

Geometry Modification For Minimizing The Aeroelastics Effect

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ABSTRACT: Resonance induced vibration (RIV) is one of aeroelastics phenomenon. It can be excited by vortex, pressure difference/separation, man and machines or cars. The following paper will report several wind engineering and industrial aerodynamics research activities to reduce the effect of aeroelastics phenomena to the structure, particularly the RIV and drag force. A comprehensive study on the geometry of structure has been done using both experimental and Computational Fluid Dynamics (CFD) analysis. It is come up that the geometry modification should not work only on streamlining the shape but also on controlling the flow just before arriving the structure.

KEYWORDS: wind tunnel test, computational fluid dynamics, long-span bridge, wind induced vibration, aerodynamic force, static pressure distribution

1 INTRODUCTION

A flexible structure in an airflow will deal with aeroelastics problems: flutter, resonance induced vibration or others phenomena. Resonance Induced Vibration (RIV) is the most interesting phenomenon to many bridge designers because it is not always a fatal or destructive oscillation but it can initiate a structural fatigue if occasionally happens. Unfortunately many RIV occurs in low wind speed, a daily wind environment. The resonance can be excited by wind, seismic, users or vehicles.

Wind induced vibration come out in two phenomena:

- Vortex Induced Vibration (VIV), a resonance that is excited by vortex sheeding in the wake of a structure (primary vortex)
- Low-wind Speed Heaving Resonance (LSHR), a resonance that is excited by the fluctuation of pressure difference between upper and lower surface of the bridge deck, where flow separataion or secondary vortex on the surface of a bridge deck occurs.

Vortex is a typical rotational flow (eddy flow) in the wake of an obstacle, so called as primary vortex. The flow fluctuates in such a pattern which is known as Von Karman Vortex trails. If the frequency of vortex fluctuation coincides with one of the structure natural frequency (f_N), a resonance phenomenon occurs. The phenomenon is called Vortex Induced Vibration (VIV).

A mathematical relation between vortex shedding fluctuation frequency (f_{vortex}) , structure reference length (l_{ref}) and wind speed (U) is known as Strouhal formula. The formula produces a constant number for a specific structure, which is called *Strouhal Number (St)*. The f_{vortex} is also sometime called as Strouhal frequency (f_s) [Simiu,1996].

The St number is a non-dimensional number and acts as one of the similarity parameter. It is often used to transform the wind tunnel speed of bridge model to the actual wind speed of prototype bridge. For flexible bridges, the value is in the range of 0.12 to 0.18. By measuring the frequency response of the model structure, the wind tunnel test could produce a relation between f_s and U . In addition, the maximum oscillation during a resonance also can be used to represent the maximum displacement (D_{max}) of the structure

Another interesting phenomenon to note during a VIV is lock-in. The vortex will not induce the model in a single wind speed, it will induce the model in a range of wind speeds. Lock-in is the phenomenon of VIV where the resonance may occurs longer in a range of wind speeds.

Two activities has been carried out to reduce the effect of RIV: a dynamics sectional model test of a long span bridge and an CFD analysis on modifying a high rise corner.

2 FAIRING FOR EXISTING BRIDGE

The purpose of the study is to modify or adding components (aerodynamics appendages) on the existing bridge structure on the possibility of appearing VIV. Certainly, the bridge owner was looking for to the most economic solution. Then, the existing configuration of the bridge structure was set as reference to the construction of the sectional model. It is called the basic model (M1).

