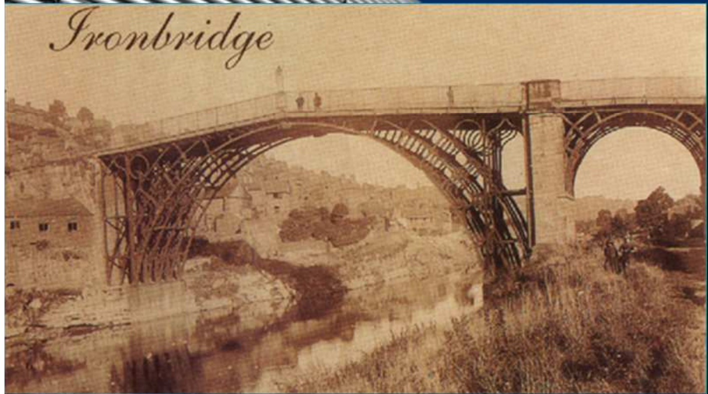
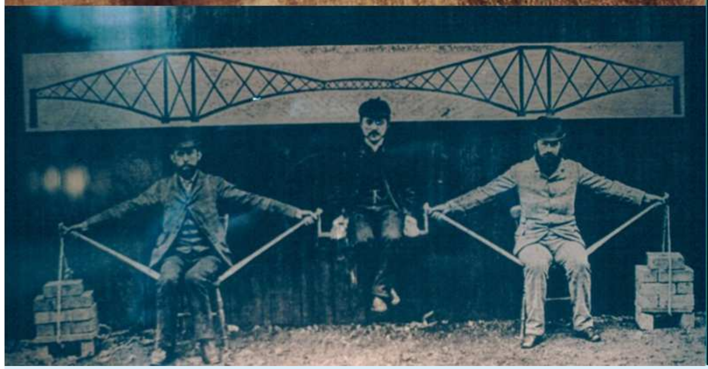




MECHANICAL PROPERTIES OF CAST IRON, MILD IRON & STEEL AT HISTORICAL STRUCTURES

Adrian DOGARIU

18/06/2014 – 8.30-10.00

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

520121-1-2011-1-CZ-ERA MUNDUS-EMMC

SYLLABUS

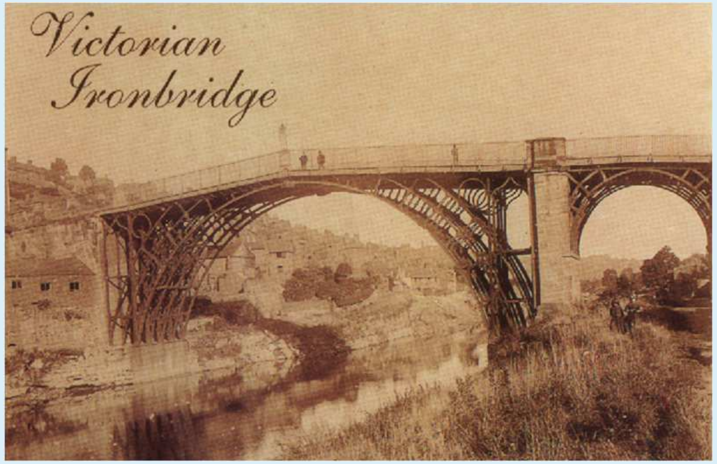
Mechanical properties of cast iron, mild iron and steel at historical structures

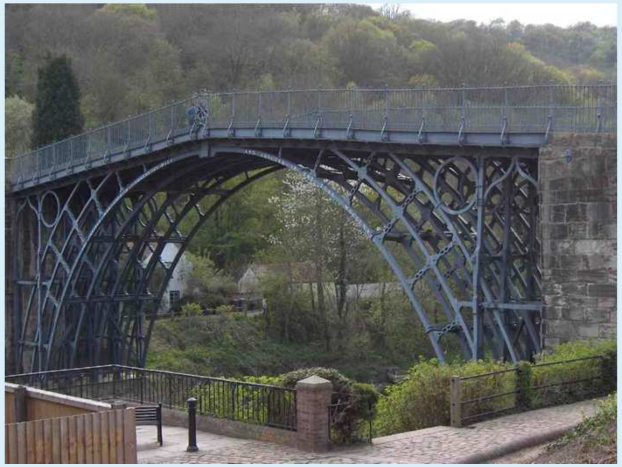
- Material used in steel structures – historical review

SIGNIFICANT STRUCTURES

1779: VICTORIAN IRONBRIDGE

- Universally recognized as one of the most important symbol of the Industrial Revolution.
- It is the first structural use of cast iron structures.
- Raising a bridge of this type became possible only after the discovery of cast iron obtained by melting iron with coke.



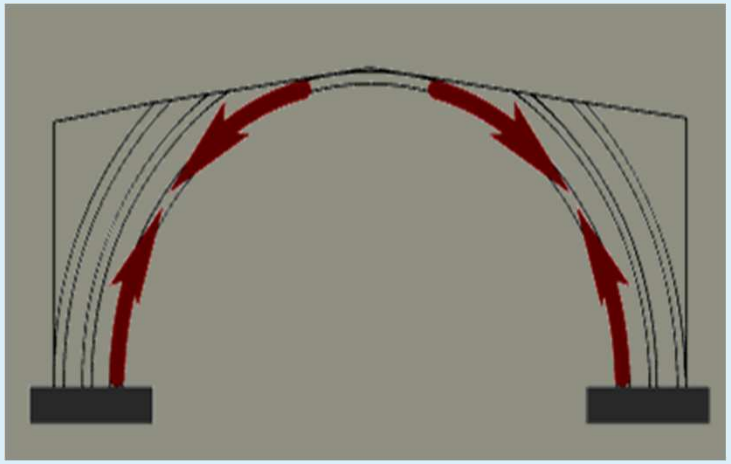


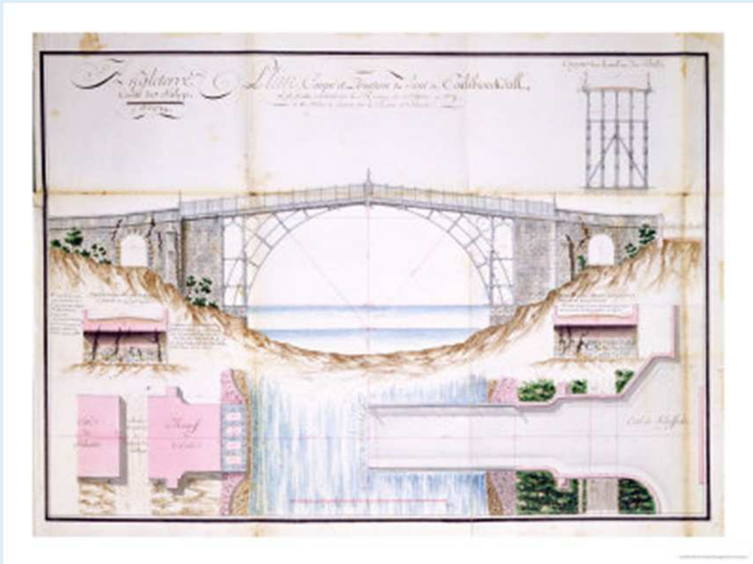
1779: VICTORIAN IRONBRIDGE

- No injuries were reported during the execution, which lasted three months, since the summer of 1779.
- Was the first arch bridge on the River Severn at Ironbridge in Shropshire, England, opened on July 2, 1779
- Although other construction activities devoted to the adjacent roads continued for another two years.

1779: VICTORIAN IRONBRIDGE

- Iron Bridge is built as an arch shape to overtake the loads by compressive forces and transmitting to the foundation soil.



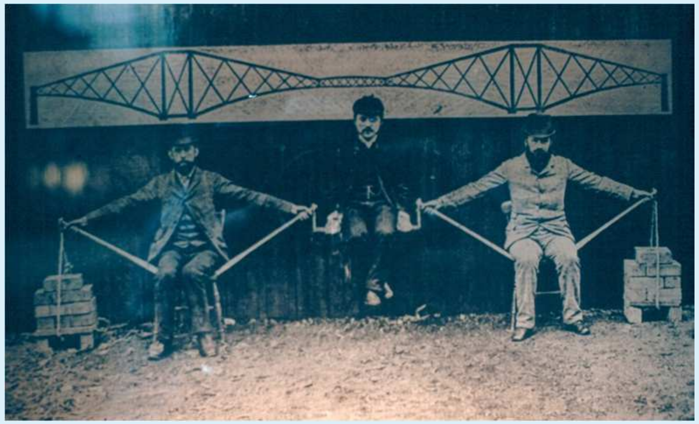


1779: VICTORIAN IRONBRIDGE

- The bridge was opened to traffic on January 1, 1781.
- Ironbridge Gorge is considered a World Heritage Site by UNESCO in November 1986.

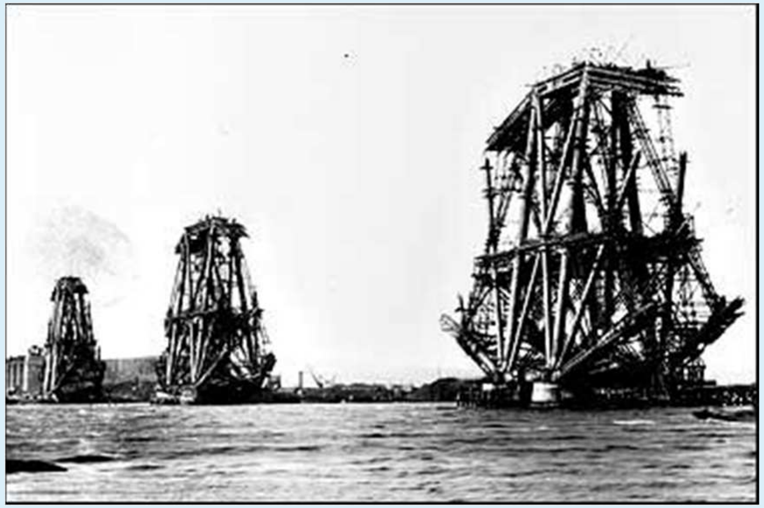
1881: FIRTH OF FORTH, SCOTLAND

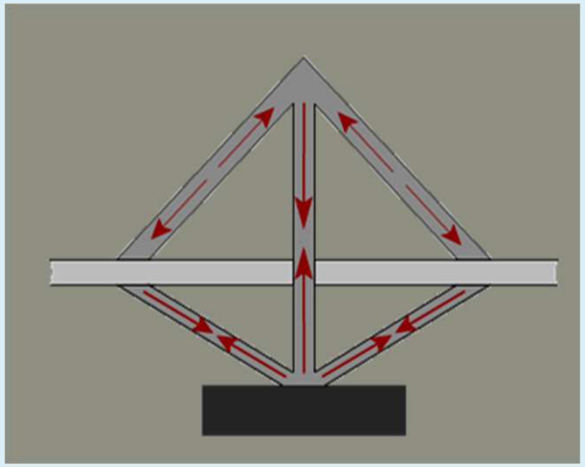
- This is the first bridge in the world built mainly forged in steel.
- Bridge has two large openings of 521 meters, with a total length of 2759 m
- Each opening consisting of a pair of cantilevers, that leaves the two main towers, connected by secondary hinged beams (Gerber system).



1881: FIRTH OF FORTH, SCOTLAND

- Diagonal elements made by means of the tubular cross-section starts from the top and from the bottom of the tower, and offer supports to the bridge beam
- The metallic members are subjected mainly to axial force either tensile or compressive forces, very often in bending (truss behavior)



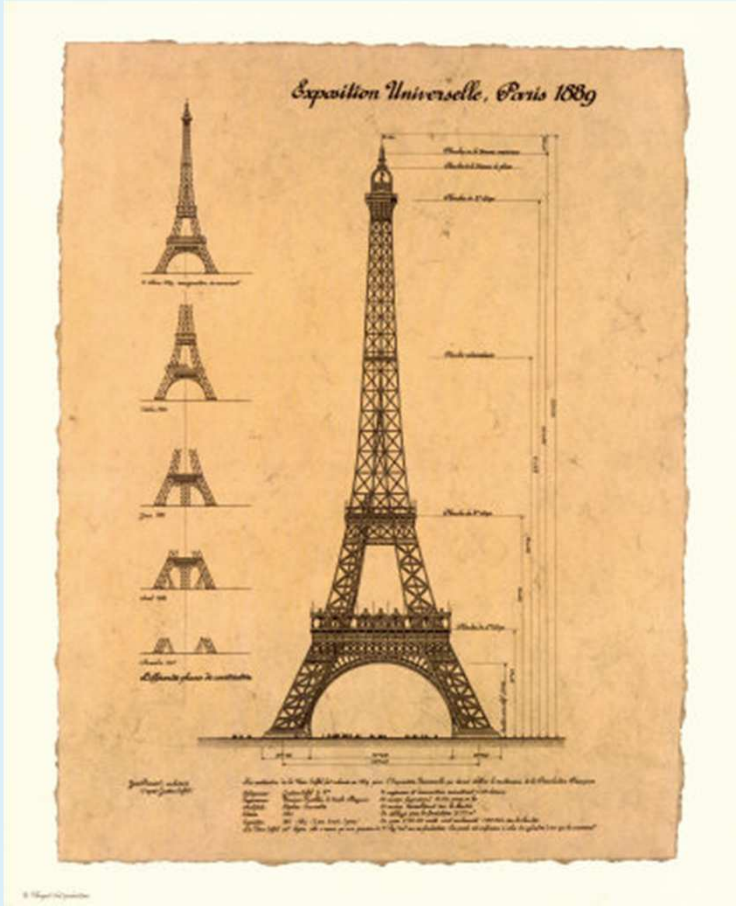


1881: FIRTH OF FORTH, SCOTLAND

- The bridge was opened on March 4th, 1890.
- The bridge is continuously painted, with its surface of 180 000 square meters.
- Since 2002, the bridge is protected against corrosion by an epoxy glass layer and a layer of gloss polyurethane to keep the special appearance of "Forth Bridge Red "

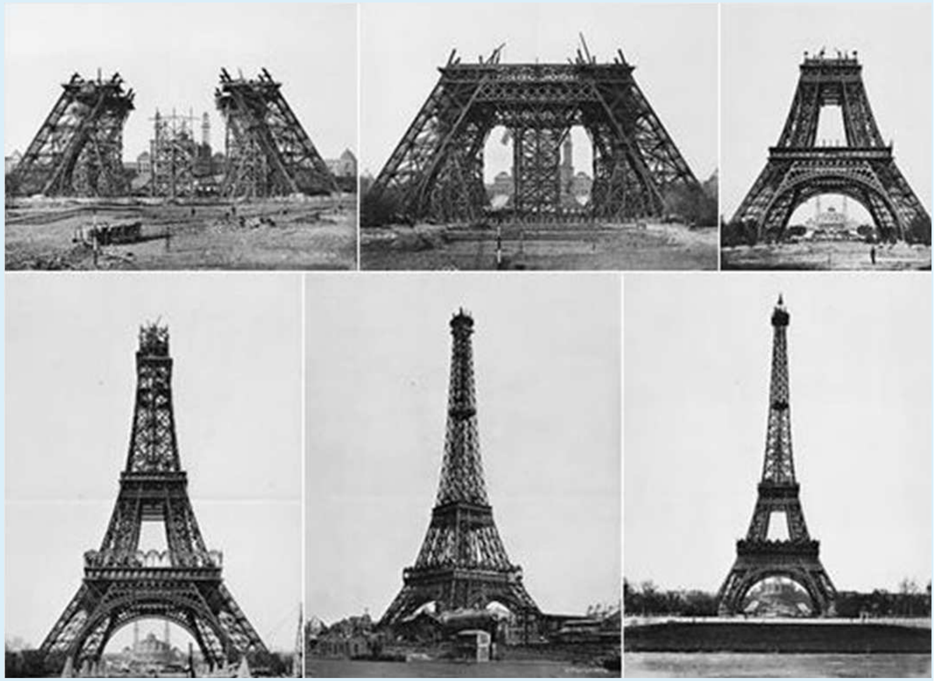
1882: EIFFEL TOWER, FRANCE

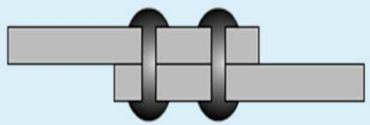
- Structural elements were made of wrought iron, with an approximate length of 5 m and connected by riveting on site.
- The four legs of 80 meters a length were assembled on the ground and raised above the ground with millimeter precision.



