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

Wind tunnel study on aeroelastic wind responses of cable-reinforced air-supported membrane structures

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SUMMARY:
In this study, effects of cable reinforcements on aeroelastic wind responses of air-supported membrane structures were investigated by wind tunnel experiments. Wind-induced displacements were measured during aeroelastic wind tunnel tests on models with and without cables. In addition, effects of internal pressures, wind velocities and membrane tensile stiffness were also considered. It has been discovered that wind induced displacements of cable reinforced models were significantly lower than those of models without cables, and with some occasions cable reinforcements can suppress the appearance of aeroelastic instability. Meanwhile, structural fluctuating wind responses also decreased with higher internal pressures, lower wind velocities and less membrane flexibility. These results have indicated the importance of cable reinforcements to increase wind-resistant performance of air-supported membrane structures.

Keywords: Air-supported membrane structures, Aeroelastic responses, Wind tunnel tests

1. INTRODUCTION

Recently, air-supported membrane structures are increasingly applied in large-span structures for public sports, exhibition, warehousing and environment protection. However, these structures are also sensitive to wind actions because of their lightweight nature. Therefore, aeroelastic wind tunnel experiments have been implemented to study wind responses of air-supported membrane structures (Newman et al, 1984; Kawamura et al., 1986; Mataki et al., 1988; Kassem et al., 1991; Sygulski, 1996; Wood et al., 2018). These studies have revealed that structural stiffness may have important effects on wind responses. In engineering practice, cable reinforcements have been widely applied to increase structural stiffness. Hence, this study is aimed to study effects of cable reinforcements on aeroelastic wind responses of air-supported membrane structures.

2. EXPERIMENTAL SETUP

Aeroelastic models of air-supported membrane structures have been made in this study with length (L) of 1.2 m, width (B) of 0.6 m and height (H) of 0.2 m. The top membrane adopted two different types of materials, latex and TPU, as shown in Table 1. The internal pressure (pressure difference between the internal volume and the atmosphere) P_I was within 50~200 Pa. To study effects of cable reinforcements, models with and without cables were investigated as configurations in Fig. 1. Four nylon wires with diameter of 1 mm and elastic modulus of 1 GPa were tensioned by the pulley system. Cable forces were measured with force sensors, and measured cable forces without wind actions are given in Table 2. Laser displacement sensors were applied to measure structural wind responses.

Table 1. Material properties of membrane.

Properties	Latex	TPU	Prototype
Elastic modulus *E*	1.3 MPa	38 MPa	1000 MPa
Thickness *h*	0.36 mm	0.05 mm	1 mm
Tensile stiffness *Eh*	468 N/m	1900 N/m	10^6 N/m
Mass per area *m*	336 g/m^2	63 g/m^2	1100 g/m^2

Table 2. Cable forces of models with cable reinforcements.

Model	The latex model				The TPU model	
Internal pressure P_I	50 Pa	100 Pa	150 Pa	200 Pa	100 Pa	200 Pa
Cable force *T*	2.3 N	4.8 N	6.5 N	9.1 N	1.9 N	5.5 N

