ARHITEKTONSKI FAKULTET
SVEUČILIŠTA U ZAGREBU

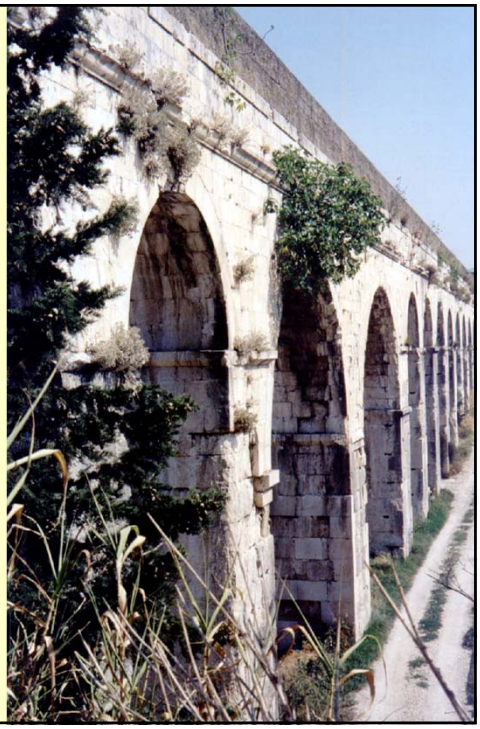
Inženjerske konstrukcije



ARHITEKTONSKI FAKULTET
SVEUČILIŠTA U ZAGREBU

INŽENJERSKE
KONSTRUKCIJE

4. POVIJEST GRAĐENJA MOSTOVA



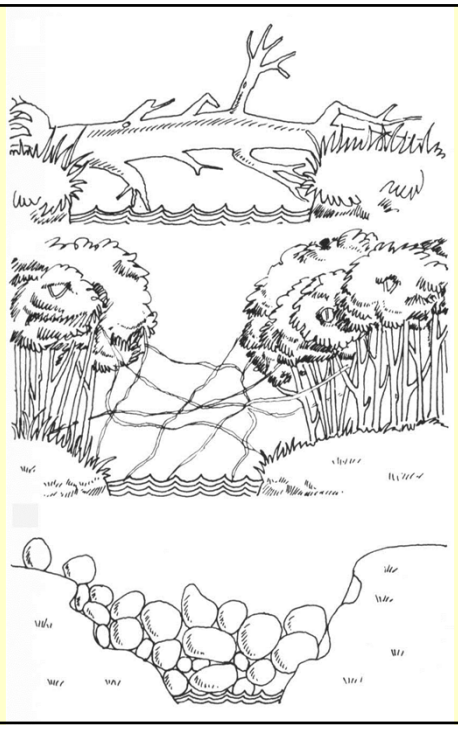
- prirodni oblici: prate i koriste značajke dostupnih gradiva

- evolucija: razvitak tehnologije, društvenih okolnosti i znanosti

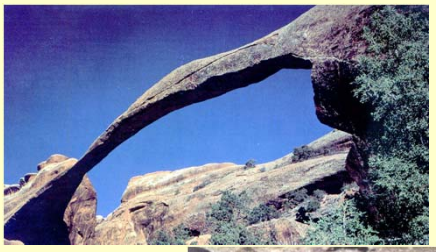
- empirijski (iskustveni) pristup graditeljstvu: do 18. stoljeća

- iskustvo nije eksplicitno sadržano u tehničkoj znanosti.

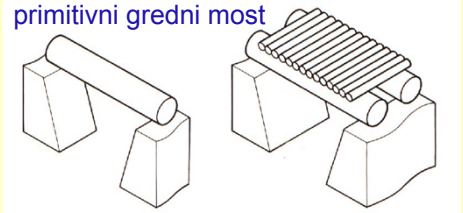
- zanatska pravila dopunjuju matematičko modeliranje



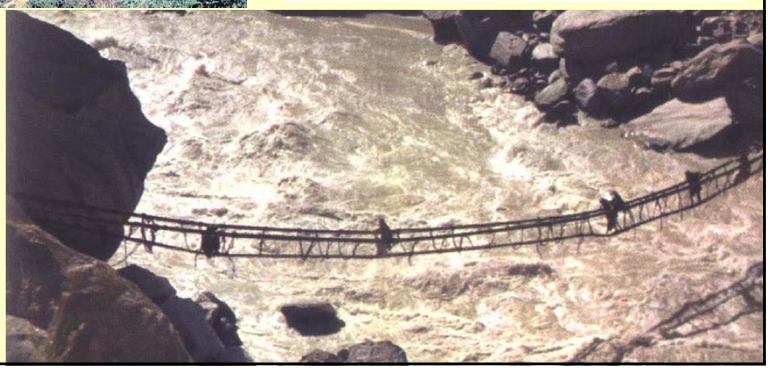
prijelaz iz kamenog u brončano doba: 4000 g.p.K.
prva mreža prometnica - razmjena dobara
prvi prijelazi: oblici kopirani iz prirode



primitivni gredni most



primitivni viseći most



Osnovni pojmovi:

stabilnost - građevina je sastavljena od elemenata, oni su načinjeni od gradiva i svi su pod utjecajem gravitacije

gravitacija djeluje kao pritisak u smjeru zemljine površine i mora se neutralizirati suprotnim silama

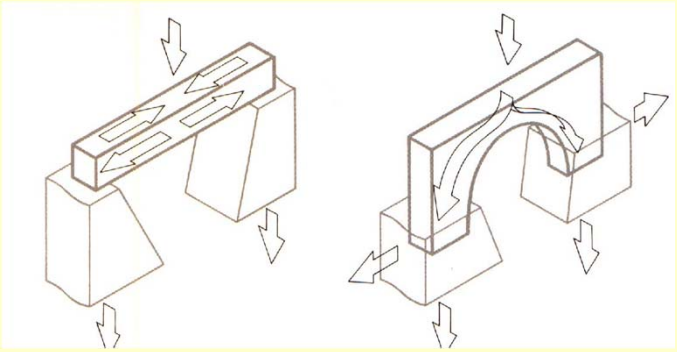
ravnoteža sila → stabilna građevina

statika određuje sile i njihove smjerove (djelovanja), a na temelju njih izmjere konstruktivnih elemenata

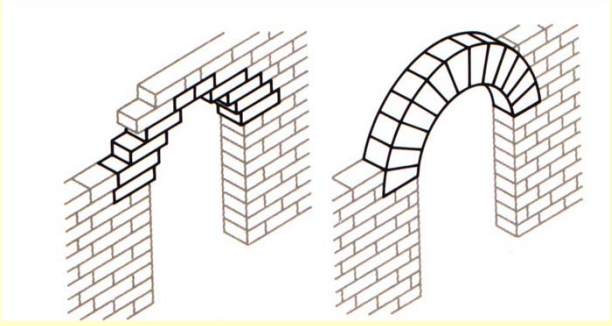
znanost o čvrstoći gradiva određuje ponašanje pri različitim djelovanjima

GREDA: kopiranje prirodnih oblika

LUK: inventivno korištenje pristupačnog gradiva

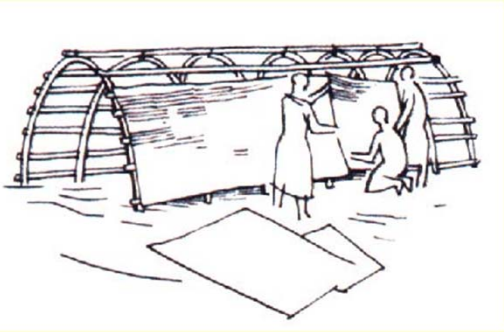


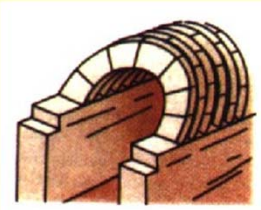
konzolni svod ili luk



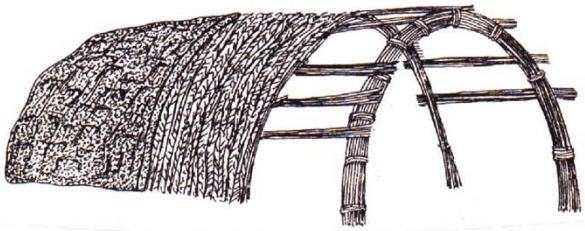
pravi luk

postanak prvih lukova:
Mezopotamija, kuće od trščanih svežnjeva pokrivene glinom
Požar - monolitni luk
(4000 g. p.K.)

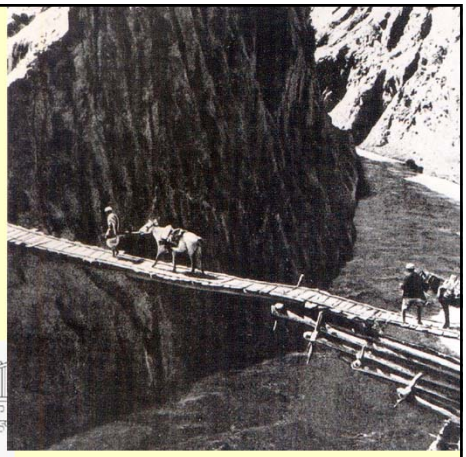


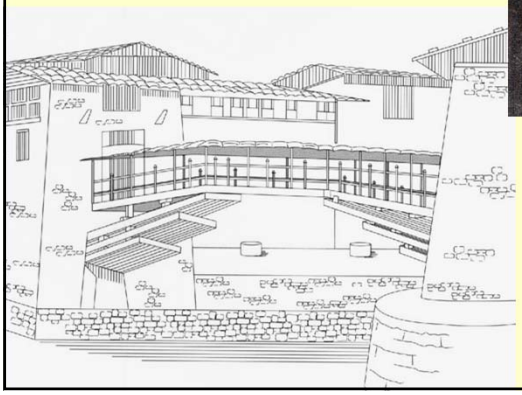


luk od opeke:
3000 g. p.K.

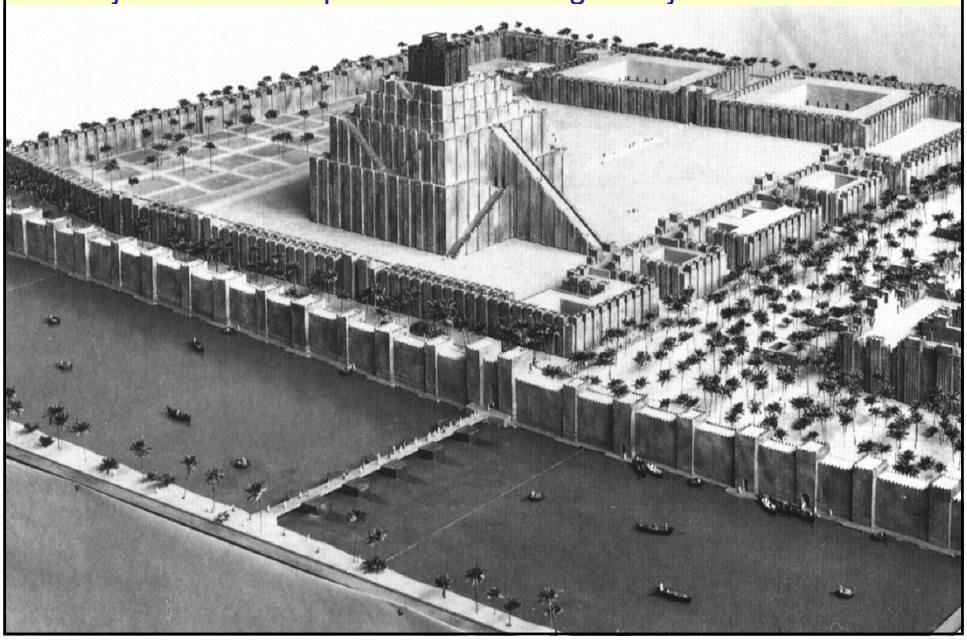


složene forme primitivnih grednih mostova:
konzolni sklopovi Tibeta

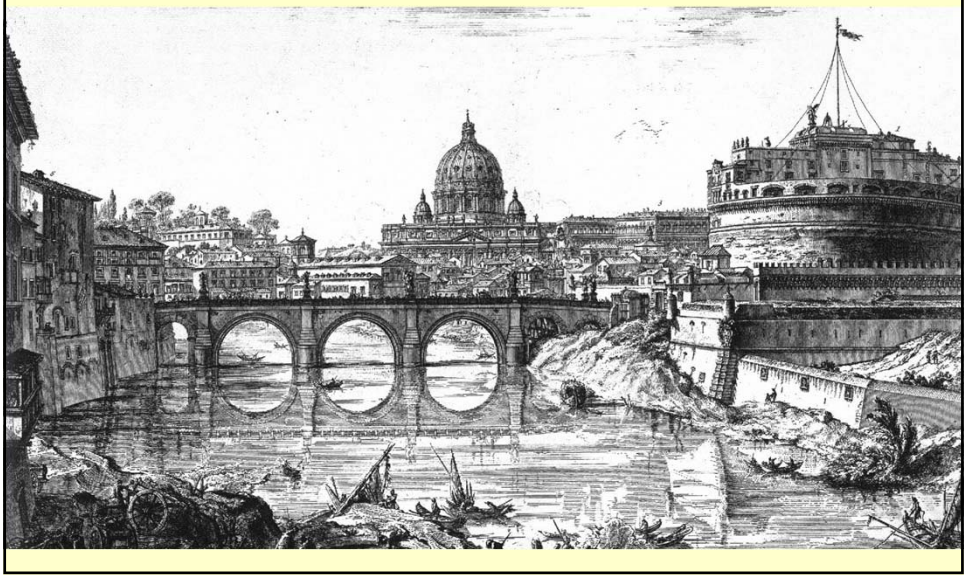


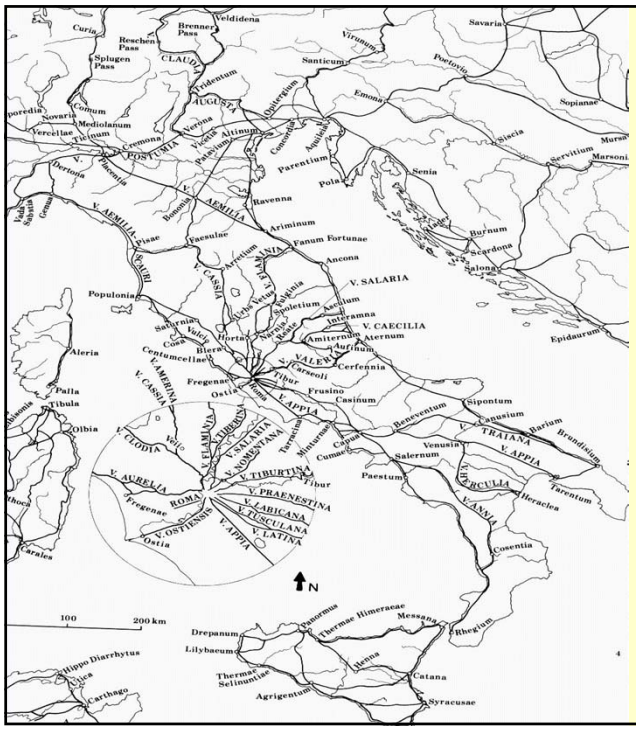


glavna pretpostavka sustavnom razvitku gradnje mostova:
razvijena državna uprava - sustavno građenje cesta



***Starorimsko razdoblje*:**
• ostaci starogrčkih i etruščanskih mostova uglavnom su nestali
• Rimska država: oko 800 g., od Britanije do Irana i Tunisa





STARORIMSKO GRADITELJSTVO:

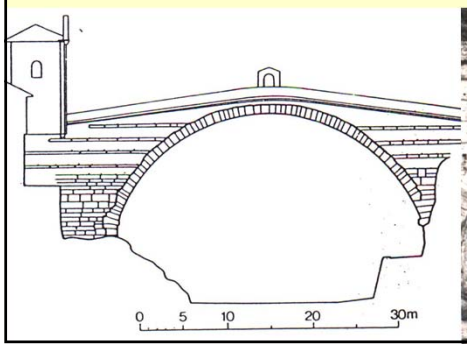
- konstruktivni principi i graditeljska vještina na zavidnoj razini
- ograničenja: nedostatak izvora mehaničke snage i ograničena uporaba tvrdih metala
- Gradiva: kamen, drvo, opeka + BETON
- vapneni mort: od Grka
- dizalice znatnog dometa i nosivosti

Starorimsko razdoblje

- mreža rimskih cesta

STARORIMSKI KAMENI MOSTOVI:

- lukovi od klesanaca, bez veziva, dobro dosjedanje
- polukružni, ali i segmentni lukovi
- slaganje svodova: štedljiva uporaba skele
- dijelovi: klesanci, spandrilni zidovi, ispuna
- najveći raspon kamenog luka: 35,6 m (St. Martin, Italija)



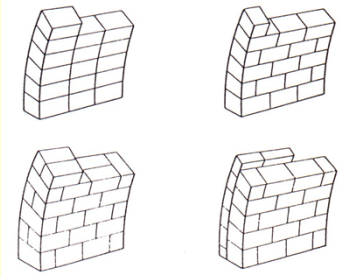


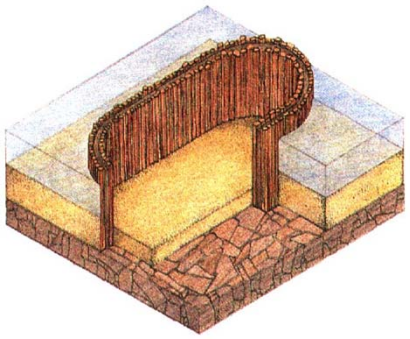
STARORIMSKI KAMENI SVODOVI:

- odnos debljine i raspona: 1/10 do 1/20
- debljina stupova: 1/2 do 1/5 raspona
- visina stupova: do 40 m
- gradnja: jedna skela pomiče se duž mosta, a ponekad i poprečno
- većinom polukružni lukovi
- segmentni lukovi: 130 do 83°

temeljenje rimskih mostova:

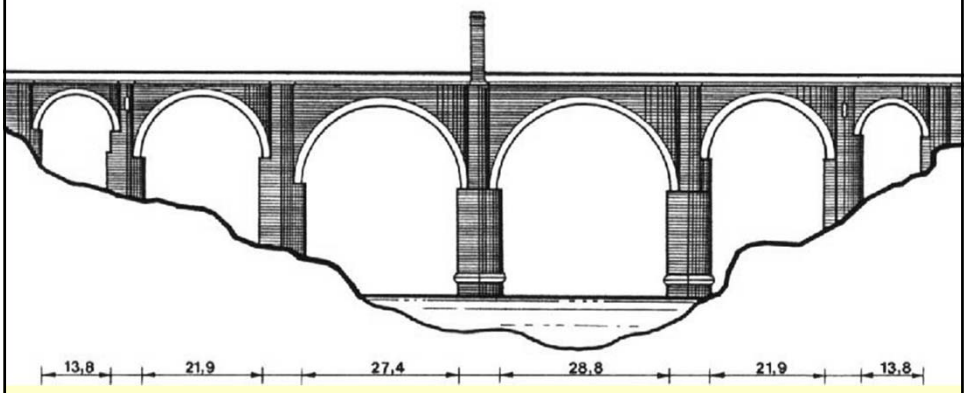
- plitko, na čvrstom tlu
- na kratkim pilotima
- ispod razine vode, u zagatu
- na sanducima s kamenom ispunom



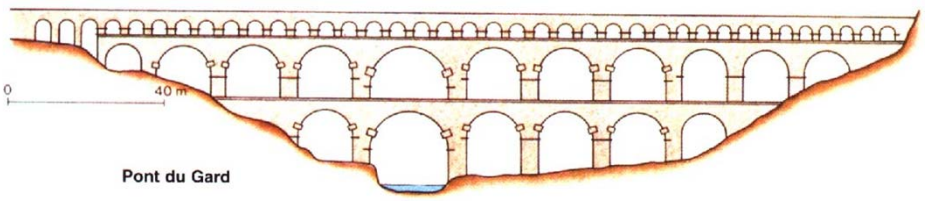


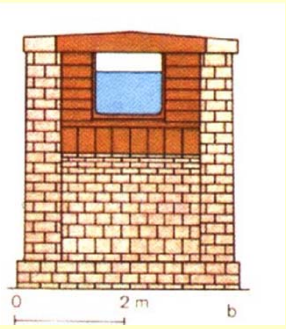
Dno stupa u vodotoku oblikuje se hidraulički, da se smanji podlokavanje.

most ***Alcantara***, Španjolska,
Graditelj: **CAIUS IULIUS LACER**
natpis: Most će trajati vjekovima
Dovršen: 106. g. po.K.)

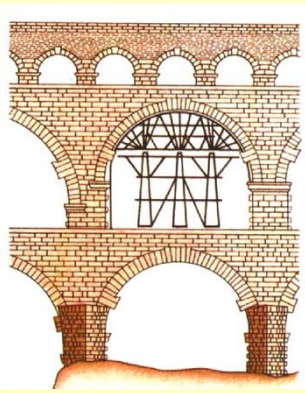








AKVEDUKTI:
Pont du Gard,
Nimes
(Francuska),
•duljina 275m
•visina do 50 m
•glavni raspon 22 m
• dio vodovoda
dugog 50 km



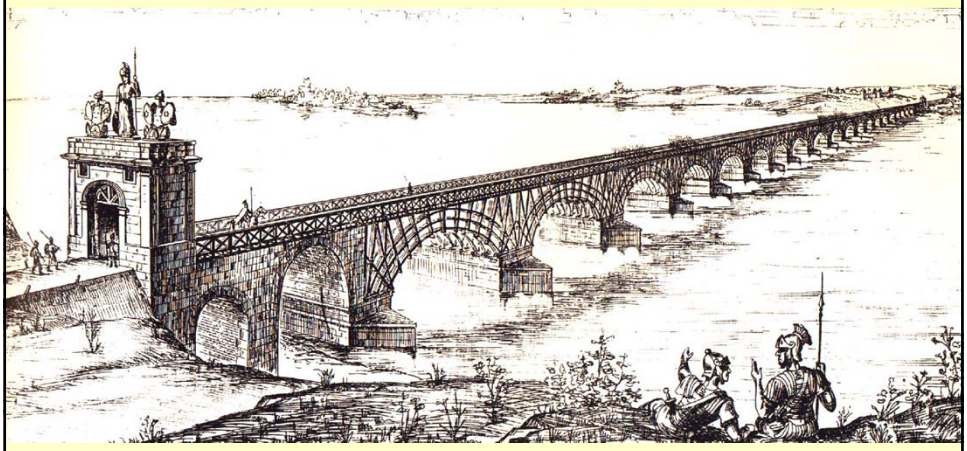


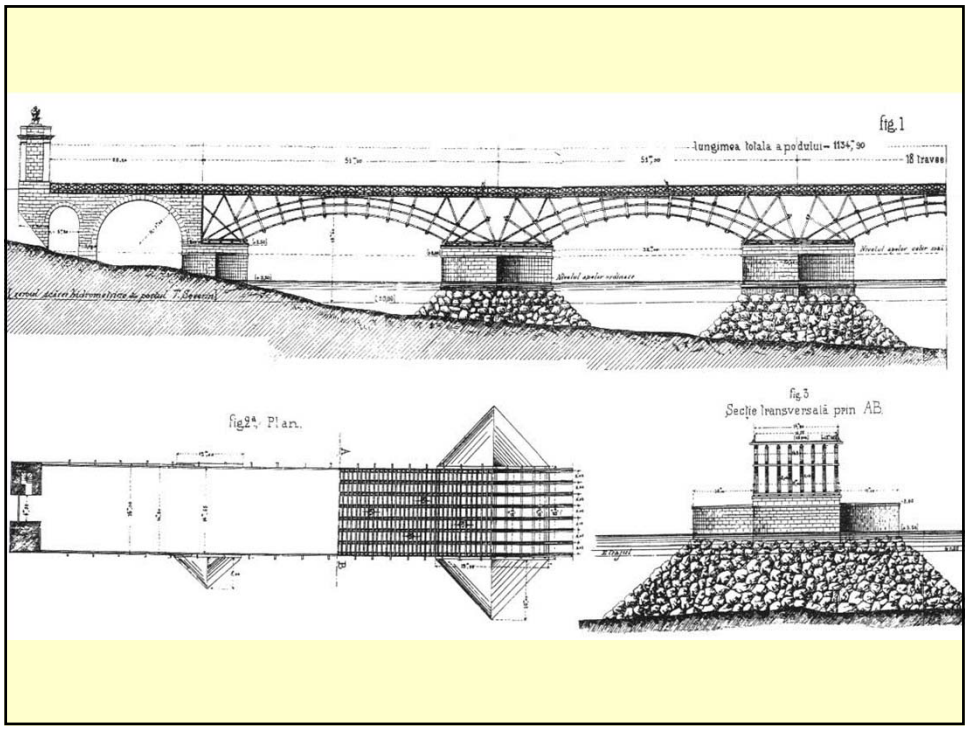

Akvedukt u Segoviji, Španjolska
- visina stupova do 28,5 m uključivo 6m temelja

***STARORIMSKI AKVEDUKTI GRADA SPLITA*:**
- 3 akvedukta Dioklecijanove palače

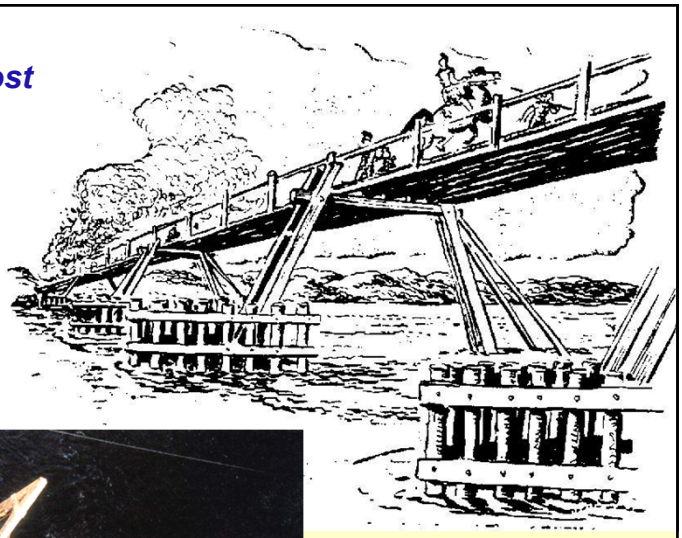


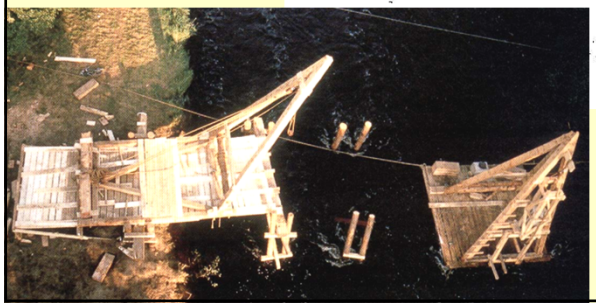
STARORIMSKI DRVENI MOSTOVI:
poznati samo iz zapisa i reljefa
- ***Trajanov most na Dunavu*** (Kladovo, Srbija - Rumunjska)
  graditelj: Apollodoros od Damaska, 104. g. po.K

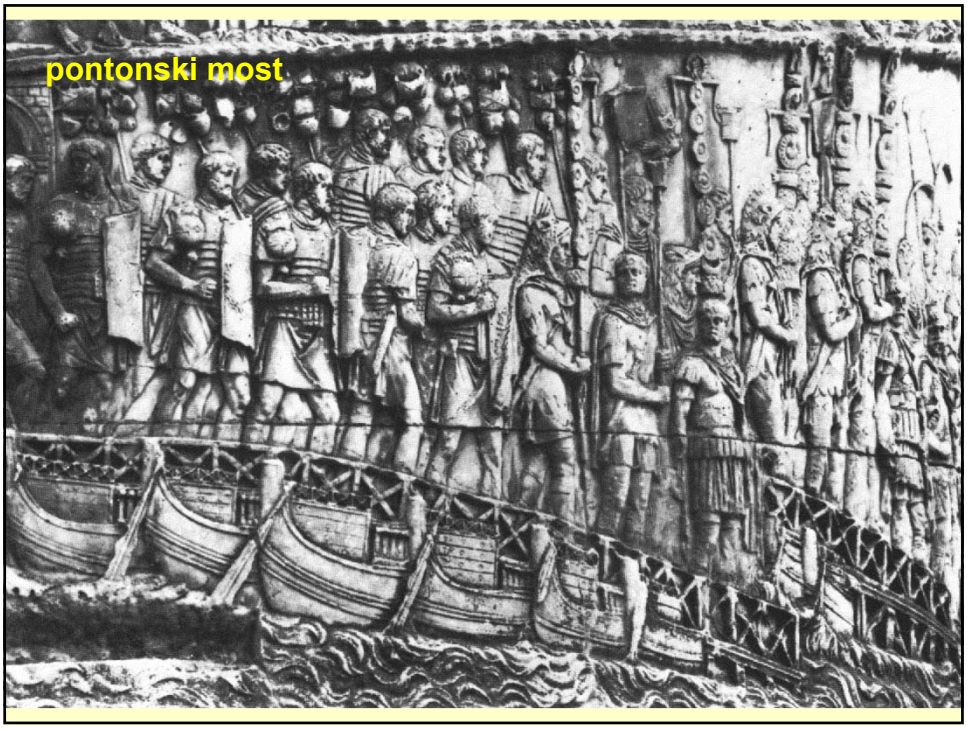




Cezarov ratni most preko Rajne







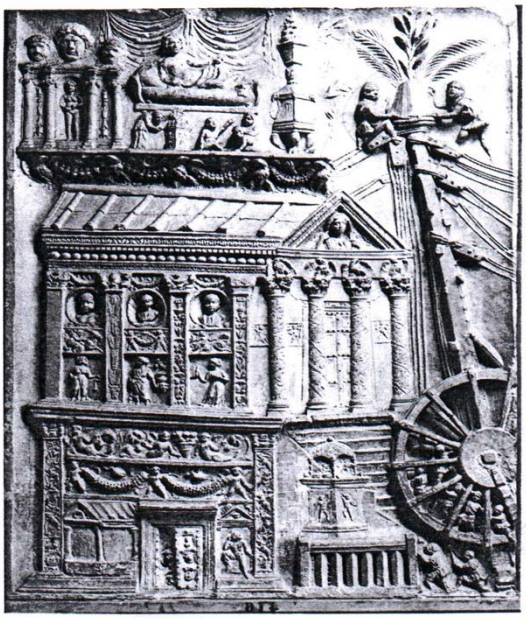
DOMETI STARORIMSKOG GRAĐENJA MOSTOVA:

- prvi graditelji koji su u punoj mjeri koristili luk i svod

- ocjena poznavanja tehnike kroz
  - pravila oblikovanja
  - temeljenje
  - gradiva
  - pomoćna sredstva

- najveći mostovi koriste gradivo i tehniku do krajnjih granica

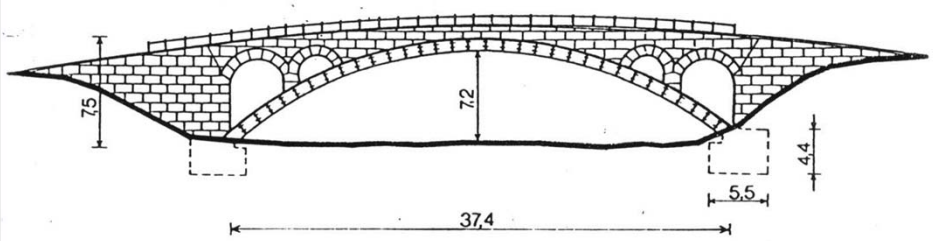
- gradnja mosta: organizacijski i logistički problem



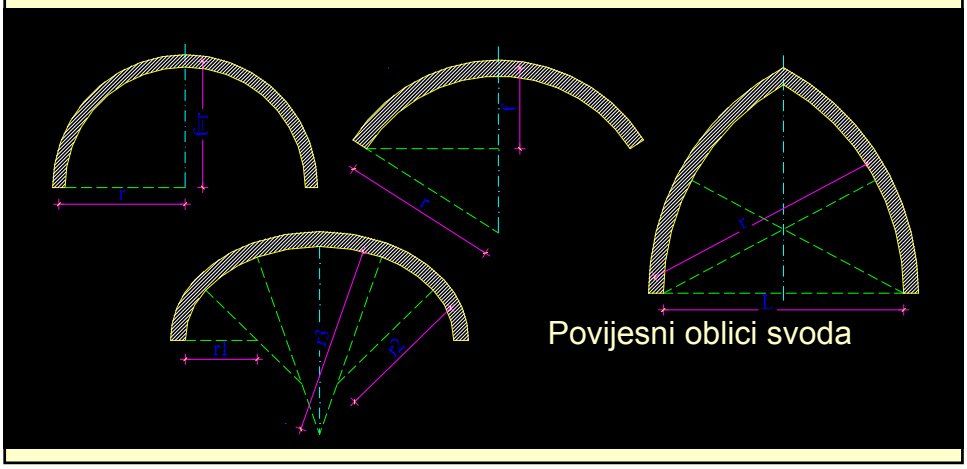
***SREDNJEVJEKOVNO GRADITELJSTVO*:**
- od pada Zapadnog Rimskog carstva 476 g. po.K.
- Europa: malo građevina do mosta u Avignonu 1185.
- Bliski i Srednji istok čuvaju znanje starorimskih graditelja
- Daleki istok (Kina) - originalni i smioni mostovi iz 5. stoljeća

Most An-Chi, oko 610.

