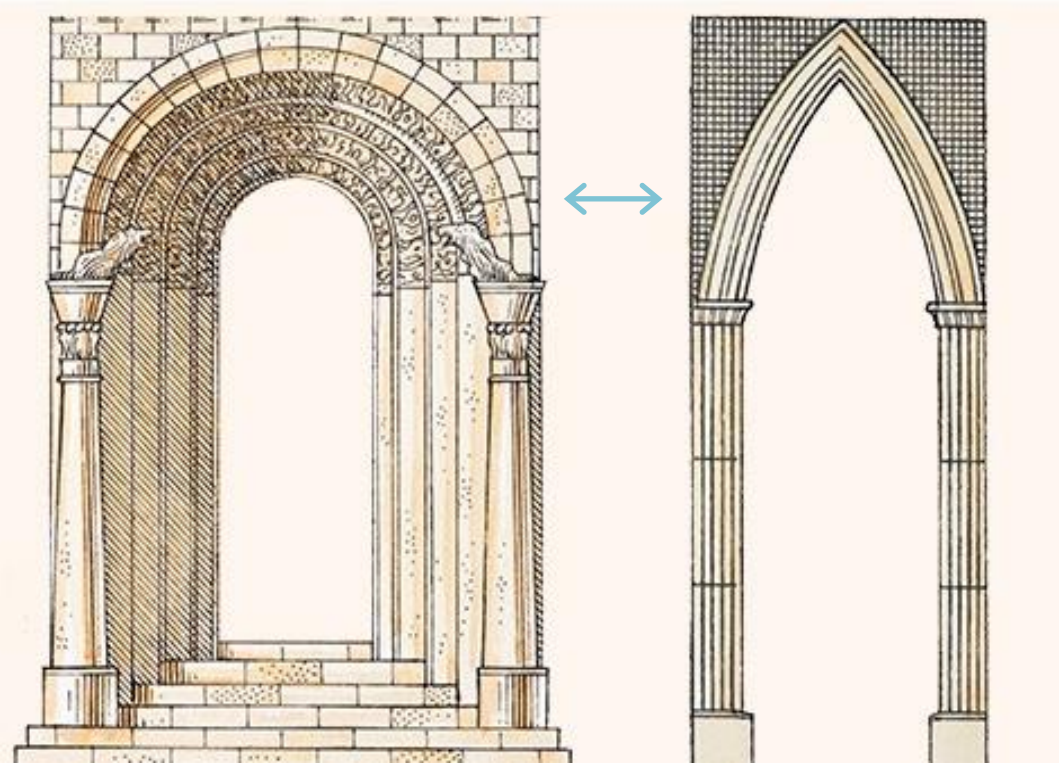
Numerical Models for Structures

DEM comparison of the horizontal reaction of Romanesque and Gothic arches



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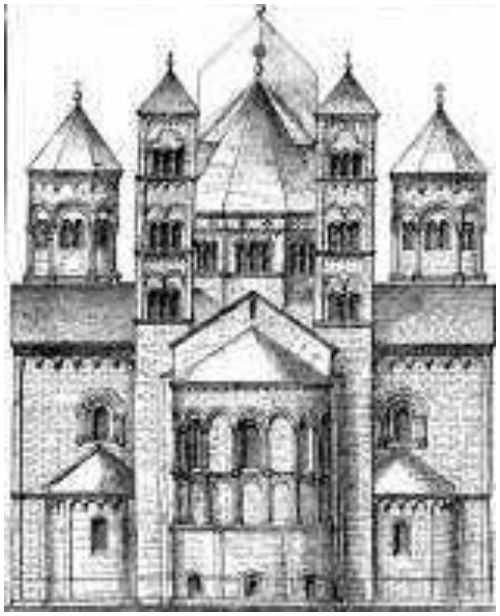
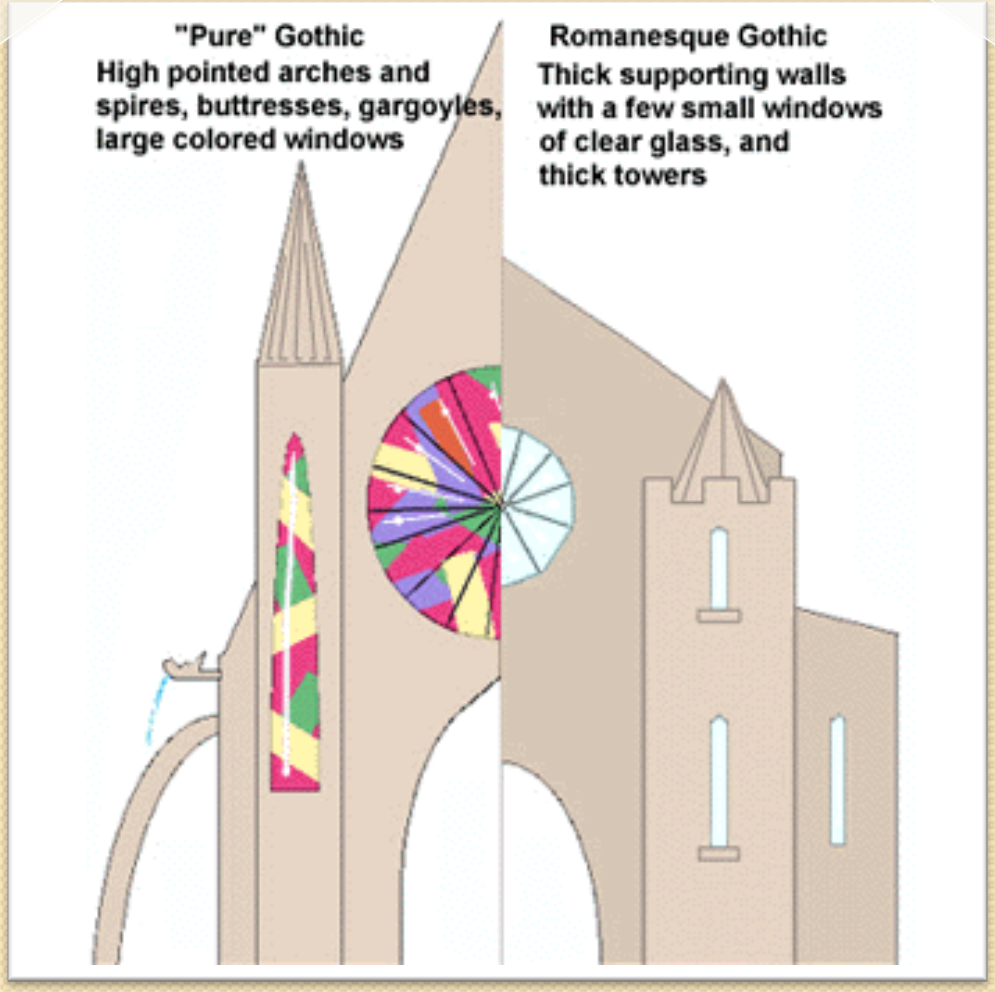
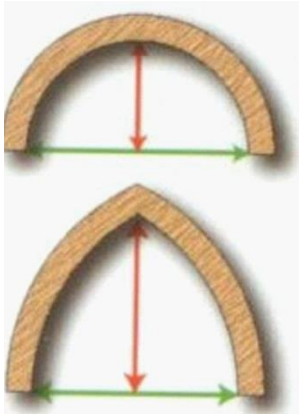