1882: EIFFEL TOWER, FRANCE

- 18038 pieces of 5 m length, with a dimensional tolerance of 0.1 mm were manufactured
- and 2.5 million rivets were used.
- It was built for the Universal Exposition celebrating the French Revolution
- Was opened on March 31, 1889.





1882: EIFFEL TOWER, FRANCE

- Thanks of its design the Eiffel Tower is one of the most recognizable structures in the world, becoming a symbol of the city of Paris.
- Contractor was Gustave Eiffel.
- It has a total weight of 10,100 tons and a height of 324m (including the flagpole) with 1665 steps.

1882: EIFFEL TOWER, FRANCE

1931: EMPIRE STATE BUILDING, USA

- Built with steel (low carbon steel - Bessemer steel) using 1930s technology, the Empire State Building (steel frame structure) was at the erection time and long after, the tallest building in the world, with a height of 443 meters.

1931: EMPIRE STATE BUILDING, USA

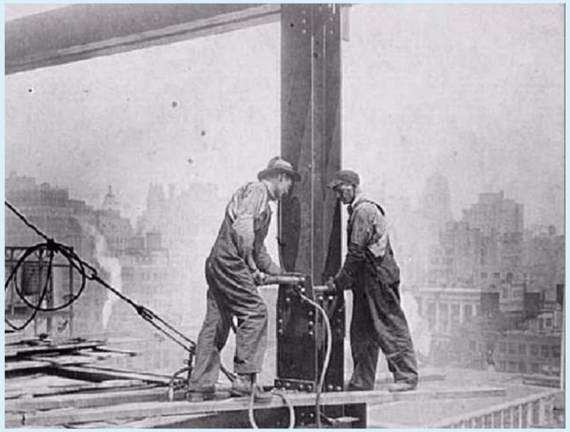
- On May 1, 1930, President Hoover officially inaugurated the building by pressing a button in Washington DC that lights on the building.
- Empire State Building is designed to serve as a lightning rod for the surrounding area. It is struck by lightning about 100 times per year.

1931: EMPIRE STATE BUILDING, USA

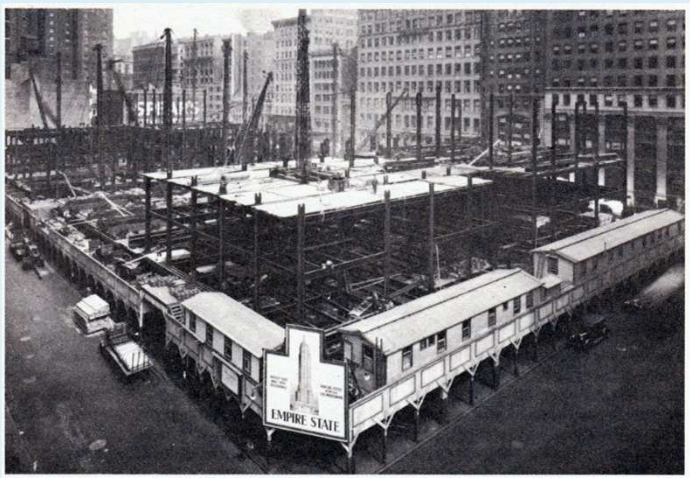








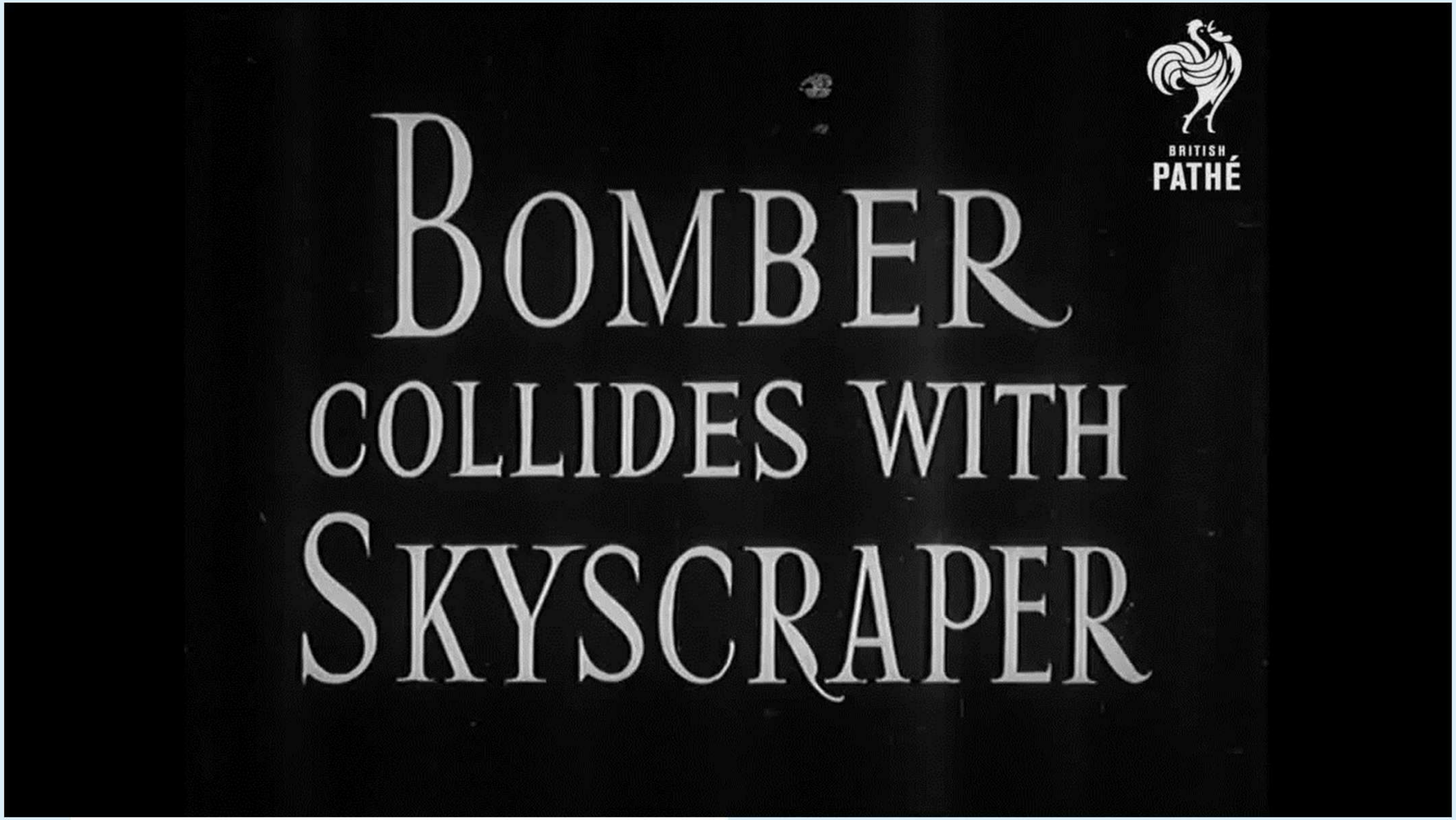
1931: EMPIRE STATE BUILDING, USA



1931: EMPIRE STATE BUILDING, USA

- Only a few skyscrapers such as the Chrysler Building at 341 meters could compare with achievement ESB technology execution.

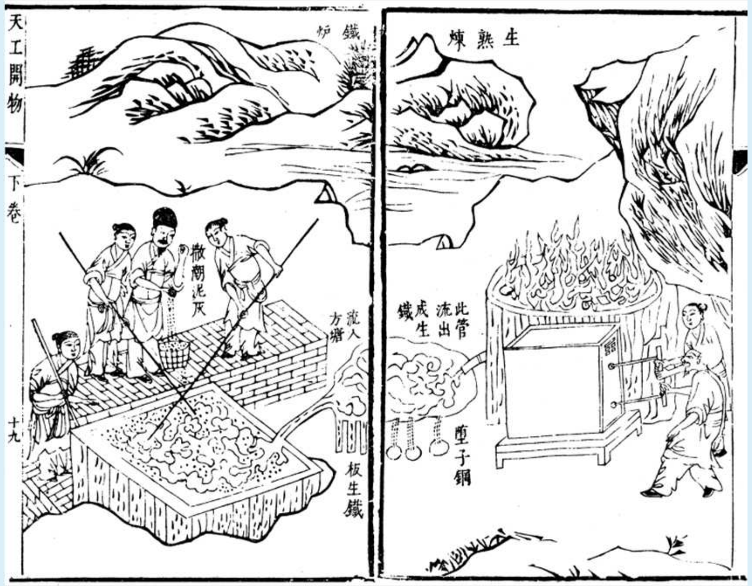
1931: EMPIRE STATE BUILDING, USA

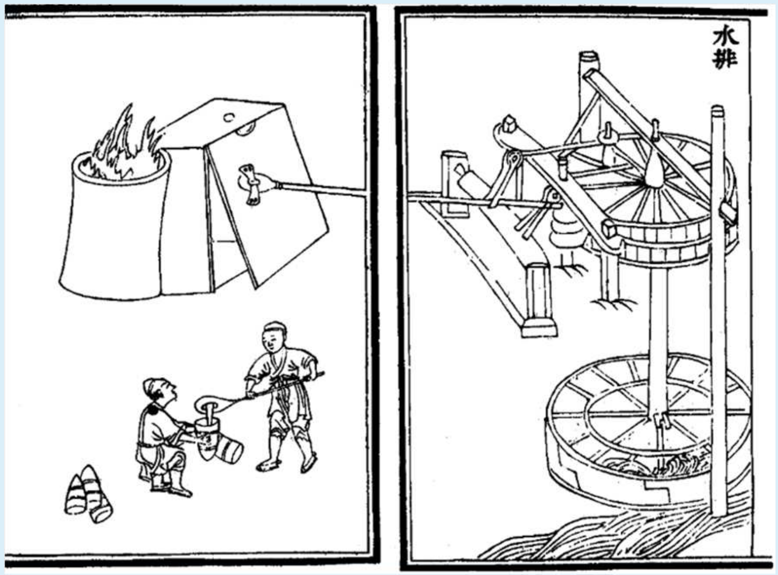


A BRIEF HISTORY OF IRON AND STEEL PRODUCTION

The production of iron began after 2000 BC in south-west or south-central Asia.

Iron was probably first discovered by chance by heating iron ore with charcoal fire was obtained the metal so appreciated.





MATERIALS USED IN STEEL STRUCTURES SINCE 1920

During in the middle ages most of the forests in Britain were destroy-ed in order to make make charcoal & smelt iron ore

Thus began the Iron Age, when iron replaced bronze in implements and weapons. This shift occurred because iron, when alloyed with a bit of carbon: is harder, more durable, and holds a sharper edge than bronze.

For over three thousand years, until replaced by steel after 1870, iron form human c sia, and Afric

A BRIEF HISTORY OF IRON AND STEEL PRODUCTION

Iron is the fourth most abundant element and makes up more than five percent of the earth’s crust.

Iron exists naturally in iron ore (sometimes called ironstone). Since iron has a strong affinity for oxygen, iron ore is an oxide of iron.

A BRIEF HISTORY OF IRON AND STEEL PRODUCTION

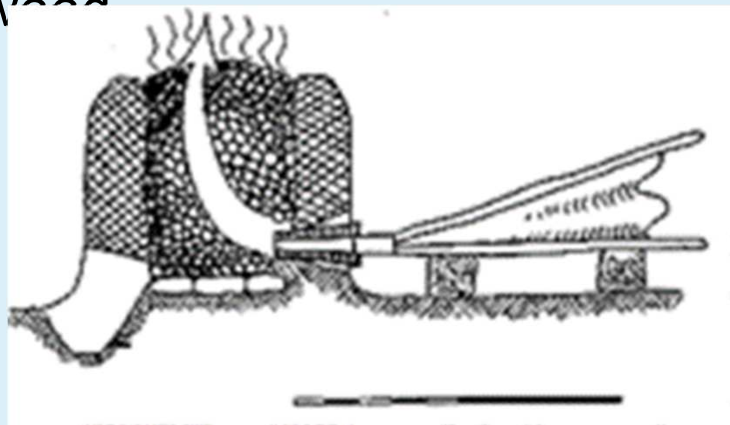
Smelting is the process by which iron is extracted from iron ore.

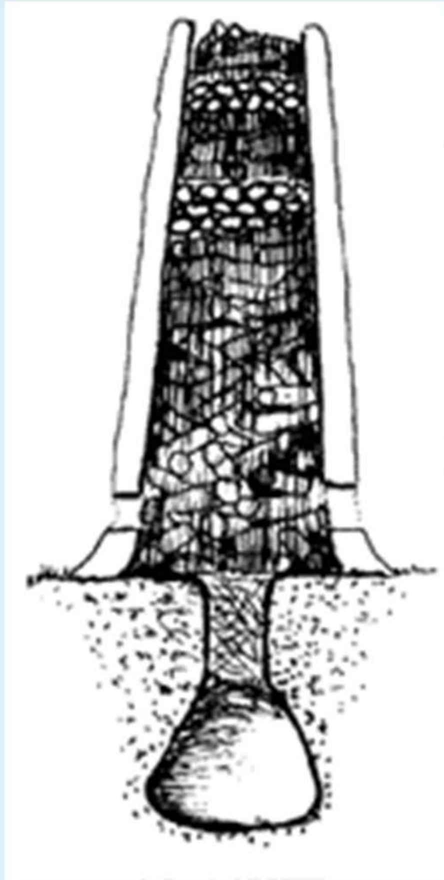
When iron ore is heated in a charcoal fire, the iron ore begins to release some of its oxygen, which combines with carbon monoxide to form ca

IRON – BLAST FURNACES

Found fire burned more efficiently when wind blowing led to the use of forced draft that increase air supply & rapidly produce iron

Primitive furnaces are the forerunners of modern blast furnaces, when charcoal was replaced by coke results product of coal & not w





WROUGHT IRON

The formation of this iron was as far as the primitive blacksmith got: he would remove this pasty mass from the furnace and hammer it on an anvil to drive out the cinders and slag and to compact the metallic particles.

This was wrought iron (“wrought” means “worked,” that is, hammered).

Wrought iron was the most commonly produced metal through most of the Iron Age.

