August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering
ICWE 16

Wind in bridge design: experiences and learnings

Mario de Miranda

Studio De Miranda Associati, Milano, Italia, DMA@demiranda.it

SUMMARY:
This paper deals with some of the direct experiences of the author in the aerodynamics of bridges assisted by wind tunnel tests during the last twenty-five years.

Real bridges that provided feedback from their behaviour under wind effects.

The case studies refer to girder bridges and cable-stayed bridges, were carried out in different wind tunnel laboratories and outline some lessons learned from these experiences, which are hoped to be useful for bridge designers.

1. ON-SITE LEARNING ABOUT REYNOLDS NUMBER EFFECTS

Our firm, DMA, was responsible for the construction engineering of the superstructures of viaducts and suspension bridge.

The suspension bridge did not give any problems during erection, only some vibrations from vortex shedding at the start of service that were later reduced by installing flaps close to the lower corners.

The viaducts were built using 193-meter-long steel spans, weighing 2,400 tonnes, and simply supported during the first stages of their erection. They were made continuous by front end lowering after rear joint welding in a second stage.

Immediately after installation, the first spans of the approach viaducts vibrated violently in the simply supported condition in a 16-20 m/sec wind. This was in May 1995, and the erection work was stopped.

This was caused by vortex shedding.

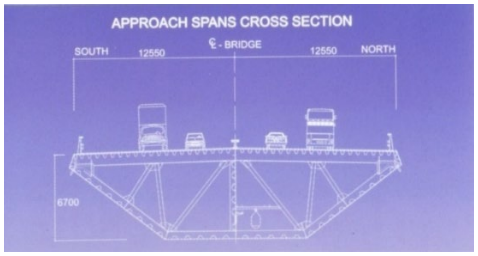
For the girder erection, a suitable weather window was chosen on the basis of the wind tunnel test results in order to avoid the wind speed defined as critical at the time.

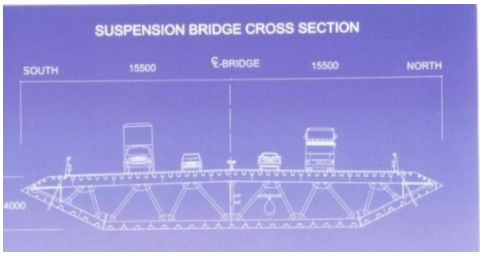
The wind tunnel investigation carried out on a 1:80 sectional model in Denmark predicted small vibrations at a critical wind speed of 23 m/sec that, unfortunately, was 28% higher than the actual wind speed of 18 m/sec that had induced the large vibrations.

The main reason for this discrepancy, as later analysed, was the Reynolds Number effect, with $R_e = 10^5$ in the model and $R_e = 10^7$ in reality, as witnessed with great evidence during this event.

The R_e effect, that was well known for circular cylinders, was often assumed to be negligible for edge shaped sections.

Our solution for this problem and for allowing the bridge construction to carry on was to increase the girder vibration frequency by installing, when the girder was simply supported, a set of temporary tie-down cables anchored at midspan of the deck by removable arms and to the sea bed by removable anchor dead bodies. The system worked well, and work resumed without further interruptions up to the completion of the bridge.





What we learned from this case was the large effect that the shift in Reynolds number can have in predicting the real bridge response even in sharp edged sections.

2. THE IMPORTANCE OF FAIR SHAPE

The second case is the Higuamo Bridge, in the Dominican Republic, for which wind tunnel investigations were carried out at the CRIACIV Laboratory in Florence.

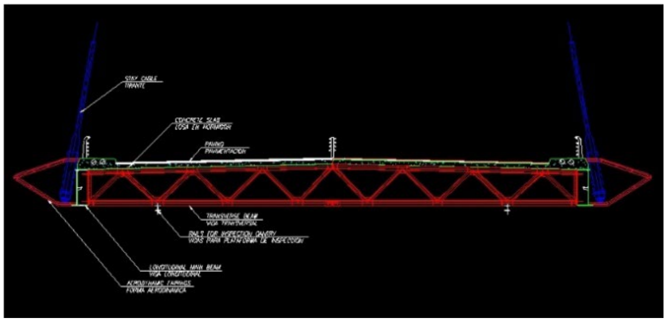
For this bridge, a high design speed of 67 m/sec (240 km/h), combined with a long span deck (390m) of relatively low weight and an open section, called for a wind tunnel study aimed at ensuring a very high critical speed for flutter.

The solution for this problem was to investigate a set of lateral fairings able to increase the critical speed of the structural section and optimize them.

