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Review and analysis of damage and existing systems of protecting tower cranes under the influence of a blast wave

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Abstract. Problem. *The problem of assessing the technical condition of stationary tower cranes of various types by expert organizations in order to determine the possibility of their further operation and the methods of capital repair is relevant. At the same time, one should take into account the nature of the consequences of damage to metal structures and the type of repair, if it is at all possible. The topic of the article is of a practical nature. An attempt was made to have an initial representation and visual analysis of the condition of different types of tower cranes under the conditions of explosive air shock waves depending on the distance to the cranes. The article attempts to substantiate the consequences of the destruction of metal structures, mechanisms or protection systems and to point out some regularities that require close attention during the operation of tower cranes and their further research.* ***Goal.*** *The purpose of the work was to make a damage survey of the different types of tower cranes that have been damaged and their existing protection systems and to provide assumptions for further research on the stability of tower cranes in the conditions of air shock waves.* ***Methodology.*** *The approaches adopted in the work to solve the set goal are based on the conditional division into categories of damage to stationary tower cranes under the action of air shock waves.* ***The results.*** *The analysis of damage to tower cranes will make it possible to take into account in the future the development of typical projects in accordance with the technical documentation regarding their disassembly-assembly, types of repairs, etc.* ***Originality.*** *The study of the stability of tower cranes under the conditions of air shock waves is a rare and specific direction in the field of engineering research. Therefore, the results of this study will fill the gaps in scientific literature and engineering practice.* ***Practical meaning****. The results of the study can lead to the development of new approaches and recommendations for the design of tower cranes taking into account possible air shock waves. This will allow engineers to create safer and more reliable designs for working in hazardous environments.*

Key words: *damage; tower cranes; blast wave; air blast; restoration; operation.*

Introduction

Since the beginning of the large-scale invasion of the territory of Ukraine, many areas have been damaged during shelling. In particular, active hostilities took place on the territory of the Kyiv region within the settlements: Irpin, Bucha, Borodyanka, Makariv, Gostomel, Vorzel, etc. The result was the destruction and damage of a large number of buildings and structures and various equipment on construction sites and, accordingly, also tower cranes. The tower cranes suffered damage to their metal structures from shock-explosive damage, and stationary cranes fell on the rails, which is not typical for further operation in peacetime conditions. Therefore, first of all, damage to the metal structures of tower cranes and the direct impact of an air blast wave on the stability of these cranes should be analyzed, which will allow a more systematic approach to solving this problem

Analysis of publications

Analyzing the research in the field of tower cranes in the conditions of air shock waves, it is immediately clear that no one has dealt with this issue.

There are studies on the stability of tower cranes under conditions of wind loads, strong gusts of wind, which can be close to an explosive wave in a certain area of damage.

So, for example, work [1] does not take into account the dynamic effect of wind load on tower cranes, but only refers to their design standards, which do not take into account the dynamic component of the wind in the calculations. At the same time, the design and operational features of cranes are not taken into account.

In work [2], there was a study of the movement of cranes under the influence of wind loads, the parameters of cranes under the influence of wind were determined. A calculation method is proposed to find the highest speed of movement of a crane by the wind and to predict the movement of the crane according to wind maps. Such work can be close to the study of the effect of an air shock wave on the stability of tower cranes on a rail track or on quick-mounting cranes.

The above-mentioned works complement each other, but, unfortunately, do not provide a holistic approach to accounting for the impact of wind loads on the work of cranes, and especially the impact of air shock waves.

Purpose and task

The purpose of the work is to analyze the nature of damage to metal structures of tower cranes under the influence of an air shock wave, as well as the existing protection systems of stationary cranes. In accordance with the set goal, damage should be conditionally divided into categories, which will make it possible to ensure optimal stability of tower cranes in conditions of possible explosions and compliance with a number of technical and organizational measures.

Presenting main material

After the de-occupation of the northern regions of Ukraine, the problem arose of restoring the lifting equipment that was damaged during air shock waves, its further operation and new directions of research into the stability of tower cranes under martial law.

It is necessary to distinguish between direct damage to metal structures from the impact of ammunition and secondary damage from the action of air shock waves. Destruction in places is large-scale, when, for example, important elements of tower cranes fall under the blast wave. Hidden defects also occur when, for example, cracks occur in the metal structures of tower cranes from impacts.

