

## Catenary Arches

- Catenary Arches
- Compression Thrust Lines
- Ideal Compression Arches
- Compression Shells
- Masonry Arches and Vaults

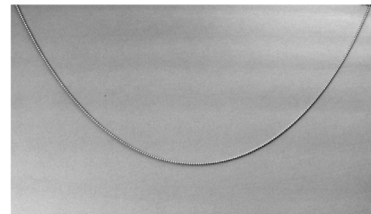
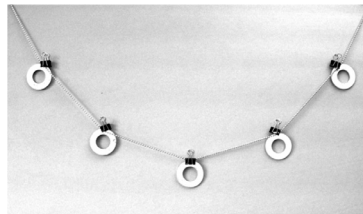
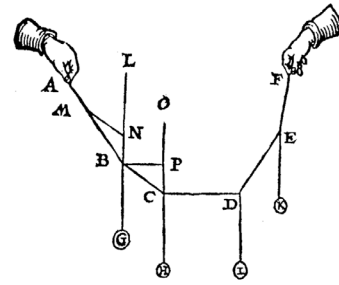


Santiago Calatrava  
Valencia, Spain

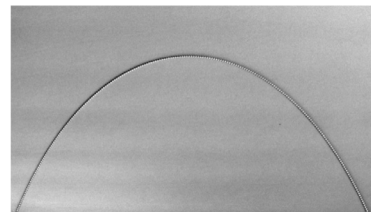
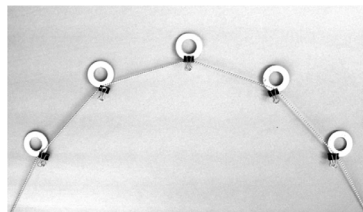
## Catenary Shapes

The shape of the catenary depends on the loading. Simon Stevin showed this vector analysis and experimentally in 1585 with a weighted cord.

Because the cord has no resistance to bending, it hangs in pure tension. The reverse shape (flipped over) will be in compression only.



Tension only shapes

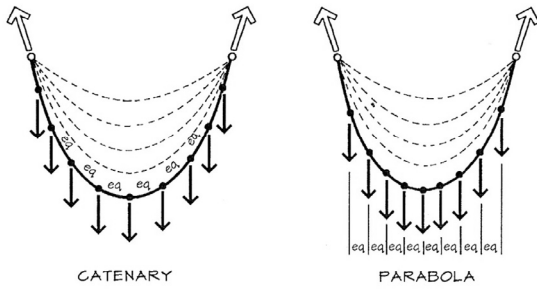


Compression only shapes

# Catenary Shapes

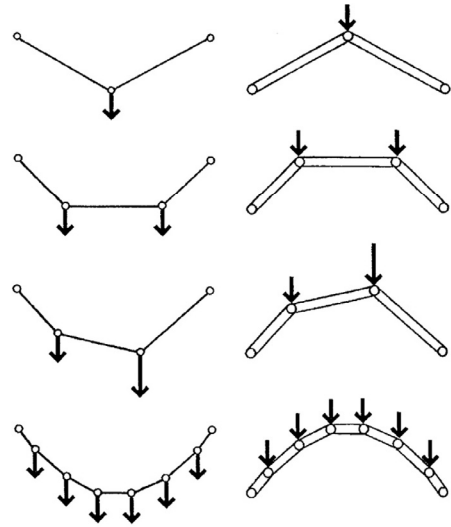
The shape of the catenary depends on the loading. Because the cord has no resistance to bending, it hangs in pure tension. The reverse shape (flipped over) will be in compression only.

Selfweight loading produces a funicular curve. Uniformly applied load (e.g. horizontal PLF load) results in a parabolic curve.



a) Selfweight funicular curve

b) Uniform load parabolic curve

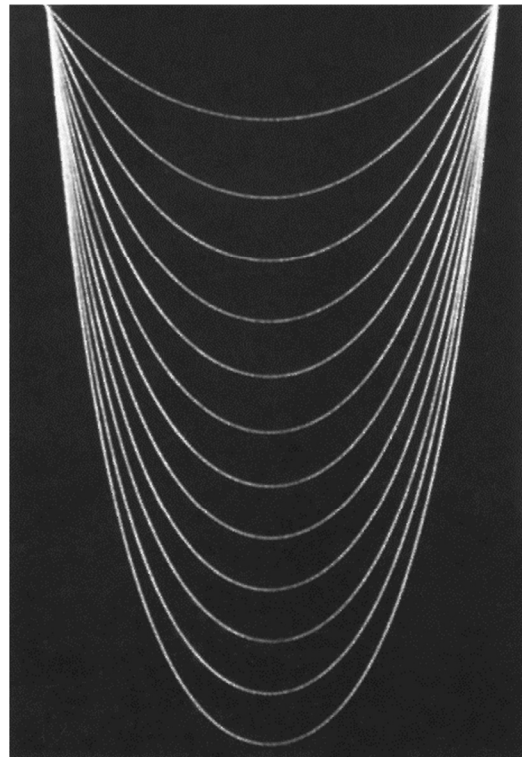
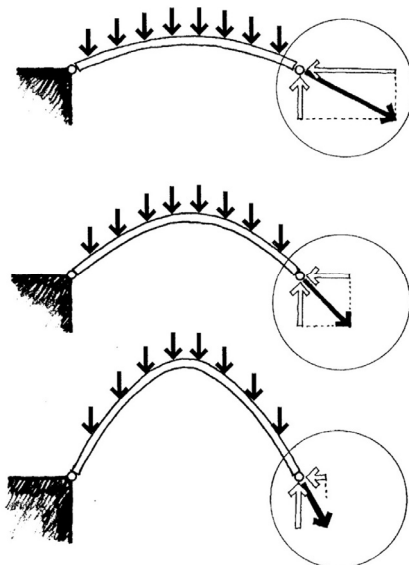