CAST IRON / PIG IRON

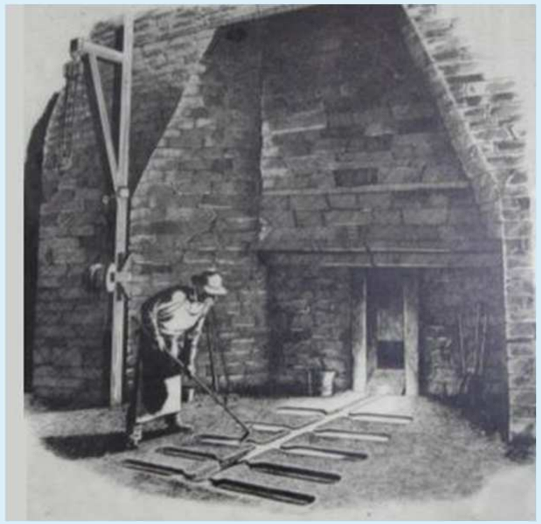
At very high temperatures: the iron begins to absorb carbon rapidly, and the iron starts to melt, since the higher carbon content lowers the melting point of the iron.

The result is cast iron, with 3 to 4.5 percent carbon:

- makes cast iron hard and brittle;
- it is liable to crack or shatter under a heavy blow,
- and it cannot be forged (that is, heated and shaped by hammer blows) at any temperature.

CAST IRON / PIG IRON

Molten cast iron would run directly from the base of the blast furnace into a sand trough which fed a number of smaller lateral troughs; this configuration resembled a sow suckling a litter of piglets, and cast iron produced in this way thus came to be called pig iron.



CAST/WROUGHT IRON

Iron could be cast directly into molds at the blast furnace base or remelted from pig iron to make cast iron stoves, pots, pans, firebacks, cannon, cannonballs, or bells (“to cast” means to pour into a mold, hence the name “cast iron”).

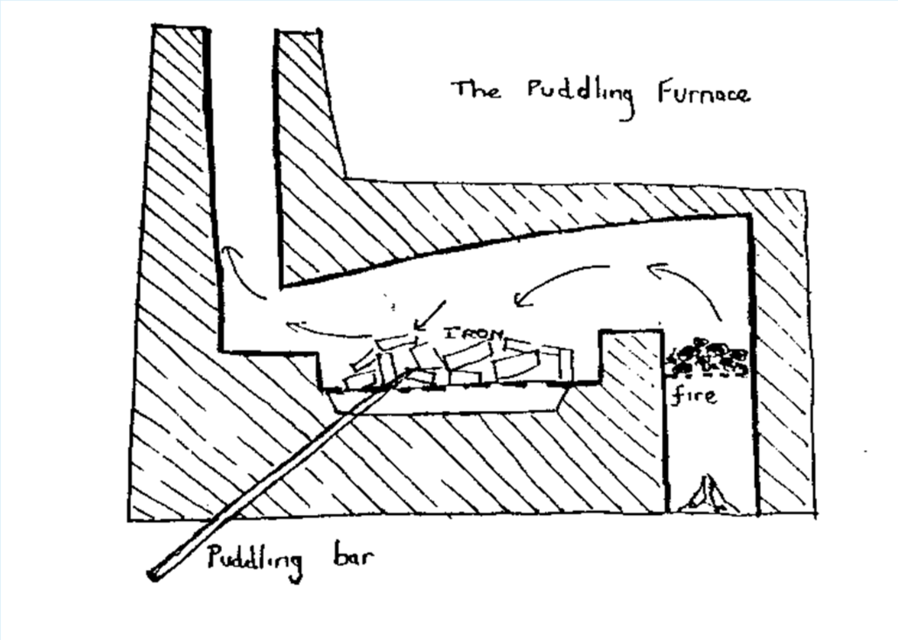
Casting is also called founding and is done in a foundry.

Cast pig iron can be transformed into the more useful wrought iron by oxidizing excess carbon out of the pig iron in a charcoal furnace called a finery.

After 1784, pig iron was refined in a puddling furnace (developed by the Englishman Henry Cort)

PUDDLER

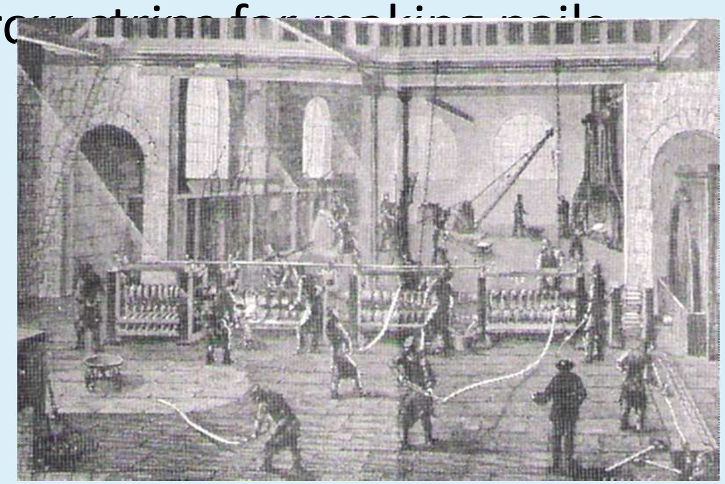
The puddling furnace required the stirring of the molten metal, kept separate from the charcoal fire, through an aperture by a highly skilled craftsman called a puddler; this exposed the metal evenly to the heat and combustion gases in the furnace so that the carbon could be oxidized out.



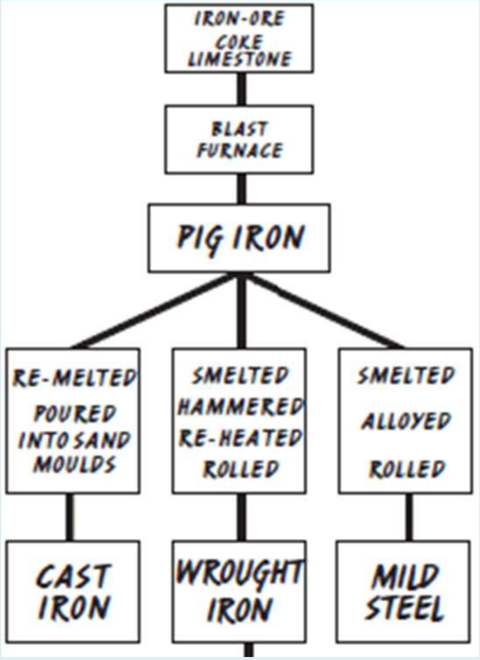
ROLLING MILL

As the carbon content decreases, the melting point rises, causing semi-solid bits of iron to appear in the liquid mass.

The puddler would gather these in a single mass and work them under a forge hammer, and then the hot wrought iron would be run through rollers (in rolling mills) to form flat iron sheets or rails; slitting mills cut wrought iron sheets into narrow strips for making nails.



IRON PRODUCTS



3 iron products are used in construction:

- Cast Iron,
- Wrought Iron
- Steel

Basic chemically difference is small consisting in the amount of carbon & other impurities which results in appreciably different mechanical properties

Material	Carbon content
Cast iron	2.0 – 4.5
Steel	0.2-1.5
Wrought iron	0.02-0.05

IMPURITIES EFFECTS

Contains varying quantities of other elements (impurities):

(a) Carbon → decreases malleability and increases hardness

(b) Silicon → prevent carbon metal solubility and increases fuseability

(c) Manganese → Increases malleability

(d) Sulphur → Increases hardness

(e) Phosphorus → metal more fusable

(f) Chromium → Increases tensile strength

(g) Copper → Increases corrosion resistance

STRENGTH AND CARBON CONTENT

Indicative properties

Material	Approx. range of carbon content (%)	Range of ultimate strength	
		Compression N/mm2	Tension N/mm2
Cast iron (grey)	2.25 – 4.0	400 – 1000	100 – 150
Wrought iron	0.02 – 0.05	250 – 400	250 – 400
Steel (weldable)	0.2 – 1.0	350 - 700	350 - 700

HISTORIC PERIODS

Main Iron & Steel Periods:

Cast Iron Period

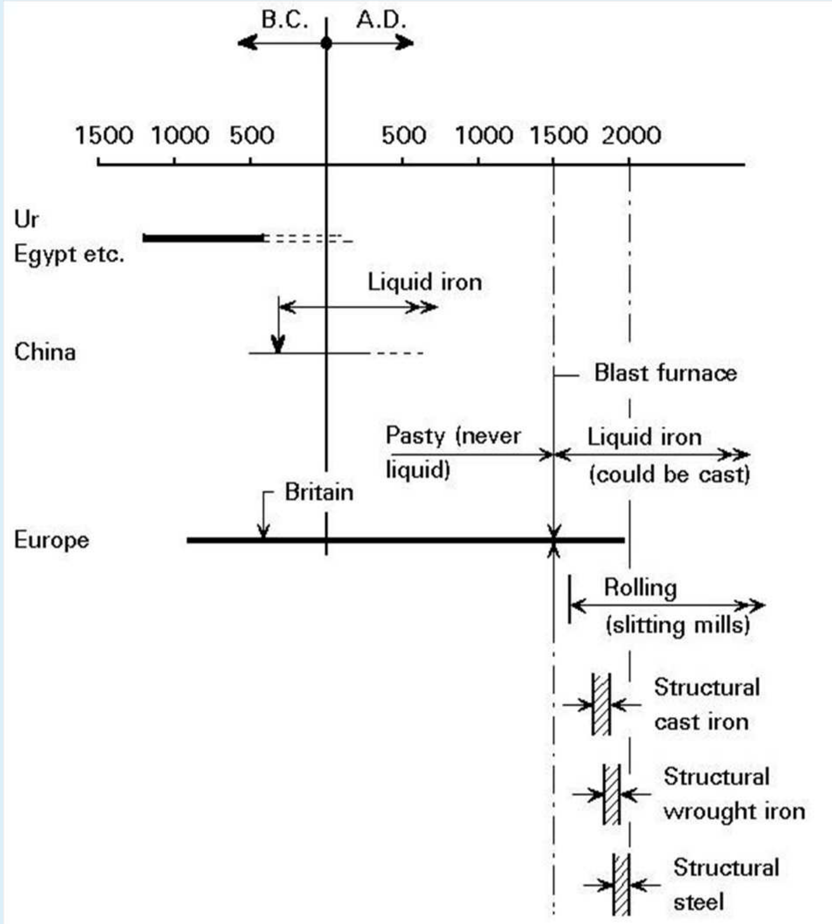
- 1780-1850 (up to 1900)

Wrought Iron Period

- 1850-1900

Steel Period

- 1880 - Present Day



HISTORIC PERIODS

Progress in construction of steel structures was accelerated by metals manufacture expansion recorded after 1785 mainly due to the appearance of cast & wrought iron

At the end of 19th century, steel began to be produced using various technologies, devised: Bessemer, Siemens-Martin & Thomas

After the World War II was introduced Linz—Donawitz (LD) system used in East Europe until 1980s and replaced by continuous steel casting

HISTORIC PERIODS

Steel is a higher-quality material than wrought iron especially regarding the mechanical properties & chemical composition stability

Since 1926 one standardized name steel was used for all forged iron manufactured in fluid state

Manufactured steels mechanical properties were gradually defined in various regulations and later in technological standards

HISTORIC PERIODS

For steel structures design it is of a particularly importance to determine the manufactured steels strength characteristics.

Allowable stress method starts to be used for assessing reliability of structures. A Regulation was published in Vienna 1904 and after, translated and published in 1911, Prague

It contains a overall review of allowable stresses for bridge construction materials. A further improvement of steel properties was recognized and decrees → 1915 & 1921 → & decisions → 1921 & 1923

HISTORIC PERIODS

Allowable stresses values were considered graduated according with the bridge elements span. This fact is based on the fact that prescribed values consider dynamical effects. Maximum allowable stresses values was limited to a absolute values of

- 90 MPa for wrought iron
- 100 to 115 MPa for fluent iron

In 1972 the reliability assessment of steel bridges design the partial safety factors were incorporated. Steel bridges European standard introduce in standards the steel strength characteristic and corresponding material resistance partial factors

HISTORIC PERIODS

To verify the existing structures reliability must use partial safety factors characteristic & design strength values steels produced since beginning 20th century

Year of production	Material strength class		Basic allowable stress σ_{allow}[MPa]	Characteristic strength value f_{yk} [MPa][2]	Design strength value f_{yd} [MPa][2]
Until 1904[1]	Wrought iron		130	210	180
Until 1937	Float steel		140	230	200
1938–1950	S 235		140[3]	230	200
	S 355		195	335	265
		Thickness in			
	S 235	mm	140	230	200
		≤25			
		>25	130	210	180
1951–1969	S 355	≤16	210	360	285
		>17	200	340	270
	S 235	≤25		260	210
1969–1986		>25		250	200
	S 355	≤50		353	280

1 For float steel from the period after 1 January 1895 and before 1 January 1905

CAST IRON AS A STRUCTURAL MATERIAL

Cast iron use as building material dates back in the 1800’s.

Wrought iron was introduced a few years later

At the beginning of the century the steel took over becoming main structural material

Cast iron name implies is "cast" or shaped pouring molten metal into a mold and solidify:

wide variety, very intricate, possible very strong in compression but relatively weak in tension, much stiffer than timber, but brittle

CAST IRON AS A STRUCTURAL MATERIAL

Cast iron types: Grey Iron, White Iron, Mottled Iron

- Grey Cast Iron was best quality pig iron & most reliable
- White Cast Iron was less rust than grey, harder and brittle & less reliable
- Mottled Cast Iron was is intermediate between white and gray iron and shows a mottled surface on fracture

CAST IRON AS A STRUCTURAL MATERIAL

Cast iron used in construction industry can be divided in 3 main categories:

Historic cast iron

we found mainly grey cast iron, which was widely used in structures between 1780 & 1880

also including malleable cast iron which was made from white iron castings heat treatment

The most notable characteristics of historical cast iron is that pose greater compression strength than in tension and have a non-linear behavior under tensile load

CAST IRON AS A STRUCTURAL MATERIAL

Cast iron used in construction industry can be divided in 3 main categories:

Modern grey cast iron

virtually the same with historic grey iron but, generally having a higher quality

Its use is covered by British Standards, but is mainly used in mechanical engineering applications rather than in structure ones

CAST IRON AS A STRUCTURAL MATERIAL

Cast iron used in construction industry can be divided in 3 main categories:

Ductile (malleable) cast iron, or spheroidal graphite cast iron

Have little used in nowadays construction industry

Also are covered in the British Standards the major future as structural material

Is relatively modern appear after 1940

CAST IRON AS A STRUCTURAL MATERIAL

Type of cast iron	Nominal composition (% by weight)	Microstructure	Physical properties	Uses	Notes
Grey	C 3.4, Si 1.8, Mn 0.5	Graphite in flake form in an iron matrix. Flakes form discontinuities.	Strong in compression. Relatively weak in tension. Good resistance to corrosion. Easily machined and cut. Very large castings practicable.	Main form of cast iron used in construction, for columns, beams, decorative panels etc., as well as machinery.	Historic cast iron nearly all grey iron. Little used in construction today except for pipes, pipe fittings, manhole covers, etc.
White	C 3.4, Si 0.7, Mn 0.6	No free graphite. Carbon combined with iron as hard carbides. Low equivalent carbons. Low silicon content.	Very hard and very brittle. Machined by grinding only.	Surfaces needing high resistance to abrasion.	Virtually irrelevant to construction industry.
Malleable	C 2.5, Si 1.0, Mn 0.55	Made by prolonged heat treatment of white iron castings. Carbides transformed into graphite in nodular form with few discontinuities in iron matrix.	Very strong in tension as well as compression, with good ductility.	Hinges, catches, step iron and similar castings of limited size. Decorative panels of fragile design.	Likely to be superseded by ductile iron which has similar properties and can be cast in a wide range of section thickness.

