

# Course Notes / Note de curs



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A219

## Bibliography / Bibliografie

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- Cadar I., Clipii T., Tudor A., Beton Armat (ed. II), Ed. Orizonturi Universitare, 2004, ISBN 973-638-176-5
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- EN 1992-1-1: Design of concrete structures - Part 1-1: General rules and rules for buildings

# Reinforced Concrete / Betonul armat



*merriam-webster.com*

*The word “concrete” originates from the Latin verb “concretus”, past participle of “concrescere” which means to grow together (14<sup>th</sup> century).*



ENG: REINFORCED CONCRETE

GER: STAHLBETON

FRA: BÉTON ARMÉ

SPA: HORMIGÓN ARMADO

ITA: CALCESTRUZZO ARMATO

HUN: VASBETON

## The History of Concrete / Istoria betonului

~3000 B.C.

In the ancient Egypt: - mortars as a mix of lime, gypsum and sand at the construction of the pyramids



## The History of Concrete / Istoria betonului

~3000 B.C.

In the ancient Egypt: - sun dried mud bricks (from Nile)

Strength  $\approx 2 \dots 3 \text{ N/mm}^2$



- sun dried mud bricks with straw

Strength  $\approx 7 \dots 9 \text{ N/mm}^2$



# The History of Concrete / Istoria betonului

Source: [www.wikipedia.org](http://www.wikipedia.org)

~ 800 B.C.

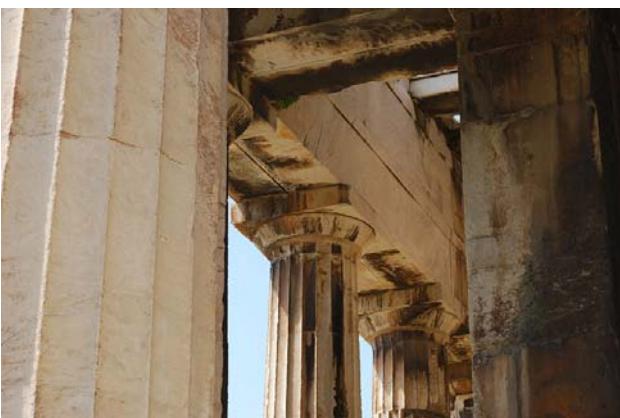
Greeks used **lime mortars**, which were much harder than later Roman mortars



Parthenon, Athens (447 BC)



Temple of Athena, Paestum  
(500 BC)



Temple of Hephaestus/Theseion  
Athens (500 BC)



Erechtheion, Athens  
(421 BC)

# The History of Concrete / Istoria betonului

Source: [www.wikipedia.org](http://www.wikipedia.org)

**300 BC - 476 AD**

**Romans** used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius → **volcanic**

- **Via Appia** (Appian Way - ITA): was one of the earliest and strategically most important Roman roads of the ancient republic



Minturno



Roma

Receipt of Vitruvius: 2 parts pozzolana  
1 part lime  
admixtures: animal fat, milk and blood

## The History of Concrete / Istoria betonului

Source: [www.wikipedia.org](http://www.wikipedia.org)

**300 BC - 476 AD**

**Romans** used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius → **volcanic**

- **Roman Bath**: baths were the ancient Roman equivalent of community centers. There were libraries, rooms for poetry readings, and places to buy and eat food. The modern equivalent would be a combination of a library, art gallery, mall, restaurant, gym and spa.



**Roman Baths** complex, Bath (ENG)



**Băile Herculane**

# The History of Concrete / Istoria betonului

Source: [www.wikipedia.org](http://www.wikipedia.org)

40 – 60 AD

Romans used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius → volcanic  
- Roman aqueduct: Pont du Gard (southern France),

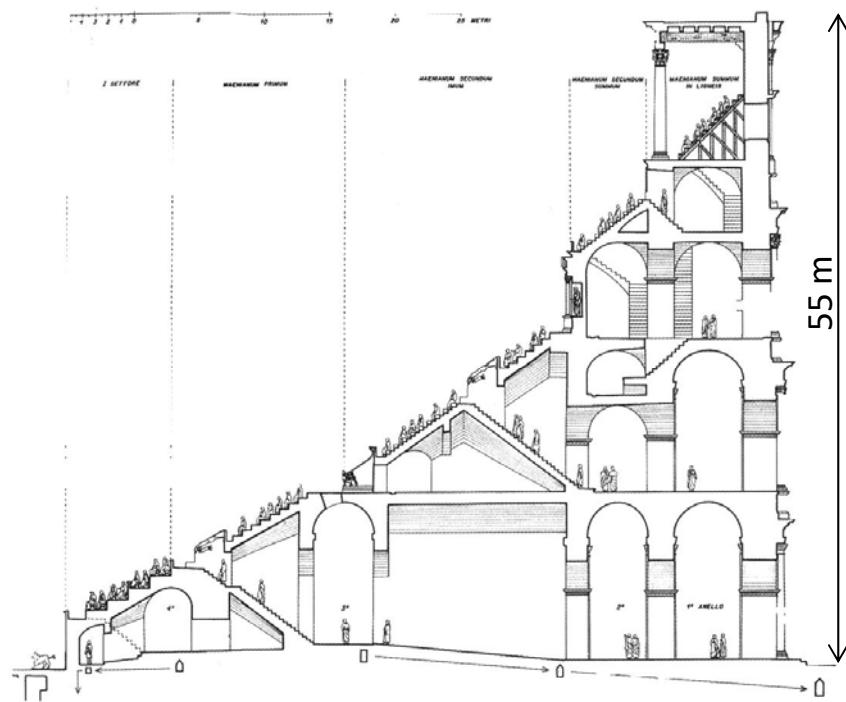
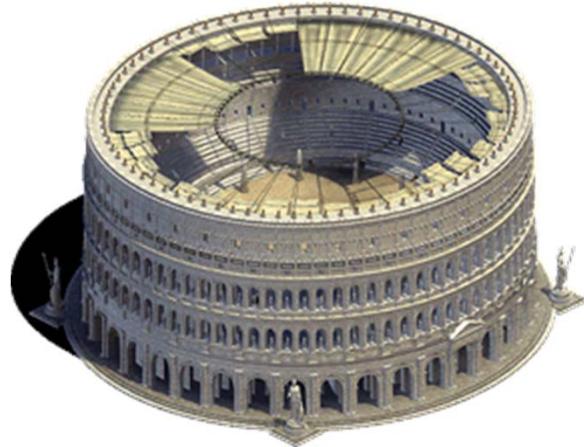


# The History of Concrete / Istoria betonului

Source: [www.wikipedia.org](http://www.wikipedia.org)

**70 – 80 AD**

**Romans used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius → volcanic  
- Colosseum → 70-80 AD**



It is the largest amphitheater ever built, by the emperor Vespasianus in the center of Rome (finished by Titus). It is elliptical in plan. It is **189 m long** and **156 m wide**, the **perimeter 520 m** and the **height 55 m**, could hold, it is estimated, between 50.000 - 80.000 spectators.  
**Foundations: approx. 12 m thickness.**  
 Function: gladiatorial contests, public spectacles (animal hunts).

# The History of Concrete / Istoria betonului

Source: www.wikipedia.org

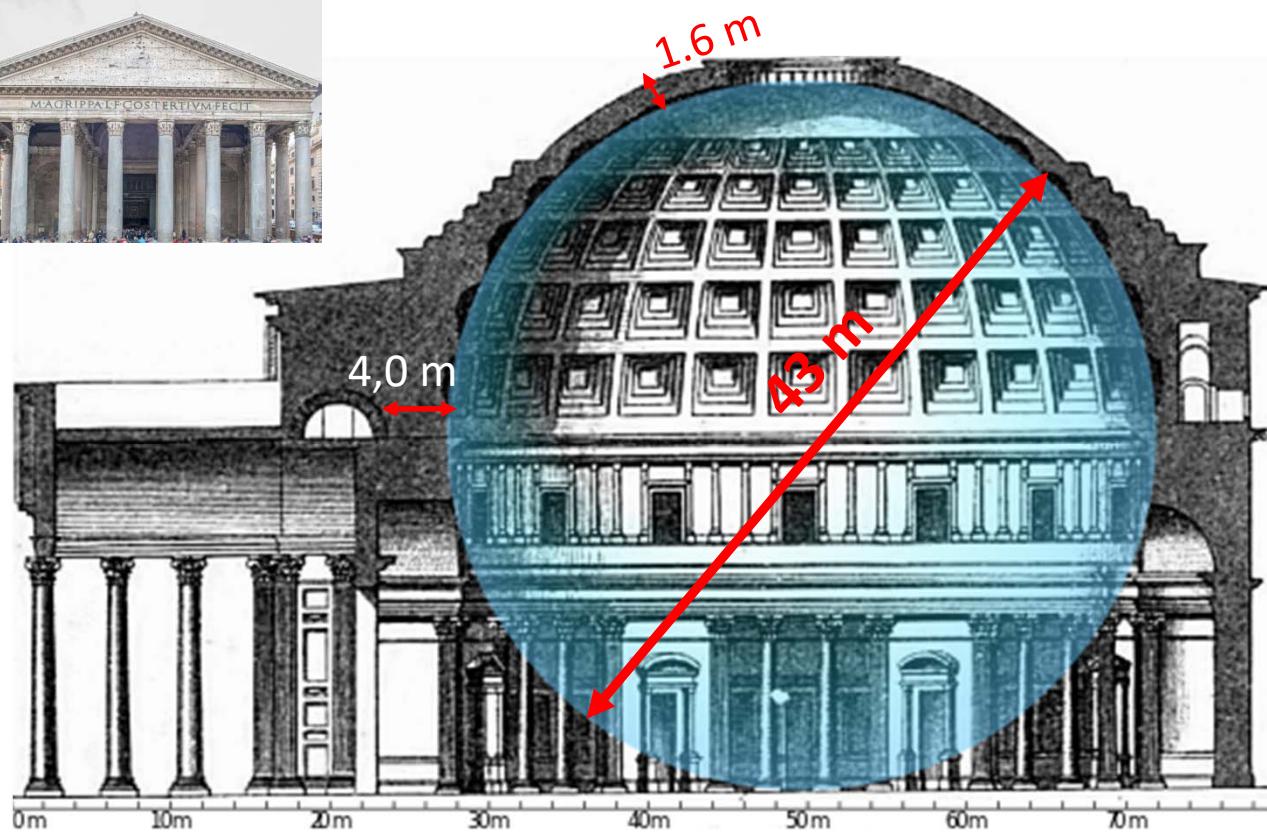
**118 – 128 AD**

Romans used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius → **volcanic**

- **Pantheon in Roma:** temple „common to all the gods” commissioned by Marcus Agrippa and completed by the emperor Hadrian, in approx. 126 AD.

**Is still the world's largest unreinforced concrete dome!**

**It is one of the best-preserved of all Ancient Roman buildings!**



## The History of Concrete / Istoria betonului

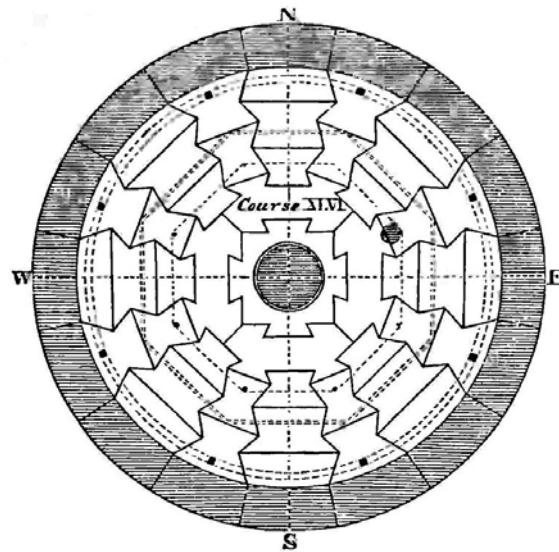
Source: matse1.matse.illinois.edu/concrete

**The quality of cementing materials deteriorated. The use of burning lime and pozzolana was lost after the fall of the Roman Empire.**

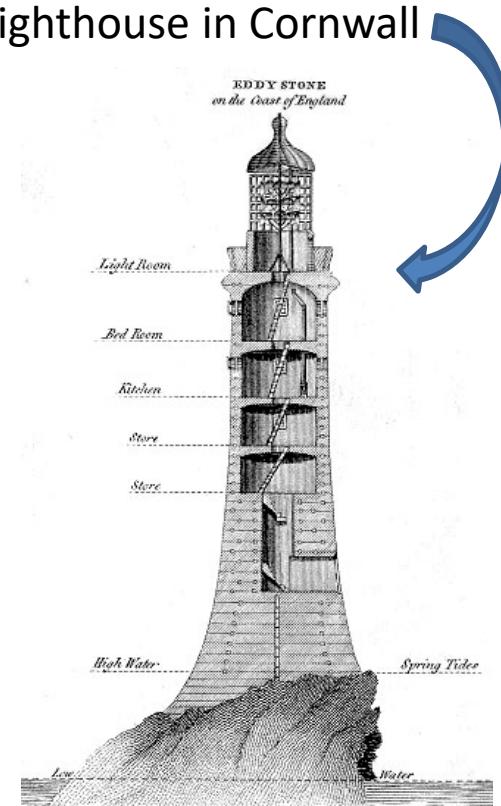
...

