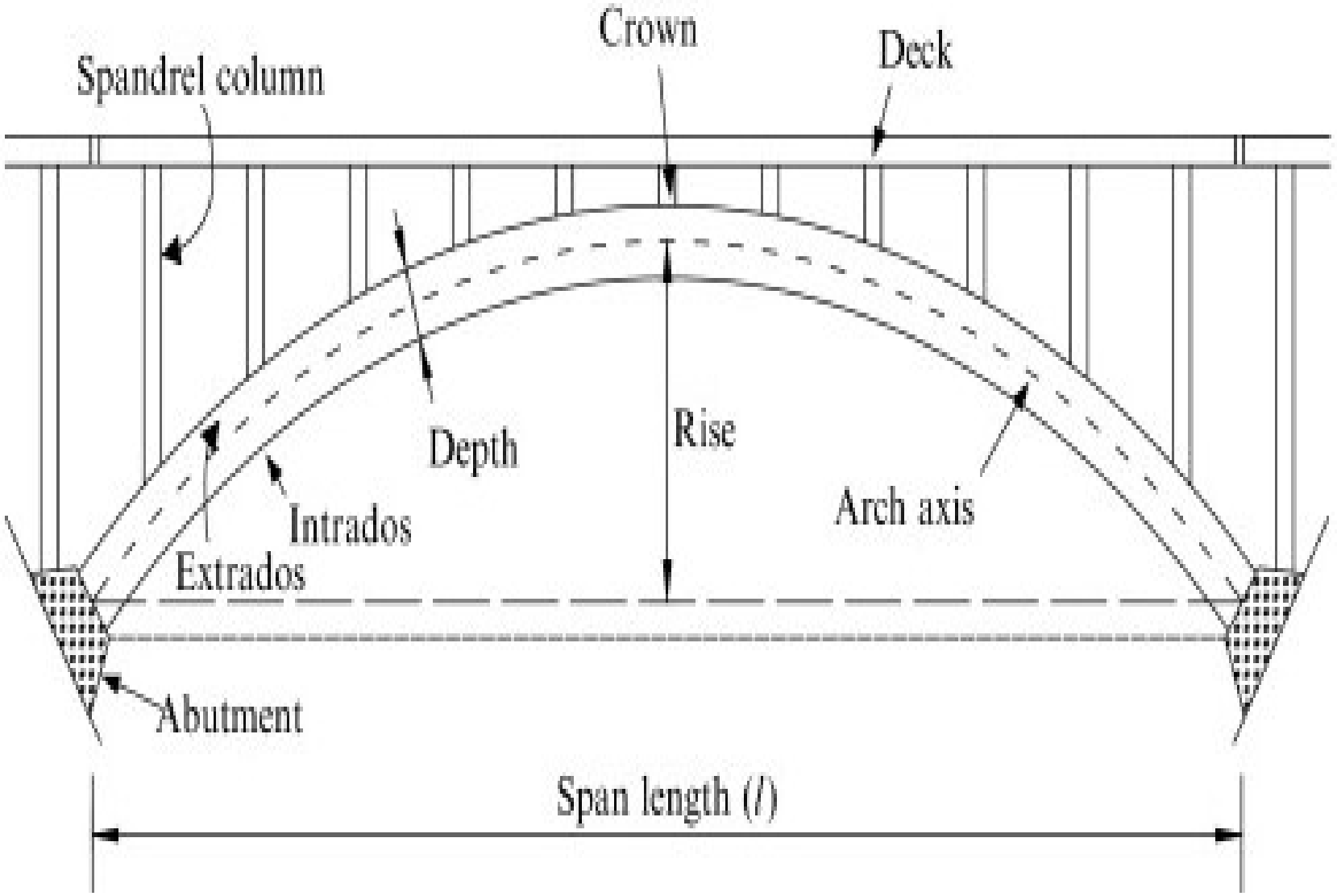
Arch :

- To sustain the weight of the structure above the opening
- In case of the arch, because of a special type of block, the blocks can support each other by providing mutual pressure of their own weight as well as the structure remain in positions by resistance from the support.

lintel :

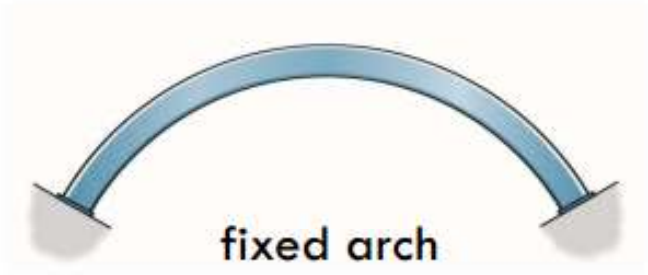
- Specially lintels are provided over windows are connected to a Sunshade to provide shelter
- Centering for lintel are much simpler as compare than that of the arch.