CAST IRON AS A STRUCTURAL MATERIAL

Cast Iron factor of safety (usually 4)

The working stresses, ultimate tensile & compressive strengths of cast iron varied appreciably

Description of Iron		Compressive Strength	Tensile Strength
		tons/sq inch	
Lowmoor Iron	No 1	25.2	5.7
Lowmoor Iron	No 2	41.2	6.9
Clyde Iron	No 1	39.6	7.2
Clyde Iron	No 2	45.5	7.9
Clyde Iron	No 3	46.8	10.5
Blenavon Iron	No 1	35.9	6.2
Blenavon Iron	No 2	30.6	6.3
Calder Iron	No 1	33.9	6.1
Coltness Iron	No 3	45.4	6.8
Brymbo Iron	No 1	33.8	6.4
Brymbo Iron	No 3	34.3	6.9
Bowling Iron	No 2	33.0	6.0
Ystalyfera Iron	No 2 (anthracite)	42.7	6.5
Ynis-cedwyn Iron	No 1	35.1	6.2
Ynis-cedwyn Iron	No 2	33.6	5.9
Average		34.24	6.77

CAST IRON AS A STRUCTURAL MATERIAL

Very hard & brittle

Strong under compression

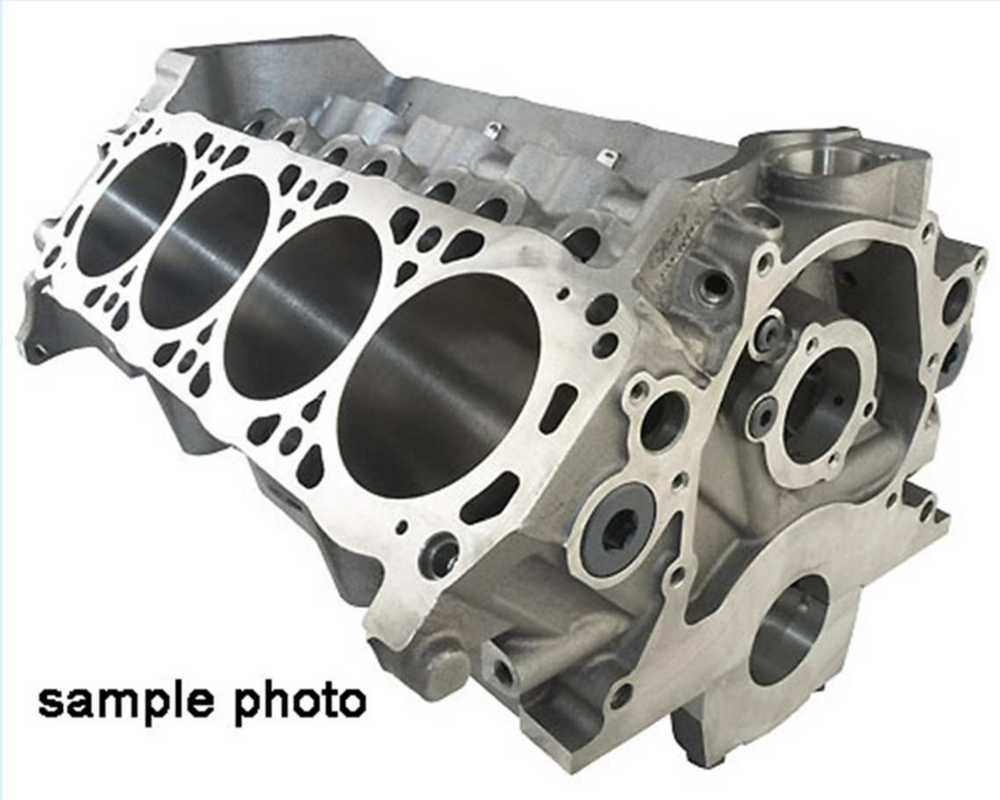
Suitable for casting [can be pour at a relatively low temperature]

Engine block, engineer vices, machine parts

Casting is generally performed by pouring molten steel into sand molds.

Casting is used instead of wrought methods when the steel product to be made is of such size and/or complexity that it is uneconomical to produce by other methods.

CAST IRON AS A STRUCTURAL MATERIAL



CAST BARS & ENGINE BLOCK

CAST IRON PERIOD (1780-1850)

Cast iron arch bridges in Britain

Thomas Wilson's Wear Bridge, 1792-6 wrought iron strapping to cast voussoirs - 72 m span

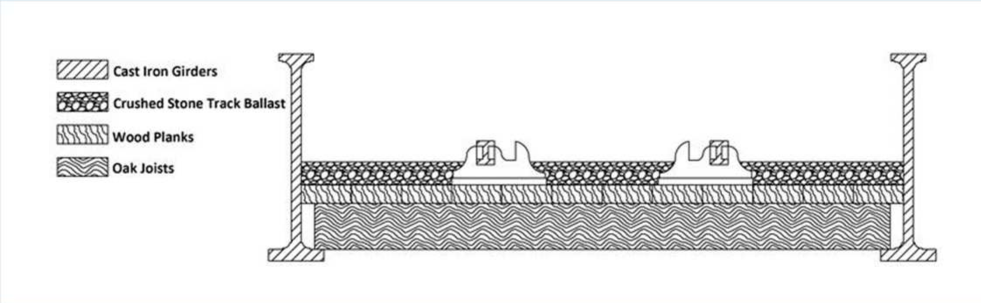
Rennie's Southwark Bridge, 1819 - 73m span

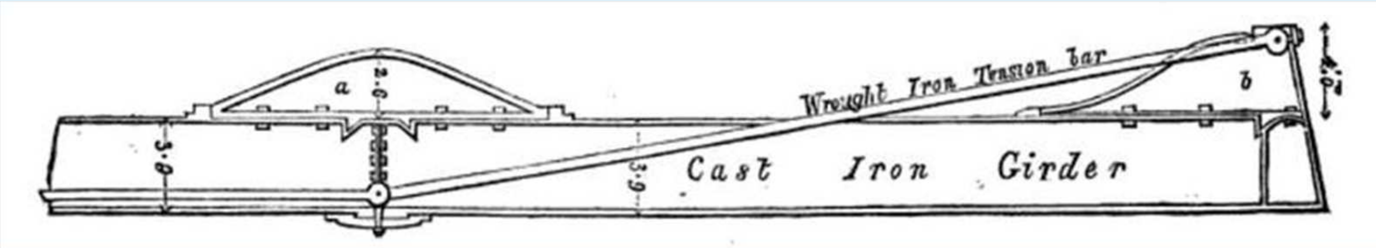
Telford's Mythe Bridge at Tewkesbury (1823-26) - 52m span great lightness & total structural logic

CAST IRON PERIOD (1780-1850)

Problems arose, bridges collapsed shortly after opening

Dee bridge disaster conducted to demolished & rebuilt of many similar bridges



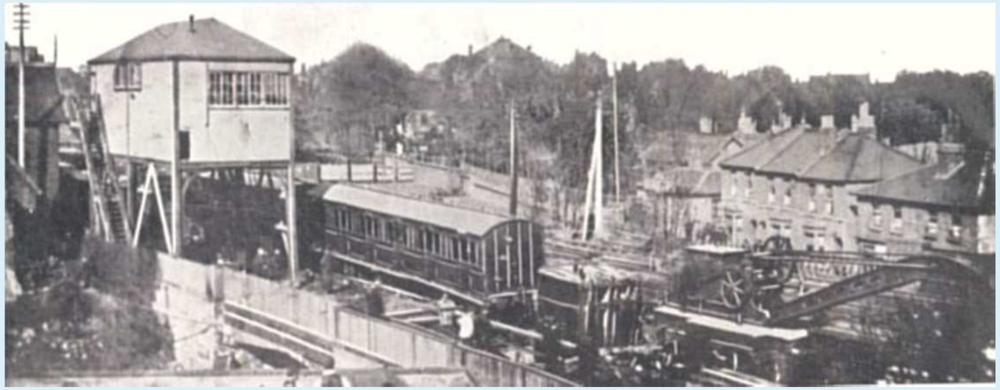


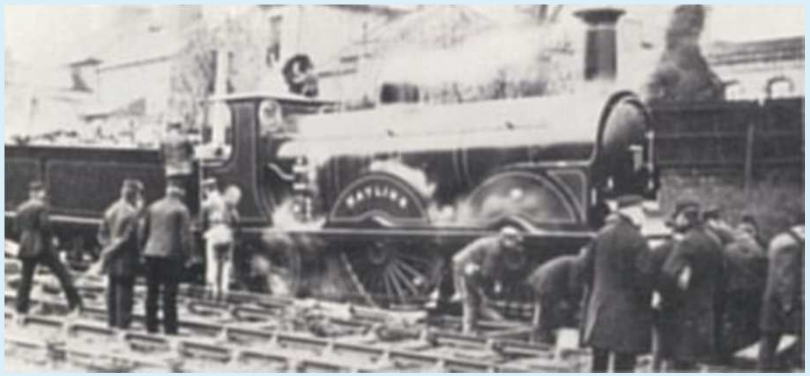
CAST IRON PERIOD (1780-1850)

Cast iron continued to be used structural support until the Tay Rail Bridge disaster in 1879

CAST IRON PERIOD (1780-1850)

and culminating with Norwood Junction rail accident, 1891





CAST IRON PERIOD (1780-1850)

Cast iron was strong enough to support heavy machinery but vulnerable at frequent fires that occurs in factories

Numerous building collapses because of large cast iron beams brittle fracture

Cast iron widely used for bridge construction for the new railway system sometimes with horrific results especially in the case of cast iron girders which were used instead of arches (Water Street terminus Liverpool & Manchester Railway, 1830)

CAST IRON PERIOD (1780-1850)

CAST IRON IN BUILDINGS

In case of all buildings fire was recurring problem for timber structures

This was the reason of very early cast iron application for columns supporting, vast cooker hood & chimney 1752 in Alcobaça Monastery kitchen in Portugal

CAST IRON PERIOD (1780-1850)

CAST IRON IN BUILDINGS

In Britain cast iron was used in early 1770^{s}:

at churches partly for Gothic ornament cheap reproduction

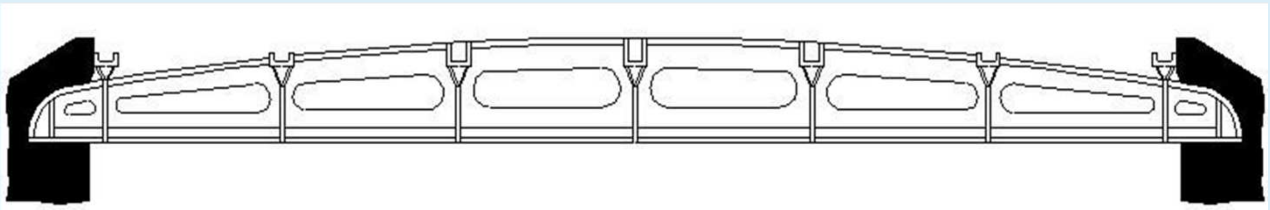
structural columns multi-storey textile mills,

In 1790 cast iron first shown a major future building structures disastrous fire in Albion Mill, Blackfriars Bridge 1791

CAST IRON PERIOD (1780-1850)

Biggest incentive was developed of totally incombustible solution cast iron & brick interiors. But this solution limits the floor spans at only 2.5 to 3 m in both direction. Later when iron mill construction spread appears warehouses and gradual span increase

Public buildings & large houses ask for long-span floors. Because timber had inadequate sag or bounce at spans above 6-7 m. The interest was increased for cast iron floor beams which reach length up to 12 m spans (British Museum early 1820).

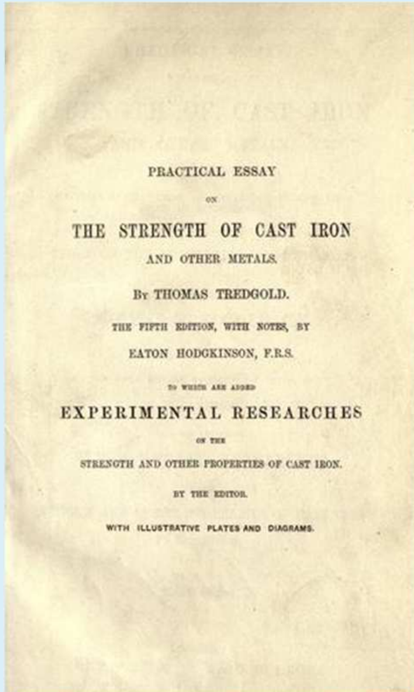


CAST IRON PERIOD (1780-1850)

Highest point reached at cast iron flooring development Charles Barry's Westminster Palace 1840

Up to mid 1840^{s} cast iron was a wonder material. A little is known about who actually fixed the size & shape of the beams used by architects.

Tredgold's cast iron book 1824 *A Practical Essay on the Strength of Cast Iron and other Metals* was undoubtedly influential but dangerously error in some respects



PRACTICAL ESSAY

ON

THE STRENGTH OF CAST IRON

AND OTHER METALS.

BY THOMAS TREDGOLD.

THE FIFTH EDITION, WITH NOTES, BY

EATON HODGKINSON, F.R.S.

TO WHICH ARE ADDED

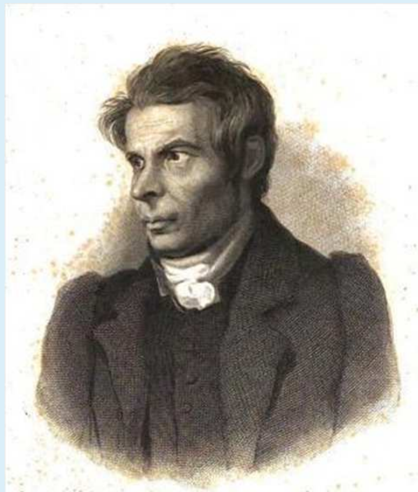
EXPERIMENTAL RESEARCHES

ON THE

STRENGTH AND OTHER PROPERTIES OF CAST IRON.

BY THE EDITOR.

WITH ILLUSTRATIVE PLATES AND DIAGRAMS.