Introduction

Romanesque and Gothic arch

Aim of homework



- Software: **3DEC 5.00.164** of Itasca
- Semi-circular barrel vault of 2 m inner span, 15 cm thickness and 1 m length,
- Pointed vault having the same inner span, length and selfweight as the semi-circular vault

First task – find the equilibrium under selfweight:

- Both vaults ⟶ horizontal component of reactions: **H**

Second task – move the supports:

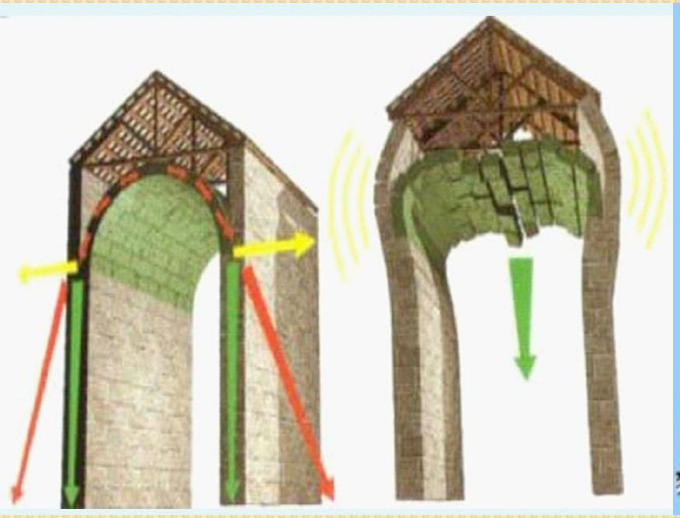
- Several support displacement (e) ⟶ measure **H**
- Compare the ***H*(e)** diagrams of the two structures