The preliminary examination of tower cranes that have suffered damage as a result of hostilities is regulated by the expert examination method [3] and the State Standard of Ukraine [4, 5]. Yes, all damage to tower cranes can be conditionally divided into three categories.

The first category includes damage without breaking the limit state, the damage is minor and can be restored through current repairs. This is, as a rule, damage to the glass in the operator's cabin (Fig. 1), ropes, rope storage blocks, electrical wiring, etc. The degree of damage to metal structures of tower cranes is up to 15%, but in practice, according to the standard [4], this percentage is even lower (up to 5...10%).Tower cranes, as a rule, have more serious damage and must be assigned to the second category.

a

b

Fig. 1. a – damage to the cabin of the tower crane operator FO23/B, Kyiv; b – damage to the cargo block and rope KB403A, Irpin.

The second category should include damage with a more massive and wider damage rate from a conditional 20% (in practice, 10% can be accepted) to 80%, which have a violation of the first limit state of metal structures, but are subject to capital repair. Such lesions include cracks that appeared in the case of deformation of the metal structure under the influence of a shock wave (Fig. 2). Such damage may, at first glance, not be noticeable, but may develop slowly (up to several years) or almost immediately (in case of brittle destruction). The latter poses the greatest danger to structures, as it occurs without noticeable deformation or the formation of visible cracks, and is therefore difficult to diagnose.

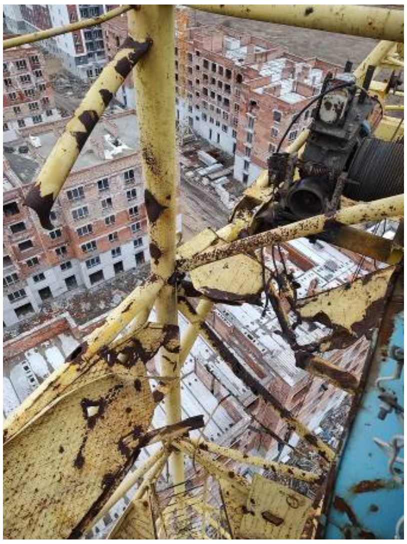
Fig. 2. Damage in the form of cracks in the head of the LIEBHERR 185HC tower crane in Kyiv

The third category of damage includes tower cranes that are subject to partial dismantling (replacement) of metal structures or complete dismantling in case of more than 80% damage, although in practice it can be stated that tower cranes with a lower total damage rate (40...50) can be classified in this category %). However, the restoration of structures, according to the technical conditions [6], is under serious question. The third category, as a rule, should include completely or partially damaged metal structures of tower cranes.

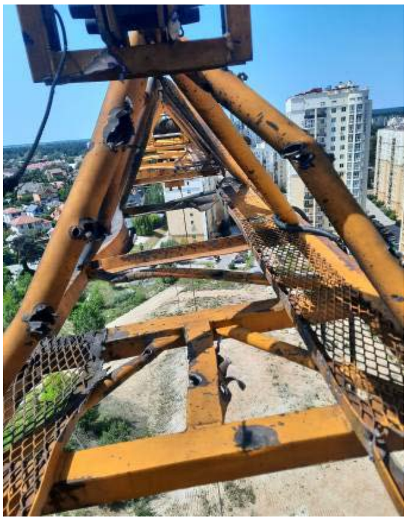
Such injuries include partially damaged metal structures caused by the impact of projectiles from guns (Fig. 3).

Such damage to metal structures cannot be repaired as they are, first of all, deformed and during a static load test will show weak points, which can cause the tower crane to fall.