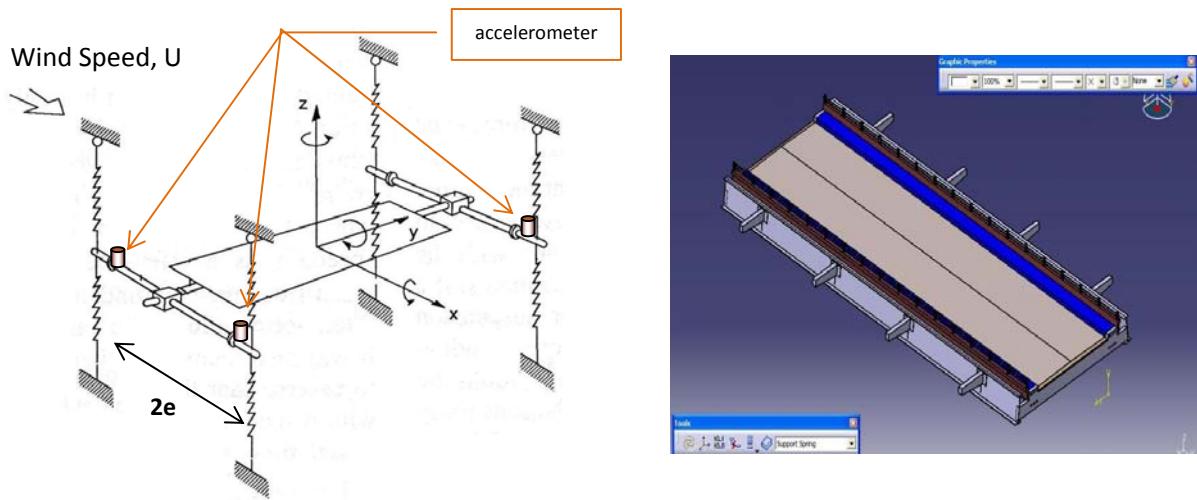


Figure 1. Dynamical system of the model and schematic view of the model structure

The model was tested in ILST (Indonesian Low Speed Tunnel) which has 4m x 3m test section area. To mount the sectional model, dummy wall system was installed to hold the model as well as providing 2 dimensional flow surrounding it. Below the model, a ground board was installed to represent the earth level, see Figure 2. There are 8 springs with the same spring-constant to suspend the model, allowing the model to oscillate in 2 degree of freedom, heaving and torsion motion.

The experiment was set to have 1 : 25 model scale, which gives the dimension of model as 450 mm width, 72 mm height (thick) and 1200mm span. For the Strouhal frequency calculation, the reference length is effective deck height that is 106mm instead. The actual deck distance from the water level is 10m, hence the model distance from the ground board is 400 mm.



Figure 2. Installation of the Sectional Model in ILST Test Section

The model was mounted on 8 springs which were mounted on 2 dummy walls frame. Under the model there is a ground board which acted as ground or water surface. On the center of ground there is an actuator, to generate disturbance to the model when flutter margin measurement was running. Above the model there is a pitot-tube probe to measure the local wind velocity. The model was instrumented by 3 accelerometers which are connected to the dynamic measurement system, outside the test section.

There are 4 configurations were evaluated on this study, that are M1, M2, M3 and M4 configuration.

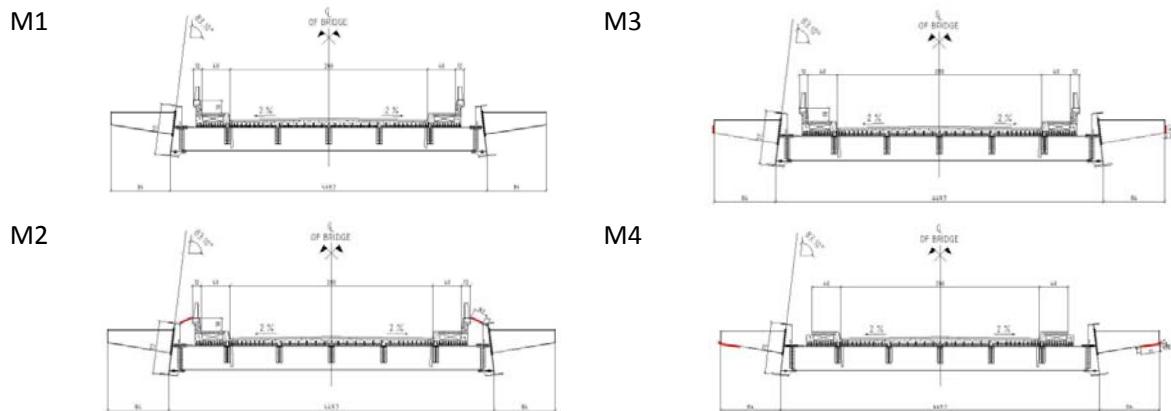


Figure 3. Dek Models: M1-Basic Model, M2-Gap Upper-cover, M3-Edge Vertical Bar

By means of modal measurement technique, the natural frequency of the model can be identified. There 3 main modes was excited, vertical bending (heaving) motion, torsion motion and rolling motion. However for the purpose of this study, only two degree of freedom or two natural frequencies were considered: heaving and torsion motion. The natural frequencies of sectional model basic configuration (deck-0) are,

