Improvements of Techniques for Determining Hazardous Area Near Facilities Under Construction

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Abstract. In this work, existing methods for determining the hazardous areas of tower crane operation were considered and analyzed, the behavior of cargo deflection, cargo weight at full wind load were revealed. The study investigates the impact of wind on lifting operations and their safety, therefore, on the hazardous area on the construction site. Improved methods for determination of the hazardous area of tower crane operation in the vicinity of facilities under construction were offered with wind velocity variations. It has been established that the deviation of the cargo caused by the wind directly affects the hazardous area. Analytical dependencies between additional wind velocity and the hazardous area of tower crane were obtained. Further development in this direction is associated with necessity of air flows impact research on the safety of erecting works, especially lifting operations with high parameters of cargo resistance to the wind.

Keywords: Hazardous area · Wind louds · Cargo resistance to the wind

1 Introduction

Construction in close city development is common, for the reason that site area is limited and there is a downward trend of free territory. There is a high probability of forming hazardous area outside the construction site [1, 2].

It is known that the border of hazardous areas, in places of cargo transfer by tower cranes [3], is taken from the extreme point of the horizontal projection of the outline smallest dimension of a moveable object or wall of a building [4] with the addition of the largest boundary dimension of a transported (falling) cargo and minimum cargo dropping distance (SP 49.13330.2010 appendix G) according to Table 1 and the diagram for determining the minimum cargo dropping distance:

$$R_h = R_{working}^{max} + L^{max} + \frac{B}{2} + r, \tag{1}$$

where $R_{working}^{max}$ – maximum working radius of operation of crane; L^{max} – largest boundary dimension of mounted construction; B – smallest boundary dimension of mounted construction; r – dispersion radius of cargo dropping with a crane.

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There are no recommendations for wind velocity accounting and its effect on the lifted cargo while determining the hazardous area [5]. Therefore, it is necessary to take into account that a powerful air flow is quite capable directly affected on the determination of the hazardous area of tower crane [6]. In this regard, the purpose of this work is to determine the dependence of wind velocity on the hazardous area of tower crane operation during construction and erection work.

Table 1. Main types of cargo.

Naming unit	Windward area, m^2	Weight, kg	Air resistance coefficient, c
Timbering MAXIMOMX (3300 × 2400 mm)	7,92	408	1,5
Aluminum form (1200 × 3000 mm)	3,6	110	1,5
Wall panel V1.3-65.27*12-1	17,28	5150	1,5
Ceiling panel PK 30-2-8	0,66	1080	1,5
Concrete bucket Zitrek BN-2.0 021-1067	3,41	330	1

During research we considered that this direction was pioneer examined in the scientific work of Chanyshev R.O. [7]. In this work, the author determined the effect of the wind load on the lifted cargo during operations of the light cranes and string lifts. Having regard to the horizontal outreach of light cranes (at string lifts – consoles) outside the construction hesitates from 0,6 to 1 m, in research we take into account that cargo in case of deviating from the vertical position must not hurt or hit the building under construction. The formula is established in the research and determines the value dependence of the cargo deviation from the lifting height, full wind load and mass of cargo.

In the science work [8] Ian Skelton considered the impact of airflow on tower cranes and their down-time due to high wind velocity. It was found out that low-powered magnification of wind velocity exercised a significant influence on the safe lifting operations of the tower crane. As consequence that led to the accelerated difficulties for the operator during lifting operations on an overloaded construction site. This posed a significant security risk not only for the crane operator, but also for all workers near the crane and cargo. In the course of research Ian Skelton proposed a new solution by new type of equipment called «Lifting Wing» [9].

In the research [10] it was noted that the wind increased the risk of delayed high-rise construction. It was also revealed that the wind could increase working radius of operation of crane, while the distance from the center of the crane grew and, therefore, the overturning moment increased, which led to instability of tower crane [11].

Formation of dangerous dynamic wind loads not only exists, which is confirmed by long-term observations, but also demonstrates a tendency of growth ability [12, 13].

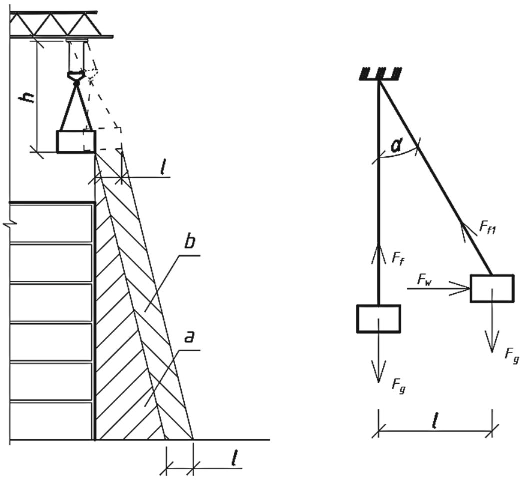

Fig. 1. Wind load impact on lifted cargo: a – hazardous area of potential cargo dropping with a crane; b – increase of hazardous area.