**1779:** Bry Higgins (IRL) was issued a patent for hydraulic cement (stucco) for exterior plastering use.

**1759:** John Smeaton (ENG) used hydraulic lime to rebuild Eddystone Lighthouse in Cornwall (ENG)



PLAN OF THE 46TH COURSE, SHOWING THE METHOD OF DOVETAILING.



Cross section – method of dovetailing

# The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete

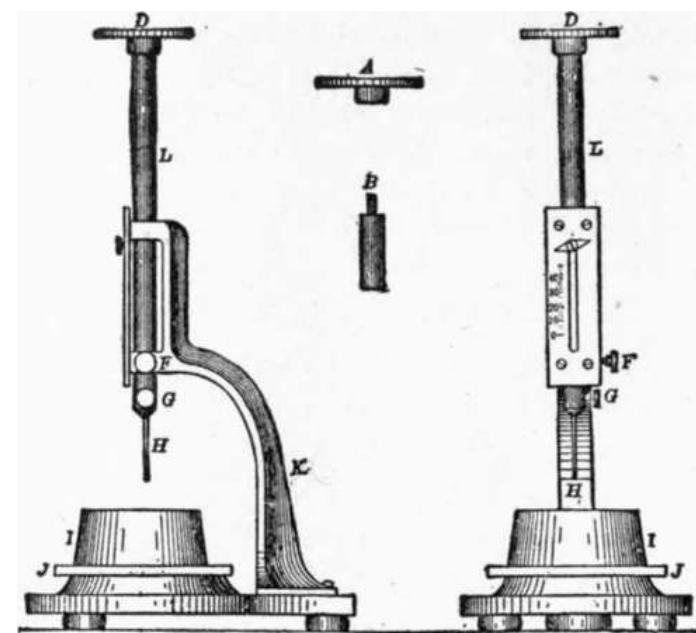
**1796:** James Parker (ENG) patented a natural hydraulic cement, called Parker's Cement or Roman Cement

**1802:** In France, a similar Roman Cement process was used.

**1813:** Louis Vicat (FRA) prepared artificial hydraulic lime by calcining synthetic mixtures of limestone and clay



Portrait de Louis Vicat jeune



## The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete

**1818:** Ralph Dodd (ENG) obtained a patent for the placement of forged iron bars into concrete.

**1822:** James Frost (ENG) prepared artificial hydraulic lime like Vicat's and called it **British Cement**.

**1824:** Joseph Aspdin (ENG) invented "**Portland cement**", named after the high quality building stones quarried at Portland, England

*"Aspdin called the product Portland cement because set mortar made from it resembled "the best Portland stone". Portland stone was the most prestigious building stone in use in England at the time." (wikipedia)*

...

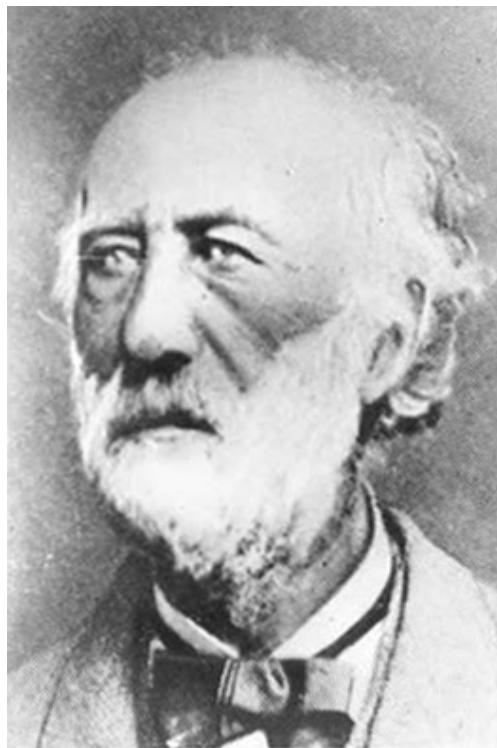
**1836:** The first systematic tests of tensile and compressive strength took place in Germany.

...

## The History of Concrete / Istoria betonului

Source : matse1.matse.illinois.edu/concrete

**1848:** Joseph Louis Lambot (FRA) was the first to use reinforcing in concrete. He constructed several small rowboats of concrete, which he reinforced with iron bars and wire mesh.



...

**1850:** The first concrete roads appeared in Austria.

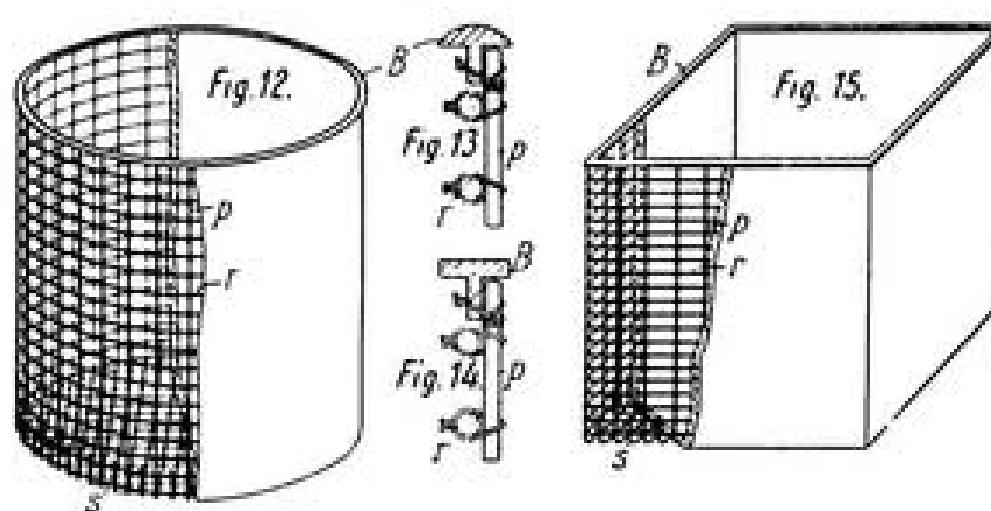
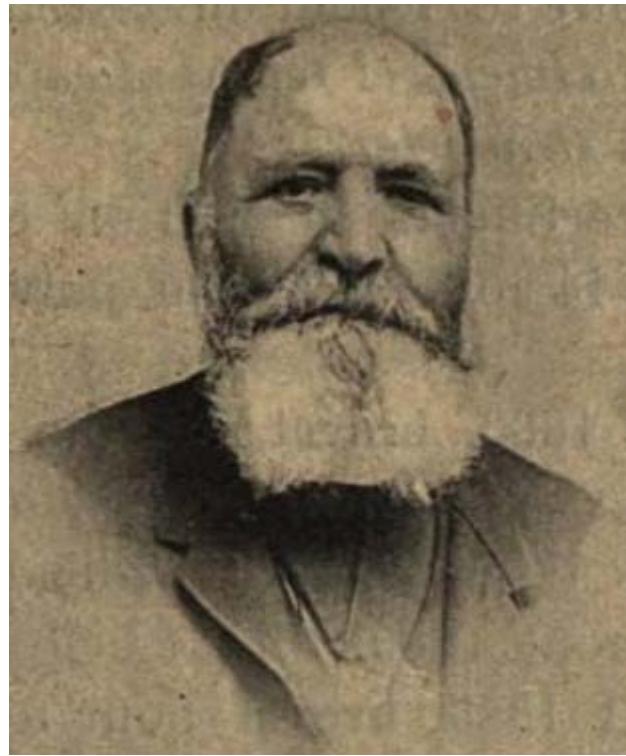
...

## The History of Concrete / Istoria betonului

Source: [www.beton.org](http://www.beton.org)

**1867: Joseph Monier** (FRA), a French gardener, patented a design for reinforced garden tubs. He later patented a design for reinforced concrete posts and beams for railway and road guardrails.

→ discovered the real perspectives of the technology



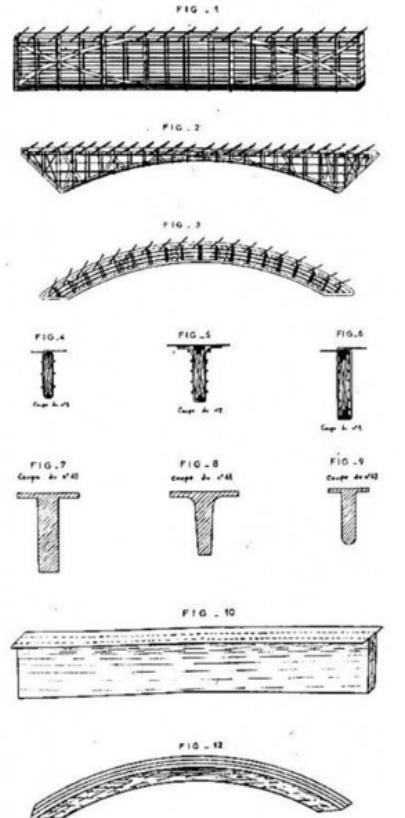
large concrete flowerpots reinforced with iron wire

# The History of Concrete / Istoria betonului

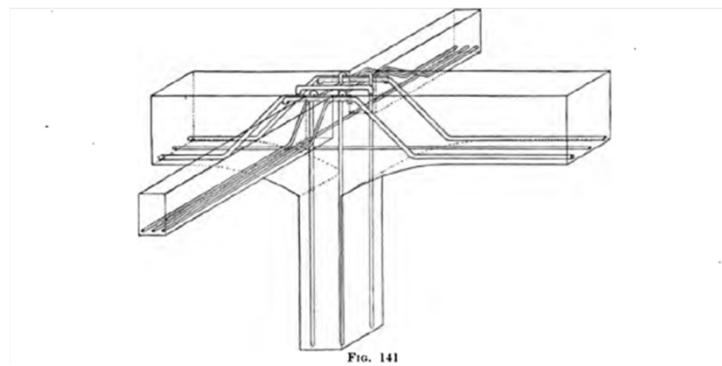
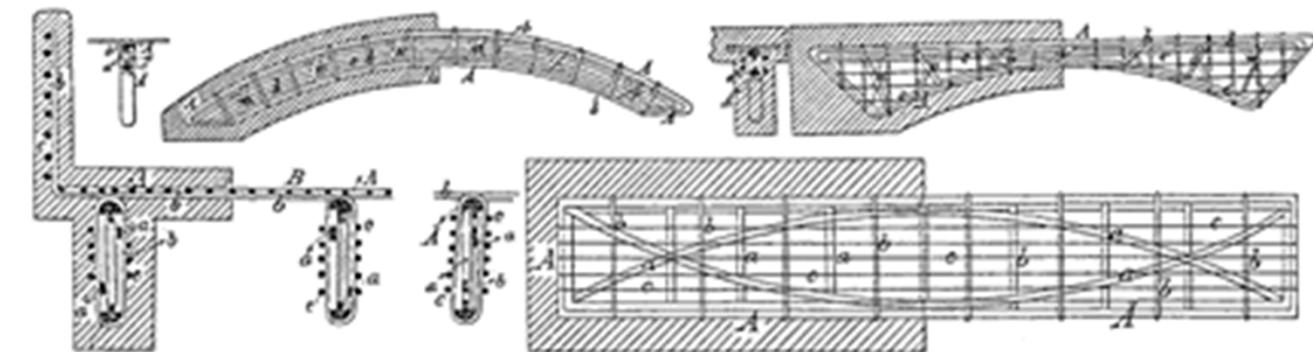
Source: matse1.matse.illinois.edu/concrete + wikipedia