- *Heaving mode is 8.58 Hz*
- *Torsion mode is 18.72 Hz*

Therefore by matching to these frequencies, several VIV and lock-in phenomena were identified of various wind speed. See Figure 4

Table 1. Wind Speed and Resonance Magnitude of VIV

Model	VIV heaving			VIV torsion			Torsion Flutter		
	U_{wt} (m/s)	U_{ac} (m/s)	Peak Max (Volt)	U_{wt} (m/s)	U_{ac} (m/s)	Peak Max (Volt)	Q (Pa)	U_{wt} (m/s)	U_{ac} (m/s)
M1	6-8	10.8-14.4	1.345	9-10	16.2-18	0.794	369	25	45
M2	4-10	7.2-18	1.926	6-12	10.8-21.6	3.429	369	25	45
M3	6-8	10.8-14.4	0.959	-	-	-	369	25	45
M4	-	-	-	8	14.4	0.286	369	25	45

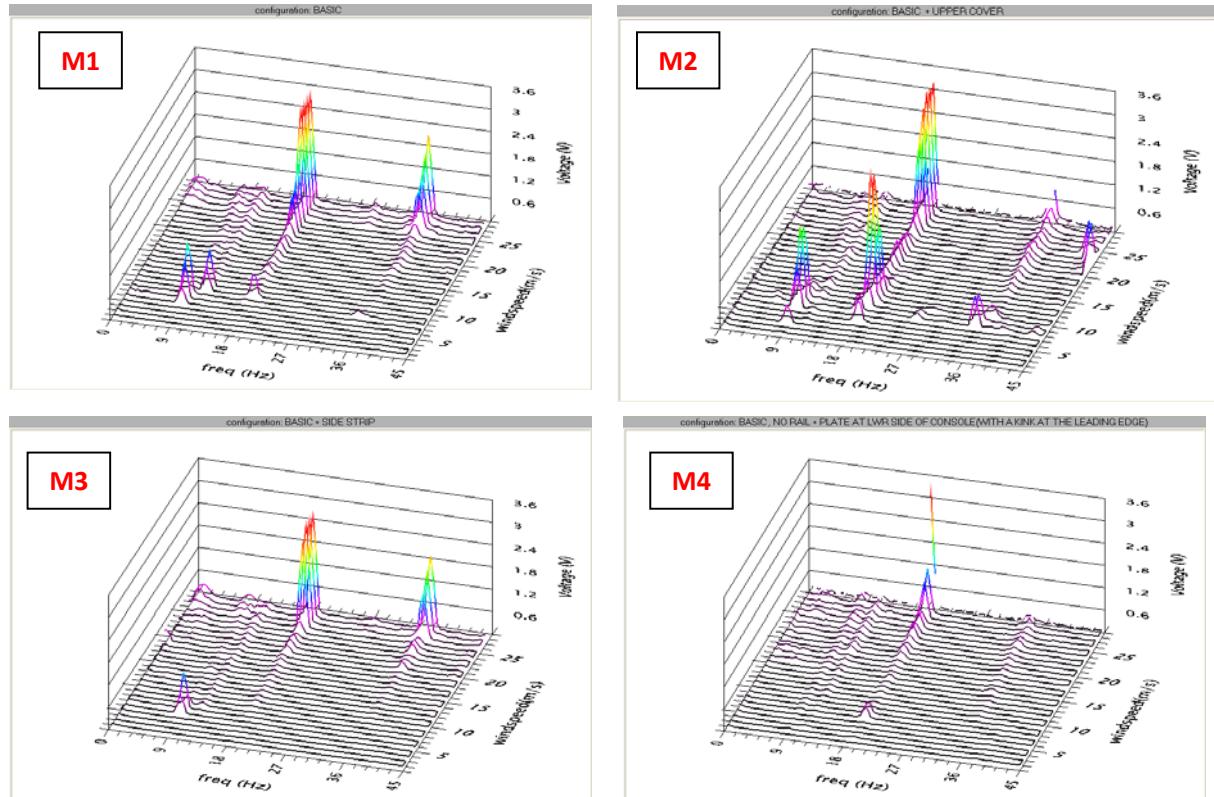


Figure 4. Measurement Results

Figure 4 shows the measurement results. It can be observed that model M4 can significantly reduce the resonance magnitude on both heaving (8.58 Hz) and torsion (18.72 Hz). Even the magnitude of heaving resonance was disappear compared to the basic configuration (M1), but there is still a small resonance on torsion.

From the obtained Strouhal number, then the actual bridge wind speed (U_{ac}) can be calculated as function of wind tunnel wind speed (U_{wt}), that is $U_{ac} = 1.8 U_{wt}$.

3 FAIRING FOR A PROTOTYPE BRIDGE

The next activity on long span bridge aerodynamics was the CFD optimization for wind fairing shape on a new prototype bridge. In contrast to the wind tunnel study which often consume time, effort and costs. The CFD study is quite effective way to see the big picture of flow pattern around a structure and to obtain predictions of the value of the style and aerodynamic moment acting on the structure. In this way the iteration process of design can be run more economics.

Six variations of the cross section of the bridge deck latitude were examined in numerical simulation approach, to obtain favourable geometry of aerodynamic perspective. This variation consists of: one basic deck without wind-fairing, and five deck using wind-fairing with the layout of the nose-fairing (point of catch the wind) are different. The dimension of fairing nose was denote by parameter h/D , where h is the distance between the point of catch wind (nose tip) to upper surface of the deck, and D is the girder height. The basic model is called deck-0.

