NUMERO: 904

DATA: 12/03/2014

A P P U N T I

STUDENTE: Sannipoli

MATERIA: Teoria e Progetto dei Ponti

Prof. Mancini

TEORIA E PROGETTO DEI PONTI 30-09-2013

Esame ORALE

Prof. Giuseppe Mancini, ing. Francesco Tondolo, ing. Gabriele Bertagnoli (ricevimento: Wednesday 14-15)

Studieremo prevalentemente i ponti in c.a. e ponti a travata.

BRIDGE DESIGN

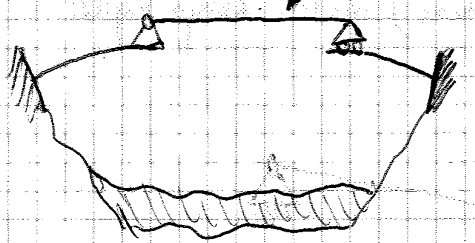
HISTORICAL NOTES ON BRIDGE CONSTRUCTION

3 ages:

- 1st age (trunks: tronchi, decks: impalcati) (abutment: spalla del ponte → riva, sponda)

cantilever: mensola ("cantiliver") 4/39

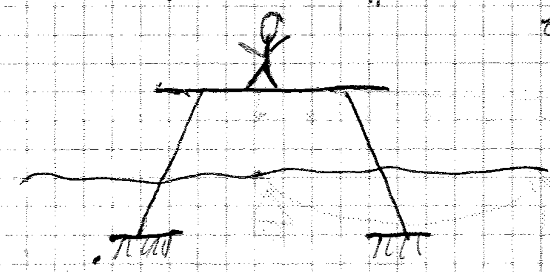
CHINA



Non ho una costruzione continua perché non riesco a trasportare un tronco così lungo → uso questo altro semplice schema statico (con 3 tronchi).

CAMBOGIA 5/39

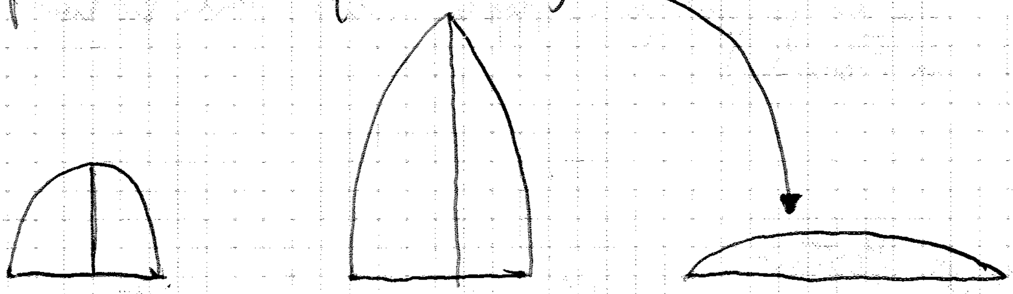
Bamboo bridge (di Apocalypse Now)



La sezione è un FRAME (portal).

[[Se la distanza tra il punto fisso e quello mobile diminuisce → la forza assiale aumenta a causa della non linearità geometrica]].

Depressed arch (arco scemo)



round arch (arco a tutto sesto (arco romano))

ogival arch (arco a sesto acuto)

depressed arch (arco ribassato)

Bridge built by Giulio Cesare
Pile boring machine: macchine che infiggono i pali.
(boring → perforazione)
It has the same static scheme of the Cambogian bridge.

Why is so famous? 2 REASONS:
- It was useless: they built and then demolished to protect themselves from the German attack (they realized that Germans were too strong!)
- It's almost impossible to build; modern engineers couldn't bridge it with that old technology

Pont du Gard 11/39

Regensburg Bridge: 20-22 m per arch, so almost no improvement in the arch in 1000 year (from the Roman)

Sezione (dell'apertura dell'arco) diminuisce ⇒ velocità aumenta ⇒ aumentano i residui solidi ⇒
→ aumenta l'erosione delle pile → not foundation in the river bed anymore

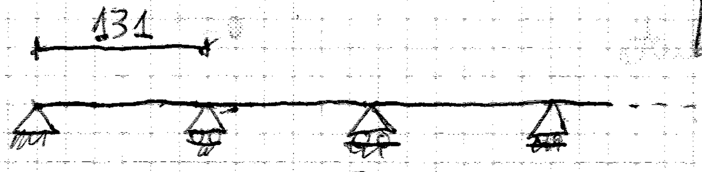
⇒ si dovrebbero costruire pile nel letto del fiume ⇒ costruivano le grandi e con grande distanza tra una e l'altra. **N.B.**

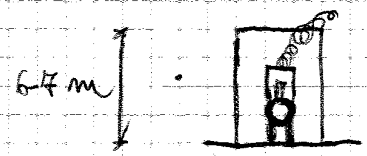
2nd AGE 25/39

Transport by rail: small slopes because of the weight of the train itself.
The higher the speed of the train, the bigger the curvature radius.

At the beginning the idea was like the Roman bridges (Arch bridges).
Before 2nd revolution ⇒ masonry and rocks
After 2nd revolution ⇒ steel (reticolare: trussed system)

Dirschau Bridge



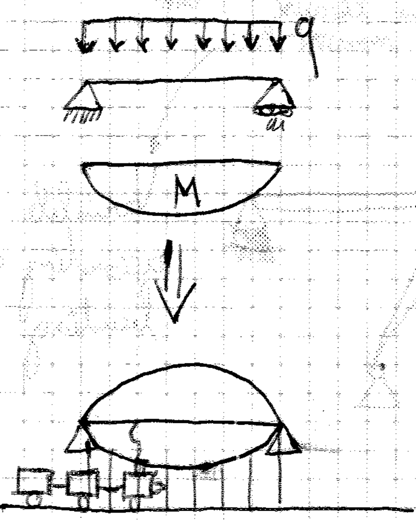


The train is running inside the box (→ big cross section)

Grandfey Viaduct: the train is running on the top, not inside.
(the structural scheme is made up of a frame with diagonal bars: it's now famous in tall skyscrapers (like in the huge cucumber in London))

Smithfield Street Bridge

Variable stiffness



Kinzua Creek viaduct

firstly: very slender, thin beam because trains were small.
("crane": gru)

slender → snello

3rd AGE

Reinforced concret (nato tra la 1° e la 2° Guerra Mondiale)

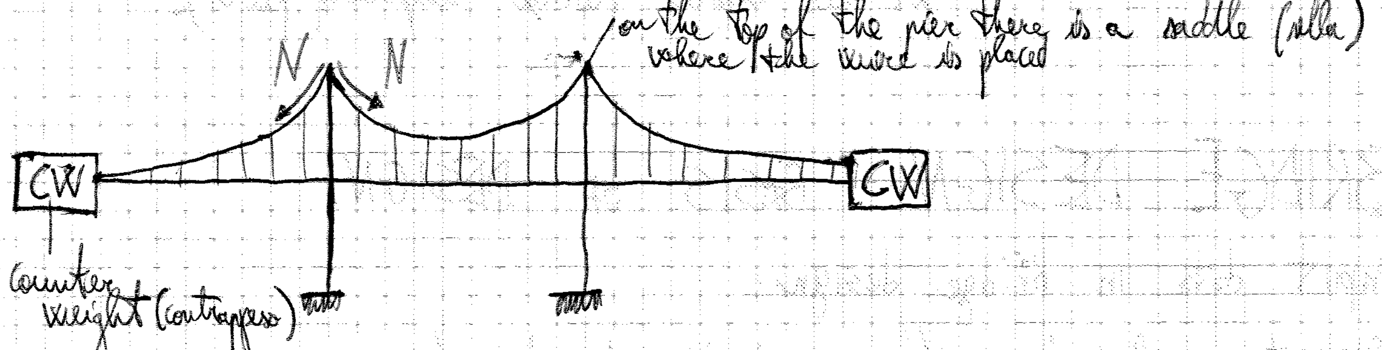
Europa bridge: reinforced concrete (now we reach the same span with steel because is more economic).

Max depth of piles: 190 m!!! (40 m more than SAN PAOLO skyscraper)

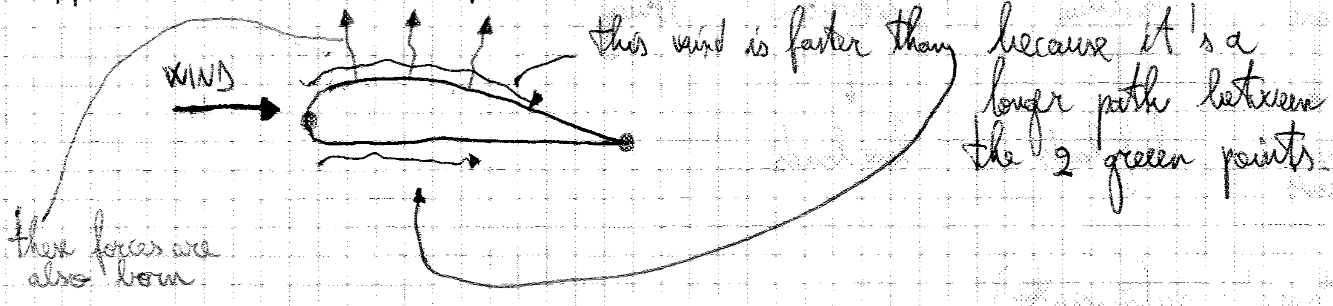
Humber suspended bridge: Brooklyn Bridge

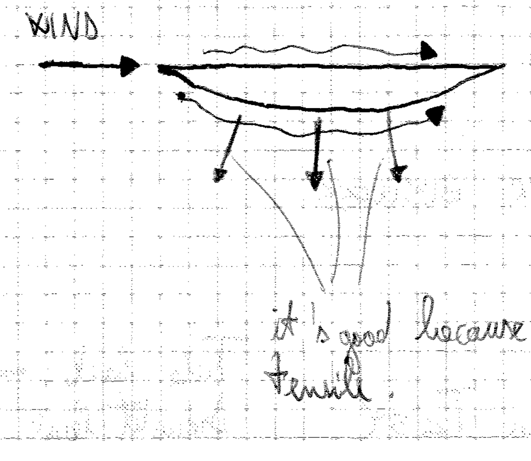
La pila è un telaio piano (plane frame)

Static scheme:



The deck is wing shaped (forma alare) but is the opposite than the shape of the airplanes.





BRIDGE DESIGN

LEZ. 30-09-2013

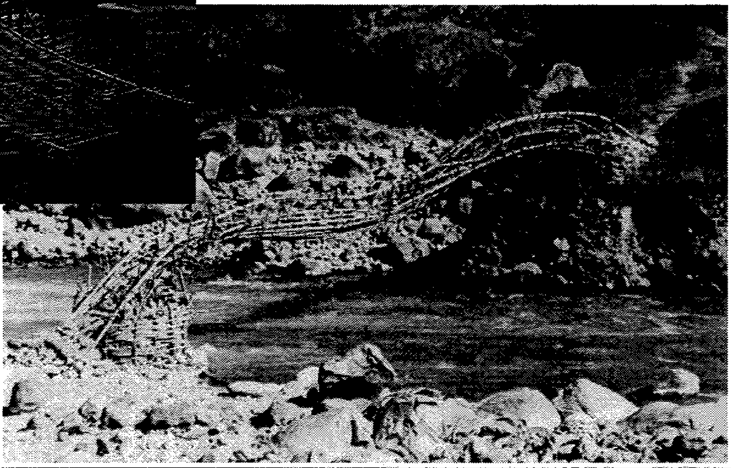
HISTORICAL NOTES ON BRIDGE CONSTRUCTION

Politecnico di Torino
Department of structural and geotechnical engineering
"Bridge design"

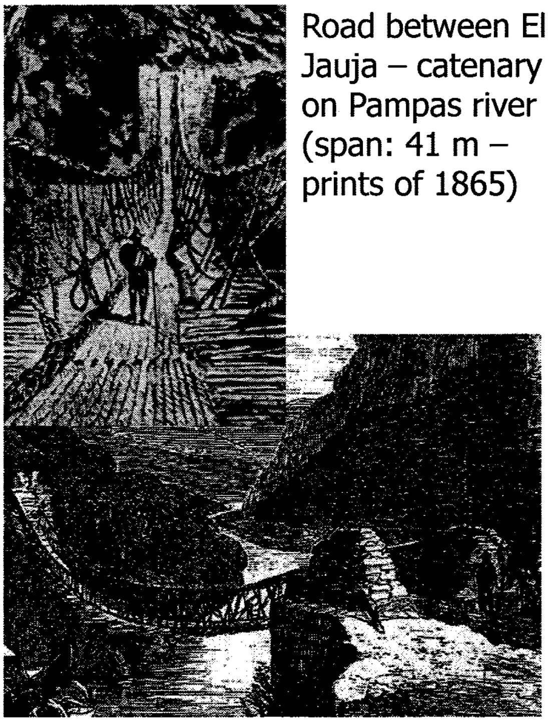
Historical notes on bridge design

- 1st Age : Since the beginning to ~ 1800 (Transport by animals)
- 2nd Age : ~ 1800 ÷ 1920 (Transport by rail)
- 3rd Age: 1920 to today (Transport by trucks)

Bamboo bridge in Nepal



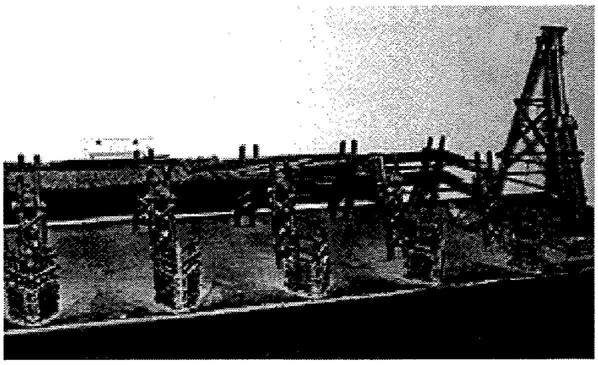
Bamboo frame bridge built in Cambodia

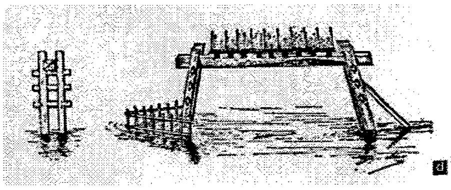


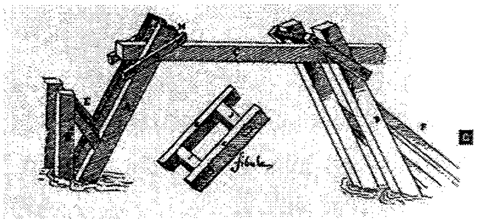
Road between El Cutzco and Jauja – catenary bridge built on Pampas river (span: 41 m – prints of 1865)

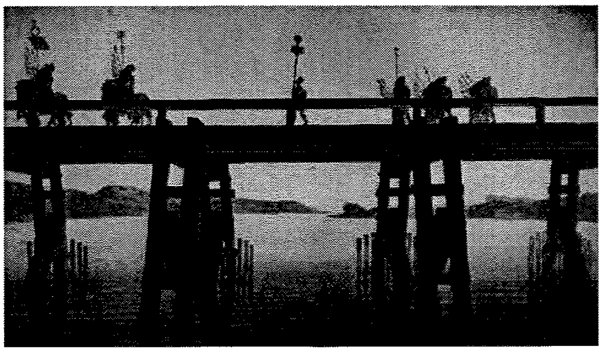
Tibetan bridge built in Karakorum for the expedition on K2 of 1953

Bridge built by Giulio Cesare during the war to Gallia, to cross the Reno River, in 55 b.C.



