

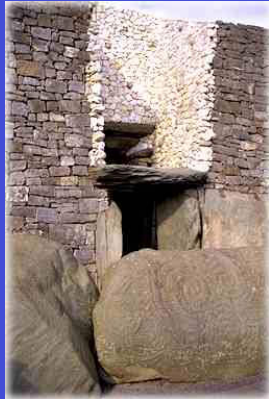
Engineering Structures 101

Structural Engineering: From the Beginning

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Newgrange, Ireland, 3200 BC
80 m diameter burial mound, Boyne Valley (where I grew up!), 40 km from Dublin, built by pre-Celtic neolithic people (Tuatha de Dannan?)



Newgrange, Ireland, 3200 BC
Exterior view of entrance, and interior of burial chamber. Note stone lintel.
At sunrise on summer solstice (21 June) sun shines through window above entrance, down the long passage, and strikes an altar at the centre of the chamber.



Stonehenge, Salisbury Plain, England. Between 3000 BC and 1500 BC. Purpose?



THE FERTILE CRESCENT
 ■ Fertile Crescent
 • Ancient city
 ● Early farming village
 — Modern boundary

Mesopotamia:
 ("Land between two rivers" - the Euphrates and the Tigris)
 Start of "modern" civilisations?
 about 7000 BC.

Very fertile then - now desert (Iran/Iraq)

Babylon
 Uruk
 Ur

Ziggurat (temple) at Ur, 2125 BC
 Mesopotamia
 (Sumerians, 3500 to 1900 BC)

Pyramids of Khafre & Khufu at Giza, Egypt
 (Old Kingdom:
 2686-2181BC)



Great Pyramid of Khufu, Giza, Egypt (Old Kingdom: 2686-2181BC). Angle $51^{\circ}52'$
146 m high, 2.3 million stone blocks, each 2.5 tonnes. Base is almost perfect square,
229 m sides. Aligned perfectly with cardinal points (N,S,E,W)



Climbers on the Great Pyramid at Giza (note sizes of blocks)
Originally, smooth surface - faced with limestone - now
weathered away



Bent Pyramid at Dahshur, Egypt, 2680-2565 B.C
Angle changes from 54 to 43 degrees (foundation/stability problems?). If it had
been completed to original plan, it would have been the biggest pyramid in Egypt.



Temple of Horus, Edfu, Egypt (3 stages between 237 BC and 57 BC)

Beams: Tension and Compression

Top half of beam in compression:
Rock: strong in compression

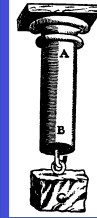


Bottom half of beam is in tension:
Rock: weak in tension

Maximum tensile stress mid-span
Value varies in proportion to L^2

Therefore, beams must be short if poor tensile strength

Egyptian & Greek columns close together
- column spacing $< 2 \times$ beam depth
- very cluttered space



Galileo's *Discorsi, his Dialogues Concerning Two New Sciences*, were published in Leyden in 1638. The second new science is concerned with the mechanics of motion; the first gives the first mathematical account of a problem in structural engineering. Galileo wishes to compute the breaking strength of a beam, knowing the strength of the material itself as measured in the tension test shown in the illustration. The drawing does not encourage belief that Galileo ever made such a test (although Galileo himself never saw the illustration - he was blind by the time the book was printed). The hook at B would have pulled out of the stone long before the column as a whole fractured. In the same way, it is thought that Galileo did not in fact drop balls of different weights from the Leaning Tower of Pisa. It is not known that Galileo ever designed crucial experiments of this sort, in order to prove or disprove a theory. What he did was to make crucial observations, from which ensued brilliant advances in every subject he touched.
Jacques Heyman « The Science of Structural Engineering » Imperial College Press

This is the famous illustration for Galileo's basic problem - the breaking strength of a beam. Again, the drawing is not really representational, although there is a wealth of circumstantial detail. In this case the hook C may well have been able to carry the load, but the masonry at AB looks insufficient to resist the turning moment at the wall.