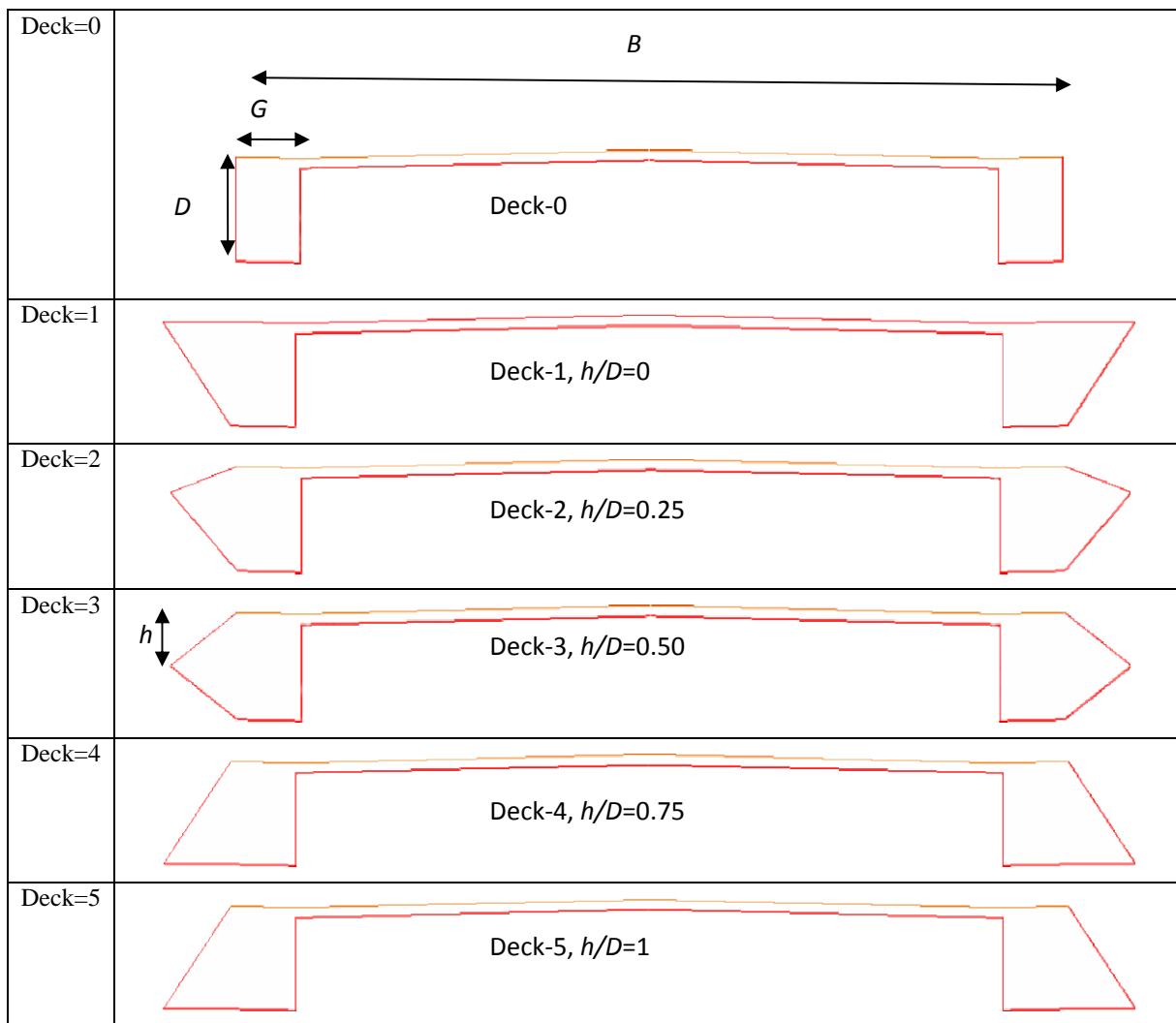


Figure 5. Six Wind Fairing Type

Numerical simulations performed using commercial software FLUENT, it is based on the finite volume methods (FVM). The computational Domain was defined with the assumption that the flow conditions on boundary domain was uninterrupted. The domain of computation took approximately 15 times the length of the stretch of bridge (B) to the upper and lower, whereas towards downstream taking a distance of 31 times the length of the stretch. Large computing domain is adopted from the results of the study parameters by Bruno and Khris (2003).

