Wind-induced vibrations of twin tandem cables in parallel and non-parallel arrangements

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SUMMARY:
This study experimentally examines the wind-induced vibrations of two tandem cables in both parallel(L/D=3) and non-parallel (L/D=3~5) arrangements (where L is the center-to-center distance of cables, D is the diameter of cables), through wind tunnel tests on aeroelastic models. For the parallel arrangement, both high-order vortex-induced vibrations (VIV) and wake-induced vibrations (WIV) were observed on cables. The WIV behaviour of the cables was quite complicated: the vibrations of upstream cable could restrain the one of downstream cylinder, but this inhibition effect died out with the increasing wind speed; the first-order symmetric mode WIV, despite a higher frequency, occurred before the anti-symmetric one. When the cables were arranged in non-parallel, no VIV was observed, and the critical wind velocity of WIV decreased. Two vibration patterns were observed on the downstream cable: in-plane vibration and multiple modal coupling vibration under high reduced wind speed.

Keywords: Wake-induced vibration, Twin tandem cable, Wind tunnel test

1. INTRODUCTION

Twin and multiple circular cylinders are widely used in various structures, such as bridges, offshore structures, and transmission lines. The wind-induced vibrations for these cable structures are more complex and unstable than those of a single cable, and have been the subject of much research in recent years. Early studies of these vibrations focused on the use of flexibly-mounted rigid models based on wind and water tunnel tests to investigate the aerodynamic characteristics and vibration responses. More recent studies have experimentally investigated wake-induced vibrations (WIV) for hangers and stay-cable by using flexible aeroelastic cable models, but have mainly focused on low mass ratios (He et al., 2018, Deng et al., 2021, Wen et al., 2018). The present study employs two aeroelastic cylinder models with super-high mass ratios ($m^*=4m/\pi\rho D^2 l=6031$, where m is the mass of the cable, ρ is the wind density, D is the cable diameter, l is the cable length) to investigate the wind-induced vibrations for twin cables in parallel (L/D=3) and non-parallel (L/D=3~5) arrangements. The structure parameters used in this study are based on one of the main cable design schemes for the Shiziyang suspension bridge (with a main span of 2180m, China). The cable suspension system and dynamic parameters for wind tunnel tests are shown in Fig 1, Table 1 and 2.

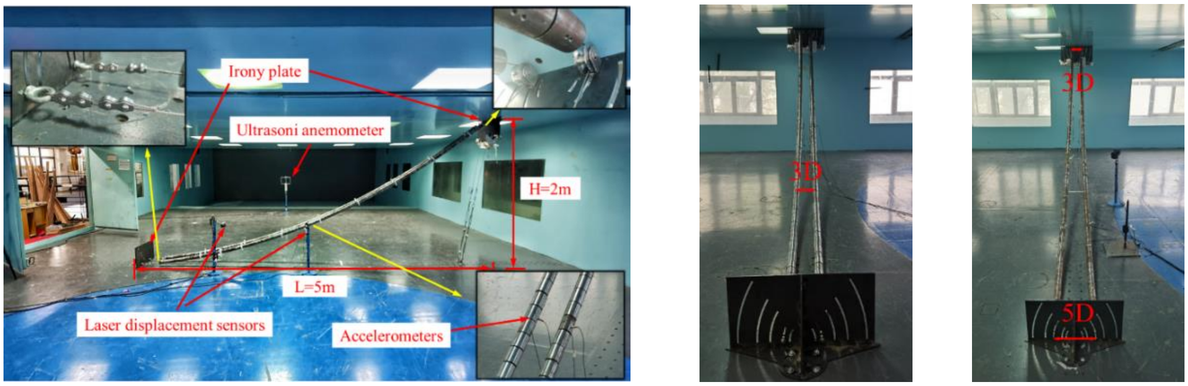


Figure 1. The cable suspension system for wind tunnel tests

Table 1. Structure parameters for cable aeroelastic models in wind tunnel tests

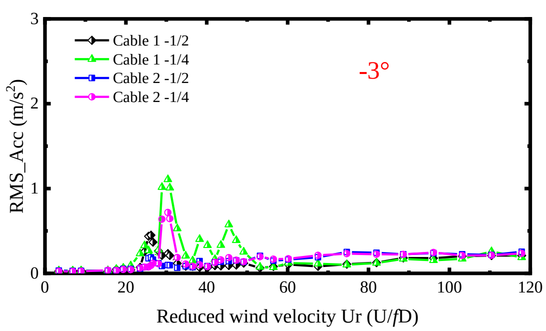
External diameter *D* (mm)	Length *l* (mm)	Linear mass *m* (kg/m)	Reduced wind speed Ur=U/f_aD	Re number	Wind attack angle
50	5400	14.5	6.25~110	3.06×10^3~6.12×10^4	-3°, 0°, +3°

