# Critical Wind Speed Analysis of Large-section Steel Box Girder Lifting in Urban Areas Based on Lifting Offset

Lei Mao [1,a], Qiliang Wu [1,b], Yuming Zhang [2,c], Shengtao Wang [2,d], and Shengwei Yang [3,e]

[1] Hefei Urban Construction Investment Holding Co. Ltd,Hefei, Anhui, China;

[2] Anhui Road&Bridge Engineering Co.Ltd,Hefei, Anhui, China

[3] Hefei University of Technology,Hefei, Anhui, China

[a] 878908313@qq.com, [b] 1095326742@qq.com, [c] 1984424043@qq.com,

[d] 2287404087@qq.com, [e] 3024319405@qq.com

**Abstract.** This study takes the lifting of steel box girders for interchanging traffic in a certain area as the research background, and considers the limitation of lifting by the surrounding buildings during the lifting process. Combined with the topographic environment and climatic conditions where the project is located, based on the key technology of large-section steel box girder lifting construction, the displacement change of large-section steel box girder lifting under different wind speeds is explored. To this end, a method for calculating the lifting offset is proposed, aiming to provide guidance for the safe construction of large-section steel box girder lifting in urban areas. Meanwhile, the concept of critical wind speed is introduced in this study to determine the critical conditions in the lifting process, i.e., the lifting process may be unsafe when the wind speed reaches the critical wind speed. The results show that the average displacement of the most unfavourable member increases from 0.024m to 1.541m when the wind speed increases from 3m/s to 27m/s; under the same wind speed, different area to mass ratios have a greater effect on the member displacement; considering the safety of the lifting construction, it is recommended that the value of the critical wind speed should be taken as 17m/s, and it is recommended to stop the lifting of the member or to strengthen the safety measures when the wind speed is greater than the critical wind speed during the lifting process. By analysing the change of lifting displacement and critical wind speed, this study provides an important reference and decision-making basis for the construction safety of large-section steel box girder lifting in urban areas.

**Keywords:** Lifting process, windward area, lifting offset distance.

## 1. Introduction

The development of national economy is closely related to road construction. Urban road construction is an important part of national infrastructure construction, while the construction of viaducts plays a key role in urban transport development. In the process of viaduct construction, the use of steel components and prefabricated components is becoming more and more common. The high strength, durability and wind resistance of steel components provide viaducts with a stable and reliable structure. Prefabricated components are produced and assembled in factories, speeding up construction and quality control. However, during the lifting process, the effect of wind speed on the lifting operation needs to be strictly considered. The safety and efficiency of lifting operations are governed by the critical wind speed. Wind speeds exceeding the critical value may lead to displacement and swinging of the lifted objects, thus posing potential risks to workers and surrounding facilities [1-3]. At present, Gao Zhengping et al [4] studied the change characteristics of wind speed at high altitude in the middle of the river by analysing the existing local wind speed observation data and meteorological conditions, in order to grasp the law; at the same time, combined with the characteristics of the seat-ground double-swinging arm rotary support holders for erecting the steel pipe tower, they studied the law of the influence of the wind load on the hoisting and positioning in the process of the construction of the high-level components and cross-bar hoisting, and put forward the corresponding safe wind speeds. Liu Mengyu et al [5] take a highly automated construction of prefabricated assembly building special lifting platform as the research object, a prefabricated assembly building construction used in lifting installation of special lifting platform for safety analysis and evaluation. Zhang Peng et al [6] considered the effects of super strong typhoon and pulsating wind. Using finite element analysis and ultimate bearing capacity theory, the ultimate bearing capacity of the platform was obtained by establishing a finite element model of the marine platform using Abaqus finite element analysis software. The safety of the offshore platform was assessed using the strength coefficient of the structure in order to achieve the safety evaluation of the platform in over-age service. Chen Peng et al [7] summarized the safety checking problem of steel structure lifting under the influence of wind load, analysed the key problems of structural lifting safety under the action of self-weight, and numerically simulated the structural response under the action of average wind and pulsating wind.