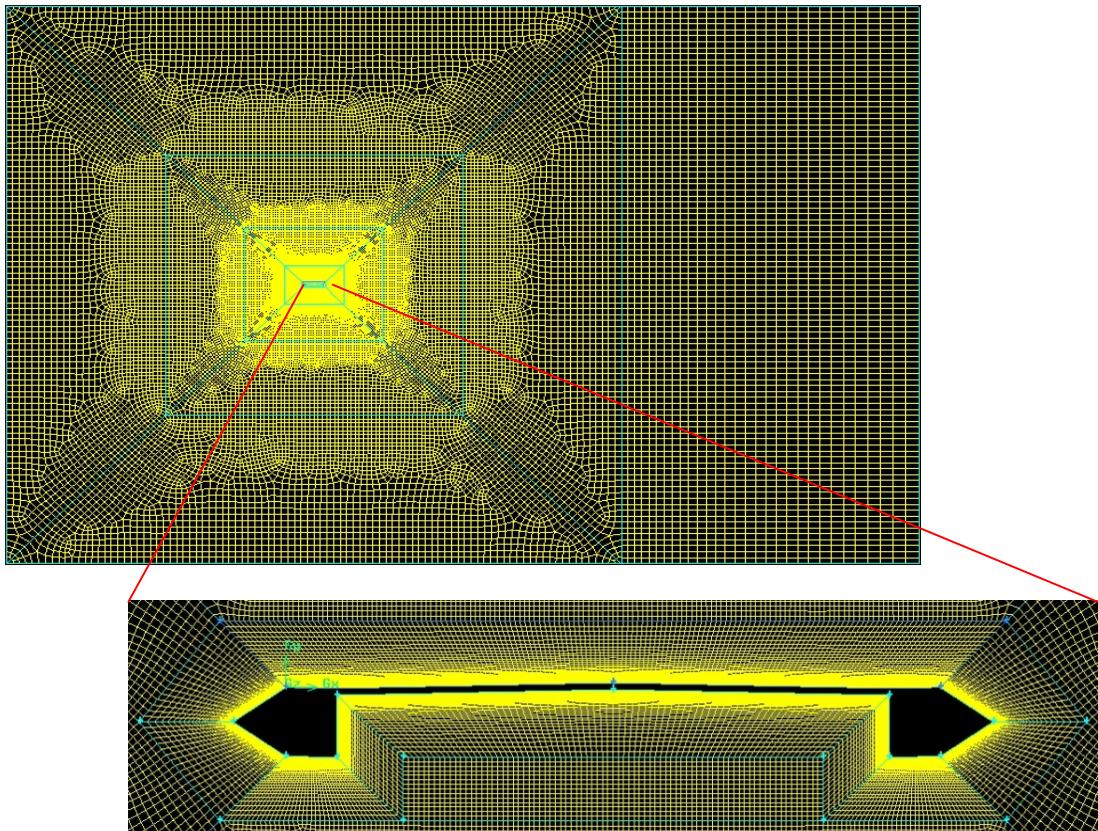
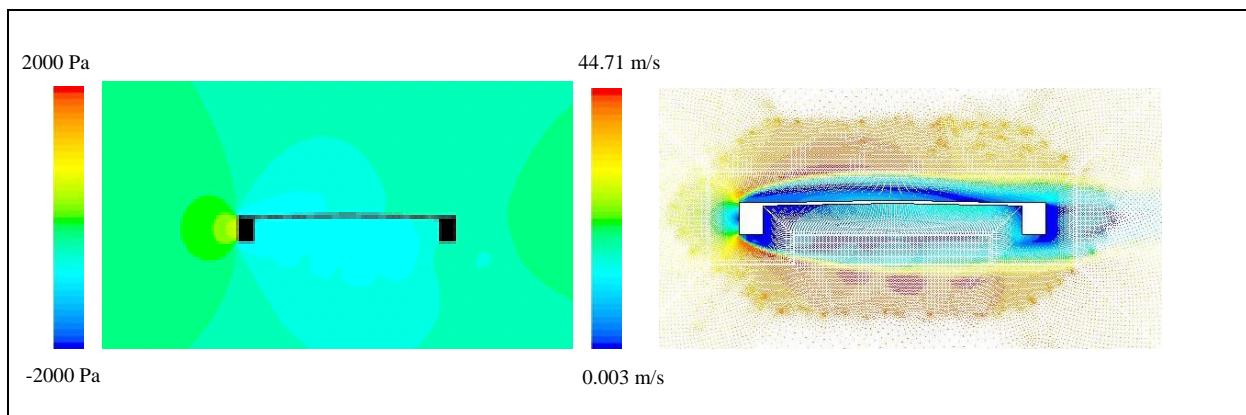