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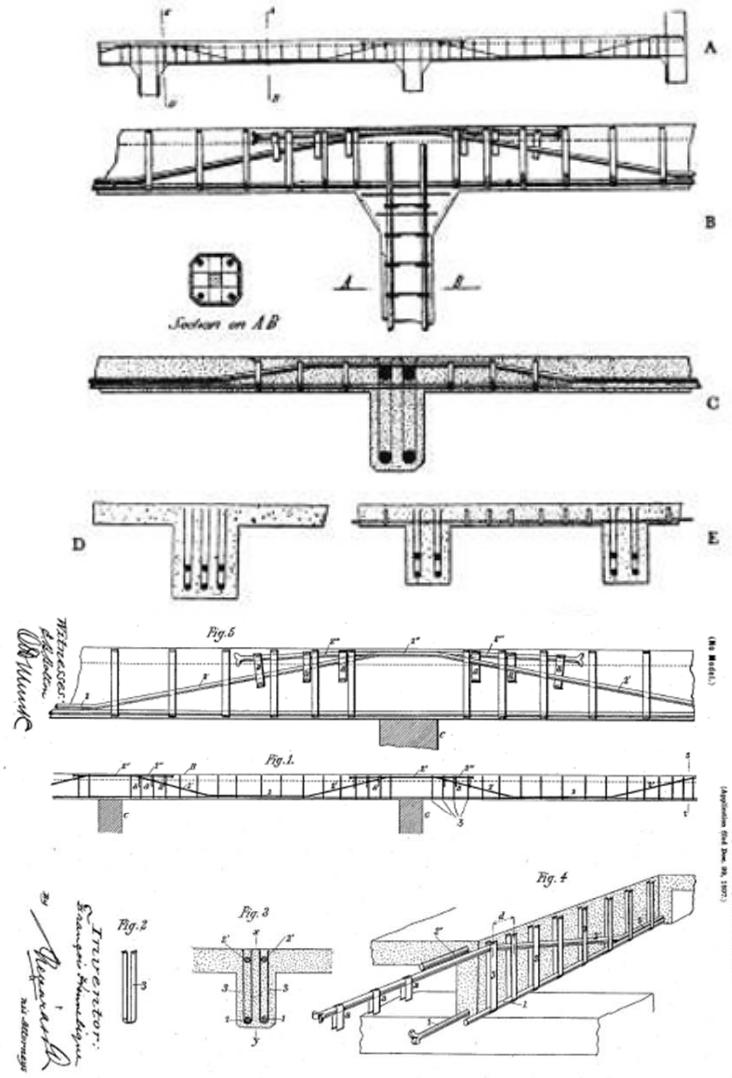
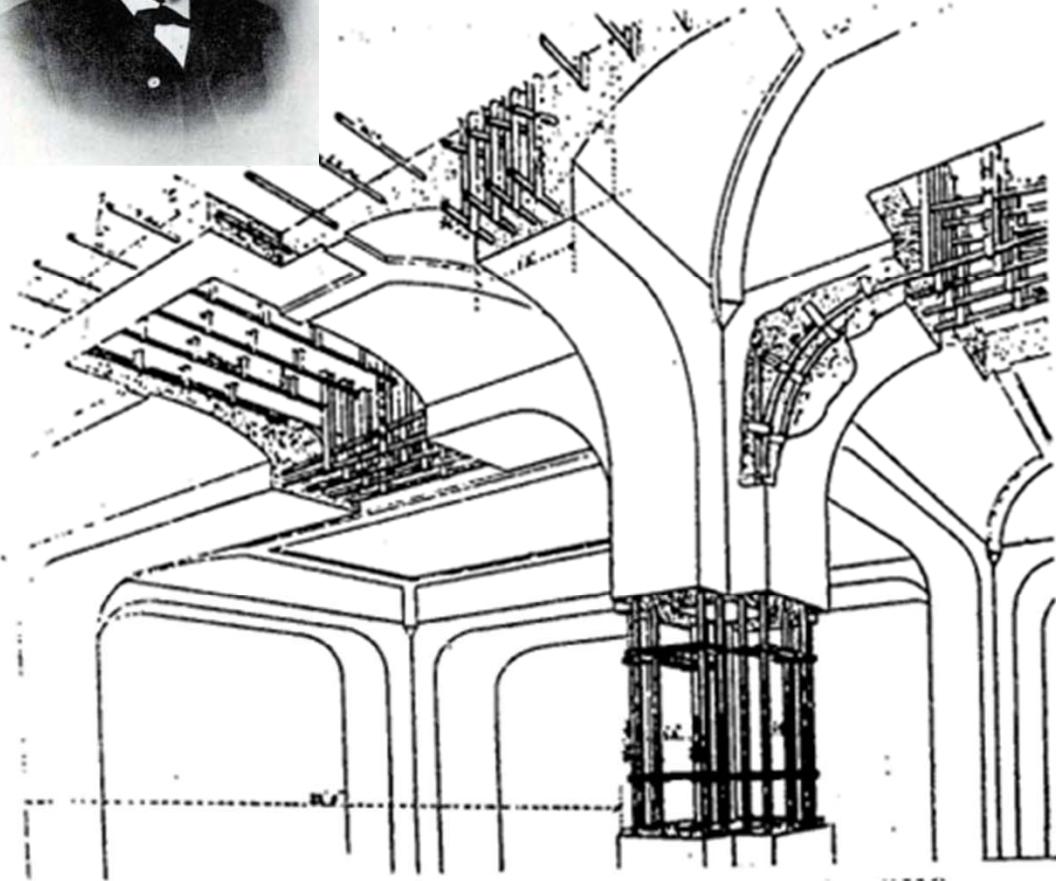
Patent on bridges made of iron-reinforced cement - 1873



# The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

**1870:** [Francois Hennebique](#) (FRA) patented a complex reinforcing system



# The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

**1885:** Emil Mörsch (GER) performed *tests* and studied reinforced concrete elements. Developed a *method for design* bearing capacity of a reinforced concrete cross section, than studied problems related to *shear forces* and to prestressed concrete.



FIG. 131.—Beam I, 3 rods 18 mm. diameter, breaking load, 25.7 t. (27.3 tons).

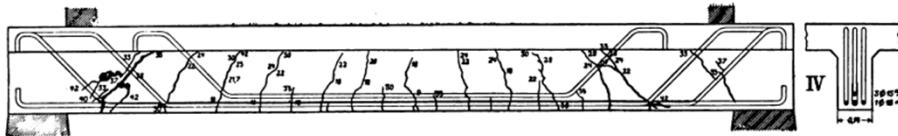


FIG. 147.—Beam IV, breaking load 42 t. (46.2 tons).

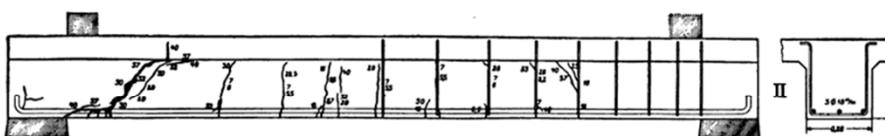


FIG. 132.—Beam II, 3 rods 18-mm. diameter, breaking load 40.0 t. (44 tons).

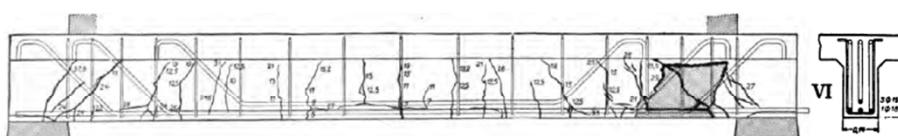


FIG. 148.—Beam VI, breaking load 37.8 t. (41.5 tons).

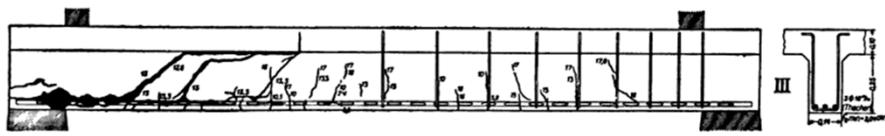


FIG. 133.—Beam III, 3 Thacher rods, breaking load 19.5 t. (21.5 tons).

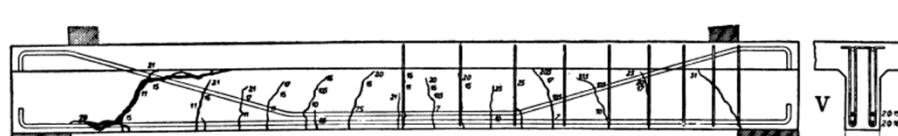


FIG. 149.—Beam V, breaking load 31 t. (34.1 tons).

...

# The History of Concrete / Istoria betonului

Source : matse1.matse.illinois.edu/concrete + wikipedia

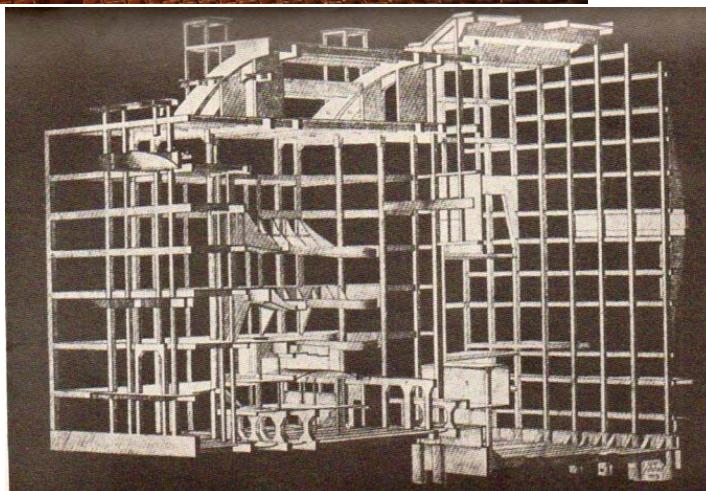
...

1903: The first concrete high rise was built in Cincinnati, OH (16 levels)

1903: Champs Elysee theatre in Paris.



© TravelPics.fr - Alexandre Rosa



...



# The History of Concrete / Istoria betonului

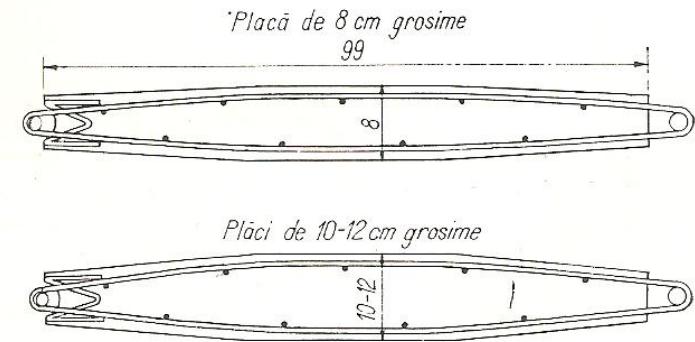
Precast concrete cereal silos

Brăila & Galați (1884 -1889)

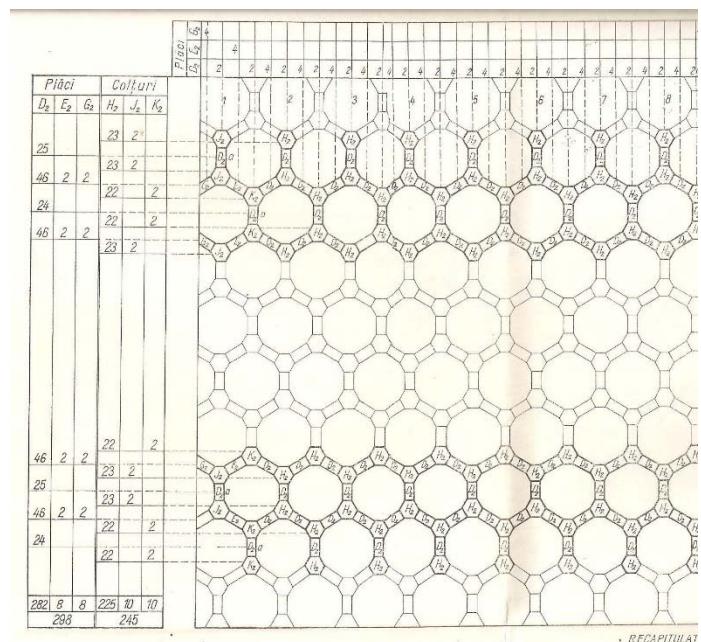
Constanța (1906)



Anghel Saligny  
(1854 -1925)



precast units for silos in Constanța



the lay-out of precast elements

# The History of Concrete / Istoria betonului

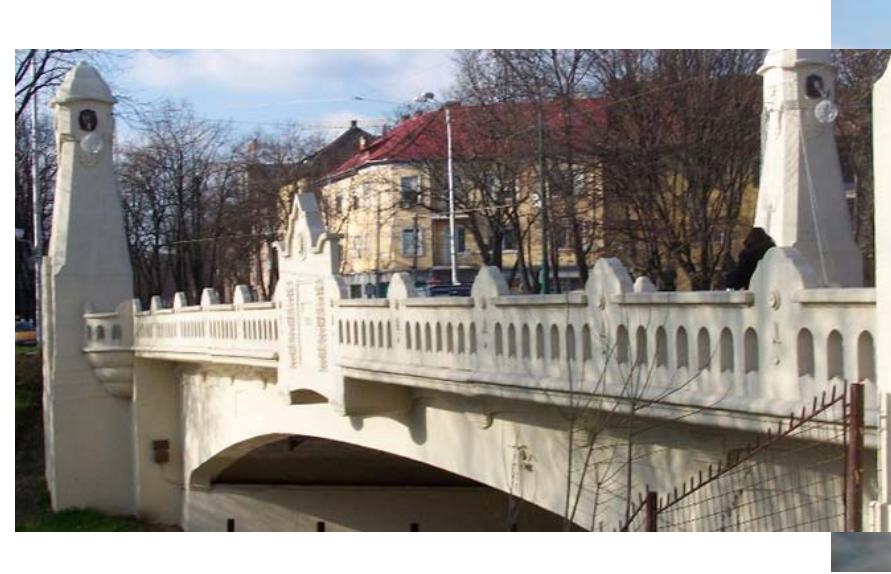
Source : matse1.matse.illinois.edu/concrete + wikipedia

**1909:** Construction of the Decebal Bridge (Parkgassenbrücke / Liget úti híd)



**The largest span bridge  
with RC beams in the world.**

- 195 m x 9 m
- prize at the World Expo from Paris (1910)