Funicular suspension cables and corresponding arches.

# Catenary Shapes

The shape of the catenary also depends on the length of the cord. For any give load and span there are an array of solutions based on the amount of sag.

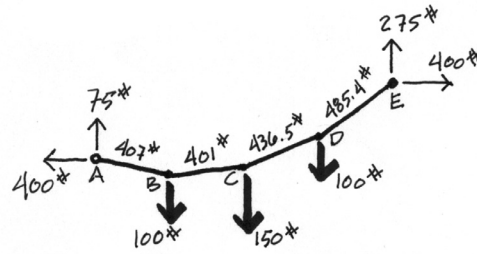
The greater the sag the less horizontal force will be present at the reaction. The same is true for pure compression arches.



# Methods to Determine Ideal Compression Arches

## Method 1: FBDs to find forces and dimensions

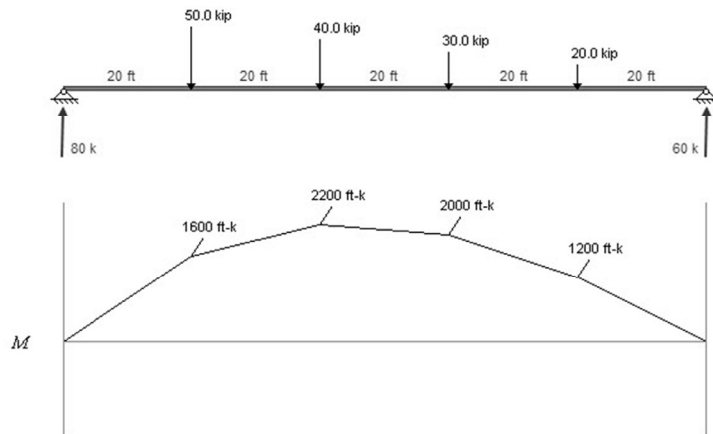
1. Choose loading
2. Set 3 points (reactions + sag)
3. Solve reactions
4. Calculate funicular shape (as a cable)
5. Invert the shape



# Methods to Determine Ideal Compression Arches

## Method 2: Moment Diagram for Even Supports

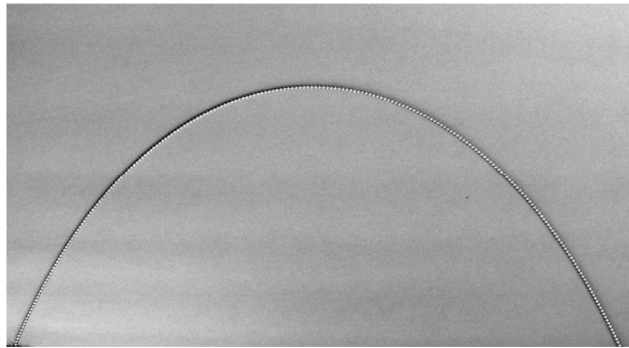
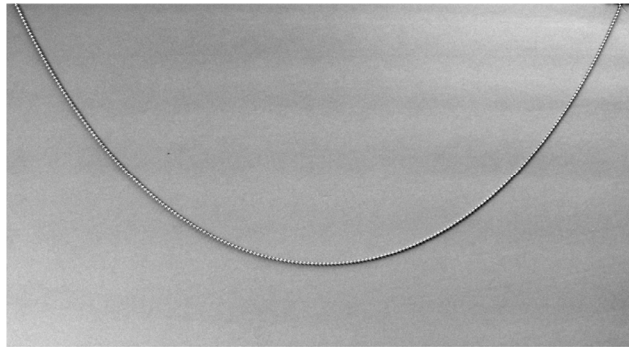
1. Choose loading
2. Draw moment diagram
3. Scale