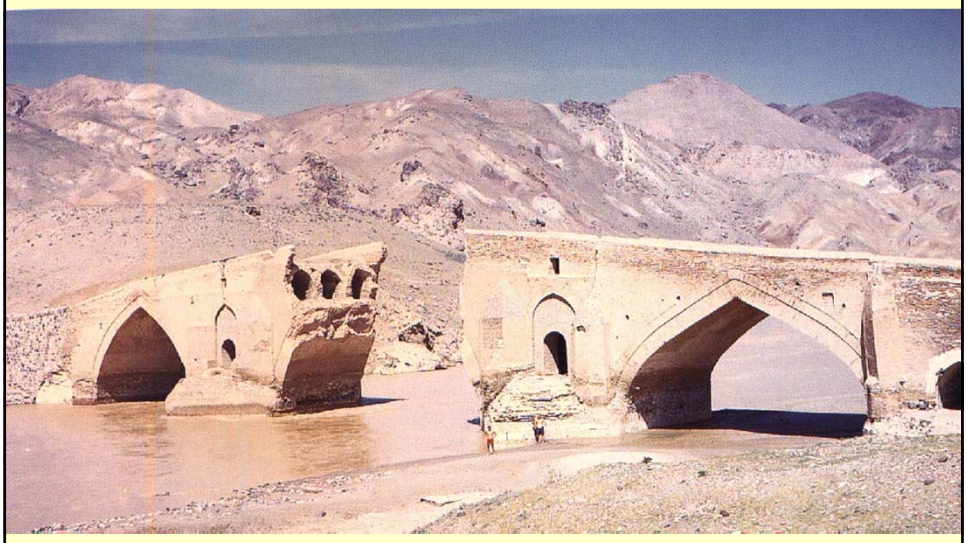


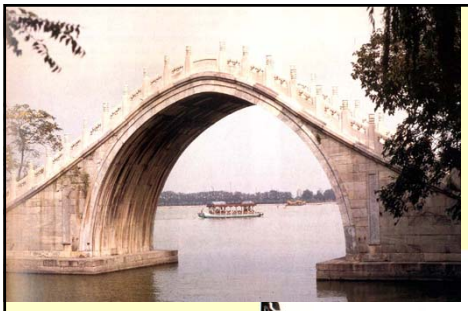


SREDNJEVJEKOVNO GRADITELJSTVO:
- Turska i srednji istok: usavršavanje nasljeđa starog Rima
- pojava šiljatog luka: u Europu dolazi s Maurima
- mostovi sa strmom niveletom
- utjecaj na Europu: kroz Španjolsku i putem Križarskih ratova



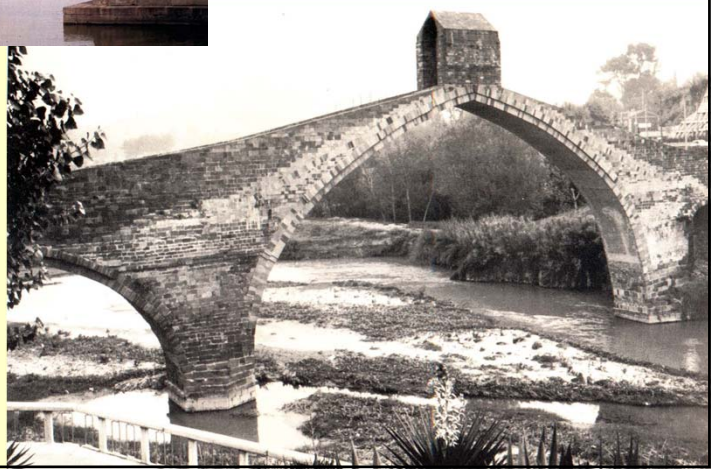
Perzija, Khuzistan, 12. st.
(danas: granica Irana i Iraka)





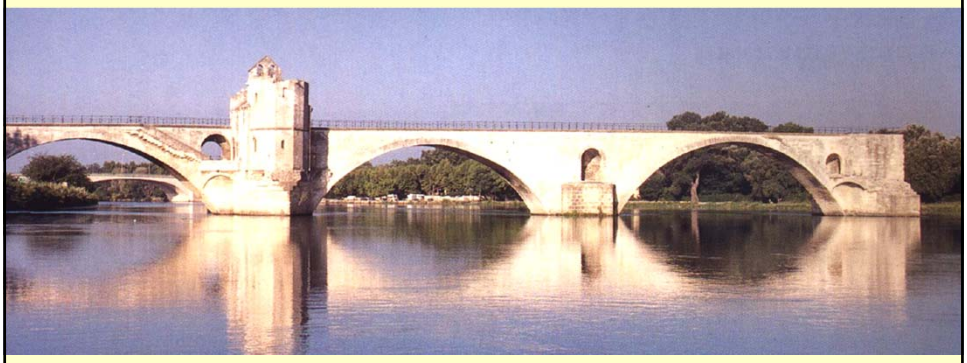
Vražji most,
Martorel, Španjolska
raspon L=37 m

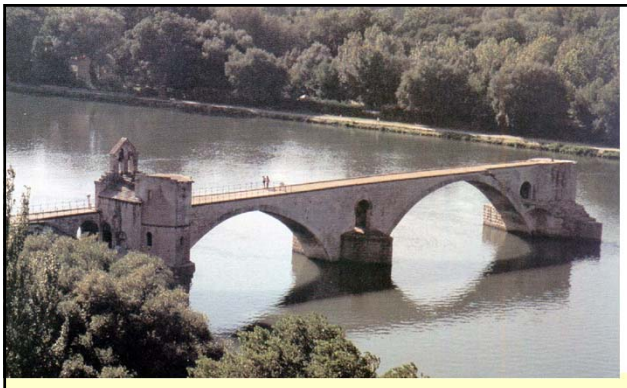
Most od žada
Vrt vječne harmonije,
Beijing

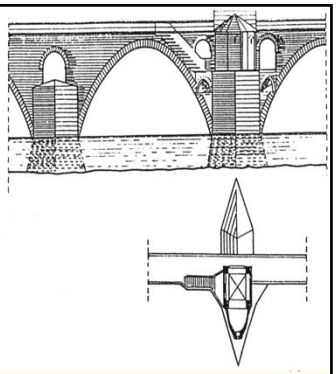


***SREDNJEVJEKOVNO GRADITELJSTVO*:**
- Europa 12. st.: Benediktinska redovnička bratstva grade ceste
- ***Most u Avignonu*** (1185) - graditelj Johan Benezet (St. Benoit)

duljina: 600 m
rasponi: 20 do 35 m
oblikovanje svoda: 3 središta zakrivljenosti



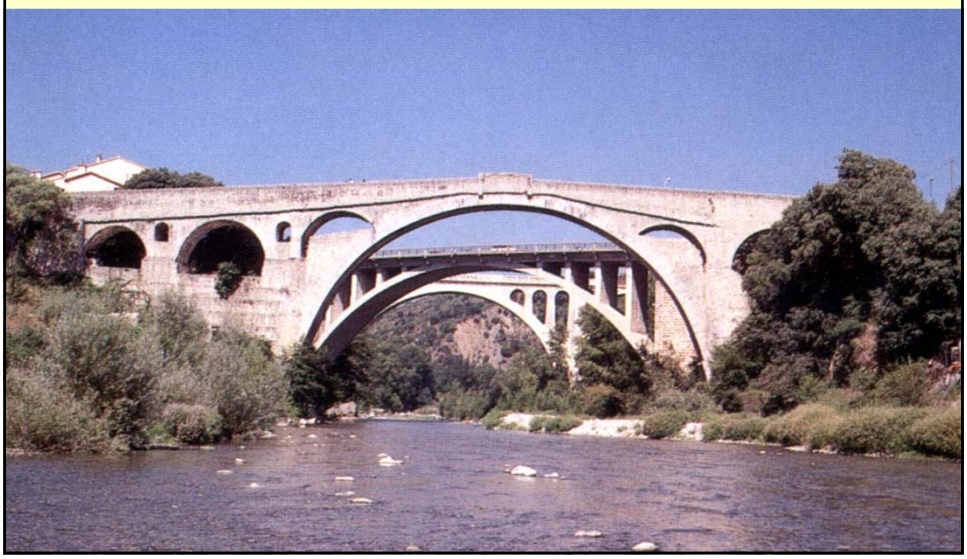




- elegancija mosta u Avignonu nasuprot malim rasponima i širokim stupovima mosta preko Temze
(***Old London Bridge*** (1209), Peter Colechurch



***SREDNJEVJEKOVNO GRADITELJSTVO*:**
- ***most preko rijeke Tech*** (1329) , Francuska
  izniman raspon L=44,5 m





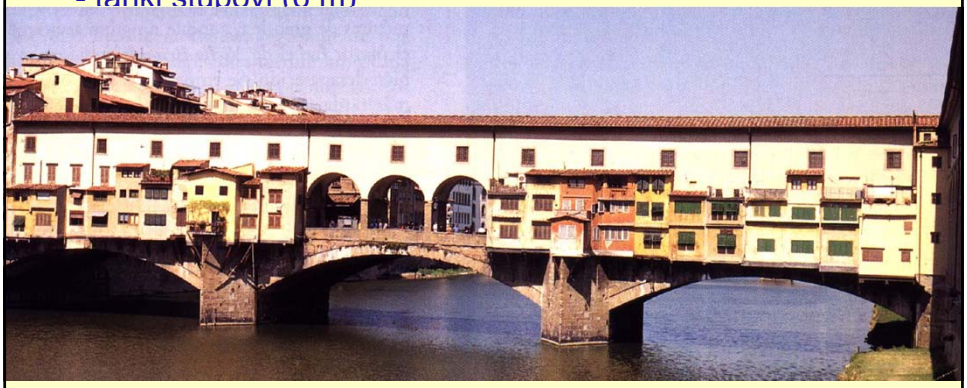
Pont Valentre preko rijeke Lot, Cahors (1355), Francuska, zašiljeni svod s dva središta rasponi oko 14 m



***DRVENI MOSTOVI SREDNJEG VIJEKA*:**
- vjerojatno je i graditeljstvo drvetom bilo razvijeno,
  no materijalnih tragova ima malo (Luzern, Švicarska)

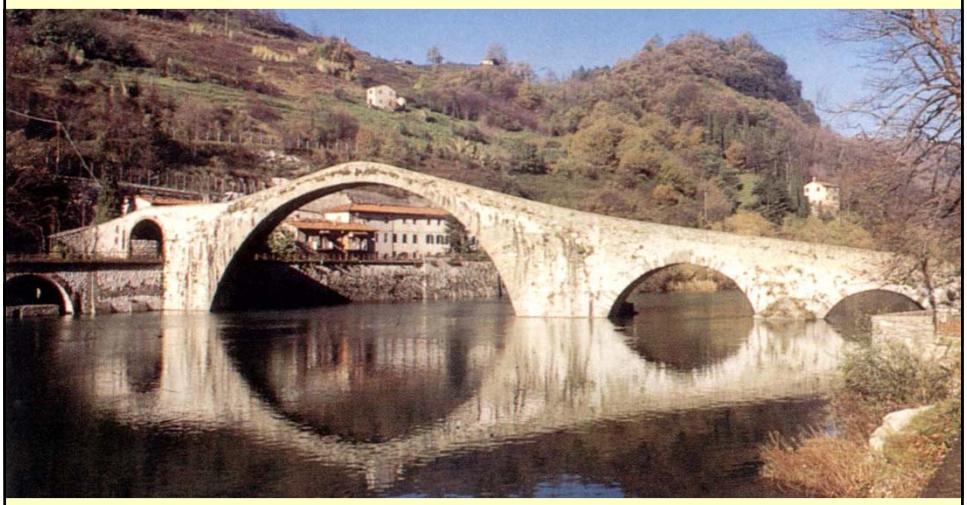


***SREDNJEVJEKOVNO GRADITELJSTVO*:**
- ***Ponte Vecchio, Ponte Castelvecchio***: navještaj renesanse
- ***Ponte Vecchio*** (1345), Firenca
- 3 plitka segmentna luka raspona 27 do 30 m (f/l=1/5)
- tanki stupovi (6 m)





***SREDNJEVJEKOVNO GRADITELJSTVO*:**
- most ***Serchio***, Luca, Italija, 12. st: raspon L=36 m
- promjenjiva debljina luka, sukladno tijeku unutarnjih sila



***SREDNJEVJEKOVNO GRADITELJSTVO*:**



- malo podataka o gradnji mostova
- masivni stupovi,
  hidraulički oblikovani
- poteškoće pri temeljenju
- nosivi sklopovi ne dosežu
  smjelost katedrala
- rasponi 12 do 22 m
- oblik svoda: polukružni luk, šiljati luk
- iznimno segmentni i bačvasti svod
- prometnica: ponekad u oštrom nagibu
-vođenje linije mosta preko rijeke: koriste se sve olakšice kod temeljenja
-**GRAĐENJE:**
- slabija obrada kamena u odnosu na rimske mostove
- temelji:
  kameni nabačaj, piloti s drvenim roštiljem, primitivni zagati

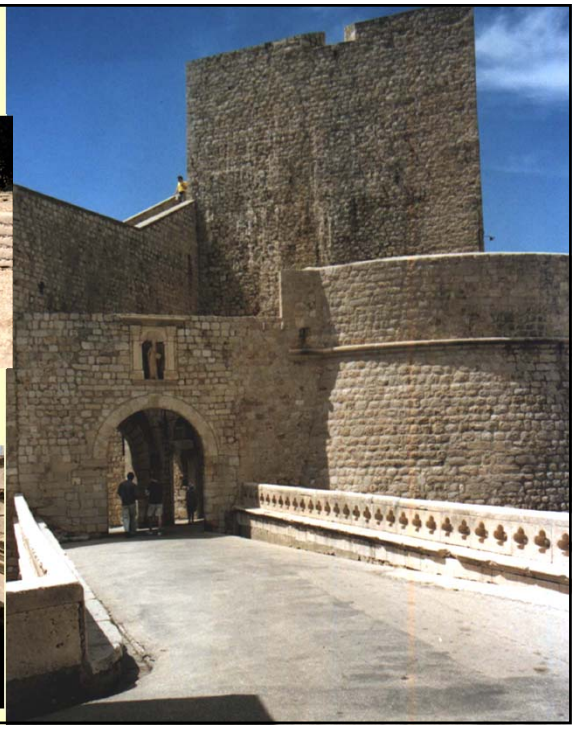
***SREDNJEVJEKOVNI HRVATSKI MOSTOVI*:**
- Dubrovnik, ***Vrata od Pila***: Giovanni da Siena, 1397.
- (1471): rekonstrukcija Paskoja Miličevića, današnji oblik

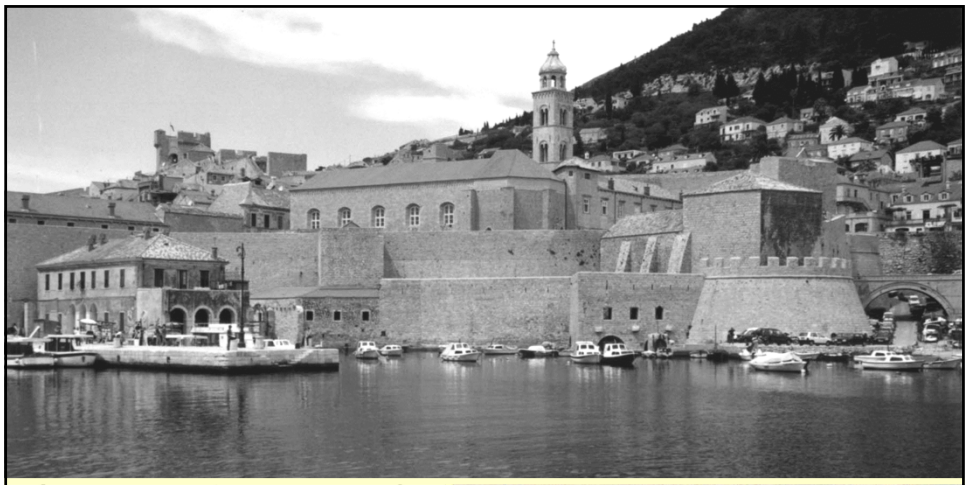


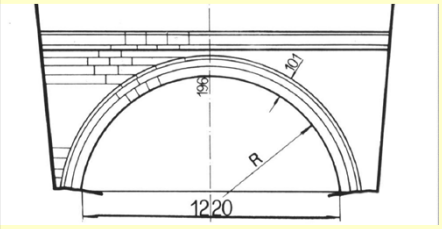
unutarnji most - tvrđava Revelin

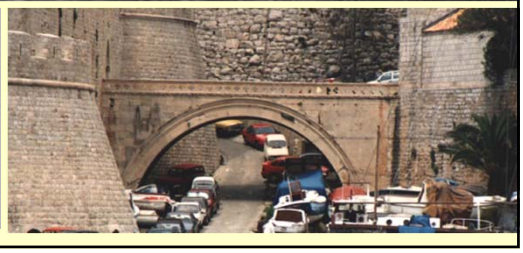










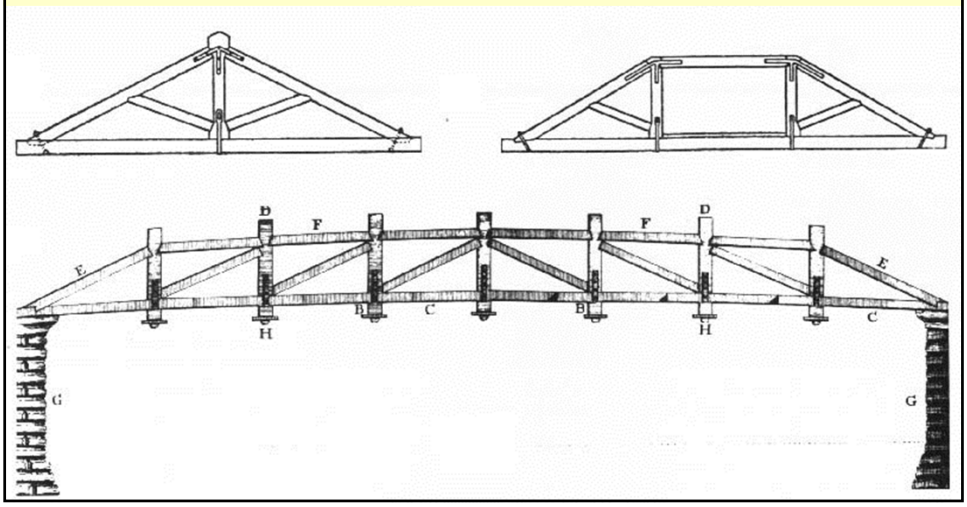


most na Vratima od Ploča



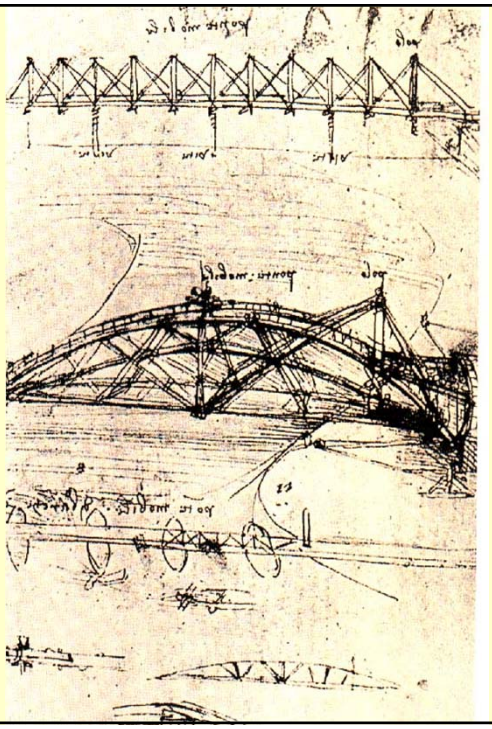
***MOSTOVI RENESANSE*:**

- Italija 15 st.: promjena svjetonazora, nastaje suvremena znanost
- s tehničkog motrišta masivni mostovi se malo mijenjaju
- arhitektonski postaju bogatiji
- gradnja drvetom - usavršavaju se rešetke

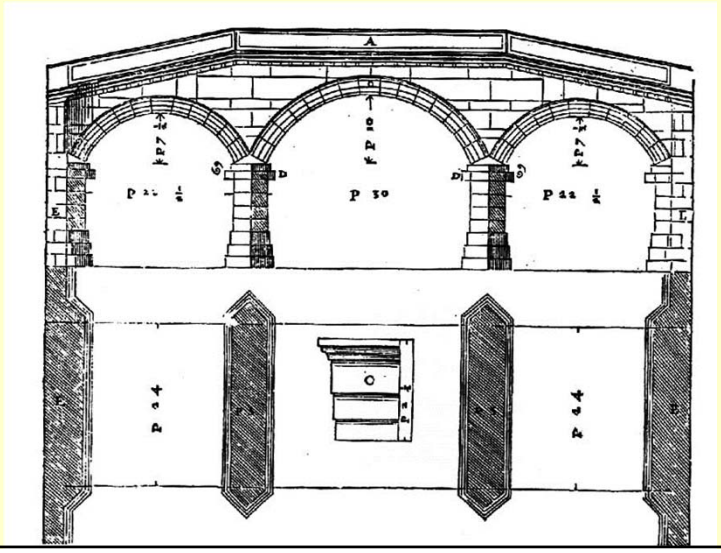


Leonardo da Vinci
(oko 1500.)