# The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

1909: Construction of the Mihai Viteazul Bridge (Mühlenplatzbrücke / Malom téri híd)

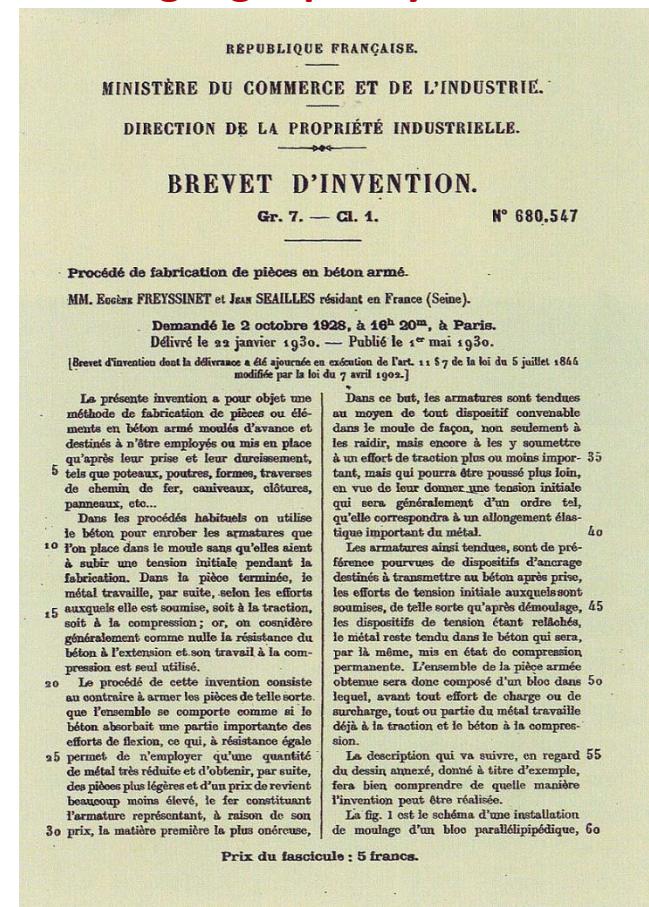


# The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

...  
1919: first patent for a concrete pump was filed. This made concrete transportation easy and allowed on site mixing.

...  
**1927: Eugène Freyssinet (FRA) developed prestressed concrete, using high quality steel**



## The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

**1927: Eugène Freyssinet (FRA) developed prestressed concrete, using high quality steel**



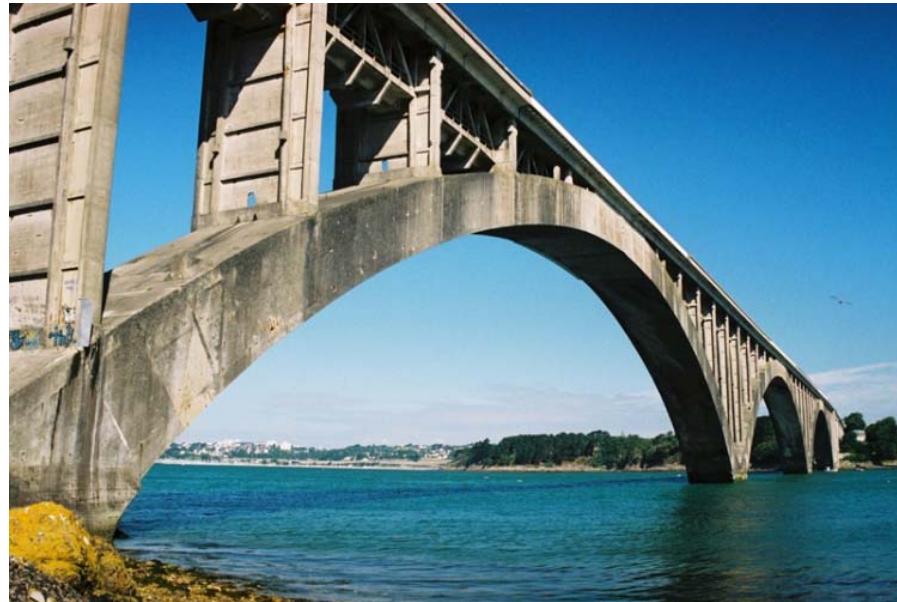
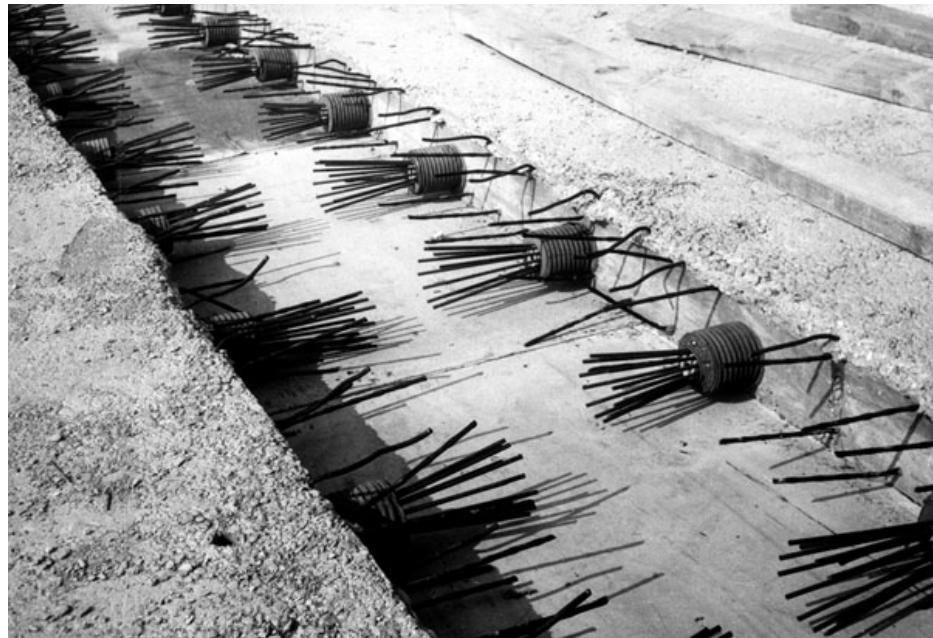
Airship Hangers - Orly (FRA)  
(1923)



# The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

**1927: Eugène Freyssinet (FRA) developed prestressed concrete, using high quality steel**



Pont Albert-Louppe  
(1930)



## The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

**1927: Eugène Freyssinet (FRA) developed prestressed concrete, using high quality steel**

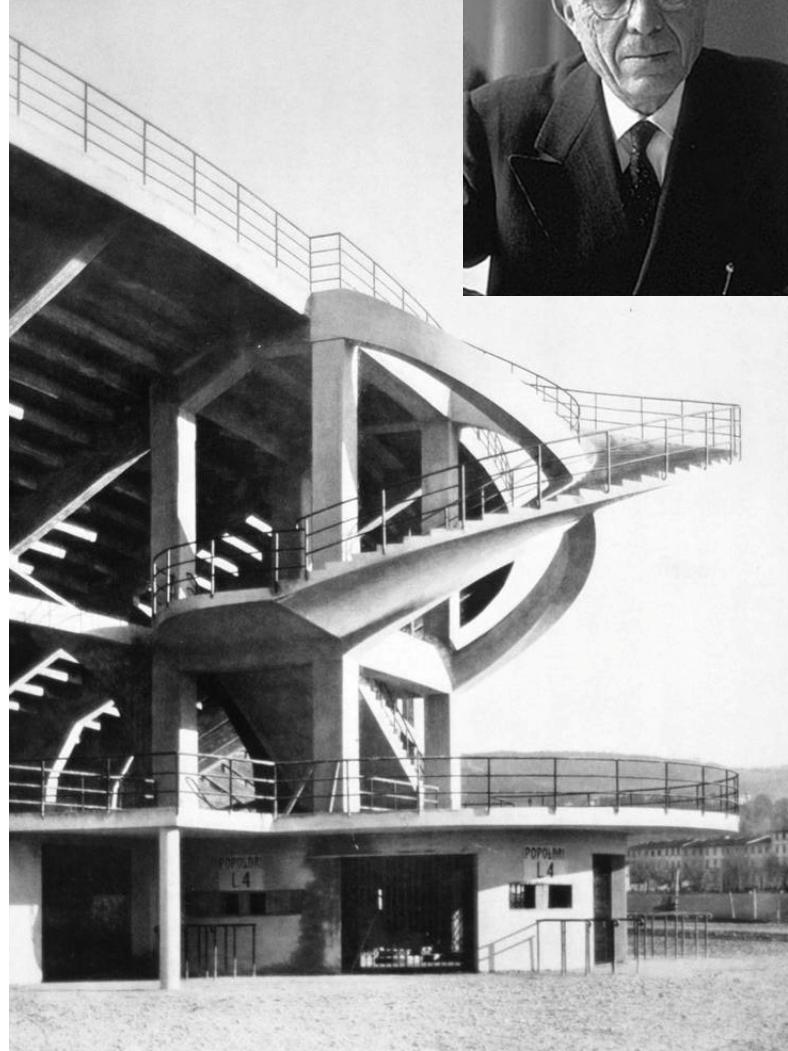
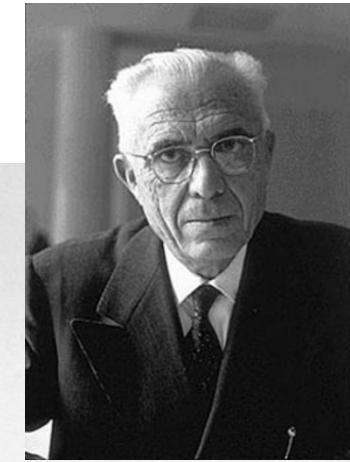


Pont Saint-Michel (Toulouse)  
(1957)

# The History of Concrete / Istoria betonului

Source: <http://en.structurae.de> + wikipedia

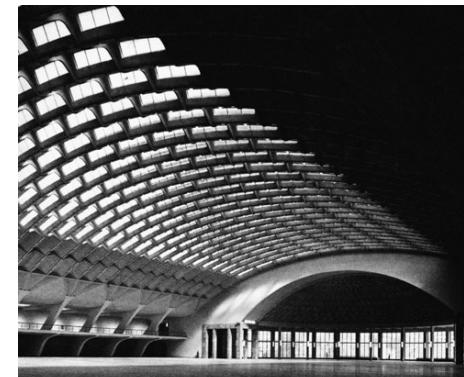
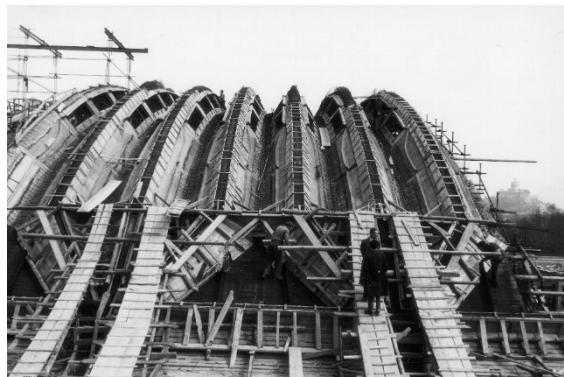
1932: [Pier Luigi Nervi](#): Stadio Artemio Franchi Florence, Italy



