Wind-induced response monitoring and study of monolayer cable net

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Abstract

Natural frequency is the reflection of structural property. The change happened in the structure will result in change of the natural frequency. Thus, it's feasible to detect the damage on the structure by monitoring the vibration. Therefore, a field monitoring project was carried out to monitor the vibration of cable-net. Fifteen acceleration sensors and an anemometer were installed. Based on the vibration data, the first-ten order frequencies of cable-net were identified. Then, the identification results were used to modify the finite element model of cable-net to get the accurate finite element model accord with the current condition. Also, the frequency domain calculation method was adapted to analyze the cable-net under different conditions. The results indicate that the natural frequencies of cable-net are a little lower than the initial condition and the structure is under safe condition. This method can also provide reference for similar projects.

Keywords: cable net, structural health monitoring, frequency domain calculation

1. Introduction

Monolayer cable net was subject to the influence of environment and wind-induced vibration under long term service. These effects can cause internal force of cable decreases and structural damage. Due to the large numbers of cable, it's difficult to measure all cable forces. Thus, it's necessary to take a new method to detect the damage.

Structural health monitoring refers to using the nondestructive sensing technology and structural response to analyze the structural characteristic [1,2]. The basic idea is to monitor the structural response under long term service to detect the damage on structures. Natural frequency is the reflection of structural property. The change occurred in the structure will cause the change of natural frequency [3]. Based on this idea, a monitoring project was conducted on the cable net with high 60.05m and wide 21m. Fifteen accelerators were installed on the monolayer cable net to monitor the vibration. And the wind field characteristics are also monitored. In order to compare the variation between the present stage and the initial stage, a FEM model was built based on the initial parameters. The comparison indicates the frequencies are basically the same with identification results are a little lower than the FEM results. At last, frequency domain calculation method ware adopt to calculate the wind-induced vibration at the present stage and the initial stage. The results are shown the cable net is in a safe condition and the monitoring method is effectivity.

2. Project introduction

The cable-net curtain wall belongs to the Lujiazui Diamond Building which is located In the Pudong district of Shanghai City. Diamond Building has two tower buildings which are independent and symmetrical. In the middle of the two tower buildings, the cable-net is built on it with 60.05m high 21m wide, as shown in Fig.1. The grid size of cable-net is 1.5×1.5m. Two types of cable are used on the cable-net. Detail material properties of cable are shown in Table 1.

Table 1 Material properties of cable

Type	**Nominal-Diameter (mm)**	**Density (kg/m)**	**Elasticity-Modulus (Mpa)**	**Equivalent-Diameter (mm)**
Horizontal	36mm	6.34	127600	31.9
Vertical	16mm	1.27	136000	14

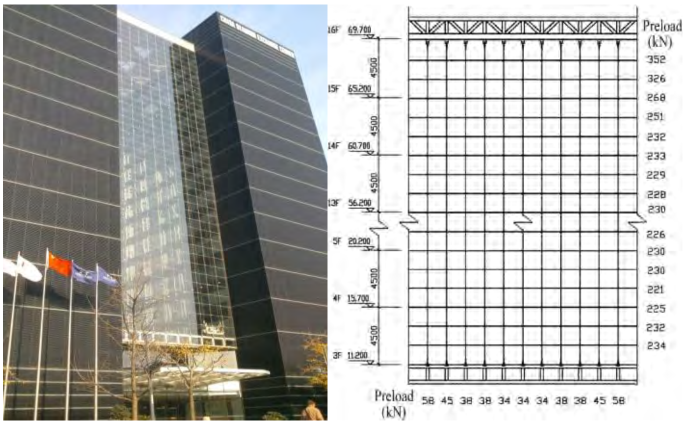


Figure 1 Photograph of cable-net of Diamond building

2.1. Dynamic property

The finite element model was established by the 3D3S software,as shown in Fig.2. The natural frequency is listed on the table 2. The results demonstrate that the natural frequencies are closely.