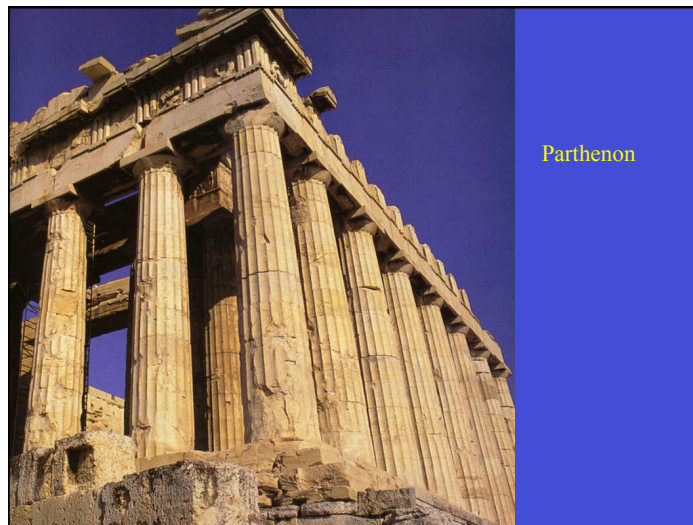
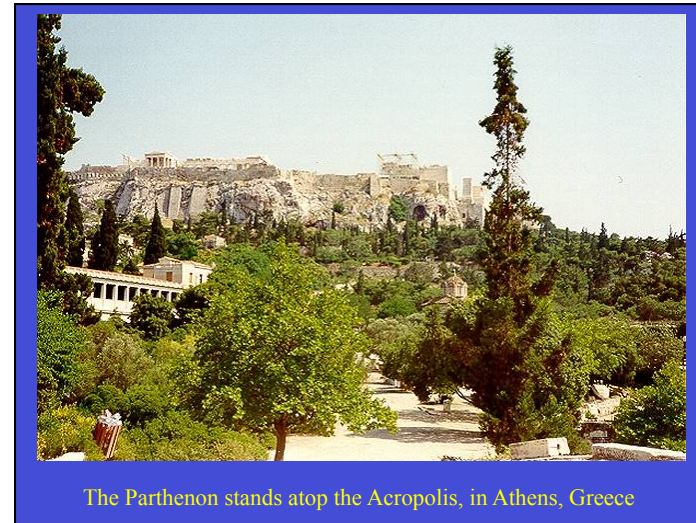
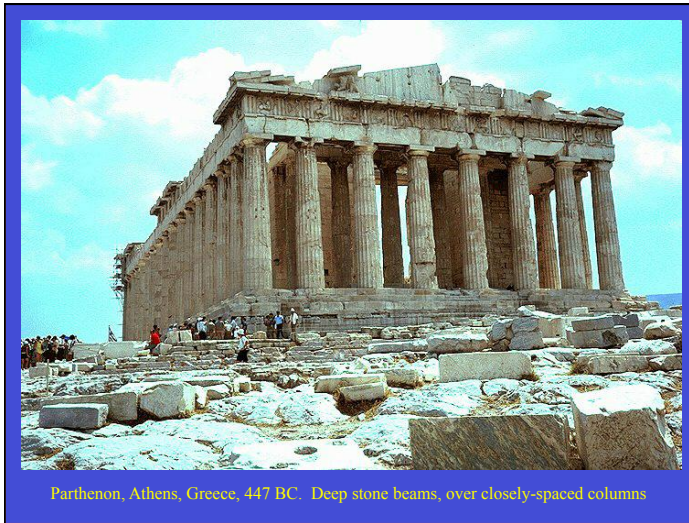
It is interesting to note that Galileo actually got the statics completely wrong - he did not understand that the stresses in the cross section had to give zero net horizontal force.



