Measurement and Analysis of Wind-Induced Vibration Response of the Overhead Working Truck

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Abstract. We obtained the vibration response of the GKZ17 overhead working truck under normal wind load through field measurement made for four operating conditions. In the test, a vibration test system was arranged on the working platform of this overhead working truck. The time-domain and frequency-domain characteristics of displacement and acceleration were obtained from analysis on the measured data. The results show that when the wind direction is perpendicular to the working plane, the downwind response is dominated, but the crosswind response is also large and shall be highly valued; and when the wind direction is parallel with the working plane, the downwind wind-induced vibration response is small and the crosswind response is dominated. The frequency domain analysis indicates that this overhead working truck is more sensitive to low-order frequencies.

1. Introduction
Overhead working truck is a special vehicle that transports people and goods to a certain height for work at the height. It is widely applied in a variety of industries such as building, municipal construction and fire extinguishing. The studies on overhead working truck mostly focused on the strength analysis and optimization of the working boom, the stability of the working truck and the leveling system. In literatures [1-3], the authors performed stress, deformation and modal analysis on work-at-height telescopic boom with the finite element method, optimized the structure and proposed an improvement on the weak load-bearing points. In literatures [4-6], the authors performed research and simulation on the leveling system of overhead working truck based on the mechanical-electrical-hydraulic integrated technology. In literatures [7], the authors using the finite element method to get a touch analysis of aerial platform arm. In literatures [8-9], the authors performed kinetic study on several overhead working trucks. In recent years, various overhead working trucks have kept increasing their working heights, slenderness ratio and sensitivity to wind load, which has become one of the main loads in the design of overhead working trucks. Continuous wind-induced vibration may result in fatigue damage to the structure and discomfort of the operators on the working platform. However, many difficulties have been confronted in the wind-resistant design and calculation of overhead working machinery due to the randomness of wind loads and the poor understanding of the wind and structure action mechanism. The theories and methods obtained through numerical simulation have large errors in actual application. Therefore, it is necessary to verify the numerical simulation results through field measurement. Currently, field measurement studies on wind-induced vibration response of structures mainly aim at important high-rise buildings, large bridges and high-rise structures, etc. Some theories and methods for the calculation of wind-induced vibration response have been summarized through decades of research and development.
Xu et al.[10] studied the wind-induced vibration characteristics of super high-rise buildings by numerical simulation and field measurement method. Yang et al.[11] performed measurement study on wind-induced vibration of Guangzhou International Financial Center under typhoon load. Li et al.[12-13] obtained the acceleration response of several super high-rise buildings through field measurement and studied the relation between the wind speed and the acceleration response at the top of the buildings. However, no enough importance has been attached to the measurement study on wind-induced vibration of overhead working machinery due to the limitation of test equipment. To a certain extent, the wind-resistant design of the structure of overhead working truck is based partly on empiricism and partly on blindness. Therefore, it is of great significance to obtain the time-frequency characteristics of wind-induced vibration response of overhead working trucks through field measurement so as to provide a reliable basis for the wind-resistant design of overhead working trucks.

2. Introduction to the structure of the overhead working truck

The GKZ series folding boom overhead working truck, with a maximum working height of 17 m, uses an automotive chassis, H-H-shaped legs and a 360° full-rotation platform and is characterized by ease of operation and good stability. Its main structure consists of an automobile chassis, a rotation platform, an upper boom, a lower boom, a small boom, a working platform and derricking cylinders, as shown in Figure 1. The working booms are folded when the truck is in driving state. During work at height, the working booms are extended to a certain angle by the derricking cylinders of the upper and lower booms, respectively, to transport workers and materials to the work positions; the working platform is ensured by the leveling mechanism to be horizontal at any position. The booms are made of welded 16Mn steel plates that are hinged by horizontal pins.

3. Field measurement of wind-induced vibration response of the overhead working truck

3.1 Test equipment and arrangement

The testing was performed using the TST5926 test and analysis system for dynamic characteristics of large structures manufactured by Jiangsu Test Electron Equipment Manufacturing Co., Ltd. This system includes hardware and software. The hardware mainly consists of a collector, a wireless router and a computer. The collector has a built-in sensor with high sensitivity and low-frequency velocity. Figure 2 shows a block diagram of the collector module. The test and analysis software is a signal processing software based on the VC++ development platform. This software, containing modules for real-time collection, display, analysis and saving, has a strong analysis and processing ability.
The GKZ17 overhead working truck was selected as a test object in the field measurement of wind-induced vibration response. Two collectors were placed in a mutually perpendicular manner to obtain wind-induced vibration response signals in downwind, cross wind and vertical wind directions. Signals obtained by the collectors were transferred to the computer via the wireless router. Figure 3 shows the test system.