# Methods to Determine Ideal Compression Arches

## Method 3: Physical model

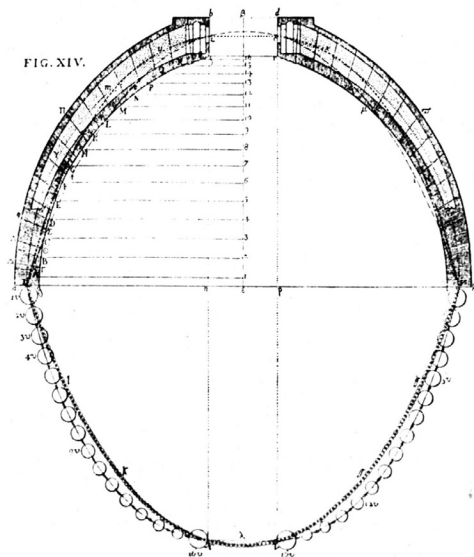
1. Choose loading
2. Hang catenary
3. Scale
4. Invert the shape



# Compression Arches

## Ideal Compression Shell or Arch

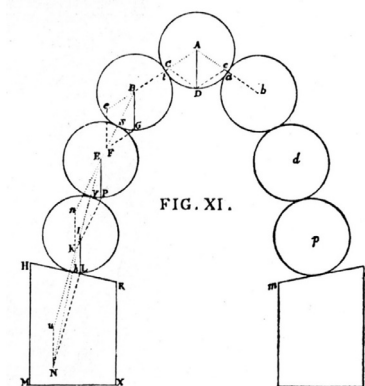
- All members in compression
- No flexure
- Encloses the catenary line



Giovanni Poleni (1683-1761)  
repairs to St. Peter's dome, 1748



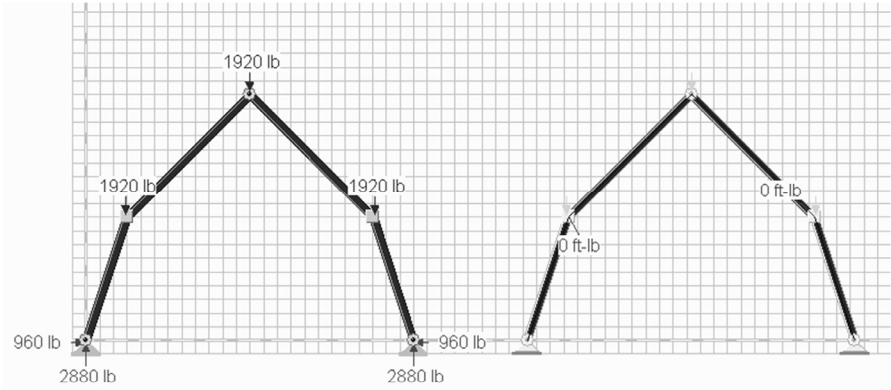
Pont du Gard  
Nîmes, France



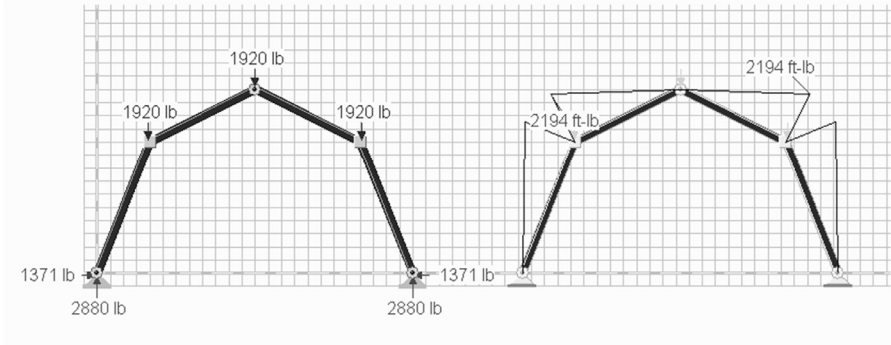
Simon Stevin (1548-1620)