Temple of Horus, Edfu, Egypt



Temple of Horus, Edfu, Egypt
Hypostyle Hall
(hall of many columns)



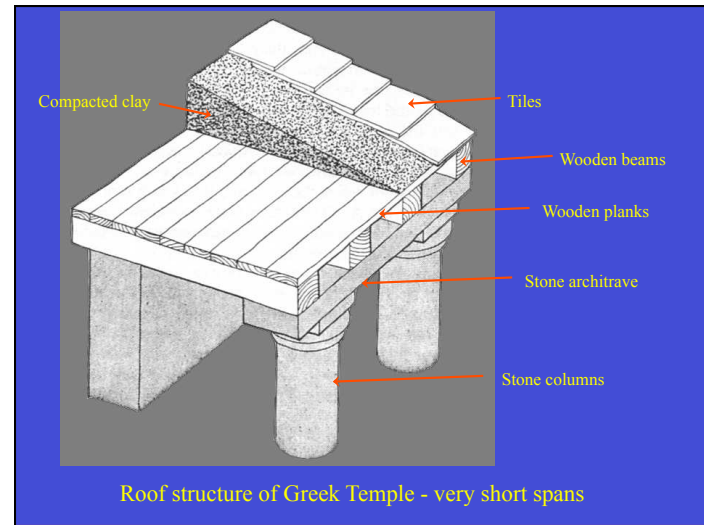
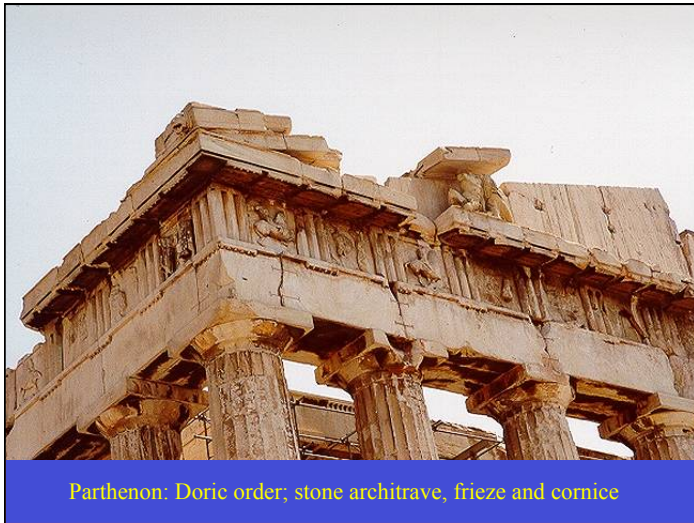
Doric Order

- cornice
- frieze
- architrave
- capital
- shaft

Doric capital Ionic capital Corinthian capital

Three types of columns (three "orders") used in Greek buildings: Doric, Ionic and Corinthian

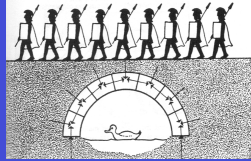
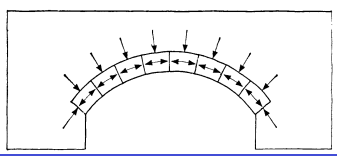
The top ("capital") of each column type is different
- in fact, whole style & proportions of each are different



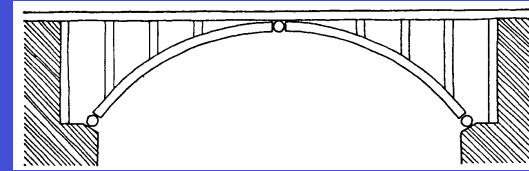
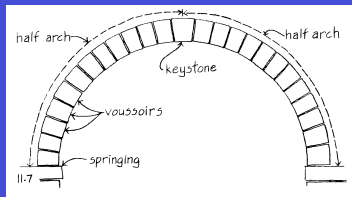
A simple masonry arch is made from identical wedge-shaped voussoirs - it is built on falsework, since it cannot stand until the last stone, the keystone, is in place. Once complete, the falsework (the 'centering') may be removed, and the arch at once starts to thrust at the river banks. Inevitably the abutments will give way slightly, and the arch will spread.