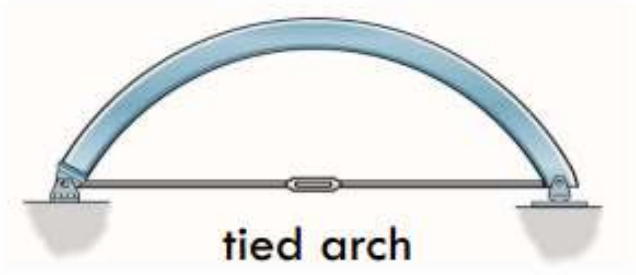
Analysis of Arches

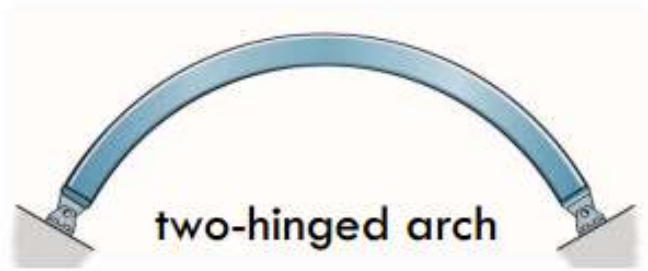


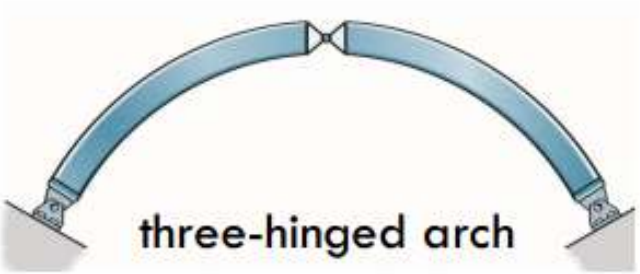
Types of Arches

Depending on its uses, several types of arches can be selected to support a loading

