Study on Bridge Deck Sections for Indonesian Long Span Bridges

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ABSTRACT: The most intensive research activities of wind engineering in Indonesia are the aerodynamic study of long span bridges. This is driven by government plan to have good inter-island transportations. The following paper will present several research results, particularly a new finding in Resonance Induced Excitation (RIE) that is Low wind Speed Heaving Resonance (LSHR) and steady aerodynamic forces. Further study was carried out to understand the characteristics of LSHR, by means of three generic shapes of the deck sections as well as typical existing deck section. It concluded that the LSHR was actually generated by secondary separation, due to several flow obstacles on upper or lower deck surfaces.

KEYWORDS: long span bridge, wind tunnel, aerodynamics, resonance induced, vibration, sectional model

1 INTRODUCTION

Inter-islands transportation is the most demanding development of wind engineering activities in Indonesia. Several long span bridges are planned and designed to build in the next coming year. The hottest proposal now, is to build large bridges between Jawa and Sumatera Island. The total length of bridge can be 31 km, including two or four flexible bridges, passing through three small islands. The longest main span of the bridge is planning to be 3000m. There is at least a technological obstacle to decrease the main span, which is the pylon must be constructed on sea bed of more than 70m depth.

Figure 1. Location of long span bridges

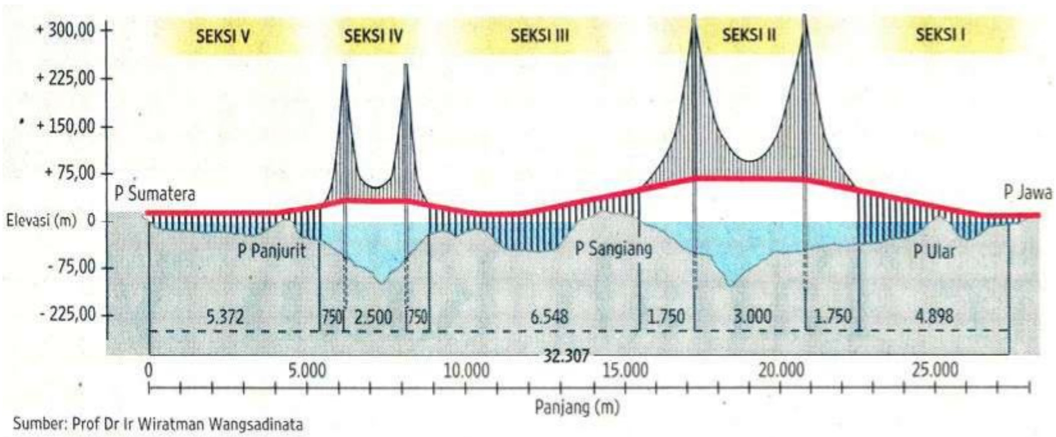

Figure 2. Proposal of new long span bridge at Sunda Straits [KOMPAS,2007]

Some initial efforts on wind engineering have been performed to realize this project. Deck selection shapes is a first step to build a full long span bridge structure. An important finding during the study is the occurrence of heaving resonance at low wind speed which is not directly caused by vortex fluctuation. This phenomenon is then called as Low wind Speed Heaving Resonance (LSHR). To observe further on LSHR characteristics, three generic models have been investigated, using smooth as well as turbulence wind which is generated by grid type generator. The study was motivated from previous work of [Owen, 1996] and [Kawatani, 1993].

2 RESONANCE INDUCED EXCITATION (RIE)

There are several important aeroelastic and aerodynamic phenomena to be observed for a long span bridge. That is flutter instability, resonance induced excitation, buffeting response and steady aerodynamic forces. Actually, flutter is not more a critical phenomenon for modern long span bridges. Resonance Induced Excitation (REI) is always the real problem, particularly Vortex Induced Vibration (VIV) [Simiu, 1996]. Sectional model test in a wind tunnel is still the popular method to study the aerodynamic behavior of a long span bridge deck.

The LSHR was found during the study of RIE in a typical model of deck cross section. Figure 3 shows the set up of model in the rig for testing and Figure 4 show the typical grid turbulent generator.