The effect of wind on the lifting load is evident in the form of load, the value of which depends on the wind velocity [14]. Depending on the wind force intensity, the area of cargo resistance to the wind and its direction, the radius of the hazardous area will increase [15–17]. From Fig. 1 it is clear that the radius of the hazardous area increases by value *l*.

We introduce the *l* value in the formula for determining the hazardous area for high cargo resistance to the wind:

$$R_h = R_{working}^{max} + L^{max} + \frac{B}{2} + r + l, \quad (2)$$

l – Increase of hazardous area due to wind pressure.

2 Materials and Methods

For illustration, we compare the main materials and elements, used during construction (Table 1).

When analyzing the data from the table, it may be said that some elements have a large area and low weight, while others, on the contrary, have a large weight and small area. It is necessary to compare their deviations in the same conditions. For this reason, we compile a table, where we compare cargo under investigation as far as they deviate vertically at different wind velocities. Moreover, all elements will have a low point on one level. That means the total distance from the lowest point of cargo to the crane trolley will be the same. Wind velocities assume 1–10 m/s. In our research we disassembled the following example: the process of lifting operations with the selected hook of the tower crane Giraffe TDK-8.180. For all cargos dimension *L* (distance from the crane trolley to the bottom of the cargo) we take 10,3 m.

These passport specifications are required for subsequent calculation Giraffe TDK-8.180:

– maximum radius of operation of horizontal crane arm – 30 m;
– maximum velocity of the cargo trolley – 0,66 m/s;
– velocity of rotation – 0,0133 p/s (1/s).

3 Results

It is known that the suspended cargo, being at rest, is in an upright position.

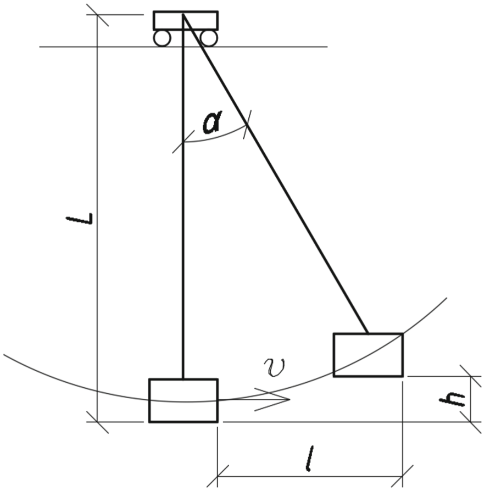

Fig. 2. Cargo deviations at trolley stop.

The cargo deviates (moves) from the original vertical position to a certain angle α under the action of horizontal force (in this case, this is a full wind load). It determines the deviation value. The suspended body is affected by gravity and the funicular force, so $F_G = F_F$. Let us assume that the force F_W of airflow affects the cargo and under this impact, the body begins to deviate and move to a distance l (Fig. 2).

3.1 Deviations of Lifted Load at Static Crane Arm

Ratio of deviation depends on wind pressure forces to gravity ratio, then:

$$tg\alpha = \frac{F_w}{F_G} = \frac{S_w \cdot p}{mg}, \tag{3}$$

where p– velocity air head.

Horizontal deviation under action of force F_W ignoring insignificant variation with altitude h, can be determined by:

$$l = L * tg\alpha. \tag{4}$$

After certain calculations, we get the behavior of the deviation distance on the physical characteristics of the cargo and on the air flow:

$$l = \frac{L * S_w * \upsilon^2 * \frac{\rho}{2}}{mg}. \tag{5}$$

It follows that the cargo, when deviating increases the hazardous area of tower crane.

It determines the impact of material characteristics and airflow rates. As a result, it turns out there is an additional new element in the formula according to SP 49.13330.2010 for determining the hazardous area:

$$R_h = R_{working}^{max} + L^{max} + \frac{B}{2} + r + \frac{L * S_w * \nu^2 * \frac{\rho}{2}}{mg}, \tag{6}$$

where L – the distance from bottom of cargo to trolley; S_w – cargo resistance to the wind; v – velocity of wind; ρ – air density 1,25 kg/m^3; m – mass of lifting cargo; g – free fall acceleration 9,81 m/s^2.

3.2 Comparison of Main Cargos

Table 2 is completed using the information from Table 1 and Formula (5). Each cargo type is determined by its deviation at different wind velocities and the same conditions.

