Convegno 17 giugno 2015
«Spazio Europa» Via IV Novembre 149 – Roma
LA MACROREGIONE DEL MEZZOGIORNO
Sicilia-Calabria, binomio inscindibile nel TEN-T 5
per una nuova centralità dell’Italia
e dell’Europa nel Mediterraneo

POLITECNICO DI MILANO

Mechanical Department

Il progetto innovativo del ponte più lungo del mondo

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Stretto di Messina

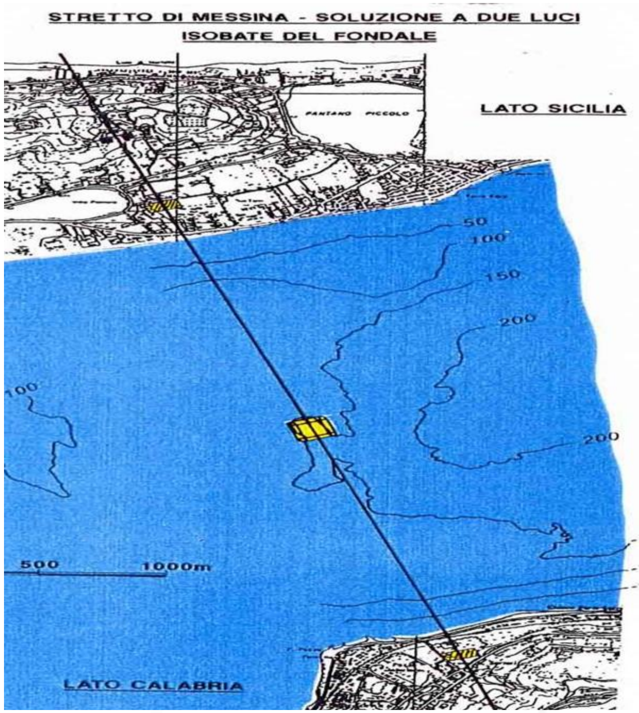
The Messina bridge design

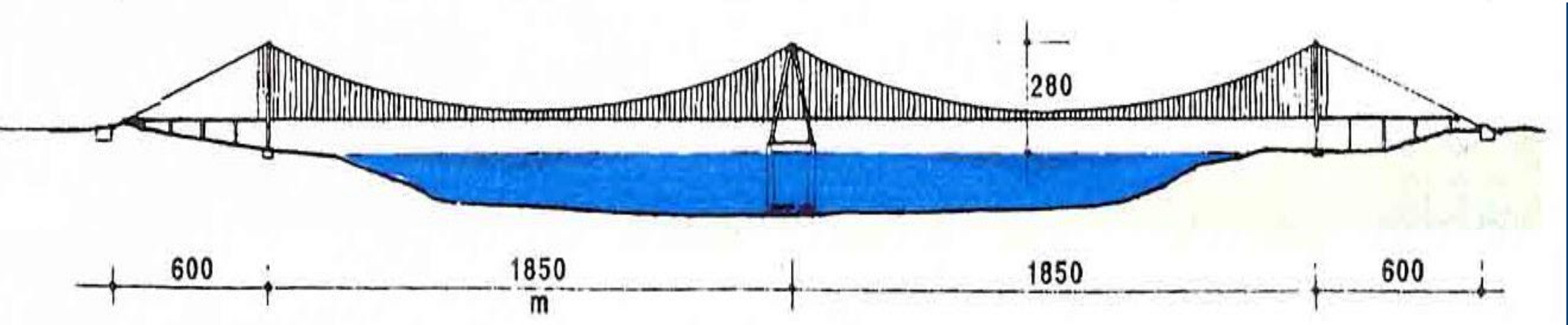
I will try to explain the problem we had to face and solve to grant the performance of the Messina bridge for a life of 200 years, under different actions:

- **Design wind speed: 60 m/s**
- **Road and Railway traffic**
- **Seismic action: 6.3 m/s^2**

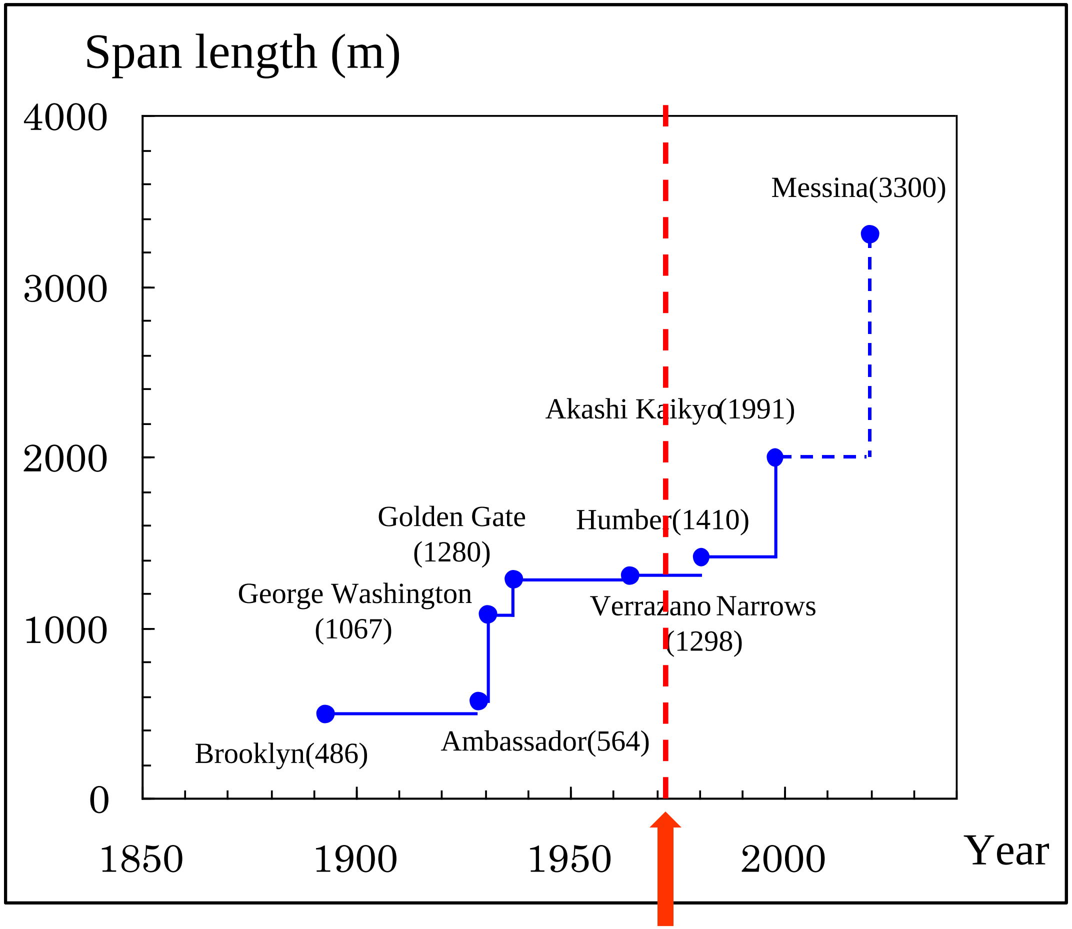
Historical overview

A suspension bridge solution was chosen, at the beginning, with 2 spans since at that time it seemed almost impossible to build a bridge with a main span of 3300 m because of wind action and in particular to the 2 degree of freedom flutter instability.





Historical overview



Akashi Strait Bridge(1998)

Great Belt East Bridge(1998)

Humber Bridge(1981)

Static loads

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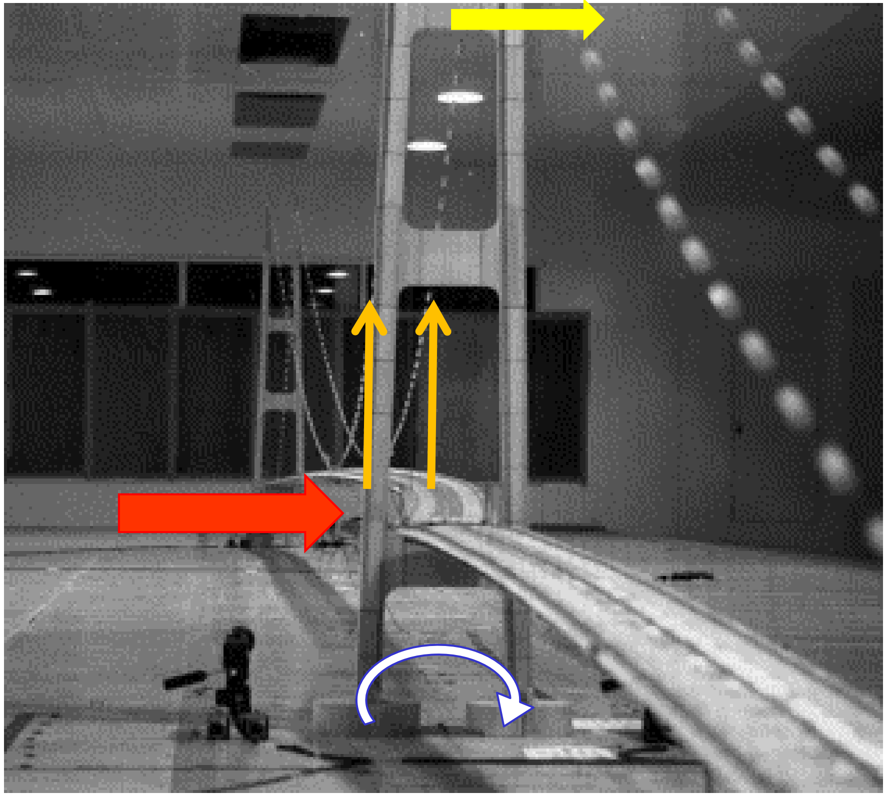
The deck produces the most important static load
that is transferred through the hangers to the main cable
and from the main cable to the top of the towers,
producing a high bending moment
that affects in a large amount
the design of the bridge

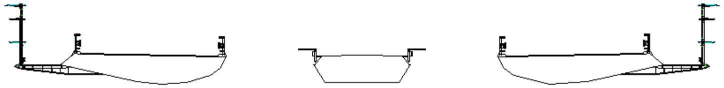
The drag of the deck must be as low as possible



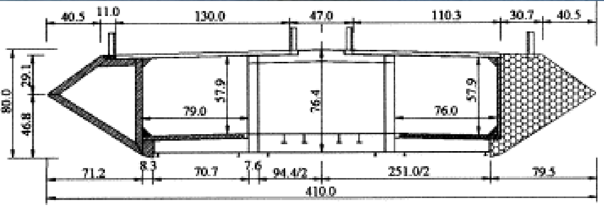
Deck shape

In order to have low drag
an airfoil section must be used

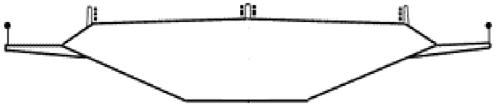
Messina Bridge (3300 m)



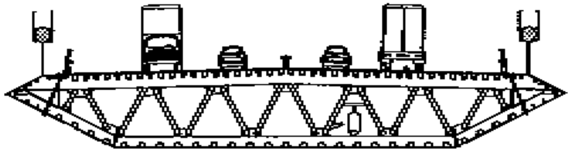
Tsing Ma Bridge (1377 m)



Humber Bridge (1410 m)



Storebaelt Bridge (1624 m)



Wing like deck shape

This type of section do not suffer of one degree of freedom instability like old Tacoma Narrow Bridge