CAST IRON PERIOD (1780-1850)

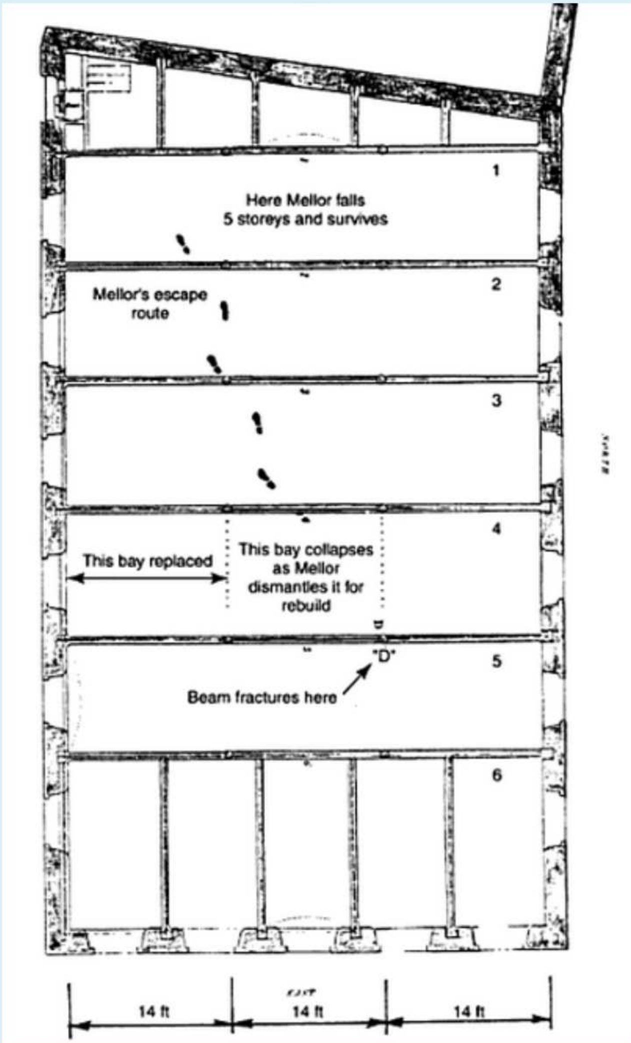
Whole range of cast iron new uses between 1810 & 1840 as on its own complete structures as

- Hungerford Market,1836 or
- Bunning's highly decorated Coal Exchange, 1847-49

CAST IRON PERIOD (1780-1850)

Close of to 1840s the cast iron lost much of his golden image and starts to be seen as an unreliable material especially for beams due to

- the progressive collapse of a 5 storey building Radcliffe's Mill, Oldham, 1844
- Dee Bridge failure, 1847



WROUGHT IRON AS A STRUCTURAL MATERIAL

Wrought iron is traditionally produced from cast iron by puddling process raising iron to high temperature in a reverberatory furnace.

Carbon & other impurities are removed due to strong air blast, being kept from direct contact with fuel

Carbon is removed, combining with oxygen as a gas. Silicon & other impurities forming a fusible slag that could be runoff

WROUGHT IRON AS A STRUCTURAL MATERIAL

Wrought iron is almost pure iron, being softer than steel as less liable to corrosion

Material being malleable could be forged and bent to shape

Wrought iron is strong both in tension & compression & ductile being much safer material for beams compared with cast iron

Main disadvantage:

never reaching fully molten state only be shaped rolling or forging limiting possible structural & decorative forms

WROUGHT STEEL PRODUCTS (FORMED THROUGH DEFORMATION)

Forging
(Hammering into shape)

Extruding
(Squeezing through a shaped die)

Hot Rolling
Progressive forming with various rolls. (with or without cold finishing)

FORGING

Forging:
Method of forming hot metal by squeezing between heat-resistant dies.

Open-Die Forging:
A large press squeezes (not strikes) steel between two heat-resisting surfaces can be used to shape very large steel ingots (the ingot may weigh several hundred tons, the forge can squeeze with a force of several thousand tons)

Closed-Die Forging:
A large hammer pounds the steel between two heat-resisting shaped dies until the product is in the desired shape

FORGED STEEL PARTS

WROUGHT IRON PERIOD (1850-1900)

Wrought Iron in Bridges

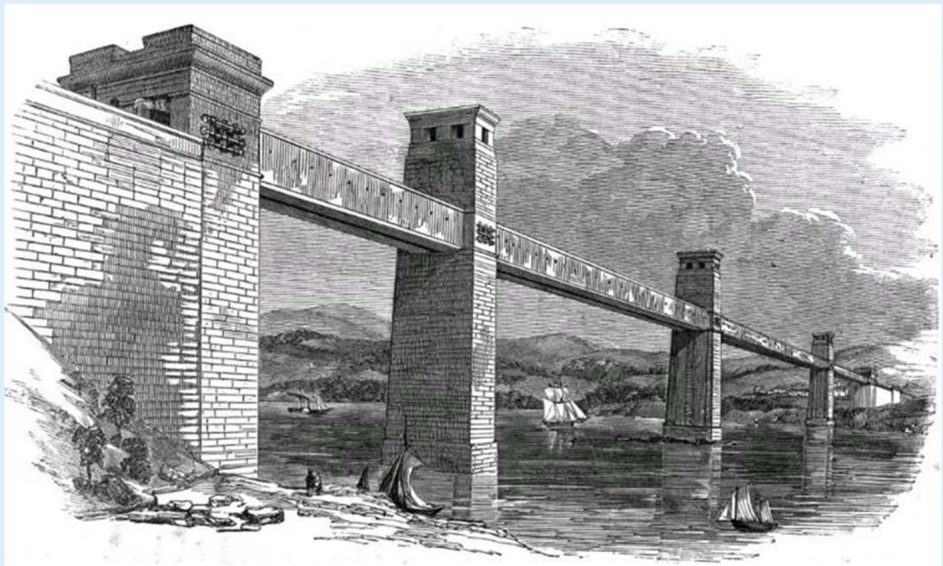
Wrought iron period is the period when riveted wrought iron beam. Dates from late 1840s by then wrought iron had fairly firm position the composite construction for long term.

Wrought iron beams birth part growing doubts cast iron safety bending & successful experience with iron ships

WROUGHT IRON PERIOD (1850-1900)

Wrought Iron in Bridges

Biggest single contribution that whole wrought iron establishment in period as dominant material for design & construction: Britannia & Conway tubular bridges



WROUGHT IRON PERIOD (1850-1900)

1845 seems an impossible task taking trains over

Menai Straits made by arches & suspension bridges shown inadequate behavior for railway loads

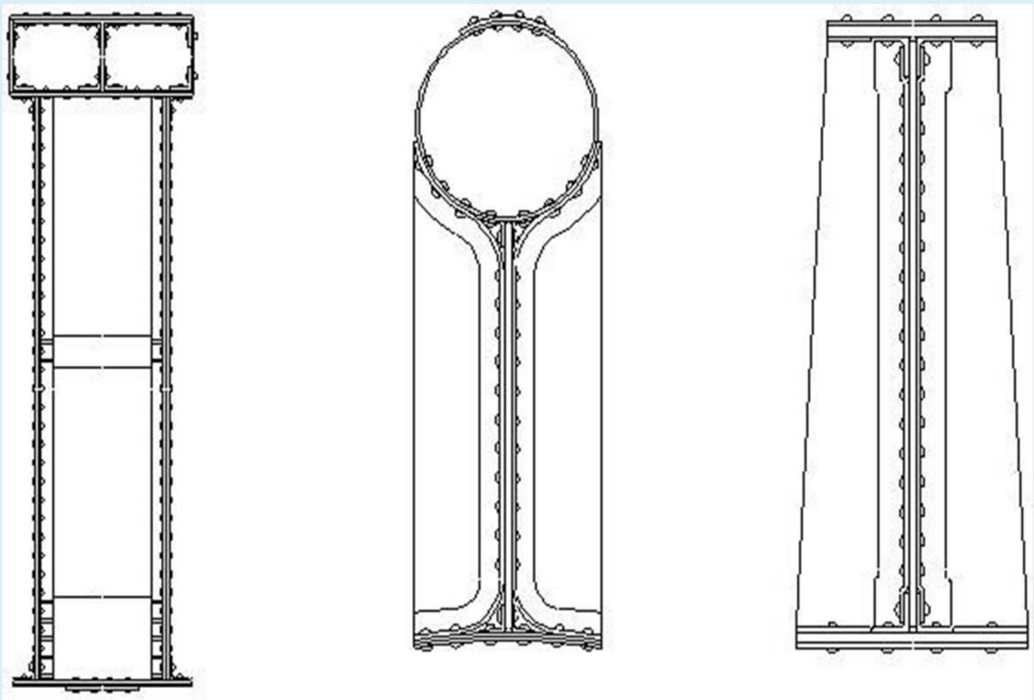
So new structural form developed box girder and demonstrated it large enough scale for trains to run inside

WROUGHT IRON PERIOD (1850-1900)

Robert Stephenson six-span Newcastle High Level Bridge with wrought iron tied arches of 1846-49

WROUGHT IRON PERIOD (1850-1900)

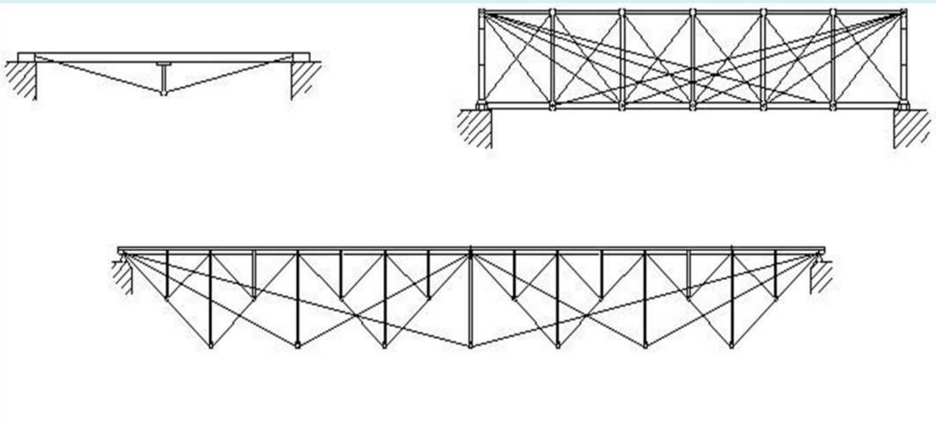
Plate girders evolution from these beams with cellular compression flanges largely in 1850[s] - transformation steps



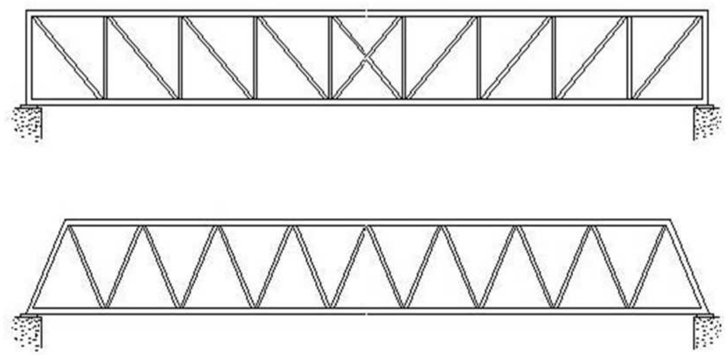
WROUGHT IRON PERIOD (1850-1900)

Truss forms reaches their full structural evolution in 1850s, deriving form timber construction in America.

Typical intuitive & mathematically rational truss forms were realize in this period with many variations of forms



(a) Early intuitive types of truss (Bollman and Fink)



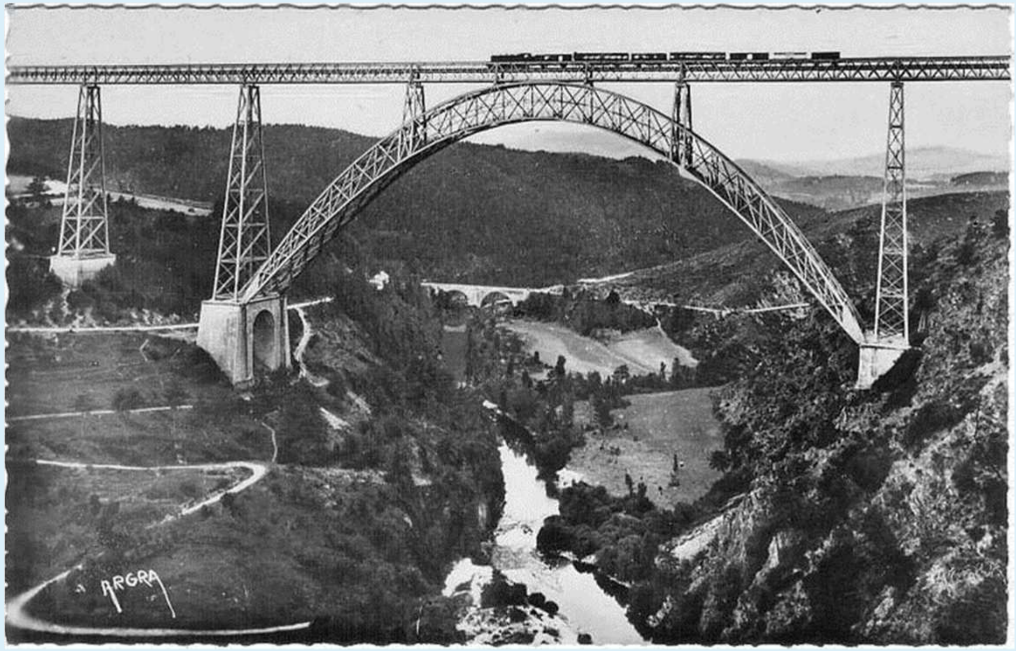
(b) Mathematically rational trusses (Pratt and Warren)

WROUGHT IRON PERIOD (1850-1900)

In Britain, Brunel's Saltash Bridge is completed in 1859 before Thomas Bouch's fatal Tay Bridge opened 1878

WROUGHT IRON PERIOD (1850-1900)

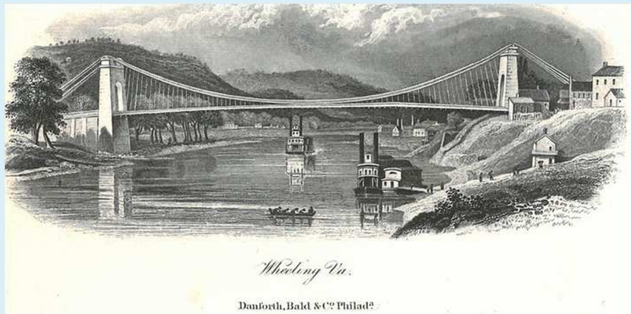
In France Eiffel's built the great arches, Oporto & Garabit 1875-7 & 1880-84



WROUGHT IRON PERIOD (1850-1900)

In America,

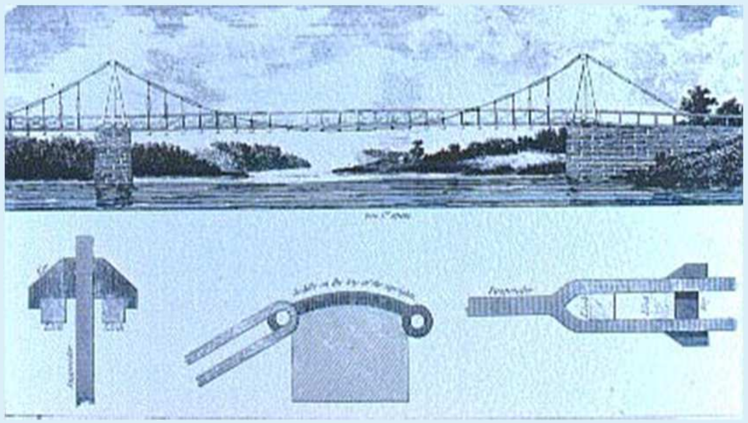
- Charles Ellet's design Wheeling Suspension Bridge of 1847-9,
- Roebling's Niagara Bridge completed 1855
- James Ead's St Louis Arch Bridge of 1867-1874



WROUGHT IRON PERIOD (1850-1900)

Suspension Bridges in America. In the first half of 19th Century have been introduced level deck suspension bridge with wrought iron chassis