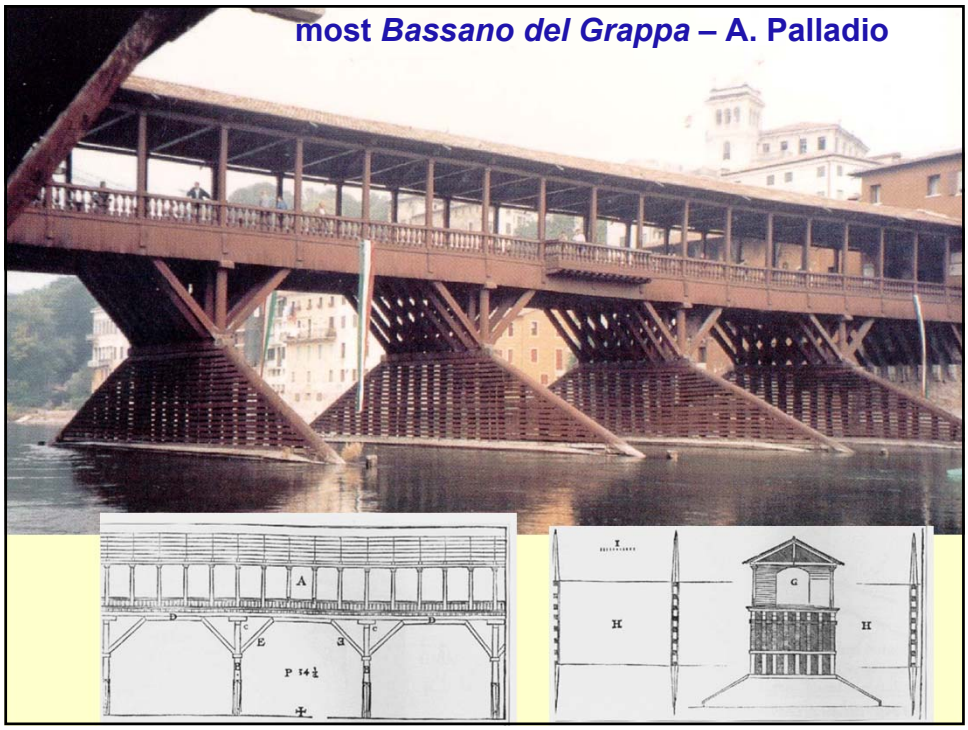
- projekt lučnog mosta raspona 300 m!
- skicirao različite konstrukcije

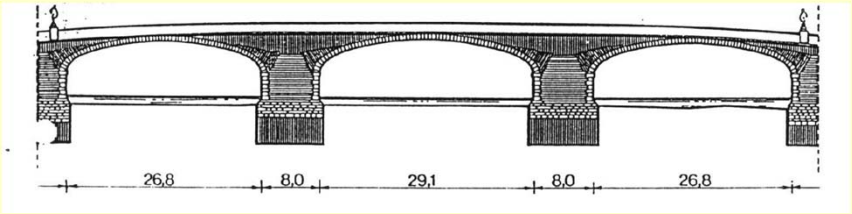


***MOSTOVI RENESANSE*:**
- Andrea Palladio:
  Quattro Libri dell'Architettura (1570)
- harmonija proporcija u graditeljstvu, po uzoru na antiku

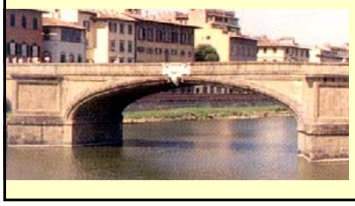


most *Bassano del Grappa* – A. Palladio



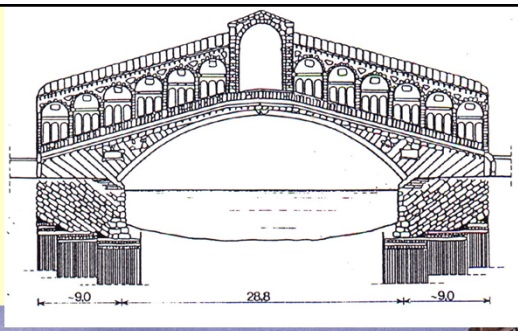


***MOSTOVI RENESANSE*:**
- Firenza: ***Santa Trinita***
- B. Ammanati 1570.
- izvoran oblik linije luka: lančanica
- f/l=1/8



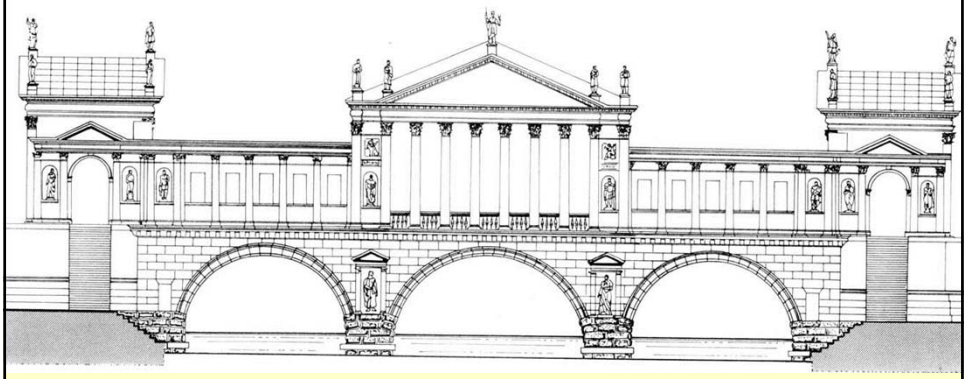


MOSTOVI RENESANSE:
- most ***Rialto***, Venecija,
- raspon L=28,8 m
- Antonio da Ponte, 1591.
- temeljenje na 10 000 drvenih pilota



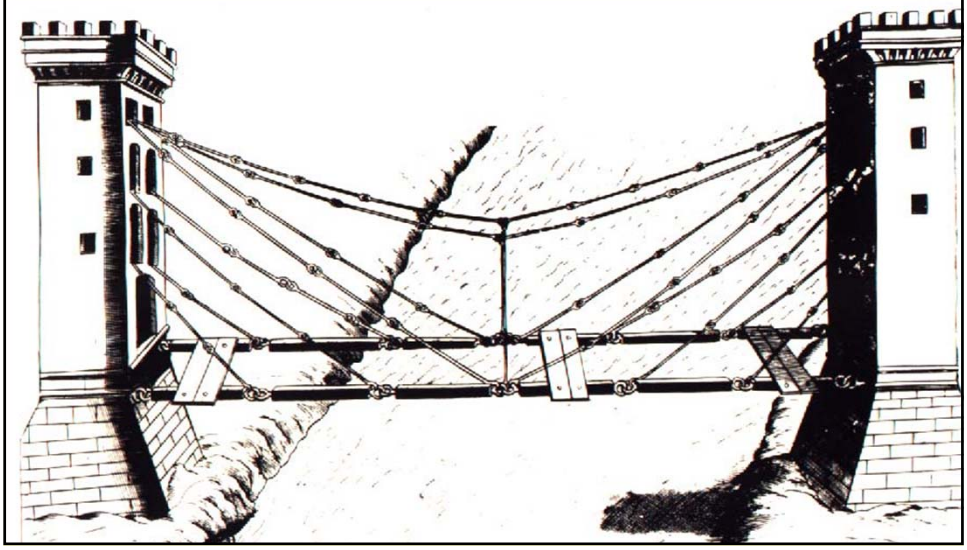


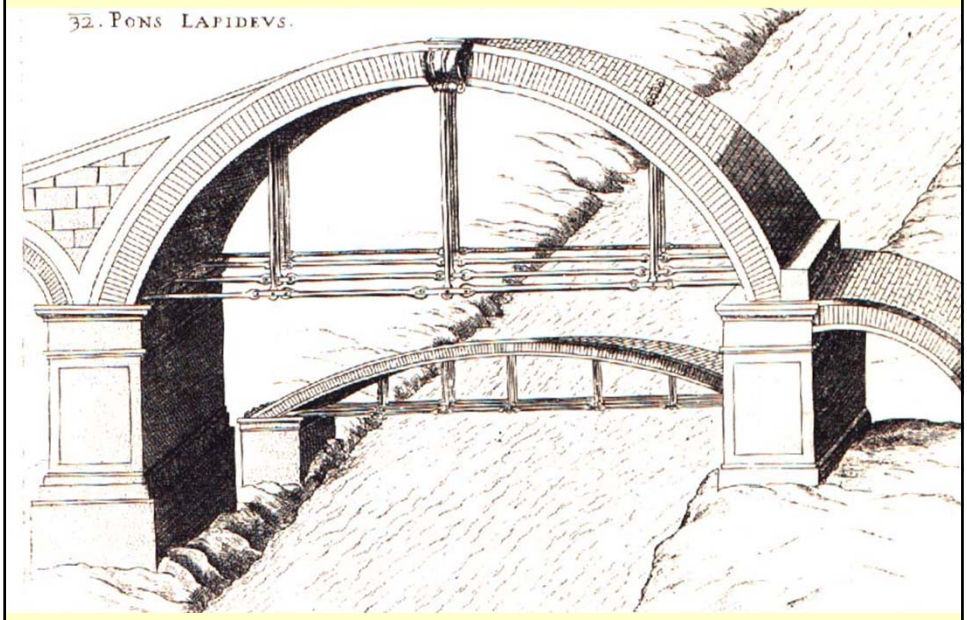
most ***Rialto***, Venecija, Palladijev natječajni rad



MOSTOVI RENESANSE:

- **Faust Vrančić (Faustus Verantius)**
  hrvatski znanstvenik, istakao se idejama novih sustava mostova
- knjiga: **Machinae Novae, 1615**



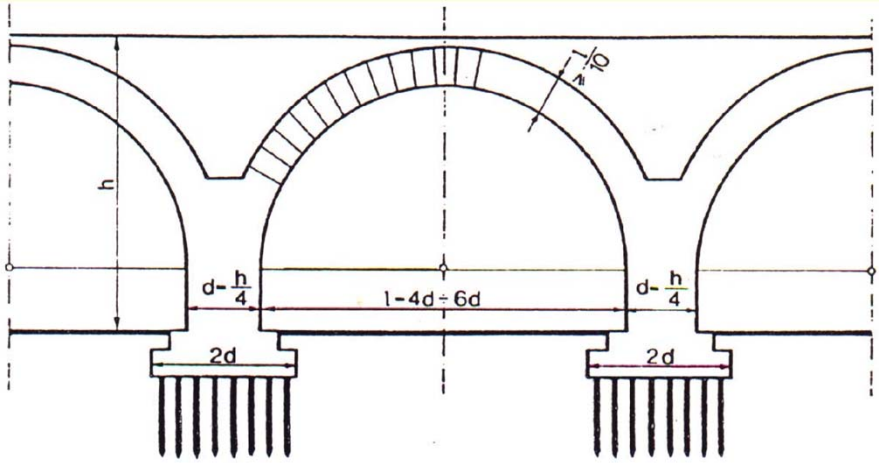


***MOSTOVI RENESANSE – FRANCUSKA*:**

- Pariz, Seina, ***Pont Neuf***: "kravlji rogovi", rasponi oko 20 m, 1606.
- ***Pont Royale***, Pariz (1687): eliptični svod
- ***Vieille-Brioude***: most najvećeg raspona u 17. st., L=54 m

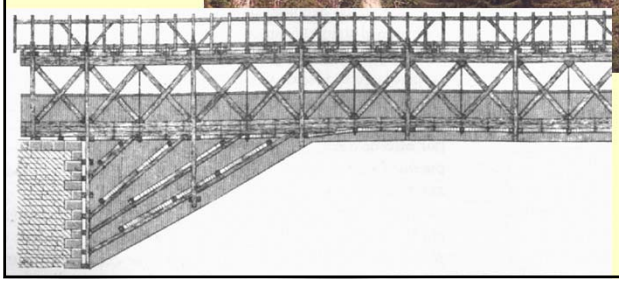


***MOSTOVI RENESANSE – OBLIKOVANJE*:**
- sve plići lukovi, različitih oblika
- Leonardo da Vinci: potisak ovisi o obliku svoda
- uobičajili se rasteretni otvori
- empirijska pravila konstruiranja: Alberti 1450.



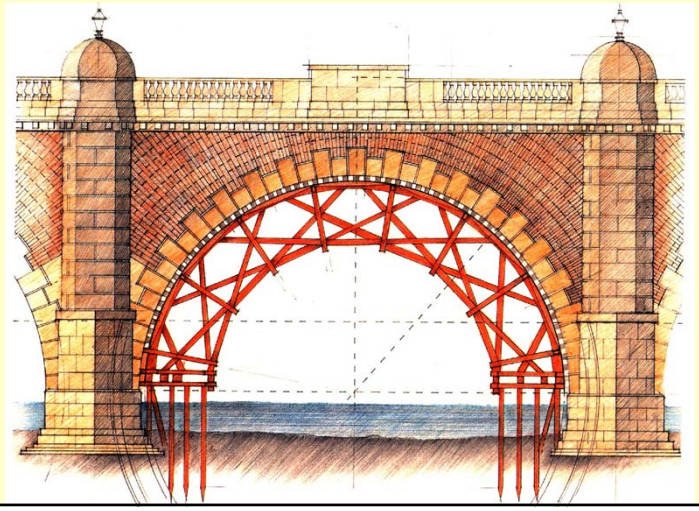
MOSTOVI RENESANSE



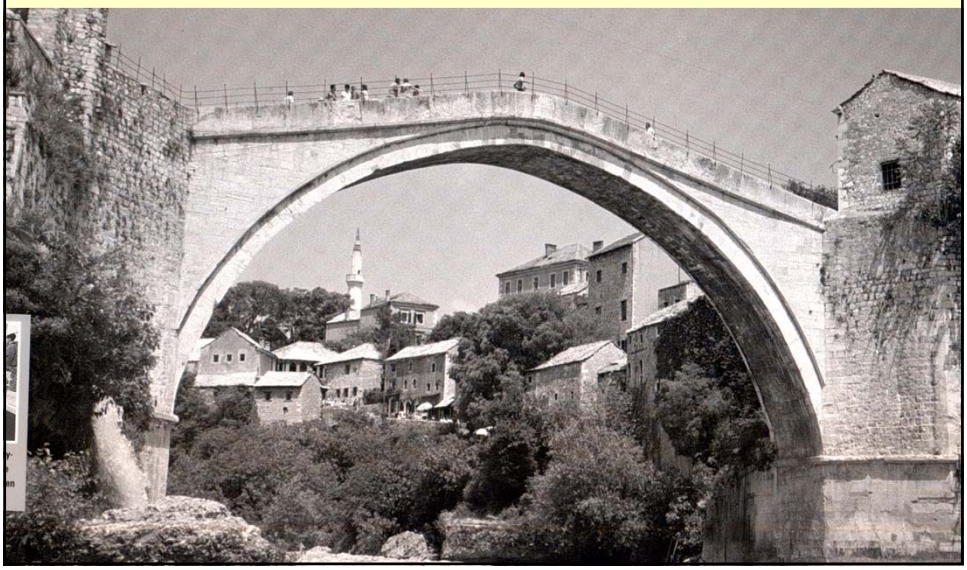


- poboljšanja i unaprijeđenja rešetkastih sustava
- veći rasponi drvenih mostova i bolje skele kamenih mostova

***MOSTOVI RENESANSE – GRAĐENJE*:**
- konstruktivna rješenja rešetke utječu na povećanje raspona
- unaprijeđeni alati i naprave za gradnju
- Alberti predlaže prethodno ispitivanje tla
- prvi opisan model kod projektiranja mosta (1600.)