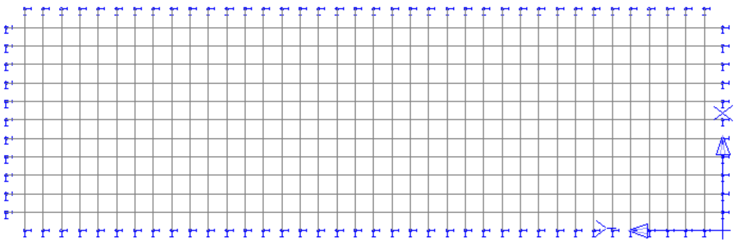


Figure 2 Finite model of cable-net of Diamond building

Table 2 Natural Frequency of cable net by FEM

Mode	**1**	**2**	**3**	**4**	**5**
Frequency/Hz	1.474	1.502	1.554	1.623	1.702
Mode	10	50	100	150	200
Frequency/Hz	2.234	4.297	5.664	7.023	8.325

3. Monitoring scheme

In order to systematically study the wind field characteristic and the response of cable net under wind. The anemograph type is Kuanker FA01XA with range 0~60m/s. The angular resolution is 0.35° . The accelerometer is Lance LC0116T with sensitivity 10.177V/g. The range is 0~300Hz.. The type of data-acquisition instrument is INV306U.The instruments are shown in fig.3. Fifteen monitoring points are installed on the cable-net. The sketch of monitoring point is shown in the fig.4.