But it suffer of two degrees of freedom instability of the flutter type

I will try to explain in a simple way the mechanism

Instability problems or aeroelasticity

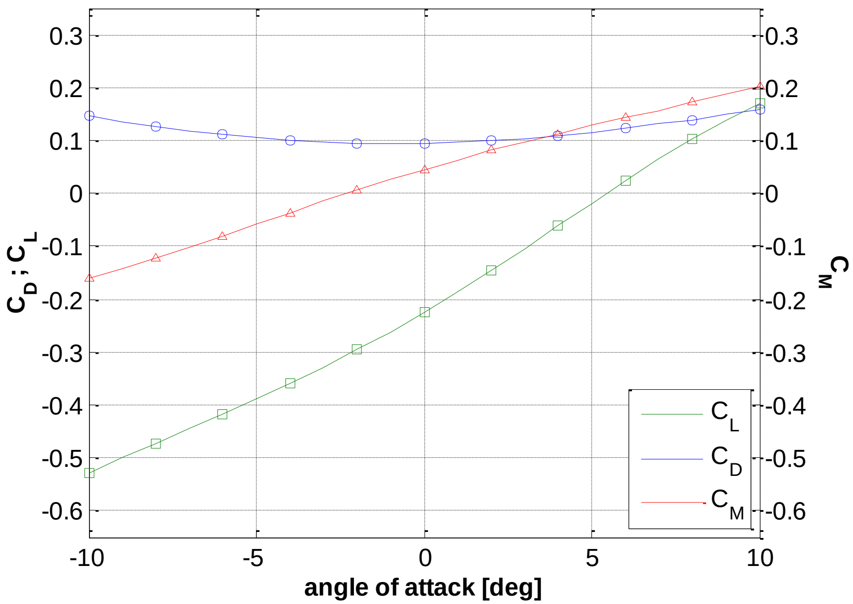
The aerodynamic force are:

$$\underline{F}_D = \frac{1}{2}\rho V^2 B L C_D(\vartheta)$$

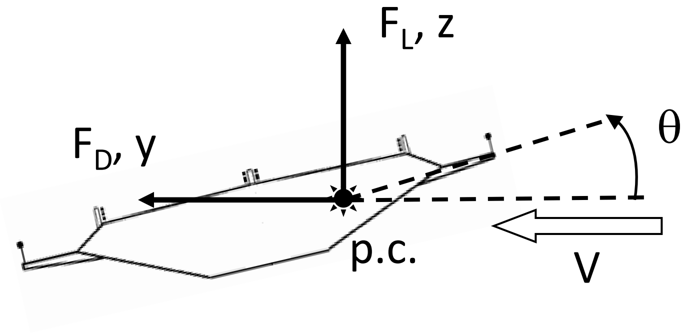
$$\underline{F}_L = \frac{1}{2}\rho V^2 B L C_L(\vartheta)$$

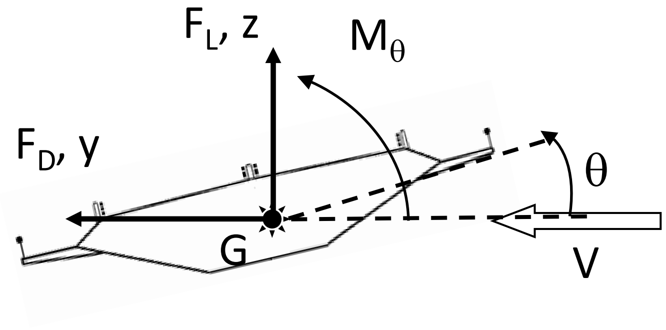
$$\underline{M}_\vartheta = \frac{1}{2}\rho V^2 B^2 L C_M(\vartheta)$$

C_D, C_L, C_M



Humber Bridge





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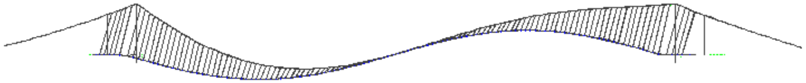
Linearization of the aeroelastic terms

The total torsional stiffness is: $K_t^{tot} = K_t^{str} + K_t^{aer}$

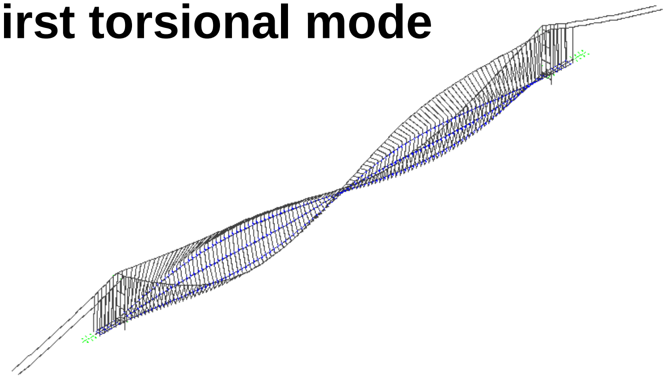
Being K_t^{aer} negative and proportional to V^2

Increasing the wind speed K_t^{tot} decreases and as a consequence the torsional frequencies are decreasing

First vertical mode



First torsional mode



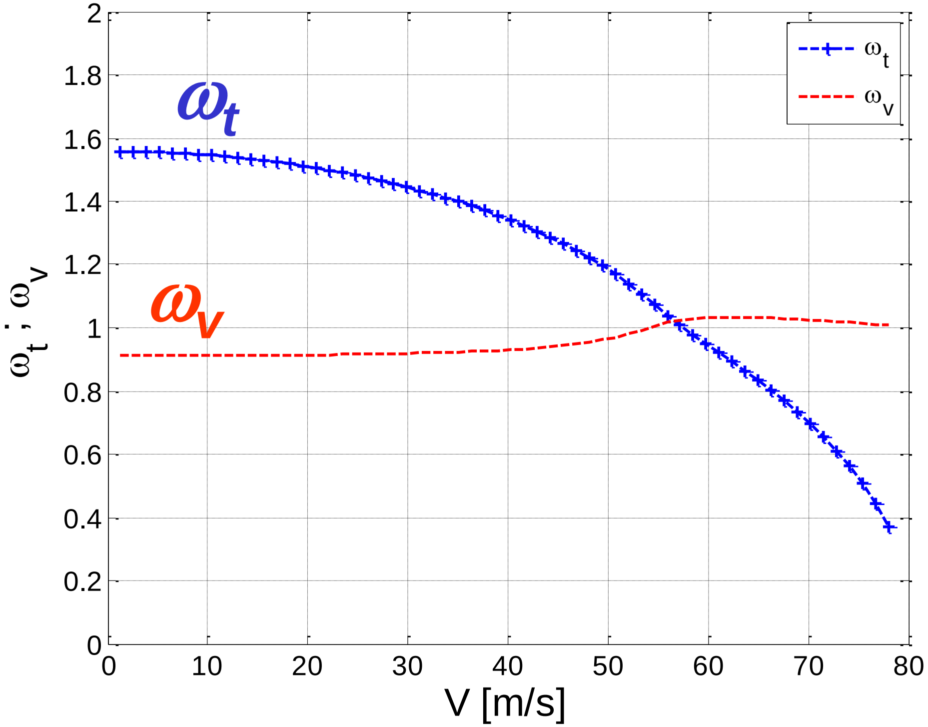
Their coupling gives rise to flutter instability

2 d.o.f. instability (flutter): natural frequencies

$$K_t^{tot} = K_t^{str} + K_t^{aer}$$

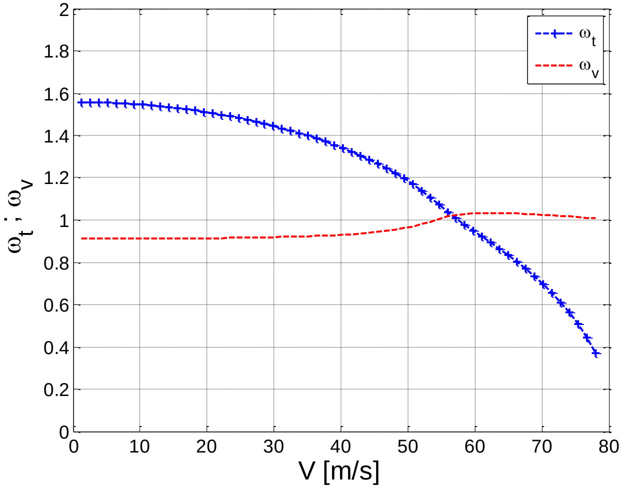
$$K_t^{aer} = \frac{1}{2}\rho V^2 B^2 L \frac{\partial C_M}{\partial \psi}$$

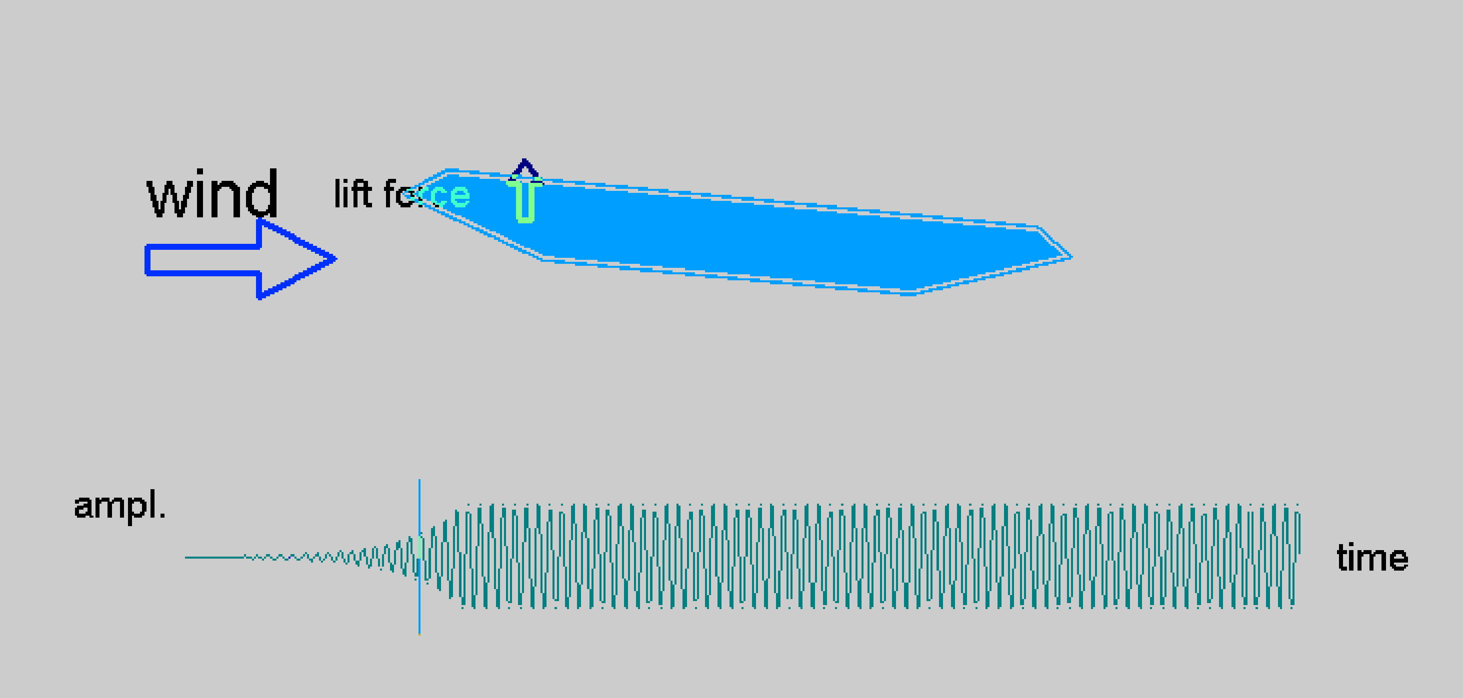
$$\boxed{\omega = \sqrt{\frac{\mathbf{k_{tot}}}{\mathbf{J}}}}$$



2 d.o.f. instability (flutter)

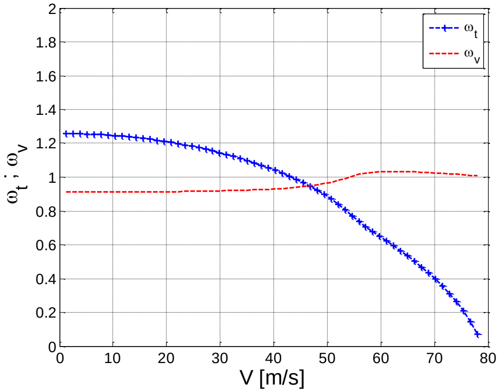
When this two frequencies become equal a two degree of freedom flutter is produced:



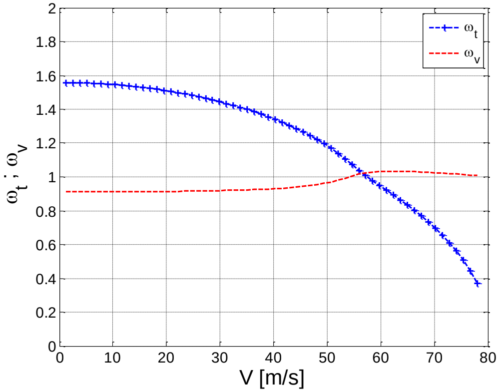


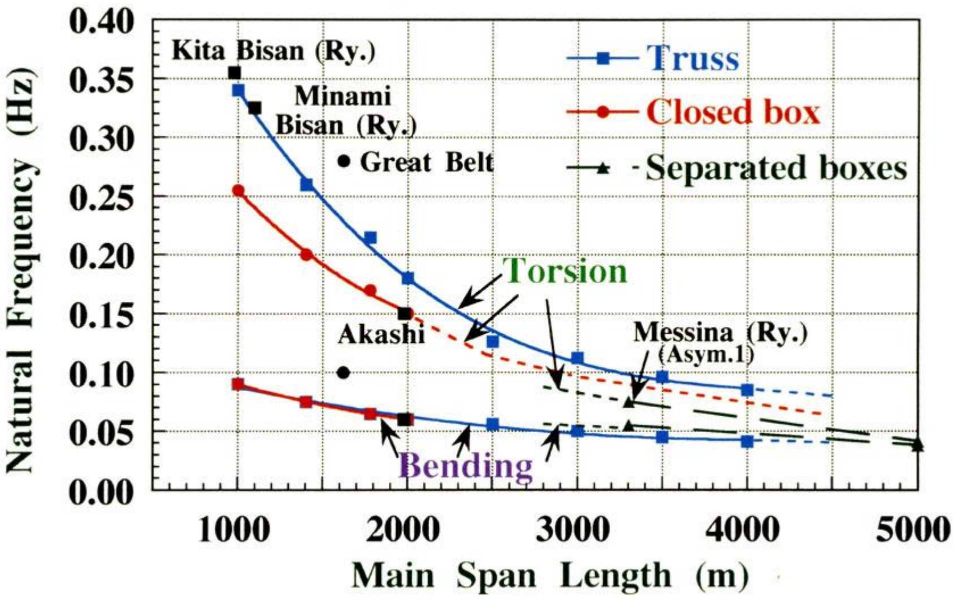
Why this is a problem increasing the span length?

$\omega_t - \omega_v$



$\omega_t - \omega_v$





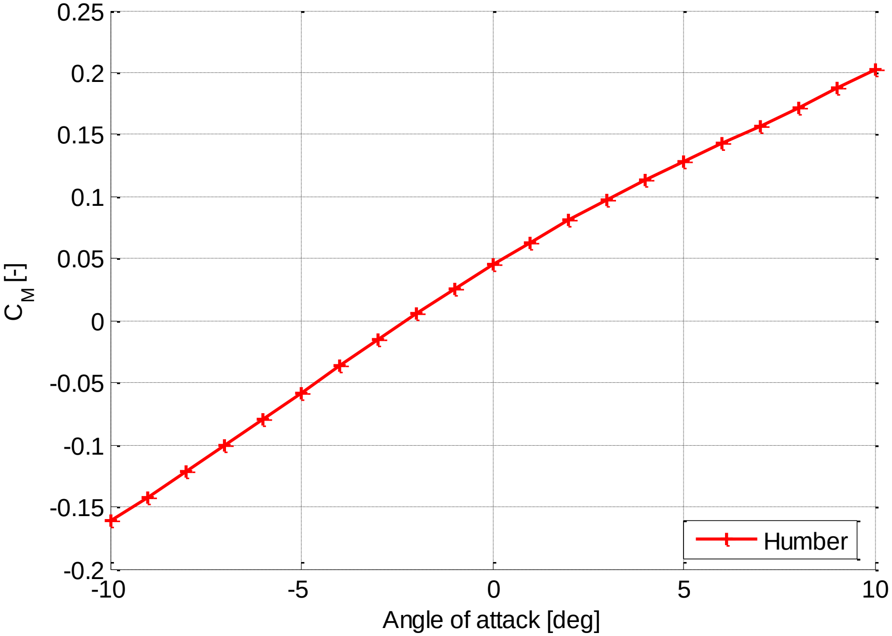
Reduction of Natural Frequency with Span Length in Suspension Bridge

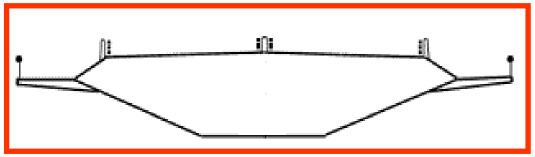
Aerodinamic optimization

If we should use the deck aerodynamic properties of the Humber or Storebealt deck section with the Messina structural properties

⇒ the flutter wind speed should be:

$$\boxed{V_{flutter} = 40 \text{ m/s}}$$





How to come out from this problem?
2 ways:

1) **Structural solution**:

by increasing the structural torsional stiffness of the deck (like Akashi)

Drawbacks:

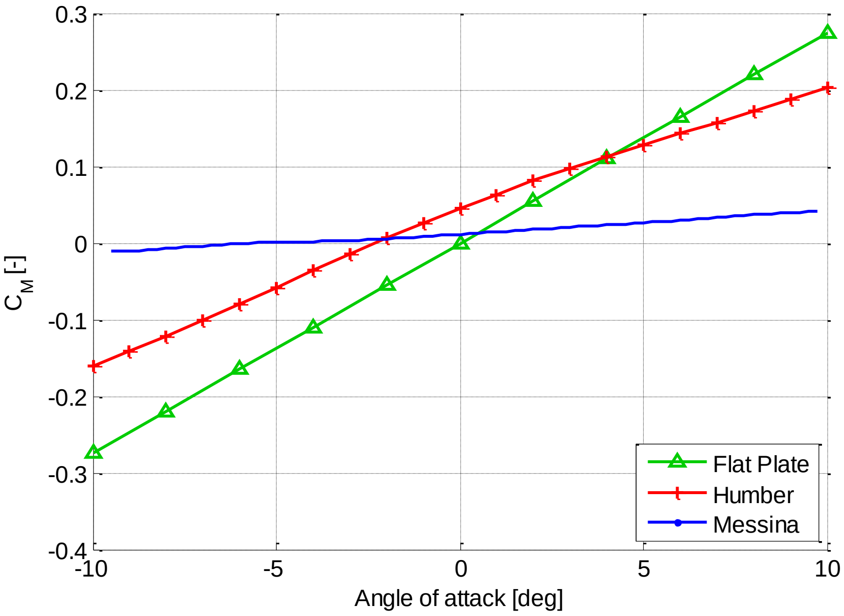
- High drag
- Not feasible increasing the span length since the cable contribution to the torsional stifness becomes larger and larger and the effect of deck stiffness becomes negligible

How to come out from this problem?
2 ways:

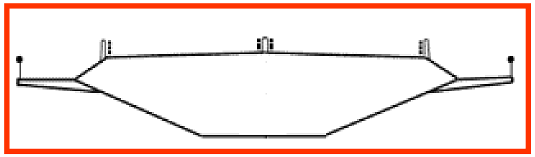
2) **Aerodynamic solution**:

by decreasing the aerodynamic torsional stiffness

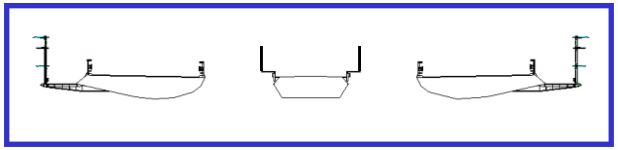
$$K_t^{aer} = \frac{1}{2}\rho V^2 B^2 L \frac{\partial C_M}{\partial \psi}$$



Using Humber bridge aerodynamics : $V_{flutter}$ = 40 m/s



Using Messina bridge aerodynamics : $V_{flutter}$ = 90 m/s



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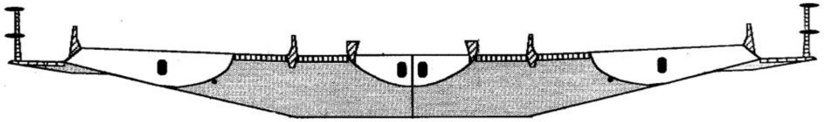
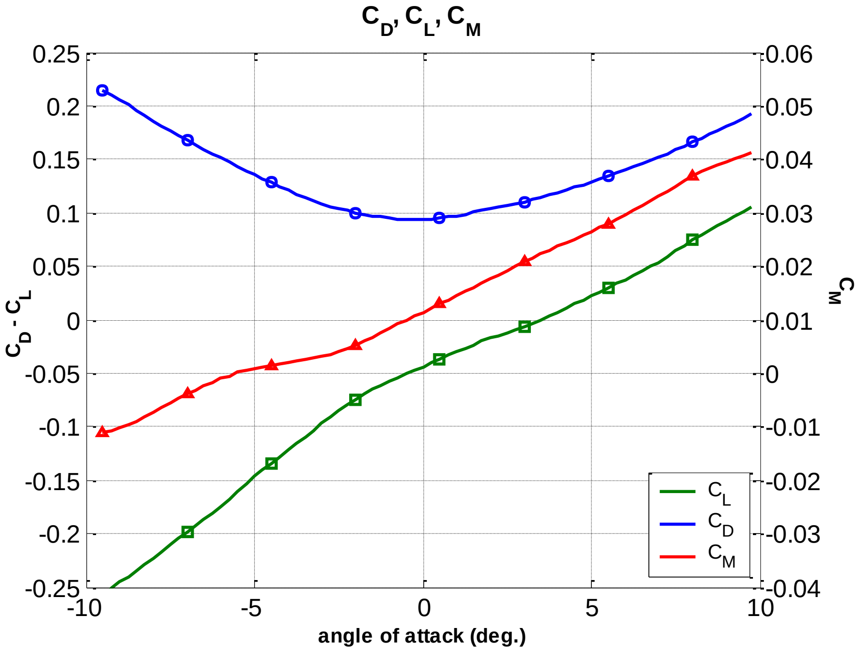
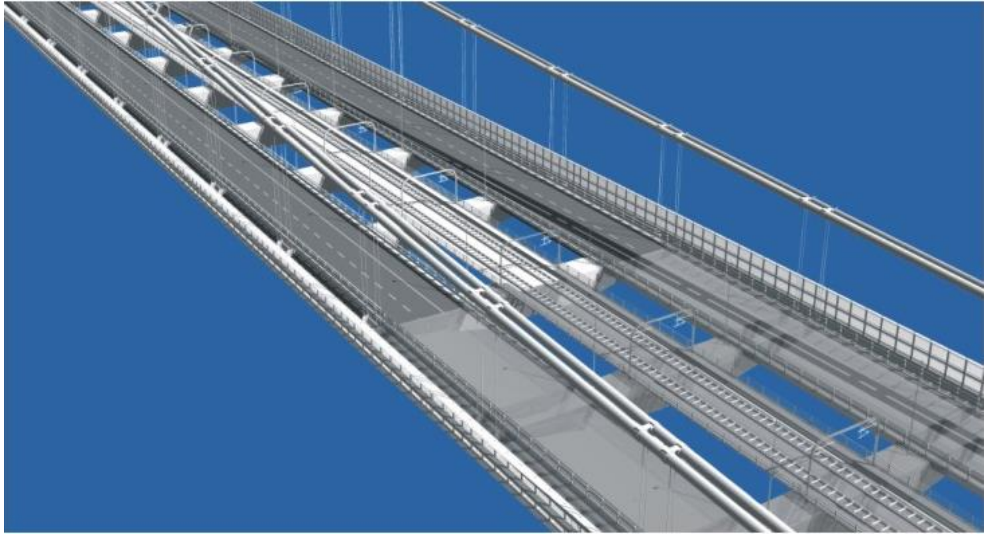
Messina bridge solution:



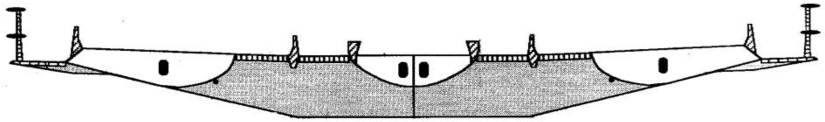
The secret of Messina bridge is the multi box deck section with:

- a very low lift and moment coefficients



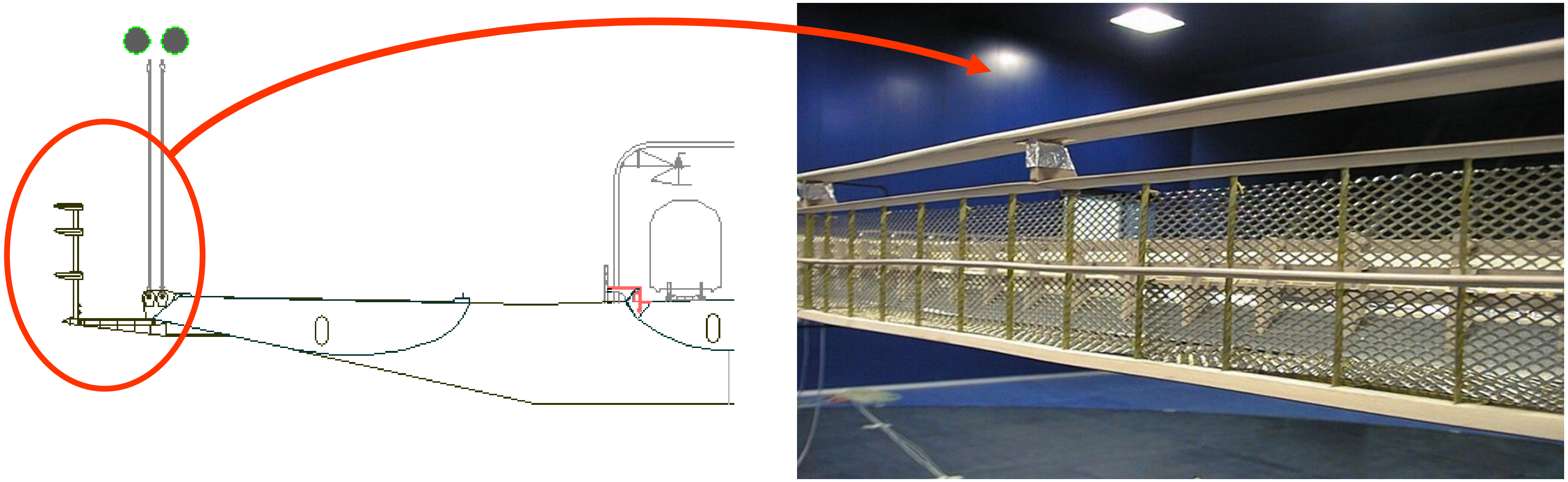


Messina bridge solution:



The secret of Messina bridge is the multi box deck section with:

- a very low lift and moment coefficients
- transparent wind screen with aerodynamic damping devices



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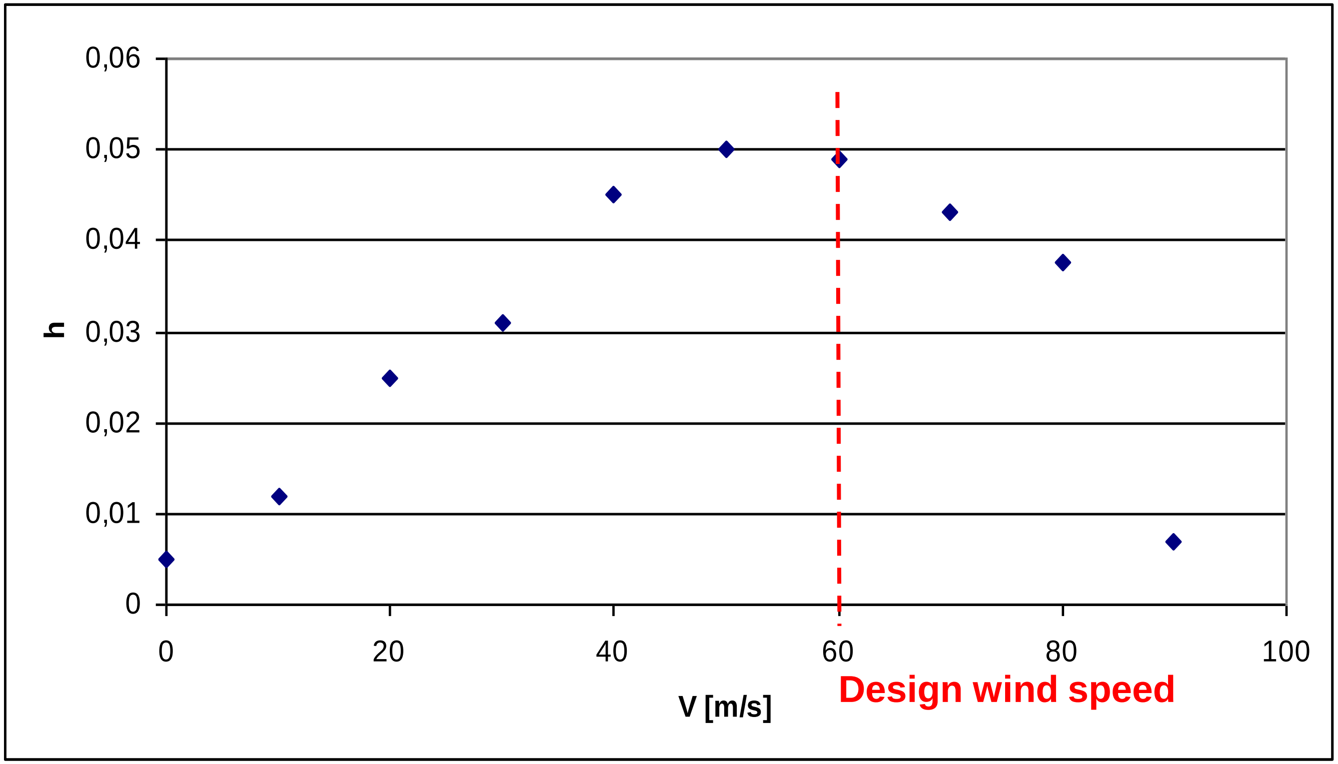
The aeroelastic problem

K_{aer} changes the bridge structural natural frequencies, as already seen

R_{aer} changes the overall damping as in figure, for Messina bridge:



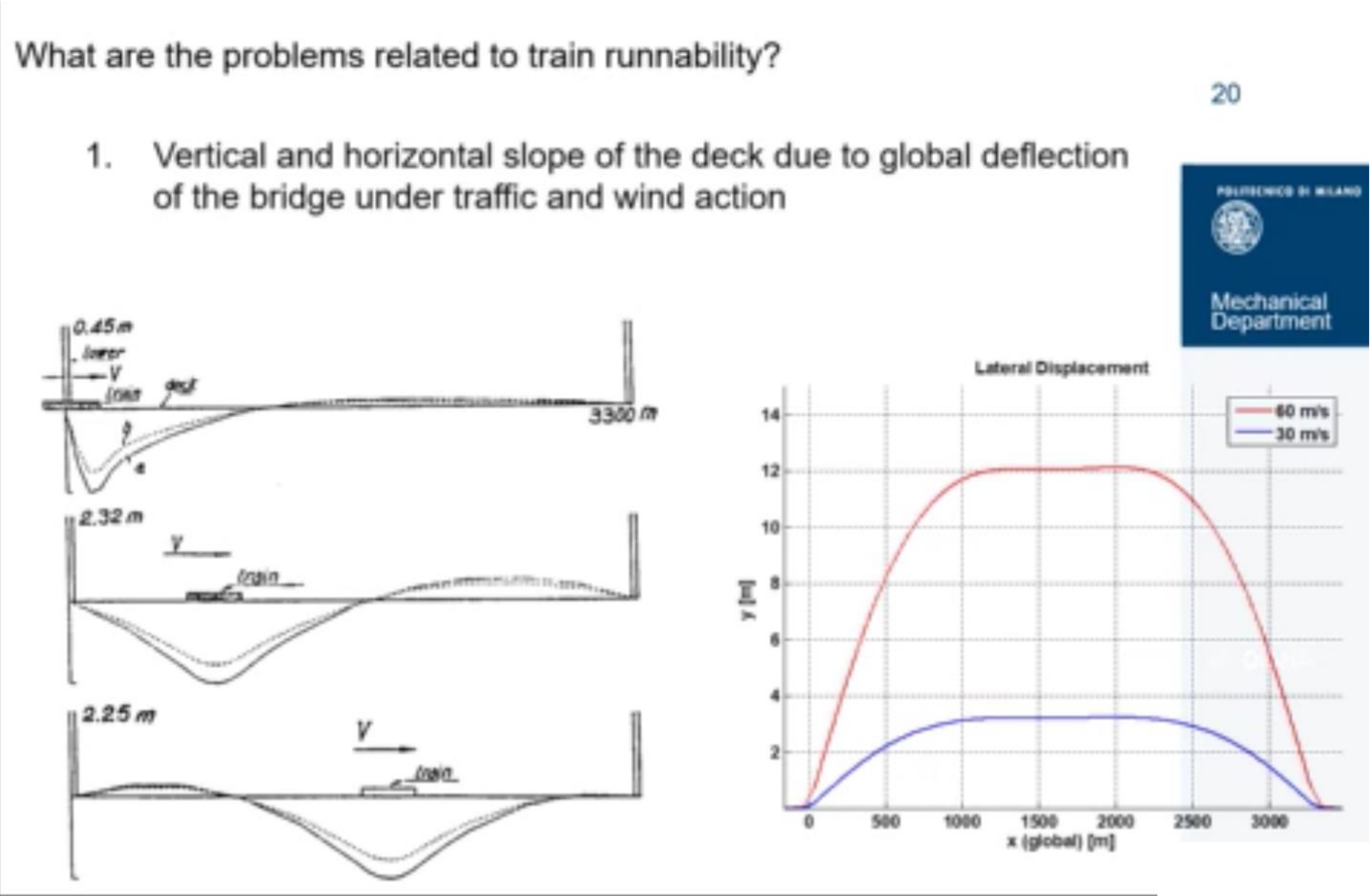
Damping variation increasing the wind speed

Railway runnability

It means to grant safety and running comfort for any operating condition:

Maximum train speed:	130 km/h
Maximum wind speed:	47 m/s
Maximum seismic acceleration:	2.6 m/s^2