# The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

1948: Pier Luigi Nervi - Palazzo delle Esposizioni, Torino



# The History of Concrete / Istoria betonului

Source: matse1.matse.illinois.edu/concrete + wikipedia

1958: Pier Luigi Nervi - Viadotto Corso Francia



# The History of Concrete / Istoria betonului

Source: <http://en.structureae.de> + wikipedia

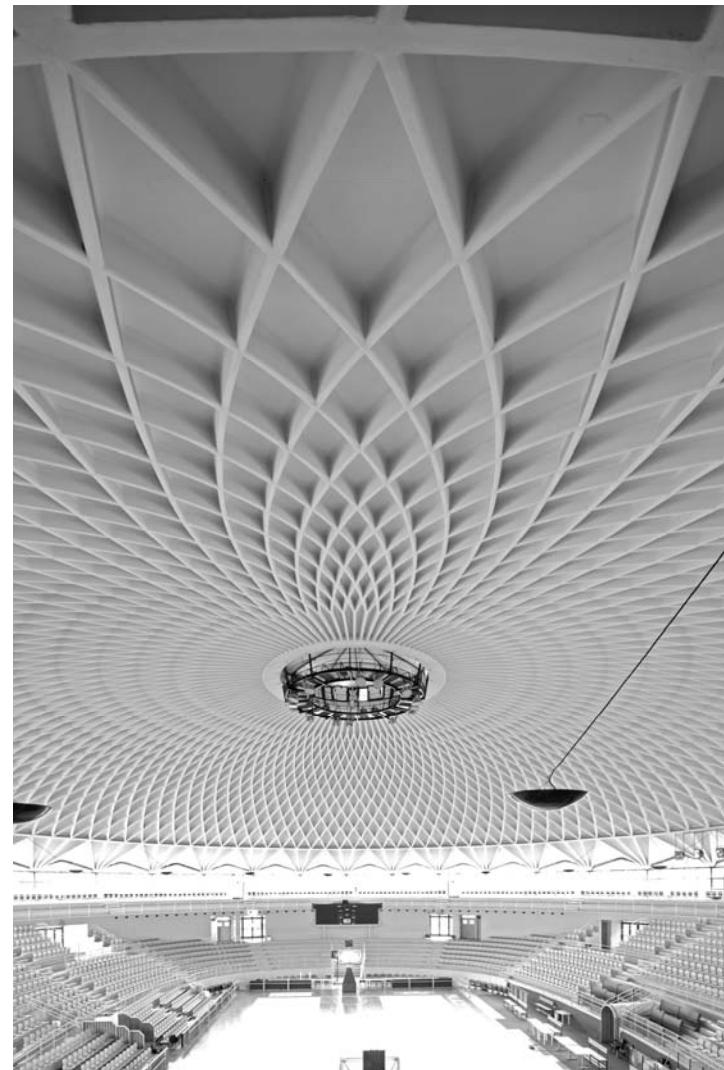
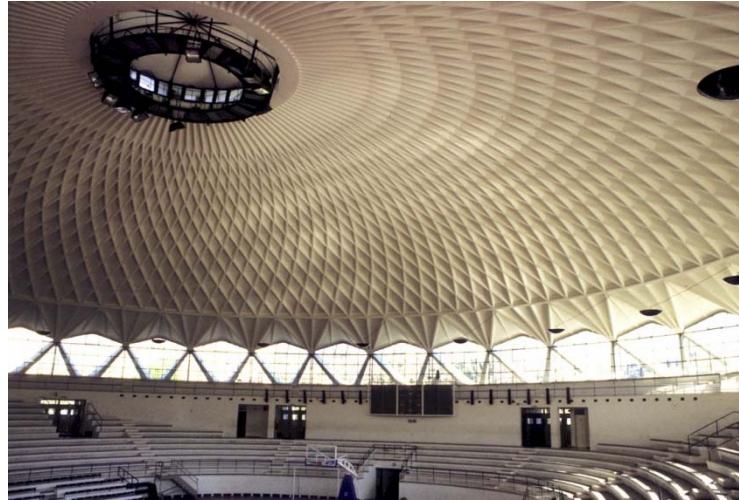
1959: Pier Luigi Nervi - *Palazzo del Lavoro, Torino*



# The History of Concrete / Istoria betonului

Source: <http://en.structurae.de> + wikipedia

1960: Pier Luigi Nervi - Palazzetto dello Sport, Roma



# The History of Concrete / Istoria betonului

Source: <http://en.structurae.de> + wikipedia

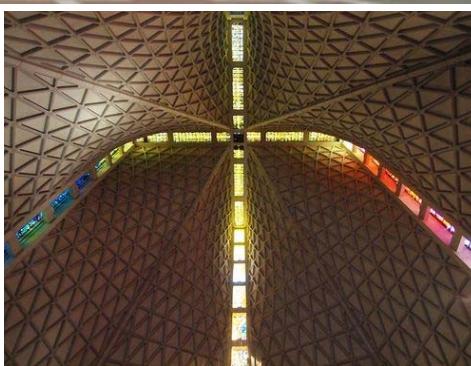
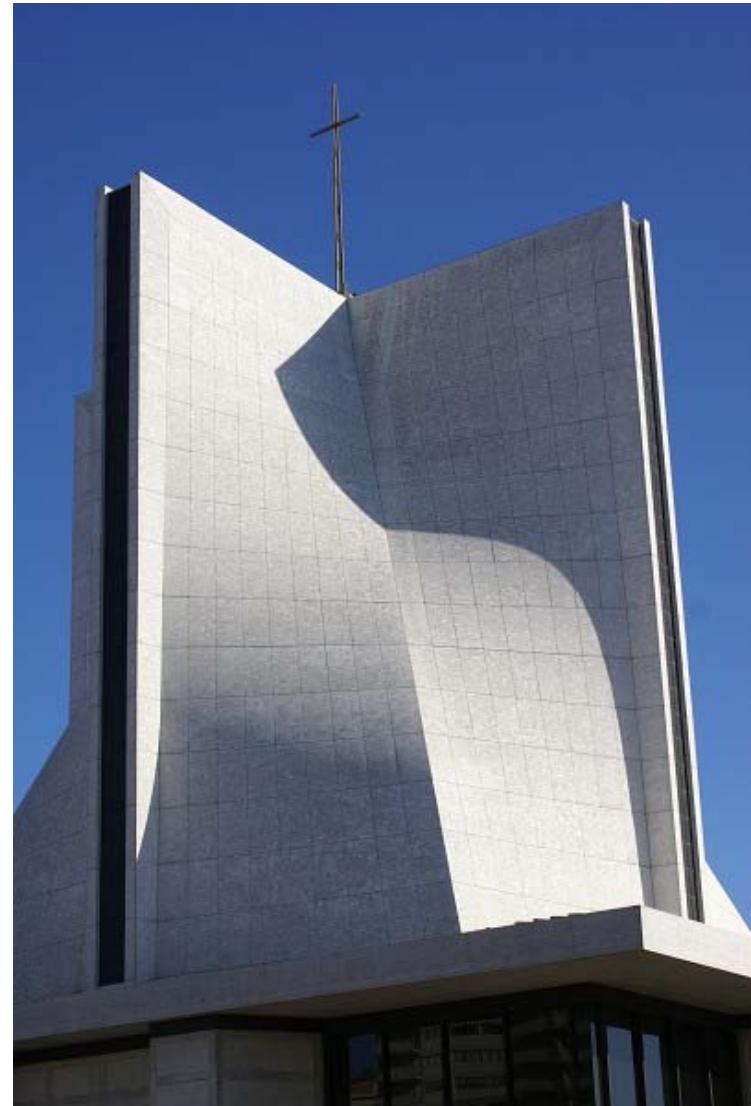
1969: Pier Luigi Nervi: Italy Embassy of Italy in Brasil



# The History of Concrete / Istoria betonului

Source: <http://en.structurae.de> + wikipedia

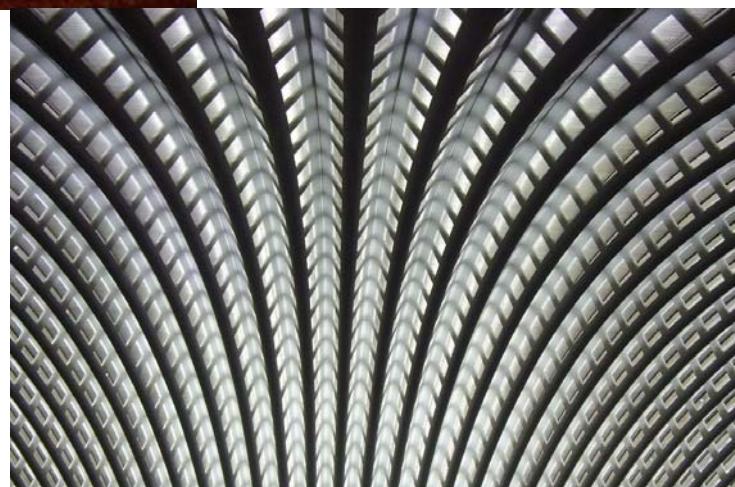
1971: Pier Luigi Nervi: Cathedral of Saint Mary of the Assumption, San Francisco



# The History of Concrete / Istoria betonului

Source: <http://en.structureae.de> + wikipedia

1971: Pier Luigi Nervi: Città del Vaticano



# The History of Concrete / Istoria betonului

Source: <http://en.structureae.de> + wikipedia

1931: Hoover Dam, USA



a concrete arch-gravity dam, built in 5 years



length: 379 m , height: 221 m

1933: Grand Coulee Dam, USA



a gravity dam, built in 9 years



length: 1592 m , height: 168 m

# The History of Concrete / Istoria betonului

Source: <http://en.structureae.de> + wikipedia

1931: Hoover Dam, USA



a concrete arch-gravity dam, built in 5 years



length: 379 m , height: 221 m

Mike O'Callaghan–Pat Tillman Memorial Bridge (2010)



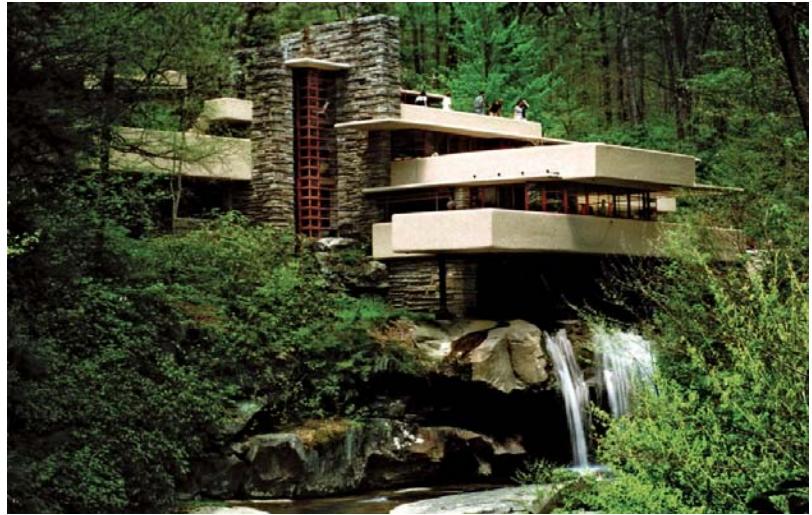
579 m



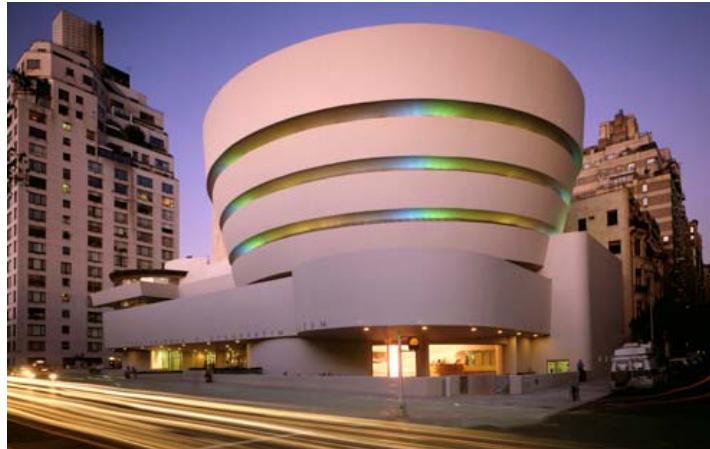
# The History of Concrete / Istoria betonului

Sursa: <http://en.structurae.de> + wikipedia

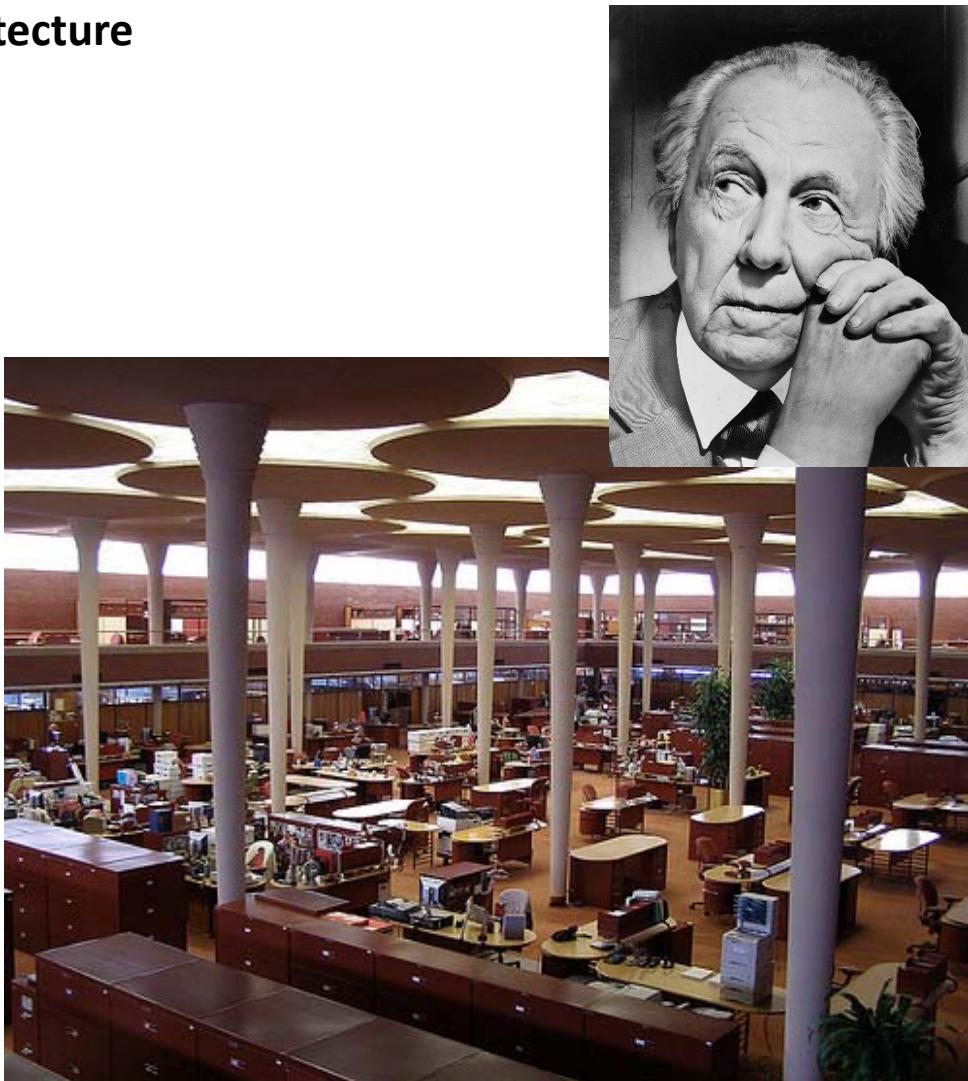
1936: [Frank Lloyd Wright](#) - believed in designing structures that were in harmony with humanity and its environment = **organic architecture**