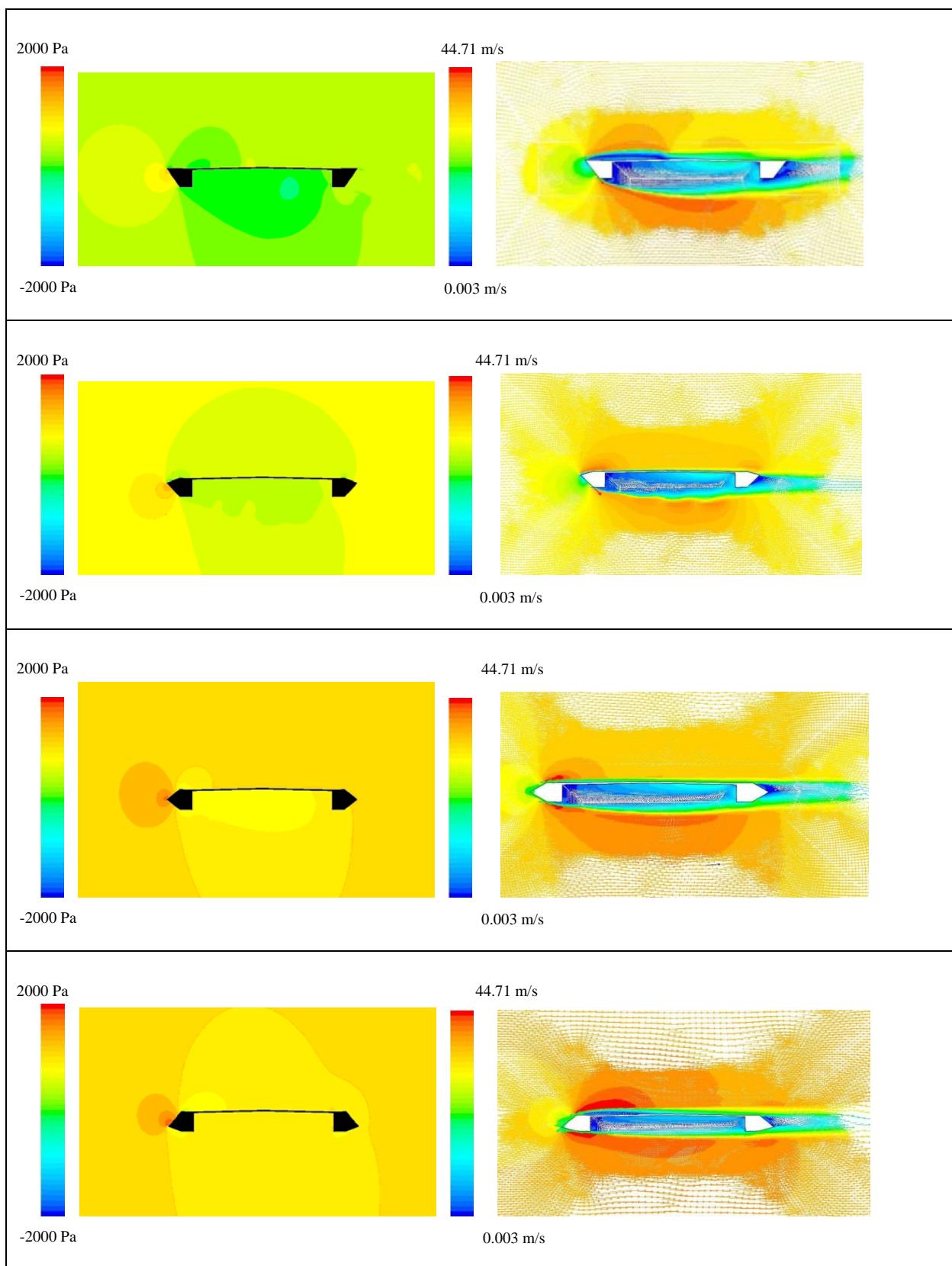