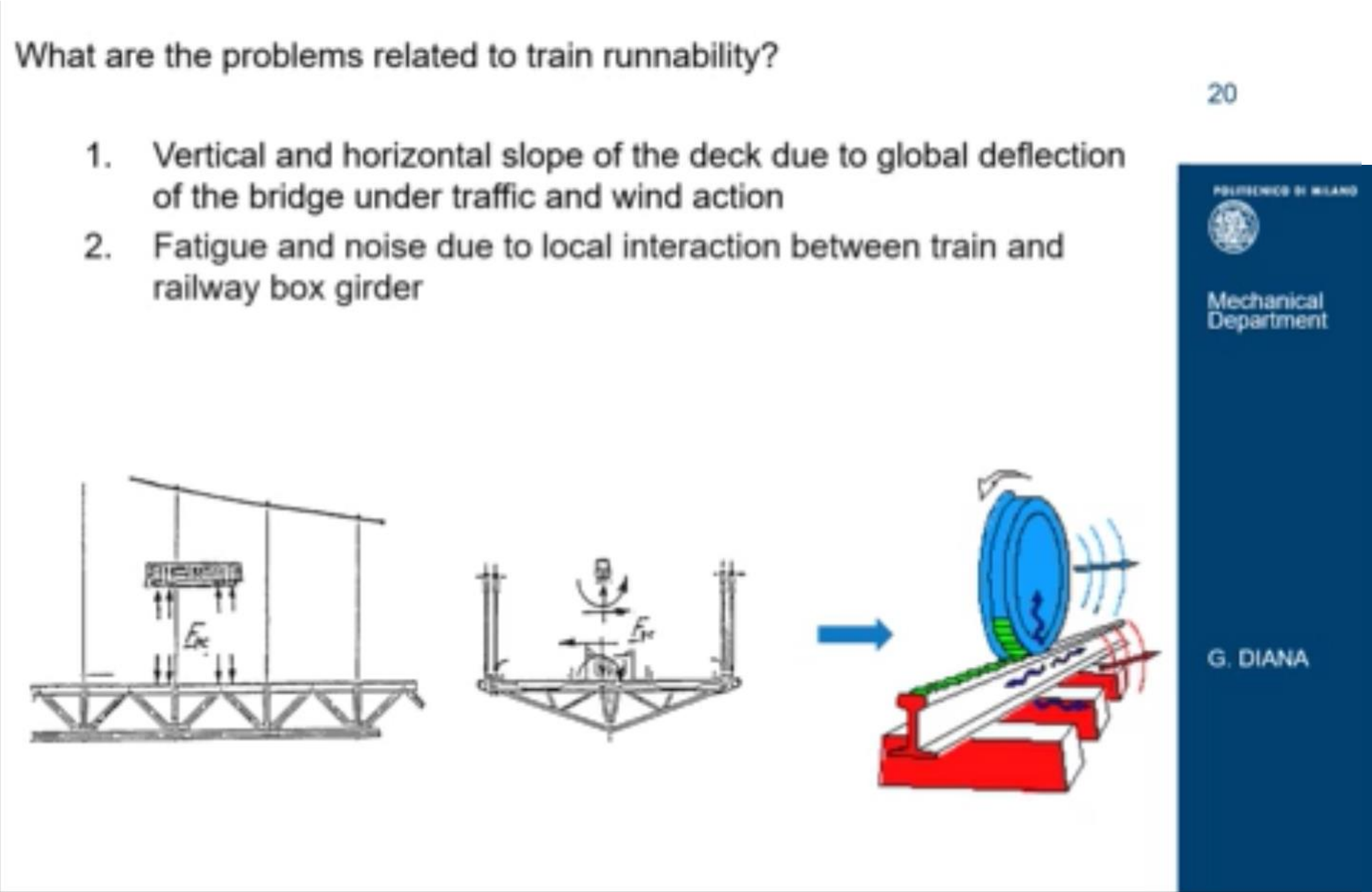
Railway runnability



What are the problems related to train runnability?

1. Vertical and horizontal slope of the deck due to global deflection of the bridge under traffic and wind action

Railway runnability



What are the problems related to train runnability?

1. Vertical and horizontal slope of the deck due to global deflection of the bridge under traffic and wind action
2. Fatigue and noise due to local interaction between train and railway box girder

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Railway runnability

What are the problems related to train runnability?

1. Vertical and horizontal slope of the deck due to global deflection of the bridge under traffic and wind action
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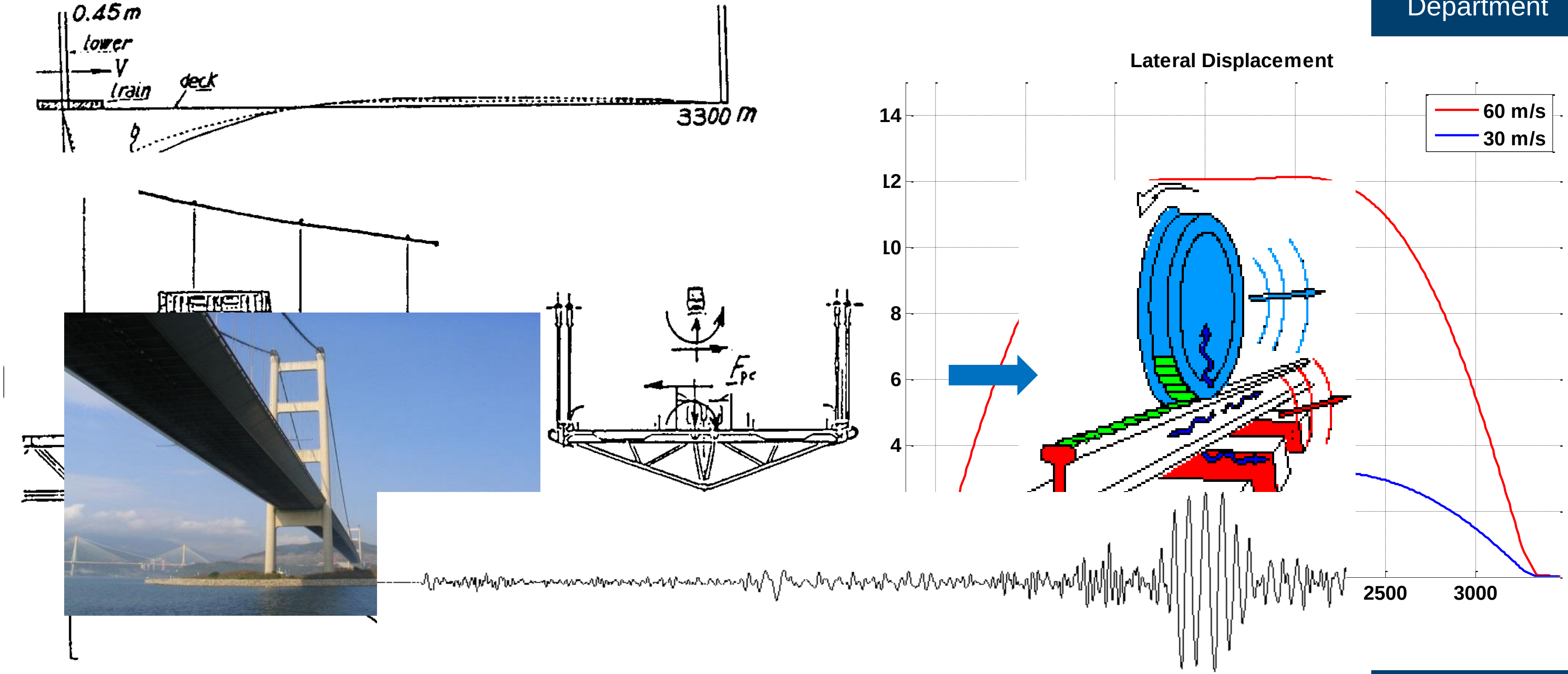
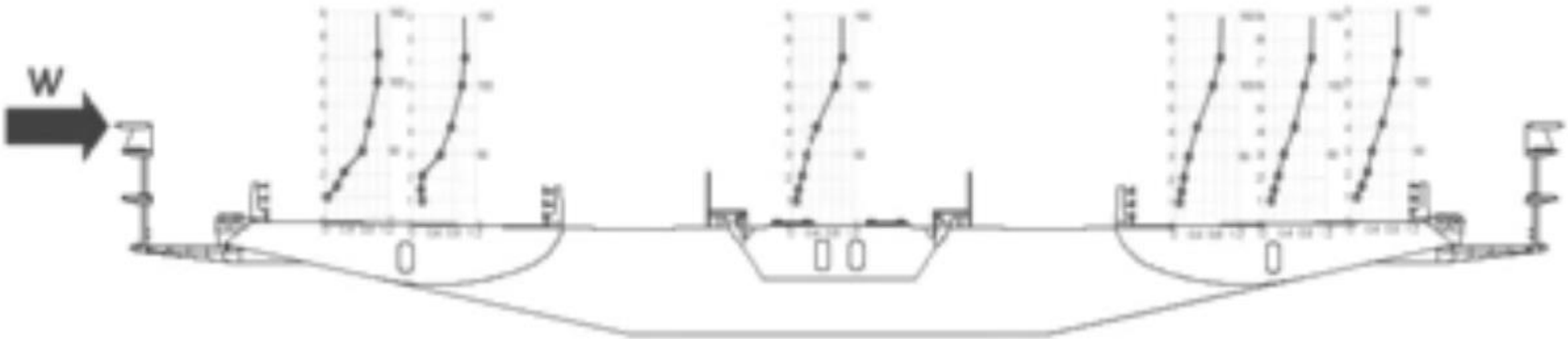


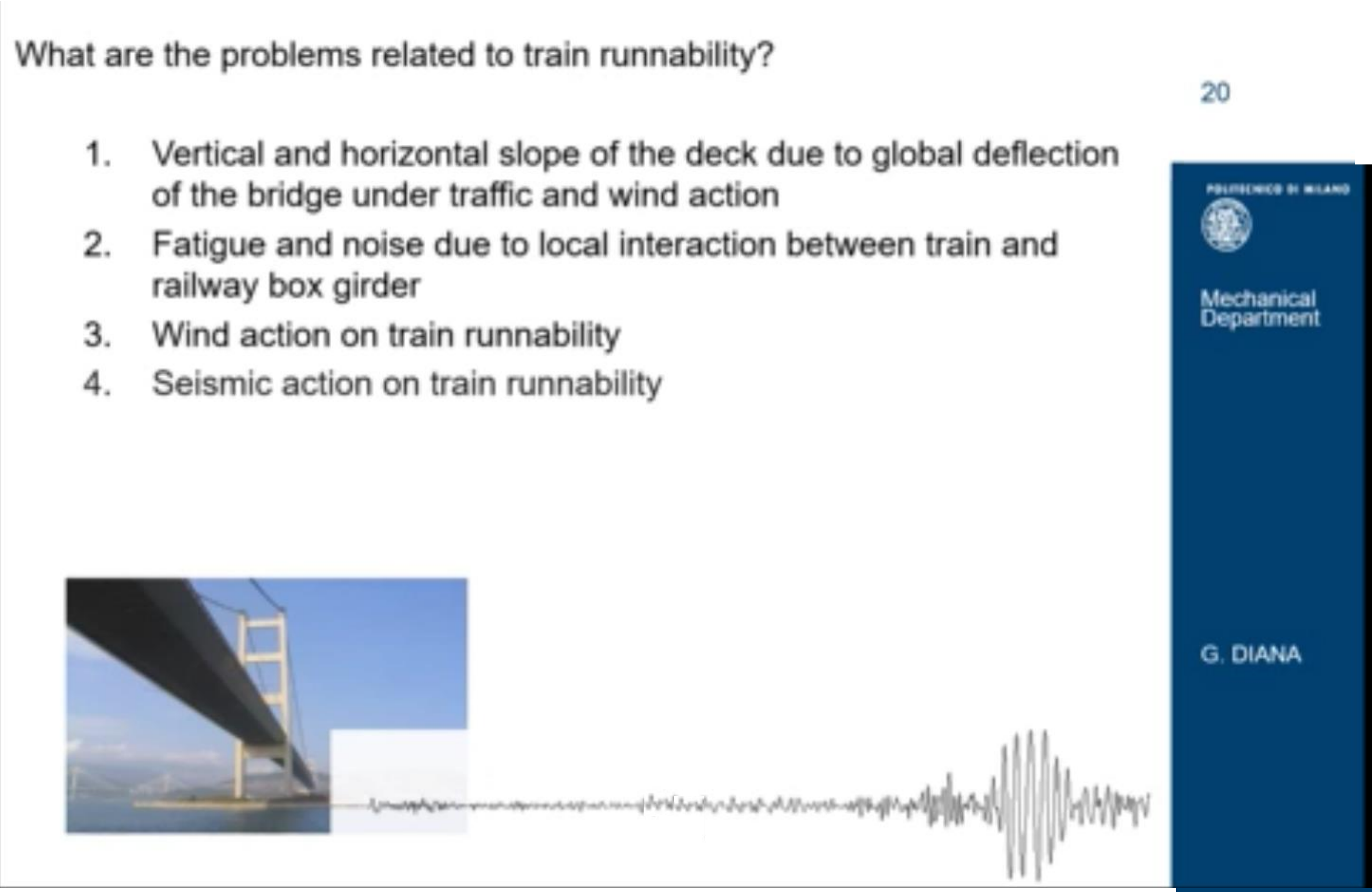
Railway runnability

What are the problems related to train runnability?

1. Vertical and horizontal slope of the deck due to global deflection of the bridge under traffic and wind action
2. Fatigue and noise due to local interaction between train and railway box girder
3. Wind action on train runnability



Railway runnability



What are the problems related to train runnability?

1. Vertical and horizontal slope of the deck due to global deflection of the bridge under traffic and wind action
2. Fatigue and noise due to local interaction between train and railway box girder
3. Wind action on train runnability
4. Seismic action on train runnability

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Railway runnability

In order to analyse these problems a suitable model was developed to take into account train and bridge interaction.