3.2 Test conditions.
The test was performed on January 24, 2016, when it had north wind with scale 4 and good weather conditions according to the broadcast of the meteorological observatory and the maximum wind speed measured with an anemograph was 6.5 m/s. There was no tall building on the test site. The average wind speed estimated according to the wind scale was about 5 m/s. Measurements were made for the following four conditions (as shown in Figure 4):

- Maximum working height condition and maximum working range condition with wind direction perpendicular to the working plane;
- Maximum working height condition and maximum working range condition with wind direction parallel to the working plane.

Figure 4. The **a**-Maximum working height condition and the **b**-Maximum working range condition
4. Time-domain analysis of measured results
The sampling frequency was set to 100 Hz in the test. The sampling mode was real-time continuous collection mode. Due to the limitation of various conditions, only eight minutes were assigned to sampling for each measurement group. The test obtained abundant vibration response data of the working platform of the overhead working truck under favorable wind load.

![Figure 5. Along-wind displacement response time history](image)

![Figure 6. Along-wind acceleration response time history](image)

Figures 5 and 6 show the displacement and acceleration response time history of the working platform under the maximum working height condition when the wind direction is perpendicular to the working plane. As shown in the figures, the displacement and acceleration response under both conditions are a zero-mean random process. Table 1 lists the root mean squares of displacement and acceleration response in different directions under both conditions. As shown in the table, when the wind direction is perpendicular to the working plane, the downwind displacement response and acceleration response are significantly greater than the vertical wind and crosswind response, indicating that the downwind response is dominated for the overhead working truck under this condition, but the crosswind and vertical wind acceleration response is also large. Although the uncertainty of wind directions during measurement may result in increased measured values, designers of overhead working truck shall pay high attention to this measurement result. When the wind direction is parallel with the working plane, the crosswind response is greater than that in other two directions, indicating that the wind-induced vibration response of this working truck is related to the structural style of the working truck. The working booms are connected using a hoist cylinder, so the rigidity of the entire structure in the working plane is enhanced, resulting in a small downwind wind-induced vibration response.

| Table 1. Root mean squares of displacement and acceleration response in different directions |
|-----------------------------------------------|------------------|------------------|-----------------|------------------|
| Maximum working height                        | Maximum working range |
| Displacement (mm)                              | Acceleration (mm/s²) | Displacement (mm) | Acceleration (mm/s²) |
| Wind direction perpendicular to the working plane | Along-wind | 1.19 | 14.9 | 0.58 | 10.23 |
| Wind direction parallel with the working plane | Along-wind | 0.49 | 16.5 | 0.06 | 5.59 |
|                                              | Cross-wind | 0.42 | 11.21 | 0.06 | 6.38 |
|                                              | Vertical-wind | 0.12 | 6.77 | 0.19 | 10.17 |
|                                              | Cross-wind | 1.21 | 20.1 | 0.78 | 12.68 |
|                                              | Vertical-wind | 0.16 | 7.53 | 0.23 | 11.92 |

5. Frequency-domain analysis of measured results
Figures 7 and 10 show the displacement and acceleration spectrum of the working platform under the maximum working height condition and the maximum working range condition when the wind
direction is perpendicular to the working plane. As indicated in the figures, this working truck has different fundamental frequencies for different structural styles and that the fundamental frequencies are 0.85 Hz and 1.32 Hz under the maximum working height conditions and the maximum working range condition, respectively.

![Figure 7. Along-wind displacement spectrum](image1)

![Figure 8. Along-wind acceleration spectrum under](image2)

![Figure 9. Downwind displacement spectrum under the maximum working range condition](image3)

![Figure 10. Downwind acceleration spectrum under the maximum working range condition](image4)

Displacement and acceleration analysis shows that the acceleration response spectrum has several response peaks at higher frequencies, but the peak response at fundamental frequencies is large on the whole, indicating that this working truck is more sensitive to low-order frequencies. The working platform showed similar frequency domain characteristics when the wind direction was parallel with the working plane.

6. Conclusions

(1) When the wind direction is perpendicular to the working plane, the peaks and root mean squares of the downwind displacement and acceleration response are greater than those of the vertical wind and the crosswind response, indicating that the downwind response is dominated for the overhead working truck under this condition, but the crosswind and vertical wind acceleration response is also large. Designers shall pay high attention to this in the wind-resistant design of overhead working machinery, though the uncertainty of wind directions during measurement may result in increased measured values.

(2) When the wind direction is parallel with the working plane, the working booms are connected using a hoist cylinder, so the rigidity of the entire structure in the working plane is enhanced, resulting in a small downwind wind-induced vibration response while the crosswind response is greater than that in other two directions.

(3) The fundamental frequencies are 0.85 Hz and 1.32 Hz under the maximum working height
condition and the maximum working range condition, respectively. The acceleration response spectrum has several response peaks at higher frequencies, but the peak response at fundamental frequencies is large on the whole, indicating that this working truck is more sensitive to low-order frequencies.

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