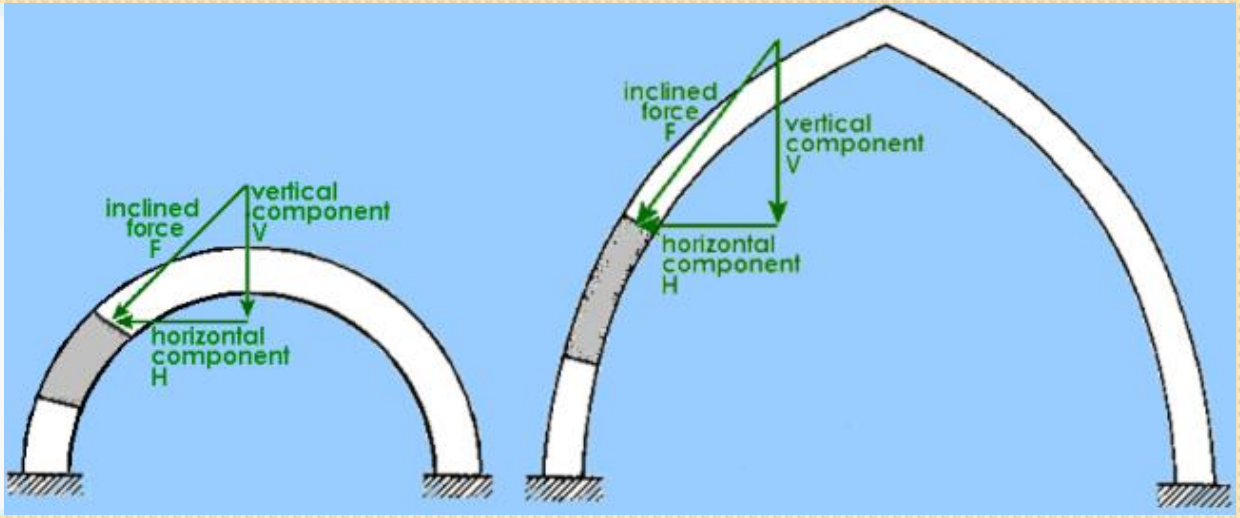
Romanesque arch

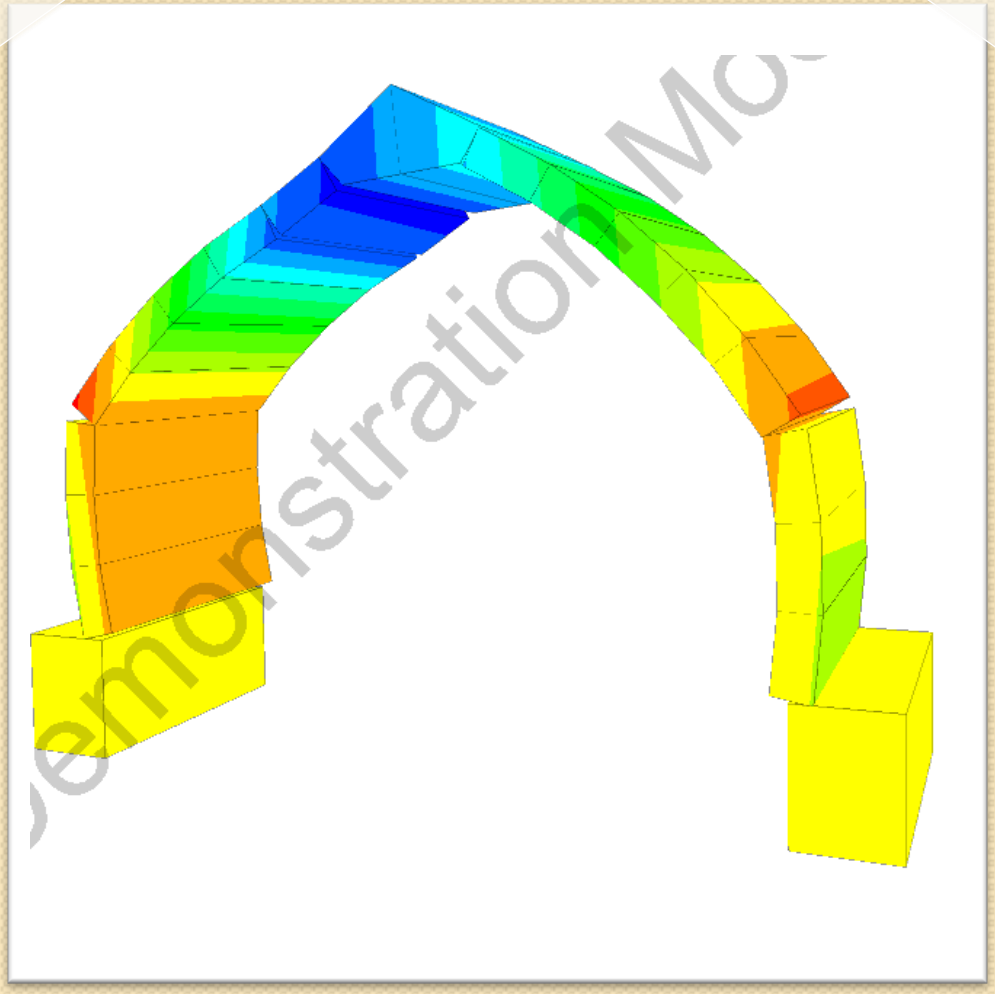
- Make them larger → fell down
- Horizontal reaction push the wall → collapse
- Small windows → dark and dreary
- Timber roofs → burn down

Gothic arch

- The centerline of pointed arches follows more closely the compression forces → stronger
- Weight → flying buttresses
- Large windows → filled with light
- Can have bigger span