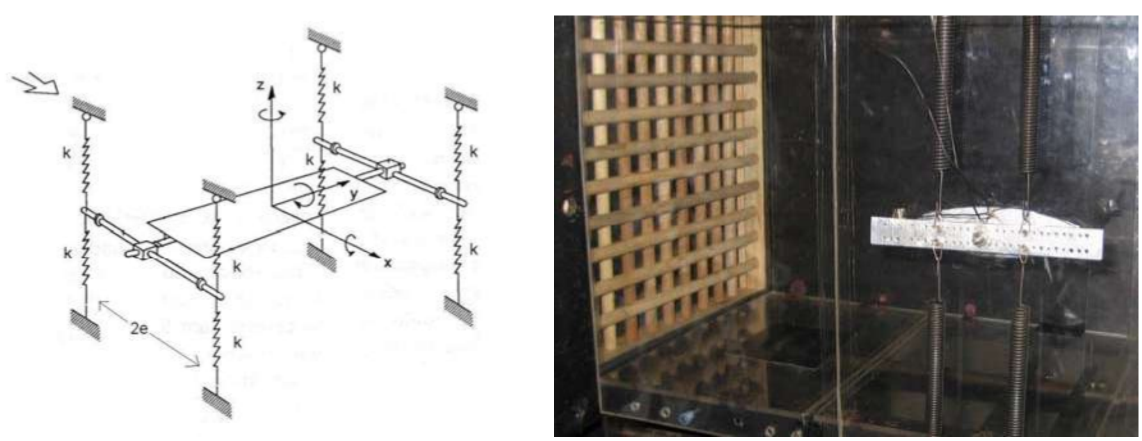

Figure 3. Model Mounting and turbulent grid generator

To see the overall pattern of vortex shedding mechanism, the results were analyzed using waterfall plots. There are three trend lines can be identified on the plot: two lines for peak of heaving and torsion frequencies and one line for vortex shedding frequency (or Strouhal Frequency) which is proportionally shifting with wind velocity. Also, the result shows that there is a peak of heaving resonance at low wind speed was not coincide or excited by the Strouhal frequency. This resonance peak does not have any relation with torsion natural frequency. Therefore, the resonance must not be induced by primary vortex shedding in the wake of body; further study was carried out using several deck sections, including the use of Computational Fluid Dynamics. Apparently it was found that the resonance was induced by pressure different between top and bottom surface of the deck. This pressure different might come from flow separation due to obstacle on the surface, or secondary vortex shedding. The author called this resonance as Low wind Speed Heaving Resonance (LSHR).