It can be seen from Table 2 that the greatest vertical deviation occurs due to lifting the aluminum panel formwork, which is 41,4% more than when lifting the MAXIMOMX 15 panel formwork. The ceiling panel has the smallest deviation from the vertical. So, at a wind velocity of 10 m/s, the deviation of the panel is 0,06 m.

To sum it up, the amount of deviation of the elements directly depends mainly on the wind velocity and the characteristics of the lifted cargos. These include weight, windward area and the position at which the movement occurs. Changing parameters such as the length from the bottom to the hook and the area of lifting cargo, as well as, increasing the coefficient of air resistance of the element, leads to a directly proportional increase in vertical deviation. In case of increase in wind velocity, it leads to the square expand [18–25].

Therefore, it is necessary to pay more attention to the airflow velocity on the construction site during work with large cargo resistance to the wind.

Table 2. Cargo deviations results.

Velocity of wind, m/s	Timbering MAXIMO MX 3.3 × 2.4 m	Aluminum form 1200 × 3000 mm	Wall panel V1.3-65.27-12-1	Ceiling panel PK 30-12-8	Concrete bucket Zitrek BN-2.0 021-1067
1	0,02	0,03	0,00	0,00	0,01
2	0,08	0,13	0,01	0,00	0,03
3	0,17 58,6%	0,29 100%	0,03 10,3%	0,01 1,9%	0,06 21,1%
4	0,31 58,6%	0,52 100%	0,05 10,3%	0,01 1,9%	0,11 21,1%
5	0,48 58,6%	0,81 100%	0,08 10,3%	0,02 1,9%	0,17 21,1%
6	0,69 58,6%	1,16 100%	0,12 10,3%	0,02 1,9%	0,24 21,1%
7	0,94 58,6%	1,58 100%	0,16 10,3%	0,03 1,9%	0,33 21,1%
8	1,22 58,6%	2,06 100%	0,21 10,3%	0,04 1,9%	0,43 21,1%
9	1,55 58,6%	2,61 100%	0,27 10,3%	0,05 1,9%	0,55 21,1%
10	1,91 58,6%	3,22 100%	0,33 10,3%	0,06 1,9%	0,68 21,1%

3.3 Consideration of Dynamic Impacts

During the tower crane operation, swinging of the cargo occurs during starting, braking, turning of the crane arm/turret, as well as during lifting and lowering of the cargo.

We investigate two types of cargo movement:

1) Movement of a crane trolley with cargo at static crane arm;
2) Rotation of a crane arm at maximum working radius and at static trolley.

The combination of two movement types will be inefficient. Firstly, when the crane arm is turned, the cargo increases the radius of work. Secondly, the movement of the trolley from the crane partially compensates for this deviation of the cargo. Therefore, it is necessary to consider these two types separately from each other.

3.4 Crane Cargo Trolley Movement

First, let us consider the case where the trolley moves with the fixed crane arm. Then the horizontal movement of the trolley from the crane axis will cause the cargo deviation for the crane. Consequently, the movement velocity of the trolley and the cargo will be identical. In the case of the cargo trolley stop, the cargo will continue moving along the circumference equal to the length of the cable and after the equilibrium point it will deviate in the opposite direction. As a result, it increases the working radius of the tower crane.

The maximum velocity of the cargo will be at the lower point – at the point of equilibrium. And at this velocity, the load will deviate from the extreme position. At the extreme position, the maximum potential energy is numerically equal to the kinetic energy at the equilibrium point.

This deviation is obtained during erection works and wind force must be taken into account. The wind pressure will only increase the deviation and the forces causing the deviation will be summed up.

Cargo deviation is determined by:

$$l = tg\alpha * (L - h). \tag{7}$$

The horizontal deviation l can be found according to the formula:

$$l = tg(\arccos\left(\frac{L - \frac{\upsilon_T^2}{2g}}{L}\right))(L - \frac{\upsilon_T^2}{2g}). \tag{8}$$

Taking into account the formulas (5) and (8), it is finally obtained that the deviation under the action of the wind load and the movement of the crane trolley is determined by:

$$l = \frac{L(S_w * \frac{\rho \cdot \upsilon^2}{2} + mg * sin(\arccos(\frac{L - \frac{\upsilon_T^2}{2g}}{L}))}{mg}, \tag{9}$$

where L – the distance from bottom of cargo to trolley; S_w – resistance to the wind of lifting cargo; v – wind velocity; ρ – air density 1,25 kg/m^3; m – mass of lifting cargo; g – free fall acceleration 9,81 m/s^2; v_T – velocity of trolley movement (passport specifications).

3.5 Rotation of Tower Crane Arm

When the arm of the tower crane rotates, a force occurs. This force applied to the suspended cargo and directed radially from the center is called centrifugal (Fig. 3).