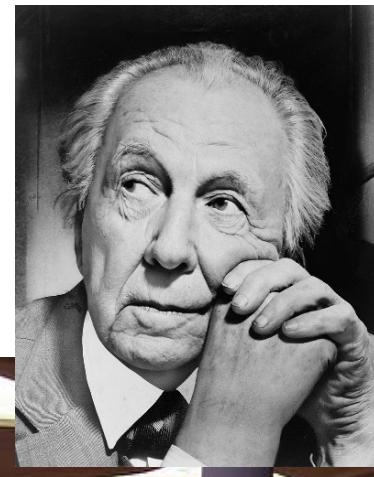
Fallingwater house



Guggenheim Museum, NY



Johnson Wax Headquarters – office area



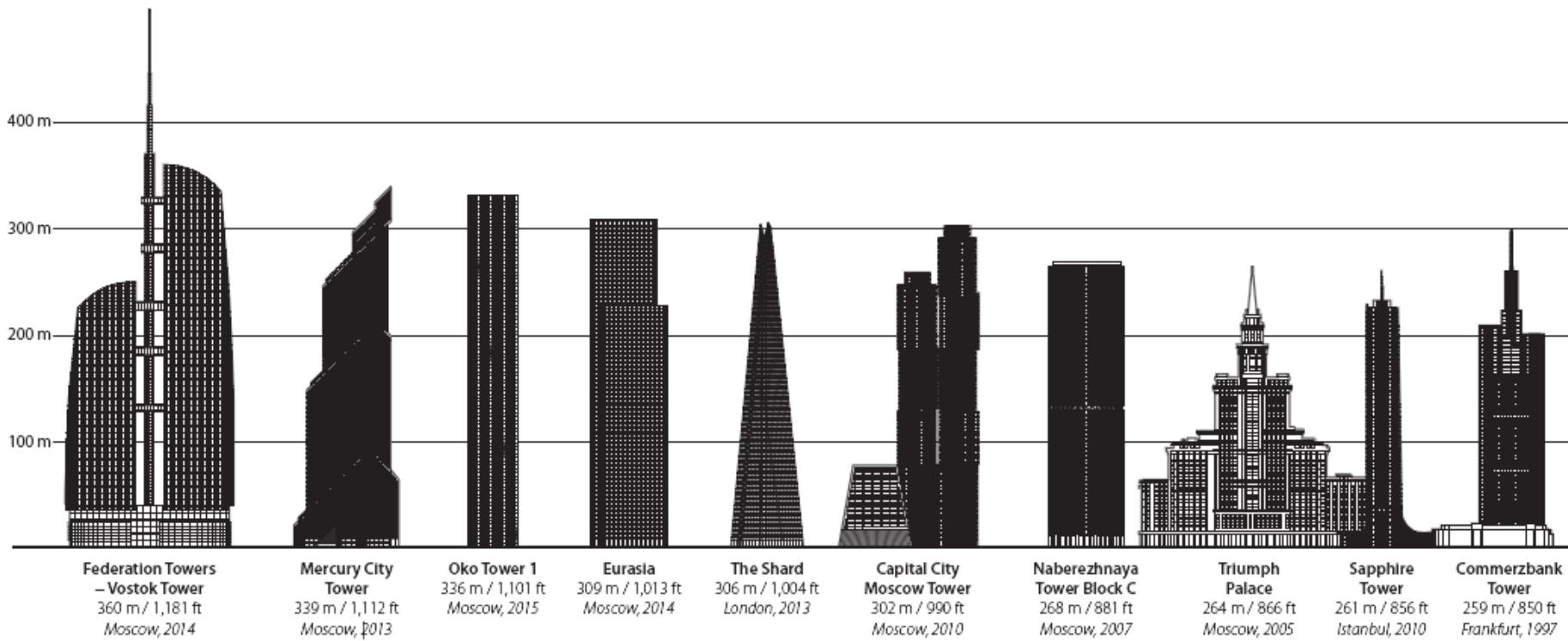
# The History of Concrete / Istoria betonului

CTBUH Journal, 2013

## Nowadays in Europe

### Europe's Future Tallest Ten: 2015

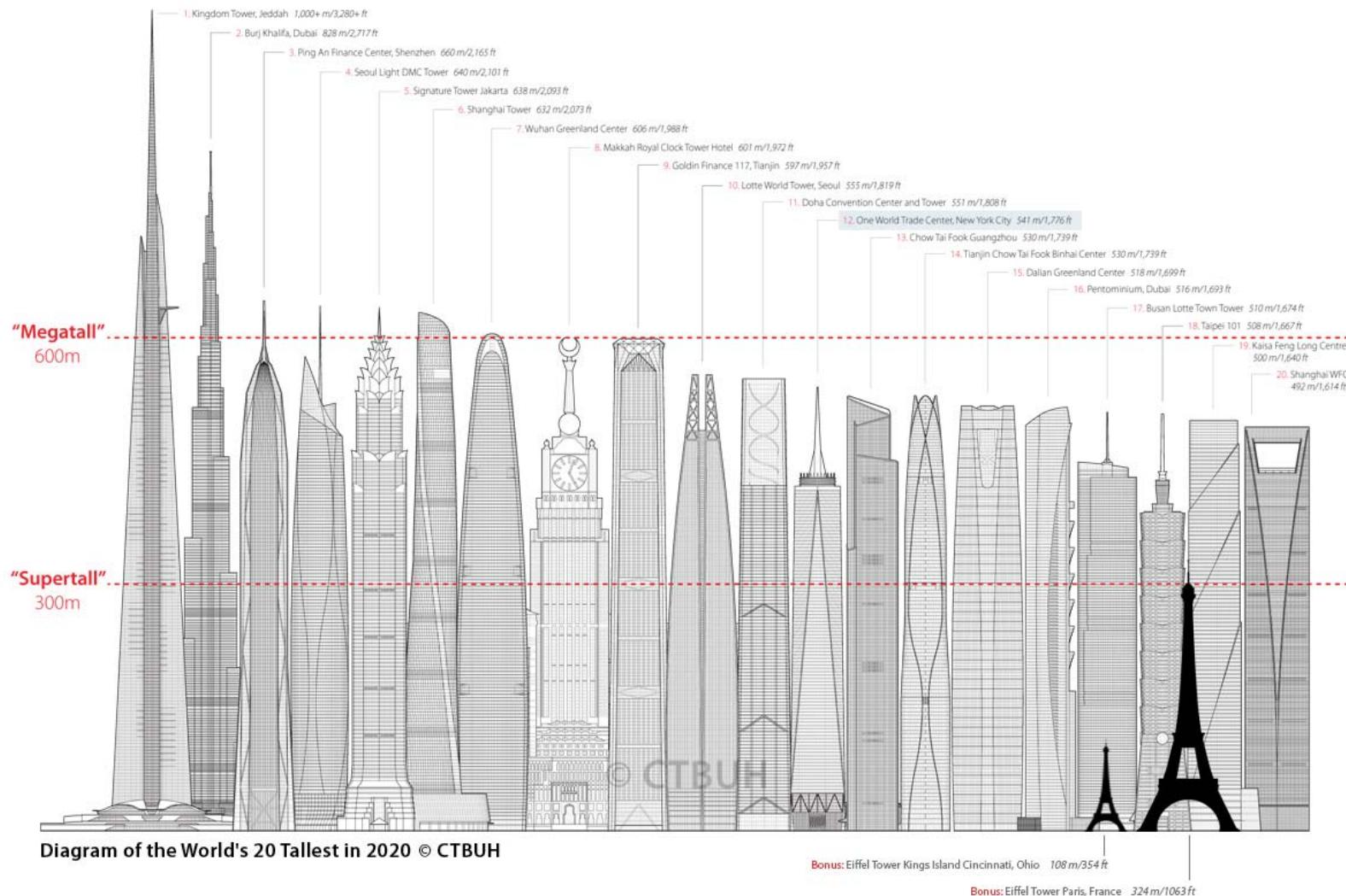
Tallest: 360 meters Average Height: 300 meters



# The History of Concrete / Istoria betonului

CTBUH Journal, 2013

## Nowadays in the world

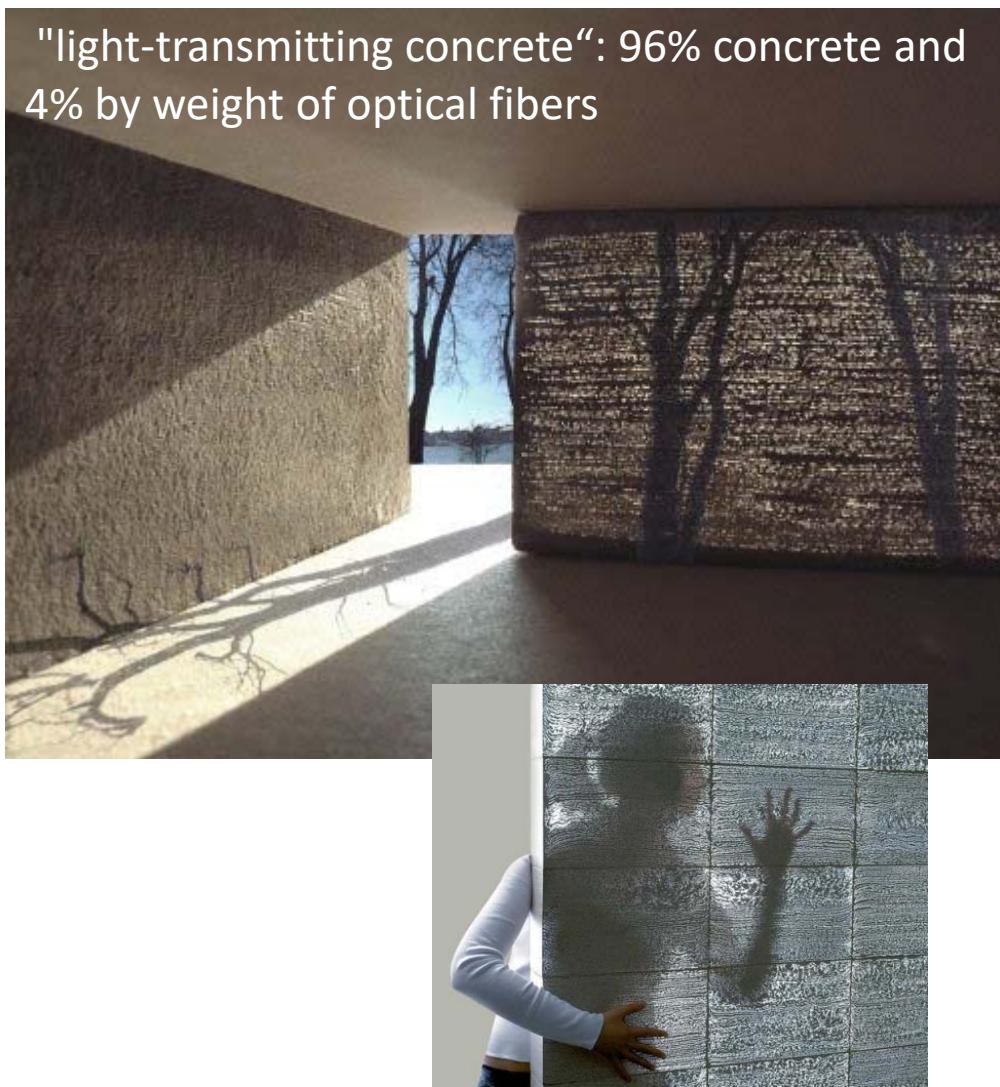


# The History of Concrete / Istoria betonului

Source: <http://en.structurae.de> + wikipedia

Nowadays

"light-transmitting concrete": 96% concrete and 4% by weight of optical fibers



2010, Burj Khalifa – Dubai (829.8 m)

