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Field Measurement Research on Wind-Induced Response of Monolayer Cable Net in Shanghai Lujiazui Diamond Tower

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Abstract

In order to deeply investigate the wind environment and the wind-induced vibration characteristics of the Monolayer Cable Net, a monitoring study on the glass curtains of Shanghai Lujiazui Diamond Tower was carried out. The wind speed and wind-induced responses were measured simultaneously. the wind field characteristics and the structure's dynamic characteristics were analyzed based on the monitoring data. It shows that the spectrum of fluctuant wind velocity measured was basically in agreement with Davenport wind spectrum. Probability distribution characteristics of wind-induced response does not belong to a Gaussian distribution because of the structure's nonlinear stiffness.

Keywords: field measurement research, monolayer cable net, wind-induced response.

1. Introduction

Monolayer cable net glass curtain is a new kind of wall structures, it was first used in practical engineering in 1980s and after that it has been used widely in in airport terminals, convention and exhibition centers and hotels [1-2] . Monolayer cable nets belong to tension structures which have the characteristics of light weight, small stiffness, low and dense natural frequency. It belongs to the wind-induced sensitivity structure, and wind load is the control load. Some researchers have studied wind-induced response of cable nets by experiments or numerical simulation[3-4]. Obtaining the wind field and the structure's wind-induced response by field measurement is the most effective means to study the wind effects of such structures, data obtained using this method is thought as the most valuable reference.

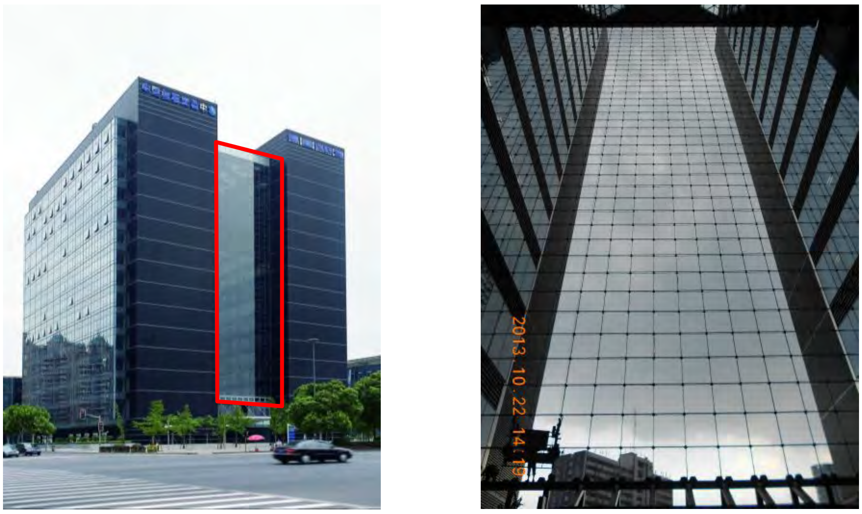


Figure 1: Shanghai Lujiazui Diamond Tower and its monolayer cable nets

Shanghai Lujiazui Diamond Tower, shown as Figure 1, is a high-rise building located in Shanghai in China, with the main building height of 68 meters. It has two tower buildings which are independent and symmetrical and there are two pieces of glass curtains between the tower buildings, with the height of 60.05m and the width of 21m known as one of the typical monolayer cable nets. The horizontal and vertical spacing between two cables are both 1.5 meters.

