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Comparison study of aero-elastic analysis of a tower with its 2D/3D wind tunnel test

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ABSTRACT

Aero-elastic analysis of a tower is conducted and compared with its 2D/3D wind tunnel tests. Dynamic wind tunnel test of the 2D section model reveals the excessive vibrations under the specific wind incidence angles and the flutter stability analysis shows the similar instability conditions. Static and RMS responses of the free standing tower measured from the aero-elastic wind tunnel test of the 3D model are compared with the buffeting analysis results with various wind speeds and incident angles. Comparison study shows the efficacy and also limitations of the aero-elastic analysis for the evaluation of the dynamic performance of a tower against wind.

1. INTRODUCTION

The structure studied in this research is a 125m height pylon for a cable stayed bridge. The width along the bridge at the top is 5m and it increases linearly at lower position, like 5.5m, 6.0m, 6.5m at the height of 105m, 85m, 65m. The width across the bridge is constant with 3.5m. Wind velocity, turbulence intensity, length scale, and power spectral density of the fluctuating wind speed are modelled through the wind climate analysis (Fig. 1). Two different construction stages of the pylon are considered: 1) erection stage with free standing tower, 2) service stage with connected deck and stay cables. Fig. 2 shows the mode shapes of the pylon at the erection stage and service stage. Here the x axis is along the bridge, y axis is across the bridge, and z is upward. Fig. 3 show the steady state wind load coefficients measured from the wind tunnel tests of the 2D section models.

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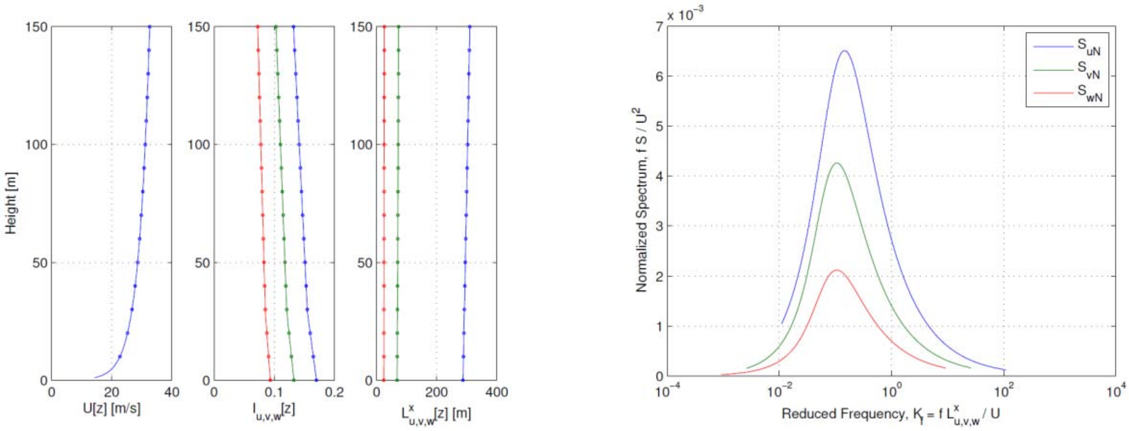
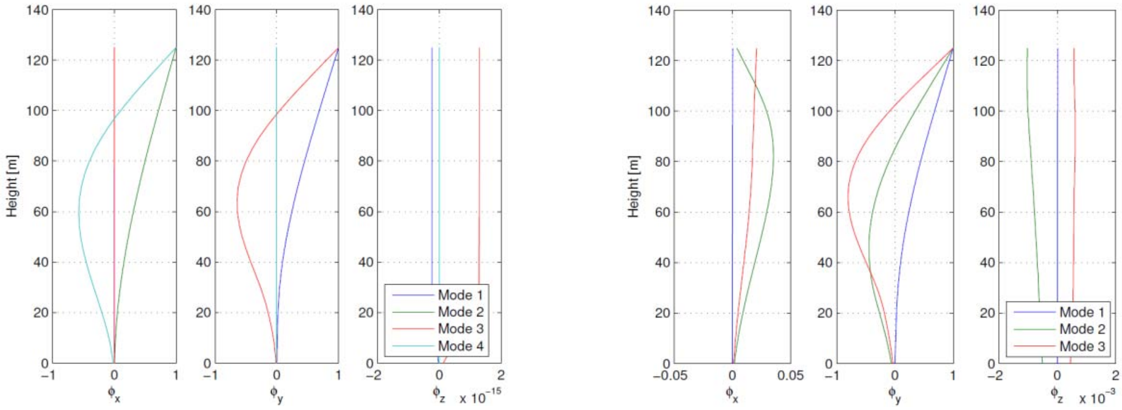