It was found that suitable fairings could increase the critical speed by a very great amount.

The fairings were defined, fabricated, and installed, and the bridge, even after having encountered some strong hurricanes, behaves well according to the forecast.

In this case, we learned about the ability of well-designed fairings to improve the aerodynamic performance of open deck cross sections to the same levels as streamlined box sections.



3. THE IMPORTANCE OF DETAILS

The third case is the Guamà Cable Stayed Bridge, in Brazil, for which wind tunnel investigations were carried out at the Porto Alegre Laboratory, Brazil.

For this bridge, the long span of 320m jointed with a relatively small width of 14.60m predicted the need for an aerodynamic study in order to obtain a sufficiently higher flutter speed, also considering the deck cross-section construction with two longitudinal side beams, which is the most advantageous layout for a cable-stayed bridge.

Consequently, the cross section was optimized for aerodynamic performance and was designed with rounded corners and slanted sides in order to reduce the vortex size, and it actually exhibited very good behaviour both against vortex shedding and against flutter.

The lesson learned from this case is the effectiveness of small details, such as rounding the corners, inclining the sides, and holing the New Jersey barrier, and the large improvement in aerodynamic performance that these details can bring.

4. DIFFERENT AIMS OF WIND TUNNEL CAMPAIGNS

The fourth case is the Storstrom Bridge in Denmark, where wind tunnel investigations were carried out at the Politecnico di Milano Laboratory in 2018.

This bridge has a concrete construction, a box girder of asymmetrical shape, and side overhangs.

Despite the high weight of the deck and the relatively short spans involved, a wind tunnel test campaign was carried out for many purposes.

First, we investigated the flutter speed, but it was clear that the high torsional stiffness and mass with a relatively small span of 160m would not have presented any problems.

The most important matter was to investigate the vortex shedding response, being a road-railway bridge and considering the high deck cross section. Accelerations had to be limited both to avoid discomfort to passengers and to reduce the risk of train derailment.

Another important effect duly investigated was the wind flow deflection around the deck cross section and, in particular, the actual wind velocity profile along height on the profile of the train, that is, the real wind profile and speed loading railway vehicles, which is different from the free-flow wind profile because of the girder obstacle.

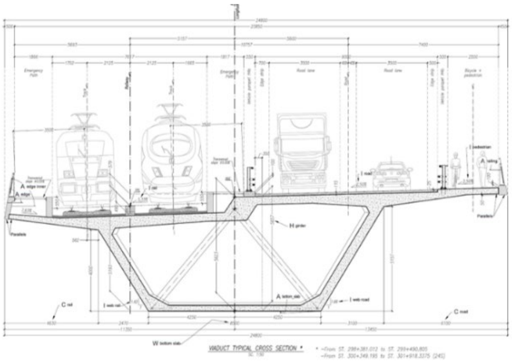
It was discovered that the average speed was reduced by 15% when compared to the undisturbed wind flow.

The lesson learned from this case is that many different topics and effects, going beyond the classical aerodynamic stability, can be investigated by wind tunnel testing.

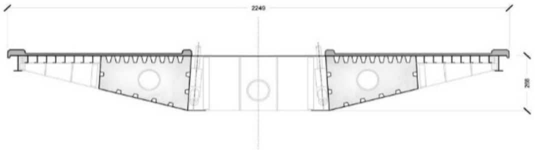
5. FIRST DESIGN AND EXPERIENCE OF DOUBLE DECK BRIDGES

The last case refers to a bridge designed by Fabrizio de Miranda in 1977, the Indiano Bridge over the Arno river here in Florence.

This bridge has two interesting and innovative features. It is the first earth-anchored cable-stayed bridge in the world and is also the first double-deck cable-suspended bridge.



The need for good aerodynamic performance was derived from the fact that stay cables were placed at the center of the girder, so the torsional stiffness was only provided by the slender deck. High flutter speed and, in general, good aerodynamic performance were witnessed at the National Physics Laboratory in the UK in 1977, confirming the good aerodynamic design and the effectiveness of the double deck concept.



6. CONCLUSIONS

In conclusion, the case studies presented here demonstrate that shape and detail optimization can significantly improve the aerodynamic performance of open deck cross sections, and that wind tunnels can be a very useful tool for aerodynamic bridge design in many areas and aspects. Additionally, it demonstrates how scale effects, particularly the Reynolds effect, can affect the validity of results. Consequently, test results should be interpreted carefully and with adequate safety margins that account for these effects as well as any additional potential unavoidable uncertainties.

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