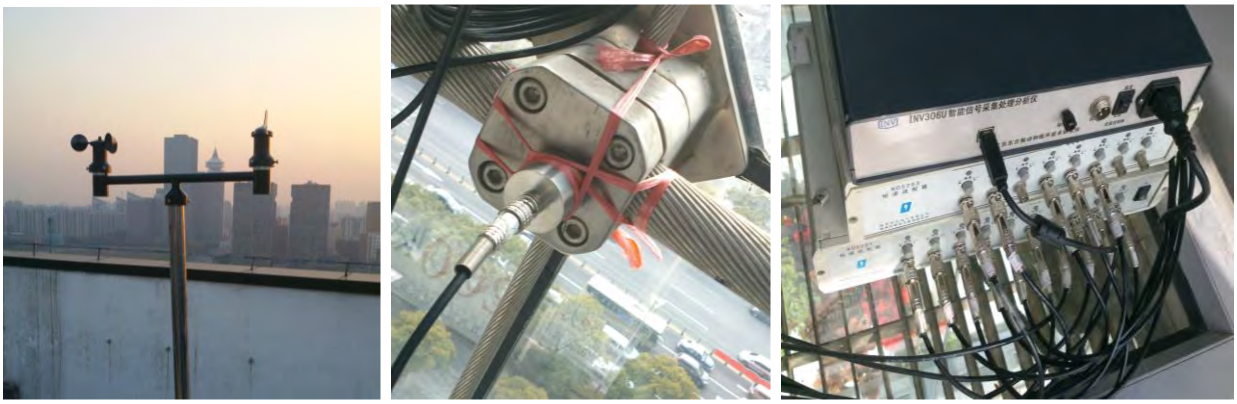
2. Instruments and measuring points

One glass curtain in the south was chosen to be the object of study.

An anemometer (shown as Figure 2 a)) produced by Nanhua Electronics CO., LTD was used to measure the wind speed and the wind direction. For wind speed, its range is from 0 to 60m/s, the resolution is 0.1m/s and the accuracy is ±1%. For wind direction, its range is from 0° to 360°, the resolution is 0.35° and the accuracy is ±2°. The anemometer was placed on the roof of the building upon the glass curtain.

In order to monitor the wind effect of the monolayer cable net, 15 accelerometers were used, divided into 5 rows along the height, shown as Figure 3. The accelerometers (shown as Figure 2 a)) were produced by Lance Measurement Technoloty CO., LTD, and the transducer type was LC0116T with the acceleration range from 0 to 0.5g (1g=9.8m/s^2) and the sampling frequency range from 0.05 to 300Hz. All of the accelerometers were fixed on the the cable nodes and the cable nodes were thought to vibrate synchronously with the glass.

A collection instrument with 16 channels and a computer were used to collec the acceleration data.



a) The anemometer b) The accelerometer c) The collection instrument

Figure 2: Monitoring instruments

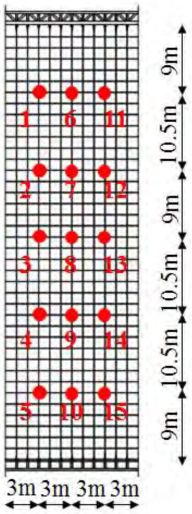


Figure 3: The measuring point layout of wind effects monitoring

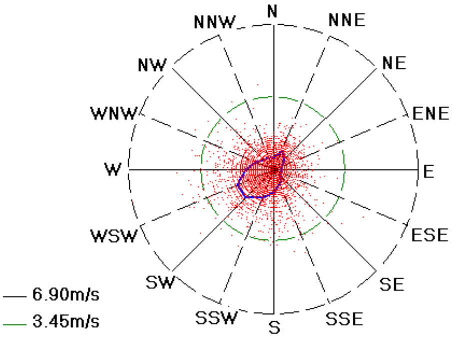


Figure 4: Wind speed and direction roses /2013.12.12

3. Wind field characteristics

In order to determine wind loads and ensure the safety of the buildings under wind, it is necessary to research wind field characteristics.

The wind speed and direction data of 2013.12.12 is chosen for example. Figure 4 shows the wind speed and direction roses, it indicates that the main wind direction is southwest winds. Figure 6 and Figure 7 show the average wind direction and speed within 10min period, and the 10mins maximum speed is 2.06 m/s. Figure 7 shows the Instantaneous wind speed within 3s period, and the extreme wind speed is 6.9m/s appeared at 12:07.