Figure (b), greatly exaggerated, shows how the arch accommodates itself to the increased span. The arch has cracked between voussoirs - there is no strength in these joints, and three hinges have formed. There is no suggestion that the arch is on the point of collapse - the three-hinge arch is a well-known and perfectly stable structure. On the contrary, the arch has merely responded in a sensible way to an attack from a hostile environment (gravity). In practice, the hinges may betray themselves by cracking of the mortar between the voussoirs, but larger open cracks may often be seen.

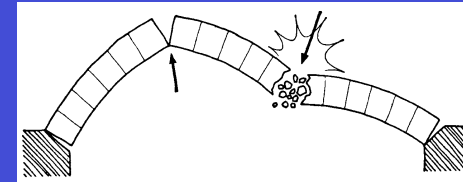
Arches:
Achieving large spans while
avoiding tension



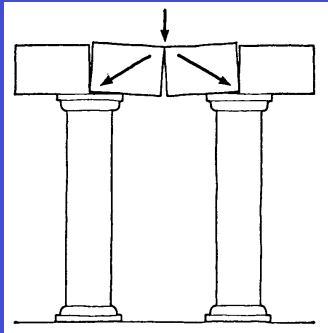
An arch supports vertical forces by generating compression between the "voissirs" of the arch. The arch abutment must be capable of supporting the resulting horizontal thrust.



An arch with three hinges can be stable - in fact many arches are built this way deliberately



Four hinges are required in an arch for collapse. Picture shows "snap-through" failure



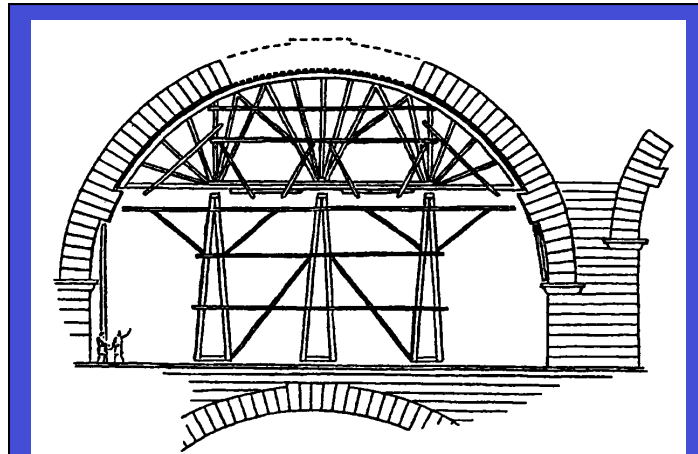
A stone beam with small span-to-depth ratio (such as those in the Parthenon) may act as a three-pin arch if it cracks at the centre, and may not necessarily collapse



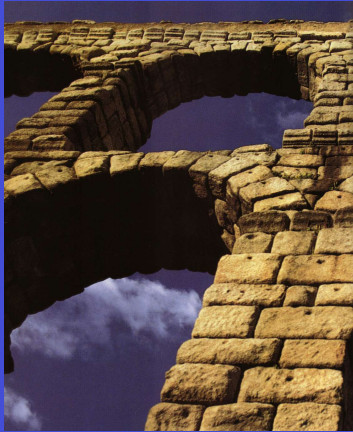
Pont du Gard, Nîmes, southern France. Aqueduct. Built by Romans, -15 BC to 14 AD. The Romans perfected the use of the arch, and used it widely.