This paper takes the lifting of steel box girders for a regional interchange traffic as the research background, considers the limitation of the lifting process by the surrounding buildings during the lifting process, for the terrain environment and climate conditions where the project is located, based on the key technology of steel box girder lifting construction of large-section steel box girders, discusses the displacement change of steel box girder lifting under different wind speeds, provides a calculation method of lifting displacement for the lifting of steel box girders of large-section steel box girders in the urban area, and at the same time, introduces the concept of critical wind speed, and gives the critical wind speed for the lifting of steel box girders of large-section steel box girders in the city.

## 2. Offsetting of large-section steel box girder lifting

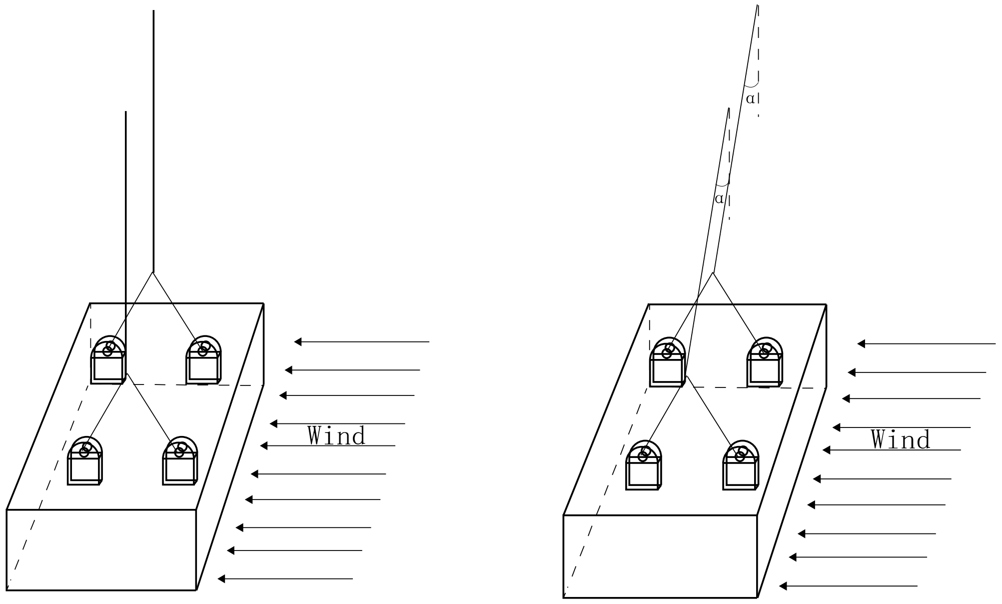
### 2.1 Project overview

A regional interchange traffic steel box girder lifting as a background, selected part of the steel box girder, including the heaviest and lightest steel box girder, according to the site construction conditions and steel box girder segmentation form, the proposed site lifting using 200t, 300t and 350t car cranes for component lifting construction. The position of lugs is determined according to the position of the centre of gravity of the steel girder, and the lugs are made of Q345qD steel plate, and the lugs are welded with the steel girder.

### 2.2 Basic mechanical formulas for component lifting

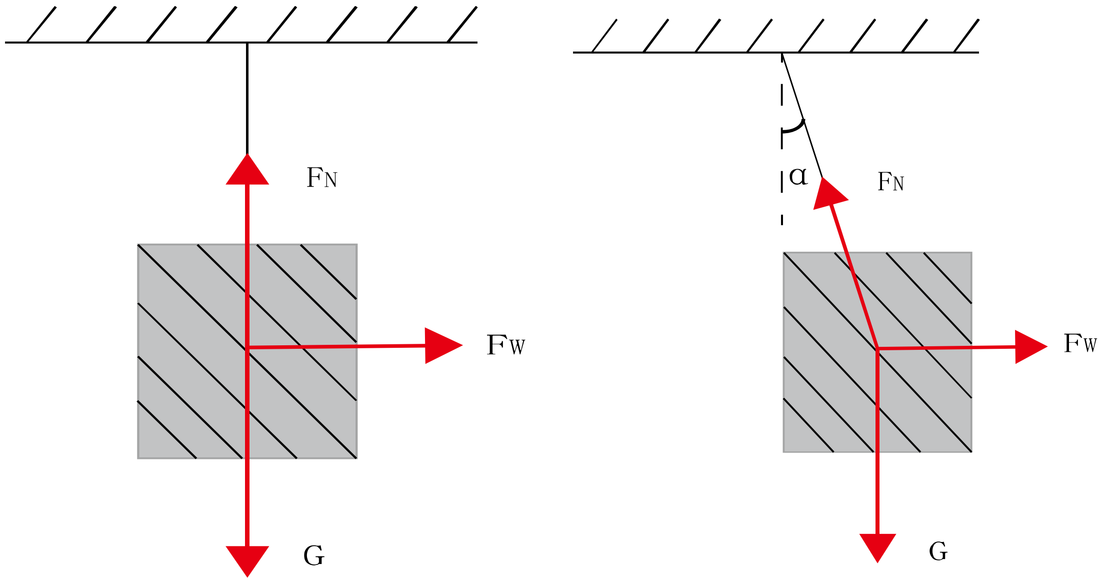
Due to the heat island effect in the city, in the process of lifting the large-section steel box girder, the steel box girder has a large surface area, which leads to a large displacement under the wind load. During the lifting process, the members are mainly subjected to the wind load, their own gravity and the tension of the rope, the lifting schematic diagram is shown in Fig. 1.