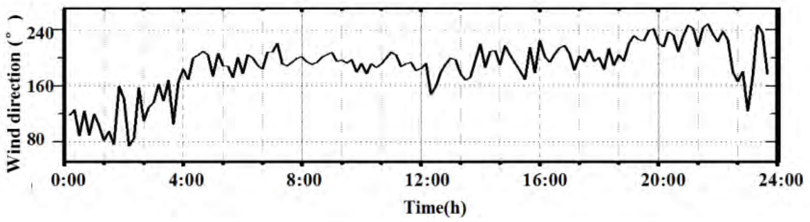


Figure 5: Average wind direction within 10min period

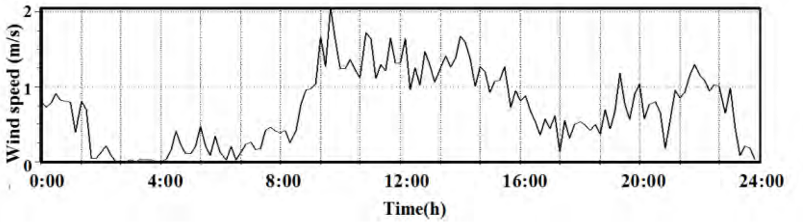


Figure 6: Average wind speed within 10min period

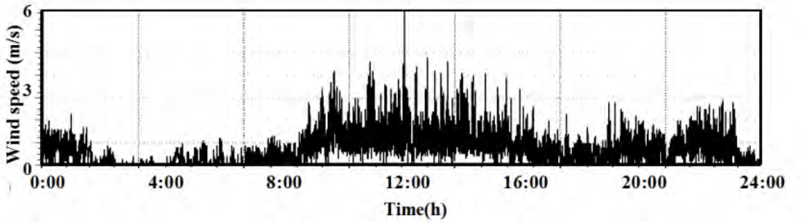


Figure 7: Instantaneous wind speed within 3s period

Turbulence intensity indicates the degree of instantaneous wind deviating from the mean wind speed, and it is one of the important indicators to evaluate the degree of the stability of the air flow. Turbulence intensity is related to the terrain, the surface roughness and other factors, and the Turbulence intensity in the height of z is calculated as:

$$I_{(z)} = \frac{\sigma_{(z)}}{V_{(z)}} \tag{1}$$

In Equation (1), $V_{(z)}$ means the average wind speed (for 10 minutes), and $\sigma_{(z)}$ means the standard deviation of the instantaneous wind speed relative to the average wind speed. Figure 8 shows the turbulence intensity in December 12, 2013. The values in some period of time rising to 7.5 because of the low average wind speed, and there are even no value near 4 a.m. because of the average wind speed value reaching 0. The average turbulence intensity reaches 1.13, But the value is 0.65 considering the time from 8 a.m. to 8 p.m..

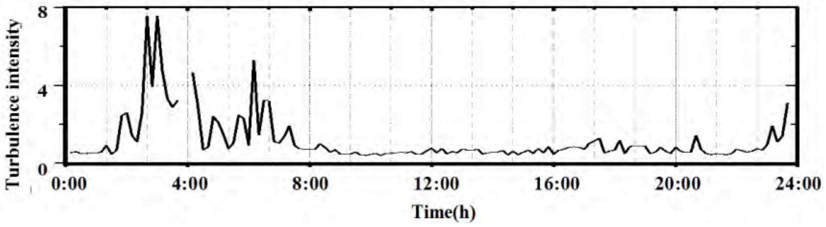


Figure 8: Turbulence intensity curve

In many design codes and standards for wind loading, a peak gust wind speed is used for design purposes, for example within 3s period. Gust factor represents the fluctuating strength of the wind and gust factor within the period of t_g can be calculated as:

$$g(t_g) = 1 + \frac{\max[\overline{u(t_g)}]}{V} \tag{2}$$

In Equation (2), t_g means the gust duration, generally taking 3s; u means the fluctuating wind speed; V means the average wind speed within 10min period.