(a) data-acquisition instrument (b) anemograph (c) accelerometer

Figure 3 Monitoring instrument

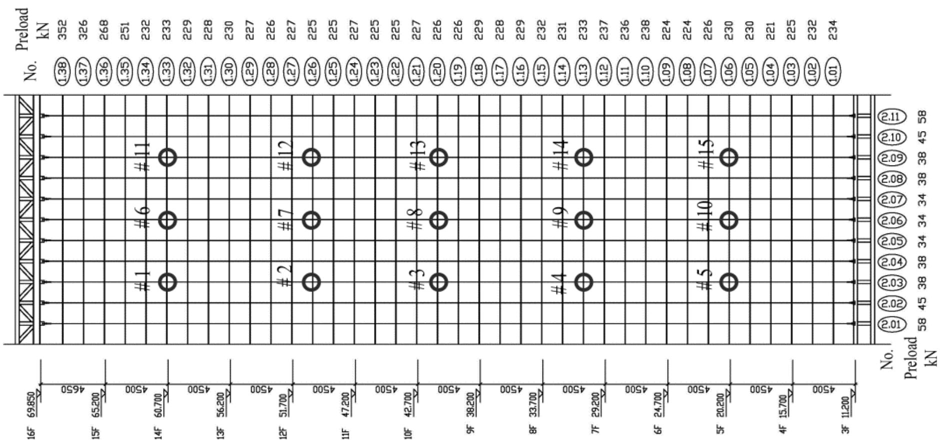


Figure 4 Sketch of monitoring point

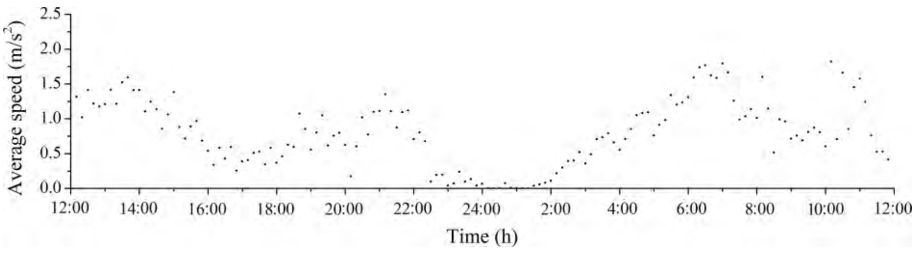
4. Monitoring data analysis

4.1. Wind field characteristic

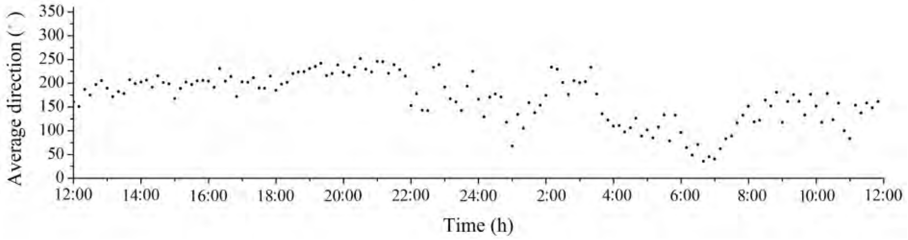
Fig.5 (a) and (b) is the average speed and direction of wind in 10 min from 12:00 on Dec12 to 12:00 on Dec 13 in 2013. The figure indicates the prevailing direction of wind is 150°~250° on Dec 12 and 100°~200° on Dec 13. Maximum wind speed is 1.867 m/s. The turbulence intensity of wind is the primary affecting factors on the cable-net wind-induced vibration [4]. The turbulence intensity $I(z)$ can be defined as:

$$I(z) = \sigma_{vf}(z) / \bar{v}(z) \quad (1)$$

Where, the $I(z)$ is the turbulence intensity at z meters high, the $\sigma_{vf}(z)$ is the root mean square of wind speed and $\bar{v}(z)$ is the average wind speed. Fig.6 showed the turbulence intensity of fluctuant wind.



(a) Average speed of wind



(b) Average direction of wind

Figure 5. Average wind speed and direction (Dec12 ~ Dec 13, 2013)

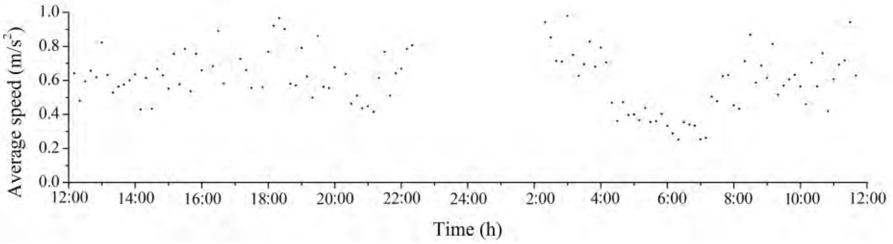


Figure 6. Turbulence intensity of fluctuant wind (Dec12 ~ Dec 13, 2013)

4.2. Vibration property of cable-net

Fig.7 show the acceleration response of the monitoring point. Table 3 shows the identification results[5]. The results indicate the identification frequencies are a little lower than the initial condition.