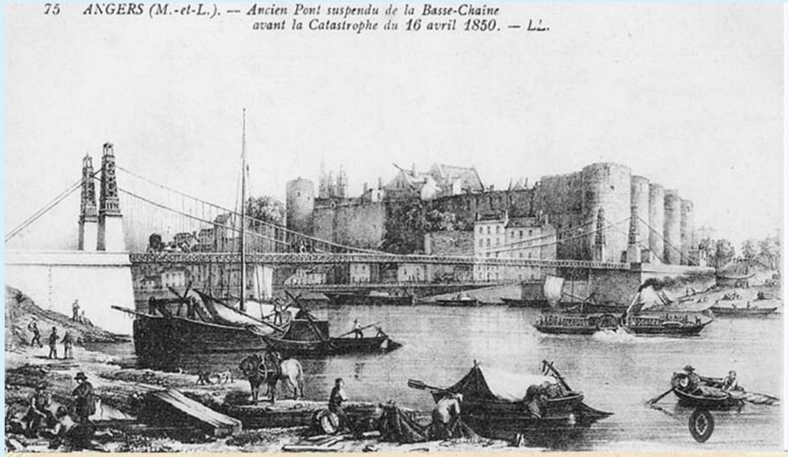
Thereafter minor battle of principles related to the form of cable made by wrought iron chains with eye-bar links. While French preferred wire cables

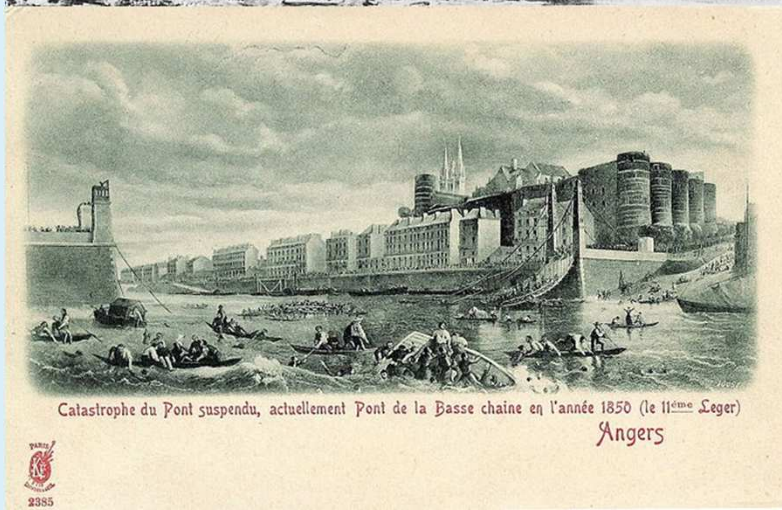


WROUGHT IRON PERIOD (1850-1900)

Starting with 1850, in France were built several hundred suspension bridges by Seguin brothers enterprise, while Britain claim scarcely more than a dozen.

If French cables sections all been well but they did not consider corrosion of the anchors for the main cables which collapse Basse-Chaine suspension bridge 1850 (226 death) (Dryburgh Abbey Bridge in 1818, The Royal Suspension Chain Pier in Brighton in 1836)

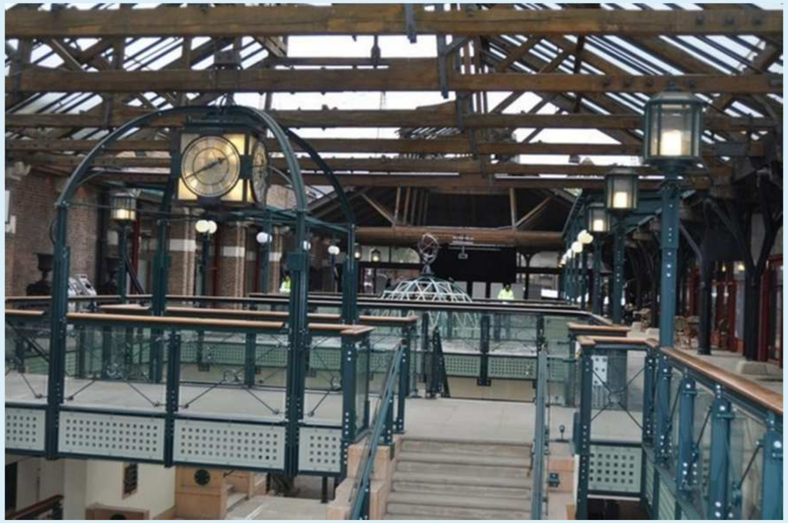




WROUGHT IRON PERIOD (1850-1900)

Wrought Iron in Buildings

In Britain, cast iron was sometimes used in combination with timber (New Tobacco Dock, 1811-14) or with wrought iron (Euston Station roof 1837)



WROUGHT IRON PERIOD (1850-1900)

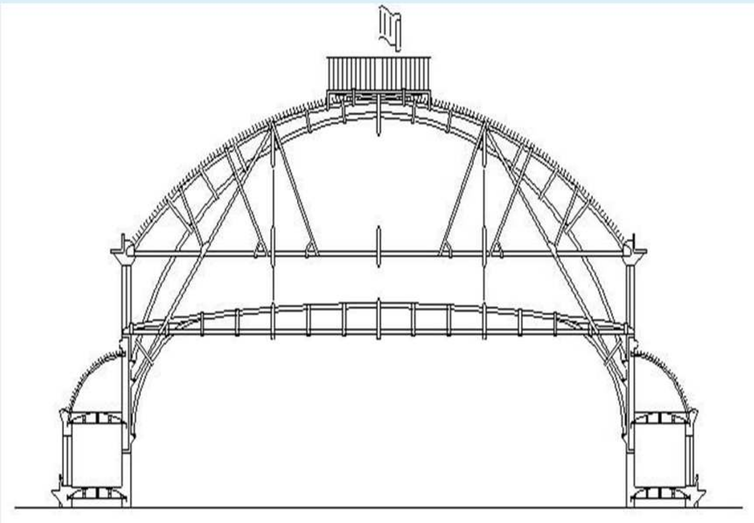
After 1840, the scale of iron construction proportion of wrought to cast iron in composite structures increased substantially

Palm House at Kew 1844-47, by Richard Turner & Decimus Burton marked advance earlier glasshouses incorporates world's first rolled I sections

WROUGHT IRON PERIOD (1850-1900)

In France - highly innovative wrought iron floors & roofs were built before the Revolution

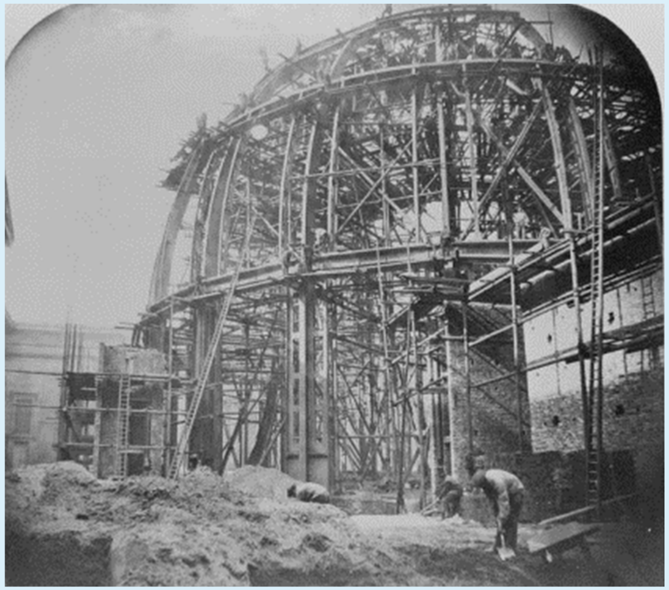
Victor Louis's 21m span roof at Palais Royal Theatre, Paris 1786. This roof has a structural logic not altogether clear

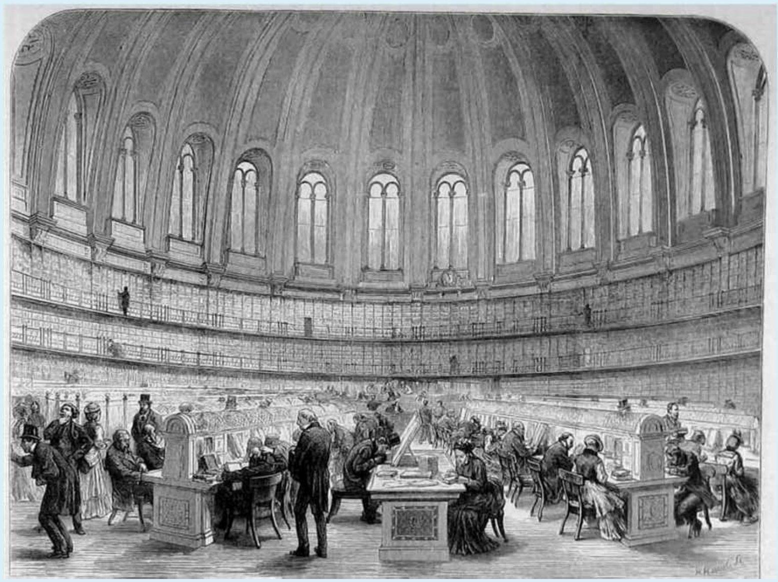


WROUGHT IRON PERIOD (1850-1900)

Ribbed iron dome from British Museum Reading Room (1854-57) - Sydney Smirke

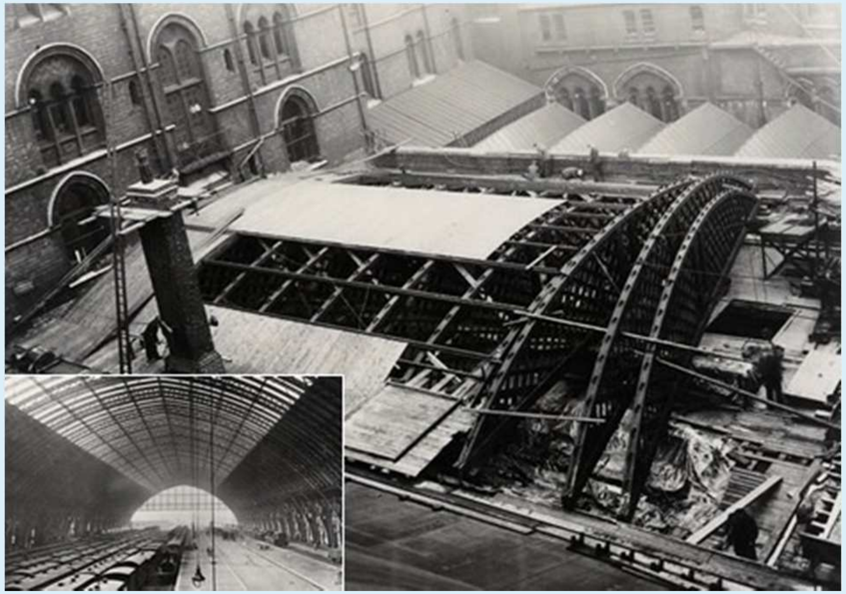
73 m made by wrought iron arches.





WROUGHT IRON PERIOD (1850-1900)

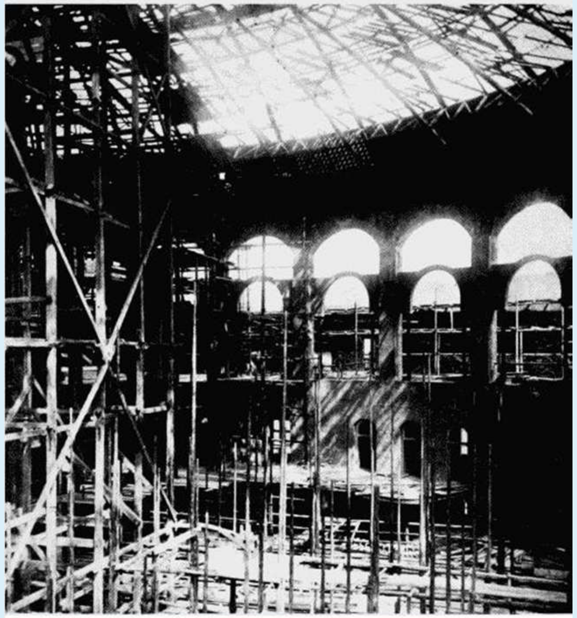
St. Pancras Station (1868) dome

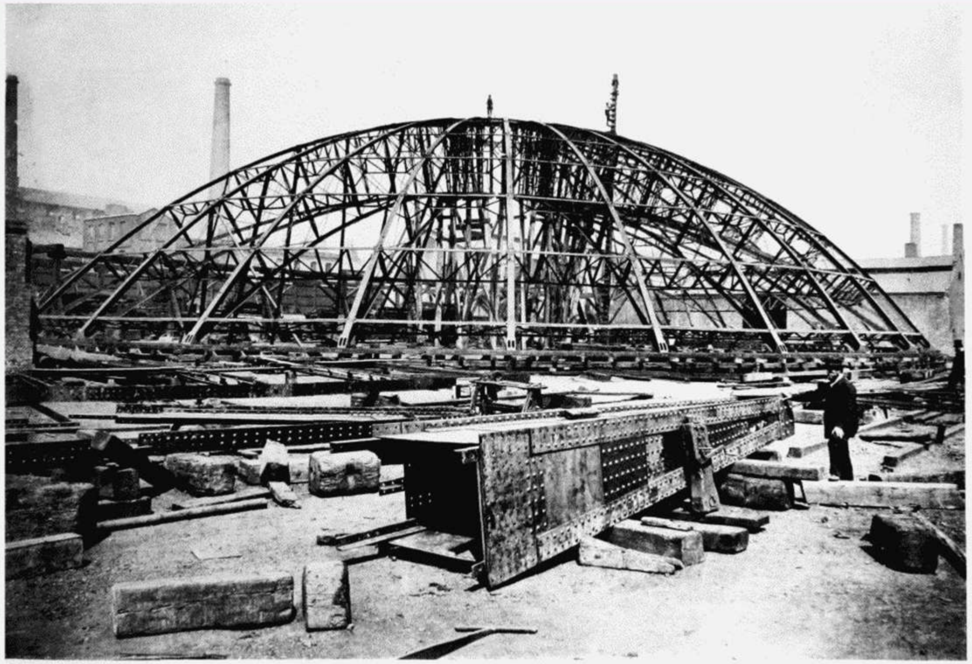


WROUGHT IRON PERIOD (1850-1900)

Albert Hall 1867-71

b. Roof in 1973

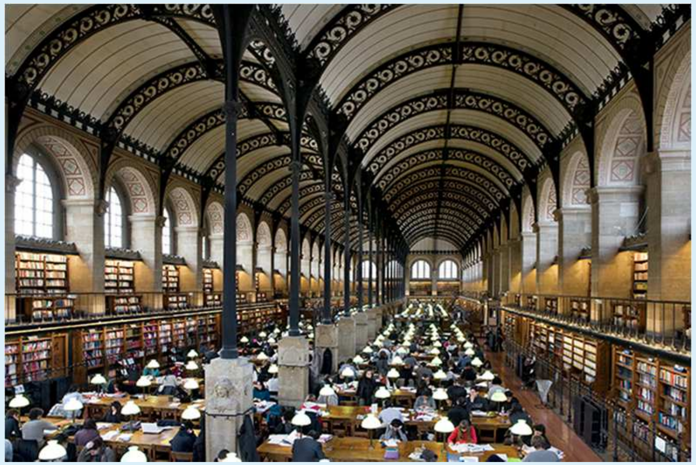




ROYAL ALBERT HALL, 1867–71. Gen. H. Scott, executant architect (p. 177)