a



b



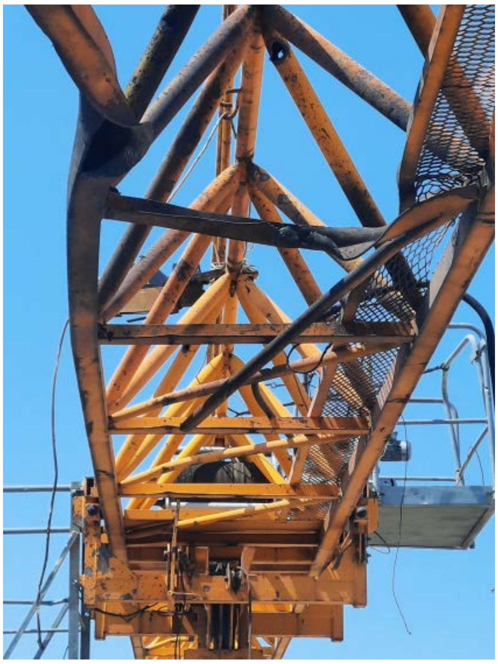
c

Fig. 3. Damage to metal structures from cannon shells: a – fastening of the cabin of the Simma Potain tower crane in Bucha; b – tower crane head KB403A, Irpin; c – boom section of tower crane FO23/B, Kyiv

They are completely damaged by the close rupture of one or another projectile next to metal structures that are not subject to restoration at all (Fig. 4). Damage to metal structures under the action of explosive air shock waves from rocket attacks (Fig. 5).

These damages occurred under the action of an explosive shock wave during rocket fire at a time when hostilities were taking place in the Kyiv region. The tower crane was dismantled with the help of a truck crane with a load capacity of 220 tons. Further operation of the stationary tower crane attached to the building is not possible.

No less damaged tower cranes during hostilities were domestically produced cranes "Nikopol Crane Construction Plant" KB-403A (Fig. 6).



a

b

Fig. 4. Damage to metal structures: a – root insert of tower crane boom FO23/B, Kyiv; b – ordinary insertion of the boom of the LIEBHERR 120HC tower crane in Irpin

a

b

Fig. 5. Damage to the counter boom of the Simma Potain tower crane in Irpin

Fig. 6. The fall of the tower crane KB405.1A in the city of Bucha

These types of rail-mounted cranes are less resistant to the overturning of the crane under the action of an air shock wave, as the rotary mechanism is located from below. This does not allow the crane to turn around its axis and, as a result, it derails or falls without further recovery.

Analyzing the conditional categories of damage to tower cranes, the following can be taken into account during further operation:

- the presence of invisible cracks in metal structures when developing an expert opinion by the relevant organizations;

- damage in metal structures that are subject to partial or major repair in accordance with technical conditions [7, 8] without a stressed state, that is, necessarily after dismantling the crane.

If you look at the damage to tower cranes, it can be noted that stationary tower cranes attached to the building are more stable than rail-mounted or quick-mounting tower cranes. This is due to the fact that overhead cranes have a non-rotating tower, from the top of which there is a rotating mechanism.This mechanism works in vane mode when the crane is idle, which makes it possible to reduce the pressure on metal structures and thereby turn the boom in the opposite direction of the wind flow.

In further consideration of the impact of blast waves on tower cranes, the analysis of the behavior of tower cranes under the action of air shock waves will be relevant.

Therefore, first of all, it should be noted that in the conditions of martial law, many construction sites operate from 30% to 90% of the total production capacity. When an air alarm is triggered, tower cranes continue to operate and therefore may be exposed to an air shock wave. This will cause damage to metal structures from rocket fragments or the very fall of cranes, especially on rail travel, or quick-mounting ones in which the overturning moment is much smaller than in the case of anchoring. Therefore, it is necessary to improve the methods of notifying the crane operator and individual measures to protect the crane in working and non-working conditions when the flow of the shock wave increases.

Currently, the existing requirements for the operation of tower cranes [8] do not provide a complete sequence of work for service personnel when preparing the crane for non-operational status under the influence of shock waves. The crane must be equipped with additional elements of safety devices that will disable certain operations and make a smoother stop of the tower crane mechanisms.

It becomes necessary to investigate and analyze the existing tower crane protection system.

Overview of existing tower crane protection systems

At the moment, there are no studies on the stability of tower cranes in the conditions of air shock waves, therefore, for the analysis, we will consider the existing crane protection systems under conditions of high wind loads, which are close to air explosions, and consider certain definitions.

In order to ensure the reliability and durability of assemblies and mechanisms, to prevent incidents, accidents and accidents in conditions of high wind loads, forklifts must be equipped with devices and safety devices in accordance with the requirements of the rules, State Standards of Ukraine and other normative documents.