# Compression Arches

'Ideal' catenary shape



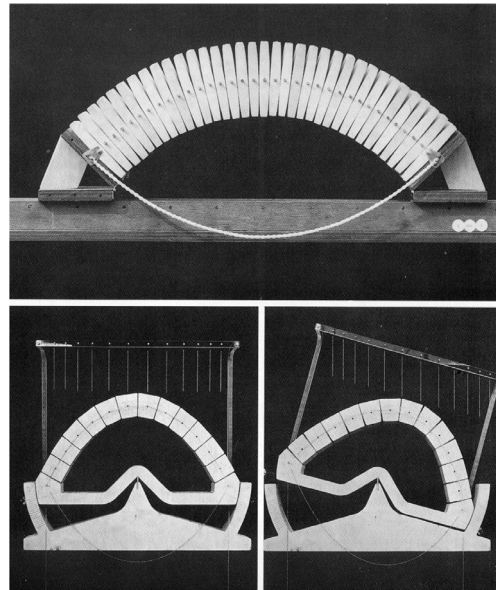
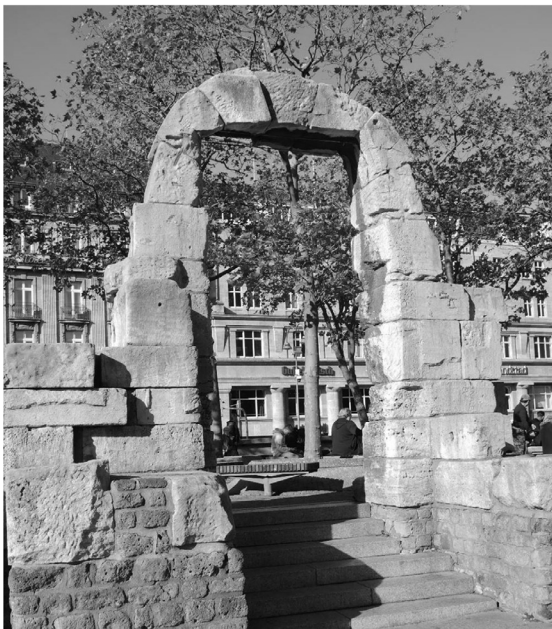
Shape with moments