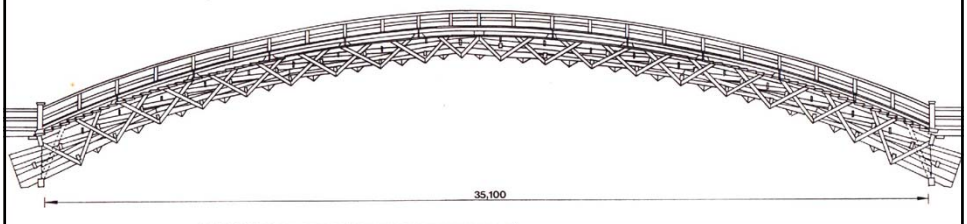
***VANEUROPSKE KULTURE*:**
- vrhunac Otomanskog graditeljstva
- Hajrudinov ***Latinski most*** u Mostaru (1556) raspon oko L=28 m



***VANEUROPSKE KULTURE* – Japan:**

- od renesanse graditeljstvo ponešto zaostaje za europskim
- most ***Kintai***, raspon 35 m





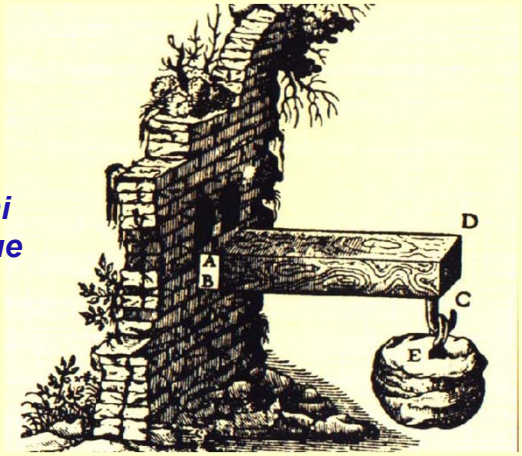




***ZANATSKO GRADITELJSTVO*:**
podloga za razvitak građevine kao znanosti

- temelji graditeljstva kao znanosti u 17. st.

- Gallileo Galilei (1638): ***"Discorsi e di mostrezioni matematiche intorno a due nuove scienze"***



- Robert Hooke: temelji teorije elastičnosti

- Pariz: *Corps des Ponts et Chaussees*, 1675.

- *Ecole des Ponts et Chaussees*, 1747. godine

- prva knjiga o građenju mostova (1714), H. Gautier, *Traite des Ponts*

INDUSTRIJSKA REVOLUCIJA I NJEZINE POSLJEDICE :

- Coulomb, 1736. do 1806.: sinteza dotadašnjih eksperimentalnih i teoretskih saznanja

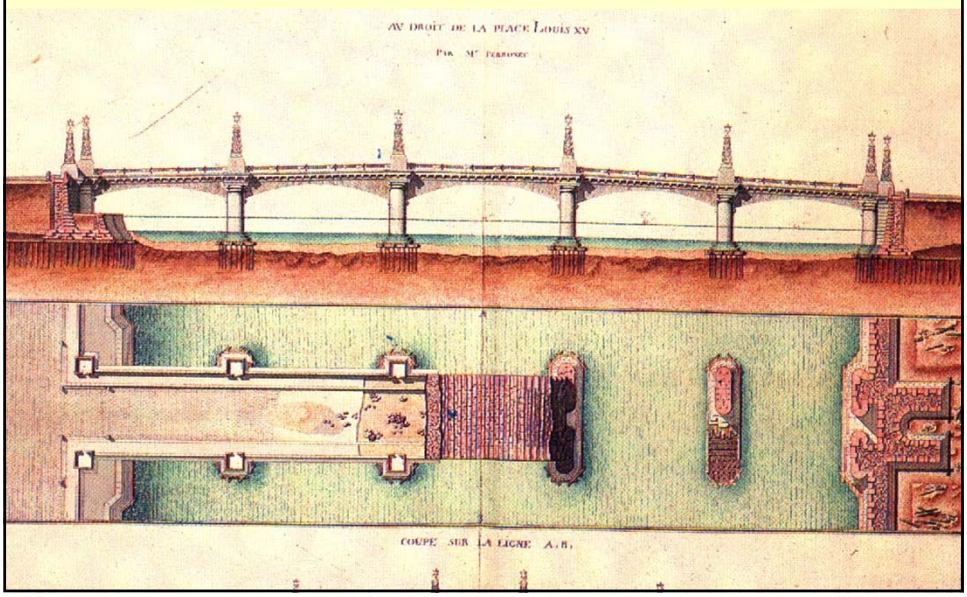
-18. stoljeće: napredak na polju gradiva npr. prva zabilježena primjena hidrauličnog veziva nakon rimskih betona (1756)

- A. Darby II (1735): sirovo željezo iz visoke peći ložene koksom. ostvareni preduvjeti za industrijsku proizvodnju lijevanog željeza

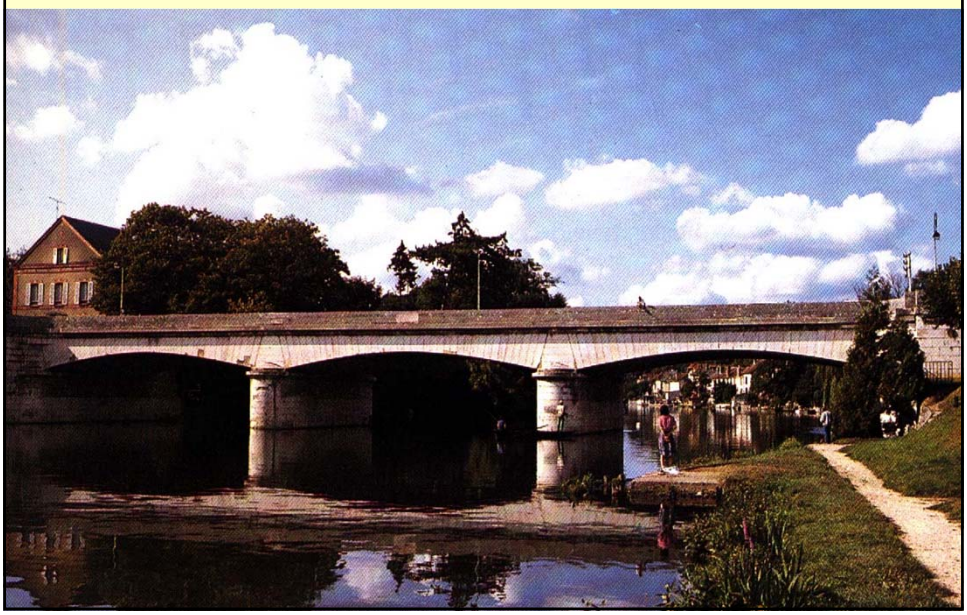
- industrijska revolucija: razvitak parnog stroja i željeznice

- pred mostogradnju postavljeni novi zadaci i stvoreni preduvjeti za razradu novih konstrukcija i ostvarenje još većih raspona

Jean Perronet,
Ecole des Ponts et Chaussees, od polovine 18. st.



most, ***Nemours*** (1771), *Jean Perronet*

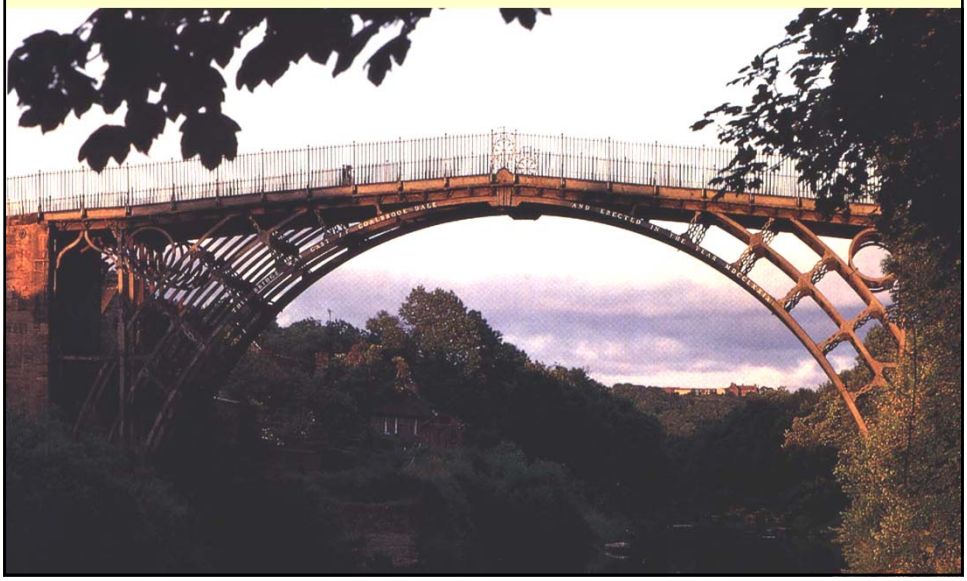


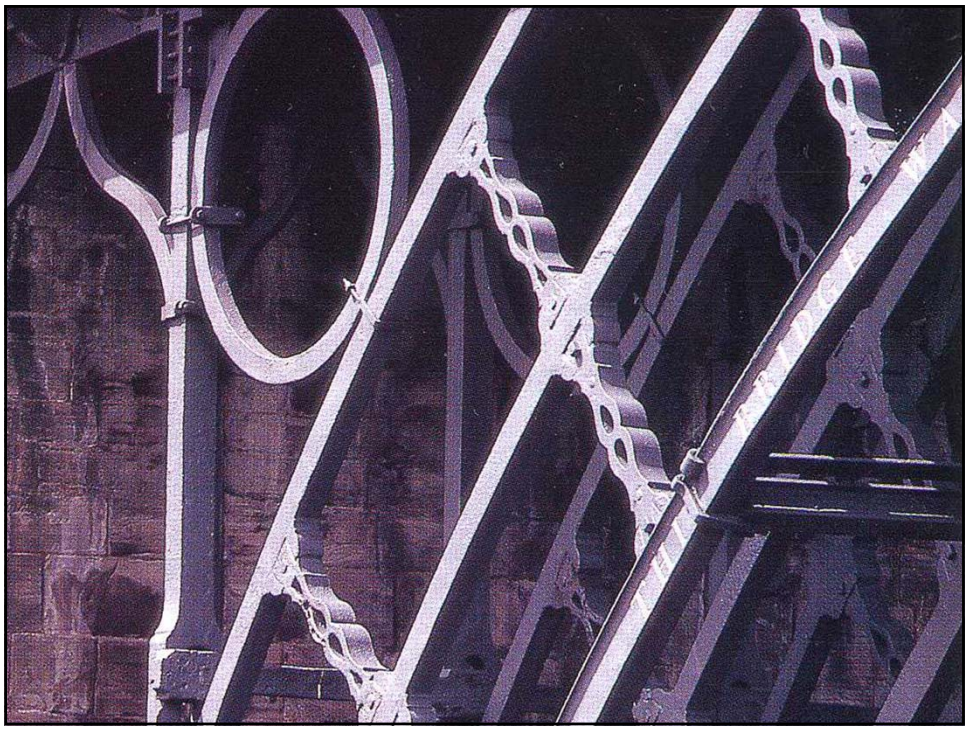
Provizoriji i specijalni mostovi:
- o pothvatima inženjeraca ima malo tragova (Napoleonski ratovi)

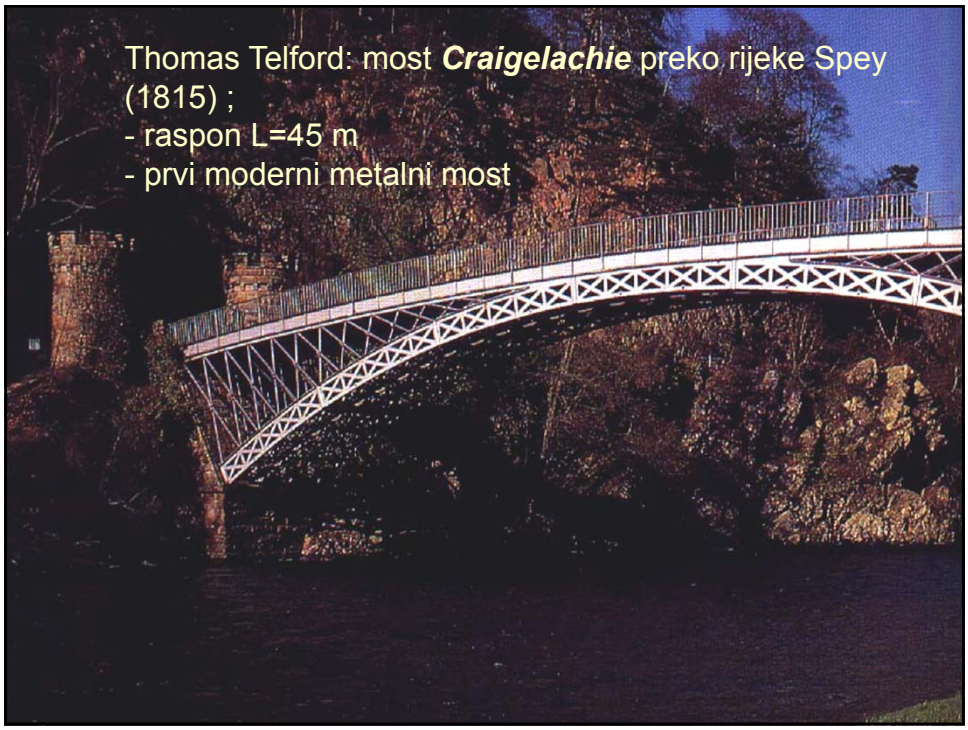


Most ***Coalbrookdale*** (1779), T. Pritchard

most od novog gradiva – lijevanog željeza, detalji oblikovani po uzoru na drvene konstrukcije, osnovni oblik slijedi kamene lučne mostove

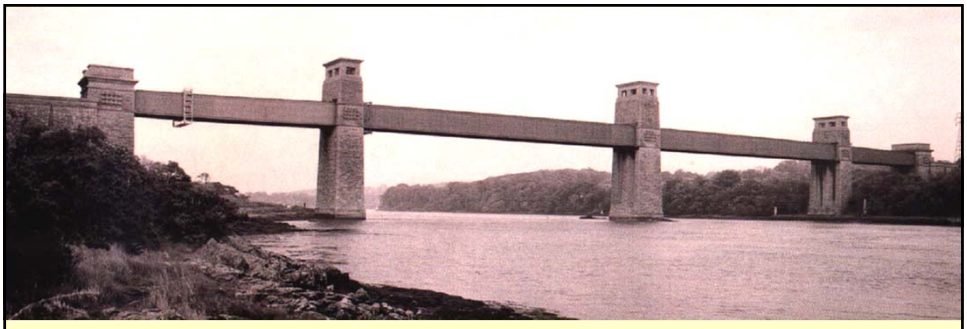





Thomas Telford: most ***Craigelachie*** preko rijeke Spey (1815) ;
- raspon L=45 m
- prvi moderni metalni most

John Rennie: *New London Bridge* (1831)

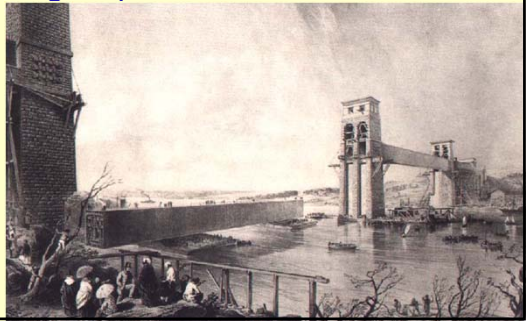


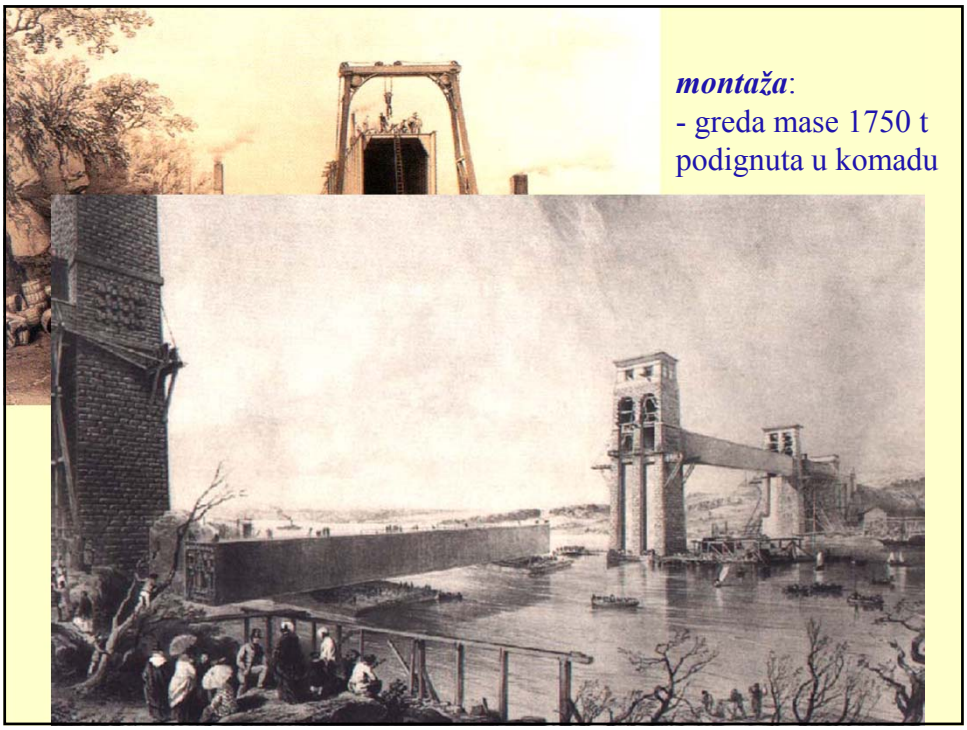


R. Stephenson 1850:
- most ***Britannia***, greda najvećeg raspona L=140 m

- 2 odvojene cijevi
kroz koje prolazi željeznica

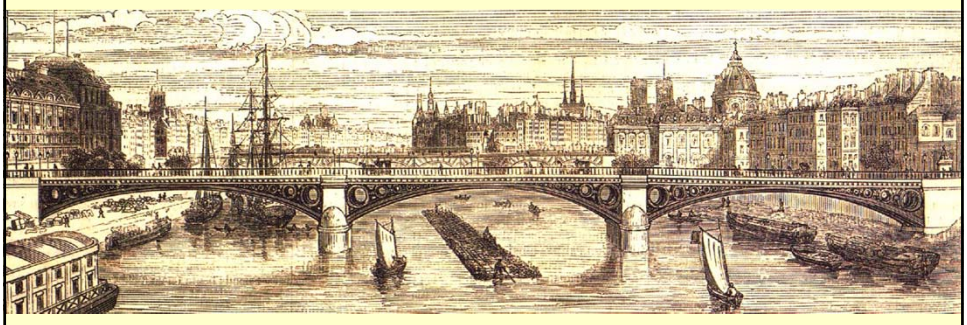
- gradivo: vareno željezo
(slično čeliku)





montaža:
- greda mase 1750 t podignuta u komadu

A. Polonceau, Pariz (1839): most *Carrousel*, raspon L=48 m



- polovina 19. stoljeća: čelik znatno jeftiniji (do 1870. cijena pala za 75% u odnosu na prethodno razdoblje)