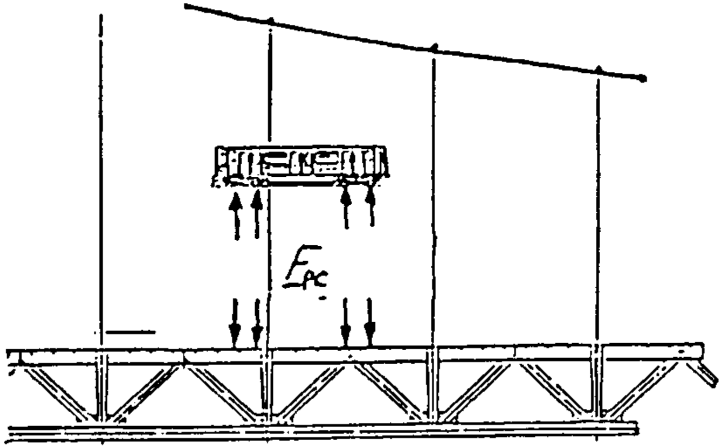
This model was checked by a research cooperation between Società Stretto di Messina and Honshu-Shikoku Bridge Authority on the Seto-Ohashi Bridge

Honshu-Shikoku Bridge
Expressway Company Limited

Stretto
di Messina

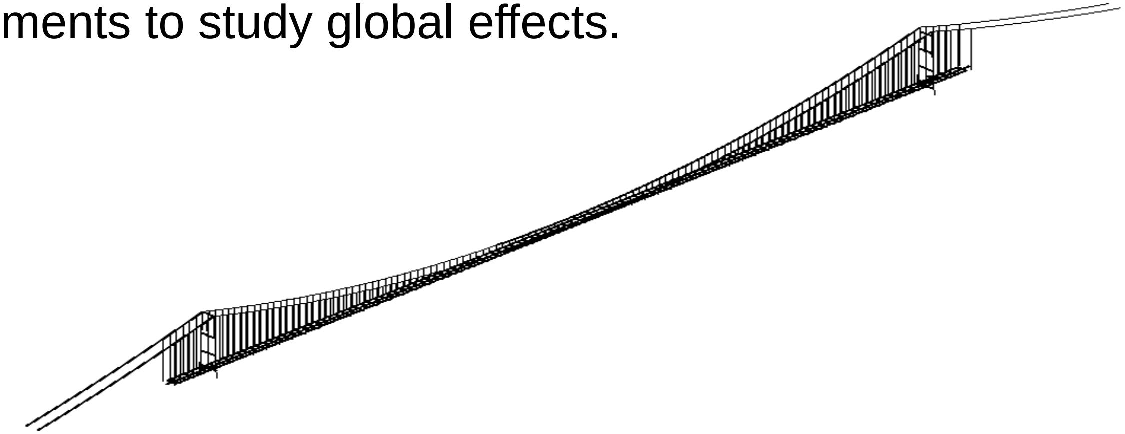
Seto-Ohashi Bridge

1100 m main span

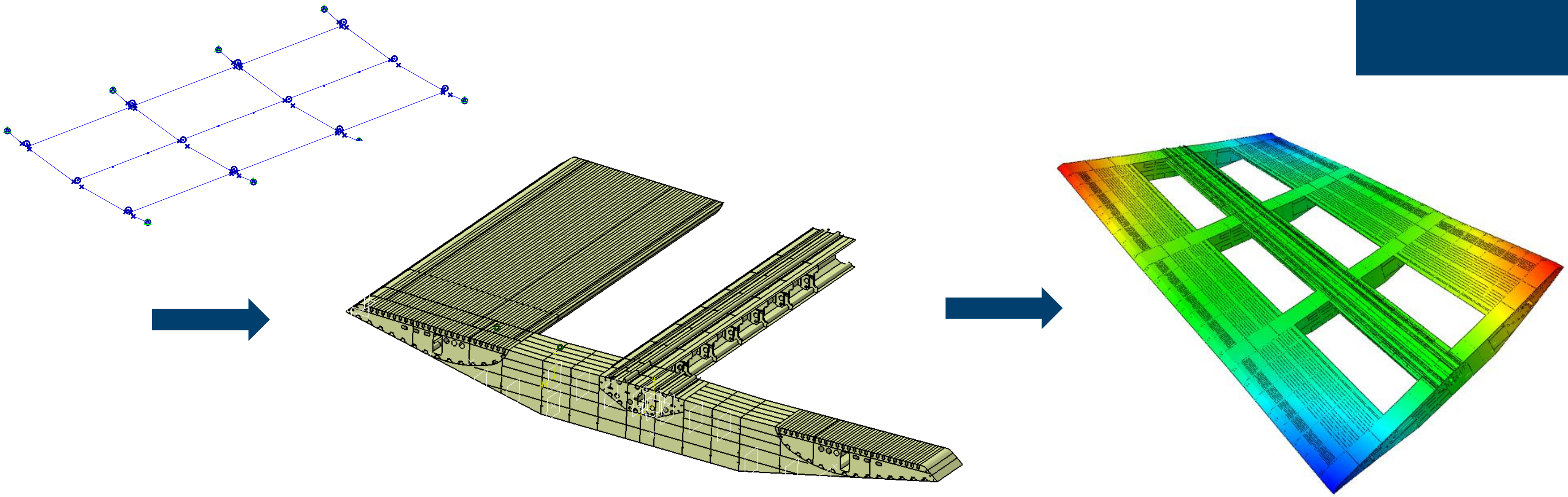


Bridge model

The model uses a Finite Element Model scheme of the bridge made by beam elements to study global effects.

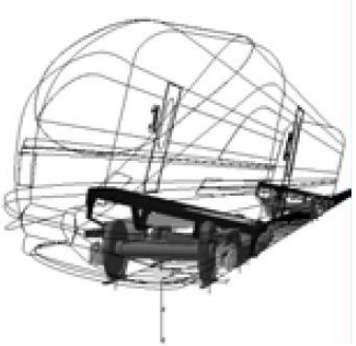


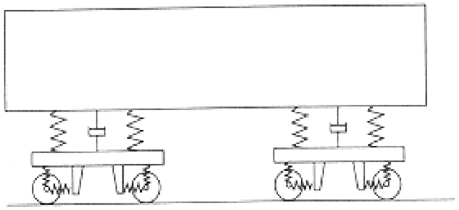
And a more refined scheme to take into account the local effects:

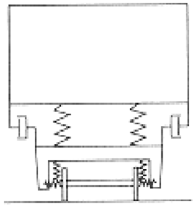


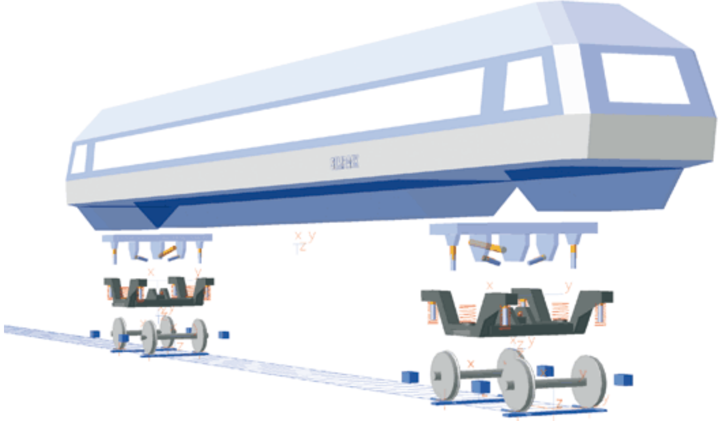
Railway vehicle model

The train dynamics is simulated by a multibody model .

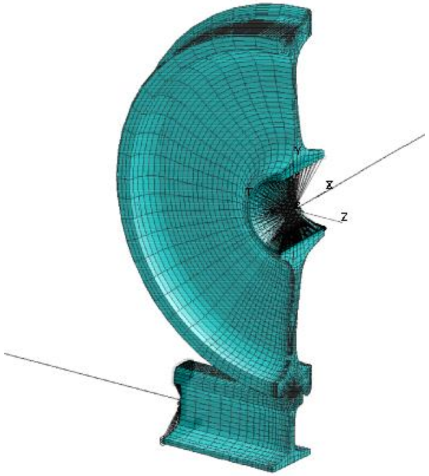


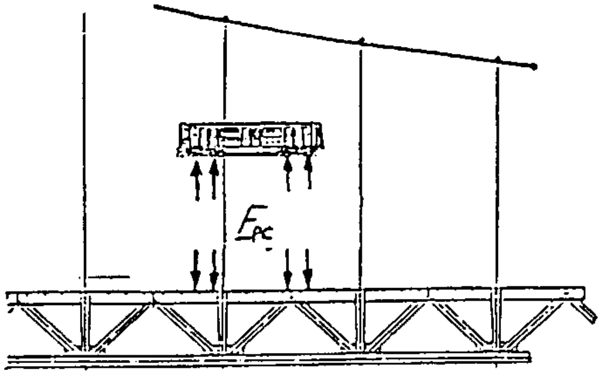


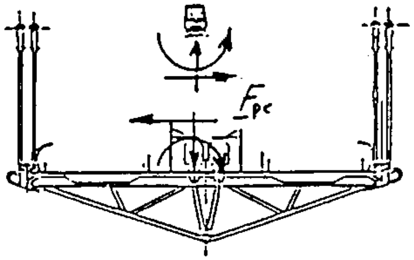




It is very important to reproduce wheel-rail interaction.

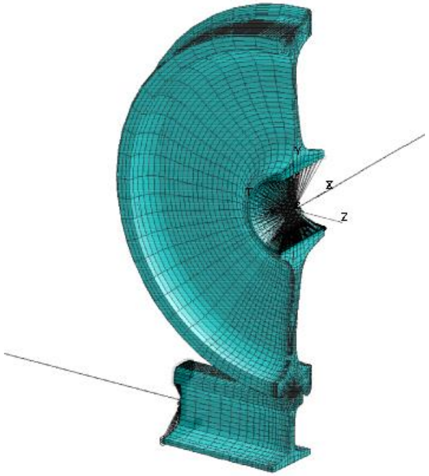


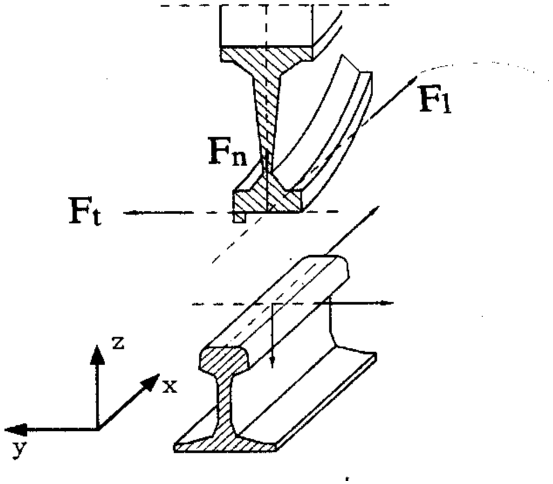


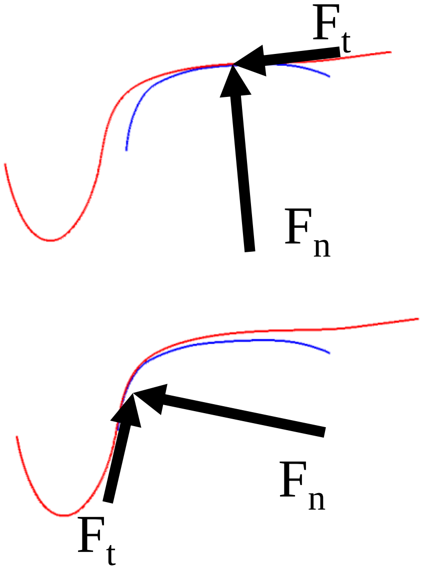


Railway vehicle model

Contact forces are <u>function</u> of the <u>bridge motion</u> and of the <u>train motion</u> and represent the most difficoult and important part of the whole model.