A safety device is a technical device of an electronic type, installed on a crane and designed to disable mechanisms in emergency situations or to prevent them, and a safety device is a technical device of a mechanical, electrical, hydraulic or other type, installed on a crane and designed to disable mechanisms in emergency situations or to warn the crane operator about an emergency situation according toNPAOP 0.00-1.80-18.

Devices and safety devices (PB) in conditions of high wind loads must:

- to ensure the safety of the personnel who maintain forklifts;

- protect forklifts from loads that can lead to their breakdowns and accidents.

Accordance with the requirementsNPAOP 0.00-1.80-18, the use of safety devices (PB) on jib cranes is mandatory.

As PB in conditions of high wind loads, the following are installed:

- load capacity limiters based on a microprocessor controller (MK) - for automatic disconnection of load lifting mechanisms and change of departure in case of lifting a load whose weight exceeds the load capacity for this departure by 15%, as well as for registration of crane operation parameters.

- anemometers – devices that automatically turn on a sound signal in case of exceeding the permissible wind speed specified in the crane operator's inspection log (passport) of the crane's operating condition. Tower cranes with a height to the top of the tower head of more than 15 m are equipped with this device.

Safety devices must meet the following requirements:

Repairability– a quality that characterizes the adaptability of the device to the convenient and fast performance of individual operations during technical inspection, repair, technical condition control, during disassembly (assembly) of blocks and sensors, their control and replacement.

Reading- PB indicators must ensure sufficient visibility of readings at night, as well as in bright sunlight.

Reliabilityis one of the most important characteristics of a safety device. PBs must be resistant to mechanical influences in the conditions of transport shaking, to the influence of vibration and shock loads under the conditions of operation of lifting machines. Safety devices must have a minimum number of contact devices.

Ease of setup– construction elements should be provided in the controlled channels of the devices, which facilitate bench adjustment and adjustment on lifting machines, taking into account parameter deviations. The parameters of the adjustable forklift truck devices should be monitored mainly on the indicators of the safety devices.

Today, there is a large number of various devices and safety devices. All the variety of PB is distinguished by type depending on whether the crane installation belongs to one or another group of equipment. The purpose of this work is to study the stability of a free stationary tower crane under the conditions of an air shock wave. Therefore, safety devices, which are installed mainly on tower cranes, will be considered further.

At present, only ACC-10 and M-95 anemometers are manufactured from safety devices in Ukraine.

To protect cranes from overloading the load lifting mechanism and automatically control the stability of load-lifting cranes in the event of excessive wind flows, load capacity limiters are used together with anemometers. Modern load capacity limiters provide the following functions: indication of the weight of the load being lifted in kilograms, tons and as a percentage of the nominal load capacity of the crane; indication of the current time; creation of a control signal to block the lifting of the load when the load is higher than the maximum permissible load capacity of the crane; fixing the value of the wind speed, entering the parameters of the nominal and maximum load capacity of the crane, the multiplicity of the hoist; registration of crane operation parameters ("black box"), recording and memorization of electrical characteristics of crane operation for further deciphering and collection of statistical data on loading and overloading of the crane during operation.

On the construction site in Ukraine, one of the widespread cranes are Chinese-made cranes, on which a multifunctional safety system is installed for the CXT-90II tower crane of the Hitec brand (Fig. 7), which includes a load moment indicator with a system of protection against collisions and zones, as well as a system of remote online monitoring. It shows the operating status of the tower crane and group of tower cranes in real time both in the operator's cabin and online. At the same time, it combines functions including "black box", collision protection and zone protection.

Fig. 7. CXT-90II multifunctional safety system for a tower crane

The system is applied to various types of tower cranes with horizontal and lifting boom. It uses advanced built-in intelligent ARM microprocessor technology, high-precision digital azimuth sensor, weight sensor, angle sensor, which has greatly expanded the ability to process data with higher precision and higher. In addition, the system is equipped with an 8-inch touch screen and bilingual display (Chinese/English), which makes it easier for operators to install and use the system. When the operator is operating the tower crane, the system can display all operating states of the tower crane, which helps him to operate the tower crane safely and efficiently. With multiple additional functions, the information display and alarm immediately notify, if the load reaches the rated load or 90% of the specified moment, the system issues a pre-warning. If the load reaches 105% of the specified moment, the system will automatically sound an alarm and stop the trolley moving outward and the hook lifting up.