- proizvodnja Portland cementa započela 1844. u Engleskoj

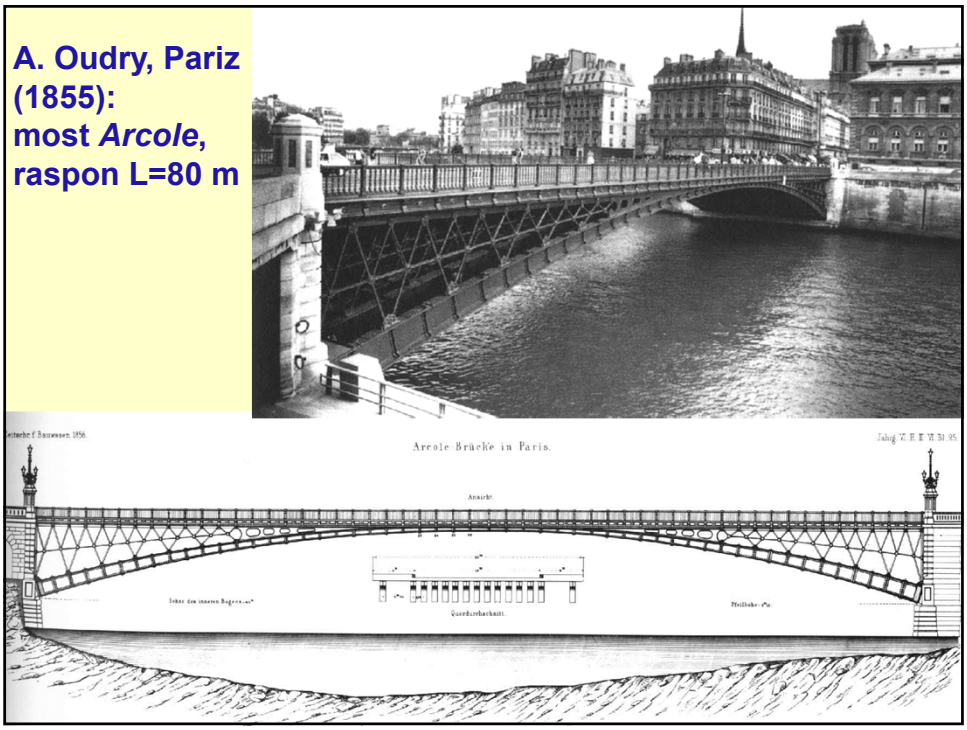
- širenje željezničke mreže - gradnja mostova:
veći rasponi (zbog ograničenja na vođenje trase)
veća nosivost (prometno opterećenje znatno više)

- temeljenje u kesonima pod pritiskom, ispod vodene razine

- konzolna gradnja (montažna gradnja bez skele): ***Eads Bridge***, St.Louis, preko rijeke Mississippi, J.B. Eads

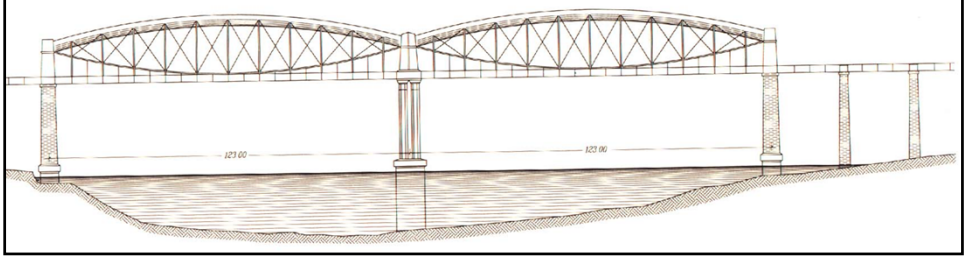
- teorija: Maxwell, Cremona, Ritter.

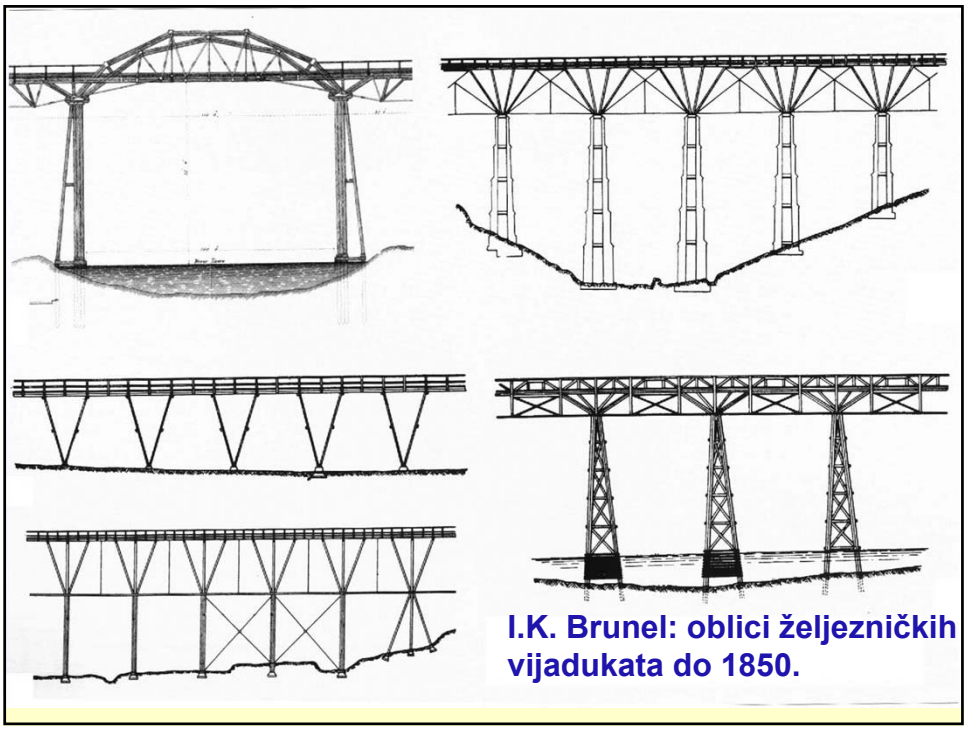
A. Oudry, Pariz (1855):
most *Arcole*,
raspon L=80 m



I.K. Brunel:
Royal Albert Bridge
(1859)

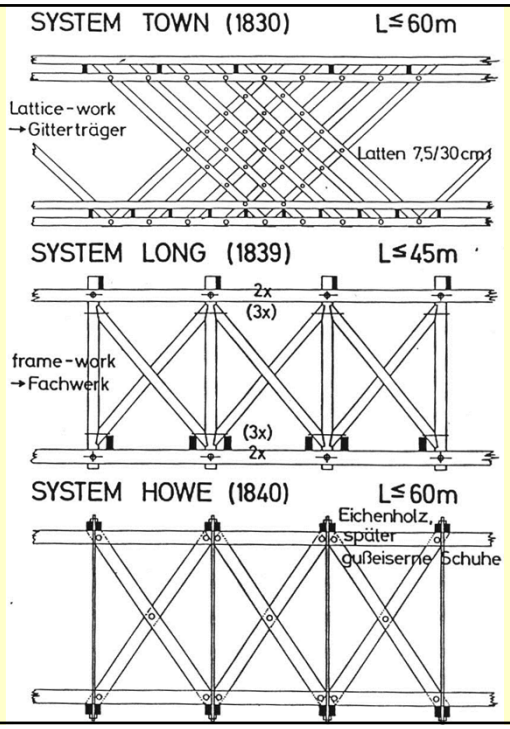


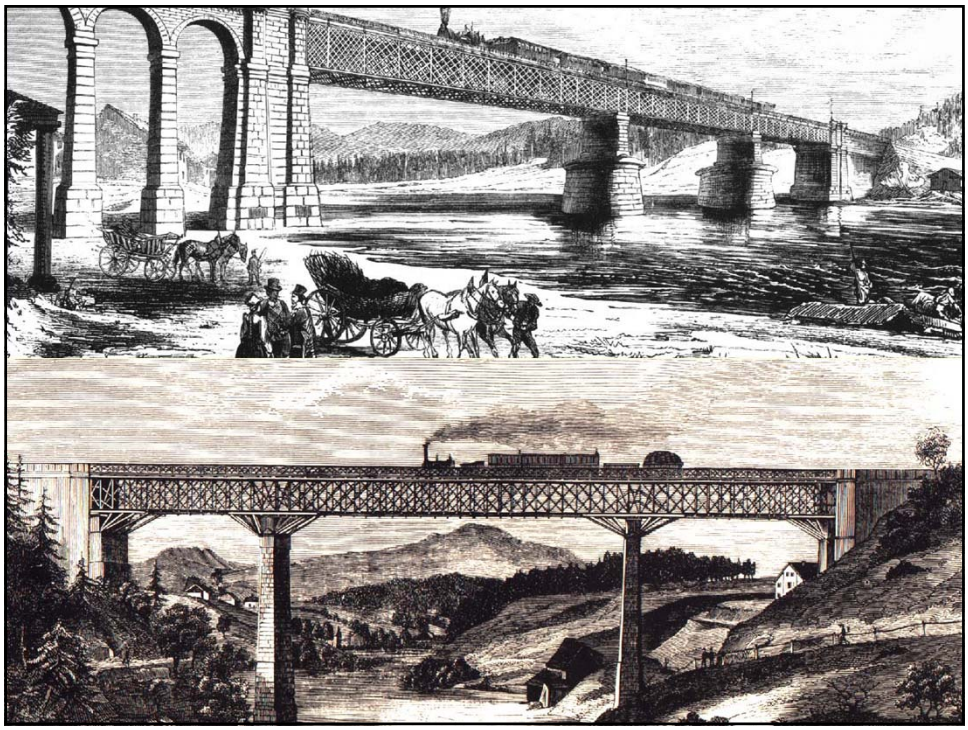


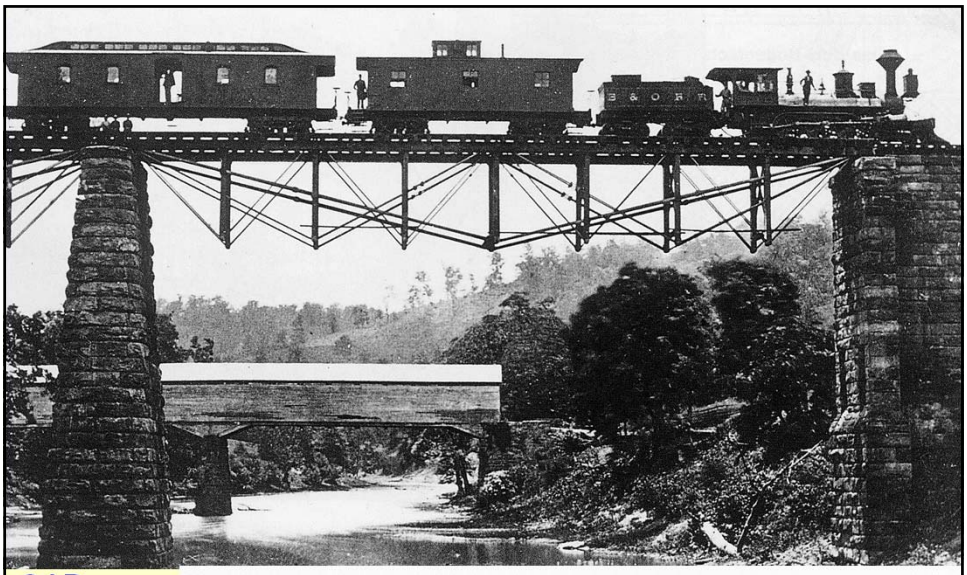


I.K. Brunel: oblici željezničkih vijadukata do 1850.

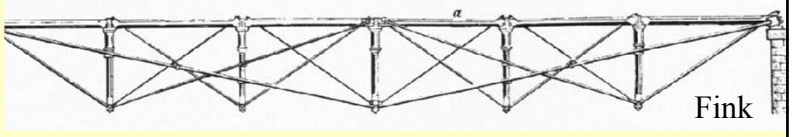
- SAD: novi oblici rešetkastih nosača mostova, izvedeni za gradnju drvom





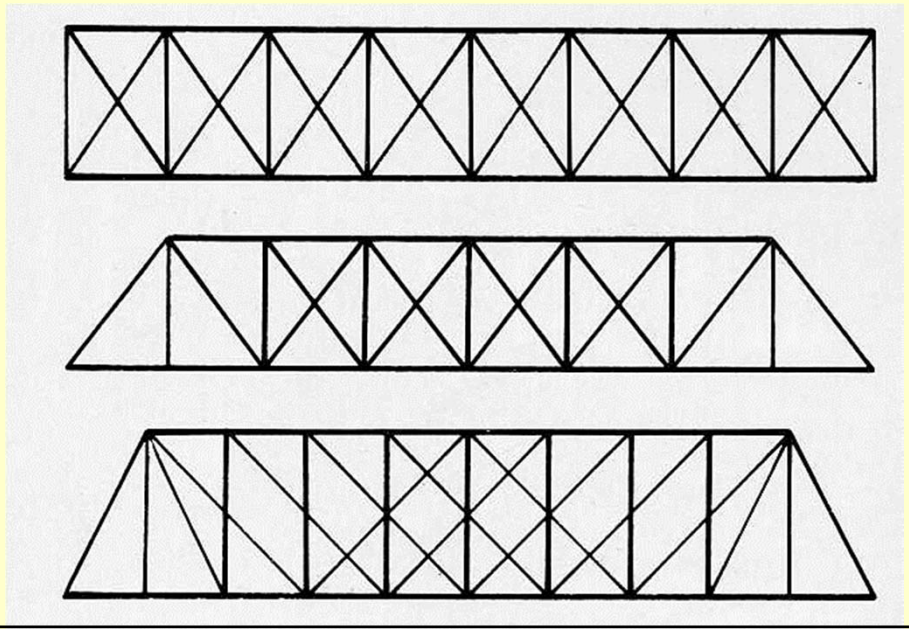


SAD: gradnja rešetkastih nosača

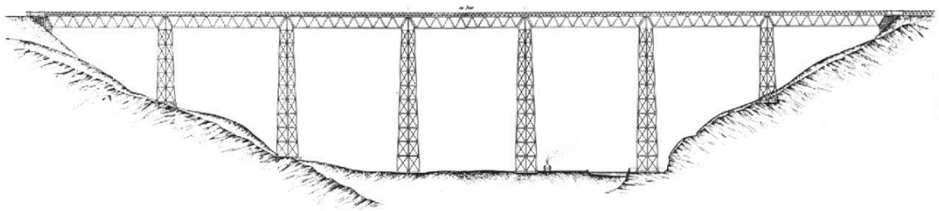


Fink

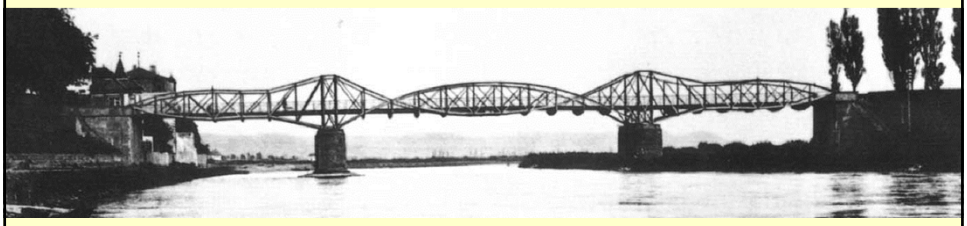
K. Culmann donosi nove oblike u Europu, gdje se dalje razvijaju



vijadukt ***Crumlin*** (1853)**,** Wales, (1853) - rešetka s ispunom tipa Warren (moderni oblik ovog tipa nosača)