WROUGHT IRON PERIOD (1850-1900)

Bibliotheque National (1868)

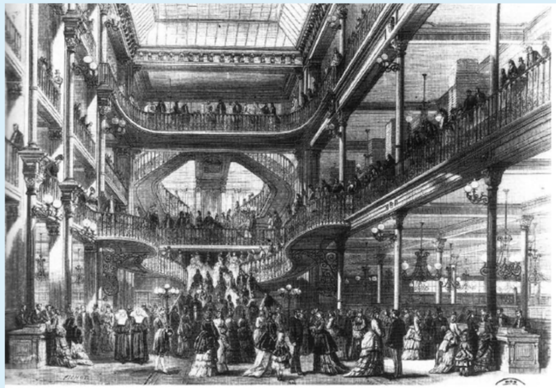


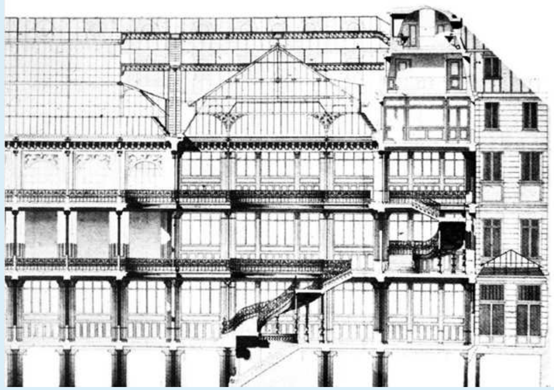
WROUGHT IRON PERIOD (1850-1900)

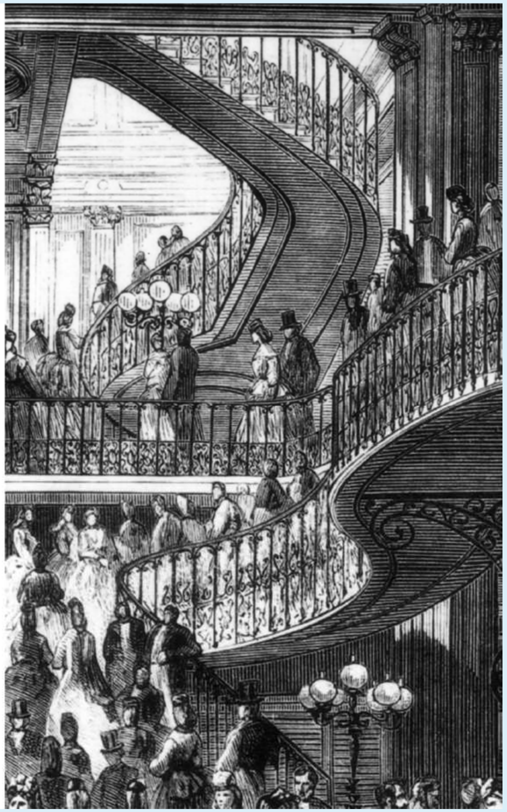
Les Halles (1854-68) Victor Baltard

WROUGHT IRON PERIOD (1850-1900)

Bon Marche Department Store (1867-78);







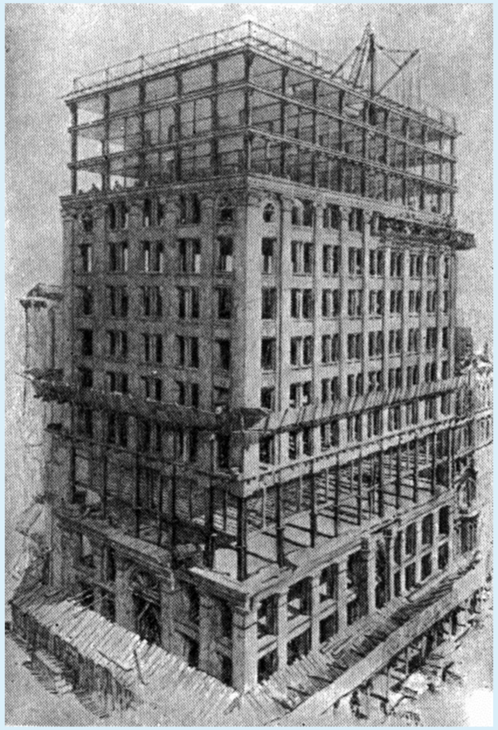
WROUGHT IRON PERIOD (1850-1900)

Capitol dome Washington (1856-64)

Most buildings, particularly that ones wit more than 1 storey depended on masonry walls for stability

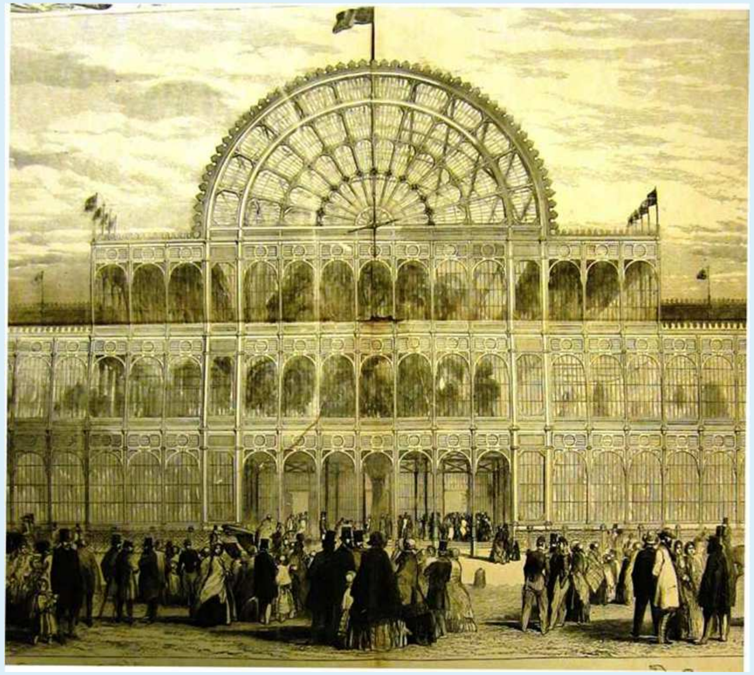
WROUGHT IRON PERIOD (1850-1900)

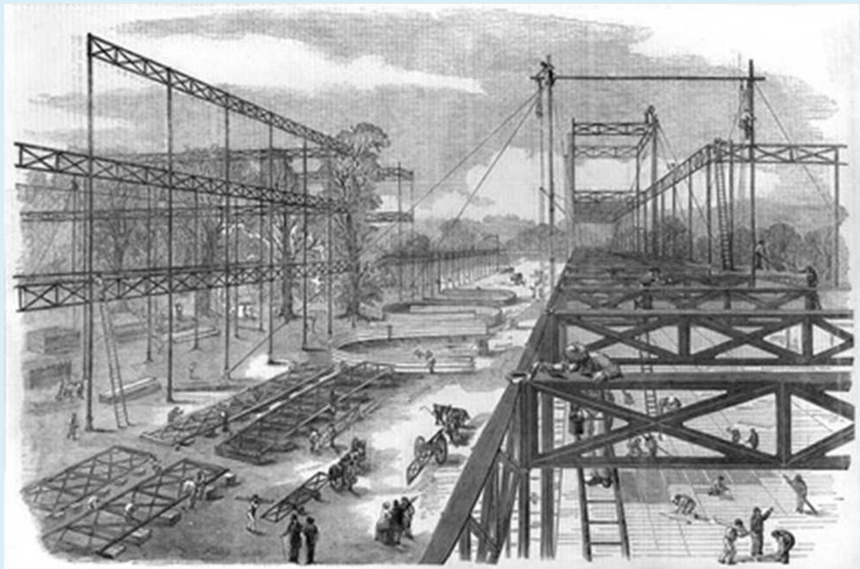
Home Insurance Building in Chicago 1884-85 was first fully framed tall building



WROUGHT IRON PERIOD (1850-1900)

Great Exhibition Building, London & Chocolat Menier Factory, Paris 1870-71 were also claimed 'first‘, but both had diagonal bracing and no apparently direct influence in multi-storey steel construction of today





STEEL AS A STRUCTURAL MATERIAL

Wrought iron was costly to produce and replaced by steel around 1850 and very little wrought iron was used after 1890.

Some wrought iron sections were use until late 1910 and also mixtures of wrought iron & steel in identical sizes

Steel was produced for structural purposes since 1850, although it took 40/60 years to entirely replace wrought iron

STEEL AS A STRUCTURAL MATERIAL

Steel has much less carbon and other impurities than cast iron produced by

(a) adding carbon to wrought iron .

(b) removing carbon from pig iron.

The first method is too expensive to be practical use so the second one was generally adopted

Steel making methods:

(1) Bessemer converter

(2) Siemens Martin open hearth furnace

STEEL AS A STRUCTURAL MATERIAL

Carbon steel is the most important commercial steel alloy

- increases hardness & strength
- improves hardenability
- but
- increases brittleness
- reduces weldability

LOW CARBON STEEL

Also known as mild steel

Contain 0.05% -0.32% carbon

Tough, ductile & malleable

Easily joined & welded

Poor resistance to corrosion

Often used a general purpose material

Nails, screws, car bodies,

Structural Steel used in the construction industry

MEDIUM CARBON STEEL

Contains 0.35% - 0.5% of carbon

Offer more strength & hardness but less ductile & malleable

Structural steel, rails & garden tools

HIGH CARBON STEEL

Also known as ‘tool steel’

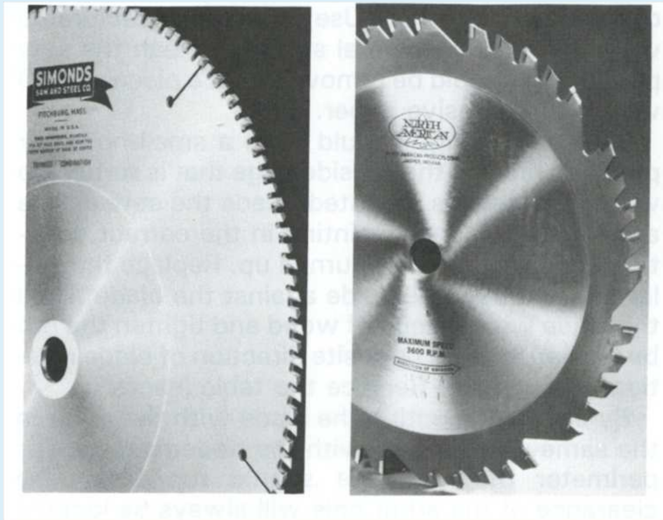
Contain 0.55%-1.5% carbon

Very hard but offers Higher

Strength Less ductile & less malleable

Hand tools (chisels, punches)

Saw blades



STAINLESS STEEL

Steel alloyed with chromium (18%), nickel (8%), magnesium (8%)

Hard & tough

Corrosion resistance

Comes in different grades

Sinks, cooking utensils, surgical instruments

HIGH SPEED STEEL

Medium Carbon steel alloyed with

Tungsten, chromium, vanadium

Very hard

Resistant to frictional heat even at high temperature

Can only be ground

Machine cutting tools (lathe & milling)

Drills

EXTRUSION

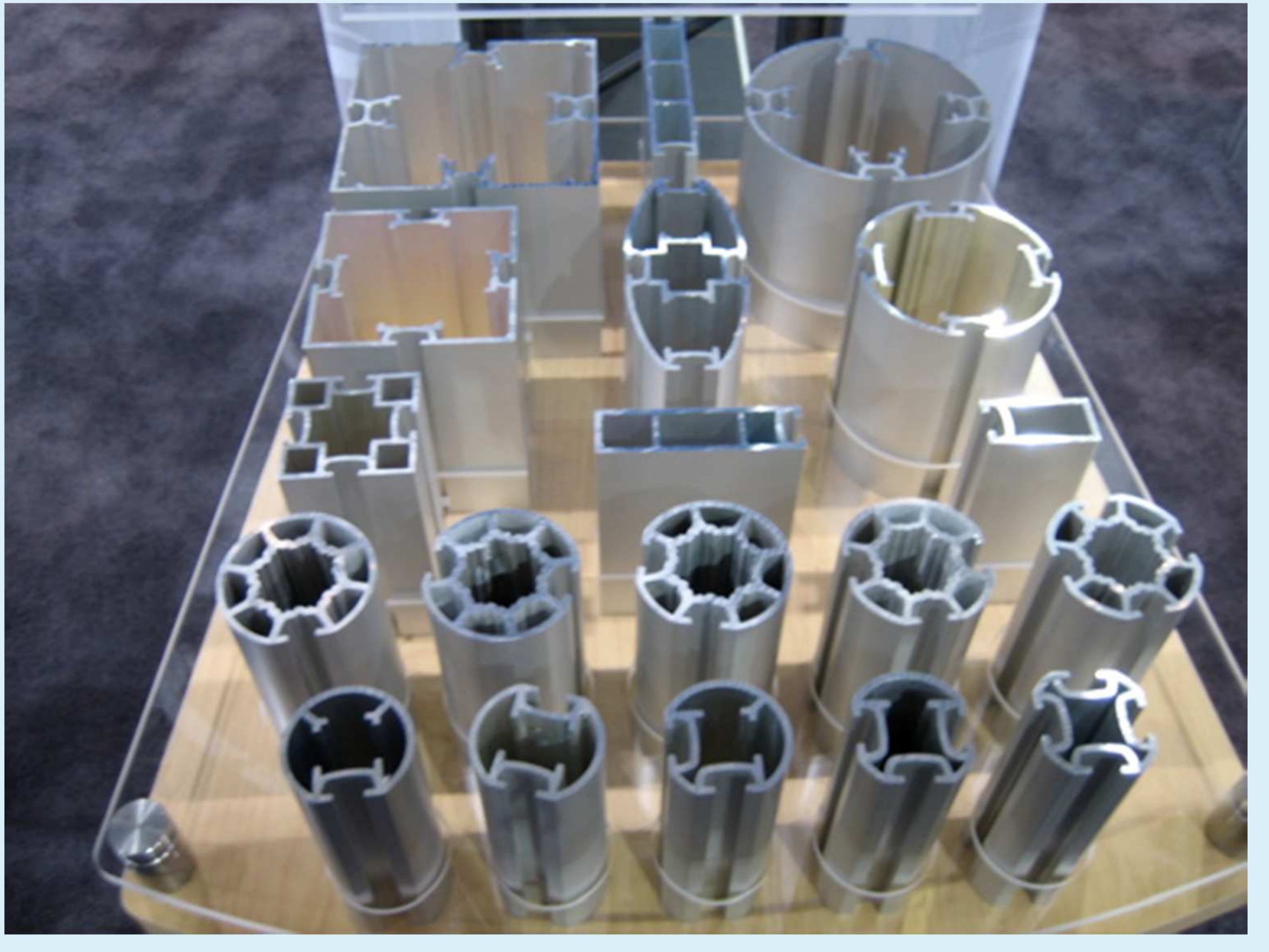
Extruding: Method of converting semi-finished shapes into lengths of uniform cross-section by forcing preheated, plastic steel through a very tough, heat-resistant die (analogy: toothpaste)

Bars, tubing, pipes, & many unusual cross-sections can be extruded. More complex shapes can be extruded than can be rolled.