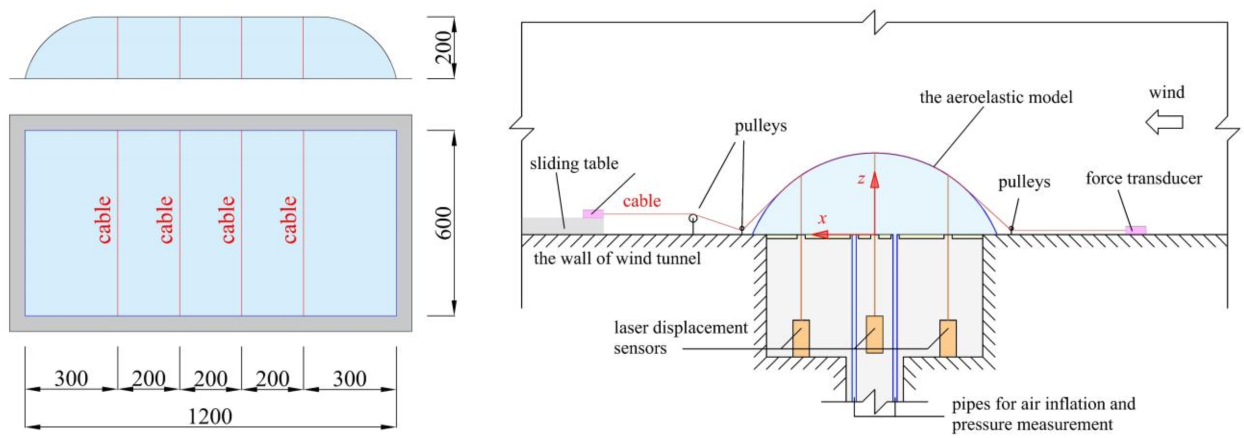


Figure 1. Configurations of wind tunnel tests

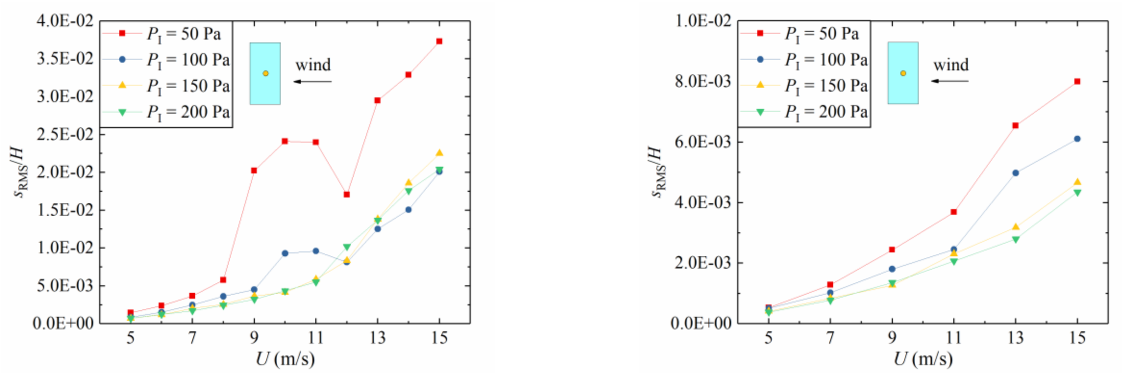
Similarity parameters of aeroelastic wind tunnel tests are given in Table 3 to show relations between the prototype and the scaled model. The prototype is with length (*L*) of 120 m, width (*B*) of 60 m and height (*H*) of 20 m. Properties of the membrane for prototype is given in Table 1, and cables of the prototype are with section area of 180 mm^2 and elastic modulus of 210 GPa.

Table 3. Scaling parameters.

Properties	Theoretical	Actual
Length scale	1:100	1:100
Wind velocity scale	1:2	1:2
Internal pressure scale	1:4	1:4
Membrane tensile stiffness scale	1:400	1:2137 (The latex model) or 1:576 (The TPU model)
Cable tensile stiffness scale	1:40000	1:48128