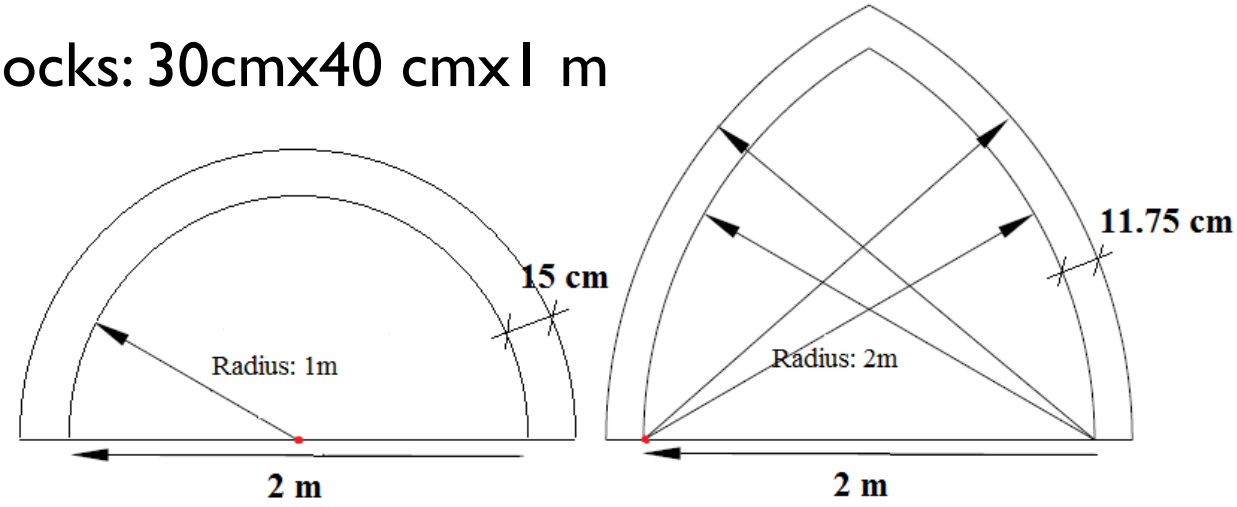


3DEC model

Polyhedron face
Polyhedron prism
Join
Range

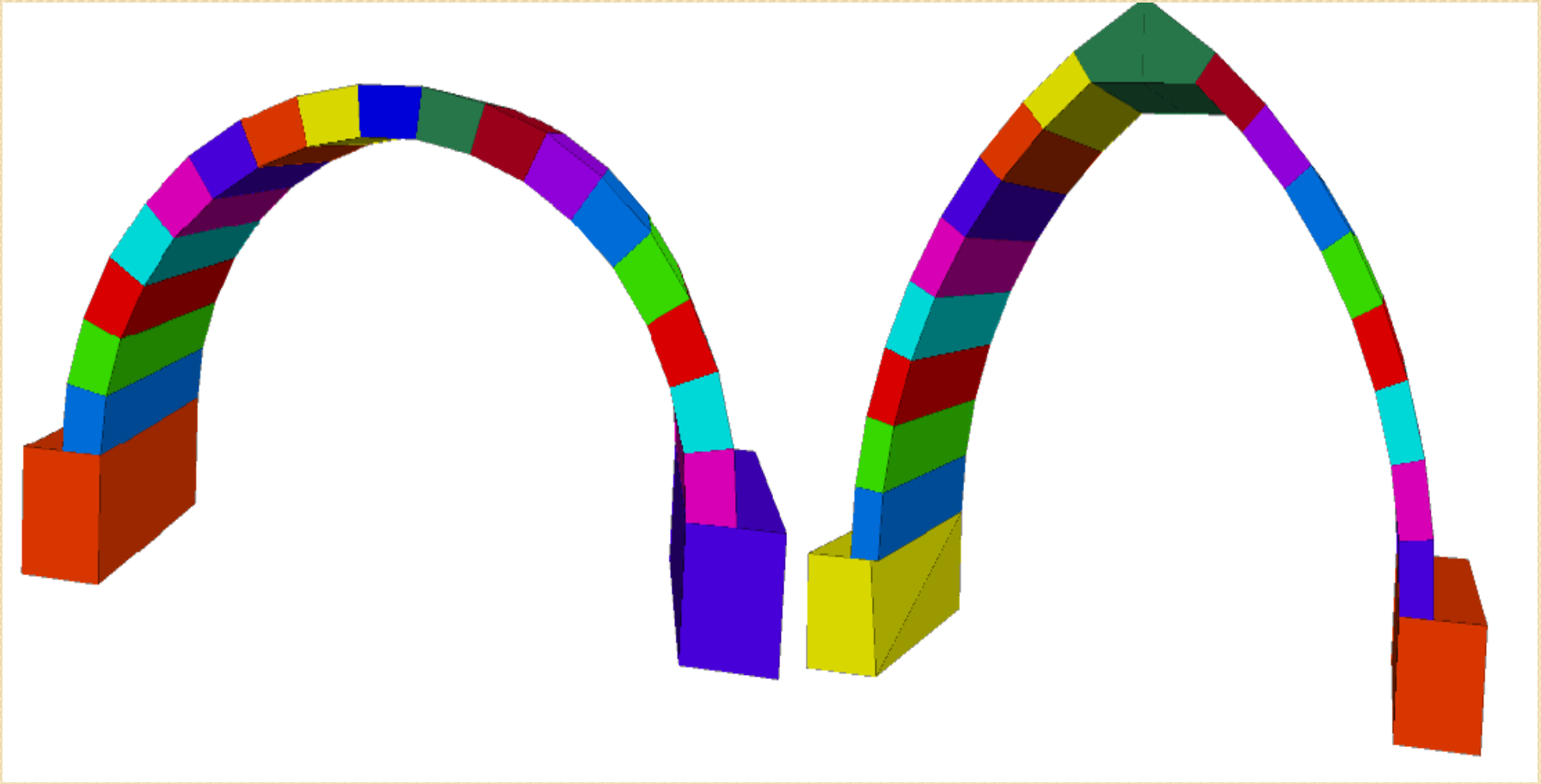
Geometry

- Semi-circular arch:
  - 2 m inner span, 15 cm thickness,1 m length
  - 17 blocks
  - support blocks: 30cmx40cmx1m
- Pointed vault:
  - same span, length, selfweight ⟶ 11.75 cm
  - 17 blocks
  - support blocks: 30cmx40 cmx1 m



GEOMETRY

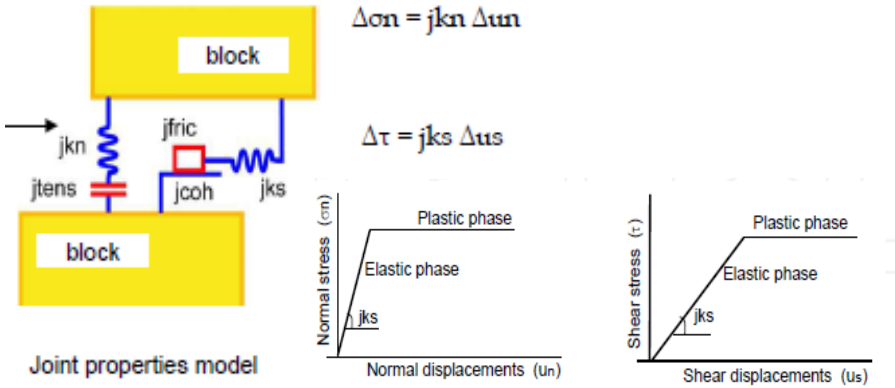
17+2 blocks of the Romanesque and Gothic arch



Material models

Prop mat
Prop jmat

- Block:
  - rigid
  - 2600 kg/m3 (limestone, sandstone, marble)
- Contacts:
  - Coulomb frictional
  - Shear stiffness (jks) and normal stiffness (jkn) are 10^{12} N/m^2
  - Friction angle: 50°