In order to facilitate the calculation of the deflection of the member under wind load, the forces acting on the member are simplified, and the wind load and gravity are equated into a concentrated load acting on the centre of gravity of the member, and the calculation sketch of wind deflection displacement is shown in Fig. 2. Based on the principle of static equilibrium, the offset angle α of the lanyard is calculated as shown in equations (1)-(3):



（a） （b）

Fig1 .Lifting Schematic



（a） （b）

Fig2. Lifting calculation sketch

$$\alpha = \arctan\frac{F_W}{G} \qquad （1）$$

$$F_{W=}F_N \sin\alpha \qquad （2）$$

$$G = F_N \cos\alpha \tag{3}$$

Where：$F_W$ is the standard value of wind load，G is the gravity of the lifting piece itself，$F_N$ is the tension of the lifting rope.

Let the length of the lanyard be L, and take the value mainly considering the difference between the height of the flat arm of the lifting equipment, the height of the tower section and the height of the stability system composed of the lifting member), then the offset value of the lifting member under the action of the wind load($\delta$) can be calculated in accordance with the formula (4):

$$\delta = l\sin\alpha = l\sin(\arctan\frac{F_W}{G}) \tag{4}$$

Standard value of wind load $F_W$ can be calculated according to equation (5-6) [8].

$$F_w = \frac{v^2}{1600}\mu_s\mu_z A B_z \tag{5}$$

$$v = k_1 k_2 k_3 v_0 \tag{6}$$

Where: $\mu_s$ is the body type coefficient; $\mu_z$ is the wind pressure height change coefficient, calculated according to class B site; A is the windward area; v0 is the basic wind speed，k1 is the wind risk coefficient，k2 is the terrain condition coefficient，k3 is the transformation of the surface category and the wind speed height correction coefficient，v is the corrected wind speed;βz is the wind vibration coefficient, the component lifting does not take into account the effect of wind vibration, so it is taken as the value of 1.0.

## 3. Critical wind speed for component lifting

### 3.1 Displacement of wind deflections from component lifting

Due to the urban heat island effect, the unstable air pressure in the area leads to large wind speed in the city, and the large spanning components with large size and windward area will have a large offset under the action of wind load, which affects the positioning of the components and the construction safety. Based on the change rule of wind speed in the city, combined with the meteorological conditions during the construction period of large components lifting, the relationship between wind speed and lifting offset for different lifting area and lifting mass ratios is given by equation (4), as shown in Fig. 3. At the same time, the most unfavourable lifting offset values of the lifting components under wind speeds of 3, 6, 9, 12, 15, 18, 21, 24 and 30 m/s are calculated, as shown in Table 1.