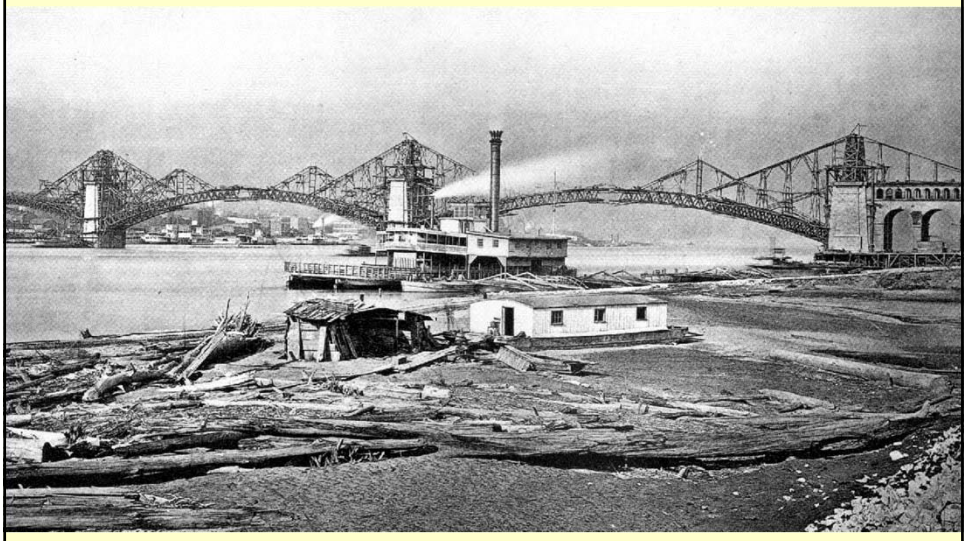
Gerber-ov patent, most iz 1867., raspon L=128 m

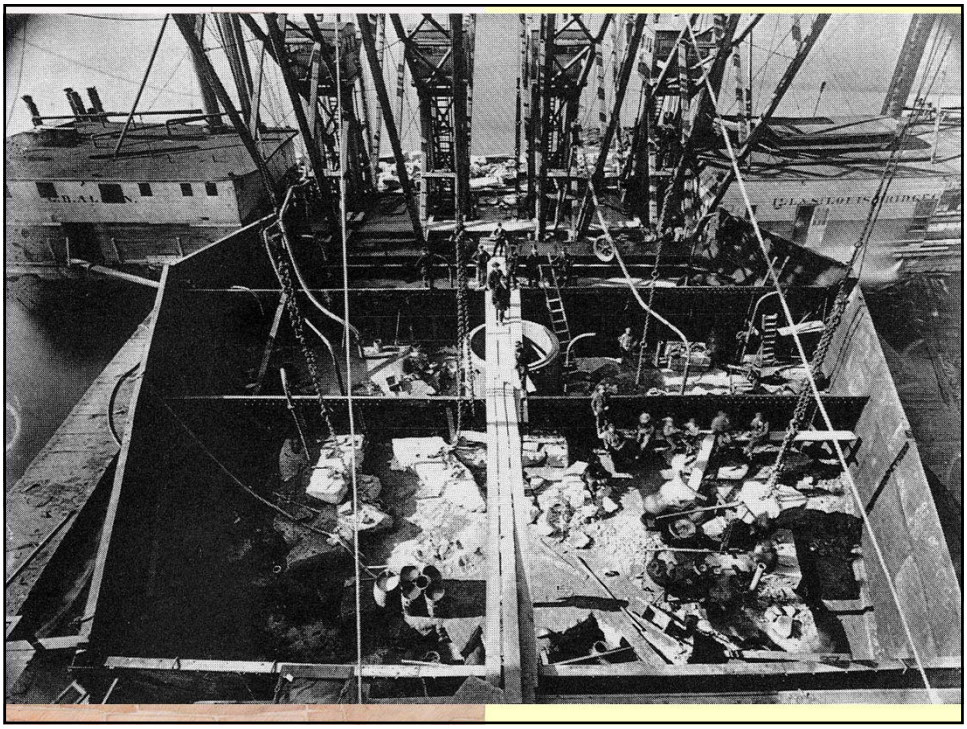


Eads Bridge (1874)**,** St.Louis, SAD – graditelj J.B.Eads

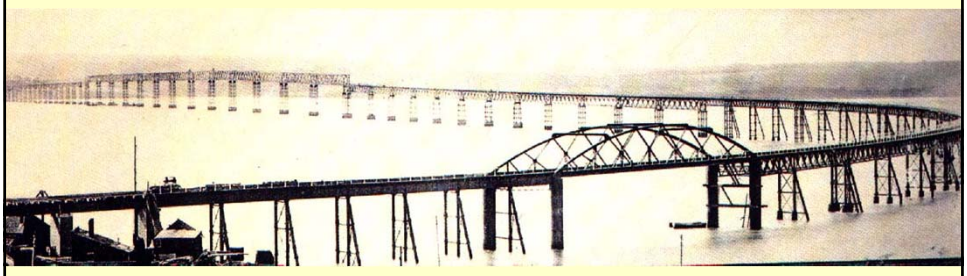


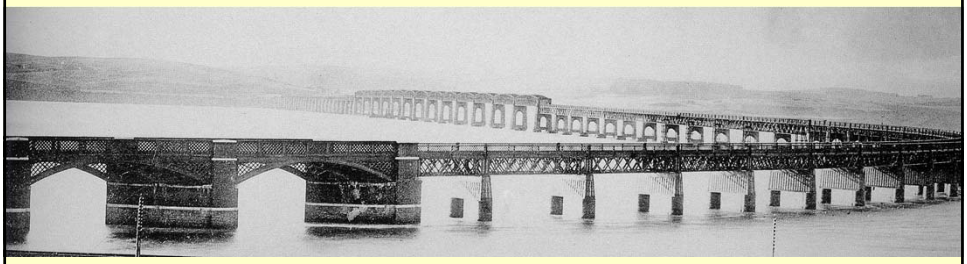
konzolna gradnja luka - bez skele

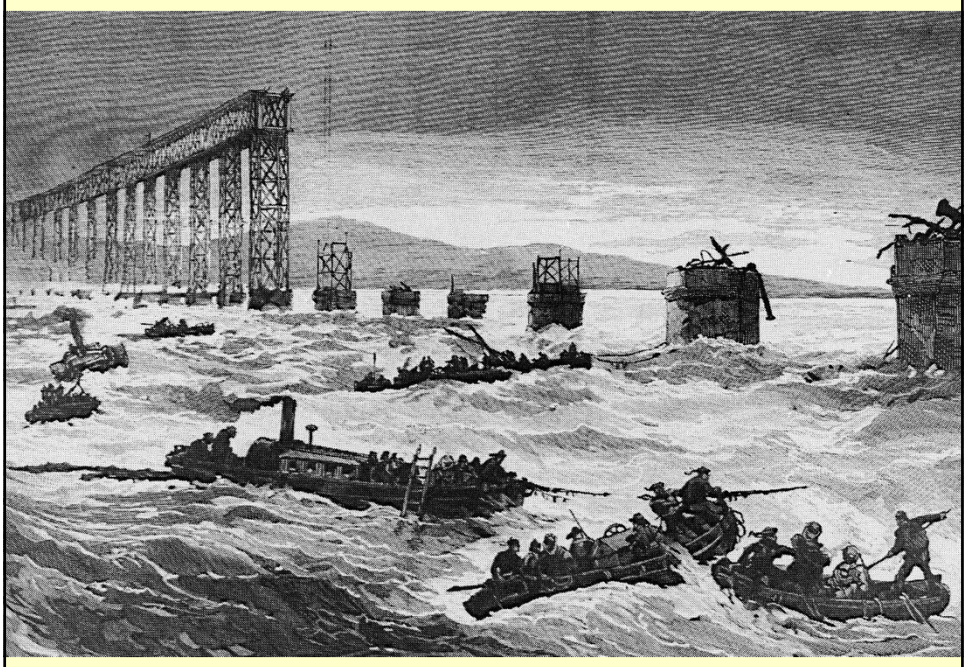


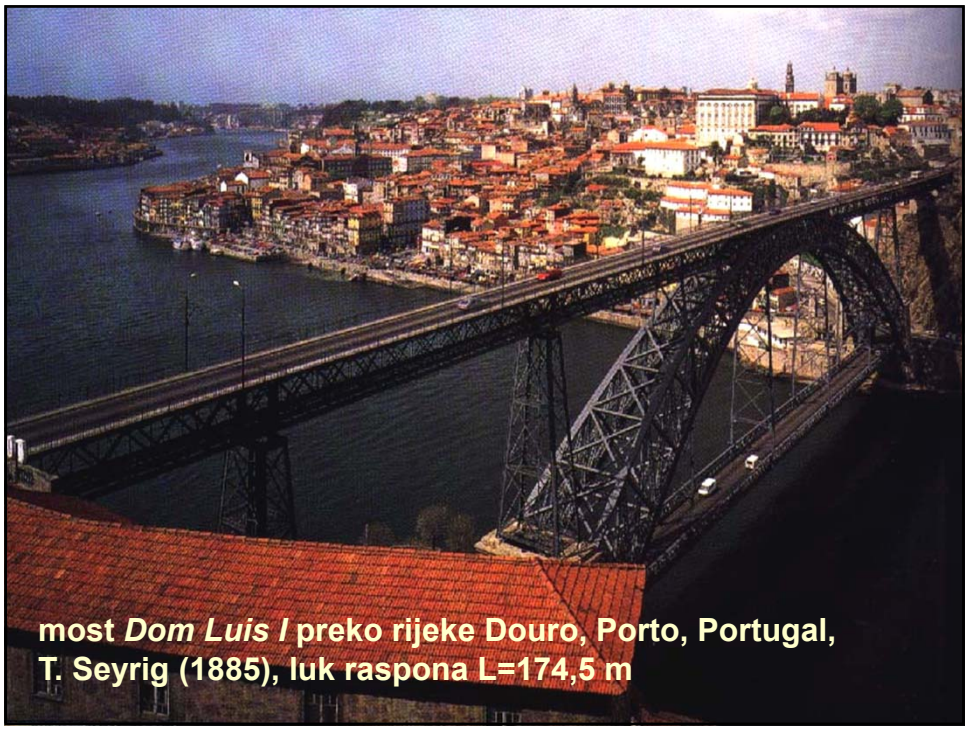


Most preko rijeke Tay, Thomas Bouch
sagrađen (1871); srušio se (1879)



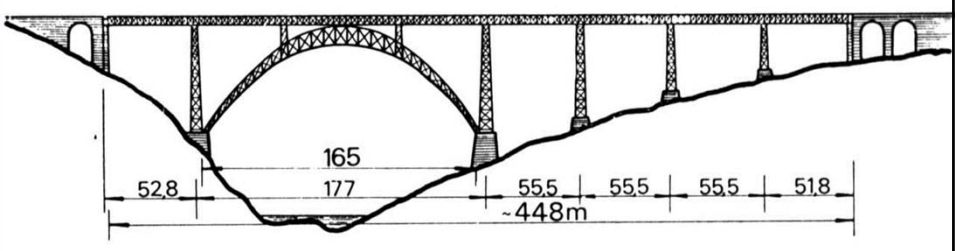






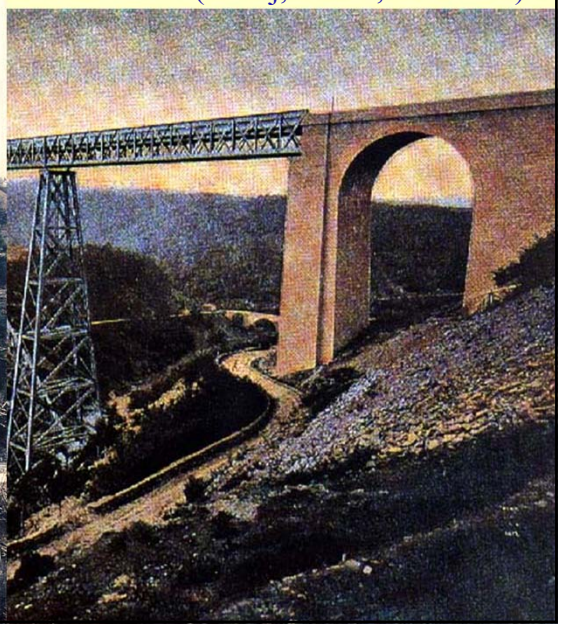
most *Dom Luis I* preko rijeke Douro, Porto, Portugal,
T. Seyrig (1885), luk raspona L=174,5 m

viadukt ***Garabit*** (1884)**,** Truyere,
Francuska, raspon L=177 m – graditelj Gustave Eiffel





vijadukt ***Garabit*** **(1884),** L=177 m
Gustav Eiffel (toranj, 300 m, 1886 - 89)



most ***Münchenstein***, Švicarska, projektant: Gustave Eiffel
sagrađen (1874), ojačan za teži promet (1890), srušio se (1891), 66 mrtvih

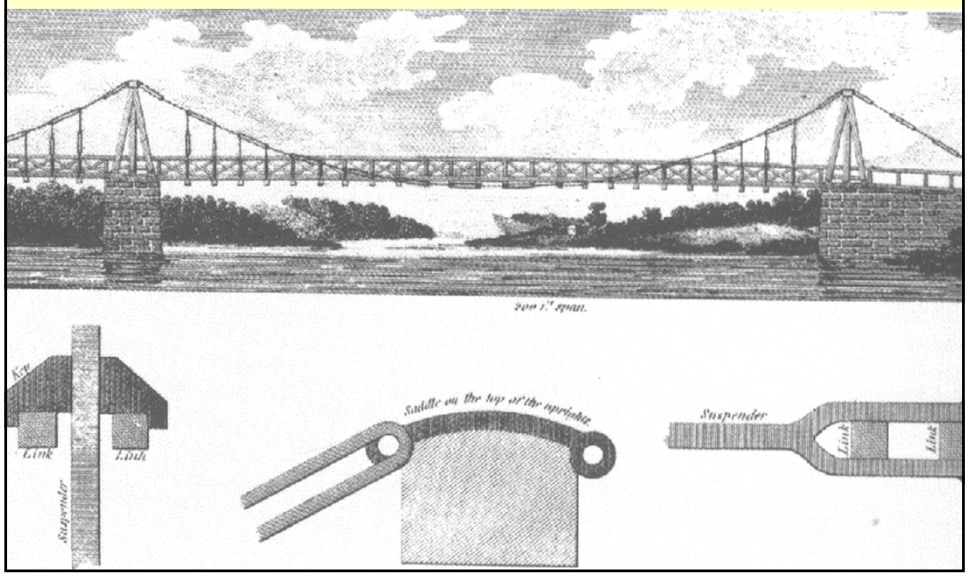


standardni most na pruzi: raspon 43,6 m
visina rešetke 7 m
utrošak čelika 1,29 t/m

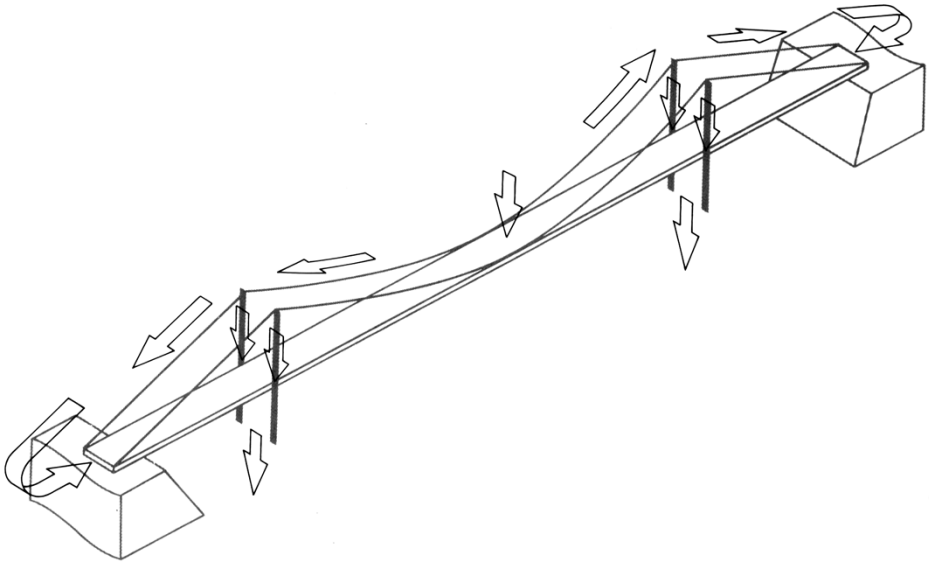
Eiffel-ov projekt: visina rešetke 6,2 m
utrošak čelika 1,20 t/m