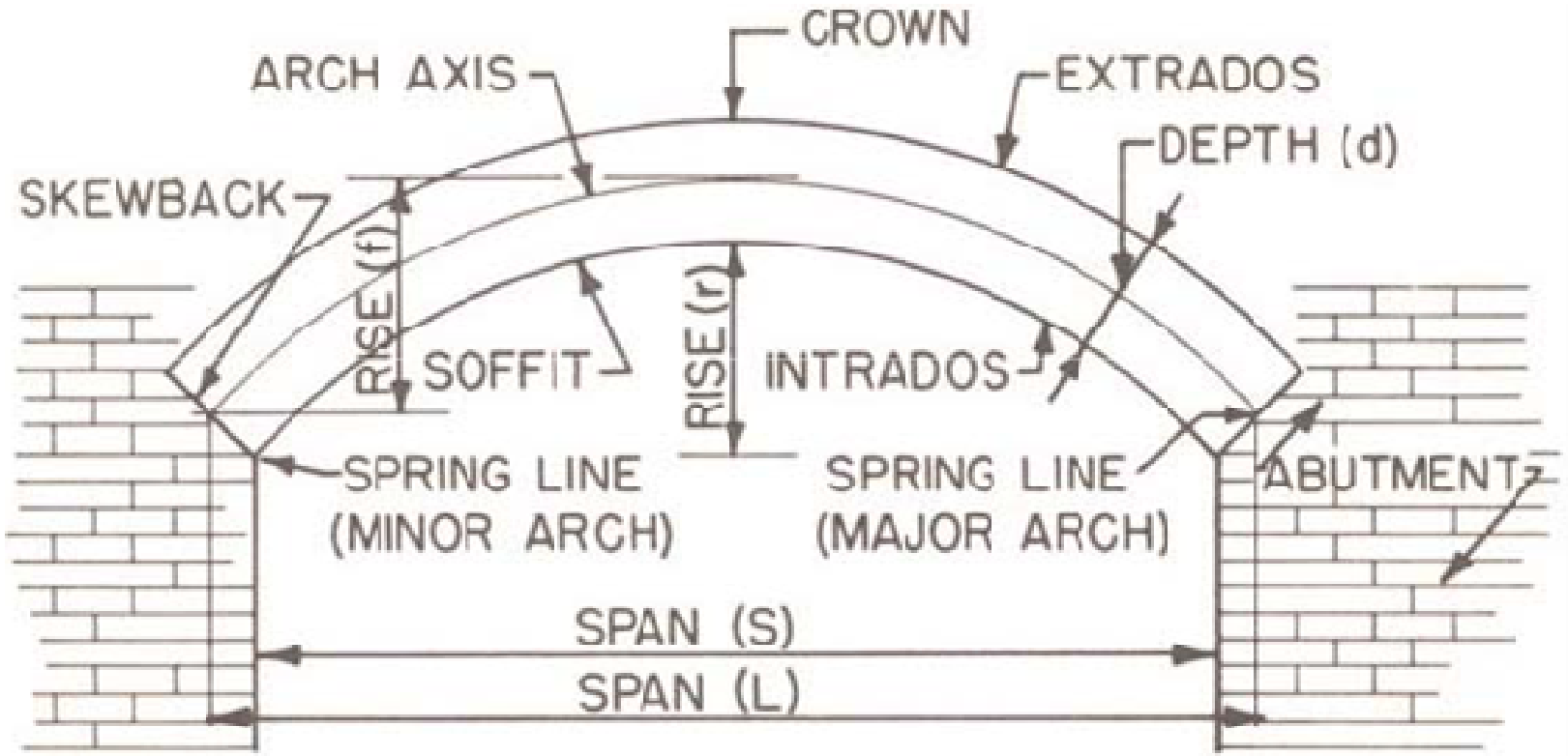








ARCH TERMINOLOGY



MATERIALS USED



STEEL-takes more tension



CONCRETE-takes more compression



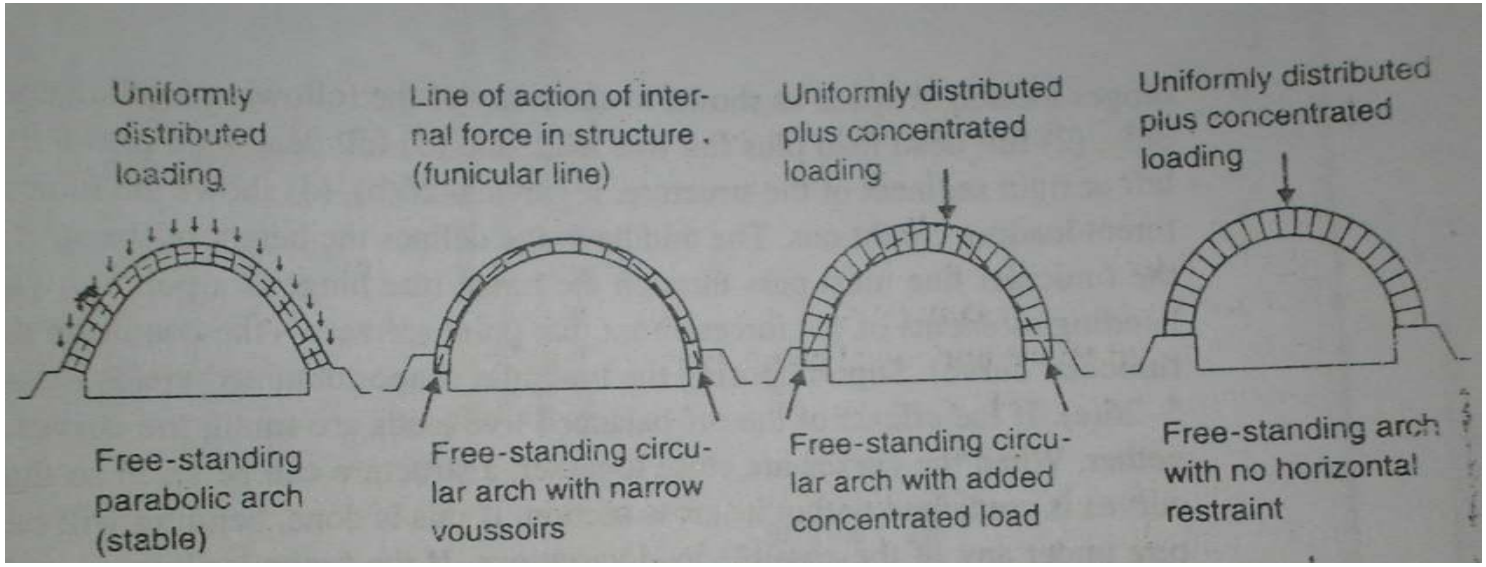
WOOD-both evenly

LOAD APPLICATIONS

FUNICULAR ARCHES – CONCENTRATED LOADS

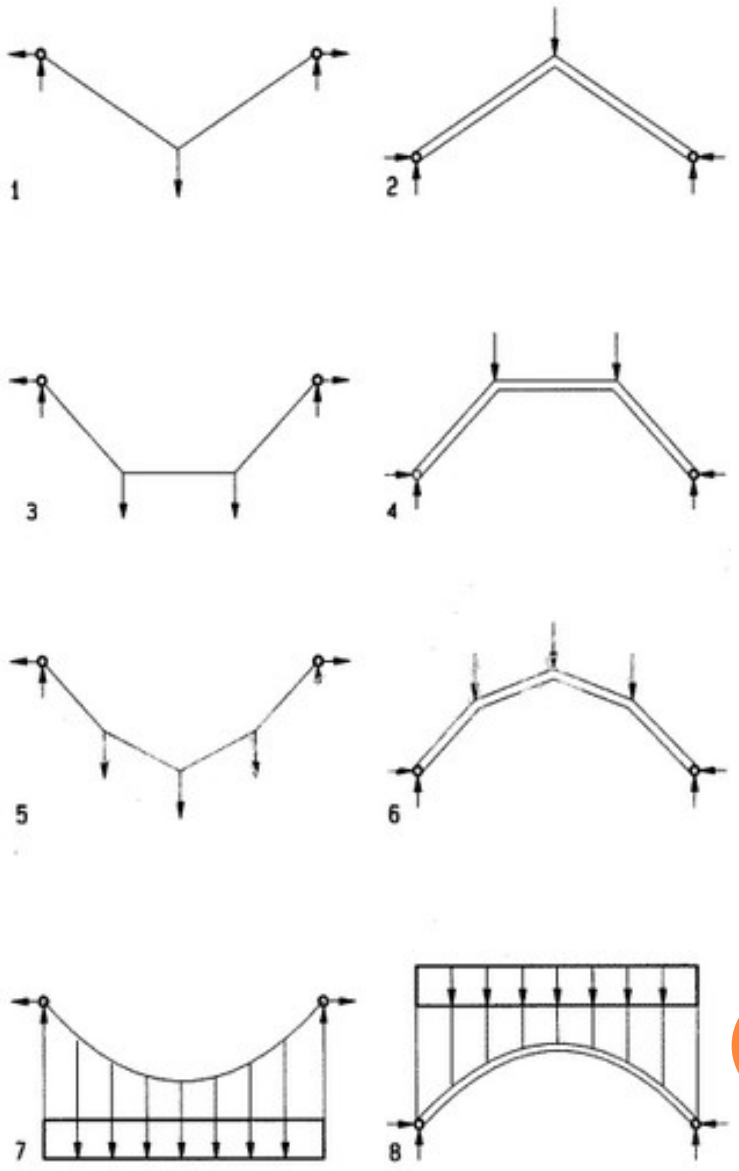
❖ The sum total of all rotational effects produced about any such location by the external and internal forces must be zero. In three hinged arch having a non-funicular shape, this observation is true only at three hinged conditions.