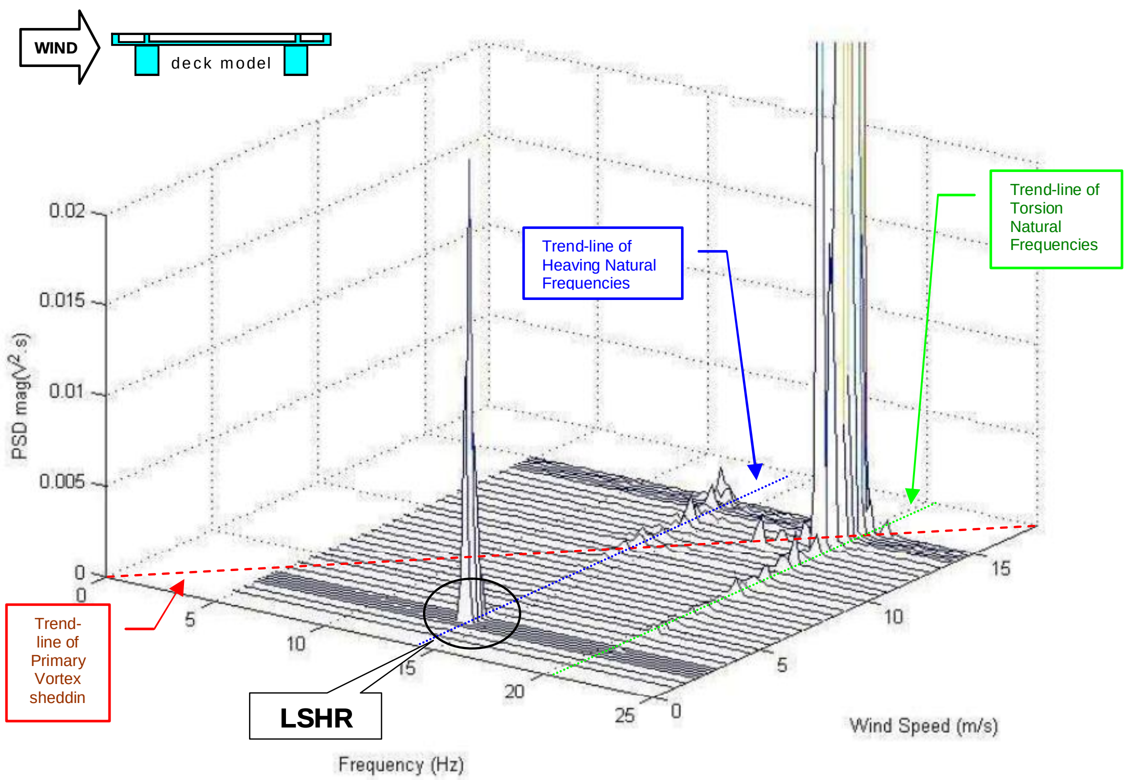

Figure 4. Appearance of heaving at low wind speed

To have a better understanding of LSHR, several experiments were carried out by using generic models with or without railing. The study was motivated from the results of the above result of a typical deck section. It clearly shows the mechanism of resonance. At first, the standard height of railing model (h_R) was used for all models and this h_R is less than deck height h_d. The model was exposed to smooth flow.

Figure 5, 6 and 7 show the results. The Sharp-Edges with Railing (SER) and Flat-Edges with Railing (FER) models have LSHR, whereas the Round-Edges with Railing (RER) do not have. For this reason, further analysis for RER configuration is required. It is thought that the occurrence of LSHR on RER is depended on railing height. Therefore, h_R was extended to 13mm to be higher than deck height, $h_R > h_d$. The LSHR and torsion peak of FER is higher than SER; also lock-in range of FER is longer than SER. However, those three configuration models have resonance at torsion. The occurrence of torsion on FER and RER is earlier than SER.

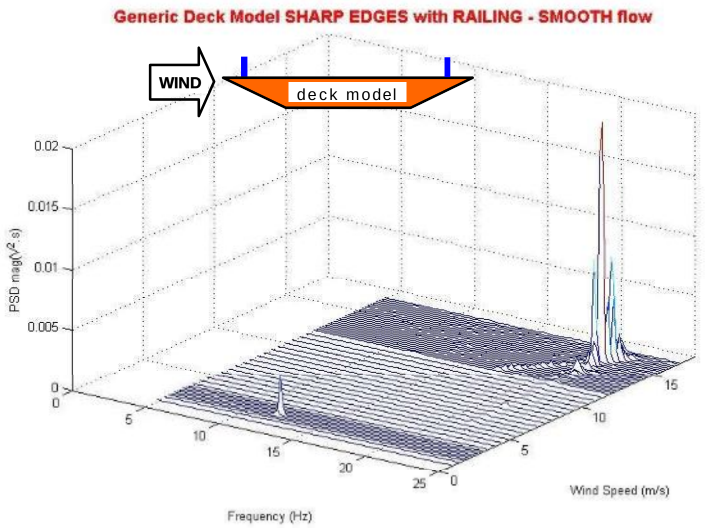

Figure 5. Power Spectrum Density (PSD) of SE model with standard railing (Re ~1.23 x10^5)

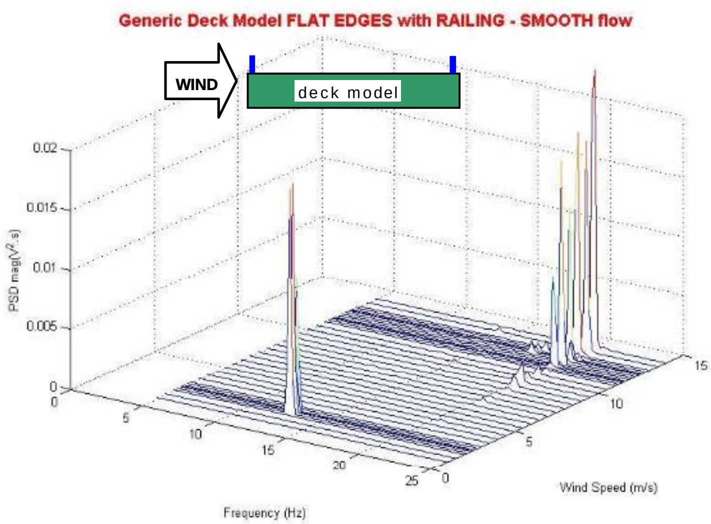

Figure 6. Power Spectrum Density (PSD) of FE model with standard railing (Re ~1.23 x 10^5)