Fig. 1 Wind velocity, turbulence intensity, length scale and PSD of wind speed



(a) Erection Stage (b) Service Stage

Fig. 2 Mode shapes of the tower

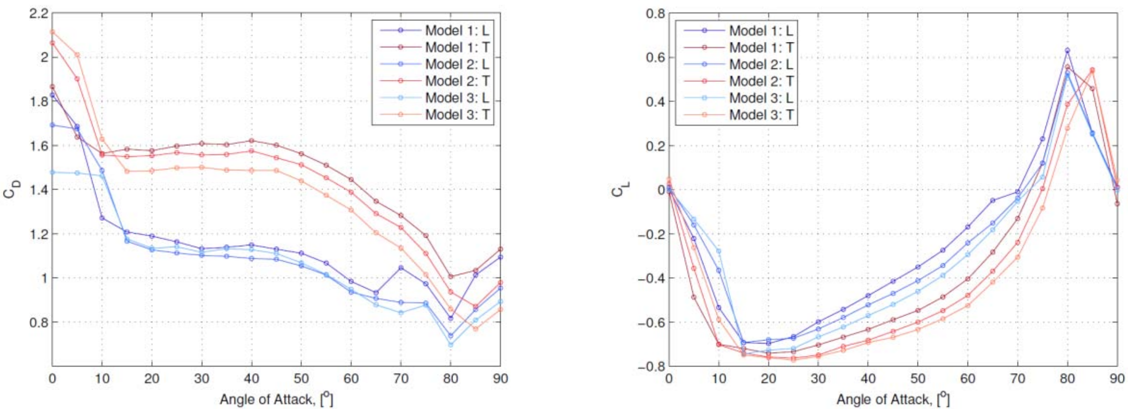
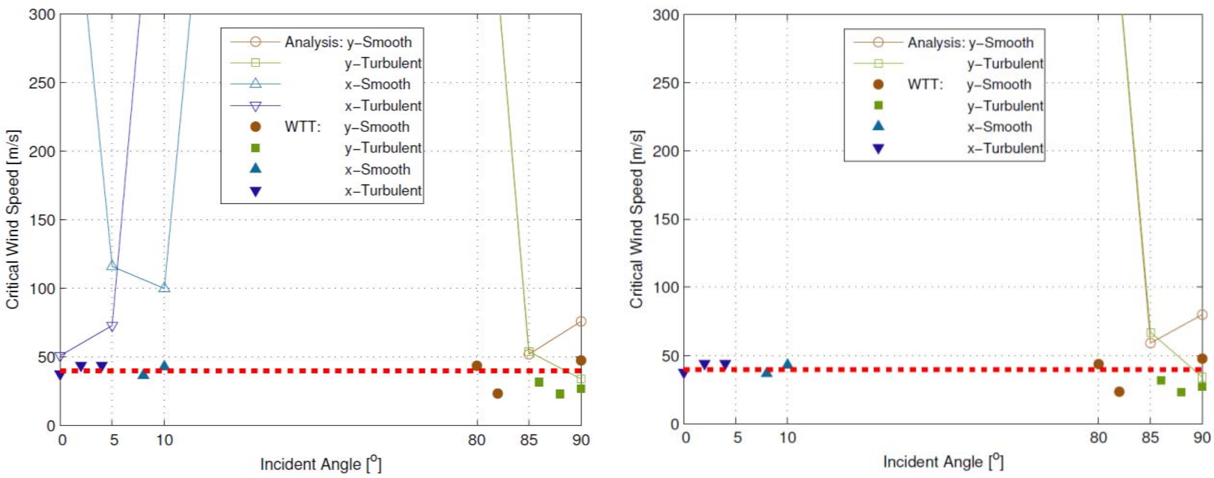