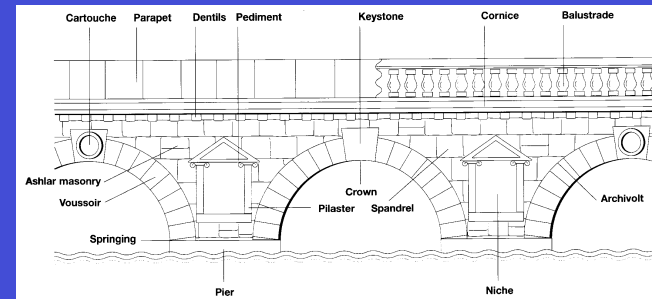
This aqueduct, over the river Gard, is 275 metres long and 49 m high. Part of an aqueduct nearly 50 km long that supplied Nîmes with water. On its first level it carries a road and at the top of the third level, a water conduit, which is 1.8 m high and 1.2 m wide and has a gradient of 0.4 per cent.



Possible falsework (or "centering") scheme used for the Pont du Gard



Pont du Gard: The three levels were built in dressed stone without mortar. The projecting blocks supported the scaffolding during construction.



Elements of a Roman Arch Bridge



Aqueduct, Segovia, Spain. Built by Romans, 1st century AD.
39 m high



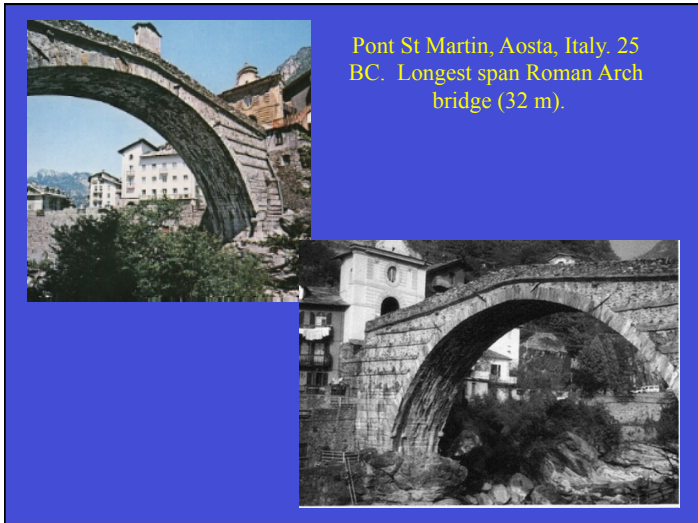
Segovia, Spain



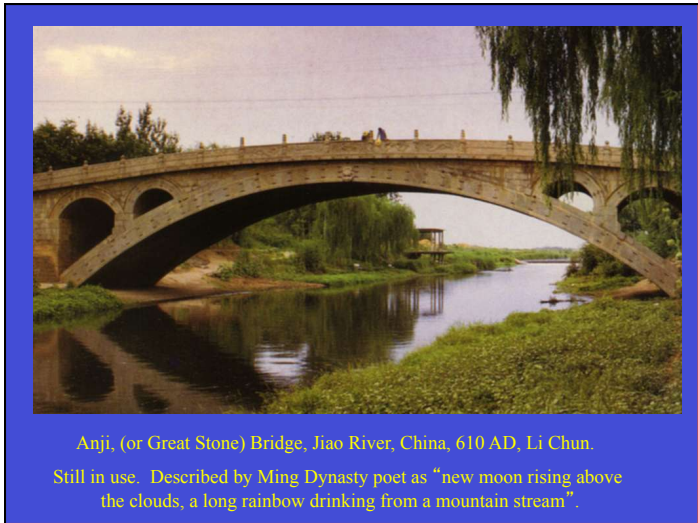
Pons Fabricius (Ponte Fabricio), Rome, Tiber. Built in 62 B.C. by
L.Fabricius. Oldest surviving bridge in Rome. Still used by
pedestrians