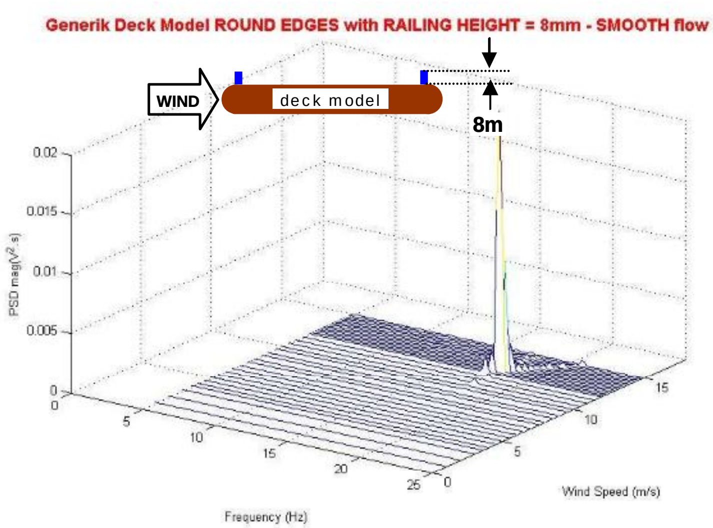

Figure 7. Power Spectrum Density (PSD) of RE model with standard railing (Re ~1.23 x 10^5)

Figure 8 shows the results when the railing height is extended, now the LSHR come out on RER model. This shows that the RER is less sensitive to LSHR, except if the railing is higher than certain limit of height, in this case is the deck height h_d.

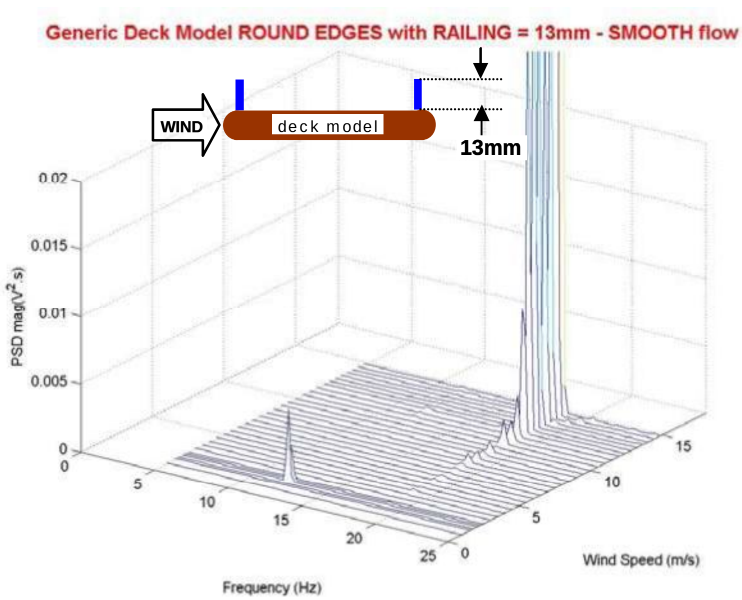

Figure 8. Power Spectrum Density (PSD) of RE model with extended railing height (Re ~1.23 x 10^5)

The effect of wind turbulent was observed by using grid turbulent generator in front of typical deck section model. The results are shown in the Figure 9. Low turbulent intensity wind (I_u < 3%) produce LSHR, whereas if the wind has high turbulent intensity (I_u = 8%) the LSHR is suppressed.