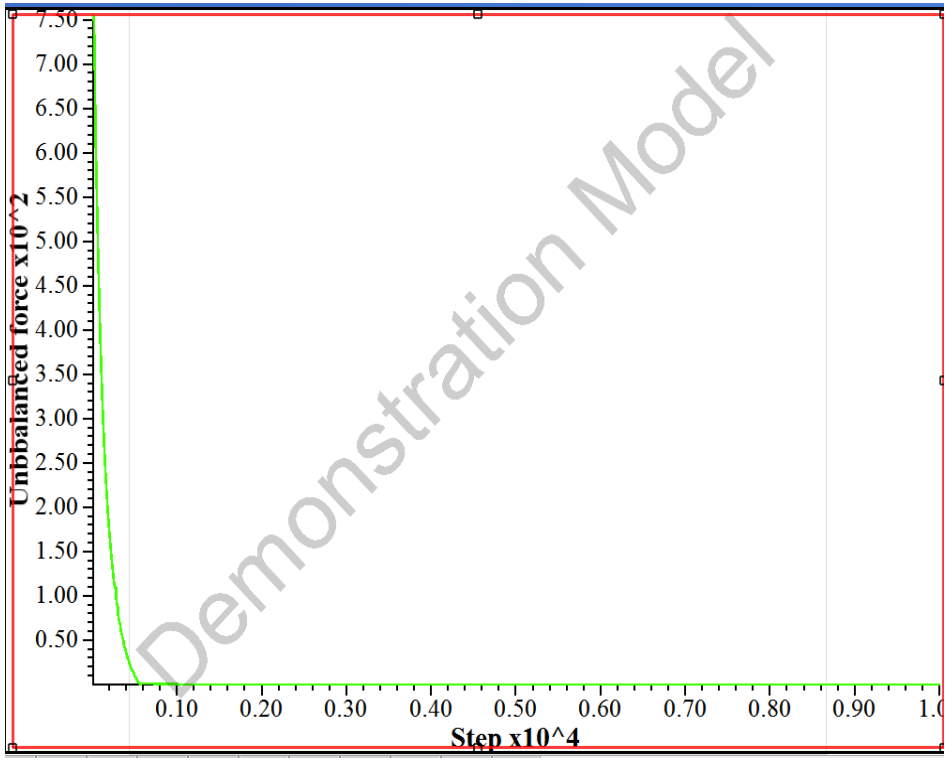
Fix
Gravity
Apply
Set dt
Cycle
Step

Boundary conditions loading

- Support blocks: fixed
- Gravity in -y vertical direction

Support displacements

- Velocity
- Length of time step
- Number of time steps

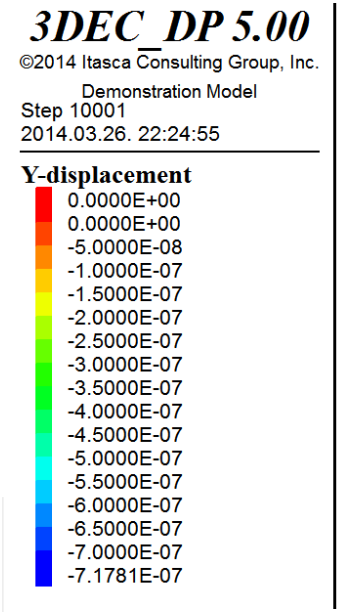

Unbbalanced force x10^2
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Step x10^4
Demonstration Model