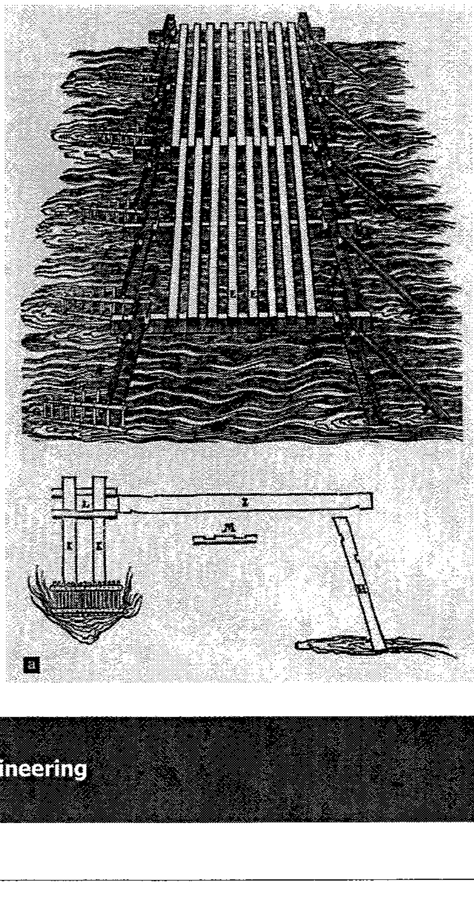


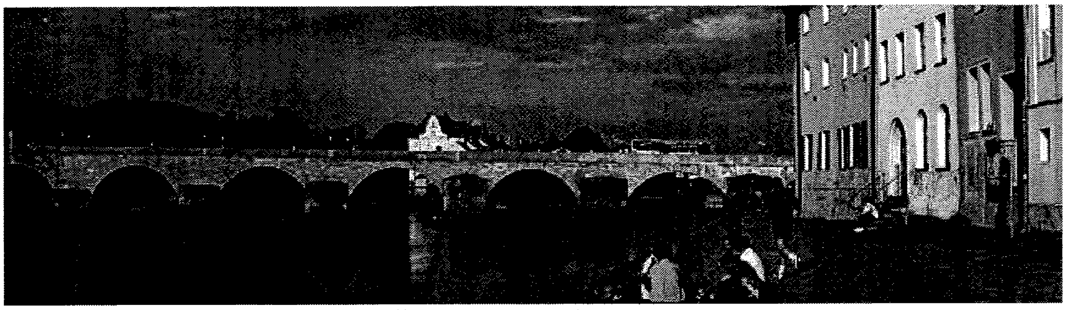




From "De bello Gallico" Book IV – XVII

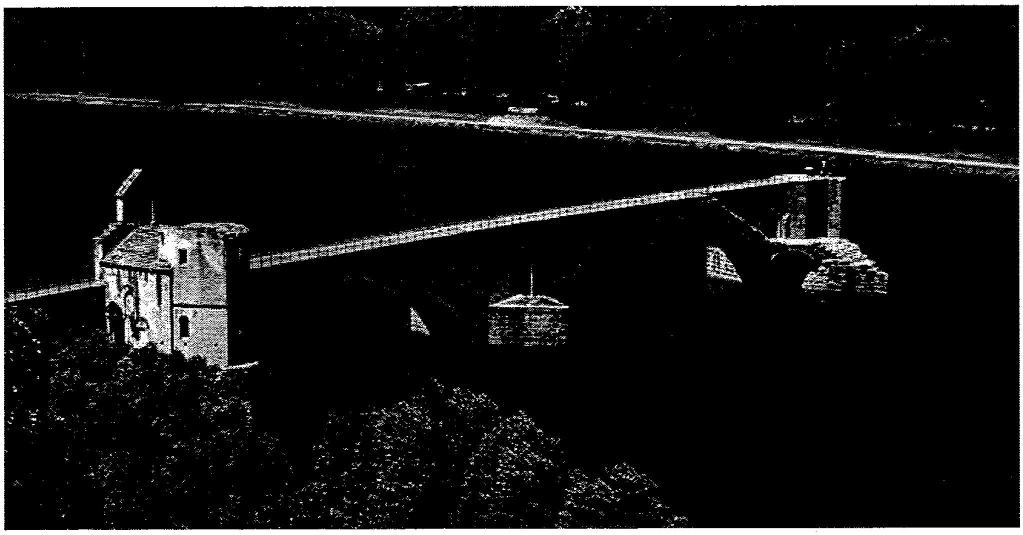
A distanza di due piedi univa, a due per volta, travi lievemente appuntite in basso, del diametro di un piede e mezzo di altezza commisurata alla profondità del fiume; poi, mediante macchinari le calava in acqua e con battipali le conficcava sul fondo del fiume, non a perpendicolo, come le travi delle palafitte, ma oblique e in pendenza, in modo da inclinare nel senso della corrente; più in basso, alla distanza di quaranta passi e dirimpetto alle prime travi, ne poneva altre, sempre legate a due a due, con inclinazione opposta all'impeto e alla corrente del fiume. Nell'interstizio collocava pali dello spessore di due piedi - pari alla distanza delle travi accoppiate - e, fissandoli con due arpioni, impediva che esse in cima si toccassero; perciò, poggiando su travi separate e ben ribadite in direzione contraria, la struttura del ponte risultava tale, da reggere, per necessità naturale, tanto più saldamente, quanto più impetuosa fosse la corrente. Sui pali venivano disposte, in senso orizzontale, altre travi su cui poggiavano tavole e graticci; inoltre, come sostegno, a valle venivano aggiunti, obliqui, pali fissati al resto della struttura per resistere alla corrente impetuosa; così pure altre travi, a monte, venivano collocate non lontano dal ponte, allo scopo di frenare eventuali tronchi o navi che i barbari avessero lanciato contro la costruzione per distruggerla: l'impatto sarebbe stato attutito e i danni al ponte limitati.





Regensburg bridge – Germany (1135 – 1146)
16 arches - total span: 350m

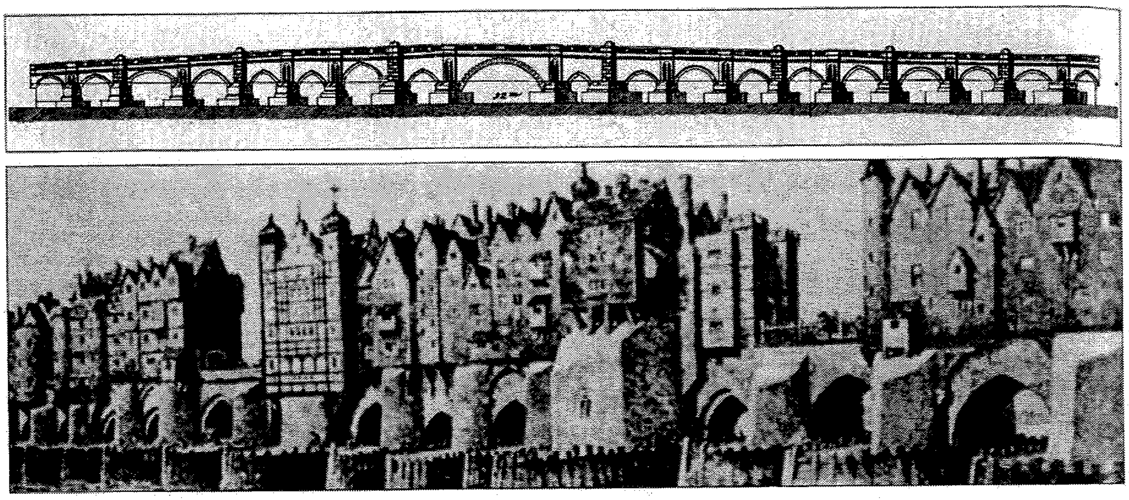
Politecnico di Torino
Department of structural and geotechnical engineering
"Bridge design"



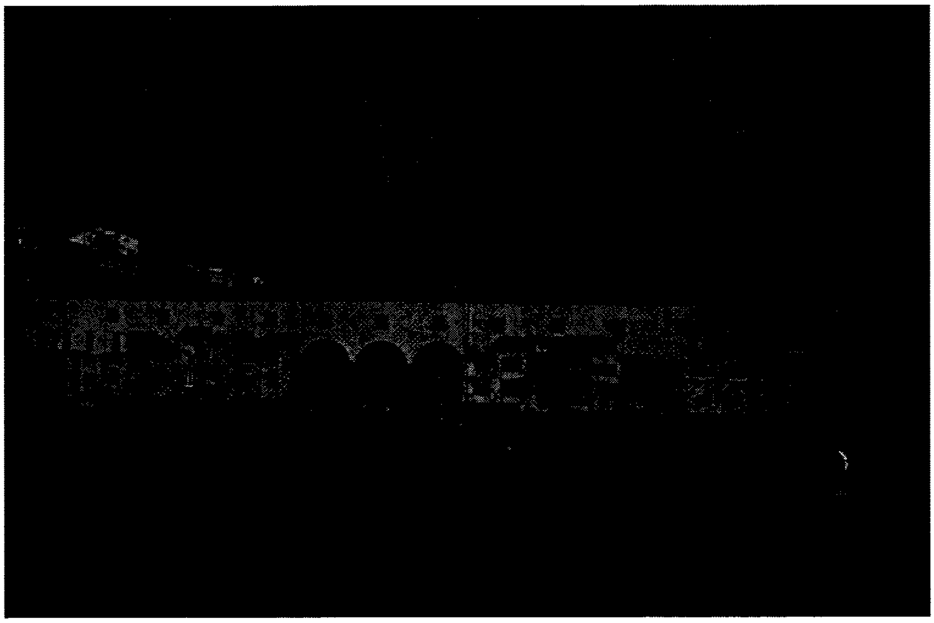
Pont St. Benezet - XII Century – Avignon – France.
Built in 1184, destroyed in 1226, rebuilt in the following century, collapsed during a flood in XVII century. Only 4 arches survived on a total amount of 22, with a total span of 850 m.

Politecnico di Torino
Department of structural and geotechnical engineering
"Bridge design"

© Proprietà riservata dell'autore - Digitalizzazione e distribuzione a cura del CENTRO APPUNTI - Corso Luigi Einaudi, 55 - Torino / Pagina 17 di 348

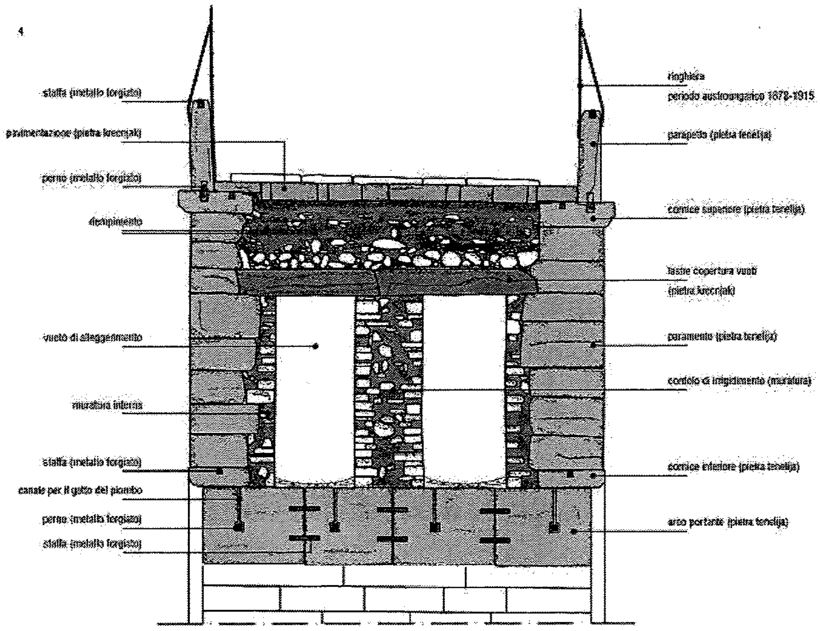


London Bridge, built in XII century (demolished and substituted in 1824)

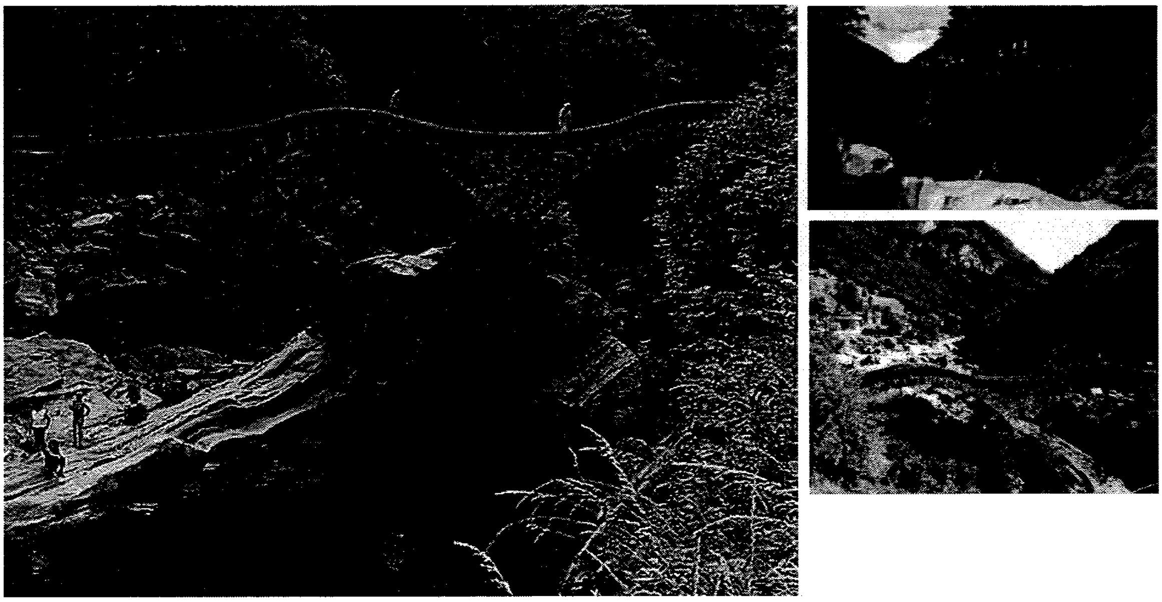


Ponte Vecchio (Florence, 1345)

Roman Bridge in Mostar: hollow cross-section



4. Sezione trasversale del ponte alle reni dell'arco portante.



Lavertezzo Cliff Bridge (Canton Ticino – CH)
XVII century, on roman ruins

2nd Age [~ 1800 ÷ 1920]

⇩

(Transport by rail)

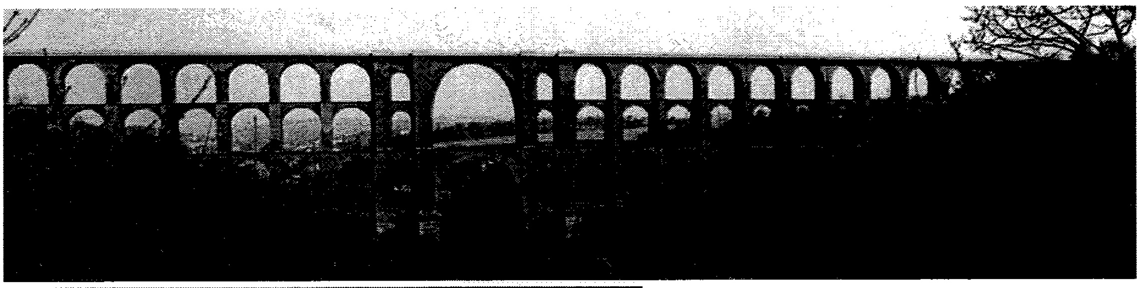
Small slopes (max 1 ÷ 2 %) — now we use ‰

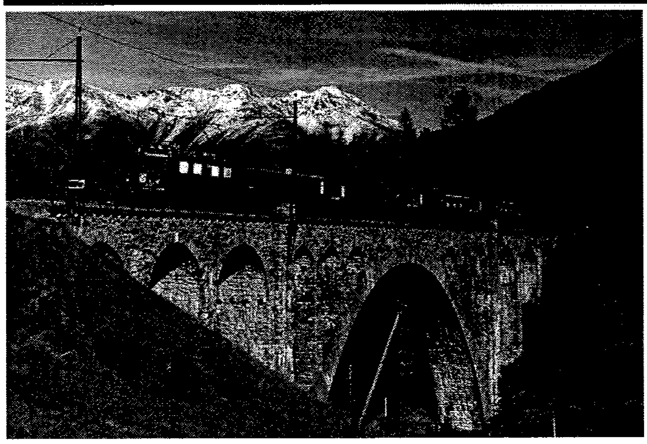
High ~~curvature~~ radius (the minimum is 100 m) — is function of the speed of the train

Now high speed lines have the minimum radius curvature of 6 Km

⇩

Big spans (Steel and Masonry)

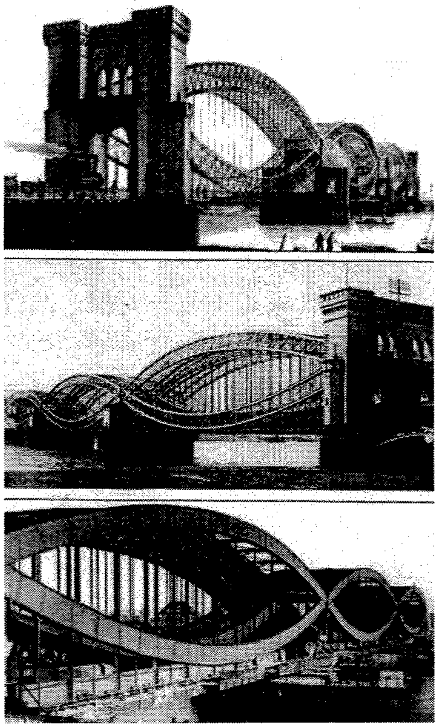




Railway viaduct on Goltzschatal – Vogtland
Total span: 578m
(Germany, 1851)