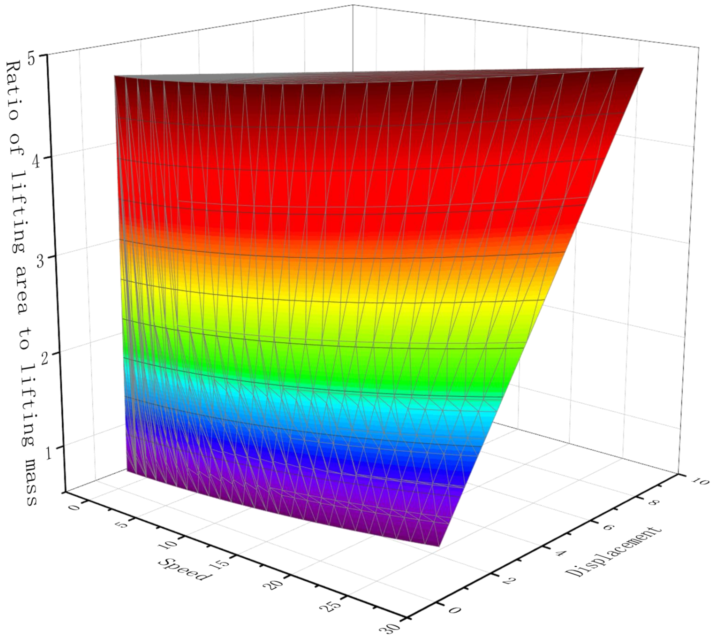


Fig 3 .Plot of wind speed versus lifting offset for different ratios of lifting area to lifting mass

Tab1.Lifting offset value of the least favourable member

| Lifting Part Number | Windward area of members/m$^2$ | Spreader quality/t | Offset values of lifting elements at different wind speeds/m | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3m/s | 6m/s | 9m/s | 12m/s | 15m/s | 18m/s | 21m/s | 24m/s | 27m/s |
| 1 | 55 | 55.8 | 0.0233 | 0.0932 | 0.2098 | 0.3730 | 0.5828 | 0.8392 | 1.1422 | 1.4919 | 1.8882 |
| 2 | 15.18 | 16.5 | 0.0218 | 0.0870 | 0.1958 | 0.3481 | 0.5439 | 0.7833 | 1.0661 | 1.3925 | 1.7624 |
| 3 | 14.835 | 16.1 | 0.0218 | 0.0872 | 0.1961 | 0.3487 | 0.5448 | 0.7845 | 1.0678 | 1.3947 | 1.7651 |
| 4 | 53.75 | 54.5 | 0.0233 | 0.0933 | 0.2099 | 0.3732 | 0.5831 | 0.8397 | 1.1429 | 1.4928 | 1.8893 |
| 5 | 81.7 | 82.6 | 0.0234 | 0.0936 | 0.2105 | 0.3743 | 0.5848 | 0.8421 | 1.1462 | 1.4971 | 1.8948 |
| 6 | 51.3 | 59.3 | 0.0205 | 0.0818 | 0.1841 | 0.3273 | 0.5115 | 0.7365 | 1.0025 | 1.3094 | 1.6572 |
| 7 | 51.3 | 56.6 | 0.0214 | 0.0857 | 0.1929 | 0.3430 | 0.5359 | 0.7717 | 1.0503 | 1.3719 | 1.7363 |
| 8 | 33.75 | 34.2 | 0.0233 | 0.0934 | 0.2100 | 0.3734 | 0.5835 | 0.8402 | 1.1436 | 1.4937 | 1.8904 |
| 9 | 9.315 | 10.1 | 0.0218 | 0.0872 | 0.1963 | 0.3490 | 0.5453 | 0.7852 | 1.0688 | 1.3960 | 1.7668 |
| 10 | 11.73 | 16.1 | 0.0172 | 0.0689 | 0.1551 | 0.2757 | 0.4308 | 0.6203 | 0.8443 | 1.1028 | 1.3957 |
| 11 | 42.5 | 54.6 | 0.0184 | 0.0736 | 0.1657 | 0.2945 | 0.4602 | 0.6627 | 0.9020 | 1.1782 | 1.4911 |
| 12 | 38.25 | 47.5 | 0.0190 | 0.0762 | 0.1714 | 0.3047 | 0.4761 | 0.6856 | 0.9332 | 1.2188 | 1.5426 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 38.25 | 48.1 | 0.0188 | 0.0752 | 0.1693 | 0.3009 | 0.4702 | 0.6770 | 0.9215 | 1.2036 | 1.5234 |
| 14 | 38.25 | 54.1 | 0.0167 | 0.0669 | 0.1505 | 0.2675 | 0.4180 | 0.6020 | 0.8193 | 1.0701 | 1.3544 |
| 15 | 38.25 | 56.1 | 0.0161 | 0.0645 | 0.1451 | 0.2580 | 0.4031 | 0.5805 | 0.7901 | 1.0320 | 1.3061 |