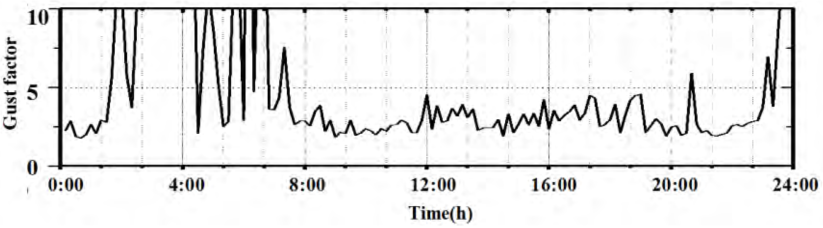


Figure 9: Turbulence intensity curve

The turbulence intensity is shown in Figure 9. Similarly with the values of turbulence intensity, the values of gust factor in some period of time rising to 58 and there are even no values near 4 a.m. The average turbulence intensity reaches 5.6, But the value is 2.86 considering the time from 8 a.m. to 8 p.m..

Fluctuating velocity spectrum reflects the distribution of the turbulent energy of the fluctuating wind in the frequency domain. In 1961, Canada's wind engineering expert Davenport put forward the fluctuation wind spectrum of the atmospheric boundary layer, and this spectrum has become the most popular one in the world.

$$\frac{nS(z,n)}{v_*^2} = \frac{4f^2}{(1+f^2)^{4/3}}, \ f = \frac{1200n}{\overline{v_{10}}}, \ v_* = K\overline{v_{10}}^2 \tag{3}$$

In Equation (3), $S(z, n)$ means the fluctuation wind spectrum; n means the fluctuating frequency; $\overline{v_{10}}$ means the mean wind speed in the height of 10m. K means the ground roughness coefficient.

The measured longitudinal fluctuation wind speed spectra are calculated and shown in Figure 10. It fits well with the Davenport spectrum.

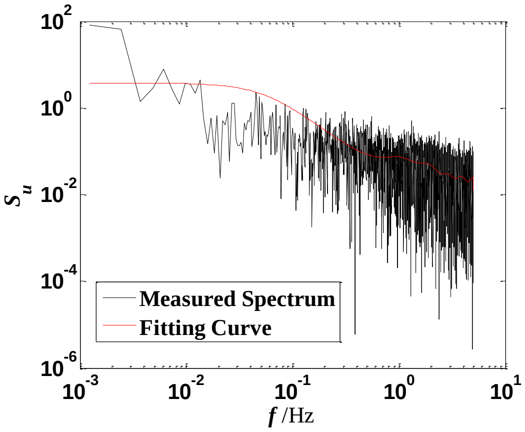


Figure 10: Fluctuation wind speed spectra

3. Probability distribution characteristics of wind-induced response

Wind-induced response is one of the important indicators to evaluate the security of monolayer cable net structure. The acceleration time history curves of some measuring points (10mins long from 12:00 on December 12th 2013) are shown in Figure 11.