# Compression Arches

Ideal Compression arch

- All members in compression
- No flexure
- Encloses the catenary line



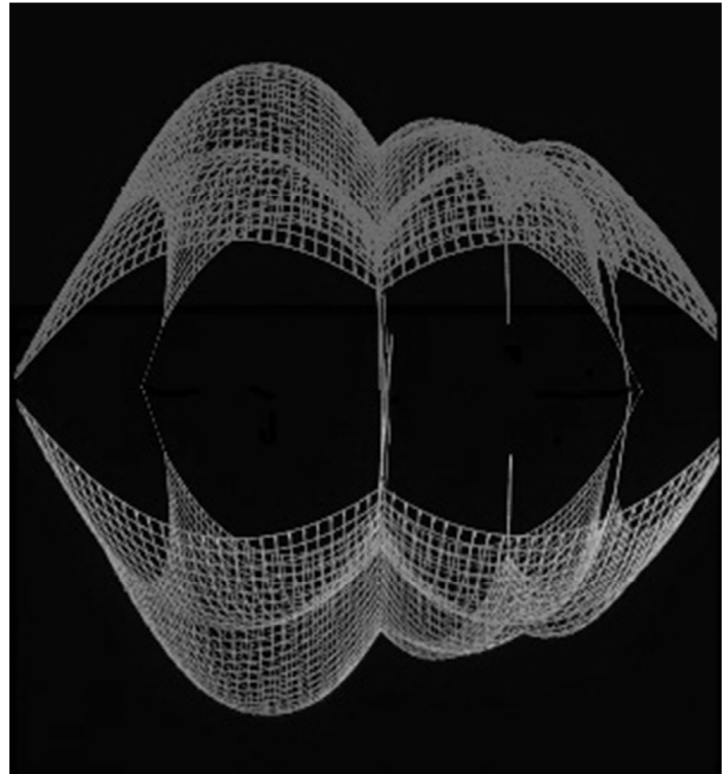
Frei Otto

Roman Gate at  
Colonia Claudia Ara Agrippinensium  
Cologne, Germany

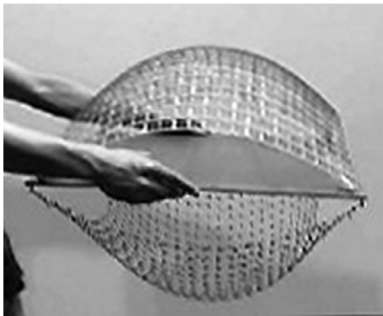
# Compression Shells

## Tensile Net to Compression Shell

- All members in tension
- No flexure

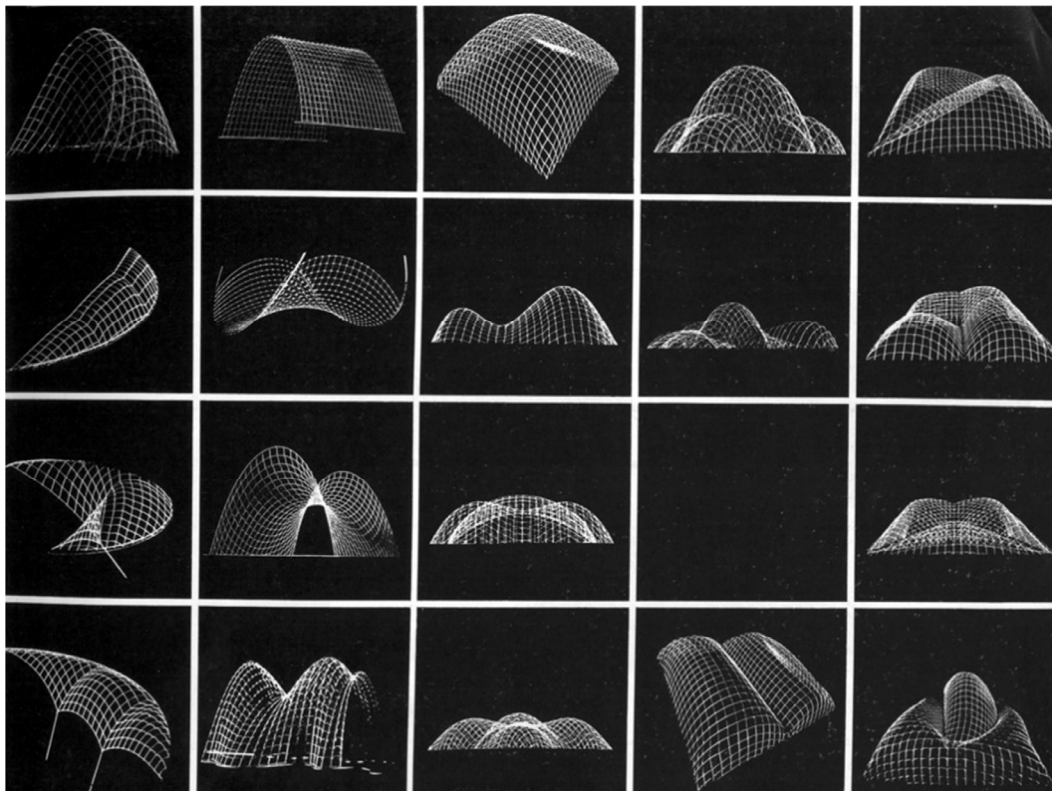


## Grid shells based on catenary nets



# Compression Shells

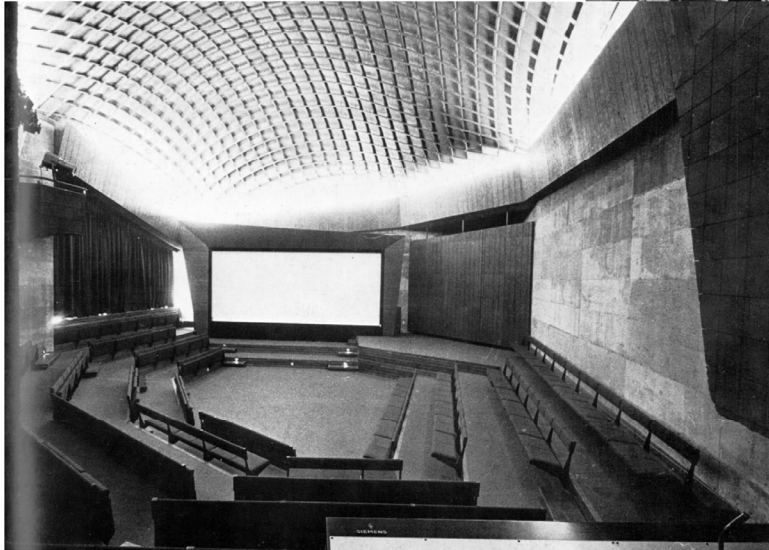
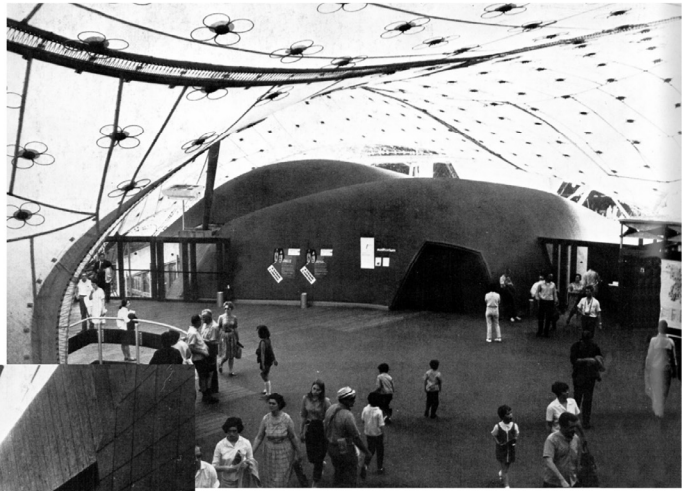
## Grid shells based on catenary nets



Frei Otto, Grid Shells (IL Series) TA 663 .G58 1974

# Compression Shells

German Pavilion Expo'67 – Frei Otto



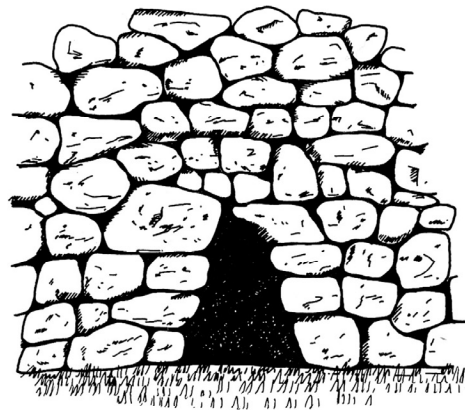
University of Michigan, TCAUP

Structures I

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# Masonry Arches

Corbeled arches and vaults



Corbelled arch in wall, Tiryns, Greece (c. 600 B.C.).