❖ The external shear at a section is balanced by an internal resisting shear force that is provided by vertical component of the internal axial force.



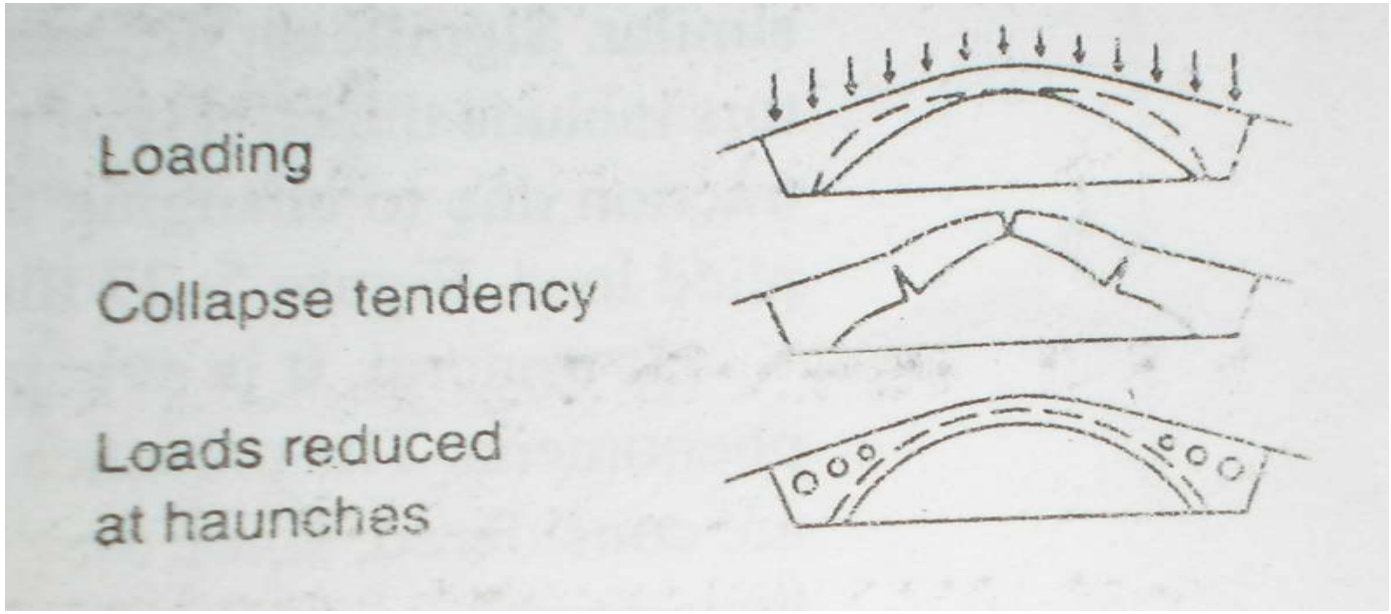
FUNICULAR Structure:

A **funicular** structure could be said to be a structure which can achieve equilibrium state by adopting a mechanism of a 'right' form (**shape**/geometry) corresponding to the applied loads.