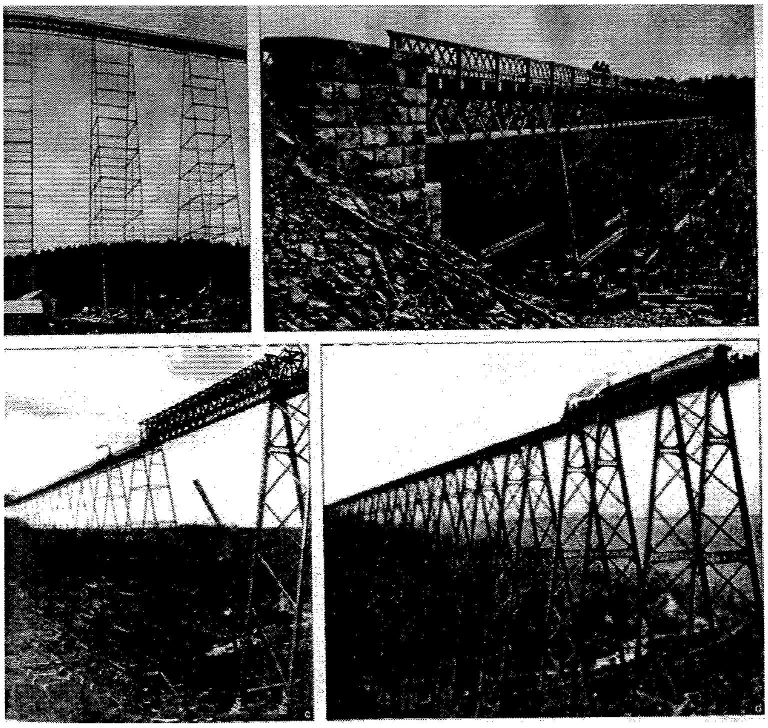
Cinus-chel Bridge on Inn River
Total span: 111m
Depth: 50m (Swiss, 1911)

Smithfield Street bridge
max span: 109m
(Pittsburgh, 1883)



Hamburg bridges
on Elba river

Kinzua Creek viaduct
a), b) : original viaduct
c), d) : new viaduct, 1900
(Pennsylvania, 1882)



Railway bridge crossing the Wupper Valley (Mungsten, Germany)
[span: 180 m, depth: 70 m - the highest railway bridge in Germany]

3rd Age [since 1920 till now]

⇩

Transport by trucks (camion)

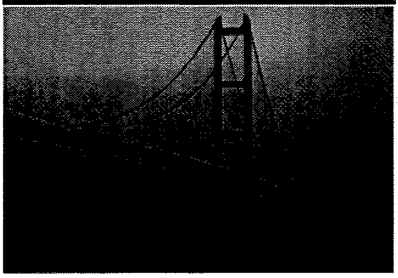
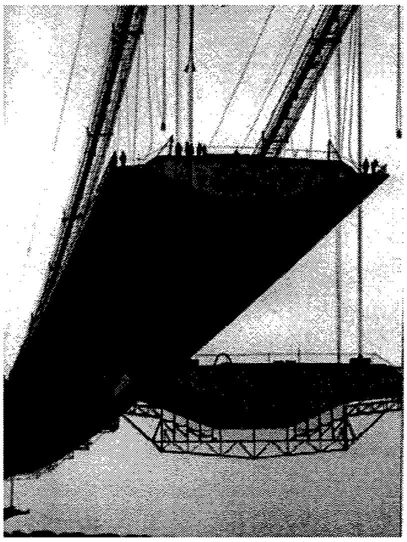
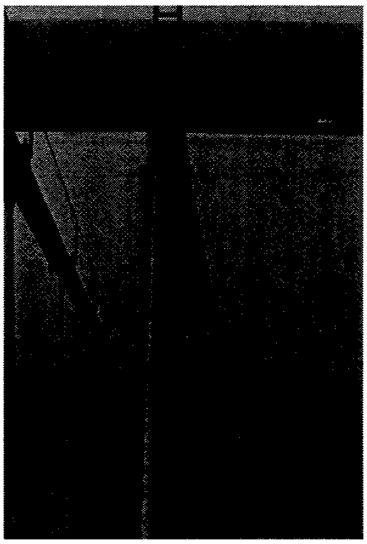
⇩

Highways: planimetrical and altimetrical constraints (vincoli) with long viaducts

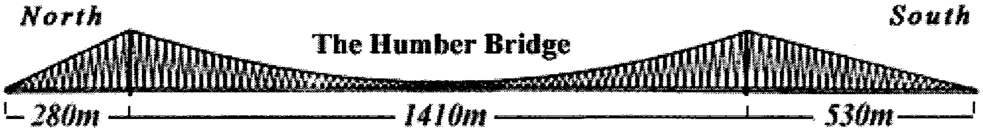
⇩

Coming of reinforced concrete.
and prestressed concrete

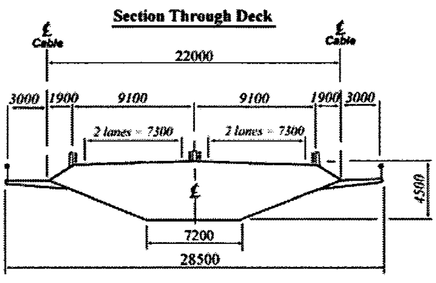
Humber suspended bridge
(UK, 1983)

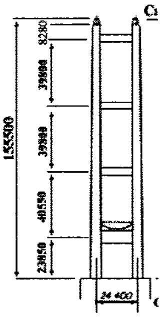





Humber suspended bridge – UK, 1983



Main span	1410m
Deck width	28.5m
Pier depth	155.5m
Rape diameter	0.68m
Rape total lenght	71,000km
Forces in ropes	194,000 kN
Amount of steel	27,500 t
Amount of concrete	480,000 t





© Proprietà riservata dell'autore - Digitalizzazione e distribuzione a cura del CENTRO APPUNTI - Corso Luigi Einaudi, 55 - Torino / Pagina 29 di 348

BRIDGE DESIGN

LEZ. 30-09-2013

BASIS OF DESIGN

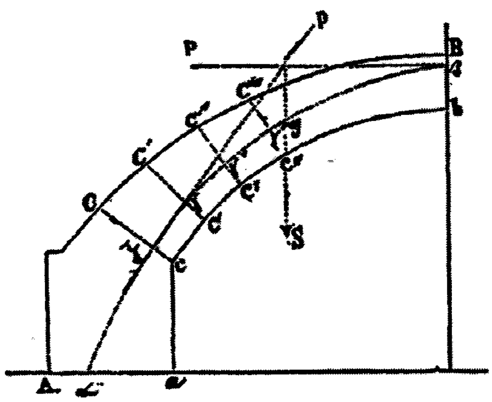
Marco Polo describes a bridge, stone by stone.

"*Which is the stone that bears the bridge?*" Kublai Kan asks.

"*There's no single stone that bears the bridge*", Marco answers, "*It's the line of the arch that keeps it standing*".

Kublai Kan stands, thinking. Then he adds: "*Why are you talking to me about stones? I'm only interested in the arch*".

Polo answers: "*There's no arch without stones*".



Italo Calvino – "Le città invisibili"

- Environmental conditions in which the bridge has to be built
  - Open field
  - *don't build bridges with antennas ... it will look like obelix in nothing*
  - Hill landscape
  - Valley between close mountains
  - Historical city (old and small depth buildings)
  - Modern city (new and tall buildings)
  - *you should have continuity between buildings and your bridge*

- Environmental requirements
  - Aesthetic requirements
  - Noise protection → *is 5m tall all long your bridge*
  - Wind protection ← *to protect the traffic*
  - Splash protection → *from the sea*

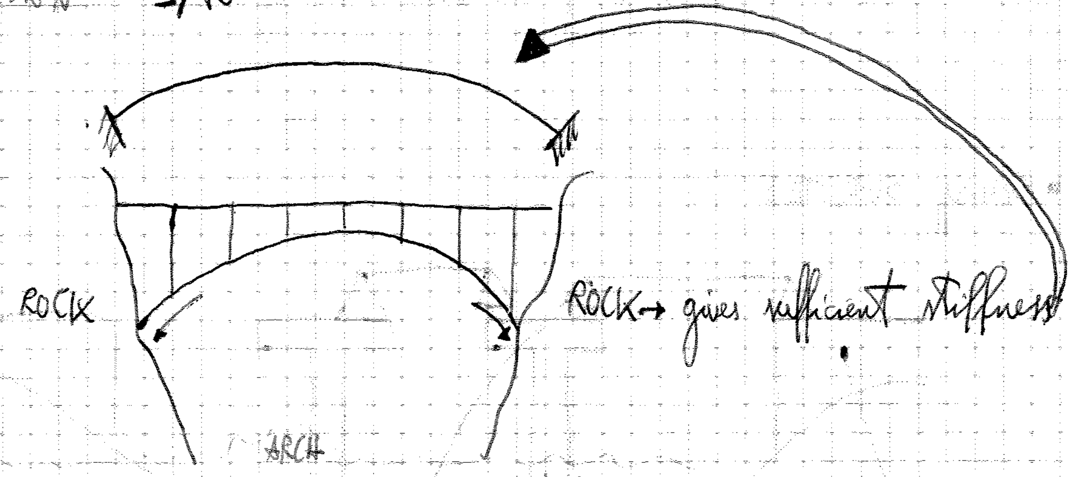
- Functionality requirements
  - Deformability limitations (High speed lines) → *is important for railway bridges (for road bridges no → also 1÷2 cm of deflection in a bridge 100 m span is absolutely normal.)*
  - Limitation and control of vibration amplitude and frequency (High speed lines and pedestrian bridges)

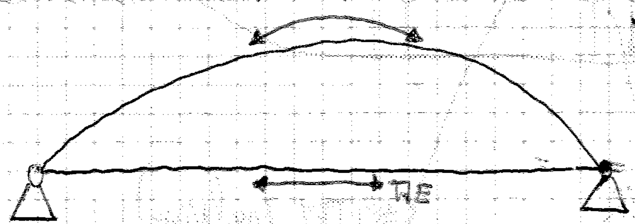
Classification criteria for bridges & design demands

1) Obstacle to be crossed
2) Specification of service
3) Material to be used
4) Statical scheme

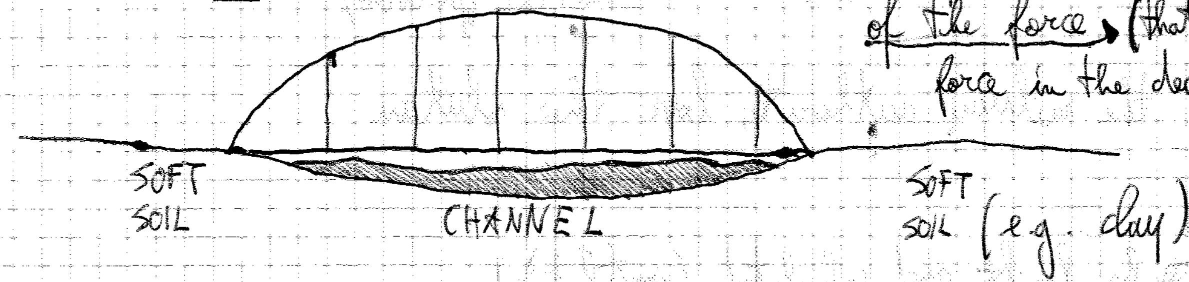
TEORIA E PROGETTO DEI PONTI 01-10-2013

BASIS OF DESIGN 9/70



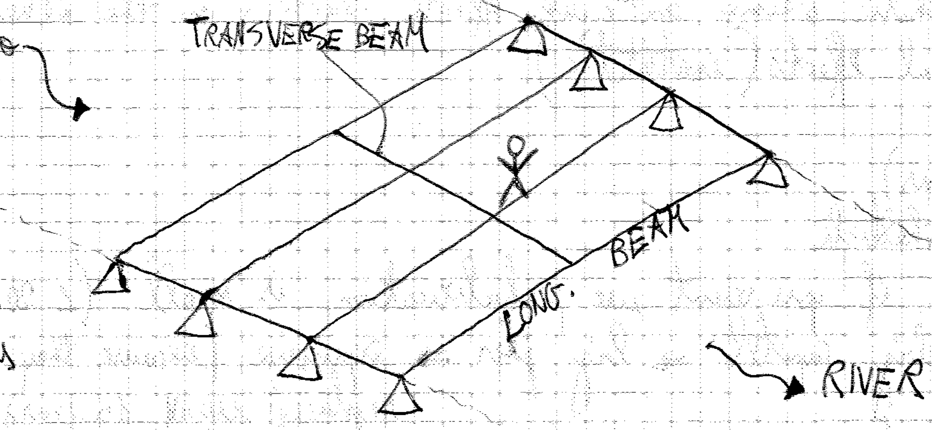


"The deck is tensed by the arch" ⇒ in the soil come only <u>horizontal component of the force</u> → (that is the force in the deck)



11/70 STATICAL SCHEME

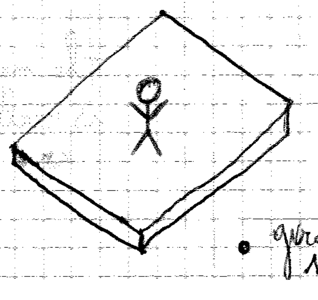
GIRDER: graticcio



3 transverse beams
4 longitudinal beams

SLAB: piastra

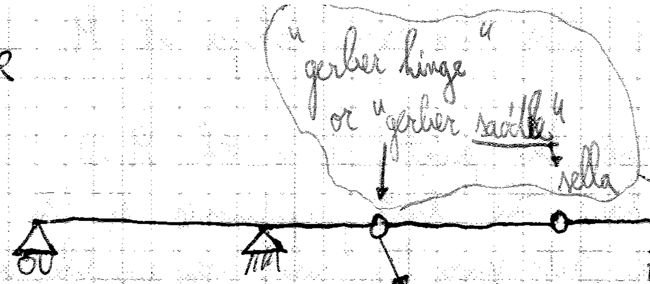
like girder, but full.



Comparison:

- generally the thickness of the slab is smaller than the thickness of the girder.
- girder: precast element
  slab: cast in situ, better durability

• GERBER



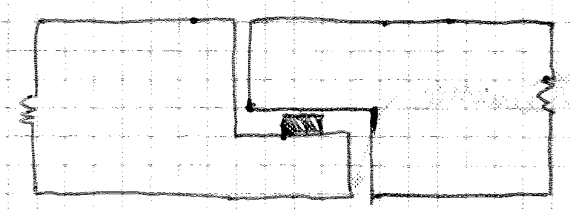
2(n-1)

DOF (Degrees of Freedom) = 3x3 = 9
→ beams

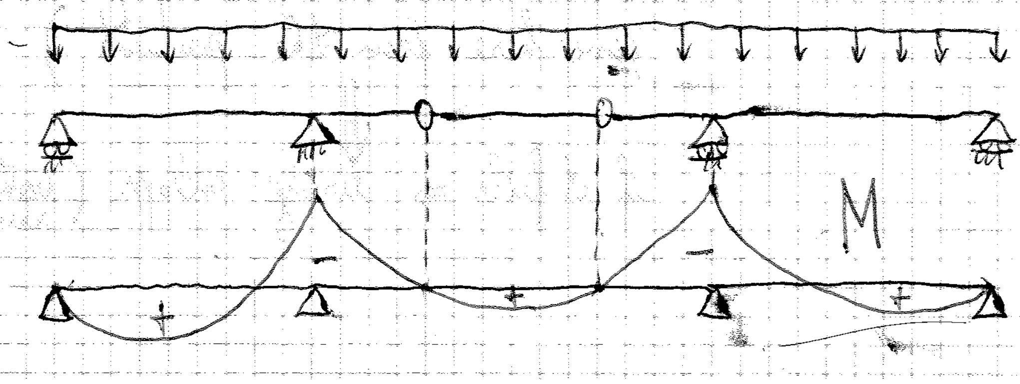
⇒ ISOSTATIC

LR (Level of Restraint) → ER = 5 (external)
IR = 4 (internal)

in reality is done like this:



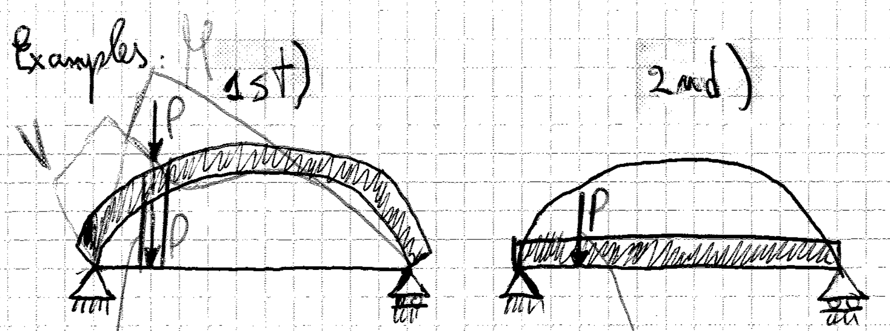
This scheme is between the simply supported and the continuos beam, because:



13/10

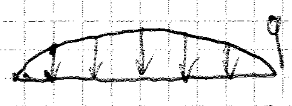
	ARCH	DECK	
1st)	Rigid N, M, V	Flexible N, (M, V) → are small, so the deck is mainly tensed	big arch with big section and small section of deck ⇒ a lot of vertical elements that take M, V and give them to the arch
2nd)	Flexible (the arch is mainly compressed) the arch is so thin ⇒ small M inside (and V too) ⇒ N	Rigid N, M, V	The number of vertical elements is smaller than 1st
3rd)	AVERAGE	AVERAGE	Both arch and deck have more or less the same stiffness

Examples:



This vertical element take P and give to the arch.
Does the arch work well with a concentrated force? No, because the arch is built to work well with a distributed load.
In the arch we'll have both M, V, N ⇒ it's difficult to design

P is transferred in the arch like a distributed load



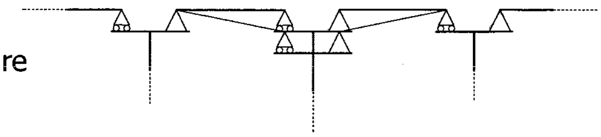
and in the arch you have only axial force ⇒ it's easy to design.