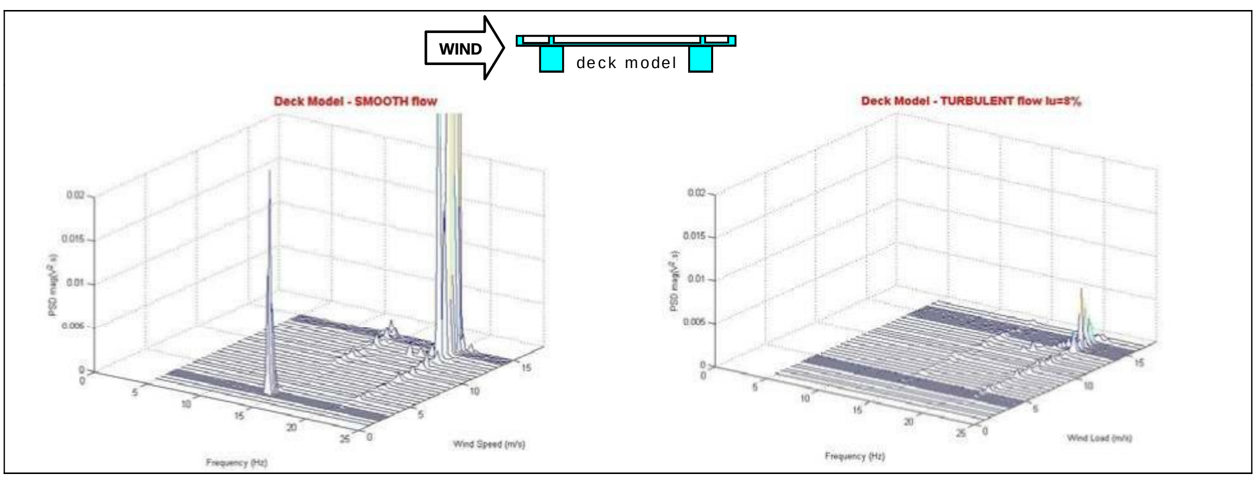

Figure 9. Effect of wind turbulence

To find the excitation factor of LSHR, CFD analysis was performed using the typical deck at 0 deg angle of attack. Figure 10 shows the result. It can be shown that smaller vortices are generated from aft-obstacle to the rear-obstacle on upper surface and bigger vortices on the lower surface. Hence, a pressure fluctuation might occur on the upper or lower surface. This will move up or down the deck vertically, on the contrary the suspension system will return back the deck to equilibrium. Therefore, the resonance fluctuation is excited on vertical mode.

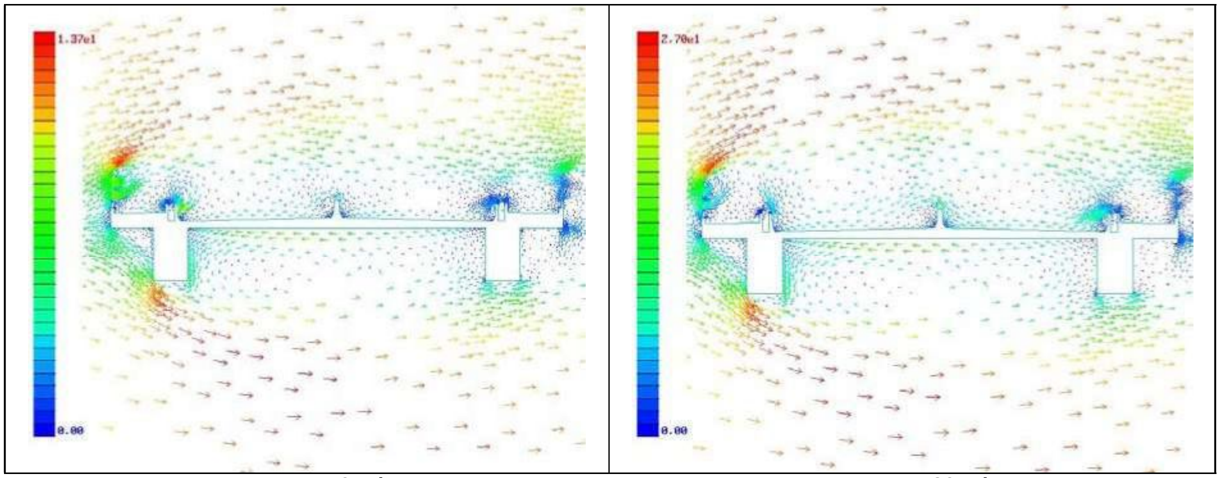

Figure 10. CFD analysis result of 10 m/s and 20 m/s wind speed

3 STEADY AERODYNAMIC FORCES

The steady aerodynamic forces and moment give information on static loads of the deck structure. The result of measurements is shown in the following figures. The measurement was performed in smooth flow with various angle of attack and two wind speed variations. The use of ground board to represent the water level distance was also observed.