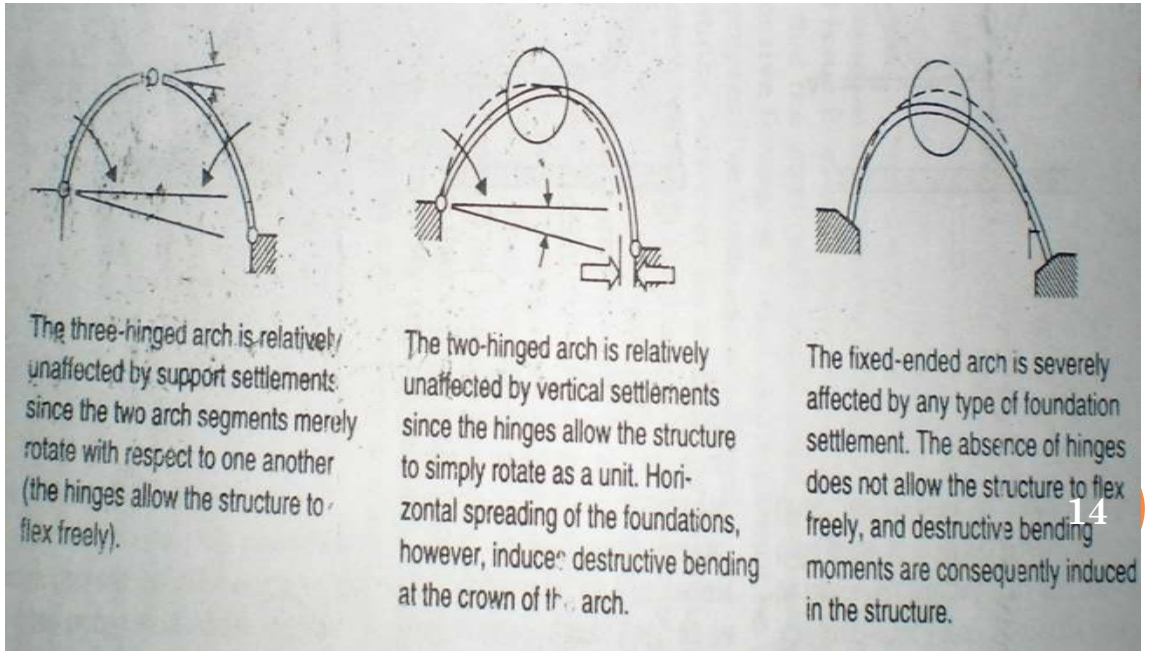
DESIGNING FOR LOAD VARIATIONS

- One of the most significant aspect of the modern arch is that it can be designed to sustain some amount of variation in load without either changing shape or experiencing damage.
- The shape of an arch is initially determined as a response to its primary loading condition (e.g.: parabolic for uniformly distributed loads)

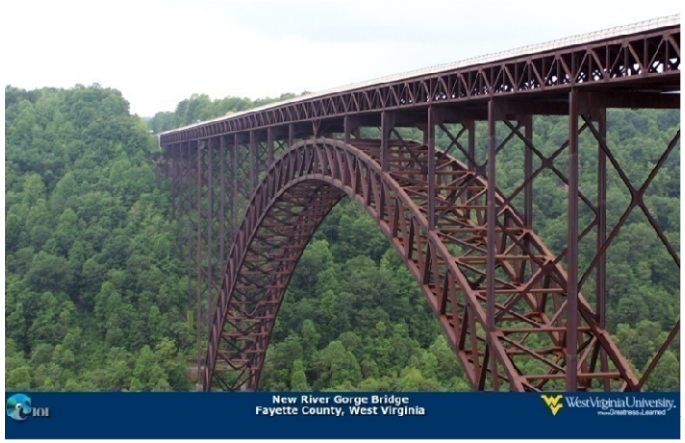


SUPPORT ELEMENTS

- A basic issue is that whether or not to absorb the horizontal thrusts by some interior element (a tie rod or by the foundations). When it is functionally possible the rods are frequently used.
- The rod is a tension element and highly efficient to take up the outward arch thrusts.
- Usually there is less need to support an arch on the top of vertical elements, the use of buttressing elements is generally preferable as head room has to be maintained.



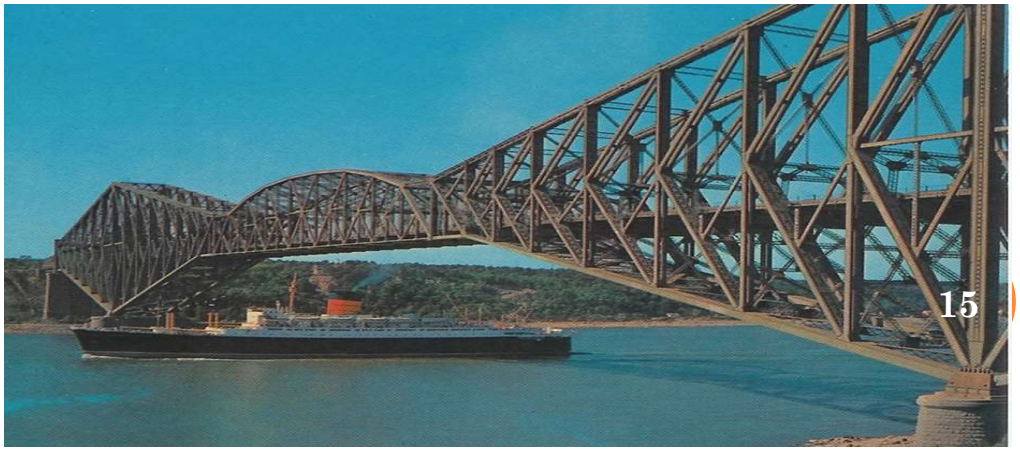
- The NEW RIVER GORGE BRIDGE in west virginia, the longest steel arch spans 1700’ (1986).
- The largest single arch span in reinforced concrete built to date is the 1280feet span KRK BRIDGE , yugoslavia.





- Combinations of trussed arches with cantilevered half arches connected by trusses were built to span as much as 1800feet in THE QUEBEC BRIDGE in 1917.

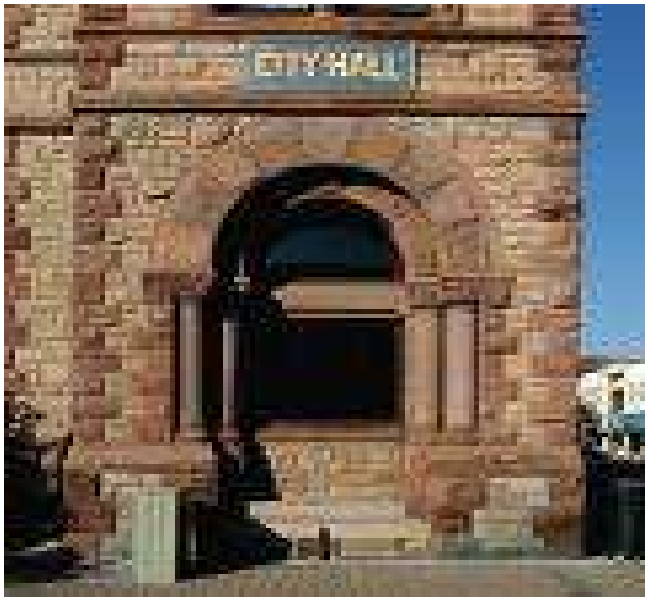
- To this day no other structural element is as commonly used to span large distances as the arch.