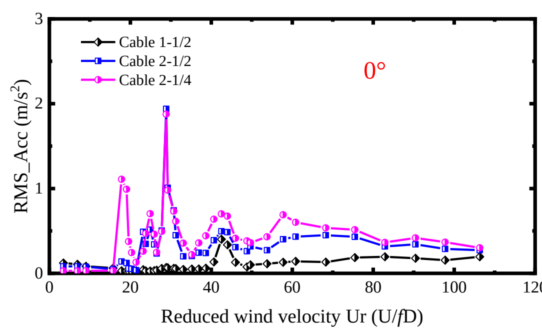
Table 2. Dynamic parameters for cable aeroelastic models

Mode		Upstream cable (Cable 1)		Downstream cable (Cable 2)	
		Frequency	Damping ratio	Frequency	Damping ratio
In-plane	1st order antisymmetric f_a	1.559 Hz	0.037%	1.568 Hz	0.020%
	1st order symmetric $f_{s\text{-}I}$	2.284 Hz	0.046%	2.298 Hz	0.022%
Out-of-plane	1st order symmetric $f_{s\text{-}O}$	0.802 Hz	0.016%	0.803 Hz	0.036%

2. RESULTS OF PARALLEL ARRANGEMENT

The standard values of in-plane acceleration at 1/2 and 1/4 span for the two cables at different reduced wind speeds are shown in Fig 2. Time history and PSD of partial reduced wind speeds are shown in Fig 3. Cable 1 and 2 correspond to the upstream and downstream cables, respectively. High-order VIVs were observed at low ranges of reduced wind velocity (U_r =10~50). WIVs were only found at +3° attack angle over U_r=50, displaying complex oscillation characteristics. The WIV of the downstream cable first oscillated with the 1st symmetric mode under U_r =51.15. Small amplitude vibrations occurred on both cables and restrained each other under U_r =55.36 to 65.94. When U_r increased to 70.28, the vibration of the upstream cable disappeared and the amplitude of the downstream one rapidly increased. Additionally, the geometric nonlinearity caused by large amplitudes led to high-order harmonic terms in acceleration.





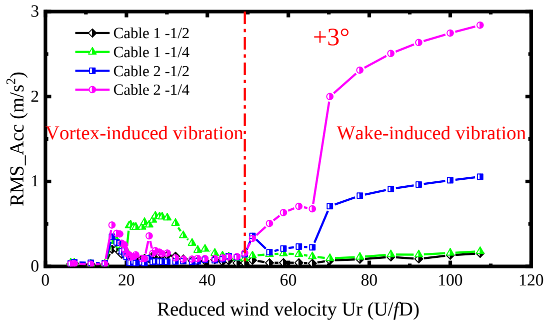
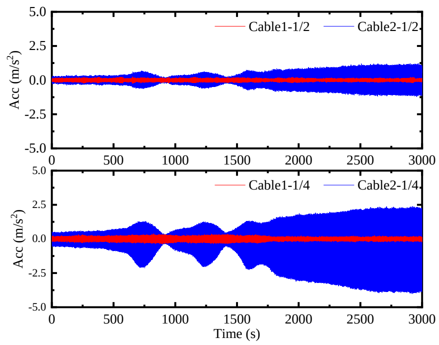
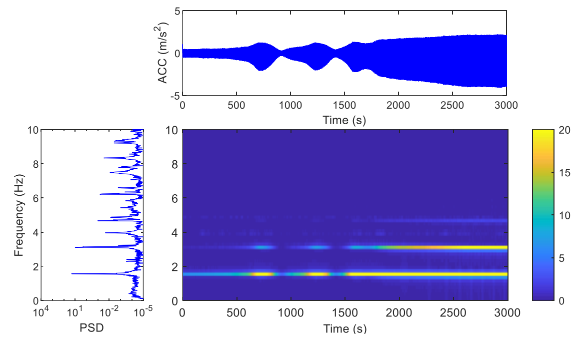


Figure 2. RMS of in-plane wind-induced responses of cables.



a) Time history of acceleration



b) Time-frequency analysis of WIV: Cable2-1/4 span

Figure 3. Time history and time-frequency analysis of cables under Ur=70.28.

3. RESULTS OF CABLES IN NON-PARALLEL ARRANGEMENT

For twin tandem cables arranged in a non-parallel configuration (L/D=3~5), only WIVs were observed at a +3° wind attack angle and no VIVs occurred. Fig 4 shows the wind responses under a +3° wind attack angle. The vibration trajectories at 1/2 and 1/4 span of the downstream cable under different wind speeds are shown in Fig 5. It was found that the non-parallel arrangement for twin tandem cables can effectively suppress VIVs but reduces the critical WIV wind speed. Additionally, the WIV of the downstream cable initially displayed in-plane vibration. The amplitude of out-of-plane vibration increased with the wind speed and suddenly increased, resulting in multiple mode coupling oscillation when the wind speed reached a certain value.