© Proprietà riservata dell'autore - Digitalizzazione e distribuzione a cura del CENTRO APPUNTI - Corso Luigi Einaudi, 55 - Torino / Pagina 39 di 348

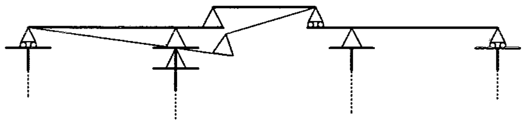
4) Statical Scheme

graticcio ← Girder bridges or slab bridges

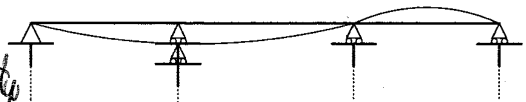
- Simply supported [Prefabrication / Settlements, temperature



- Gerber (evolution of the simply supported) [Internal actions distributions / Settlements, temperature



- Continuous [Best use of material



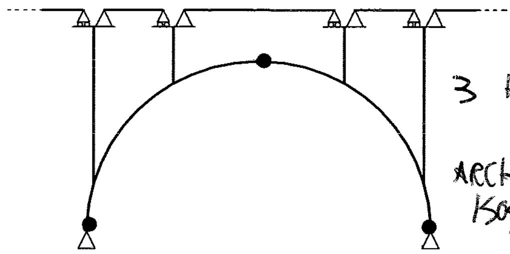
PRO
- best use of materials, lower deformability

CONTRO
- iperstatic (→ long calculation), if settlements or temperature effects → reactions

Arch bridges

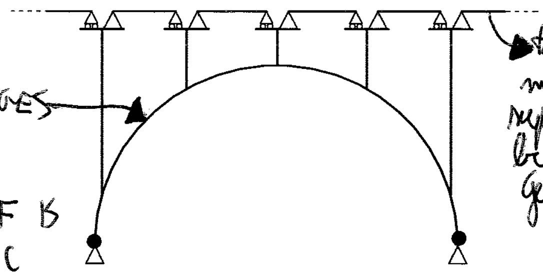
UPPER DECK

- Three hinges arches



3 HINGES ARCH ⇓ ARCH ITSELF IS ISOSTATIC

- Two hinges arches

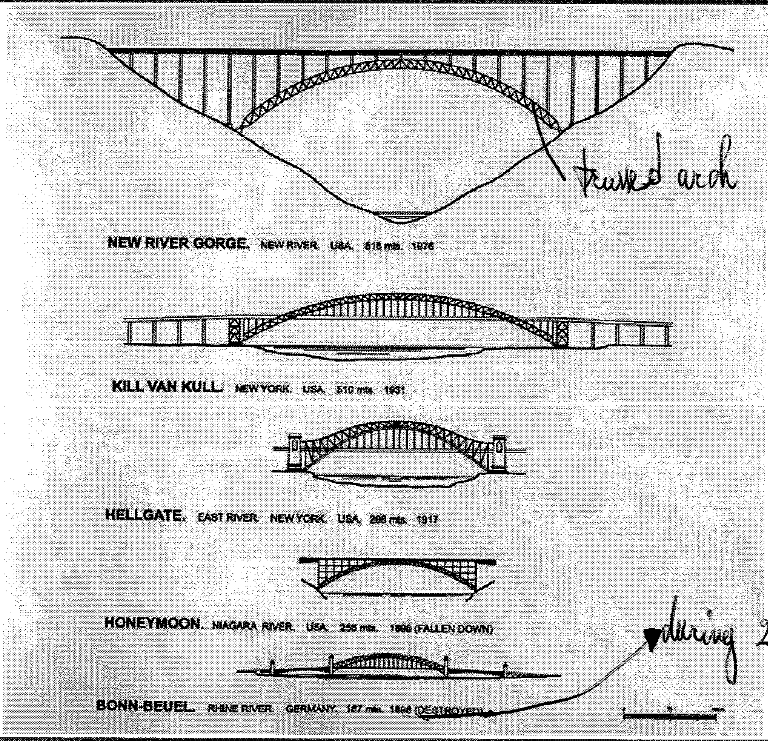


2 HINGES ARCH ⇓ ARCH ITSELF IS IPERSTATIC

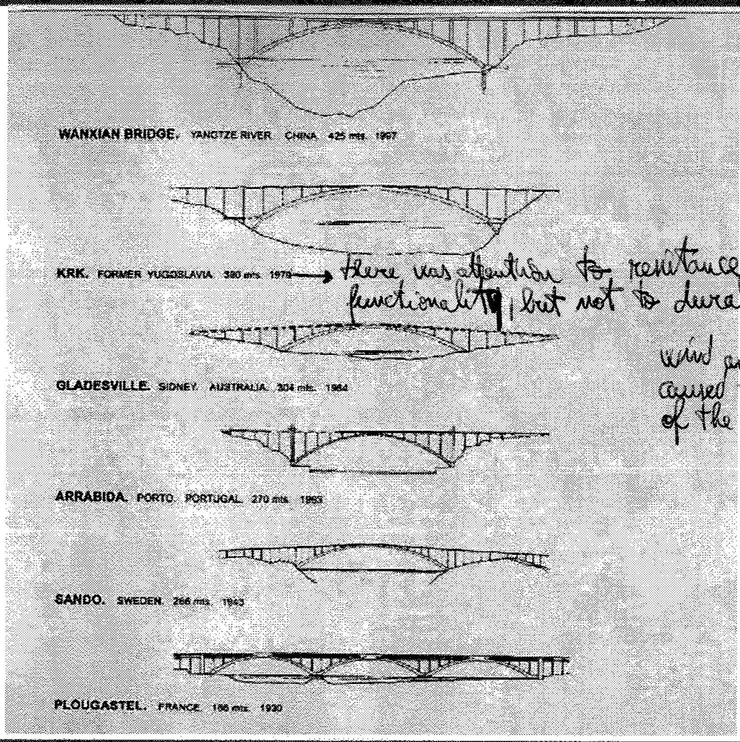
→ the deck is made by simply supported scheme but can be also Gerber or continuous. → most used

© Proprietà riservata dell'autore - Digitalizzazione e distribuzione a cura del CENTRO APPUNTI - Corso Luigi Einaudi, 55 - Torino / Pagina 41 di 348

The largest steel arch bridges (1856-1976)



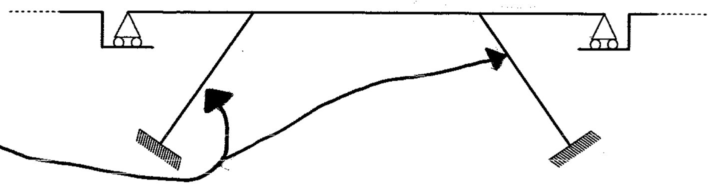
The largest concrete arch bridges (1927 – 2000)



Trestle bridges

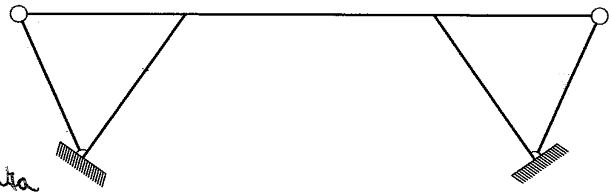
a cavalletto

- Single trestle



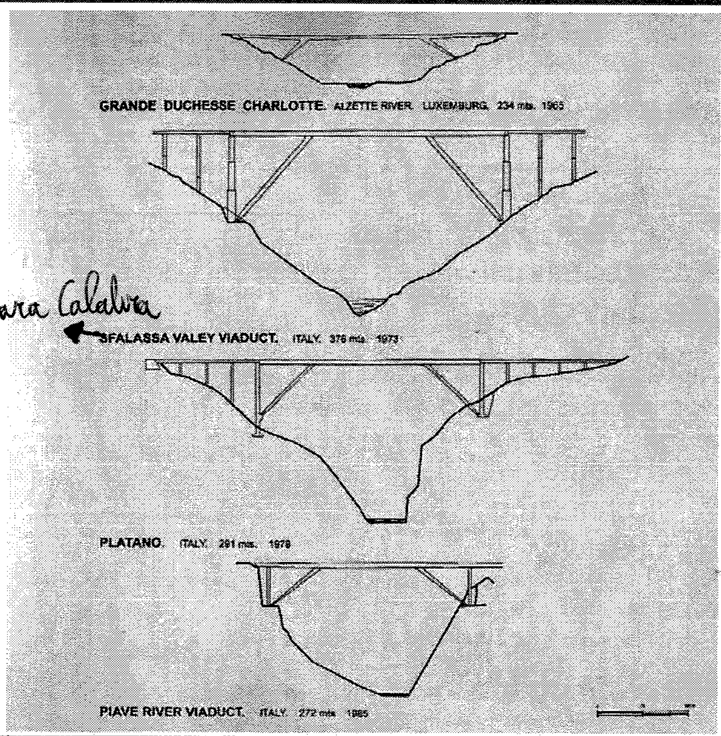
- Tied trestle

It's the scheme of the overpasses Turin-Piacenza



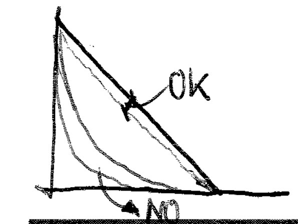
The largest trestle bridges

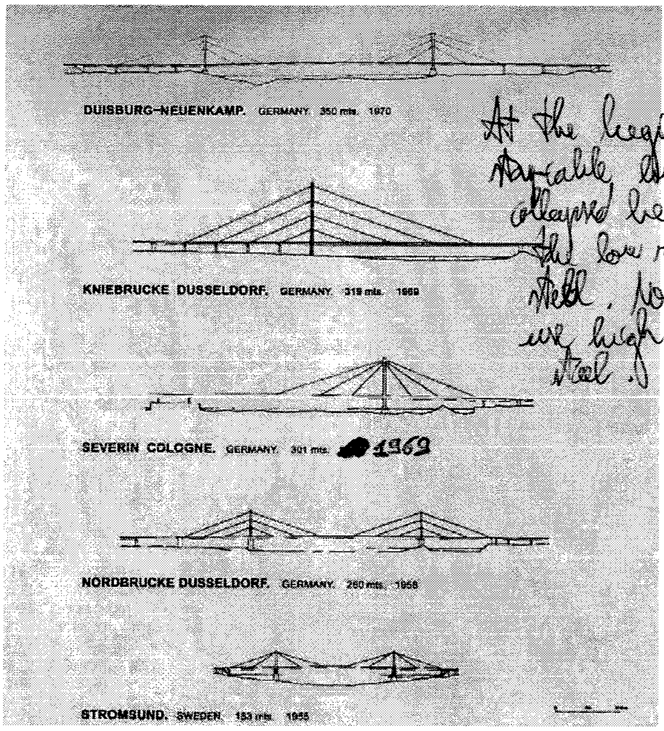
in Bagnara Calabra



The largest stay-cable bridges (1955-1975)

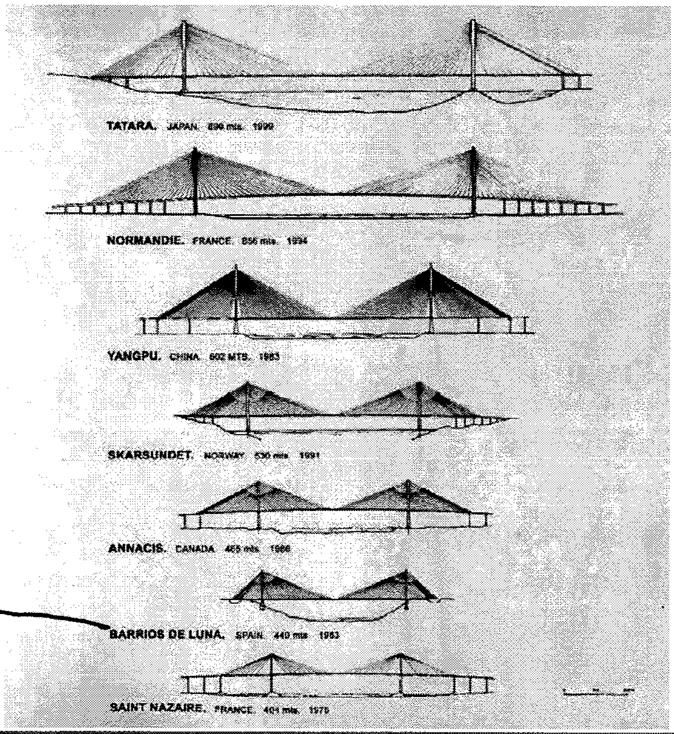
All'inizio i cavi non erano pretesi, quindi si mollavano, quando l'impalcato, per resistere, doveva deformarsi molto e arrivava a collasso prima che i cavi andassero in tensione.





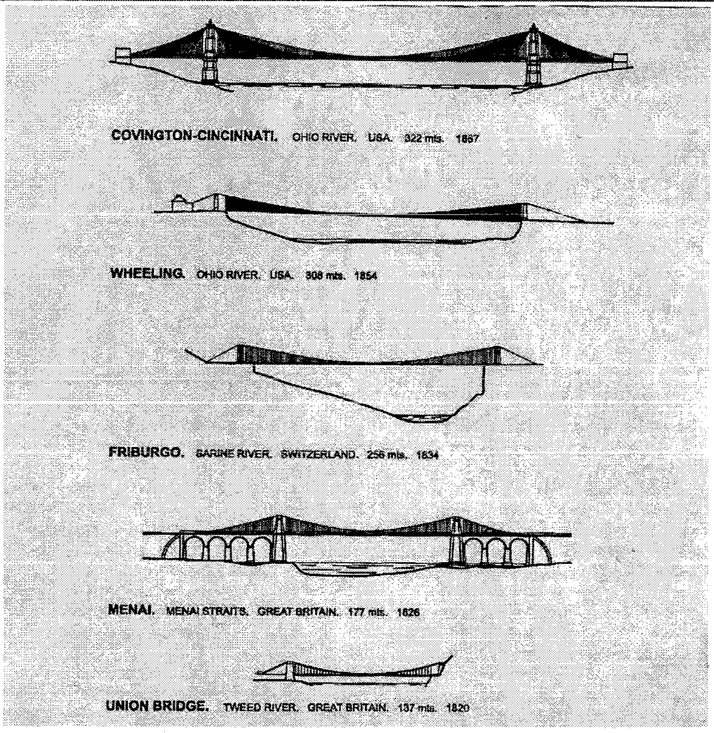
At the beginning stay-cable bridges collapsed because of the low resistance of steel. Nowadays we use high resistance steel.