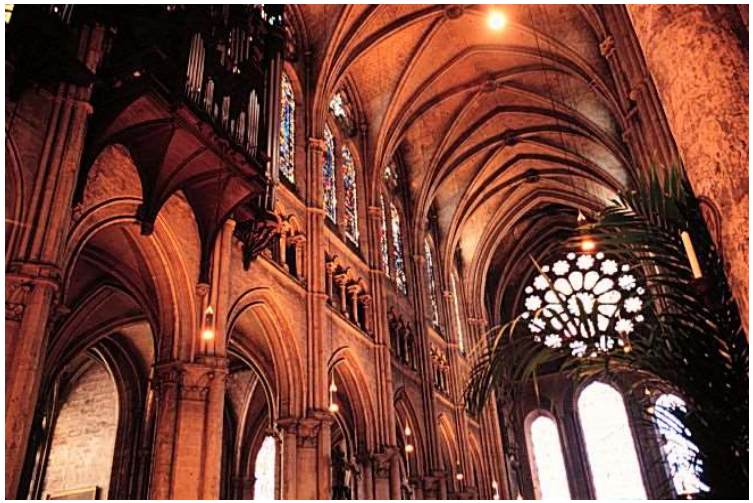


More examples….









List of Pros of Arch Bridges

1. They have excellent strength.

Arch bridges are some of the strongest types of bridges because of their unique arch design. These bridges are built with a keystone (a wedge-shaped stone that helps lock all the other stones into place) in the middle of the arch. When people or vehicles cross the bridge, the keystone distributes their weight by pressing on the stones beside it which, in turn, passes the weight to the stones beside them. The weight is distributed evenly instead of just staying in the middle portion of the bridge, which can weaken and become damaged over time when exposed to too much pressure.

2. They get stronger as years pass.

Other bridge types get weaker as time goes by, but this isn't the case for arch bridges. In fact, these structures get stronger over time because of their design. As mentioned above, the keystone distributes the weight of the bridge's load to the stones beside it, which pass on the weight to the stones beside them. This "domino effect" continues until the weight reaches the abutments, which pass the pressure on to the ground.

List of Pros of Arch Bridges

3. They can be made of any kind of material.
Arch bridges can be made of any material that can withstand pressure. Ancient arch bridges were made of stone (both cut and uncut), and later versions were constructed from bricks. Modern arch bridges are made of steel and reinforced concrete.

4. They look attractive.
Since they have been around for a long time, arch bridges have become associated with romantic poems and heroic stories. They have become the meeting place of fictional lovers and the dying places of fictional heroes and villains.

List of Cons of Arch Bridges

1. They are difficult to build.
Designing arch bridges can be challenging since there are lots of factors that have to be taken into account. Building them can also be time-consuming, and many workers are required to put them up.

2. They require stronger supports.
Arch bridges need stronger supports than ordinary bridges would since, as explained above, their structural integrity greatly depends on how sturdy their abutments are and how they're well-set into the ground. This is one of the reasons why arch bridges take a lot of time and effort to be built; if engineers want to have bridges that can withstand a lot of load and can last for years, they must first build supporting structures that are stronger than normal.

3. They have limited spans.
By their own nature, arches need to have starting and ending points. Unlike other designs, they just can't go on for long stretches of distance; they need to stop at a certain point or else they'd become too weak to handle their load. This is one of the limits of arch bridges: a single arch won't be enough if a long distance has to be covered or if the bridge needs to support a lot of weight and traffic. If this is the case, the bridge must be built with several arches or constructed with reinforcing material that will allow it to withstand the pressure.

List of Cons of Arch Bridges

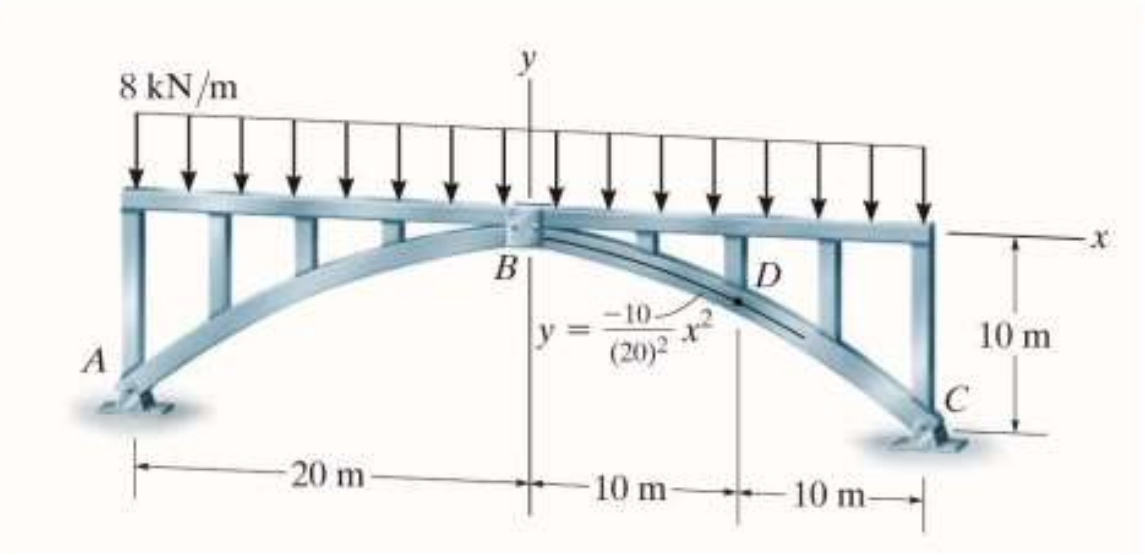
4. They can't be built just anywhere.
Several requirements must be met before an arch bridge can be built in a certain spot. One of these is the condition of the ground, which has to be strong and compact enough to support the force that would be distributed along the bridge and down to the abutments. It's important to note, though, that the design and materials of modern bridges allow them to tolerate pressure within their structure and make it possible for them to be built on weaker ground.