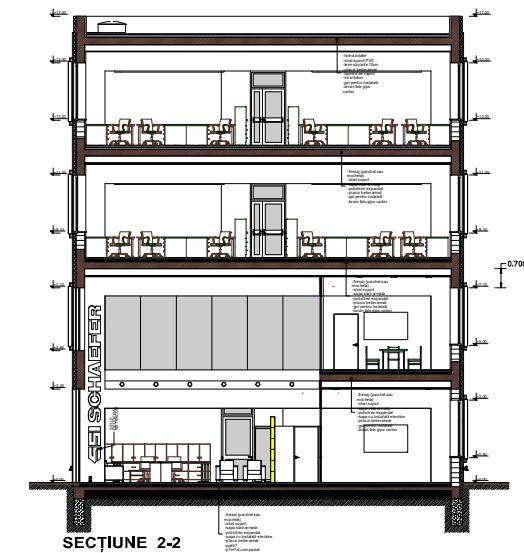
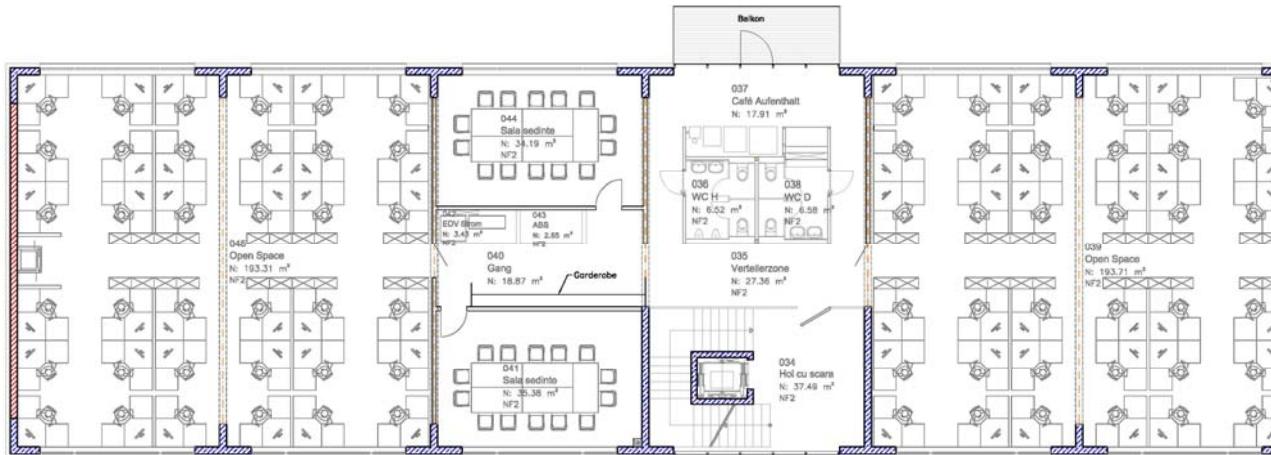


Built in 5 years with 1.5 milliard \$

## Elements of a RC building / Elemenetele unei structuri de beton armat

Architecture

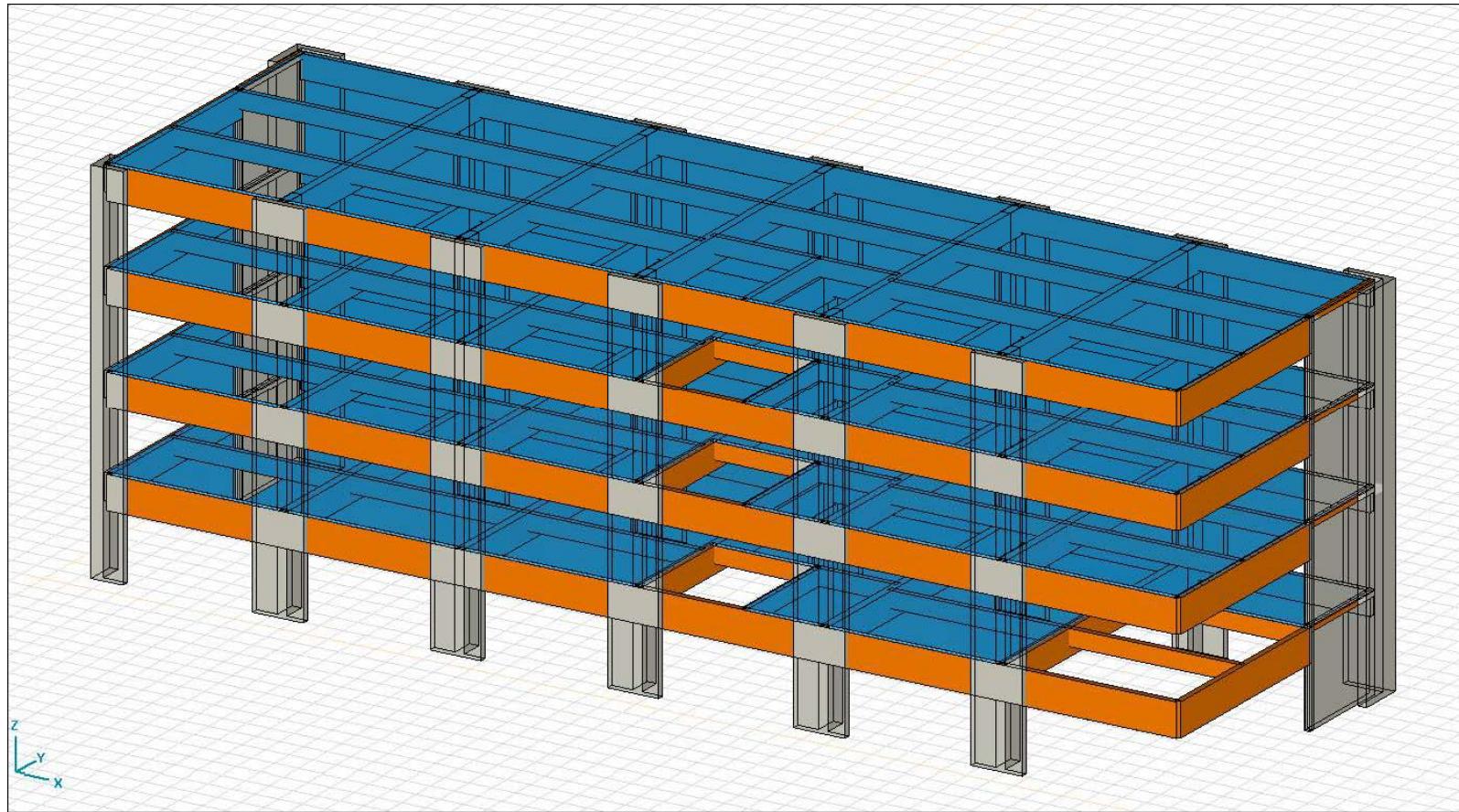
- concept → aesthetics + functionality
- based on imagination + functional requirements



## Elements of a RC building / Elemenetele unei structuri de beton armat

Engineering

- dimensioning → safety + economy
- based on calculus and design codes

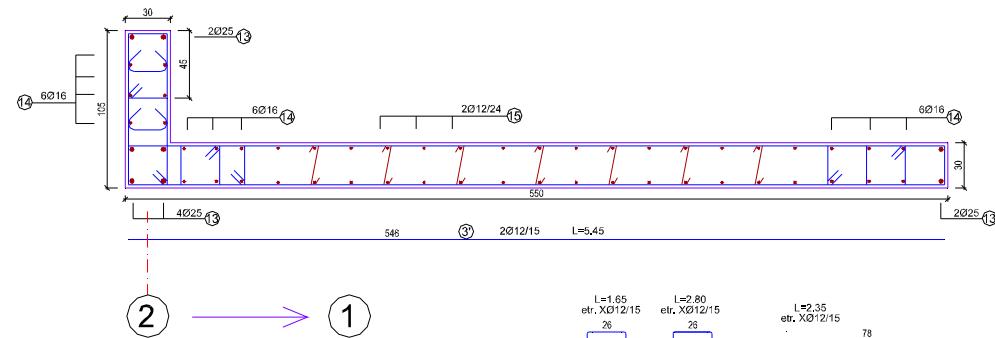
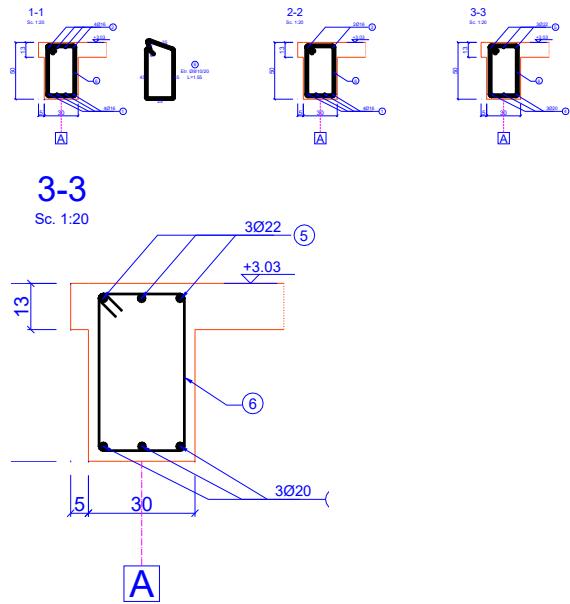
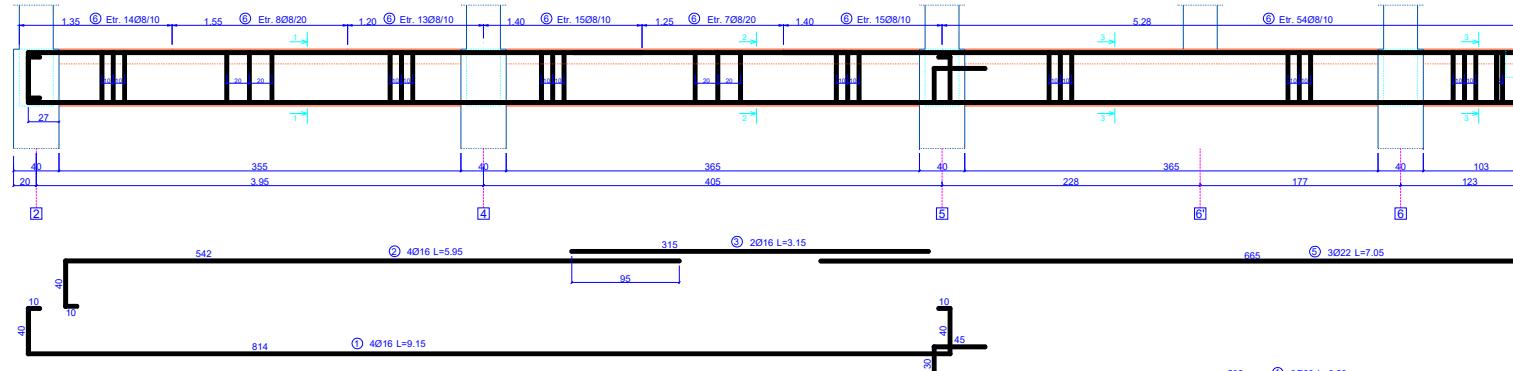


# Elements of a RC building / Elemenetele unei structuri de beton armat

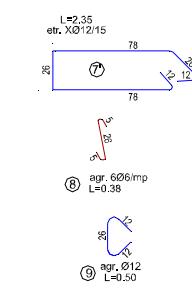
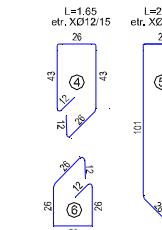
Structural engineer

→ detailing based on the design and codes

ARMARE GRINZI G A-1 (30x50cm)  
COTA +3.03  
Sc 1:50



2 → 1



## Component materials / Materiale componente

Concrete is a composite material, a mixture of:

- aggregate
- cement
- water
- additives
- admixtures



Obs:

- Aggregates provides higher density and resistance
- The fine part (sand) fill the gaps between large aggregates and increases the resistance of cement binder

Concrete:

- **heterogeneous** (composite) material
- anisotropic
- elasto-plastic material

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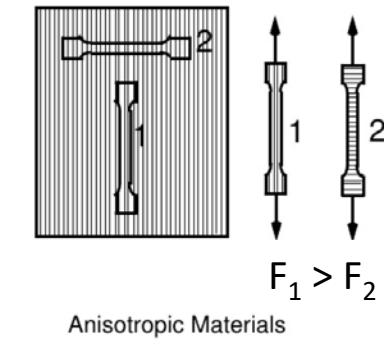
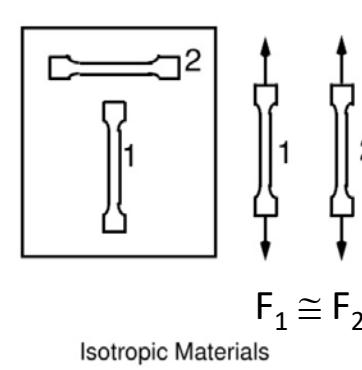


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## Component materials / Materiale componente