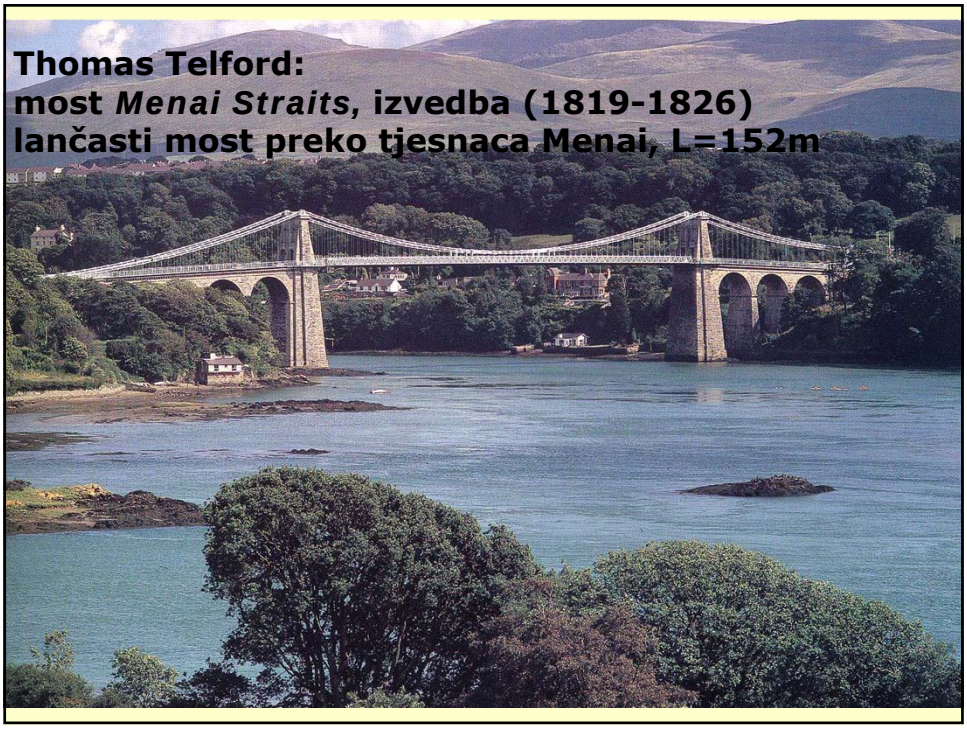


***Viseći mostovi* - moderni oblici od početka 19. st.**
Finlay: lančasti viseći most (1807)

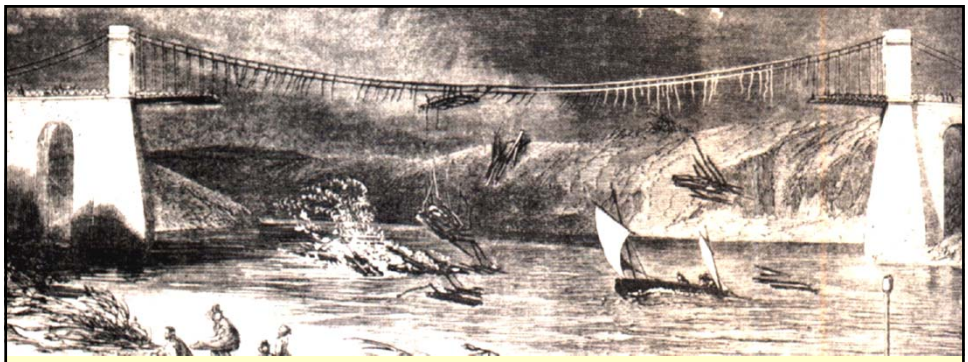


- **od prve teorije - Navier (1823) znanstveni doprinosi prate nove izvedbe visećih mostova**

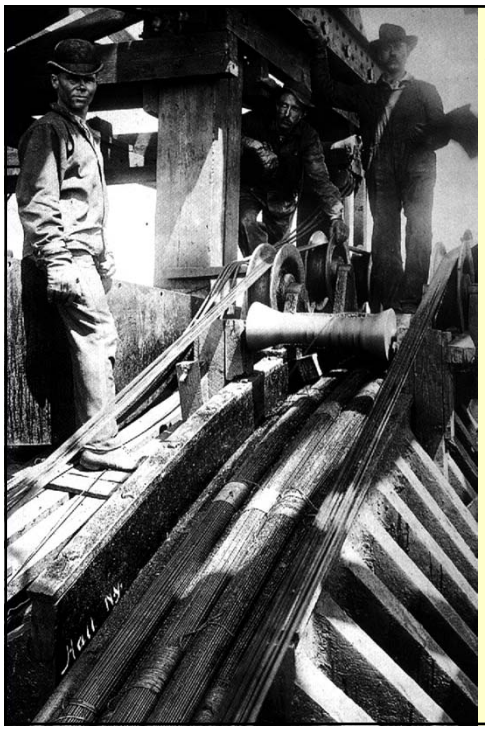






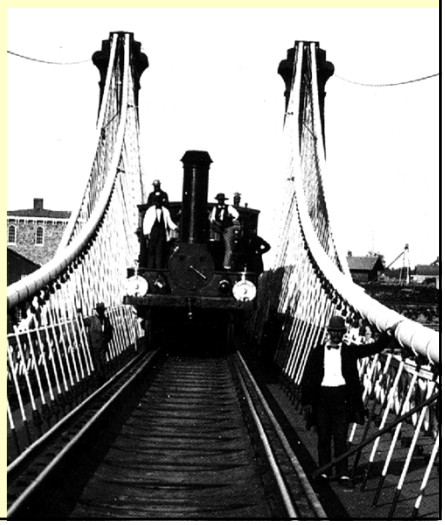


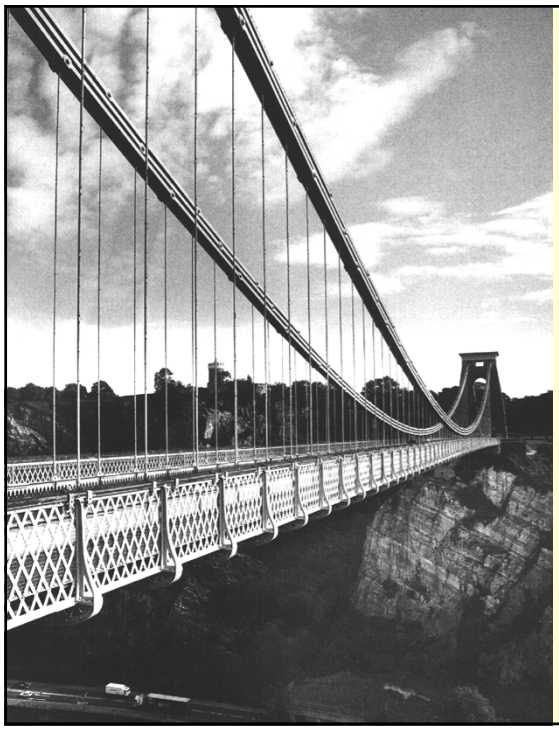
više visećih mostova srušilo
se zbog aerodinamičke nestabilnosti
polovicom XIX stoljeća



most preko Niagare

(1859)
projektant: Johann Roebling
noseća užad od čeličnih žica



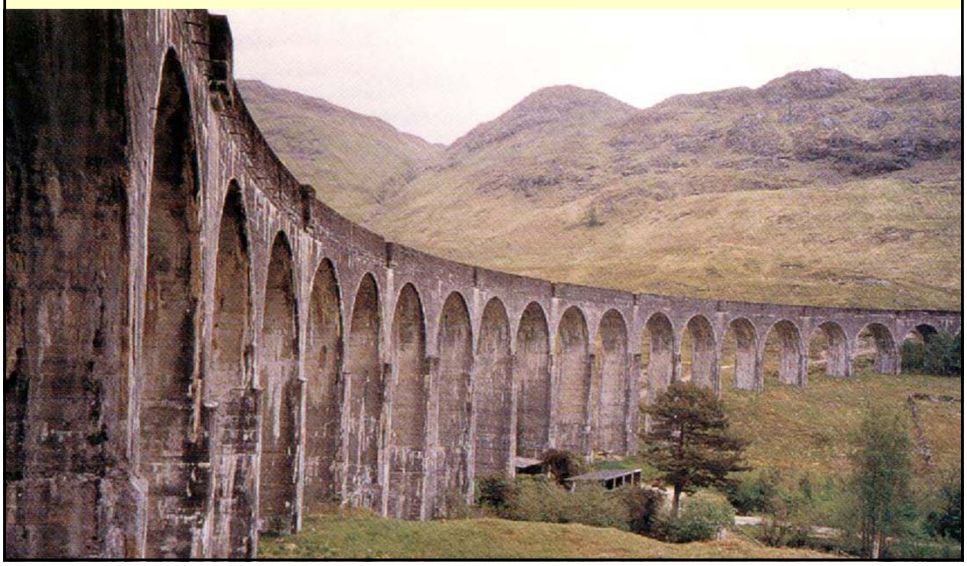


most *Clifton*, UK (1864)

projektant:
Isambard Kingdom Brunel



armirani beton **– gradivo koje će obilježiti 20.st.**
- Monier - patent iz 1867., 1873. - dodatak za mostove
- Melan, patent iz 1892.: kruta armatura od čeličnih nosača



ZNAČAJNI MOSTOVI S KRAJA 19. I POČETKA 20. st.:
industrijsko oblikovanje nosivih struktura:

- utilitarnost
- forma koja slijedi tijek unutarnjih sila
- prilagodba postupku izvedbe
- dodatni ukrasi (rijetko)

reprezentativni primjeri mostova:

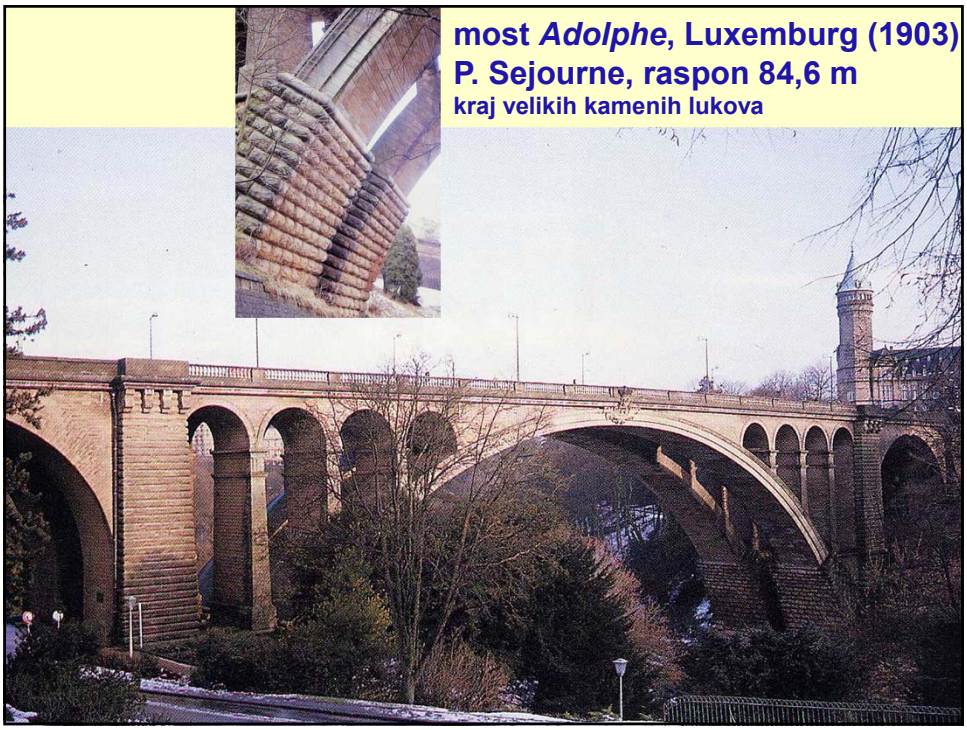
Firth of Forth: čelična konzolna rešetka

most Adolphe: među posljednjim velikim kamenim lukovima

most *Aleksandra III*: dekorirani plitki luk

viadukt *Viaur*: rešetkasti lučni most

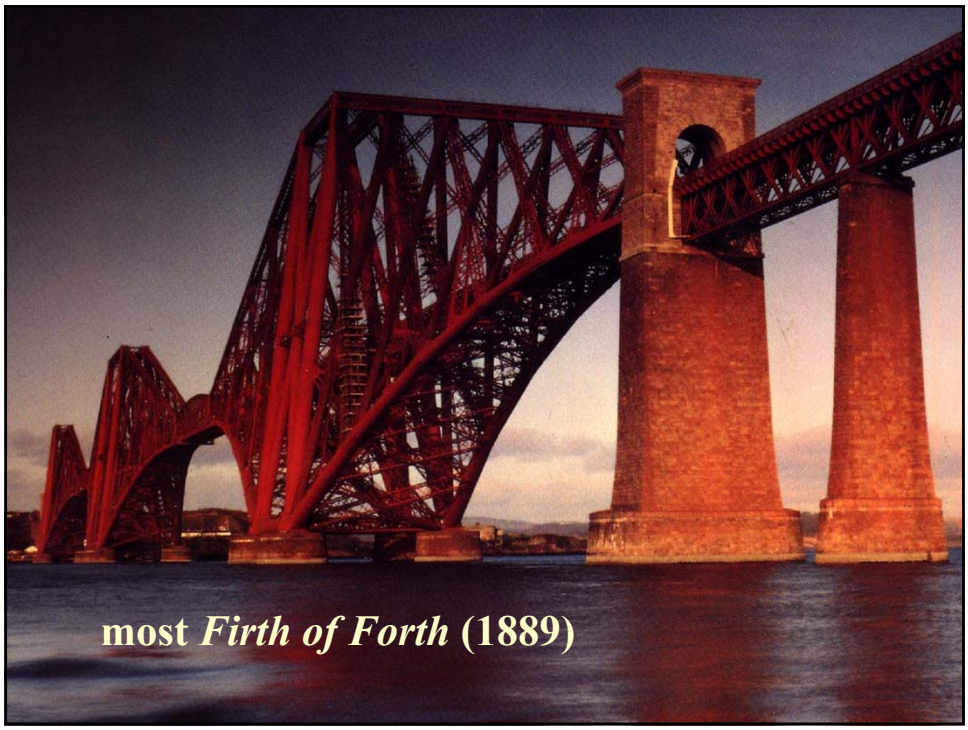
most ***Brooklyn***: viseći most iznimnog raspona, najava novih ostvarenja



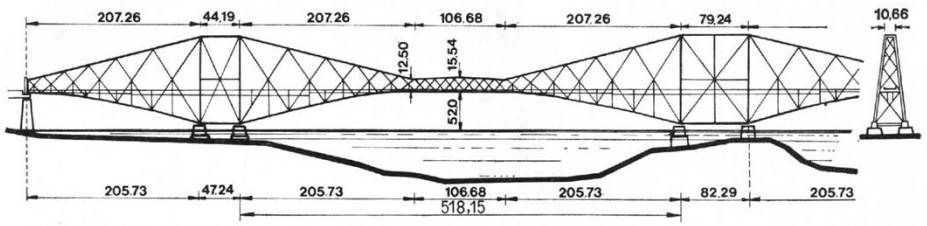
most *Adolphe*, Luxemburg (1903)
P. Sejourne, raspon 84,6 m
kraj velikih kamenih lukova

Most *Aleksandra III*, Pariz (1900)



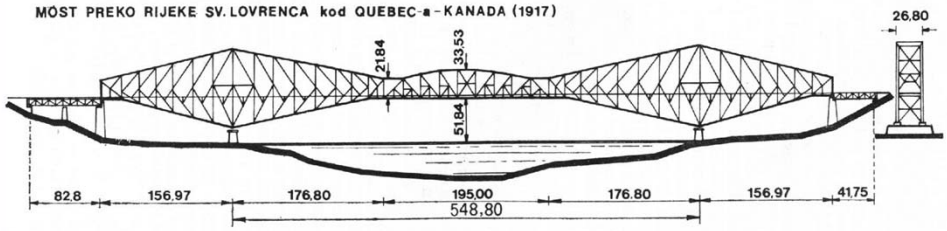


DVOKOLOSIJEČNI ŽELJEZNIČKI MOST „FIRTH OF FORTH"-ŠKOTSKA (1889)



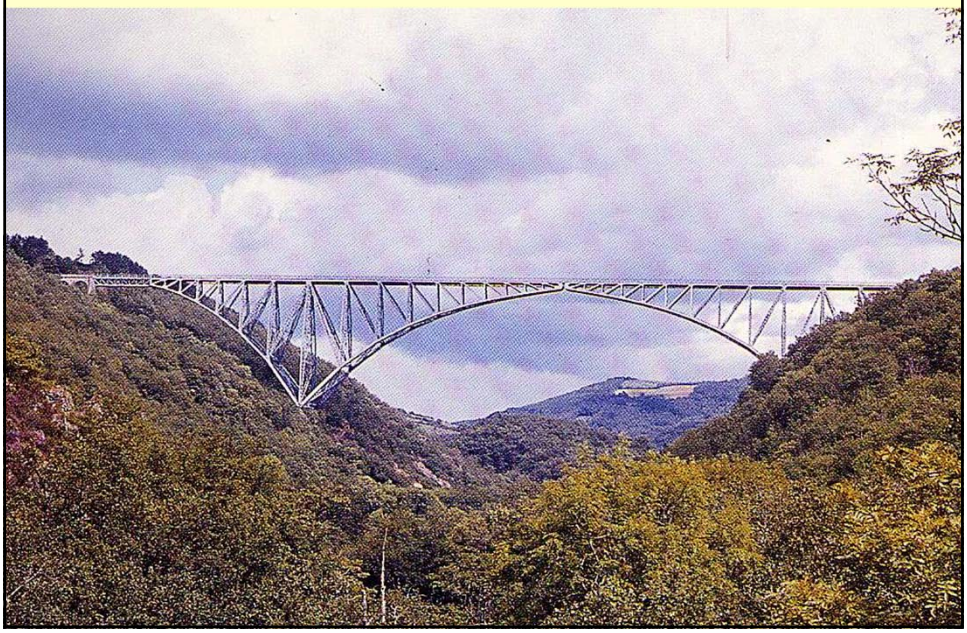
Slika 1.4. Pogled na dio Forthskog mosta, V. Britanija, 1889.

MOST PREKO RIJEKE SV. LOVRENCA kod QUEBEC-a - KANADA (1917)



Slika 1.5. Gredni most s najvećim rasponom na svijetu, 1917.

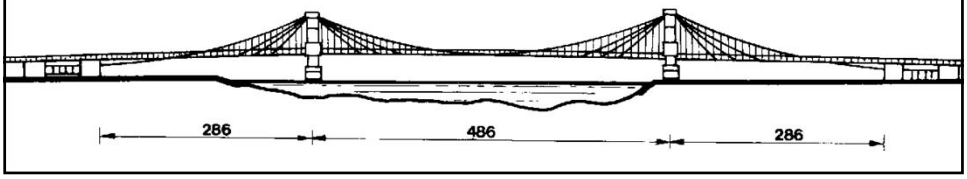
Bodin: vijadukt *Viaur* (1896-1902); raspon L=220 m



most *Brooklyn*

- projektanti: Johann i Washington Roebling
- vrijeme izgradnje: (1870-1883)
- glavni raspon: L=486 m
- razmak sidrišta (3 raspona): 1.053 m
- širina: 26 m, 6 prometnih traka





kraj 19. i početak 20. st.: tipizirani čelični sklopovi
- primjer: *Crveni most* u Zagrebu