The largest stay-cable bridges (1975 – 2000)

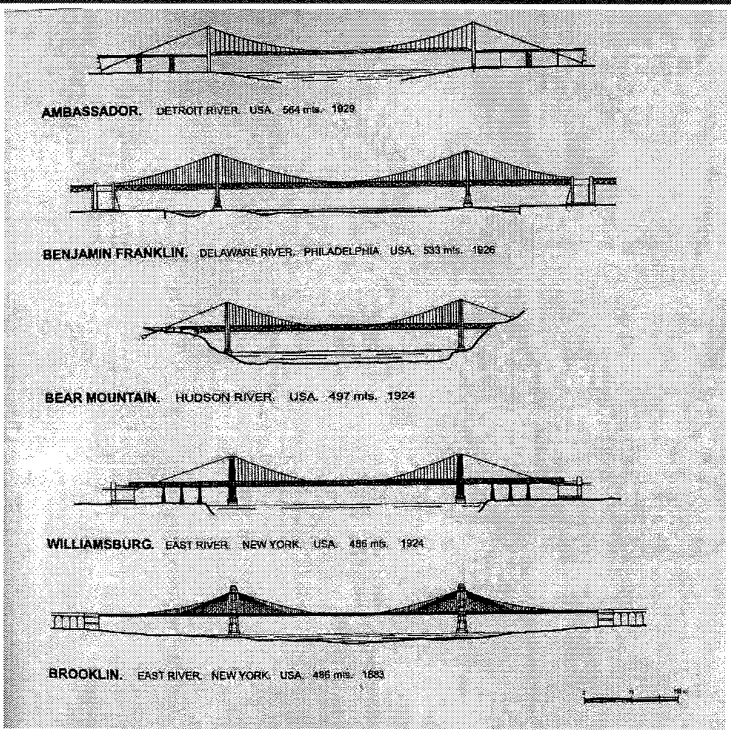


one of the largest with deck completely in concrete

The largest suspended bridges (1820 – 1882)



The largest suspended bridges (1883 – 1930)



"Scaffolding" (→ ponteggio): is a temporary structure used to support people and material in the construction or repair of buildings and other large structures

Most used construction system

- Formwork ("casseforme") on fixed falsework (it's supported directly on the soil, ground)
  - Falsework safety
  - Deformation during the casting
  - Removal of falsework → you transfer loads from formwork to the structure itself → you should do it progressively (not suddenly), you should remove in a symmetric way and you should consider the evolution of the static scheme.
- Formwork on mobile falsework
  - Sliding beams of formwork
  - Foundations of formwork
  - Deformation during the casting

(vedere su Wikipedia il disegno animato. Tempre di Wikipedia: "Falsework also includes temporary support structures for formwork used to mould concrete to form a desired shape...")

It's a weak structure (we used safety coefficients lower than normal ones)

Formwork is made of panels and accessories that act as a mold to form a desired shape with concrete (for any purpose), Falsework is the temporary support structure for the forms. (stampo)

Falsework (structure supporting the formwork) refers to temporary structures used in the construction to support arched structures and concrete forms (moulds) in order to hold the component in place until its construction is sufficiently far advanced to support itself.

One of the main problem is the deformation during the casting, so you have to start with a camber ("monta").

Furthermore you will have imposed deformation on the fresh concrete by the new concrete that you put over the fresh. The fresh concrete has low tensile strength → sliding between concrete and steel → you will see huge cracks when you remove the formwork.

It's required to the contractor the verify of deformation, displacement (max: 1/200 L).

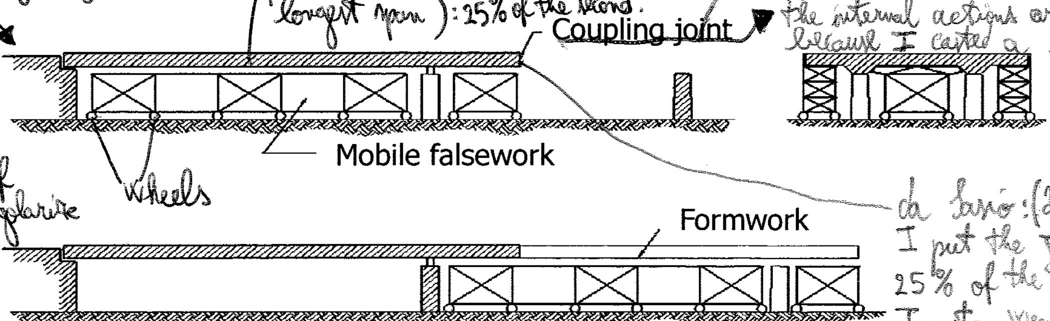
The sequence of casting is important: it must be chosen by the designer.

a) Falsework on the ground (h ≤ ~ 10 m)

(6–8 hours to complete the cast)

This tecnique is used for long bridges (long span).

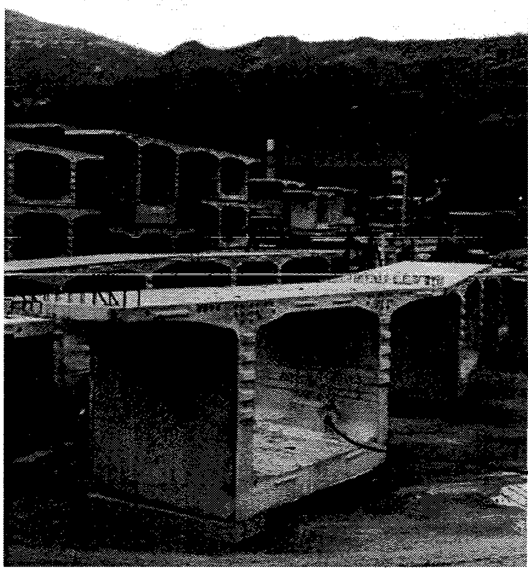
You cast this first part and then a small part of the second (and longest span): 25% of the second.

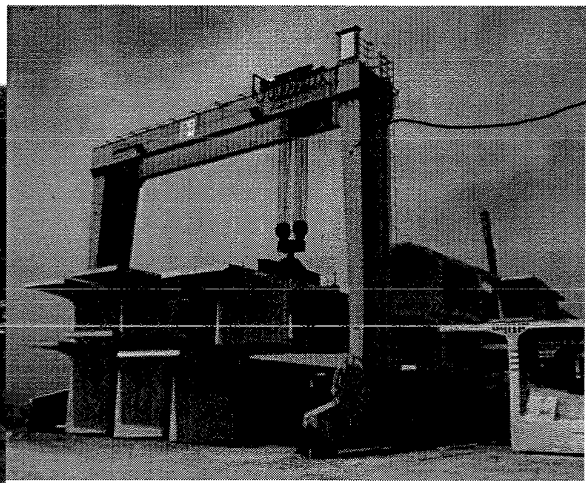


("giunto di accoppiamento") here the resistance is small, [illegible] the internal actions are small, because I casted a small part of the second span

da [illegible]: (non sono sicuro che sia giusto) I put the joint at 25% of the span, so I put a weakness where the internal action is null (M=0)

Another tecnique is to use precasted elements:

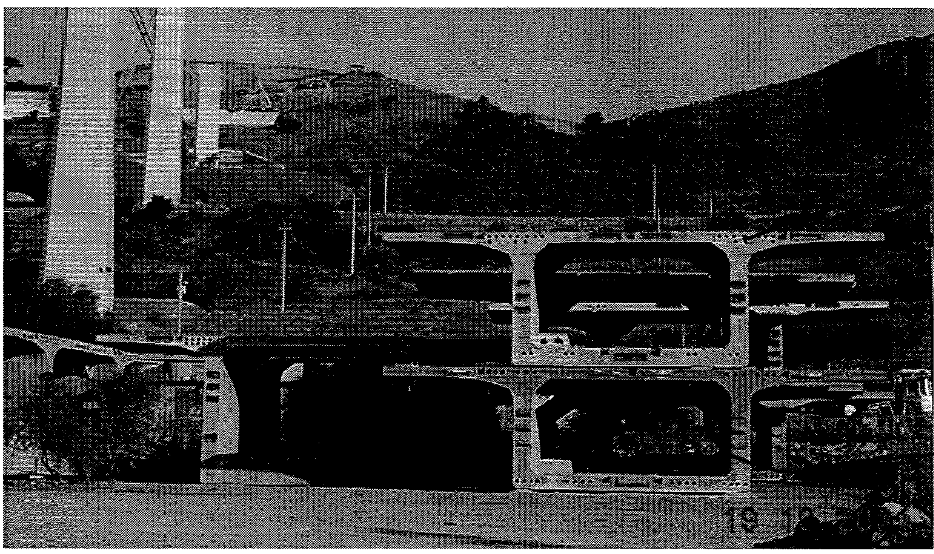




this frame moves on rails

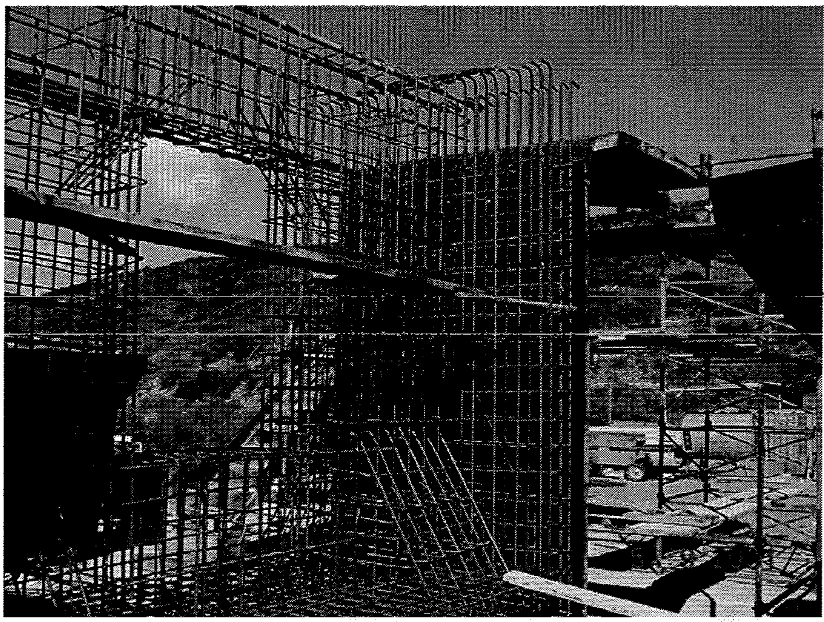
anchorage of internal tendon

Segments storage

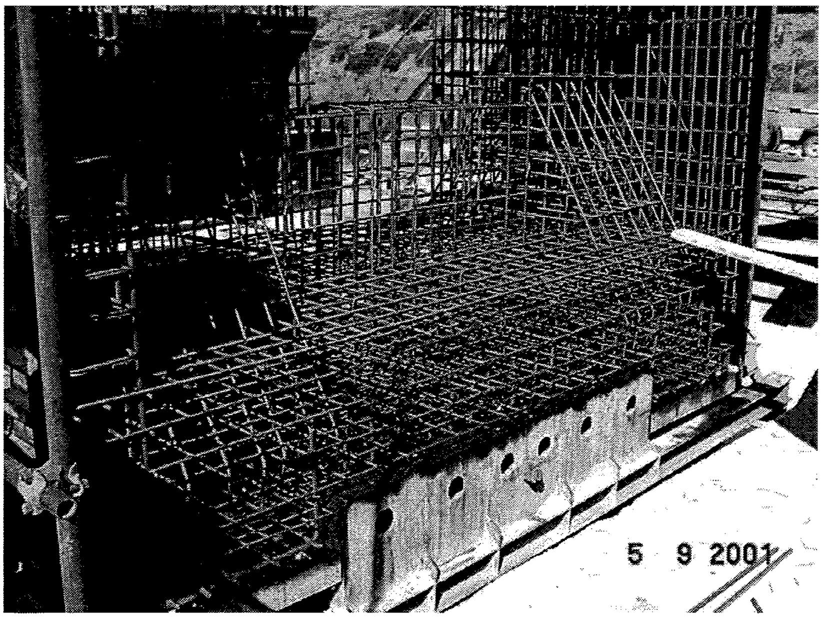


there are the holes for internal tendons, that then will be anchoraged here

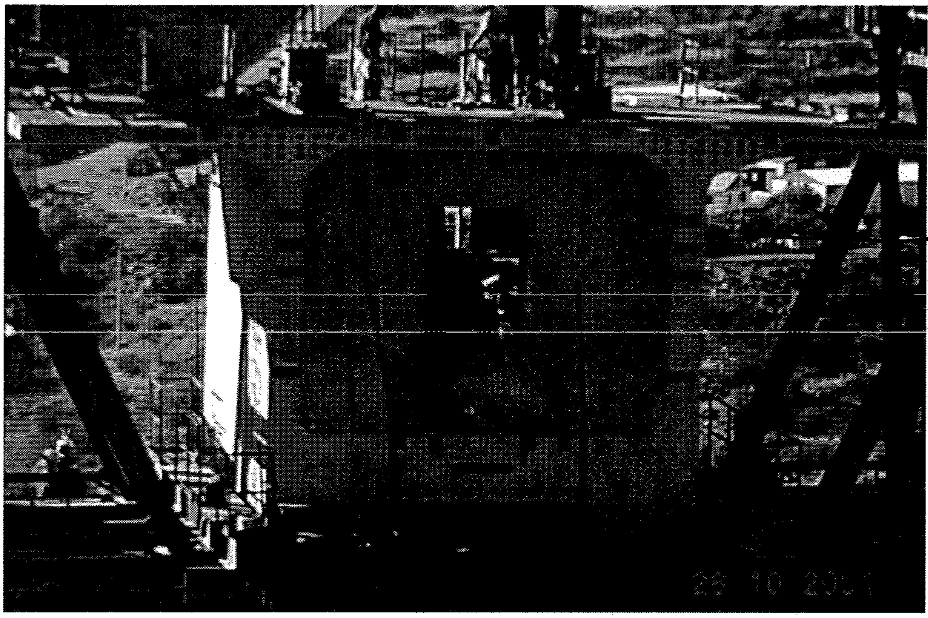
Prefabrication yard → cantiere di prefabbricazione



Pier-segment reinforcement

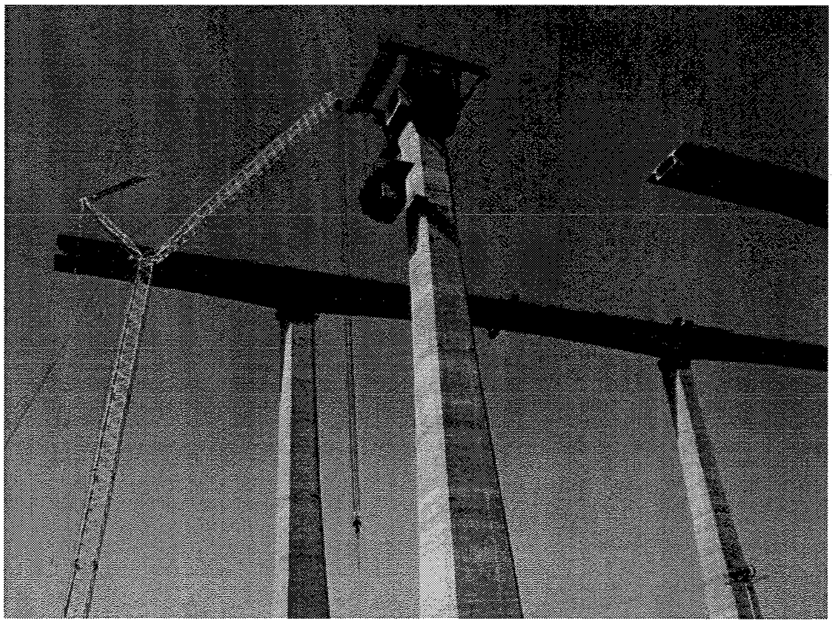


Pier-segment reinforcement

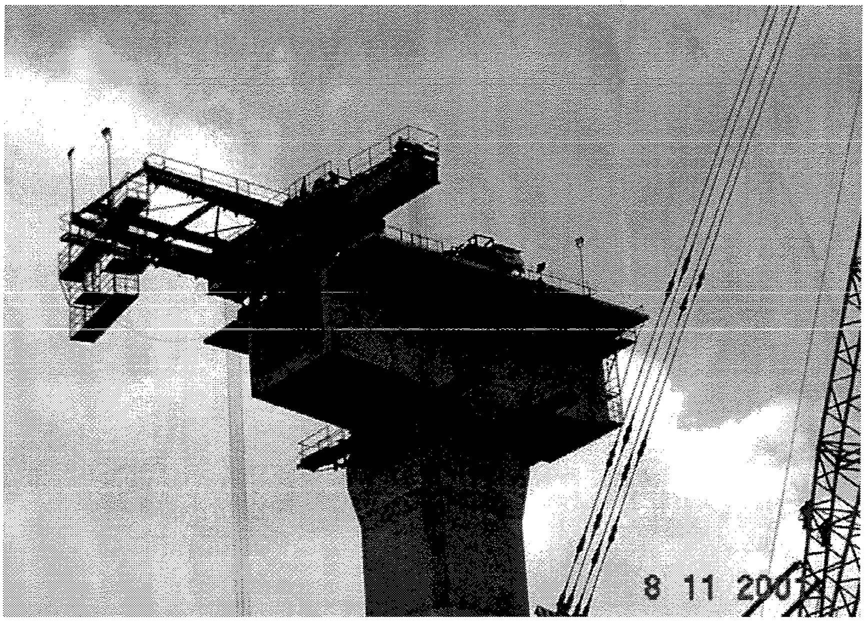


shear Keys ("chiavi di taglio")