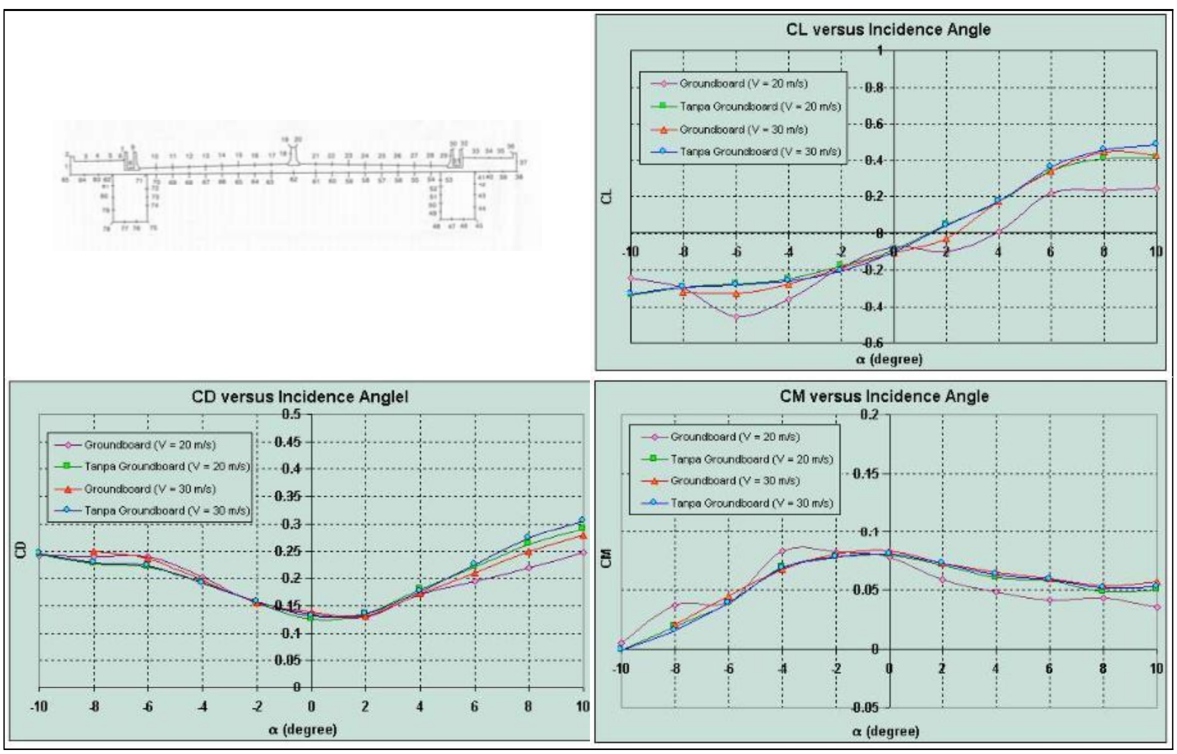

Figure 11. Experimental Results

It can be seen that the ground board existence is significant in sectional model test. The force/moment variation pattern was the same for 20m/s and 30m/s. This means the effect of wind speed fluctuation is less influence to the steady force/moment of the deck.

4 CONCLUSIONS

The low wind speed heaving resonance (LSHR) is an important phenomenon to recognize, because it appears on very low wind speed of very low wind turbulence intensity. The phenomenon is not the same as VIV on torsion mode, where the resonance is excited by primary vortex shedding fluctuation. The LSHR is another RIE which is excited by secondary vortex shedding fluctuation.

The study found that,

- The LSHR is function of the existence of deck-surface obstacles to the flow: railing, track separator or other roughness. It will not occur on clean deck geometry where deck-surface obstacles do not exist.
- The LSHR is function of the deck geometrical shape. Although, the round edge deck has railing (RER), it is less sensitive to LSHR. Only at certain level of railing height, the RER configuration is sensitive to LSHR.
- LSHR is significantly suppressed by high turbulent wind. As results, in high turbulence area such as urban, LSHR will not be a problem to the long span bridge structure. In low turbulent area such as the sea, where the turbulence intensity may be low, LSHR may give a serious problem, particularly to the deck of a long span bridge.

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