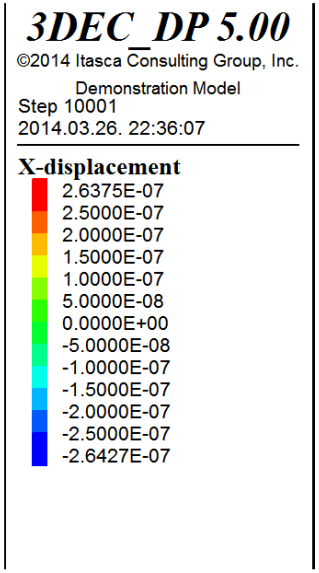
Results

Displacements

- Romanesque

Hist
Cycle
Plot hist
Plot contour

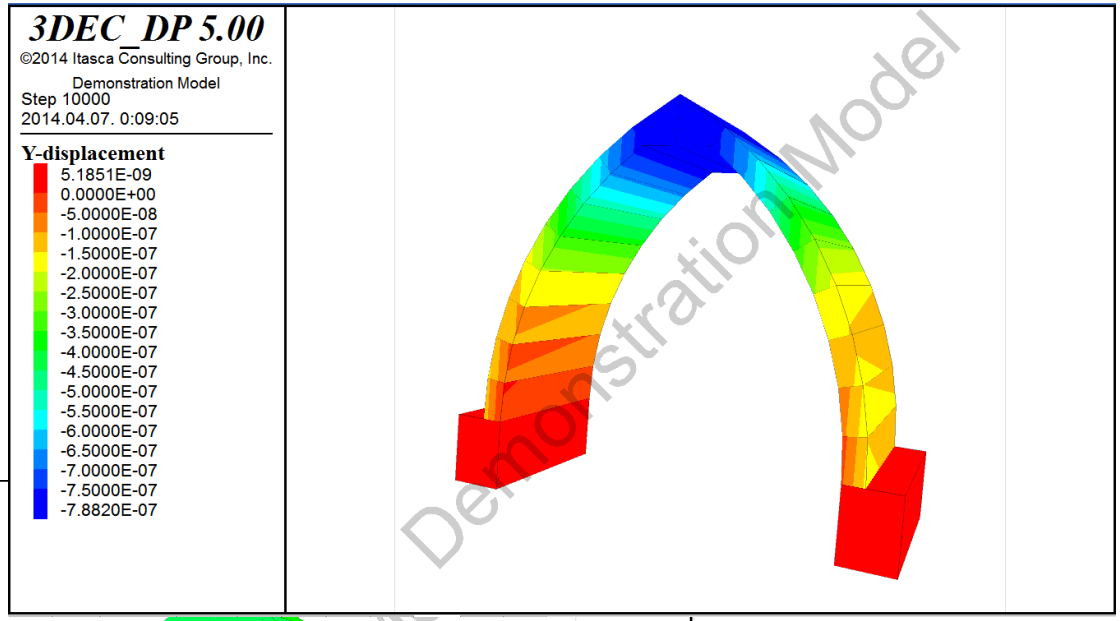


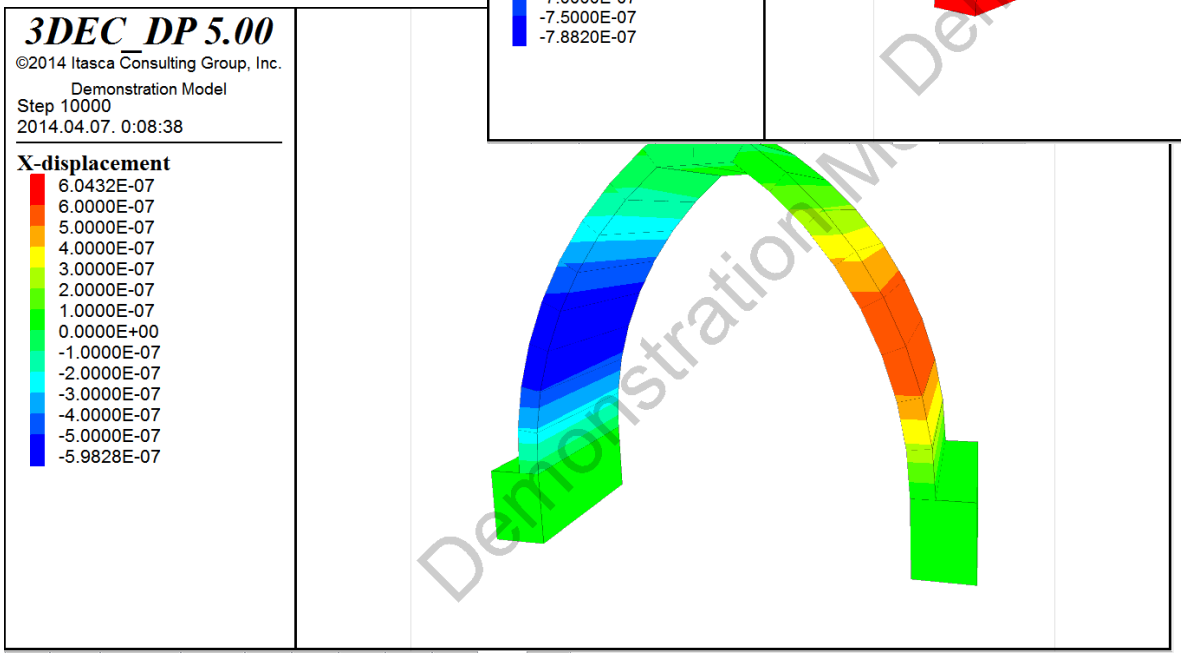


Displacements

- Gothic

Hist
Cycle
Plot hist
Plot contour





Displacements

Hist
Cycle
Plot hist
Plot contour

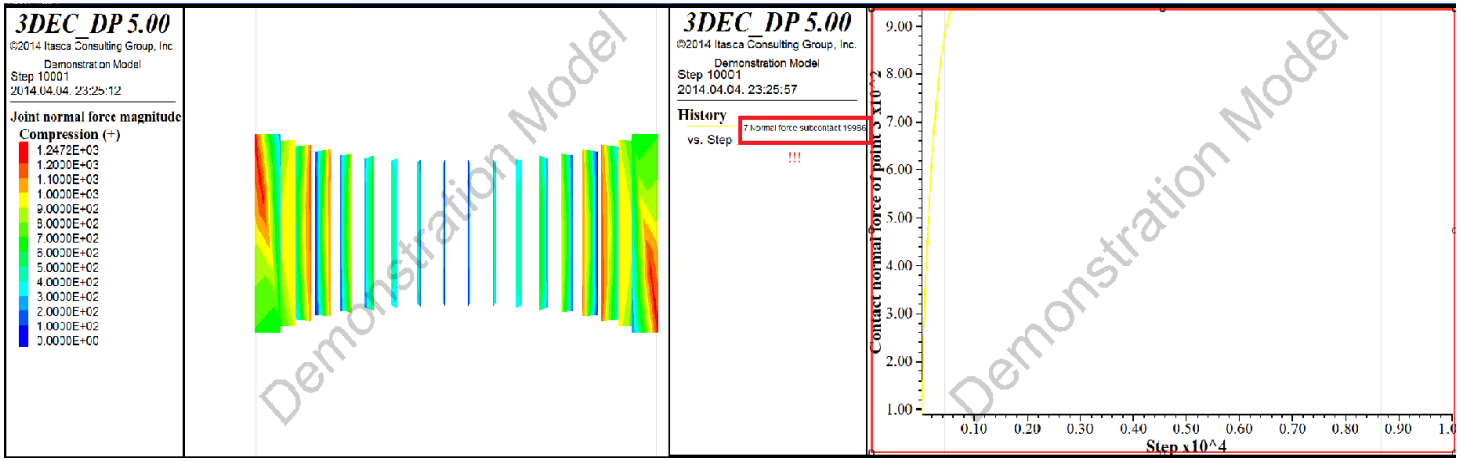
	Romanesque arch	Gothic arch	Difference
Maximum vertical displacement [m]	$-7.1781*10^{-7}$	$-7.9286*10^{-7}$	9.47 %
Maximum horizontal displacement [m]	$-2.6427*10^{-7}$	$-6.0149*10^{-7}$	56 %

- Gothic > Romanesque
- Very small displacements!

Horizontal reaction

Plot hist
Plot jointcontour
List block vel
List contact state
List contact stress
Set log on

- Plot – problems
- solution: check the normal forces



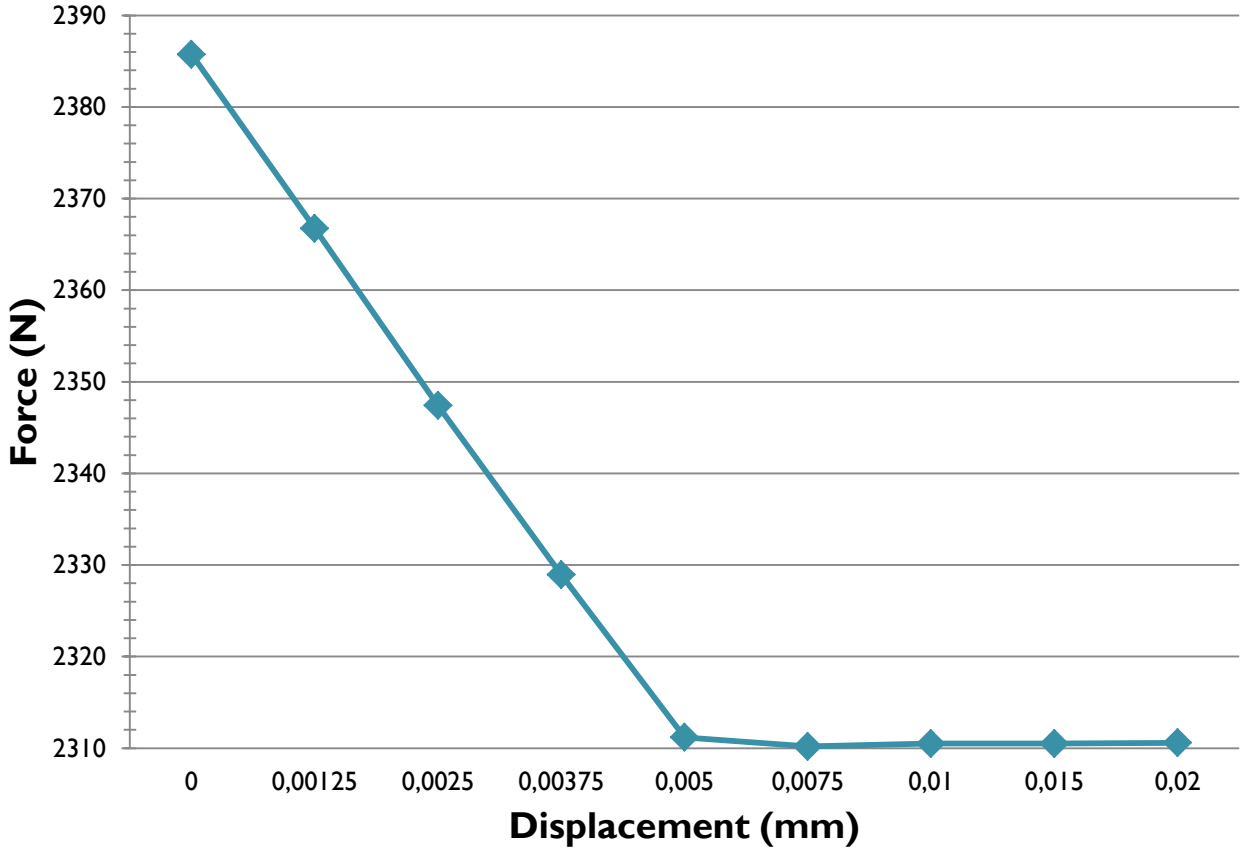
- Contact shear force (N)