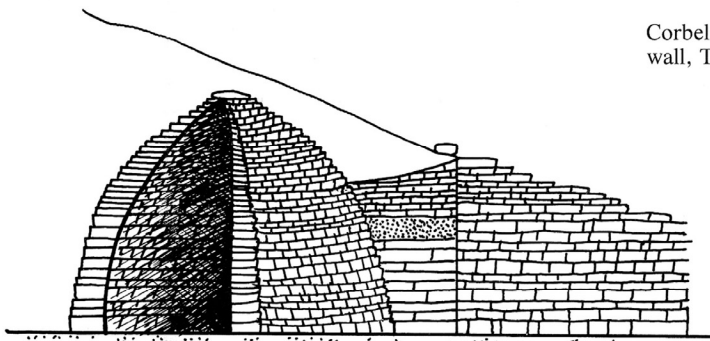


Figure 1.21 Tomb of Agamemnon (c. 1325 B.C.).

Ostia

University of Michigan, TCAUP

Structures I

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# Masonry Arches



Ostia, Italy

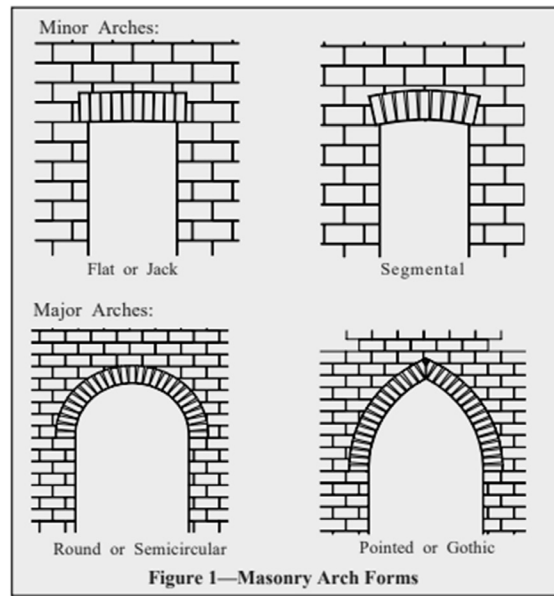


Figure 1—Masonry Arch Forms



Pont du Gard  
Nîmes, France

# Masonry Arches

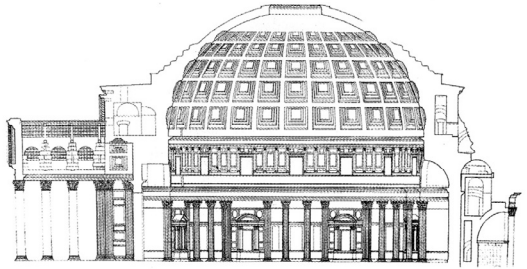




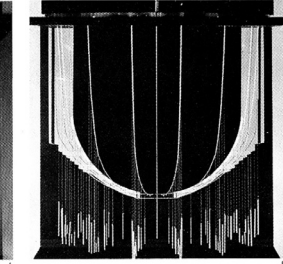
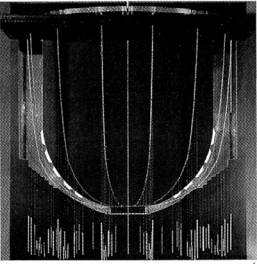
# Masonry Arches

## Thrust lines

Institute for Lightweight Structures (IL)

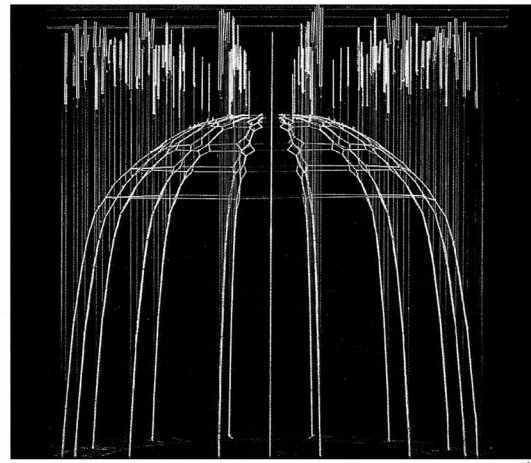


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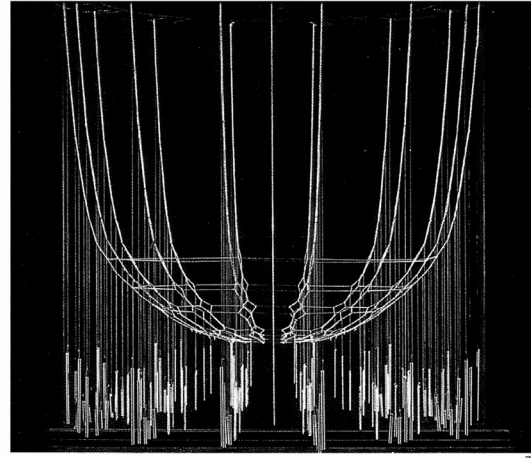