5. They can be expensive.
As mentioned above, arch bridges require lots of time and labor, which can translate to thousands of dollars. It also requires the expertise of numerous engineers and builders which, again, equates to a substantial amount of money.

6. They need regular maintenance.
Arch bridges become stronger over time, but this doesn't mean that they should just be left on their own. In fact, they need more frequent repair and maintenance than other kinds of bridges since their flexible design makes them more prone to cracking and tearing when exposed to harsh elements. The costs that come from keeping them in good shape can make them more expensive over time.

Analysis of Three Hinged Arches:

The three-hinged open-spandrel arch bridge has a parabolic shape and supports a uniform load. Show that the parabolic arch is subjected *only to axial compression* at an intermediate point such as point *D*. Assume the load is uniformly transmitted to the arch ribs.



Analysis of Three Hinged Arches:

Applying the equations of equilibrium, we have:

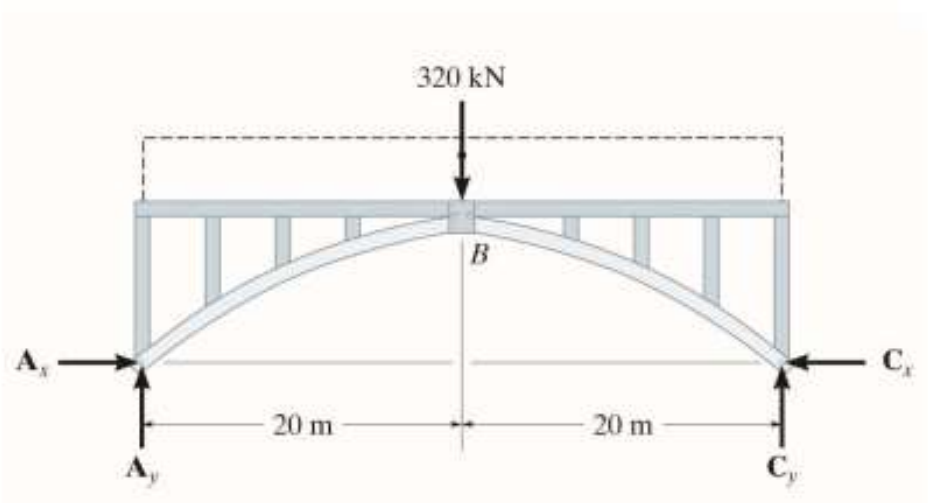
Entire Arch:

With anti-clockwise direction moments as $+$ve,

$$\sum M_A = 0$$

$$C_y(40\text{m}) - 320\text{kN}(20\text{m}) = 0$$

$$C_y = 160\text{kN}$$



Analysis of Three Hinged Arches:

Arch segment BC:

With anti-clockwise direction moments as $+$ve,

$$\sum M_B = 0$$

$$-160\text{kN}(10\text{m}) + 160\text{kN}(20\text{m}) - C_x(10\text{m}) = 0$$

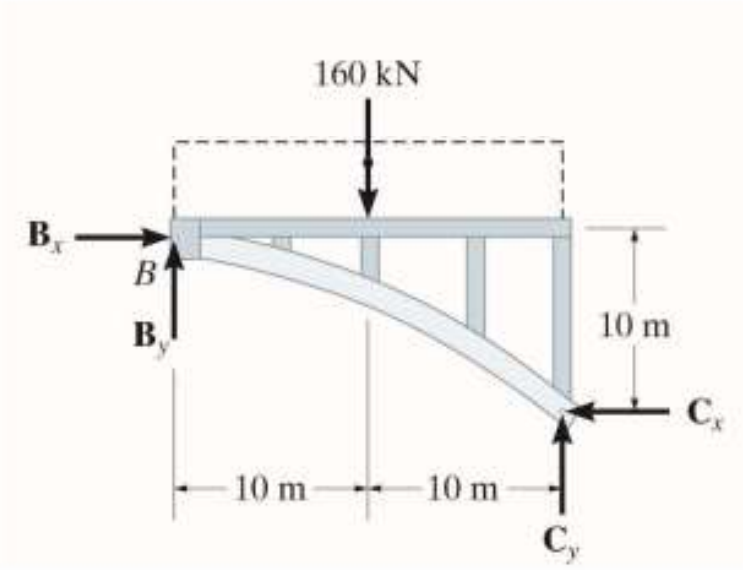
$$C_x = 160\text{kN}$$

$$\pm\sum F_x = 0 \Rightarrow B_x = 160\text{kN}$$

$$+\uparrow \sum F_y = 0$$

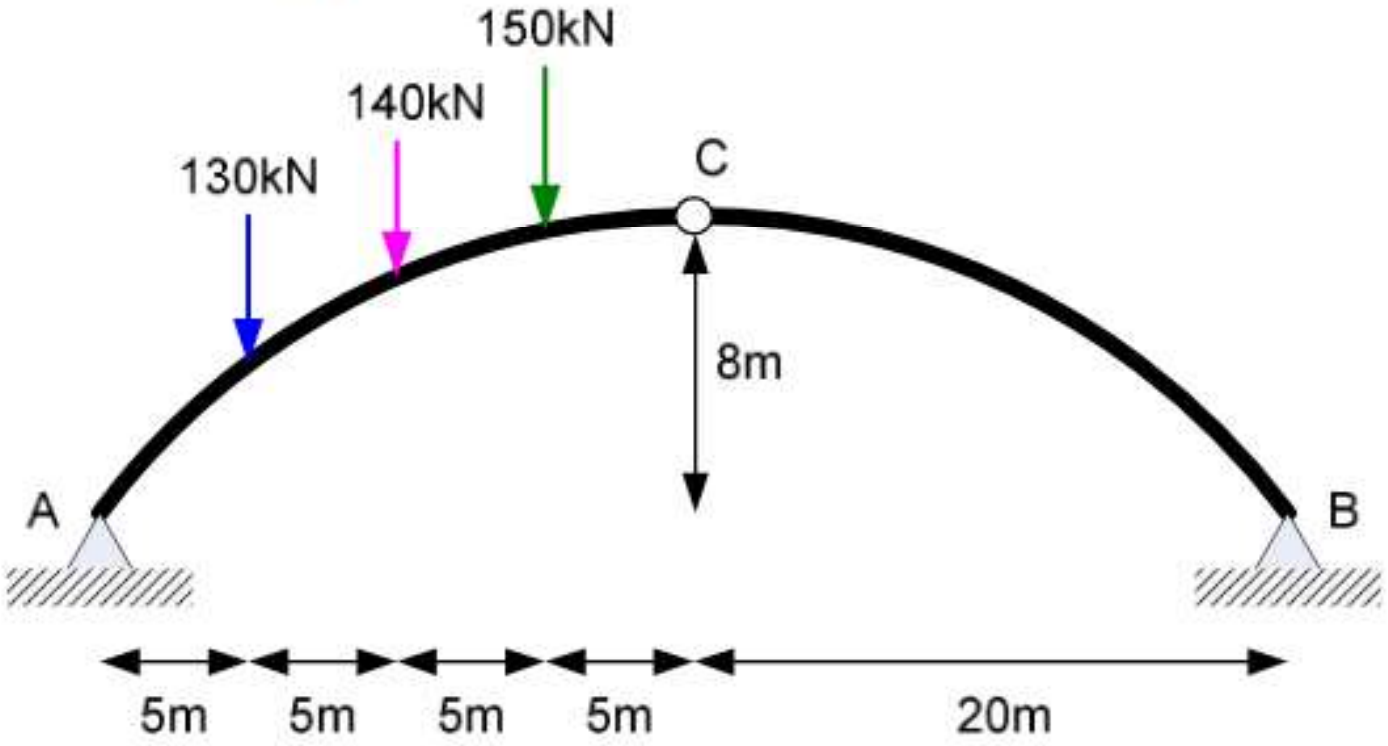
$$B_y - 160\text{kN} + 160\text{kN} = 0$$

$$B_y = 0$$



Analysis of Three Hinged Arches:

Calculate the reaction at support A and B as shown in figure below.



Analysis of Three Hinged Arches:

Consider the whole structure

$$\sum M_A = 0$$

$$130(5) + 140(10) + 150(15) - V_B(40) = 0$$

$$V_B = 107.5kN$$

$V_B = 107.5kN$

$$\sum F_y = 0$$

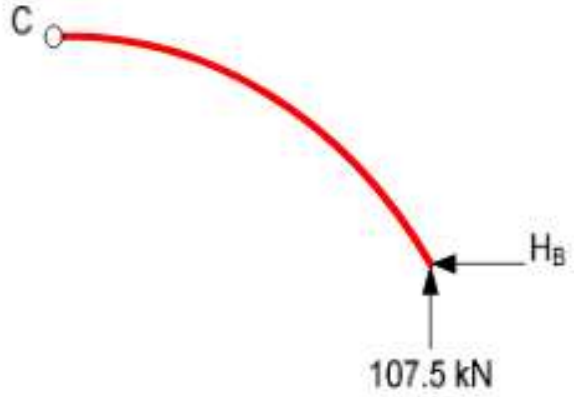
$$V_A - 130 - 140 - 150 + 107.5 = 0$$

$$V_A = 312.5kN$$

$V_A = 312.5kN$

Analysis of Three Hinged Arches:

Now, consider segment CB



$$\sum M_C = 0$$

$$107.5(20) + H_B(8) = 0$$

$$H_B = 268.75kN$$

Hence, $H_A = 268.75kN$