Romanesque	Gothic
2385,75	1628,39

H-e diagram

- Romanesque

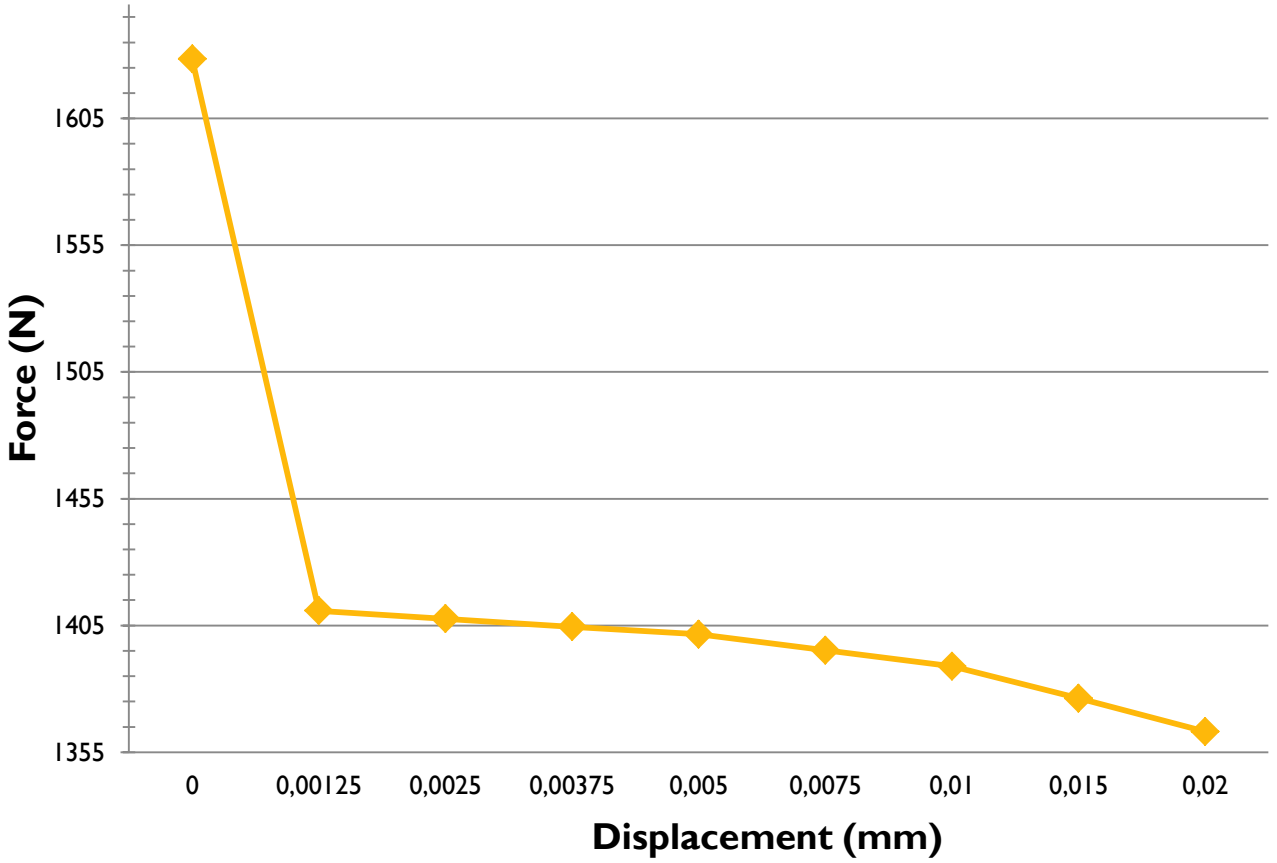
Set dt
Free!!
Apply!!
Cycle 250-2000
Set log on
List contact state
List contact stress