More economical for small quantities but with a limitation that cross-section must be uniform.

Plain round bars could be extruded or rolled, but Ribbed round bars (like rebar) could not be extruded, must be rolled

ALUMINUM EXTRUSIONS



HOT ROLLING

Hot Rolling: Used to make semi finished shapes as well as some finished products.

May be started with reheating of large steel ingots from steel producer, or may be sequenced directly after the continuous strand casting process.

Hot steel passes through a system of heat-resistant rolls which gradually, roll by roll, change the ingot or strand into one of three basic intermediate shapes:

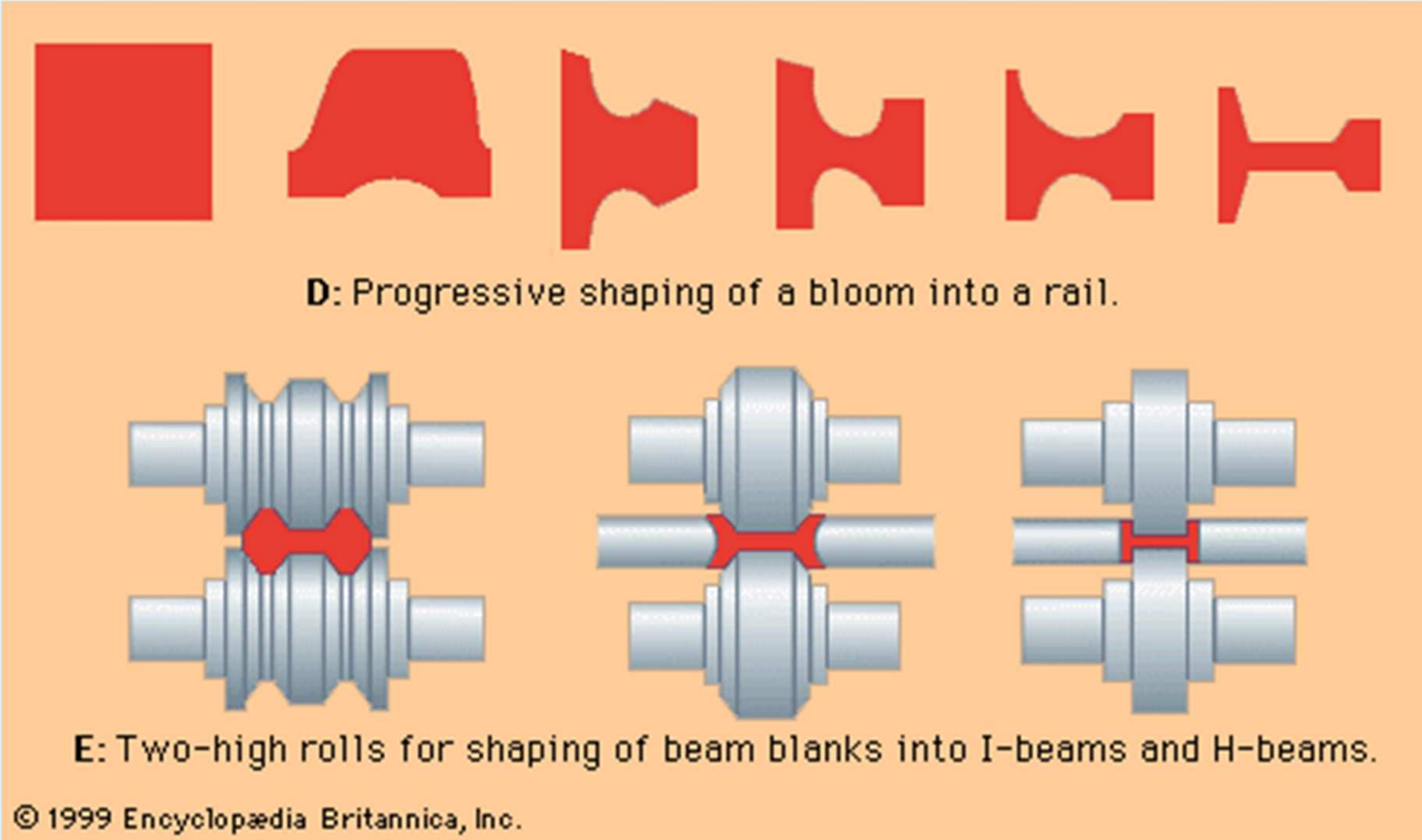
HOT ROLLING

Slabs: Flat, rectangular shapes with width > 2x thickness; Will later become plates, sheets, strips, or products like pipe & tubing (made from plates, sheets, strips)

Blooms: Rectangular cross-sections, generally larger than 36 sq. in.; Will later become structural shapes, rails, seamless pipe

Billets: Rectangular cross-sections, less than 36 sq. in. Will later become bars (including rebar), rods, wire

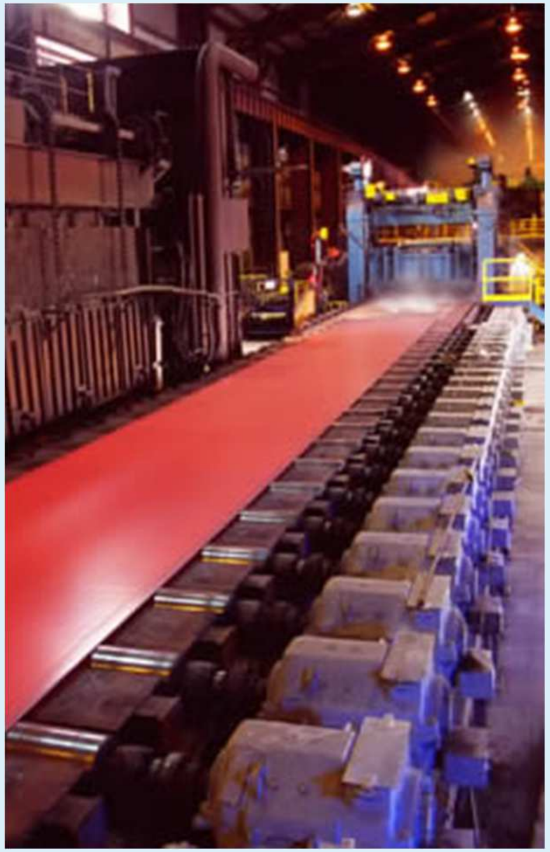
HOT ROLLING I & H BEAMS



D: Progressive shaping of a bloom into a rail.

E: Two-high rolls for shaping of beam blanks into I-beams and H-beams.

ROLLED SHEET & RAIL



COILED & STRAIGHT RE-BAR

STEEL PERIOD (1880-PRESENT DAY)

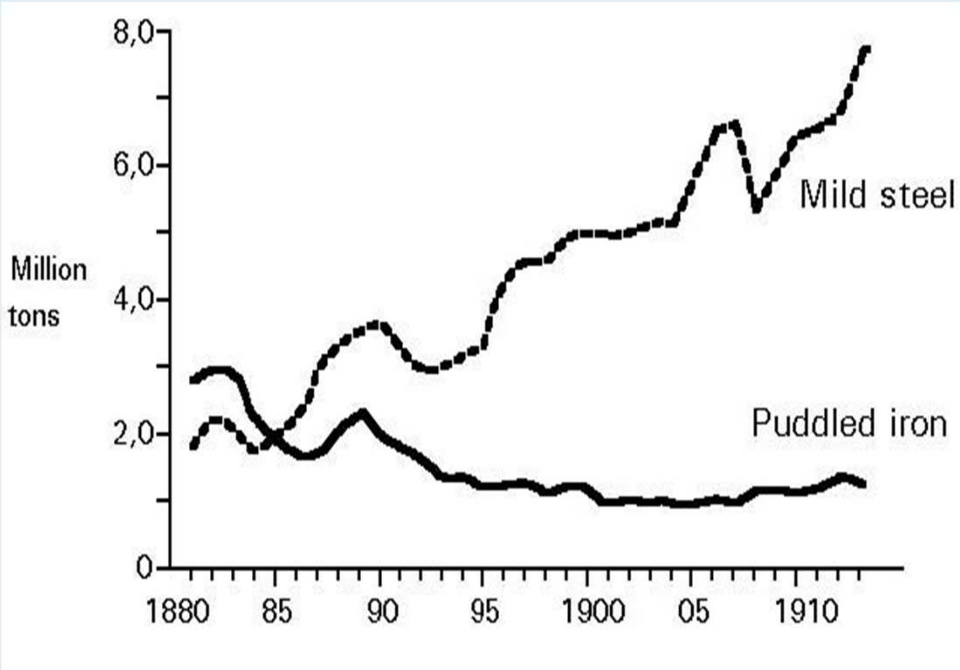
Steel is not only stronger that an wrought iron but produced in molten state made larger rolled or forged units

However was not easy to identify which is which. For several decades steelwork was fabricated by riveting in the same way as wrought iron and when riveted look almost exactly the same

Forth Bridge made of steel & Eiffel Tower of wrought iron were completed almost exactly same time 1889-90. Looking at them who could tell the difference?

STEEL PERIOD (1880-PRESENT DAY)

Steel quantity took over in Britain from wrought iron



STEEL PERIOD (1880-PRESENT DAY)

Bridges in the steel period have increasing size & span

All great suspension bridges were build up to 1945 was built riveted steel with high tensile steel wire

- Golden Gate
- George Washington
- Transbay

STEEL PERIOD (1880-PRESENT DAY)

Based on steel use buildings such as 'Skyscraper' America, long span roofs appears in France & America:

- Great three-pin arch structures over Philadelphia railway stations, 1893 (79 & 91 metre spans)
- Galerie des Machines for 1889 Paris Exhibition with a 111m span
- Louisiana Superdome 207 m span, 1975

A turning point was in 1930$^{s\ by}$ introduction the welding

Riveted connections were used wrought iron production

Nowadays, welds & bolts dominate all steel construction

CONCLUDING SUMMARY

Use of iron & steel structures have evolved related to production & properties from cast iron to wrought iron and steel

Cast iron formed into final shape from molten metal poured into mold & solidifies.

Wrought iron never reaches a fully molten state and was shaped by rolling & forging.

Mild steel can be cast as well as rolled and have lower corrosion resistance than wrought iron

CONCLUDING SUMMARY

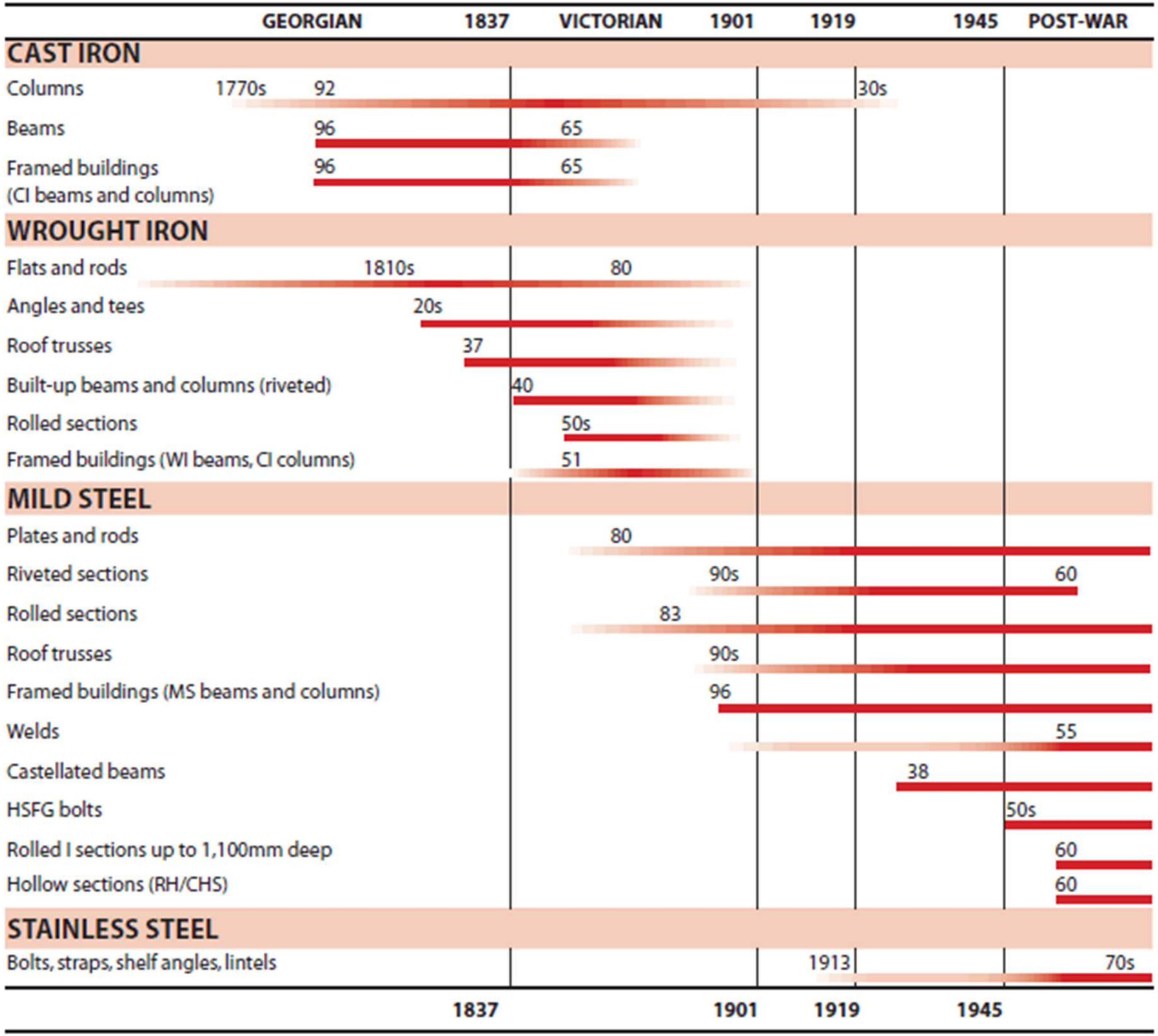
Iron was known and used for more than 3000 years but only in the last 250 years due to new production methods have a large scale use

Cast iron was widely used for bridges & buildings between 1750 - 1850

Wrought iron was popular between 1850 – 1900, when many novel bridges & building structures with increased size & span were built

Steel was use from about 1880 being stronger than wrought iron allowing even larger structures to be built

Steel welding was a major innovation in connection techniques which facilitates the wider use of steel


GEORGIAN
1837
VICTORIAN
1901
1919
1945
POST-WAR
CAST IRON
Columns
1770s
92
30s
Beams
96
65
Framed buildings
(CI beams and columns)
96
65
WROUGHT IRON
Flats and rods
1810s
80
Angles and tees
20s
Roof trusses
37
Built-up beams and columns (riveted)
40
Rolled sections
50s
Framed buildings (WI beams, CI columns)
51
MILD STEEL
Plates and rods
80
Riveted sections
90s
60
Rolled sections
83
Roof trusses
90s
Framed buildings (MS beams and columns)
96
Welds
55
Castellated beams
38
HSFG bolts
50s
Rolled I sections up to 1,100mm deep
60
Hollow sections (RH/CHS)
60
STAINLESS STEEL
Bolts, straps, shelf angles, lintels
1913
70s
1837
1901
1919
1945

European Commission
ERASMUS
MUNDUS

ADRIAN DOGARIU
2014

Pedro Vellasco
29/11/2012