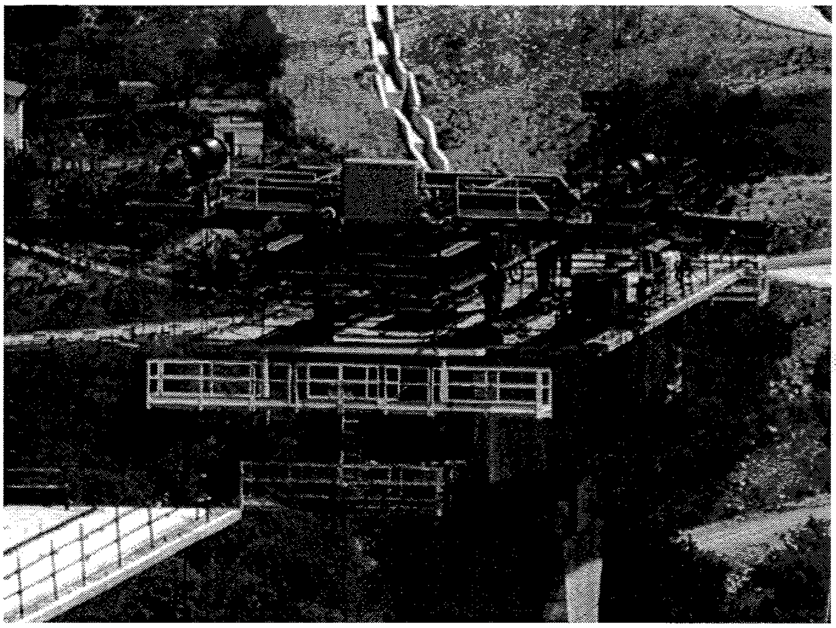
Pier-segment



Pollina Viaduct: first segment outside the pier



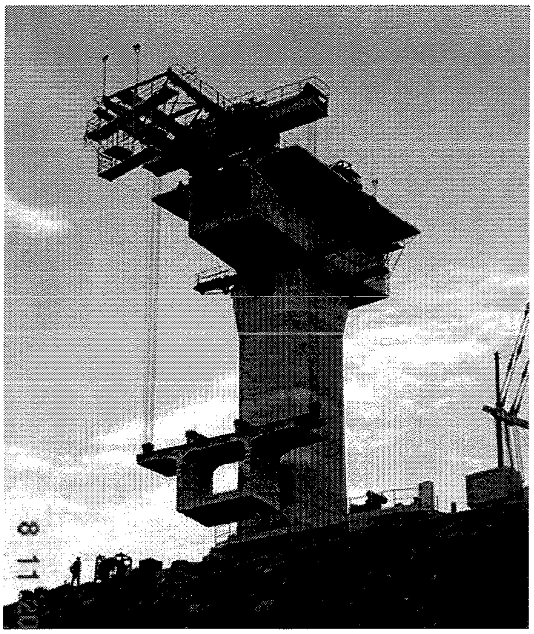
Positioning of segment two (3)

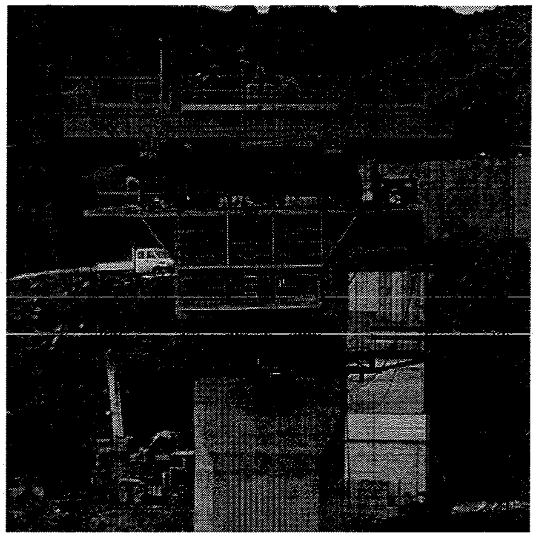


Pier-cap with first segments

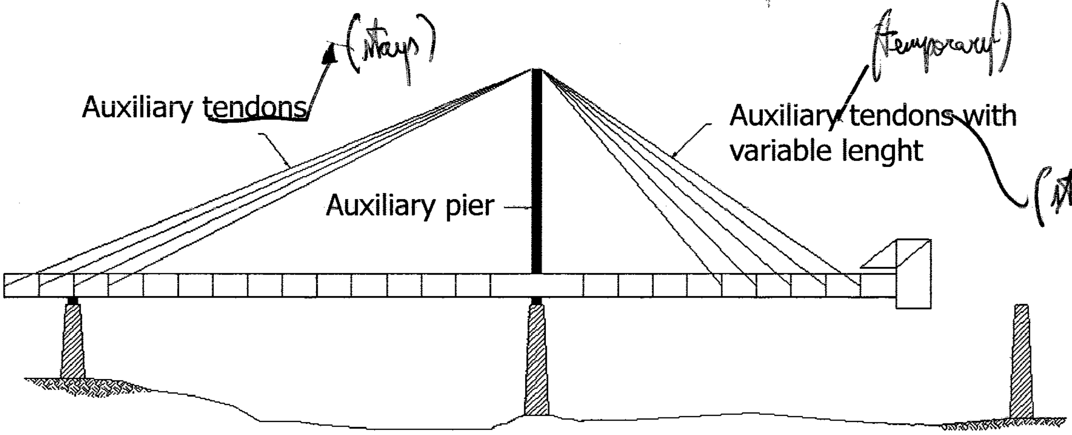
Tusa Viaduct

Another image of the uplift of the segment ("sollevamento")





b) Cantilever with auxiliary tendons



© Proprietà riservata dell'autore - Digitalizzazione e distribuzione a cura del CENTRO APPUNTI - Corso Luigi Einaudi, 55 - Torino / Pagina 61 di 348

NON FATTA

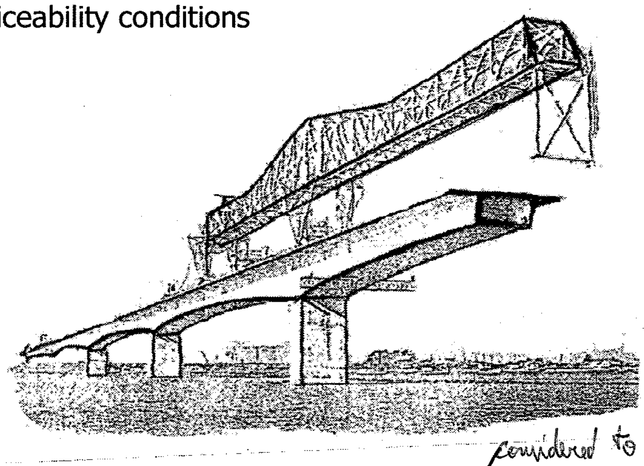
Both **overhead travelling** cranes and **gantry cranes** are types of Crane which lift objects by a **hoist** which is fitted in a trolley and can move horizontally on a rail or pair of rails fitted under a beam. An overhead travelling crane, also known as an overhead crane or as a suspended crane, has the ends of the supporting beam resting on wheels running on rails at high level, usually on the parallel side walls of a factory or similar large industrial building, so that the whole crane can move the length of the building while the hoist can be moved to and fro across the width of the building. A gantry crane has a similar mechanism supported by uprights, usually with wheels at the foot of the uprights allowing the whole crane to traverse.

"montacarichi"

A **hoist** is a device used for lifting or lowering a load by means of a drum or lift-wheel around which rope or chain wraps. It may be manually operated, electrically or pneumatically driven and may use chain, fiber or wire rope as its lifting medium.

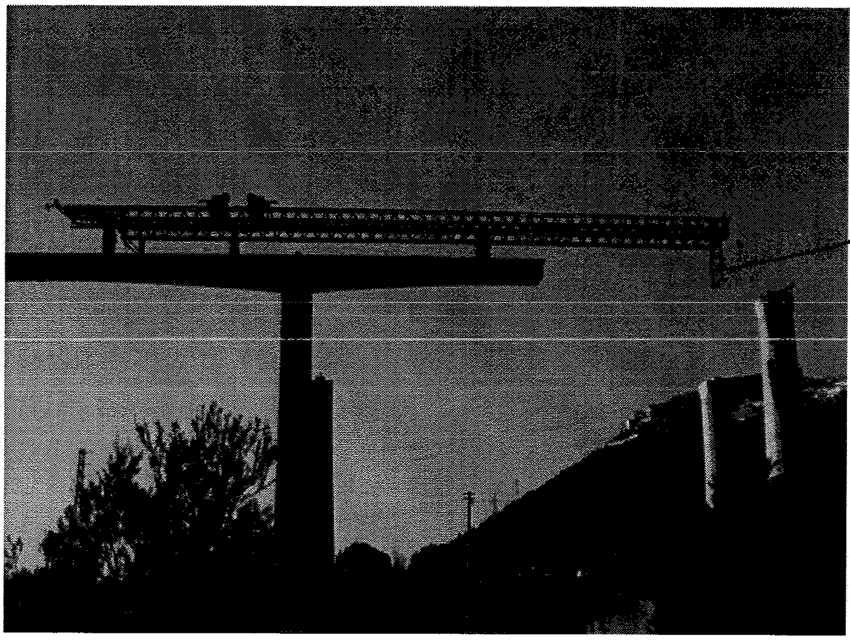
- Precast segmental construction → was invented by French people in the middle of '70ies.

No tensile stresses at the edges in serviceability conditions



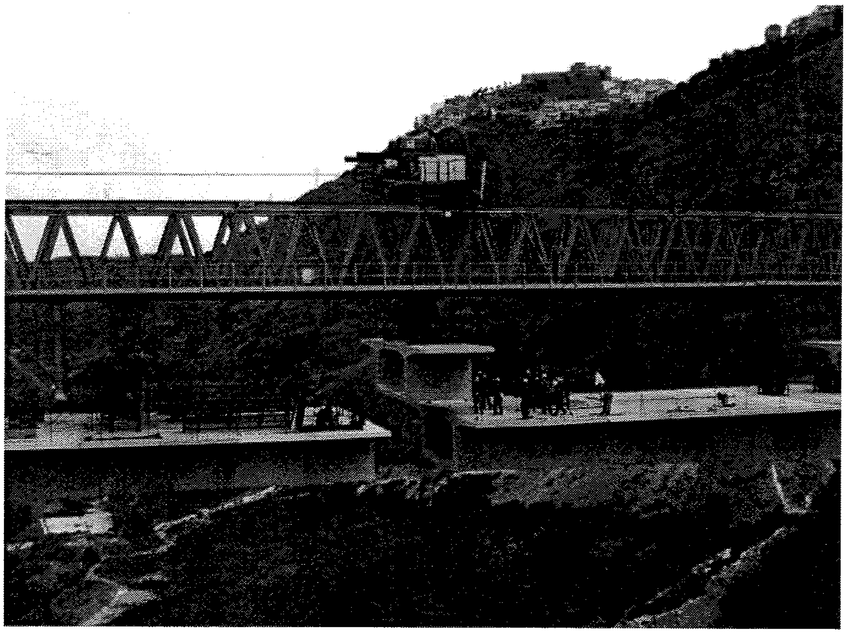
If you use precasted segments → no longitudinal reinforcements → no control of the cracking → Joints must remain compressed.

Maximum span 135 ÷ 140 m (considered to be economic realization)



movable pendulum leg

Launching girder



Before the closing of the central (last) Key and

Launching of last segment

Economical criteria for multispan bridges

$$C = C_d + C_{pf}$$

- C = Total cost
- C_d = Deck cost
- C_{pf} = Foundations and pier cost

From the back analysis of existing bridges

$$C_d \cong A_1 + A_2 l$$

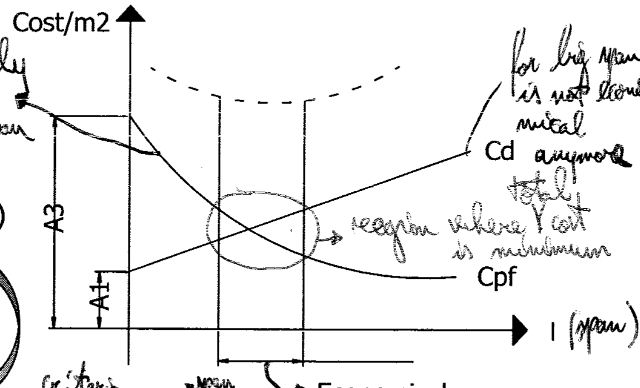
$$C_{pf} \cong A_3 + \frac{A_4}{l}$$

Minimum cost

Deck cost ≅ Cost (pier + foundations)

Construction system
Need for prefabrication and transport

Quality of the soil
Expensive protections is needed



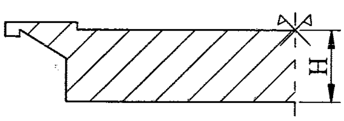
Aesthetic: l > h

Bridge transversal section shape

➢ Influencing parameters:

- Span, with reference to statical scheme
- Depth or slenderness required (l/h)
- Available technology for execution
- Cost (slenderness implies increase of steel quantity)
- q/g ratio (live load/dead load) for dynamic behaviour

➢ Slab bridges cast in situ

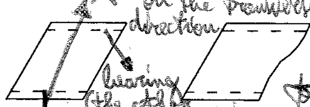


Isostatic ⟶ Span ≤ 20 m

Continuous ⟶ Span ≤ 30 m

25 ≤ depth ≤ 70 cm

Good solution for skew crossing or irregular shapes



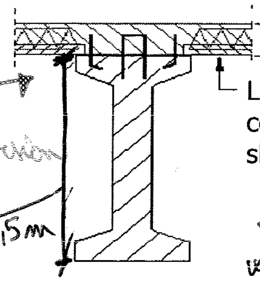
Slenderless R.C. l/H = 15 ÷ 22

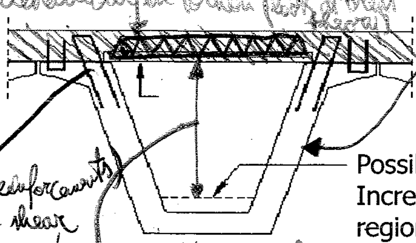
P.C. l/H = 18 ÷ 30

When we talk about girder bridges, most part of them is [redacted] prefabricated. Only a small part is casted in situ.