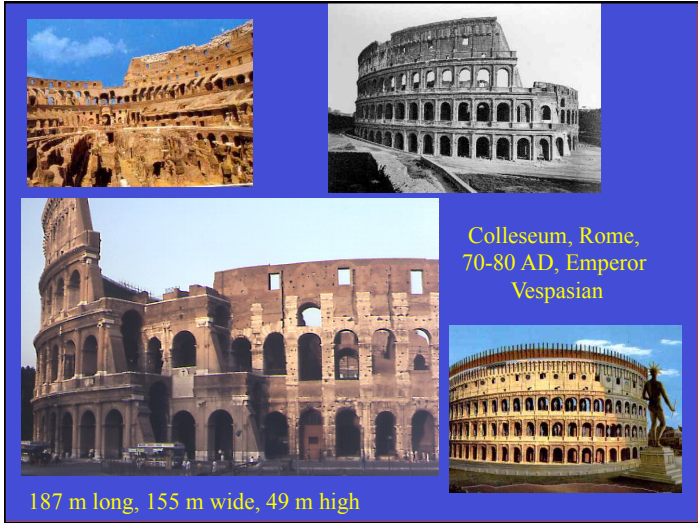
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Pont St Martin, Aosta, Italy. 25 BC. Longest span Roman Arch bridge (32 m).



Anji, (or Great Stone) Bridge, Jiao River, China, 610 AD, Li Chun.
Still in use. Described by Ming Dynasty poet as "new moon rising above the clouds, a long rainbow drinking from a mountain stream".

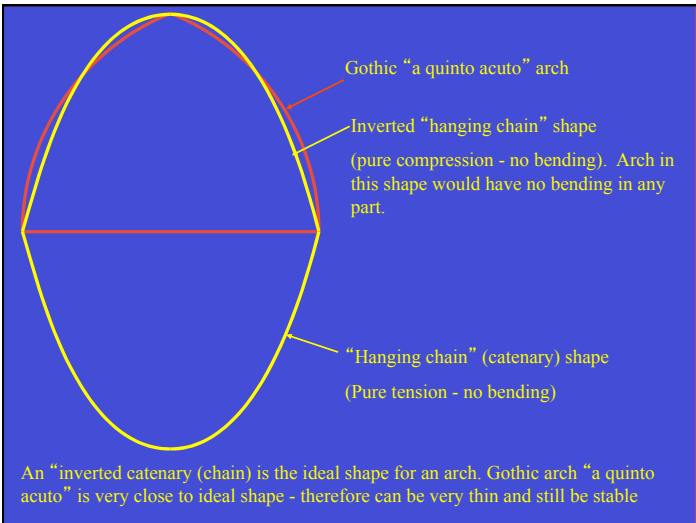
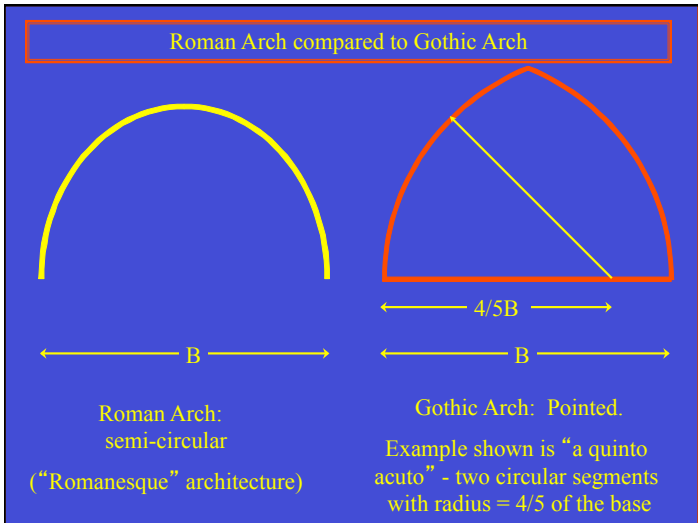
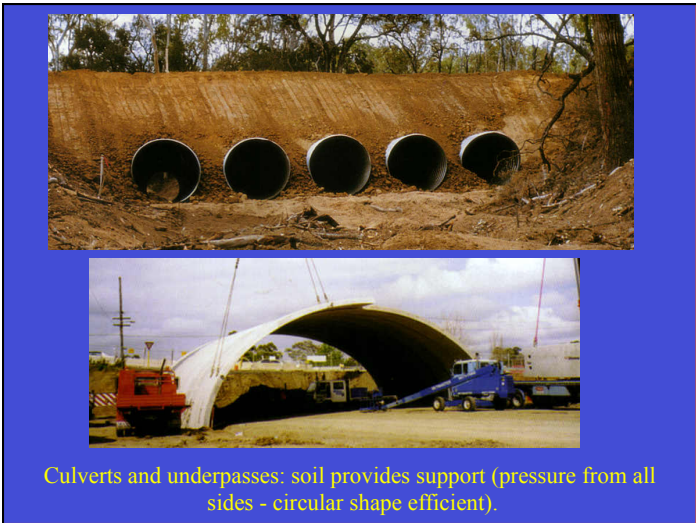