**Concrete is a composite material, a mixture of:**

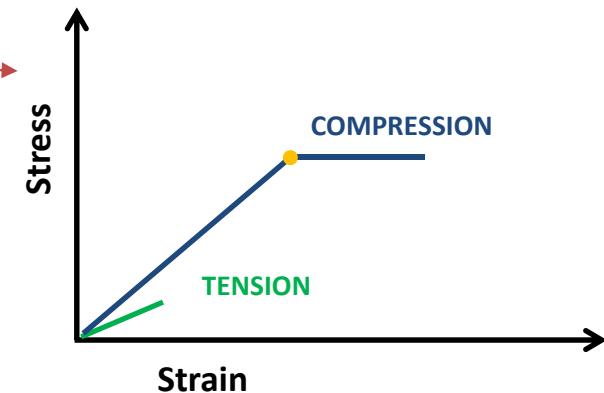
- aggregate
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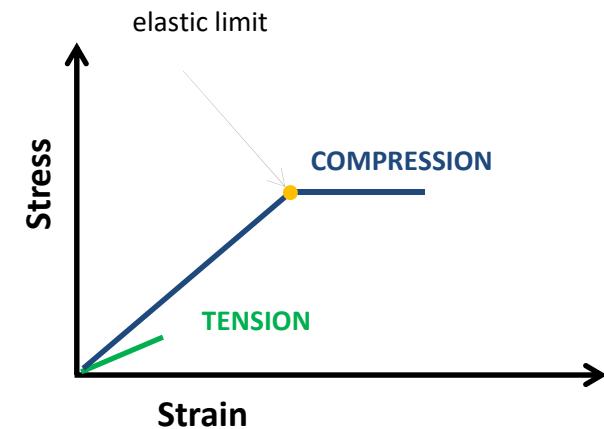


- Obs:*
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  - The fine part (sand) fill the gaps between large aggregates and increases the resistance of cement binder

**Betonul este :**

- heterogeneous (composite) material
- anisotropic
- **elasto-plastic material**

- *Elasticity: due to aggregates and cured cement paste*
- *Plasticity: due to microcracking*
- *Viscosity: due to uncured cement paste.*



## Behaviour of plain concrete, RC and PC/ Comportarea betonului simplu, BA și BP

### Good behavior in compression:

- Relatively high compressive strength  $f_c = 20 \dots 120 \text{ N/mm}^2$
- Ultimate strain (at failure) in compression  $\varepsilon_{cu} = 3.5 \dots 7 \text{ \%}$

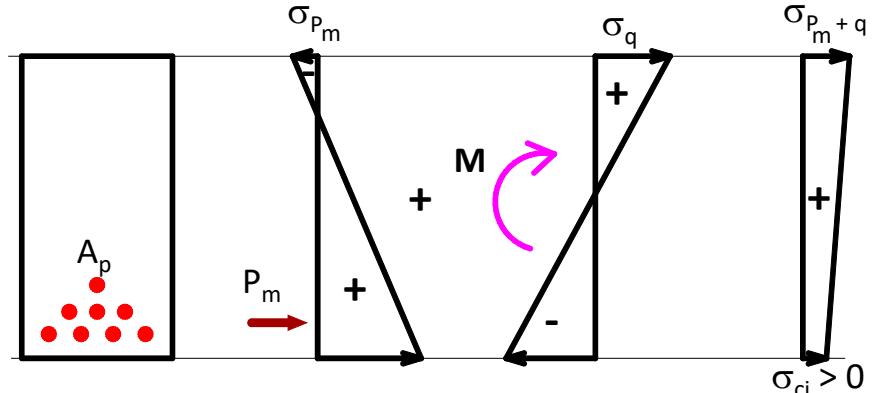
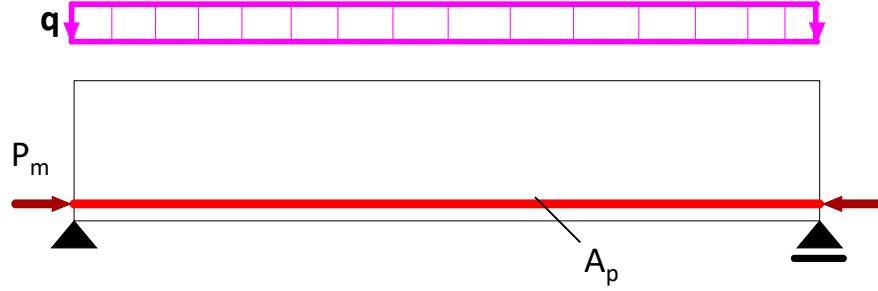
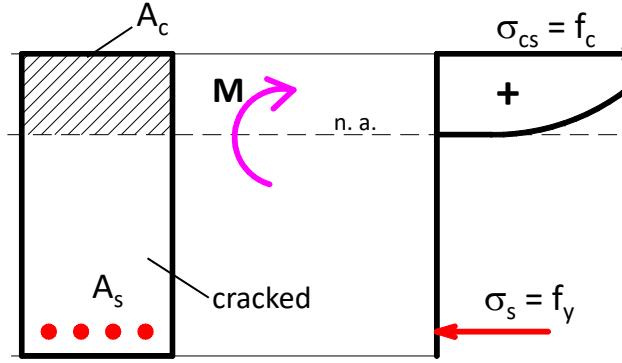
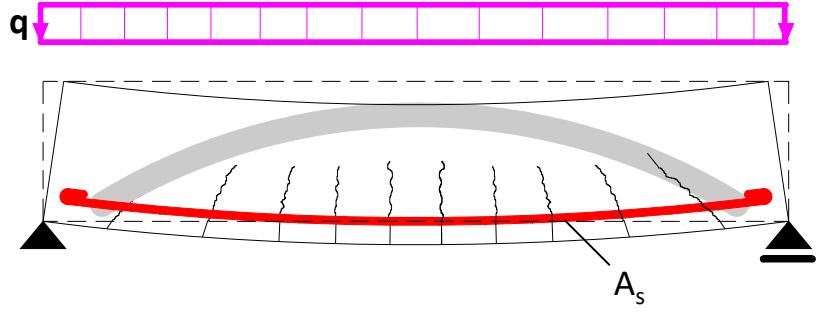
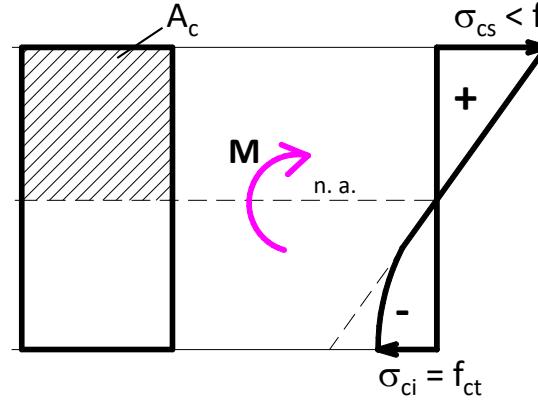
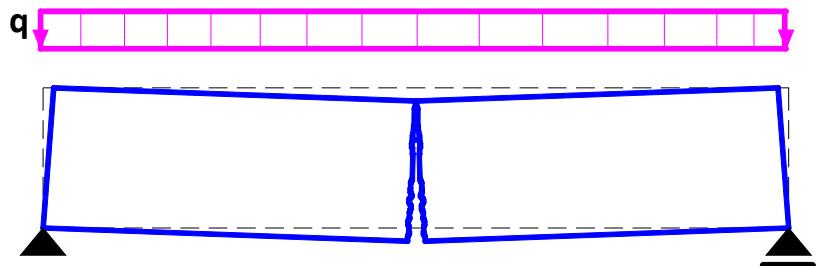
### Poor behavior in tension:

- Low tensile strength  $f_c / f_{ct} = 10 \dots 20$
- Strain in tension  $\varepsilon_{ctu} = 0.1 \dots 0.15 \text{ \%}$

Plain concrete could be used rationally in structures in which are subjected to compression

- solid/massive foundations
- roads basement
- some hydro-technical constructions

# Behaviour of plain concrete, RC and PC / Comportarea betonului simplu, BA și BP



## Reinforced Concrete / Betonul armat

### Advantages

- Relatively low investment to realize the structure
- High durability
- High fire resistance
- Various structural forms

*(fresh concrete easily takes formwork form)*



- Good behavior under external actions, due to high stiffness
- Possibility of prestressing, allows large span elements
- Parts of concrete are local materials (sustainability!)
- The properties of concrete can be made as needed *(strength, durability)*

S	P	V	E	N	I
R	T	L	E	R	E
E	R	E	S	E	V
C	O	N	C	R	E
Y	N	T	I	S	R
C	G	I	E	A	U
L	F	N	T	Y	X
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B	L	E	H	W	A
E	E	L	E	A	E

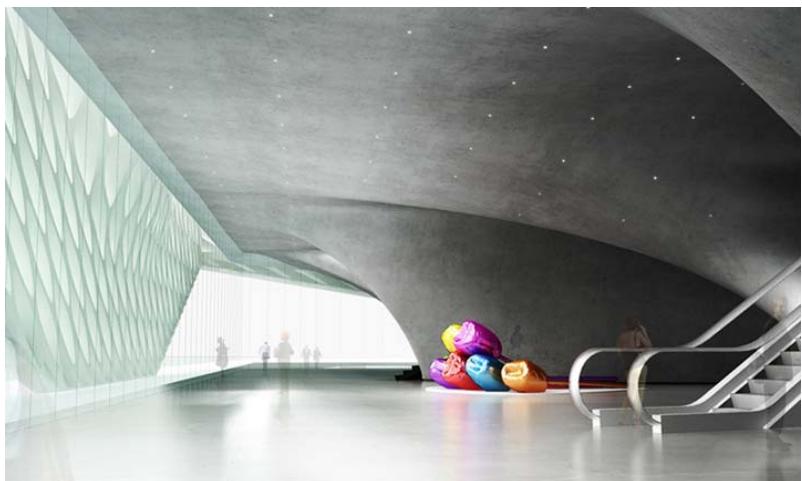
## Reinforced Concrete / Betonul armat

### Disadvantages

- Lower tensile strength, cause cracking → reinforcement corrosion occurs under certain conditions
- High weight-to-strength ratio → not allows slender structures with large spans
- Corrosion in aggressive environments can occur, but also in ordinary environments, in certain situations
- Permeability, due to porous structure of concrete → water can carry aggressive agents, or cause freeze-thaw cycles in concrete mass
- Formwork and scaffolding requires
- Subsequent changes or strengthening are difficult to make, sometimes leading to uncertain results
- The demolition is costly and the resulting materials is hard to be reuse
- Cement is polluting

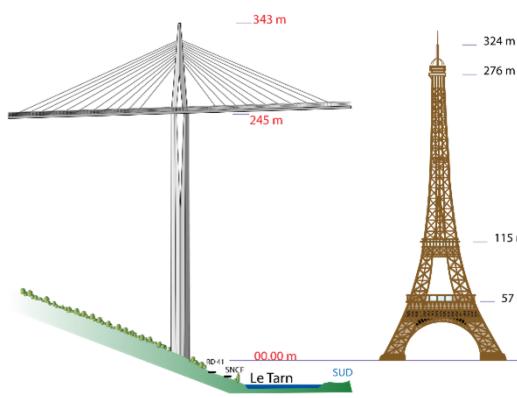
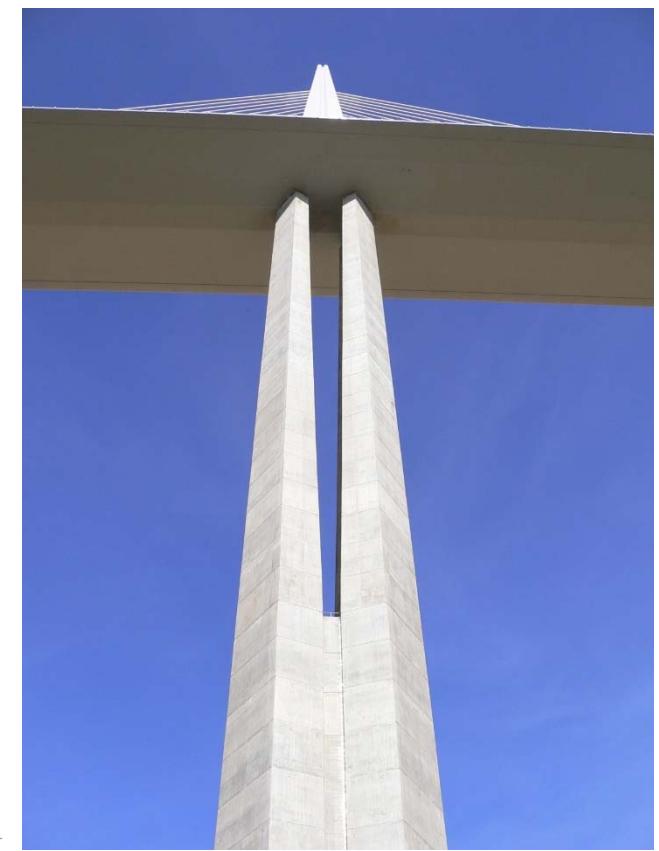
# Reinforced Concrete / Betonul armat

## The Broad Museum, Los Angeles



# Reinforced Concrete / Betonul armat

## Millau Viaduct, France



# Reinforced Concrete / Betonul armat



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*Professor*

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# THANK YOU FOR YOUR ATTENTION!