- T or V precast beams, connected by casting to the slab

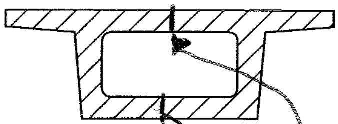
both solutions require a connection between the slab and the beam (and provide a shear resistance)





- Box girder beams

High performance! $\eta \cong 0.5$ $\frac{l}{h} \leq 30$ (continuity)



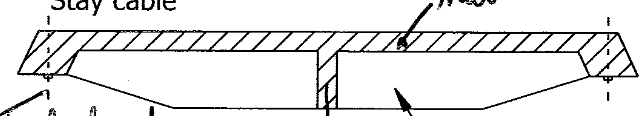
Depth
- Constant → $l < 60\,m$ (if span)
- Variable → $l > 60\,m$ ($< 120\,m$) thin in mid span and thick on the bearings (for continuous beam) because here there is the highest bending moment

good for torsional effects (especially when the span is very long, and previous solutions are not able to resist torsion like this) (because bottom and top should have the same area)

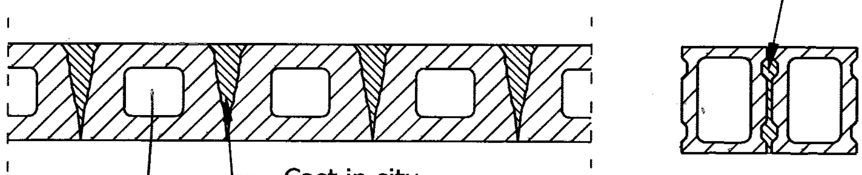
- Box girder with double deck
  - Internal → Railway
  - External → Road

if I want to reach 90-160 m → I build steel webs (not concrete)

- Suspended slabs



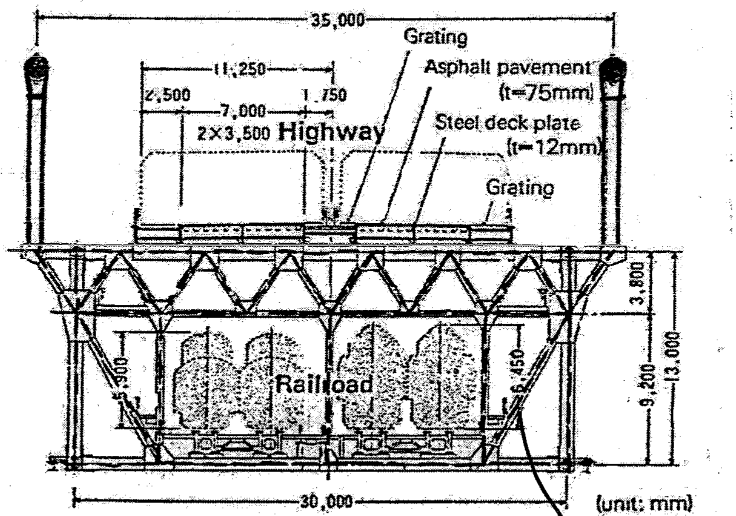
- Precast slabs



$l \leq 20\,m$

the same problem of voided slab (slide 65/70)

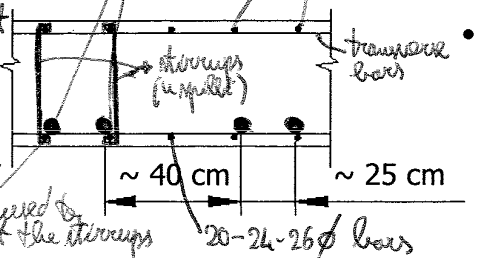
- Cross section of suspended bridge with mixed traffic (for very big suspended bridge)



Let's have a look at prestressing:

prestressing tendons: are small and very diffused (better than bigger and farer away one from each other)

Span l ≥ 15 m   Slabs in P.C.

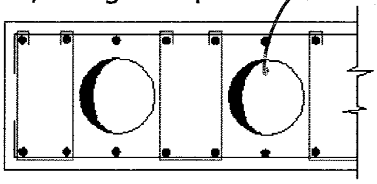


- Small tendons at small distance to reduce the diffusion region.
- Transverse prestressing is not necessary for small widths. For widths greater than 12m may be useful to introduce it, in order to avoid the longitudinal cracks due to concentrated loads; If transverse tendons are used, they should be included within the core of the section.

ordinary reinforcements: they have a distance smaller than that one for prestressing bars. "nucleo", "centro".

2) Voided slabs with orthogonal edges → voids are used to reduce the weight.

- Internal actions analysis done as for massive slabs; anisotropy effect is disregarded. In transverse direction the stress flow is disturbed by voids, then massive regions should be introduced in correspondence of bearings and, in case, along the span.



- The presence of voids implies an increment of tangential stresses, then stirrups are necessary.
- Transverse reinforcement is realized by a double mesh (upper and lower).

you have to be sure that voids are completely dry and no water can go inside (otherwise, in winter, it will be ice → expansion and stresses).

If slab is very large → transverse prestressing is used (→ be careful: put it where there are no voids)

If span becomes important → the slab is prestressed, and is prestressed in the longitudinal direction

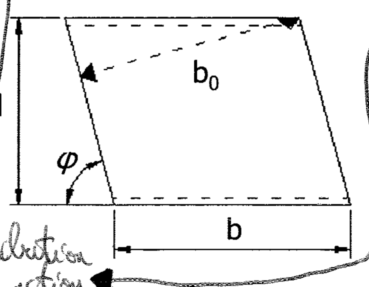
- Generally transverse prestressing is not used. If used, it should be concentrated in transverse massive regions; those regions should then be at a small distance. Of course transverse massive regions should be realized in correspondence of intermediate supports (continuous slabs or several piers).

If I will prestress in transverse direction → I have to interrupt voids where I prestress transversely.

3) Skew slabs

Slabs are used when there are geometric constraints that derive from the geometry of the road.

$20^\circ \le \varphi \le 70^\circ$

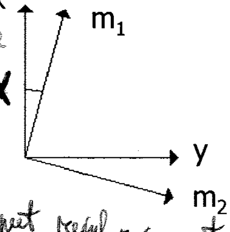


- With $\varphi > 70^\circ$ are dealt like slabs with orthogonal edges.
- Internal action analysis for the evaluation of principal bending moment m_1/m_2 (depending by the load case).

here the distribution of the internal action is totally different than in the orthogonal slab.

$$m_{1,2} = \frac{m_x + m_y}{2} \pm \frac{1}{2}\sqrt{\left(m_x - m_y\right)^2 + 4m_{xy}^2}$$

one is max. and the other is min.



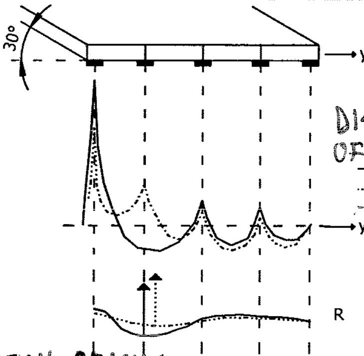
in this direction and the orthogonal → the torque moment is nil!

$$tg2\alpha = \frac{2m_{xy}}{m_x - m_y}$$

"tangent". formula similar to that used for principal stresses.

For slab in concrete you can't design / you can't put reinforcement like m_1 and m_2, because their direction is different inside the slab (change)

Skew slabs: clever solution, even thinner, slender → difficult to design



we have reduction of the peaks and a better distribution of the external actions in the bearings

Practical rules:

- Linear continuous bearing suitable for φ > 40° and b ≤ 10 m (very narrow slabs)
- For large slabs provide a spherical bearings (and concentrated bearings)

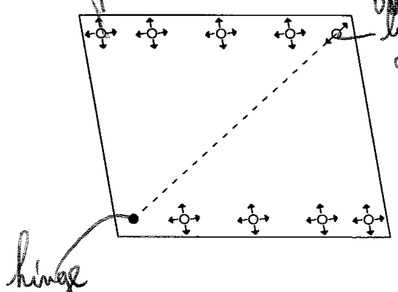
because in these slabs along the edge there is very important torque moment.

Reinforcement

MULTIDIRECTION BEARING: the displacement is free in every direction.

$\varphi \geq 60^0$ $\frac{b_0}{l} \geq 0.5$ — Longitudinal and transverse reinforcement generally parallel to free edges. Stirrups along the free edges.

UNIDIRECTION BEARING: bearing in which the displacement is possible only in the direction of ... (and rotation is free)



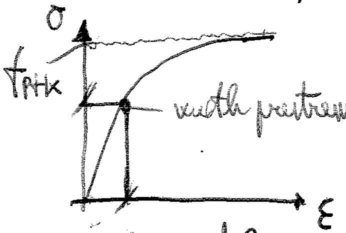
$\varphi < 60^0$ — Orthogonal mesh along the direction orthogonal to supports, or (better) longitudinal reinforcements orthogonal to supports and transverse reinforcement with a small inclination with respect to bearings. Along the free edge provide stirrups and additional reinforcement parallel to edges.

The important is to put the minimum bearings (constraints) that are necessary for the equilibrium. Otherwise, also without actions, but only with temperature effects → stresses. (also without dead load)

Prestressing

Acting effect (serviceability) as equivalent load applied to the slab.
Resisting effect taken into account directly in the section verification.

For the evaluation of acting effect the influence surfaces of slabs should be used or, alternatively, the finite difference method or the f.e.m..



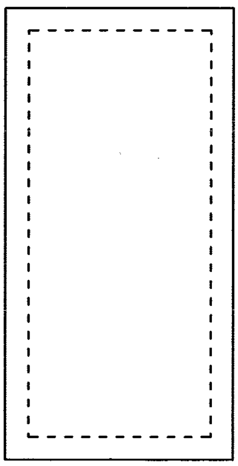
with prestressing you are here. The limit of prestressing is 0,6 fptk

If fptd = 1450 MPa and 0,6 fptd = 1080 MPa → it remains 420÷400 MPa (reserve of resistance) → you have the same strength of a ordinary steel (that you can use) → (450 MPa)

Design criteria

- Few longitudinal beams if are cast in situ
- Higher number longitudinal beams if precast elements are used (to reduce their weight).
- Generally for casting in situ i= 5÷10m and with precast beams i= 2.5÷7m.
- Transverse beam on the bearings to bear torque moments in beams (bending moment in transverse beams). Transverse beams can be omitted along the span and with thick slabs; a transverse beam in the mid-span produces about the same effect of two transverse beams in l/3. Further transverse beams are not useful.
- Web thickness is decreasing with the increasing number of beams. High thickness produces a high torsional rigidity and then helps in the transversal distribution of actions. In the cracked stage this effect is strongly reduced because the torsional rigidity drops of 4÷5 times.

Slab design



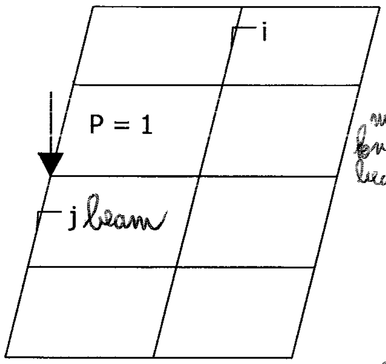
The static scheme is a "long" slab continuously supported in the longitudinal direction, and supported only on the extreme transverse beams in the transversal direction (in fact generally it is not in contact with intermediate transverse beams, if any, in order to uniform the internal actions).

The design implies the evaluation of internal actions corresponding to the combination load and to the load case the most unfavorable ones for the structural region in consideration.

"Transversal distribution of actions"

The problem is the

Evaluation of transversal distribution coefficient:



$\rho_{ij} \equiv$ Percentage of load P acting on beam i when the load is on the beam j. I can't tell that all P is absorbed by J beam, because there wouldn't be any connection between beams, but in reality there are transverse beams, so the longitudinal beams are not independent.

It should result: (n = number of longitudinal beams)

$$\sum_{i=1}^{n} \rho_{ij} = 1$$ Vertical equilibrium condition (all the load should be transferred)

$$P_i = \rho_{ij} P$$ For $P \neq 1$ the principle of superposition may be used

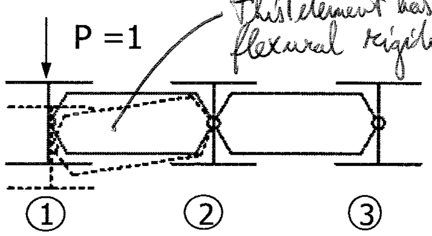
If the load is uniformly distributed:

$$\rho_{ij} = \frac{1}{n}$$ n = beam number

I calculate ρ_{ij} for P=1, but that ρ_{ij} are also good for $P \neq 1$ (principle of superposition) (the same)

Limit cases for deck behaviour

a) Transverse beams and slab without flexural rigidity or connected by means of hinges to the beams.

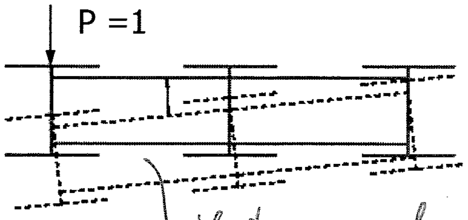


$\rho_{11} = 1$

$\rho_{21} = \rho_{31} = 0$

b) Transverse beams with infinite flexural rigidity and beams with null torsional rigidity.

This situation was analyzed by Courbon.



$\gamma_p = 0$ of longitudinal beams

$\rho_E = \infty$ enter trans: in french (transverse beam)

the transverse beam remain straight (because ∞ flexural rigidity)

© Proprietà riservata dell'autore - Digitalizzazione e distribuzione a cura del CENTRO APPUNTI - Corso Luigi Einaudi, 55 - Torino / Pagina 79 di 348

After seen the previous images, we can say that the

- Main parameters influencing the girder behaviour
  - Flexural rigidity of transverse beams and beams
  - Torsional rigidity of beams *longitudinal (of transverse beams is not so important)*

- Main analysis procedures
  - Finite element (combination of slab and beam elements)
  - Courbon method (valid for case b)
  - Orthotropic slabs analysis: Massonnet *(case e)*
  - Beam girders (beam finite elements) *in any case (3D FEM)*

- Most used methods in the design
  - Courbon, Massonnet → Analytical calculation; Conceptual design and preliminary design (and detailed design in some cases) → Acceptable approximation in cases that respect the basic hypotheses
  - Beam girders (f.e.) → Computer Design → Detailed design and slab drawings

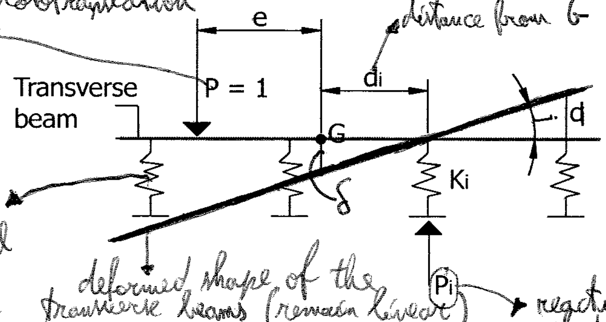
Courbon Method

Hypotheses: transverse beams with infinite flexural rigidity ($\rho_E = \infty$)
beams with null torsional rigidity ($\gamma_p = 0$) *no torsional restraint between slab and beams*

in reality it happens when:

Girder decks with double-T beams in steel or concrete and close and high rigidity transverse beams

Static scheme of transverse beam ⇒ continuous beam on elastic bearings

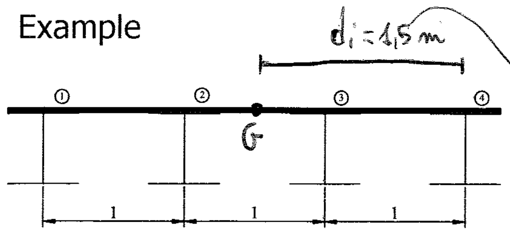


G = gravity center of spring rigidities

δ = displacement of transverse beam in correspondence to the rotation center

φ = rotation angle of transverse beam

Example



We see the load carried from Beams 1 e 4 for different portion of the load.

$$\rho_{1,e} = \frac{1}{4} + \frac{1.5e}{2(1.5^2+0.5^2)} = 0.25 + 0.3e$$

(per simmetria)

40% of the load is carried by the beam 1, when the load is on the beam 1

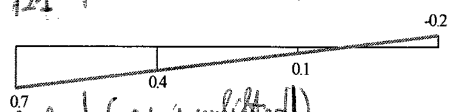
$\rho_{1,1} = 0.25 + 0.3*1.5 = 0.70$

$\rho_{1,2} = 0.25 + 0.3*0.5 = 0.40$

$\rho_{1,3} = 0.25 - 0.3*0.5 = 0.10$

$\rho_{1,4} = 0.25 - 0.3*1.5 = -0.2$ → uplift of 20% of the load (n° 1 is uplifted!)

$\sum = 1$ — Betti Maxwell Theorem →



η_{21} for P applied in 1 is equal at η_{12} for P applied in 2 — displacement of point 2 due to P applied in 1.

Obviously is linear because $J_T = \infty$

$\rho_{ij} = \rho_{ji}$

load carried by the beam 1, when the load is on the beam 2.