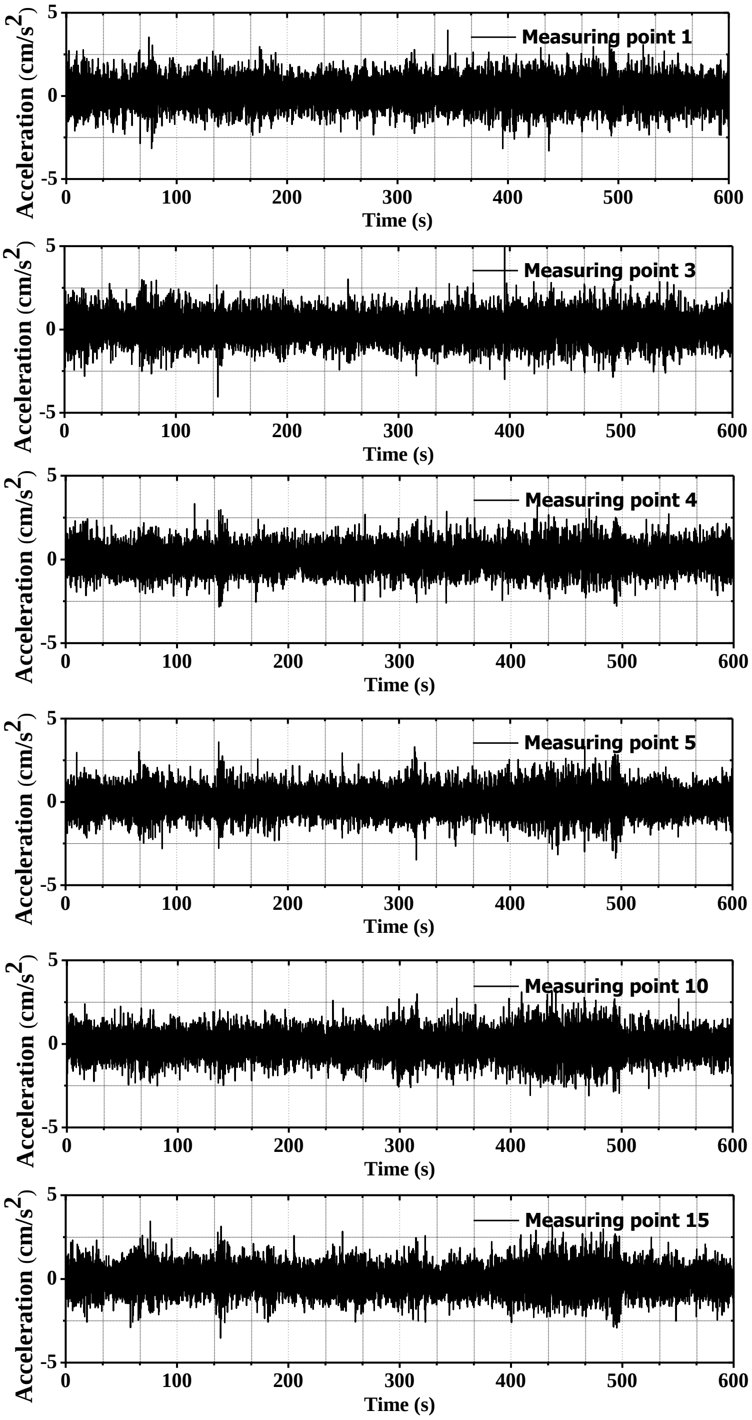


Figure 11: Acceleration time history curves

Probability distribution characteristics of measured acceleration with great significance can be obtained through Probability and Statistics Analysis. The probability statistics of stochastic processes are commonly described by the third and fourth order statistics, named skewness and kurtosis. Skewness can reflect the symmetry of the probability distribution and kurtosis can reflect the steepness of the probability distribution curve. The skewness of Gaussian distribution is 0, and the kurtosis of Gaussian distribution is 3. If the kurtosis of the measured acceleration is greater than 3, the probability distribution of the measured acceleration will be steeper and have a thin tail.

Figure 12 shows the probability density distribution of normalized acceleration, it can be obtained that the probability distribution of the measured acceleration matched normal distribution well.