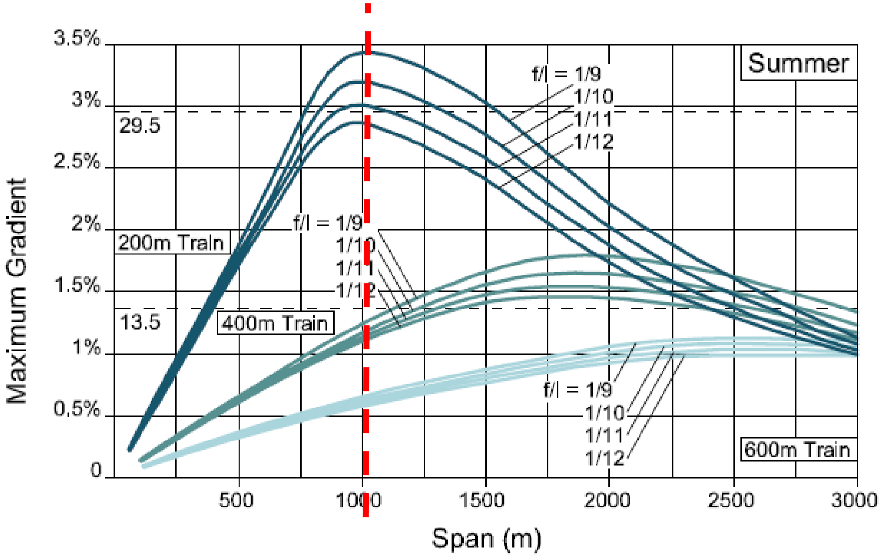
The problem is complex and I don’t want to go into detail that are reported in the paper

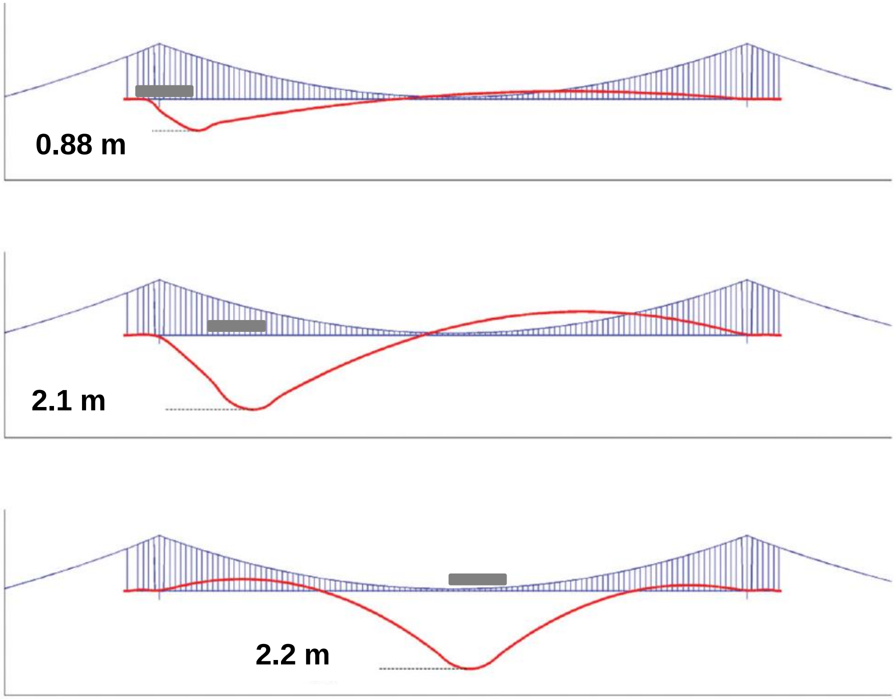
Global effects on the deck

SLOPE IN THE VERTICAL PLANE

Critical for span length of 1000 m not for long span suspension bridges

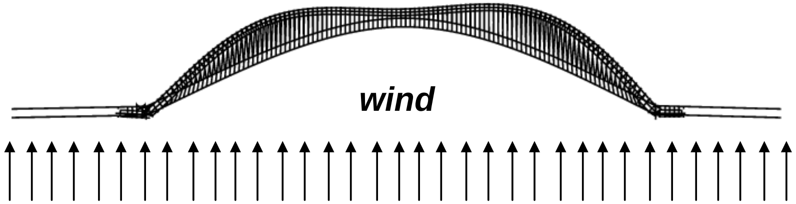
- maximum slope in the vertical plane as a function of span length





Global effects on the deck

LOCAL CUSPS OF THE DECK



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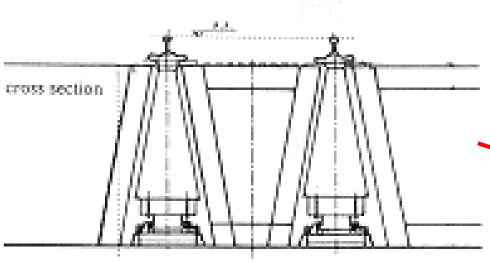
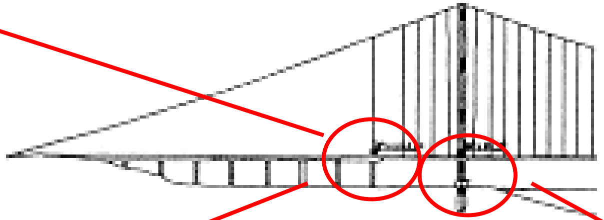
- Wind action produces horizontal deflection of the deck
- minimum curvature radius of the rails, in the vertical and horizontal plane are controlled by the design;
- position of the joint is very important;

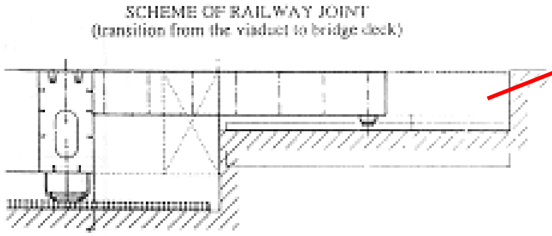


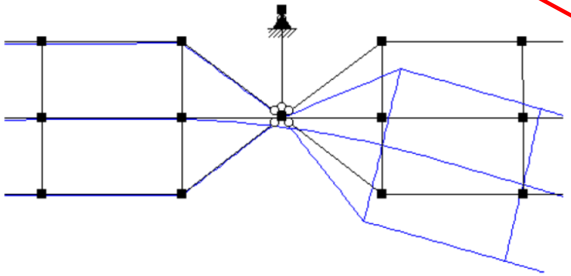
Transition girder

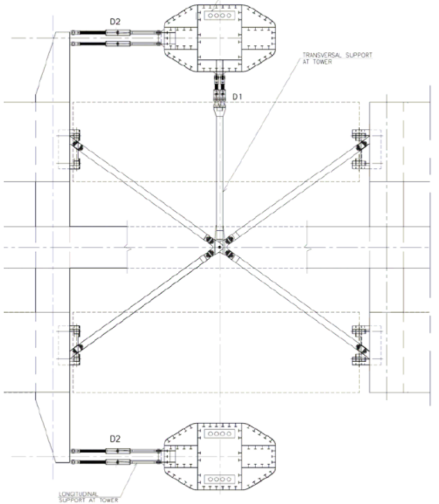


Railway joint

SCHEME OF RAILWAY JOINT
(transition from the viaduct to bridge deck)





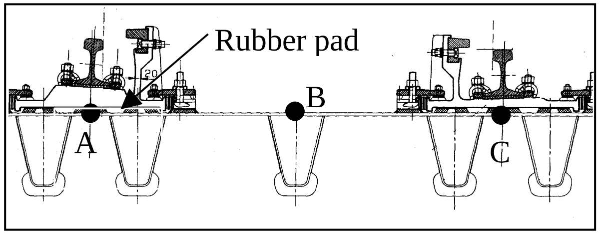


Local effects

INFRASTRUCTURE

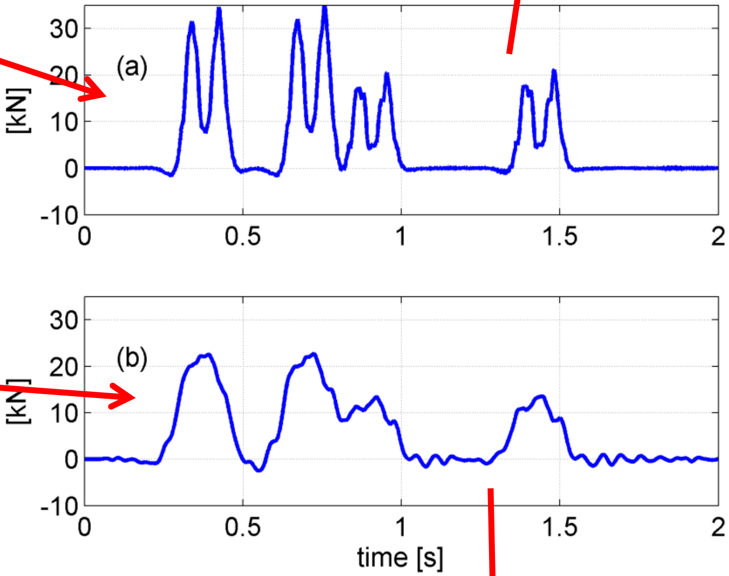
Produce high noise and fatigue problems on the upper plate of the railway box

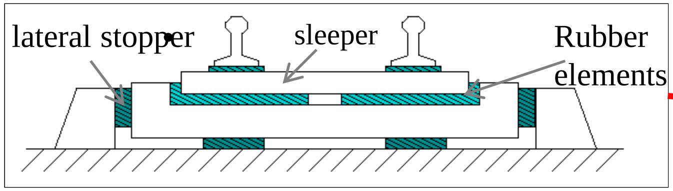
The type of infrastructure is very important