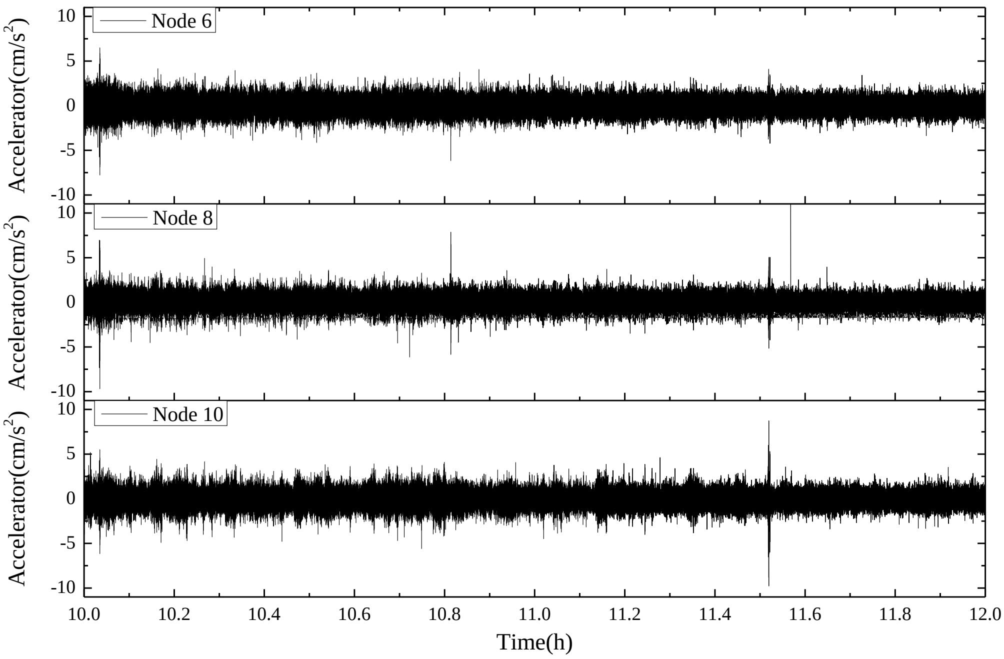


Figure 7. Acceleration response for two hour (10:00~12:00, Dec 13, 2013)

Table 3 Result of Natural Frequency of cable net by monitoring

Mode	1	2	3	4	5
Frequency/Hz	1.366	1.417	1.451	1.499	1.464
Mode	6	7	8	9	10
Frequency/Hz	2.115	3.660	4.997	6.579	7.829

5. Theory of frequency domain method

Frequency domain calculation method is one of the major methods on wind-induced vibrations analysis [6]. In order to analyze the wind-induced response of cable-net under different stages, the frequency domain calculation method was adopted. The initial FEM model was modified based on the identification parameters to obtain the FEM model corresponding to present condition. Then the frequency domain method was applied to obtain the wind-induced response (root-mean-square displacement, RMS) of cable net under the different condition.

Fig.9 show the RMS of displacement of cable-net under initial and current condition. The results indicate the vibration of the current cable-net has a little larger than the initial condition, but it still in the allowable value. It means the structure is in a safe condition.

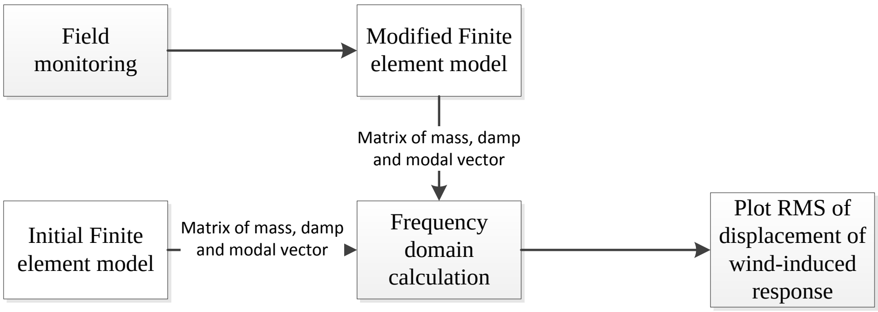
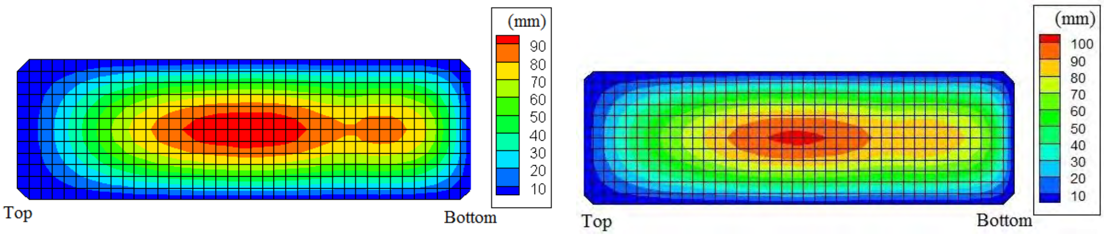


Figure 8. Program flowchart of calculating wind-induced vibration



(a) Initial condition (b) Current condition

Figure 9. RMS of vertical displacement in different condition

6. Conclusion

This paper shows the efficiency of the health monitoring technique for evaluation the health condition of the cable-net. From the analysis, we can conclude that:

(1) The identification frequency indicates the identification frequencies are a little lower than the initial condition.

(2) The results of frequency domain calculation method indicate the vibration of the current cable-net has a little larger than the initial condition. But it still in the allowable value. It means the structure is in a safe condition.

(3) This health monitoring technique can also provide reference for similar projects.

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