H-e diagrams

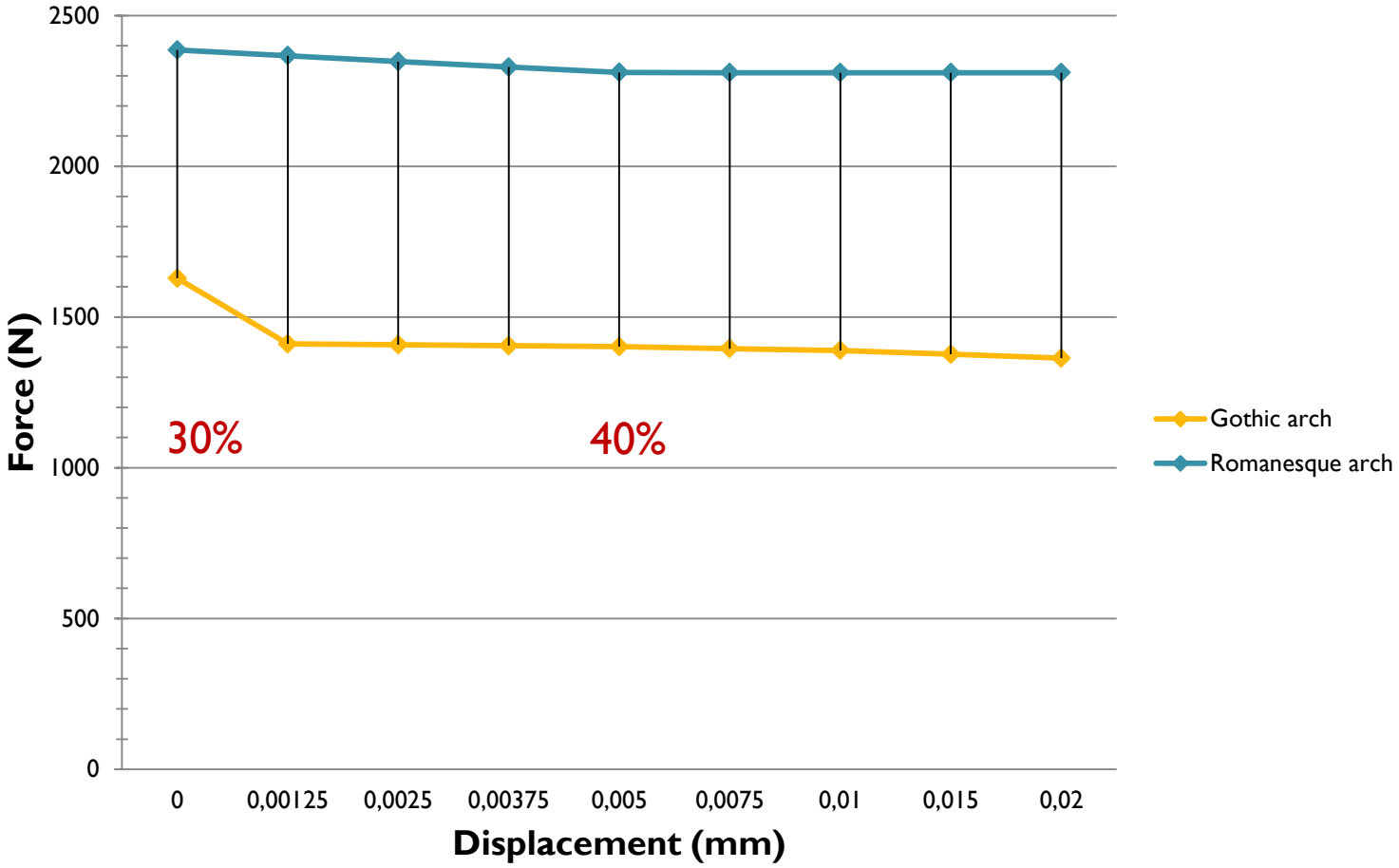
Set dt
Free!!
Apply!!
Cycle 250-2000
Set log on
List contact state
List contact stress

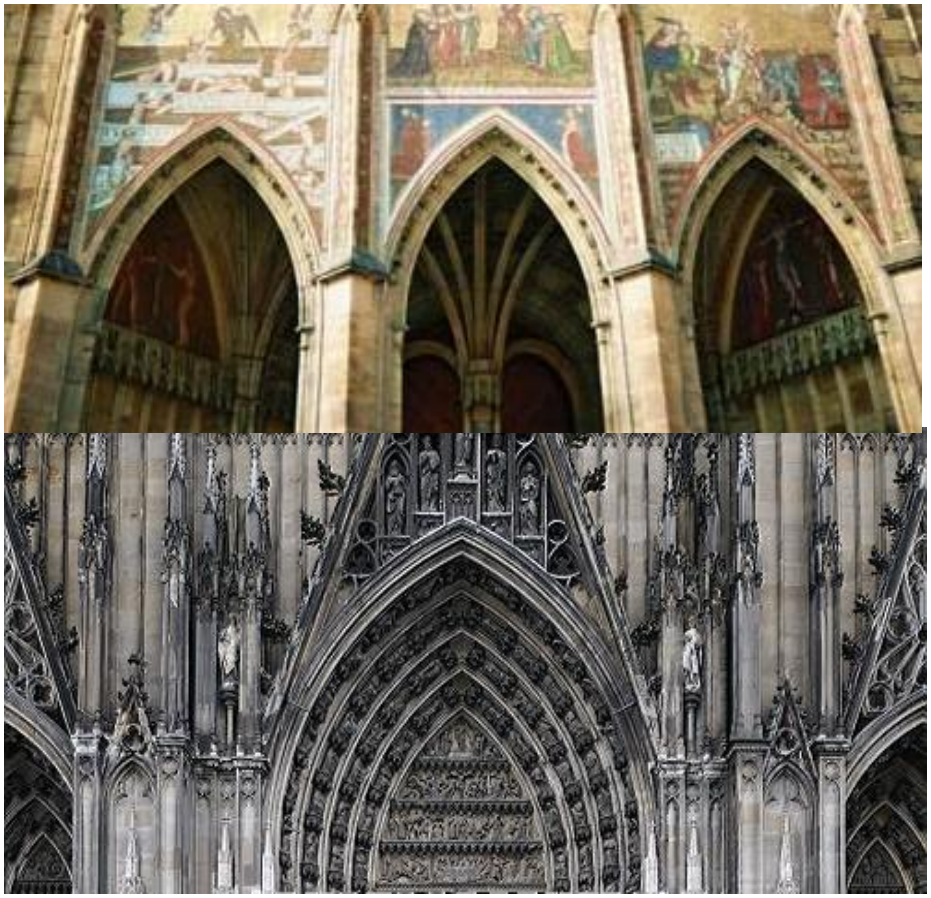
- Gothic



H-e diagrams

- Comparison





Conclusions

Conclusions

- Horizontal reaction of the Gothic arch is much smaller than the reaction of the Romanesque arch.
- If the arches are under selfweight the horizontal reaction of the Gothic arch is 31% smaller.
- When we are on the constant section of the force-displacement diagram the difference become even larger (40%).
- Structure of the Gothic arch has an advantageous effect on the support structure, because the **horizontal force component is smaller**.
- We have fewer problems with the stability of the supporting walls, so actually we can have **thinner walls** with **bigger windows**.

THANK YOU FOR YOUR ATTENTION!