Figure 6. Computational Grid





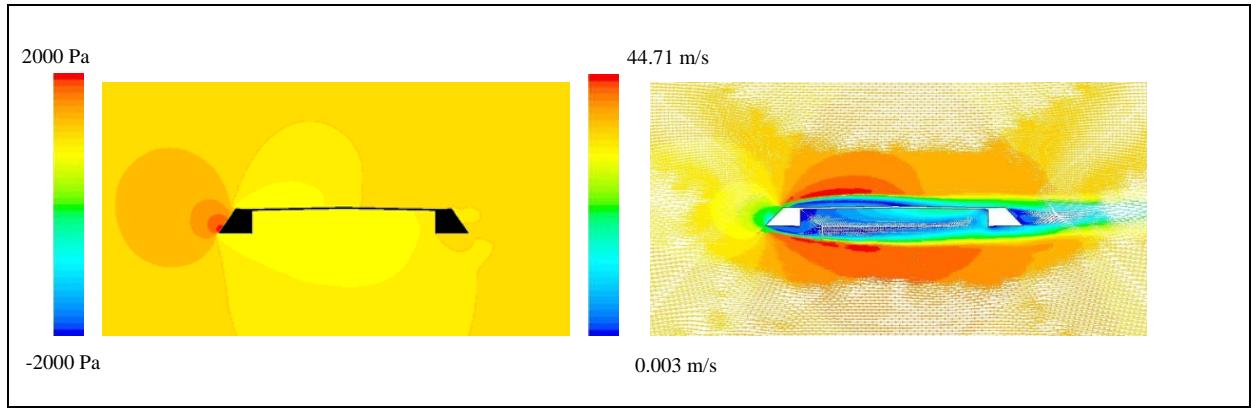


Figure 7. CFD results

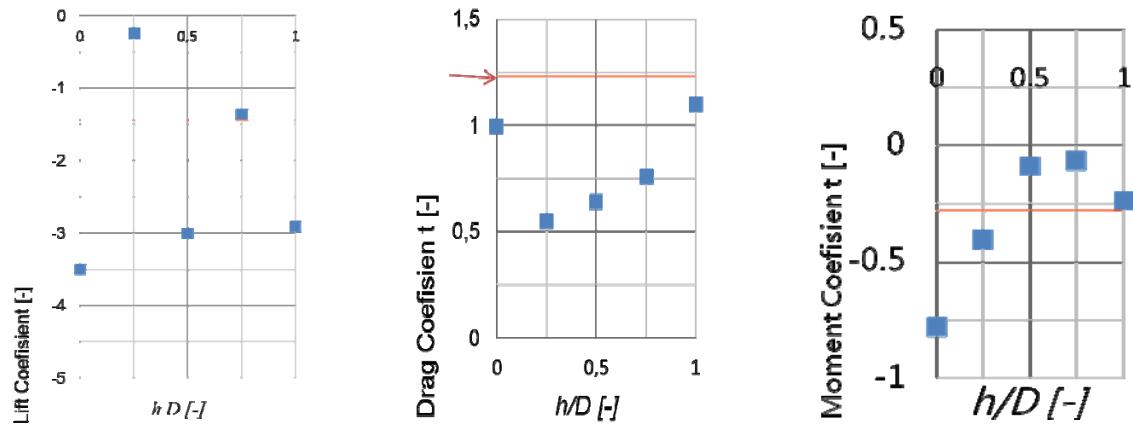


Figure 8. Aerodynamic Forces/Moments Results

The above results shows that:

The drag force can be listed from the smallest value to the highest: $h/D = 0.25, 0.5, 0.75, 0, 1$.

The lift force can be listed from the smallest value to the highest: $h/D = 0.25, 0.75, 0.1, 0.5, 0$.

The moments can be listed from the smallest value to the highest $h/D = 0.75, 1, 0.5, 0.25, 0$.

The optimization parameter can be set whether on CL, CD or CM values. However, based on the request of client as well as several scientific report [Ostenfeld, 1992], this research used the drag coefficient as optimization parameter. In other words, the study was looking for wind fairing shape and deck geometry which have the minimum drag. It is found that the deck-2 wind fairing where the point catch wind of $h/D = 0.25$ gave a good aerodynamic performance from the viewpoint of stability of the bridge.

This is also conform to the report of [Sukamta, 2008] which produced the same indication, where the fairing with nose-tip higher than $1/2D$ gave the lowest CD.

4 CONCLUSION

Two case studies with two solution methods have been explained to reduce the effect of wind induced vibration of a long span bridge.

On the existing bridge geometric modification, the basic configuration seem to have wind induced vibration at low wind speed, there are resonance on both heaving and torsion motion. It is also happen if the modification is only by covering the deck side-gap (M2). By mounting a horizontal vertical strip bar (M3), the magnitude of heaving resonance can be reduced, even the torsion resonance was disappear. By modifying the strip as shown in M4 configuration, that is by mounting a horizontal strip bar with small kink at the most outer edge, the results almost excellent, both heaving and torsion resonance can be reduce significantly.

It is found that geometry modification should consider not only streamlining the deck structure but also disturbing the incoming flow could give a better solution. The strip bar has function as flow splitter and probably as turbulence generator. The strip installation is also the most economic solution to the existing bridge structure modification.

On the prototype bridge modification, it is found that wind fairing of deck-02 with $h/D=0.25$ has the minimum drag coefficient.

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