Fig. 3 Steady state wind load coefficients

2. FLUTTER STABILITY ANALYSIS

Fig. 4 (a) shows the results of the flutter stability analysis of the 2D section model of the tower in erection stage. For the vibration of the x-axis (along the bridge), the instability occurs at the incident angles of 5 and 10 degrees at smooth flow and 0 and 5 degrees at turbulent flow. For the vibration of the y-axis (across the bridge), the instability occurs at the incident angles of 85 and 90 degrees at both of the smooth and turbulent flows. These results are almost same as the wind tunnel tests. Fig. 4 (b) shows the results of the flutter stability analysis of the 3D section model of tower in service stage. Even though the modal parameters like the natural frequency is little bit increased and the 3D effects are considered through the mode shapes and three different models of the wind load coefficients are utilized, the instability conditions are almost same with the results of the 2D model of erection stage. Only the critical wind speeds are slightly changed. However, dynamic wind tunnel test of the 3D model of the tower in service stage shows no stability problem.



(a) Erection Stage (2D) (b) Service Stage (3D)

Fig. 4 Flutter stability analysis of the tower

3. AERO-ELASTIC ANALYSIS OF 2D MODEL OF TOWER IN ERECTION STAGE

Fig. 5 shows the frequency response function of the tower in erection stage and the power spectral density of the RMS response of the tower. Fig.6 shows the static and RMS response of the tower. Especially the responses at the wind speed of 40m/s are compared with the results of the wind tunnel tests. Comparison of static responses shows a good agreement between the analysis results and wind tunnel test results, while the RMS responses of the analysis are larger than the results of the wind tunnel tests. Abrupt increases of the RMS response at the 0 degree for the x-axis (along bridge) and at the 90degree for the y-axis (across bridge) arise because the aero-dynamic damping at that condition is decreased and the total wind-tower system becomes unstable.

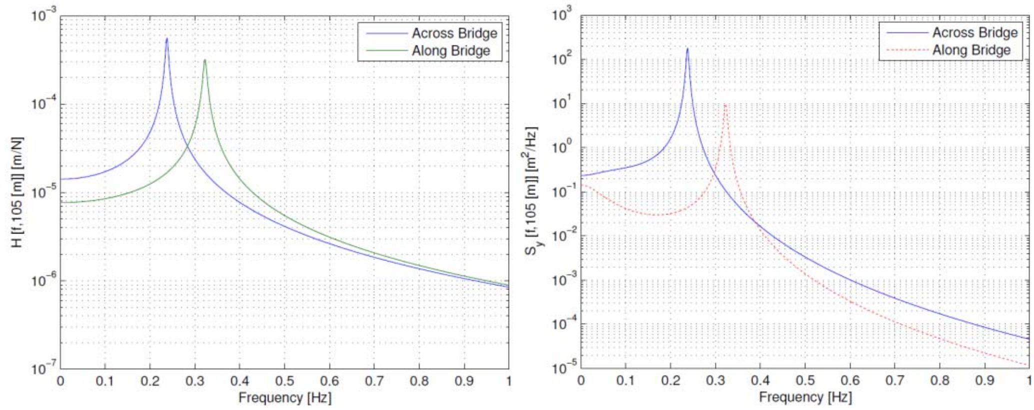
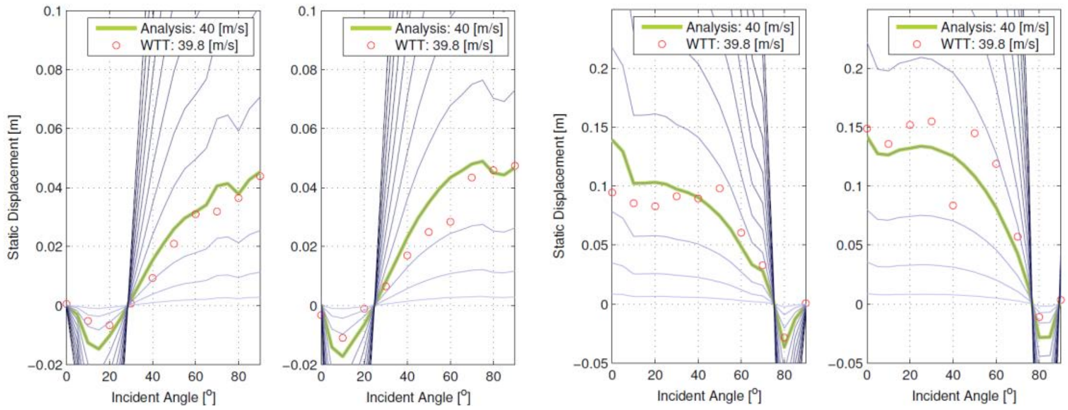
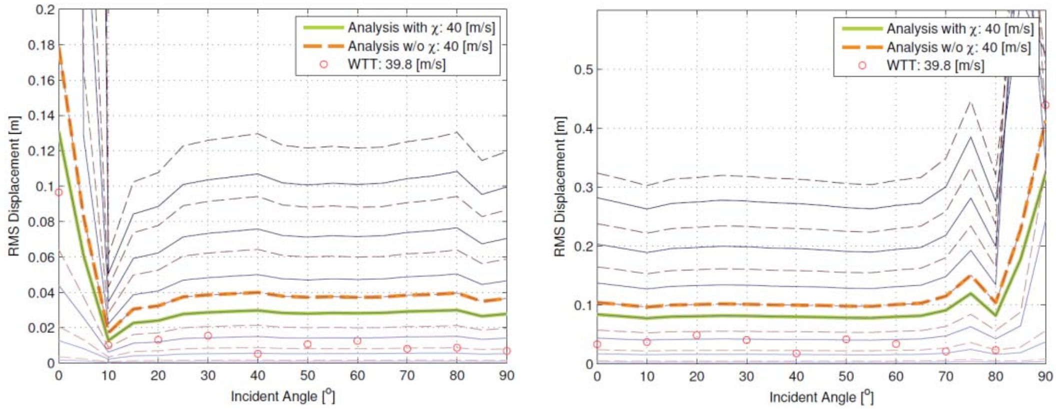