4

5



6



7

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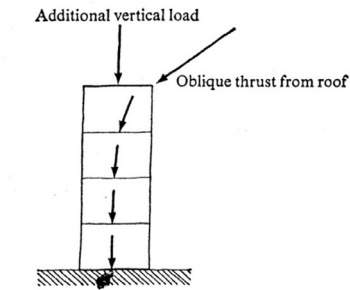
Structures I

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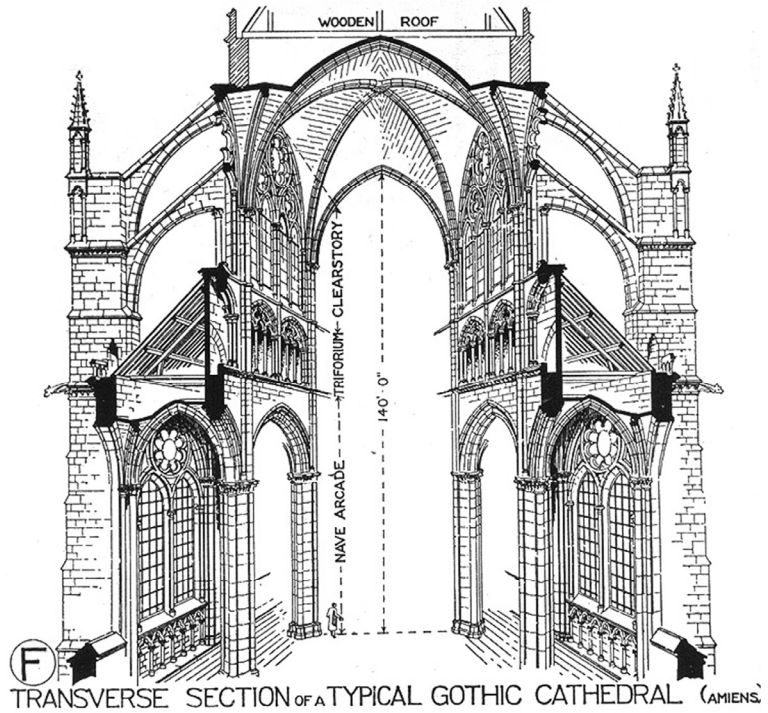
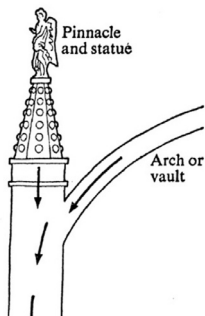
# Gothic Masonry

## Gothic vaults

- Amiens
- 1220-1225



The effect of an additional load at the top of the wall is to *reduce* the eccentricity of the thrust line.



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Masonry

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# Catenary Masonry

## Catalonian

- Antonio Gaudi 1852 - 1926
- Catalonian Art Nouveau
- Park Guell



# Catenary Masonry

## Catalonian

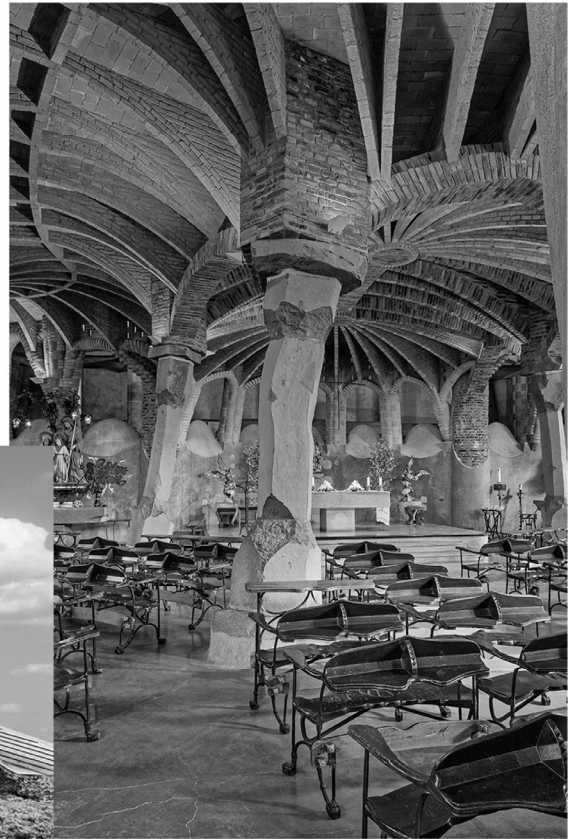
- Antonio Gaudi 1852 - 1926
- Catalonian Art Nouveau
- Church at Colonia Güell