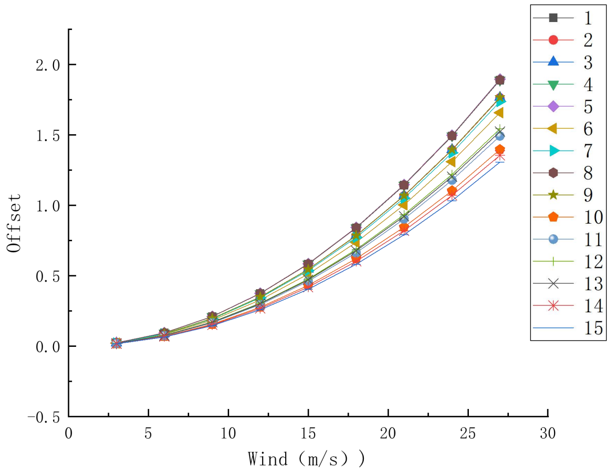


Fig 4. Least favourable member offset

It can be seen from Fig. 3: in the same ratio of windward area to component mass, the wind speed and the offset of the lifting component are approximately quadratic, Fig. 4 gives the offset of the most unfavourable component when the wind speed increases from 3m/s to 27 m/s. According to Table 1 and Fig. 5, the average offset of the most unfavourable component increases from 0.024m to 1.541m, which is nearly 604 times; component 15 has the smallest offset among all components due to its smaller windward area and larger mass; component 1 has the smallest offset among all components due to its larger wind pressure despite its larger mass; component 1 has a relatively larger windward area due to its larger wind pressure, so it has the smallest offset among all components. component 15 has the smallest offset among all the components due to its small windward area and large mass; component 1 has a relatively large windward area due to the large wind pressure although it has a large mass, so its offset is smaller among all the components. The ratio of windward area to mass for the least favourable members is given in Table 2. According to Tables 1 and 2, it can be concluded that at a certain wind speed, the larger the ratio of windward area to mass of a member is, the larger the value of the member's deflection is.

Tab2. Ratio of windward area to mass for different components

| Lifting Part Number | Area/m$^2$ | Quantity/t | Ratio of windward area to mass |
|---|---|---|---|
| 1 | 55 | 55.8 | 0.986 |
| 2 | 15.18 | 16.5 | 0.920 |
| 3 | 14.835 | 16.1 | 0.921 |
| 4 | 53.75 | 54.5 | 0.986 |
| 5 | 81.7 | 82.6 | 0.989 |
| 6 | 51.3 | 59.3 | 0.865 |
| 7 | 51.3 | 56.6 | 0.906 |
| 8 | 33.75 | 34.2 | 0.987 |
| 9 | 9.315 | 10.1 | 0.922 |
| 10 | 11.73 | 16.1 | 0.729 |

| | | | |
|---|---|---|---|
| 11 | 42.5 | 54.6 | 0.778 |
| 12 | 38.25 | 47.5 | 0.805 |
| 13 | 38.25 | 48.1 | 0.795 |
| 14 | 38.25 | 54.1 | 0.707 |
| 15 | 38.25 | 56.1 | 0.682 |

### 3.2 Critical wind speed values

Based on the study of the influence of wind load on component lifting, the wind speed that meets the safe construction conditions for lifting, i.e. the critical wind speed for construction, is examined according to calculation formula (5). Combined with the actual project construction safety needs, it is proposed to limit the value of lifting components offset should not exceed 0.5 m. Table 3 gives the critical wind speed limit values under different most unfavourable lifting components offset limit values. From Table 3, it can be seen that: for the most unfavourable component lifting, with the increase of the ratio of the area to the mass, the critical wind speed limit value decreases; for the ratio of the area to the mass is small, compared to the other components, the critical wind speed value is larger, this is mainly because of the larger mass of the lifting component, the wind area is relatively small; for the ratio of the area to the mass is large, compared to the other components, the critical wind speed value is smaller, this is mainly because of the smaller mass of the lifting component, the wind area is relatively small; for the area to the mass is large, compared to the other components, the critical wind speed value is smaller, this is mainly because of the lifting component In order to ensure the safety of component lifting construction, it is recommended that the safe wind speed value is 17 m / s. When the wind speed at the lifting place exceeds the critical wind speed value, it is recommended that the project stops the component lifting construction or strengthens the safety measures.