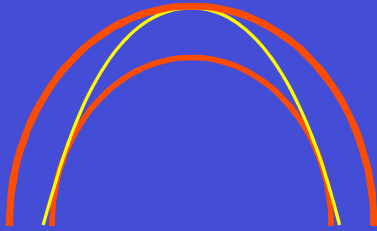
Coliseum, Rome, 70-80 AD, Emperor Vespasian

187 m long, 155 m wide, 49 m high



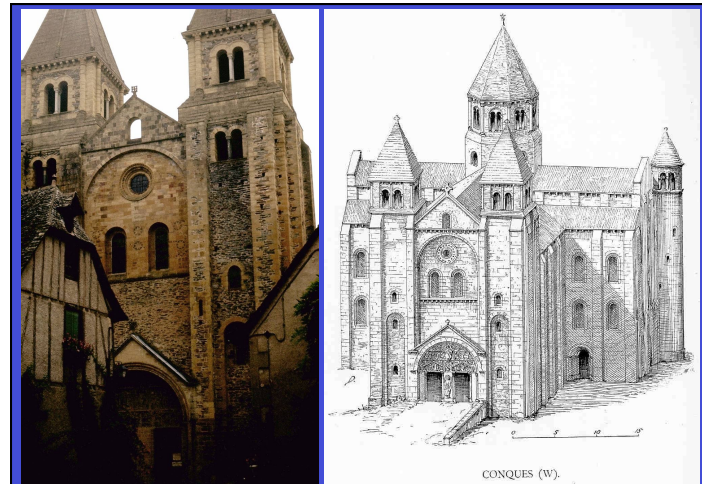
Arch of Titus, Rome, AD 81.
Triumphal Arch, celebrating victory in war



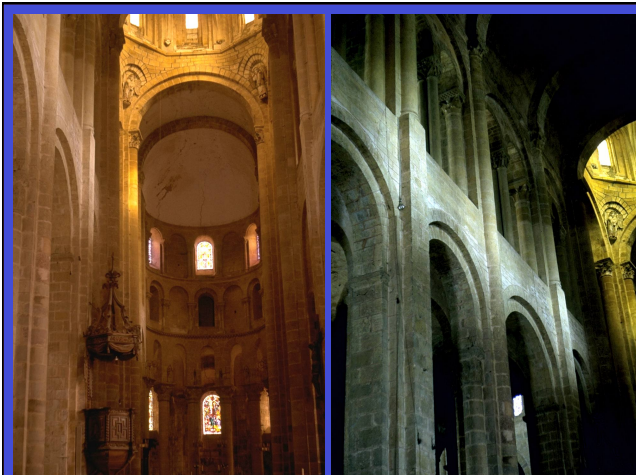


For stability, a circular Roman arch supporting only its own weight must be thick enough to contain an equivalent "inverted catenary" arch

Therefore, Romanesque architecture typically very massive ("heavy")



Romanesque: Church of Sainte-Foy, Conques, France, 1050-1120



Romanesque: Church of Sainte-Foy, Conques, France, 1050-1120



La Madeleine, Vezelay, France: interior, nave, 1120-1132. Typical Romanesque church

Sources

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