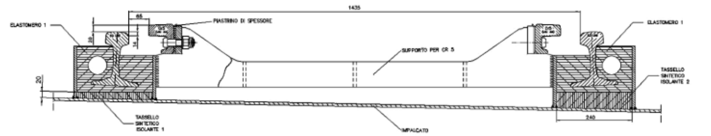
Direct fastening track solution

Transmitted force





Slab track solution II



Embedded rail

It is a very good solution but it increases too much the deck weight

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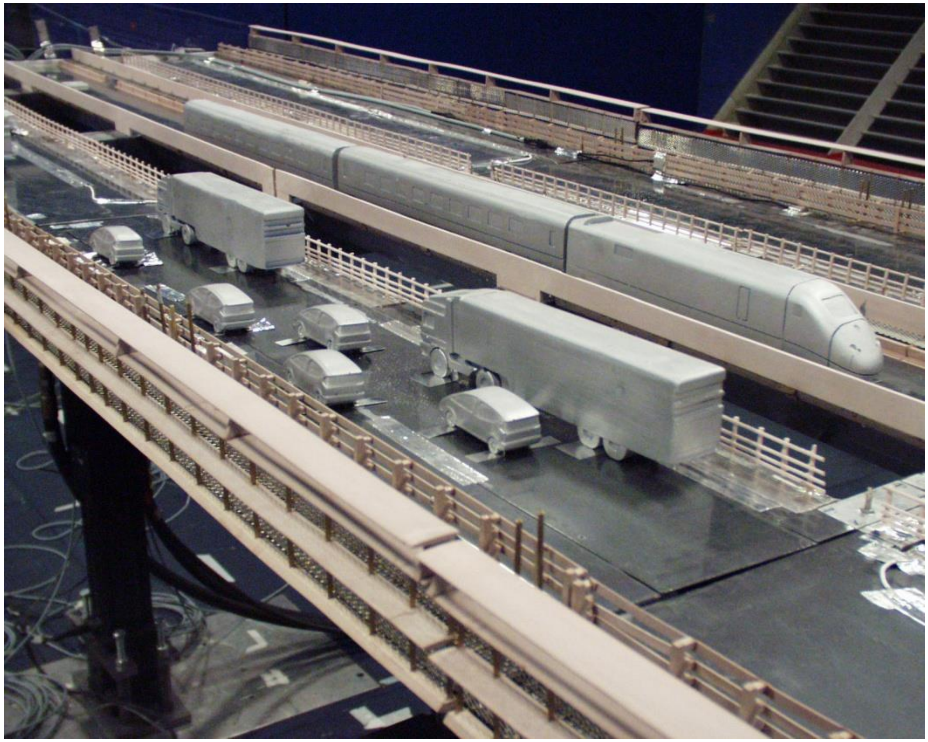
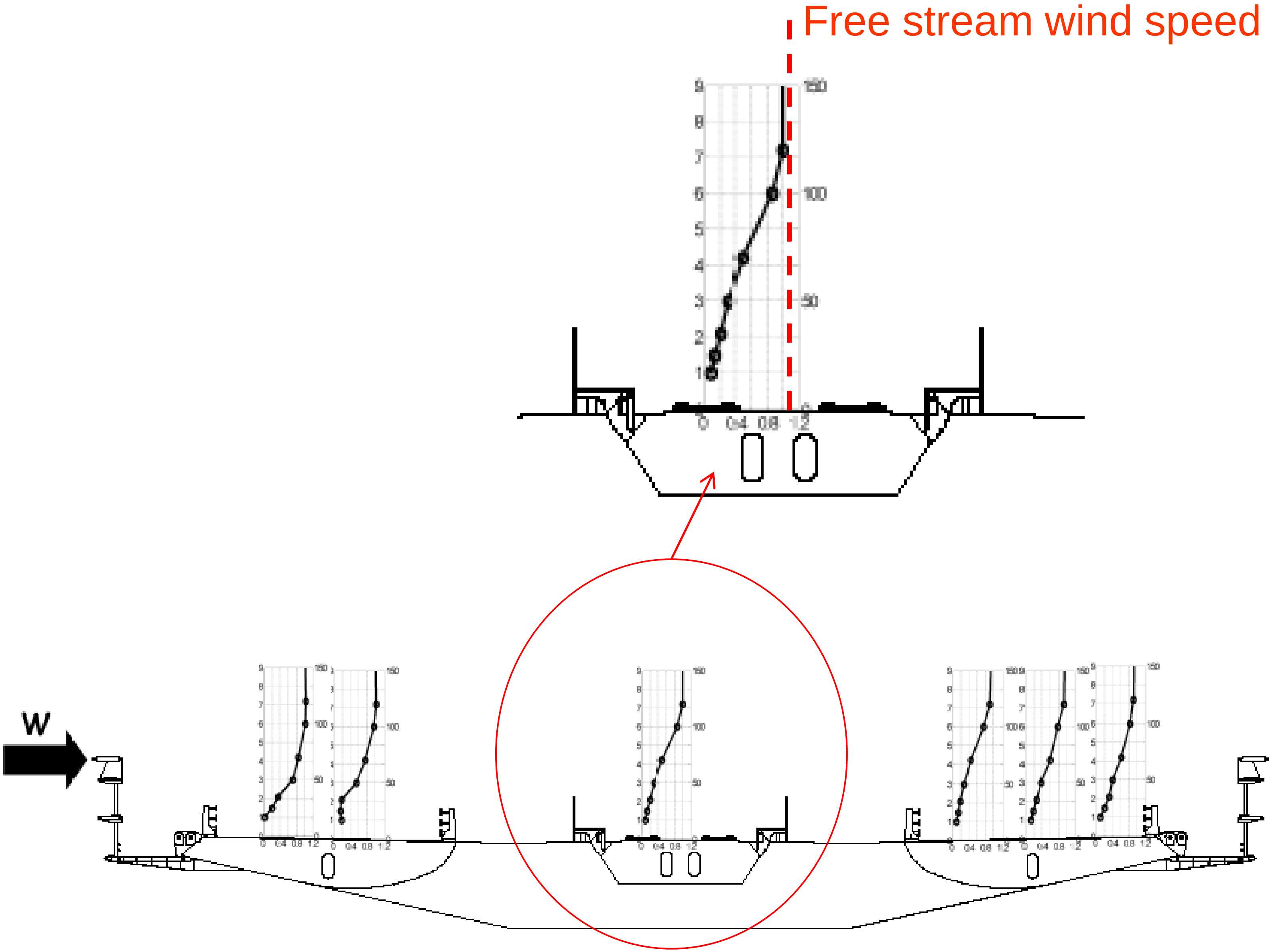
Wind action on the bridge and on the train

In order to reduce the wind forces on the train there are wind barriers at the deck edges



But also solid barriers on the railway girder reducing the wind speed in large amount

Wind profiles on the running lanes


Free stream wind speed

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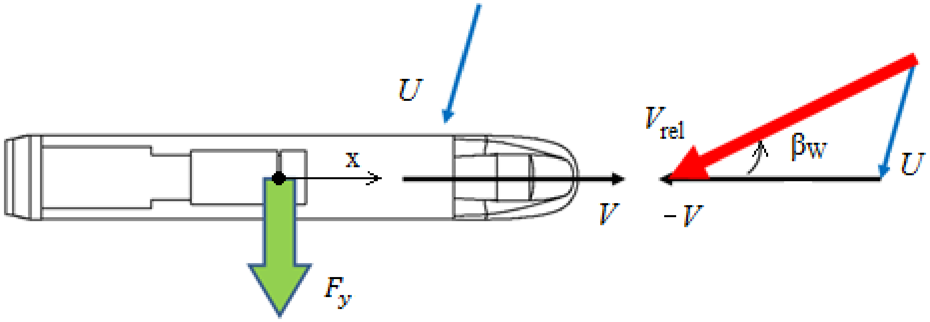
Wind action

The incoming wind is turbulent and produces fluctuations of the forces on the train function of the aerodynamic coefficients of the train and of the train velocity

$$F = \frac{1}{2}\rho A C_F(\beta_w) V_{rel}^2$$



Wind action

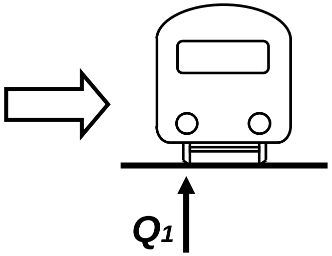
Wind produces a lateral load on the train that increases the lateral forces between wheel and rail and can also produce overturning that represents the critical situation

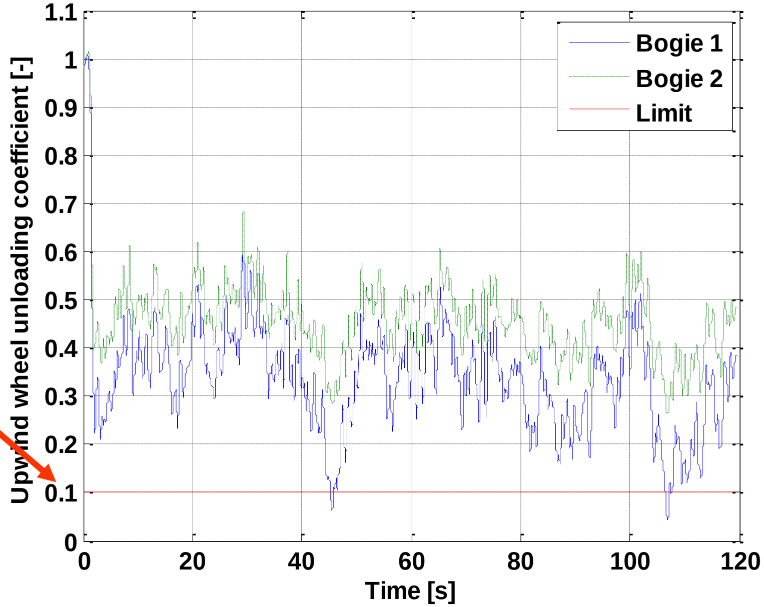
The motion of the bridge makes the problem more critical

In figure, the overturning coefficient for a wind speed of 47 m/s and train speed of 130 km/h for an ETR500 vehicle is reported

Wheel unloading coefficient

$$\frac{Q_1}{Q_{10}} < 0.1$$

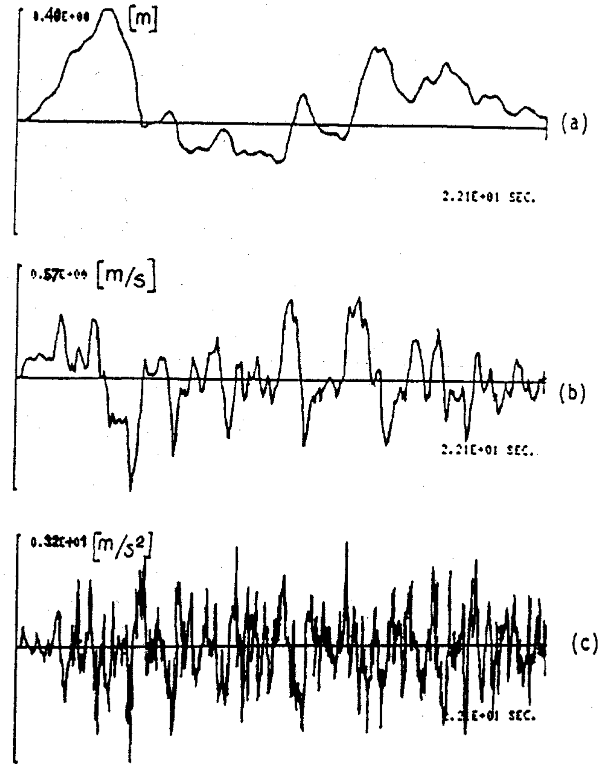


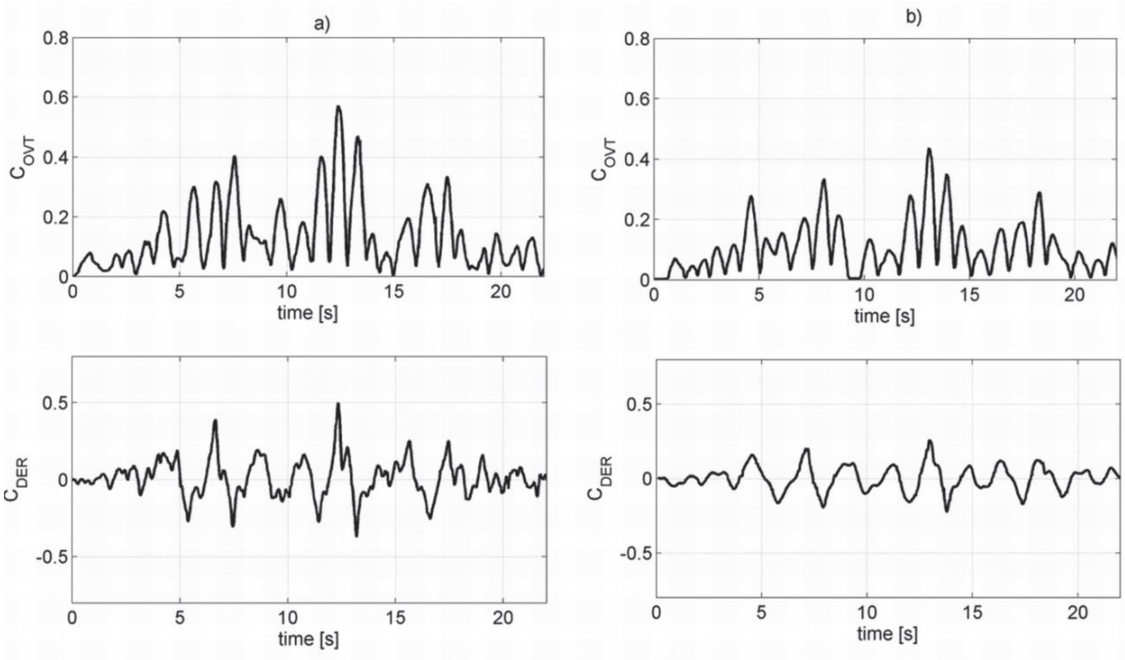


Q_{10} static force due to only weight

Seismic action

The time history of the ground motion is reproduced at the cable fundations and at the tower base and the response of the bridge is computed with the train running on the bridge under cross wind conditions





Time histories of the simulated earthquake

Overturning and derailment on ground and on the bridge

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Convegno 17 giugno 2015
«Spazio Europa» Via IV Novembre 149 – Roma
LA MACROREGIONE DEL MEZZOGIORNO
Sicilia-Calabria, binomio inscindibile nel TEN-T 5
per una nuova centralità dell’Italia
e dell’Europa nel Mediterraneo

Il progetto innovativo del ponte più lungo del mondo

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