Fig. 5 Frequency response function and power spectrum of response



(a) x_s (smooth) (b) x_s (turbulent) (c) y_s (smooth) (d) y_s (turbulent)



(e) x_{RMS} (turbulent) (f) y_{RMS} (turbulent)

Fig. 6 Static and RMS response of the tower in erection stage (2D model)

4. AERO-ELASTIC ANALYSIS OF 3D MODEL OF TOWER IN SERVICE STAGE

Fig. 7 shows the frequency response function of the tower in service stage and the power spectral density of the RMS response of the tower. Fig.8 shows the static and RMS response of the tower. The responses at the wind speed of 40m/s are compared with the results of the wind tunnel tests. Comparison of static responses shows a small difference between the analysis results and wind tunnel test results. The 3D model used in the wind tunnel test was tuned to match the dynamic parameters of the prototype model, and only the wind load coefficients of three representative 2D section models at 105m, 85m, 65m heights are used for the analysis. The RMS responses of the analysis show a good agreement with the results of the wind tunnel tests. Fig. 9 shows the RMS response as a function of wind speed. In the case of the wind incident angle of 40 degree shows a good agreement between the analysis and the wind tunnel test. However at the incident angle of 90 degree, the RMS response of the analysis increases rapidly after the wind speed of 33 m/s where the total damping of the wind-tower system goes negative.