Beams 2 e 3
$$\rho_{2,e} = \frac{1}{4} + \frac{0.5*e}{2(1.5^2+0.5^2)} = 0.25 + 0.1e$$

Betti, Maxwell → ρ_{12}

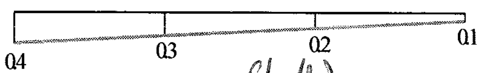
$\rho_{2,1} = 0.25 + 0.1*1.5 = 0.40$

$\rho_{2,2} = 0.25 + 0.1*0.5 = 0.30$

$\rho_{2,3} = 0.25 - 0.1*0.5 = 0.20$

$\rho_{2,4} = 0.25 - 0.1*1.5 = 0.10$

$\sum = 1$ — Betti Maxwell Theorem →



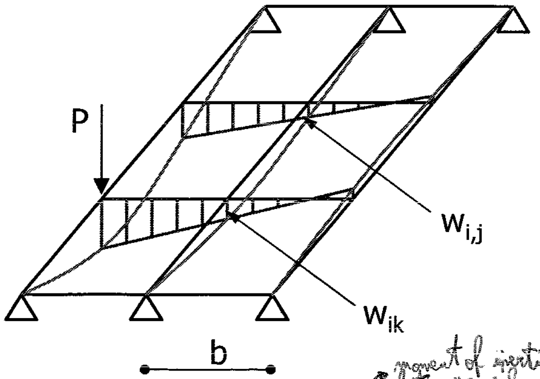
width (depth) of the deck

Within the Courbon formula it can be introduced $e = e' b_0$ and $d_i = d'_i b_0$ then:

$$\rho_{i,e} = \frac{1}{n} + \frac{e' b_0 d'_i b_0}{\sum_{i=1}^{n} d_i'^2 b_0^2} = \frac{1}{n} + \frac{e' d'_i}{\sum_{i=1}^{n} d_i'^2}$$

→ indipendent by b_0

b_0 is a constant → out of $\sum$



For a general beam i:

$$\frac{w_{i,j}}{w_{i,k}} = \text{cost.}$$

As the loaded transverse beam is linear, the unloaded one is too (because the transverse beams are constraint to remain straight)

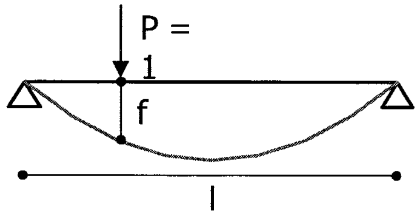
The transverse beam "j" follows the deformation of the "k" one, remaining linear.

On the opposite if $I_{ft} \neq \infty$ (moment of inertia of transverse beam), the deformed shape of transverse beam is curved like the one of "j" transverse beam.

⇨ Internal actions arise, which have an influence on the girder behaviour.

In practice the spring deformability depends on the transverse beam position.

$$f = c\frac{l^3}{EI_{fb}}$$ (l power 3) (for z = l/2 → c = 1/48)



If we suppose that $I_{ft} \neq \infty$, the solution of continuous beam on elastic bearings shows that the distribution of internal actions is a function of following parameter:

$$Z = \left(\frac{l}{b}\right)^3 \frac{I_{ft}}{I_{fb}} c$$ (c is < 1), if $Z = \infty$ ⇒ infinitely rigid transverse beam

For $Z = \infty$, because $I_{ft}/I_{fb} \cong 1$, it is necessary that l>>b (long and narrow decks).
In practice, with $Z \geq 20$ ~~one~~ we can consider $Z = \infty$.

Then with $I_{ft}/I_{fb} \cong 1$ it should result (l / b) > 10 so that the transverse beam can be considered like infinitely rigid.

Example:

Deck: l = 30 m (deck of 30 m) B = 10 m (total width of the deck) 4 beams b = 2.5 m (interaxis of beams)

$l/b = 30/2.5 = 12$ Mid span transverse beam ⇒ $c = 1/48$ $Z = 1/48 \cdot 12^3 \cdot 1 = 36$

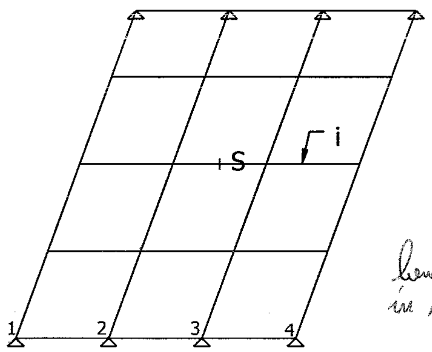
If the number of transverse beams is ≥ 3 the differences between the previous approaches are negligible. Any case the Engesser method is closer to the reality for the shear evaluation.

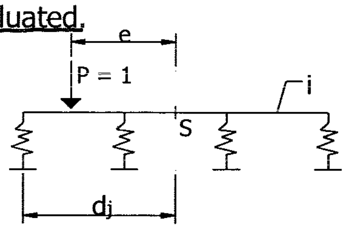
Internal actions in transverse beams

Once known the repartition coefficients ρ_{ij} , the evaluation of internal actions in transverse beams is very easy.

a) The load is moved transversely along the transverse beam: the influence line of bending moment in section S is to be evaluated.

"deve essere valutato"



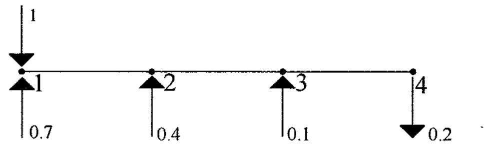


$$M_s = \sum_{sin} \rho_{ij} d_j - 1e$$

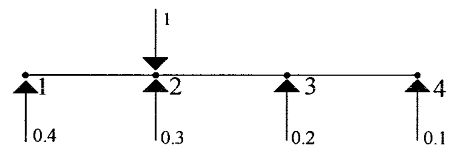
bending moment in section S

$$\rho_{ij} = \begin{cases} 0.7/0.4/0.1/-0.2 & \text{Beams 1/4} \\ 0.4/0.3/0.2/+0.1 & \text{Beams 2/3} \end{cases}$$

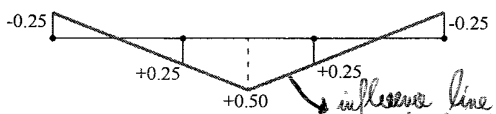
Those values have been calculated before



$$M_s^{\,1} = (0.7-1)*1.5+0.4*0.5 = -0.25$$



$$M_s^{\,2} = 0.4*1.5+(0.3-1)*0.5 = +0.25$$



Two points of the influence line are enough, because one deal with midspan section and the function is linear.

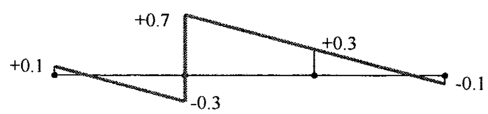
influence line for the bending moment along the transverse beam

Now we can evaluate the shear influence line on beam 2 (right side).

when the load is in the 2nd one

$$T^{1}_{2d} = -1+0.7+0.4 = 0.1$$

$$T^{2}_{2d} = +0.4-1+0.3 = -0.3$$



BRIDGE DESIGN

COMPUTER AIDED DESIGN OF GIRDER BRIDGES

SUMMARY

1) Generation of [k] stiffness matrix of the structure

2) Criteria for the definition of girder mesh (cioè: to transfer the actual structure to mathematical model)

The beam parameters are assembled in the nodes where they converge; the different internal actions in the nodes are composed and their resultants must equilibrate the applied actions.

In the global system for the girder we read:

$$F = [K]\{u\}$$

it's known because is the acting forces; it's known

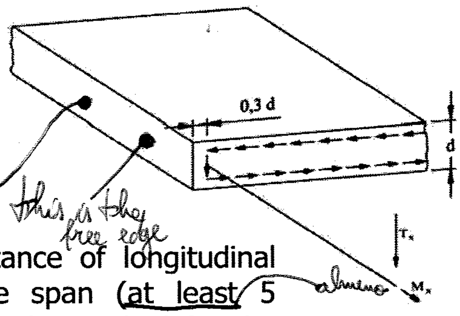
Where [K] is a symmetric square matrix, having the order corresponding to the number of unknowns degrees of freedom and is obtained by assembling $[k_i]$ matrixes of each element.

→ we calculate $\{u\} = [K]^{-1} F$

Solving the system we get {u} then, entering back in the matrices of the single beam elements, the internal actions in the nodes $\{S_i\}$ may be evaluated.

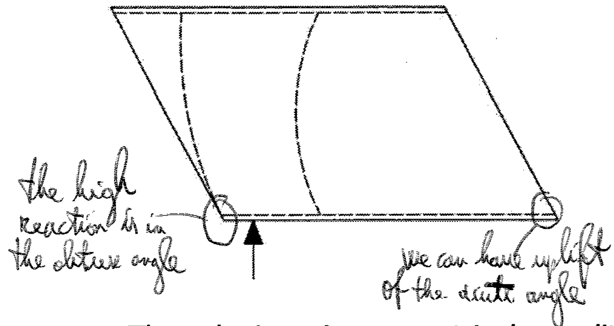
We have to design the girder in the mathematical model to represent good the reality:

2) Criteria for the definition of girder mesh



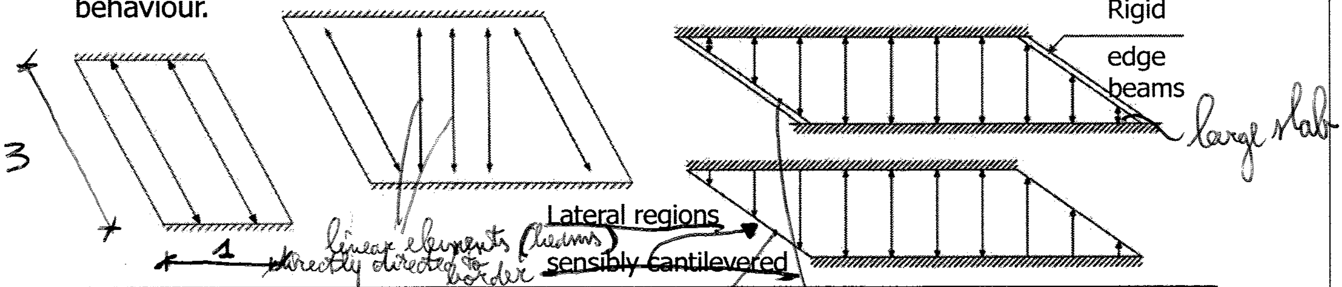
- Take care of actual flow of stresses to design the mesh. In this case introduce a longitudinal beam in the position in which the vertical flow of t is located, so that the corresponding shear Tx is correctly evaluated. this is the free edge
- For decks described like slabs the mutual distance of longitudinal beams should be lesser than ¼ of effective span (at least 5 longitudinal beams). The same procedure has to be applied for the transverse beams (at least 5 transverse beams). almeno → where the bearings are
- Decks with a skew angle up to 20° may be described as with orthogonal edges; for greater angles a skew mesh is necessary, having transverse beam directed along the direction of reinforcement or of real transverse beams.
- If we only need a refinement in a limited region of the deck, the global analysis may be performed with a rough mesh, and then the local analysis with a more refined mesh with impressed deformations at its boundary deriving from the global analysis and the actual loads.

Skew and curved bridges



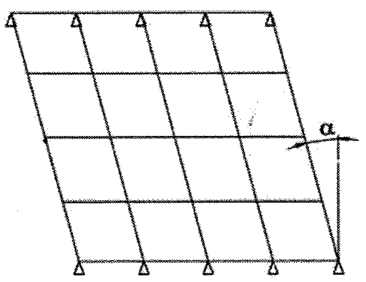
- High reactions in obtuse angle.
- Uplift of acute angle.
- In the central region, positive bending moments in direction orthogonal to the abutments (because it's the most rigid way)
- In the edge region, positive bending moments in directions parallel to the free edge.
- High torque moments, higher as much is higher is the torsional rigidity of beams.

- The planimetric geometrical conditions play an important role on the deck behaviour.

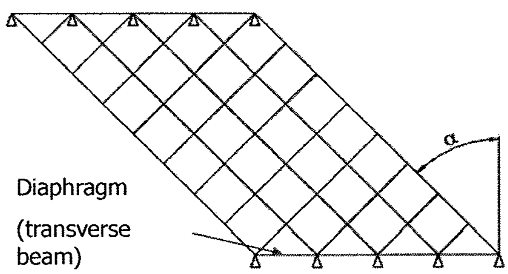


and here we'll have very high torque moment (the same order of magnitude of the bending moment)

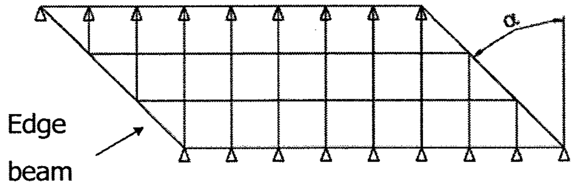
I need this rigid beam if I want to transferr the load like that: ↕



Mesh for α ≤ 30°



Mesh for α ≥ 30° without edge beam



Mesh for α ≥ 30° with edge beam

orientate the mesh along the expected directions of internal forces.

BRIDGE DESIGN

LEZ. 29-10-2013

LOCAL EFFECTS

what happens locally when we apply the actions like the wheels of the trucks

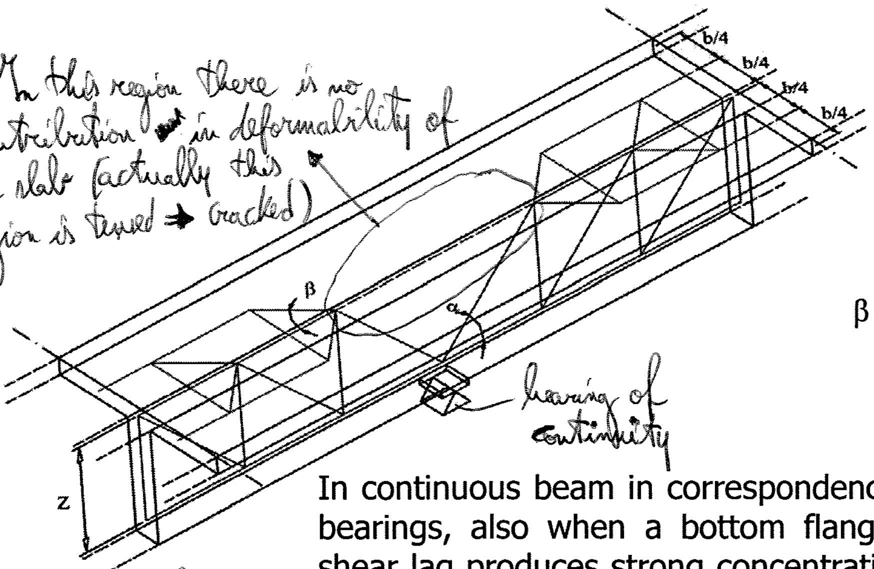
Politecnico di Torino
Department of structural and geotechnical engineering
"Bridge design"

SUMMARY

1. Shear lag in T beams → it can not be directly translated in italian (it would mean "delay on shear", that has no sense)
2. Curved beams
3. Design for local effects
4. Slab design as rectangular slab
5. Local effects in steel orthotropic deck : they have 2 orthogonal preference directions for the bearing capacity
   5.1. Steel slab behaviour
   5.2. Steel stiffened slab behaviour
   5.3. Overall section behaviour

Politecnico di Torino
Department of structural and geotechnical engineering
"Bridge design"

In this region there is no contribution in deformability of the slab (actually this region is tensed → cracked)



$\beta \cong 40° \div 45°$

In continuous beam in correspondence of intermediate bearings, also when a bottom flange is present, the shear lag produces strong concentration of longitudinal stresses within the webs and increment of creep effects in serviceability conditions. In some cases also the bearing capacity may be reduced.

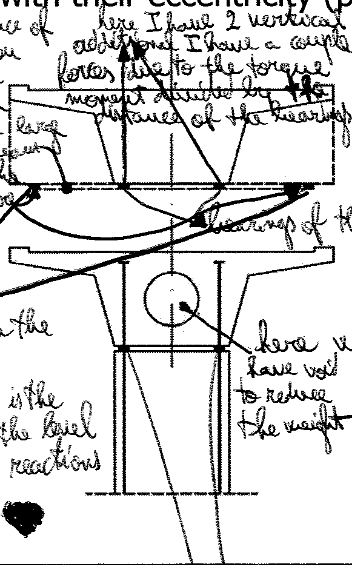
Shear lag is a problem ONLY in serviceability limit state. In SLU we have redistribution of stresses

more than what is expected from linear elastic analysis → creep increases

We see other particular cases of girder bridges:

Single beam deck → used for b ≤ 6 ÷ 7 m. (used to carry the railway)

The web should be designed to carry the torsion coming from live loads with their eccentricity (primary torsion, governing the equilibrium!)



A solution: increase the distance of bearings when you operate on the abutment: you cast in situ a large transverse beam and you put the bearings here

The torsion is the same, but the level arm of the reactions is bigger → no uplift

In the support regions the torsion should be equilibrated by means of two bearings with enough distance; if necessary, use a transverse beam to increase the lever arm of support reactions.

If it is impossible the equilibrium with dead and live loads (light beams), the deck shall be connected rigidly to the pier. (you maintain the distance of the bearings)

If necessary, use tensioned prestressing bars, crossing the bearings. Those bars should be extended within the pier so that they are anchored in a section on which the dead load of the upper part of the pier is enough.

If the distance of the bearing is relatively small, it's possible that you have the uplift so you have failure (the reactions due to the torque moment are bigger than the reactions due to live loads)

If distance of bearing is small → there can be uplift (because the level arm of reactions is small → they don't contrast the torsion)