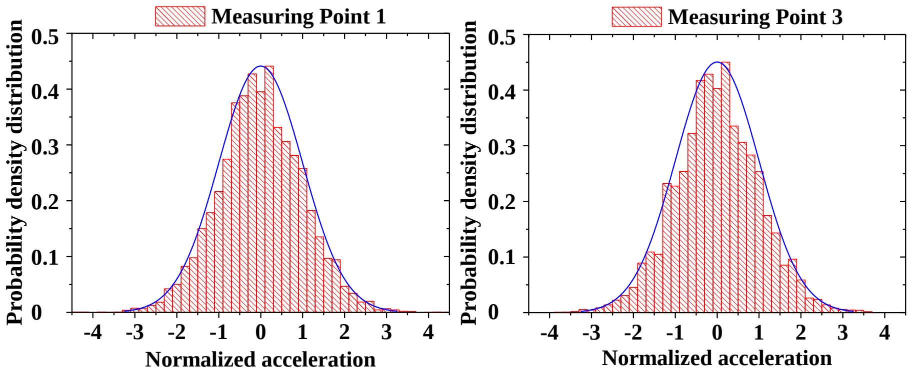


Figure 12: Probability density distribution of normalized acceleration

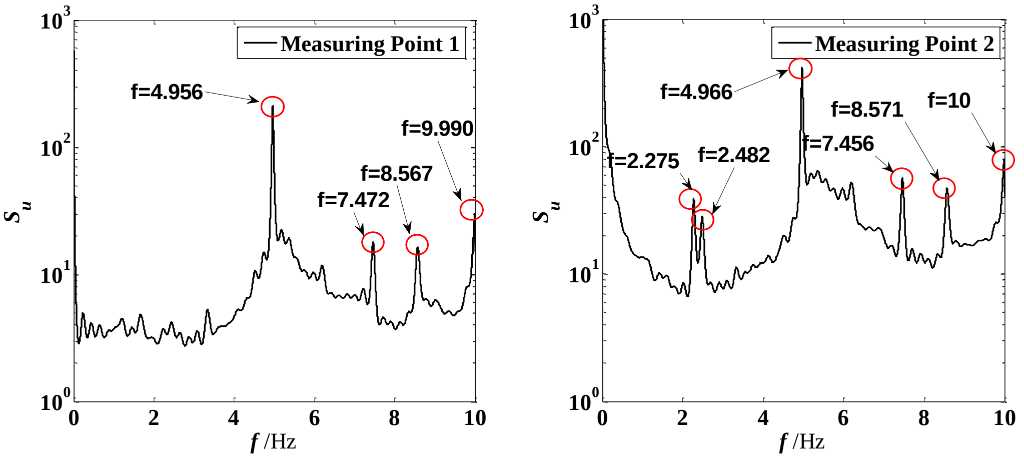
Table 1 shows the statistics of measured acceleration of some measuring points. The kurtosis is far less than that of Gaussian distribution. The reason of this phenomenon is that the monolayer cable net has a nonlinear stiffness under normal operating conditions. The wind-induced response of the monolayer cable net does not belong to a Gaussian distribution.

Table 1 Statistics of measured acceleration

Measuring Point	Mean (cm/s^2)	Standard Deviation	Skewness	Kurtosis	Minimum (cm/s^2)	Maximum (cm/s^2)
1	0.18564	0.7849	0.02868	0.34961	-3.2898	3.94775
3	0.12239	0.79023	0.02788	0.44874	-4.03748	5.26367
4	0.12584	0.72453	0.07373	0.69235	-2.96082	4.57581
5	0.03812	0.73498	0.02845	0.84073	-3.58887	3.58887
10	-0.05694	0.75313	-0.0148	0.47342	-3.11035	3.17017
15	-0.03742	0.75086	0.06247	0.50159	-3.52905	3.43933

4. Modal parameters

The modal parameters of the glass curtain were calculated by power spectrum analysis of measured acceleration. Figure 13 shows the power spectrum of measured acceleration. Peaks of the power spectrum are relatively evident, so the natural frequencies can be easily recognized.