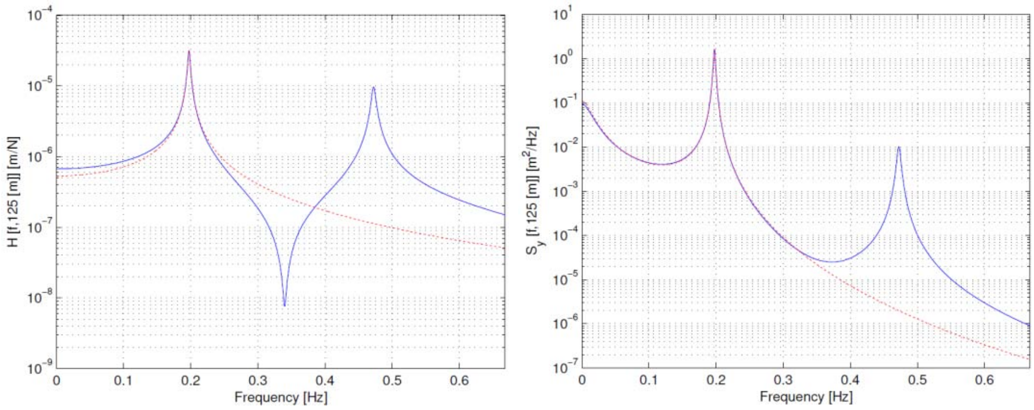
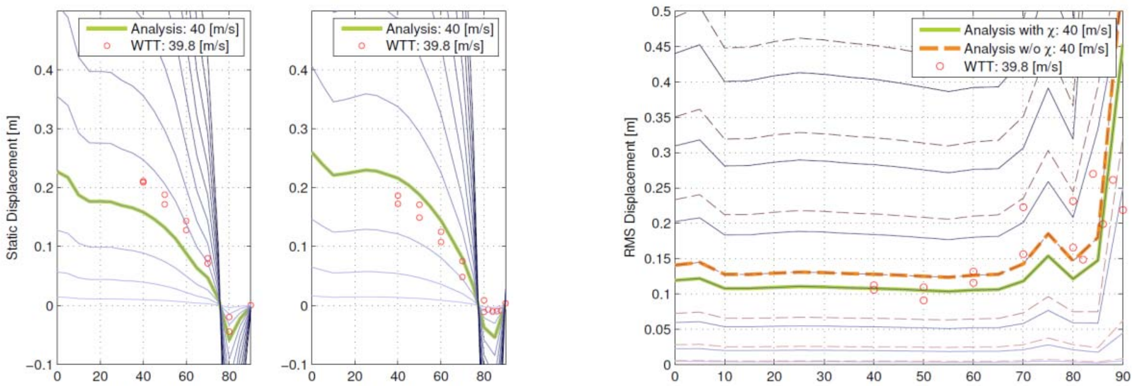
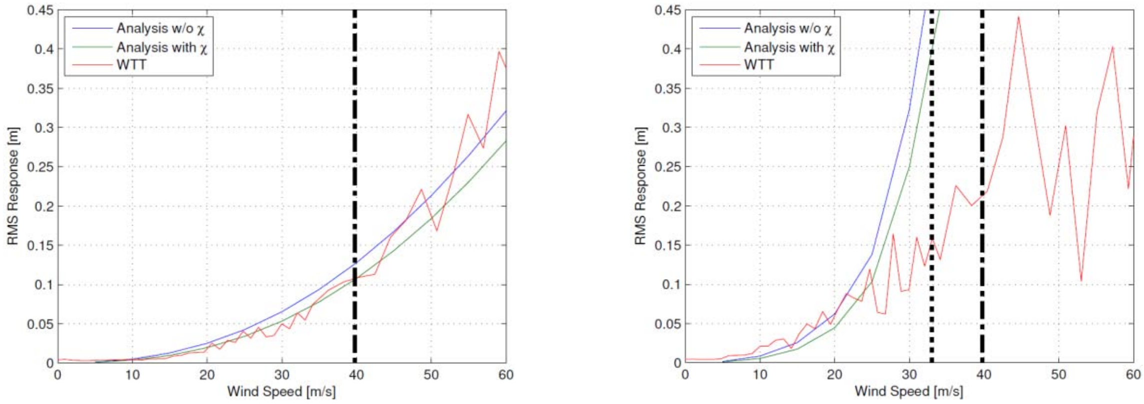


Fig. 7 Frequency response function and PSD of the response of the tower



(a) y_s (smooth) (b) y_s (turbulent) (c) y_{RMS} (turbulent)

Fig. 8 Static and RMS response of the tower in service stage (3D model)



(a) Wind incident angle: 40 degree (b) Wind incident angle: 90 degree

Fig. 9 RMS response of the tower in service stage as a function of wind speed

3. CONCLUSIONS

Aero-elastic analysis of a tower is compared with the 2D/3D wind tunnel tests. Flutter stability analysis shows a good agreement with the dynamic wind tunnel test of the 2D section model. However it should be careful for the application to the 3D model. Generally the static and RMS response of the analysis shows a good agreement with the wind tunnel test. However the aerodynamic damping effects should be considered carefully.

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