Horizontal deviation by force F_{cf}, ignoring the change in height h, as insignificant, can be determined by:

$$l = L * tg\alpha = L * \frac{F_{cf}}{F_G}. \tag{10}$$

Horizontal deviation l under the action of centrifugal force:

$$l = \frac{4L * R * \pi^2 * \nu^2}{g}, \tag{11}$$

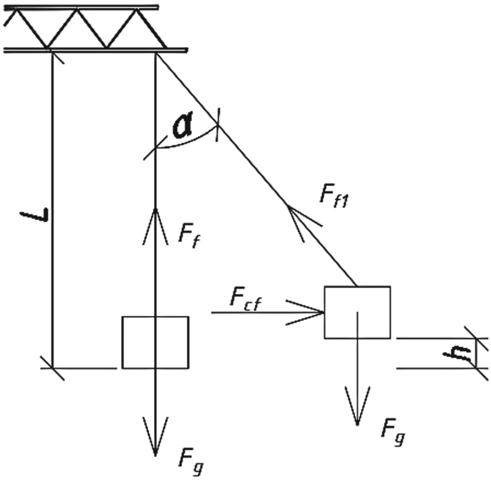

Fig. 3. Deviation under centrifugal force.

where *L*– length of cable; *R*– maximum operating radius of the crane; *ν*– crane velocity of rotation (passport data); *g*– free fall acceleration.

This deviation is obtained during erection works. Moreover, wind load must be taken into account. The wind pressure will only increase the deviation and the forces causing the deviation will be summed up. Thus, the force of the wind load F_W and the centrifugal force F_{cf} are summed. Considering the formulas (10–11), we obtain that the deviation under the action of wind load and crane arm rotation is determined by:

$$l = \frac{L(S_w \cdot \frac{\rho \cdot \upsilon^2}{2} + 4m \cdot R \cdot \pi^2 \cdot \nu^2)}{mg}, \quad (12)$$

where *L*– the distance from bottom of cargo to trolley; S_w – resistance to the wind of lifting cargo; *v* – wind velocity; *ρ* – air density 1,25 kg/m^3; *m* – mass of lifting cargo; *g* – free fall acceleration 9,81 m/s^2 (passport specifications).

Table 3 is compiled on the basis of foregoing formula. The dynamic effects arising during the operation of the tower crane and the air flow pressure are considered in Table 3. The most susceptible to cargo deviation is considered to be large-shield formwork. Calculations show that the maximum working radius of operation of crane is 30 m.

The results of the calculation show that the greatest danger is the deviation arising from the movement of the cargo trolley. In all investigated wind ranges, this deviation is 18% greater than in crane arm rotation when using MAXIMO formwork and 12% greater when in aluminum formwork.

Table 3. Results of deviation calculation (m) with an allowance of crane dynamics.

Velocity of wind, m/s	Timbering MAXIMO MX 3300 × 2400 mm		Aluminum form 1200 × 3000 mm	
	Movement of carriage	Boom swing	Movement of carriage	Boom swing
1	0,70 100%	0,24 34,3%	0,72 100%	0,25 34,7%
2	0,76 100%	0,30 39,5%	0,81 100%	0,35 43,2%
3	0,86 100%	0,39 45,3%	0,97 100%	0,51 52,6%
4	0,99 100%	0,53 53,5%	1,20 100%	0,74 61,7%
5	1,16 100%	0,70 60,3%	1,49 100%	1,03 69,1%
6	1,37 100%	0,91 66,4%	1,84 100%	1,38 75%
7	1,62 100%	1,16 71,6%	2,26 100%	1,80 79,6%
8	1,91 100%	1,44 75,4%	2,75 100%	2,28 82,9%
9	2,23 100%	1,77 79,4%	3,29 100%	2,83 86%
10	2,59 100%	2,13 82,2%	3,91 100%	3,44 87,9%

4 Conclusions

In this work the problem of determining the hazardous area increase of the tower crane, depending on the wind velocity, was solved. During operation, the crane will swing the lifted cargo due to the influence of the wind load on it and the dynamic impact during erection. The amount of deviation mainly depends on the parameters of the cargo, and this is necessary while calculating the hazardous area in order to increase the safety of construction and erection work. Dependencies recommended to determine the increase in the hazardous area of operation of tower crane, variation with the wind velocity were obtained. The main cargos used with high resistance to the wind are also considered and their possible deviations in the construction and erection works are determined theoretically.

The wind load is a dangerous factor that must be taken into account as an influence of increase the radius of operation of crane and, first of all, the hazardous area. It is very important to take into account wind velocity at the design stage of the construction general plan.

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