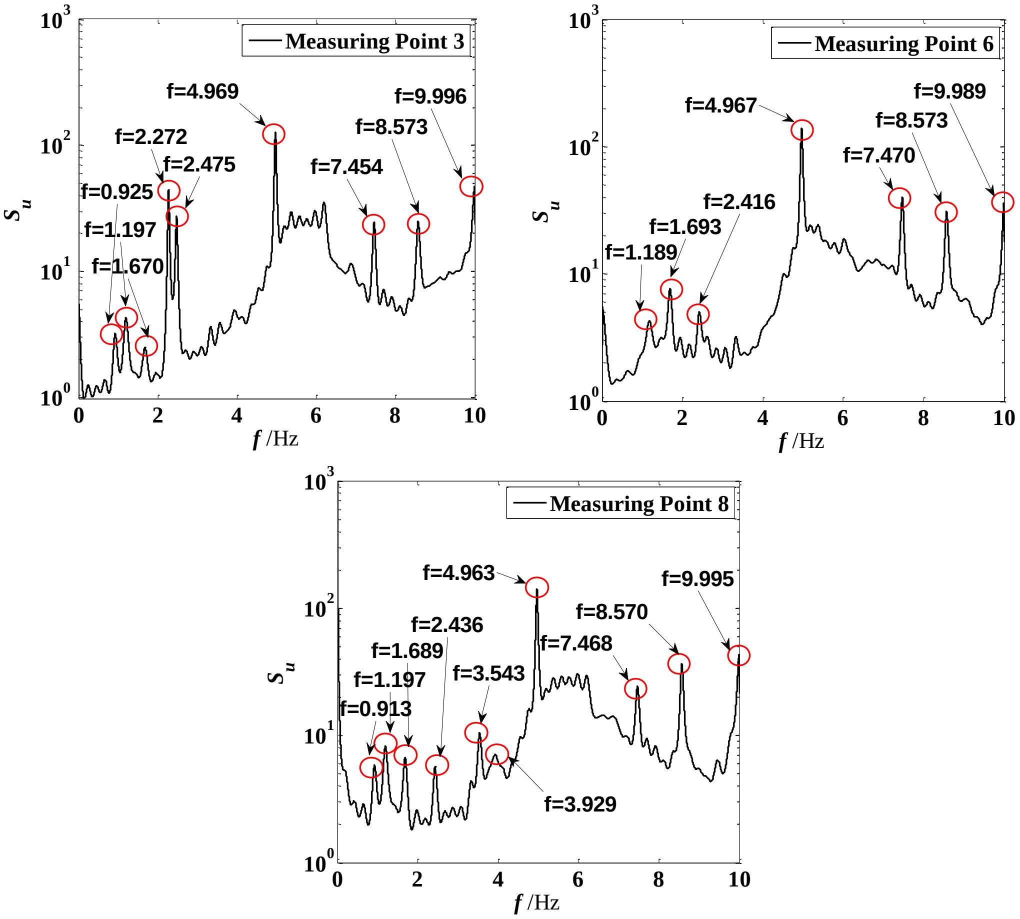


Figure 13 Power spectrum of measured acceleration

Table 2 shows the natural frequency of some measuring points. It is Obvious that there are some similar natural frequencies in different measuring points. Measuring Point 8 has most natural frequencies because of the maximum freedom.

Table 2 Natural frequencies of the measuring points

Measuring Point	Natural Frequency (Hz)								
	f1	f2	f3	f4	f5	f6	f7	f8	f9
1								4.966	7.456
2				2.275	2.482			4.966	7.456
3	0.925	1.197	1.670	2.272	2.475			4.969	7.454
6		1.189	1.693		2.416			4.967	7.470
8	0.913	1.197	1.689		2.436	3.543	3.929	4.963	7.468

5. Conclusions

This paper introduces the field measurement of Shanghai Lujiazui Diamond Tower and shows the wind environment and the wind-induced vibration characteristics of the monolayer cable nets. The main conclusions are as follows:

(1) Obtaining the wind field and the structure's wind-induced response by field measurement is the most effective means to study the wind effects of monolayer cable nets.

(2) Wind field characteristics were analysized and the spectrum of fluctuant wind velocity measured was basically in agreement with Davenport wind spectrum

(3) Probability distribution characteristics of wind-induced response were analysized, and it does not belong to a Gaussian distribution because of the structure's nonlinear stiffness.

(4) Natural frequencies of the glass curtain were calculated by power spectrum analysis of measured acceleration.

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