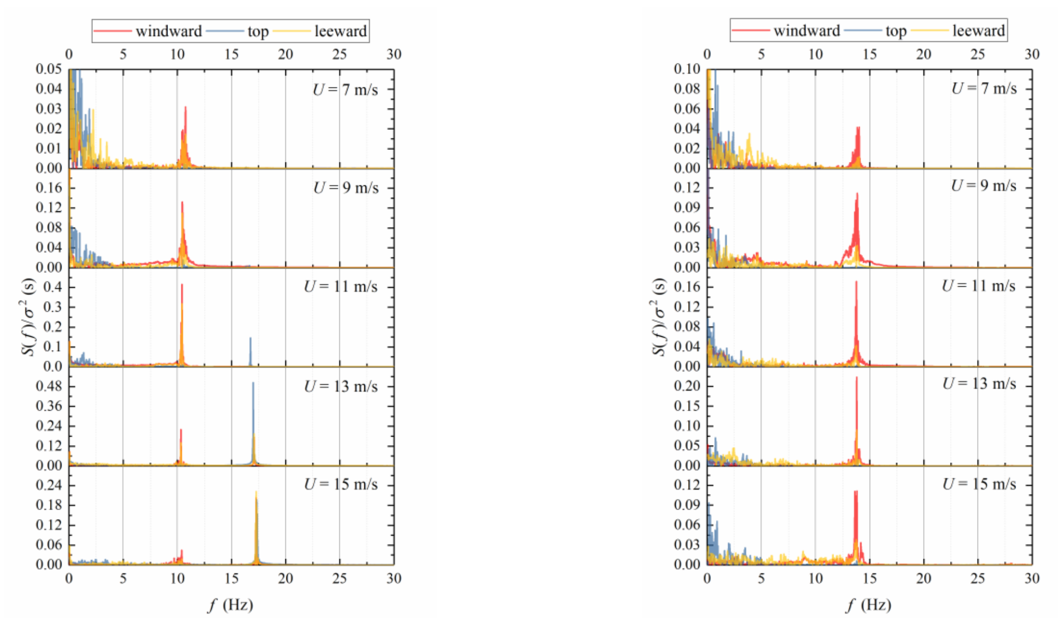
3. RESULTS

Fig. 2 presents fluctuating wind responses of the latex model. Generally, structure responses were higher with decreasing internal pressures and increasing wind velocities. For the model without cables, a sharp increase of dynamic wind response appears when the wind velocity exceeds over certain values, which is typical of aeroelastic instability (Wu et al., 2015). However, with cable reinforcements, aeroelastic instability was significantly supressed due to increasing structural stiffness.



(a) Without cables (b) With cables

Figure 2. Structural dynamic wind responses at top centre of the latex model

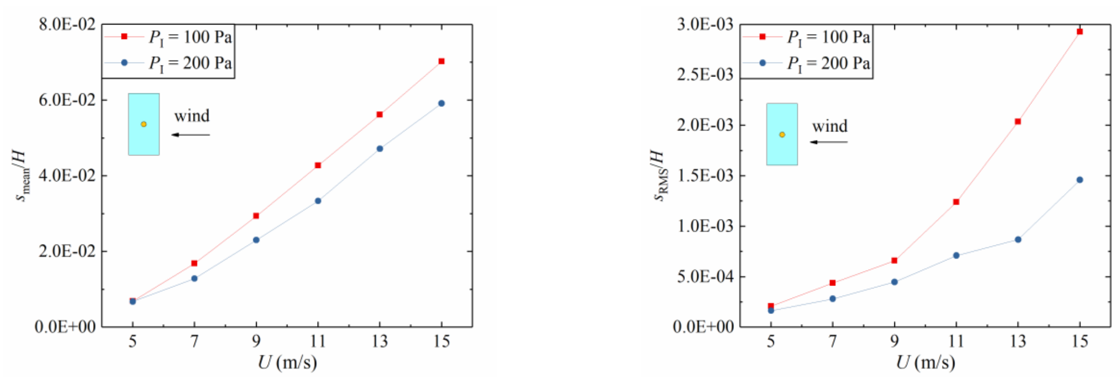


(a) Without cables (b) With cables

Figure 3. Displacement power spectra densities for the latex model (P_I = 200 Pa)

Fig. 3 further reveals difference patterns of structural dynamic wind response with and without cables by displacement power spectra densities (PSDs) results. For the model without cables, appearance of the 2nd mode occurs as aeroelastic instability happens. However, with cable reinforcements, higher structural stiffness has suppressed the occurrence of the 2nd mode, and the structure remained aeroelastic stable.

As for the TPU model, though no aeroelastic instability has been discovered for both models with and without cables, it is observed that cable reinforcements can also significantly reduce structural dynamic wind responses (Fig. 4). PSDs of both models are similar, exhibiting characteristics of structure buffeting with broad band patterns in frequency domain.



(a) Without cables (b) With cables

Figure 4. Structural dynamic wind responses at top centre of the TPU model

4. CONCLUSIONS

This study carried out wind tunnel experiments on aeroelastic wind responses of cable reinforced air-supported membrane structures. Structural wind responses generally decreased with more cable reinforcements, increasing internal pressures, lower wind velocities and higher structural stiffness. Meanwhile, cable reinforcements can also inhibit the appearance of aeroelastic instability. These results above have revealed importance of cable reinforcements on wind resistance of air-supported membrane structures.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (Grant No. 51878129, 52078163) and the Fundamental Research Funds for the Central Universities (Grant No. HITCE202004)

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