# Catenary Masonry

Catalonian

- Antonio Gaudi 1852 - 1926
- Catalonian Art Nouveau
- Crypt at Colonia Güell



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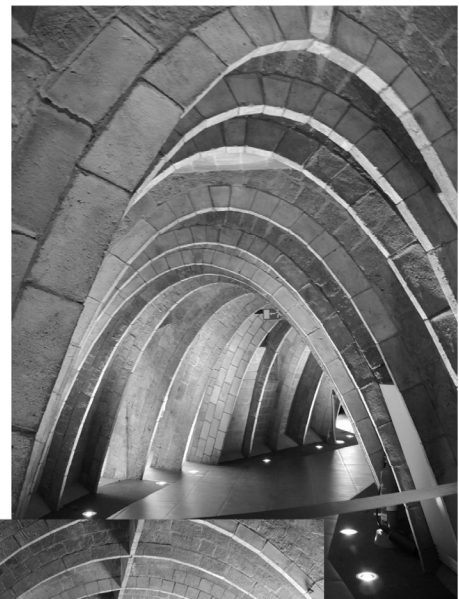
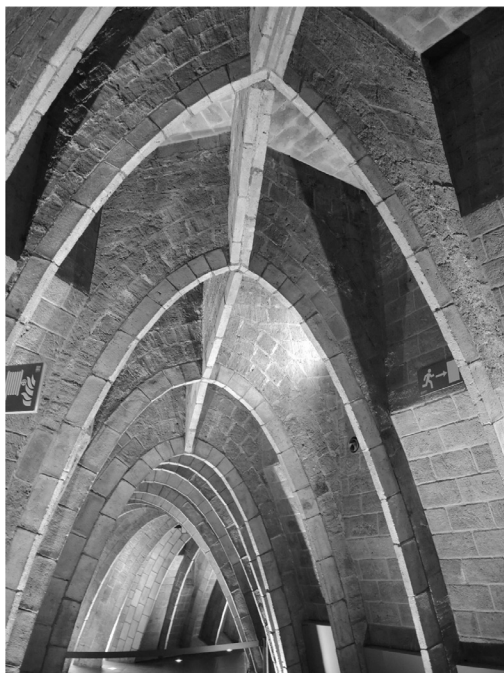
Masonry

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# Catenary Masonry

Catalonian

- Antonio Gaudi 1852 - 1926
- Catalonian Art Nouveau
- Casa Mila



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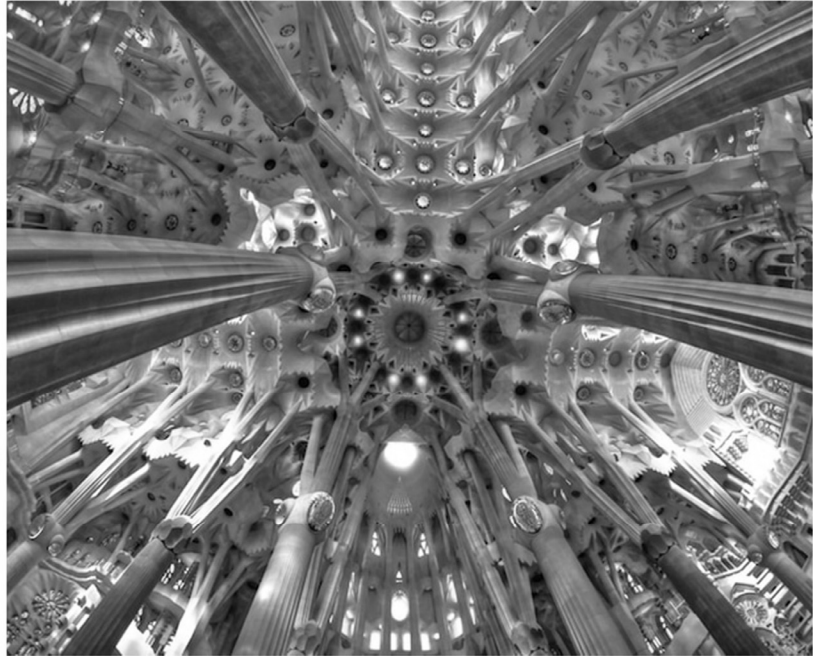
Masonry

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# Catenary Masonry

## Catalonian

- Antonio Gaudi 1852 - 1926
- Catalonian Art Nouveau
- La Sagrada Familia



# Catenary Masonry

## Catalonian

- Antonio Gaudi 1852 - 1926
- Catalonian Art Nouveau
- La Sagrada Familia