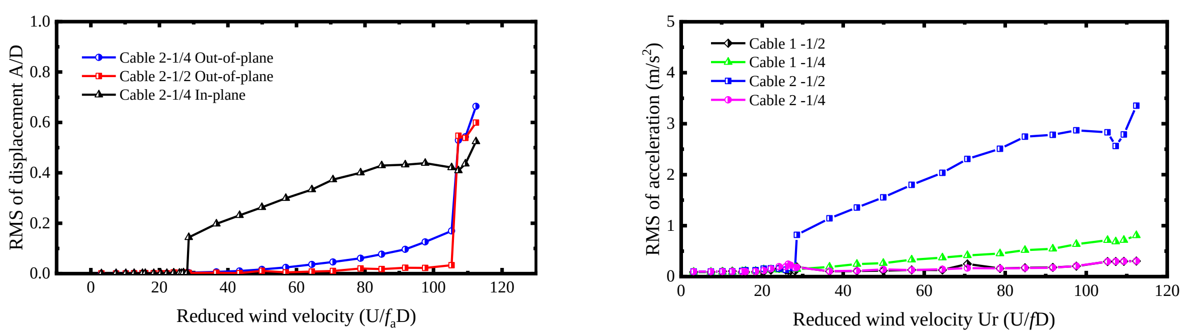
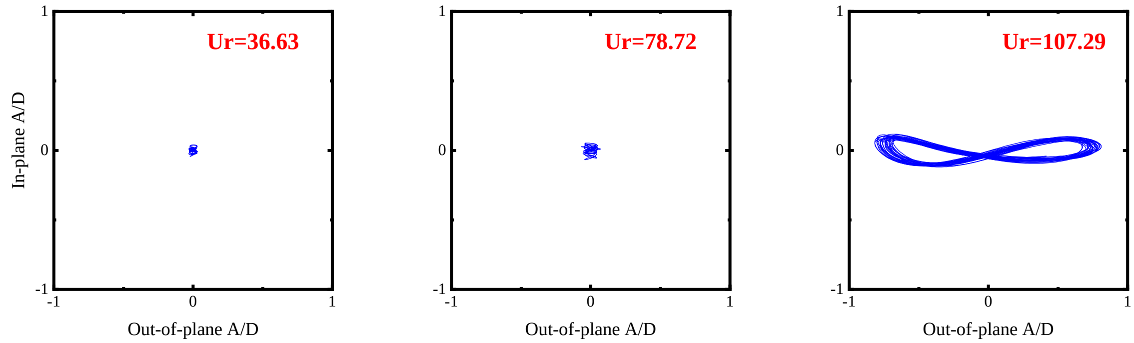
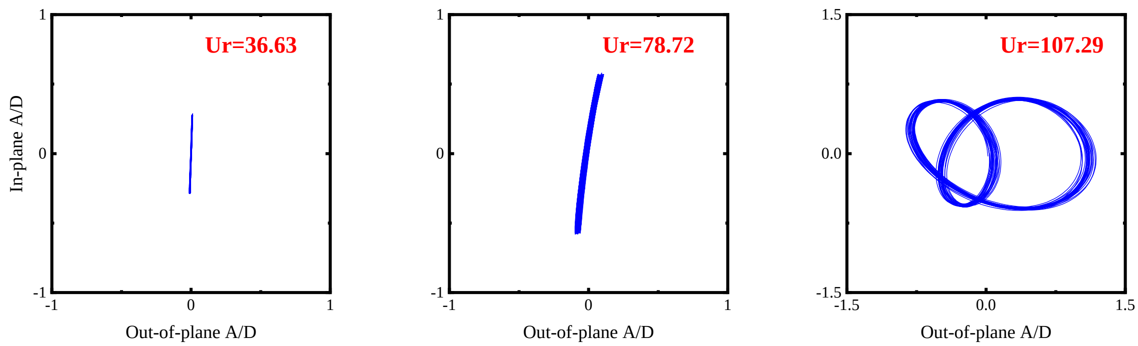


Figure 4. RMS of displacement and acceleration wind-induced responses of cables.



a) 1/2 span



b) 1/4 span

Figure 5. Non-dimensional vibration trajectory of downstream cable under different wind speeds.

4. CONCLUSIONS

The wind-induced vibrations of twin tandem cables are more complicated than those of a single cable. When the cables are arranged in parallel, high-order VIVs and complex WIVs are observed. On the other hand, the non-parallel arrangement of tandem cables effectively suppresses VIVs and decreases the critical wind speed of WIVs.

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