Tab3. Critical wind speed limit

| Lifting Part Number | Area/Quantity（$m^2/t$） | critical wind speed(m/s) |
|---|---|---|
| 1 | 0.986 | 17.378 |
| 2 | 0.920 | 17.988 |
| 3 | 0.921 | 17.974 |
| 4 | 0.986 | 17.373 |
| 5 | 0.989 | 17.348 |
| 6 | 0.865 | 18.550 |
| 7 | 0.906 | 18.123 |
| 8 | 0.987 | 17.368 |
| 9 | 0.922 | 17.966 |
| 10 | 0.729 | 20.213 |
| 11 | 0.778 | 19.556 |
| 12 | 0.805 | 19.227 |
| 13 | 0.795 | 19.348 |
| 14 | 0.707 | 20.519 |
| 15 | 0.682 | 20.895 |

## 4. Conclusion

Taking the construction of steel box girder lifting in a certain area of interchange traffic as the engineering background, considering the change rule of urban wind speed, carrying out the research on the influence of wind load on the key lifting and positioning in the process of lifting construction of high level components, and obtaining the following conclusions.

(1) In the same ratio of windward area and component mass, the wind speed and the offset of the lifted component are approximately quadratic function.

(2) When the wind speed is certain, the larger the ratio of windward area to mass of the component, the larger the value of component offset; the smaller the ratio of windward area to mass of the component, the smaller the value of component offset.

(3) For the most unfavourable component lifting, as the ratio of area to mass increases, the critical wind speed limit value decreases; as the ratio of area to mass decreases, the critical wind speed limit value increases.

(4) In order to ensure the safety of component lifting construction, it is recommended that the critical wind speed value is 17 m/s. When the wind speed at the lifting height exceeds the safe wind speed value, it is recommended that the project be stopped or safety measures be strengthened for component lifting construction.

## Funding

This work was supported by the Anhui Province Natural Science Foundation of China (Grant Nos: 2208085ME151).

## Reference

[1] Jimmy C. Ho, Hyeonsoo Yeo.Analytical study of an isolated coaxial rotor system with lift offset[J],Aerospace Science and Technology,100(2020)105818

[2] Kaito Hayami, Hideaki Sugawara , Takumi Yumino , Yasutada Tanabe ,Masaharu Kameda ,CFD analysis on the performance of a coaxial rotor with lift offset at high advance ratios[J].Aerospace Science and Technology,135(2023)108194.

[3] Xiaotong Zhang, Yafeng Gao , Qiuhua Tao , Yunran Min , Juntao Fan ,Improving the pedestrian-level wind comfort by lift-up factors of panel residence complex: Field-measurement and CFD simulation.Building and Environment229(2023)109947

[4] GAO Zhengping，HUANG Shijun，HUANG Fenghua，.Safe wind speed for hoisting components and cross-arm of the large span transmission tower[J].JOU R NAL OF NANJING TECH UNIVE R SITY ( Natural Science Edition),2019,41(02):206-211.（in Chinese）

[5] Liu mengyu. Research on the influence of wind load on the safety of special lifting platform for hoisting and installation of industrial building components [D].North China University of Water Resources and Electric Power Dissertation,2021.DOI:10.27144/d.cnki.ghbsc.2021.000350.（in Chinese）

[6] Zhang peng. Safety evaluation of overage service offshore platform structures under super typhoon[D].Qingdao University of Technology Dissertation ,2021.DOI:10.27263/d.cnki.gqudc.2021.000134.（in Chinese）

[7] Chen peng. Security analysis of large-scale steel structures during hoisting under the wind[D].Southeast University Dissertation,2017.（in Chinese）

[8] China Academy of Building Research. Code for structural loading of buildings: GB 5509-2012 [S]. Beijing: China Construction Industry Press, 2012.