On the market of the aggressor country, the most common microprocessor load capacity limiters of tower cranes with the function of registering wind parameters are devices: ONK-160 and OGM-240 (Fig. 8)

a

b

Fig. 8. Microprocessor security system for tower crane: a – OGM-240; b – ONK-160M

The use of MC in PB provides increased safety and work productivity due to increased accuracy of the task of load characteristics and reduced psychophysical loads on the operator. The use of microprocessor limiters allows you to reduce the cost of development and production of equipment modification for different brands of cranes, reduce power consumption, dimensions and almost double the time of trouble-free operation.

Wind speed sensors - anemometers, which are designed to measure wind speed in industrial conditions and determine dangerous wind gusts, are used to register wind flow speed parameters. Several types of anemometers are produced by Russian manufacturers: ACC-3, ACC-P (Fig. 9).

a

b)

Fig. 9. Anemometers: a) ACC-3; b) ASC-R

Anemometer signal crane digital ACC-3 is designed for installation on all existing types of tower, portal, gantry cranes and all types of objects that require emergency wind protection equipment [9, 10, 11].

The digital signal anemometer ACC-P is designed to control the wind speed on cargo-lifting equipment, which does not require a stationary device (for cargo-lifting towers with a lifting height of more than 22 m).

M-95 and ATC (ACC-10) anemometers are produced in Ukraine (Fig. 10).

The disadvantage of the M-95 device is the permanent magnet in the speed sensor, which is subsequently demagnetized, and the sensor begins to underestimate the value of the wind speed, giving a lower voltage at the same wind speed.

The wind sensor of the ASK-10 anemometer is a digital optocoupler. Therefore, it is devoid of the disadvantage of the M-95 sensor and after long-term operation does not underestimate the value of the wind speed.

a

b

Fig. 10. Anemometers: a –M-95; b – ACC-10

The most promising safety devices being developed are multifunctional safety systems for tower cranes of the CXT-90II type, which are based on a microprocessor, which include such systems as: load capacity limiters, recorders of wind load parameters and work modes, coordinate protection, etc.

The disadvantages of the existing safety devices in conditions of high wind loads are operation in the indicator mode, without the possibility of forecasting the dynamics of the wind flow and determining the margin of stability of the crane. Another drawback is the lack of a function of automatic adjustment of stability according to known parameters in the event of external excitation (speed, wind direction, etc.).

Conclusions

The problem of finding and assessing damage to stationary tower cranes under the influence of an explosive air wave as a result of armed aggression is urgent. Conditionally divided damage to metal structures of tower cranes into three categories. This will make it possible to take into account in the future when developing, according to [12,13,14,15], technical documentation of typical projects regarding the disassembly-assembly of tower cranes, types of repairs, etc. At the same time, it can be seen that attached tower cranes are more resistant to blast waves than rail-mounted or quick-mounting cranes. There is also an imperfect system for protecting tower cranes during the dynamics of changing wind flows without determining the stability margin of the tower crane.

The stability of tower cranes in the conditions of blast waves is an important issue from the point of view of safety and durability of the equipment. To ensure optimal stability of the tower crane in conditions of possible explosions, it is important to observe a number of technical and organizational measures:

1 Positioning and planning: first of all, it is necessary to correctly position the tower crane, taking into account the possible sources of blast waves. The planning of the placement area should provide for the possibility of moving away from dangerous places, in particular, this applies to quick-mounting tower cranes in which the overturning moment is much smaller;

2 Construction: the tower crane must have a stable structure, which includes a strong frame, foundation support and additional rigidity;

3 Materials: the use of high-strength materials in the design helps to increase the crane's resistance to blast waves;

4 Automatic safety system: installing an automatic safety system that can automatically turn off the faucet in the event of an explosive event can significantly reduce risks;

5 Technical inspection and expert examination: regular technical accounting and examinations will allow timely detection of damage and wear that may affect its stability;

6 Training and classification of service personnel: personnel must be adequately prepared for the conscious risks associated with possible explosions.

In general, the stability of tower cranes in conditions of blast waves requires a comprehensive approach that combines constructive, technical, and organizational measures to ensure the safety and reliability of the cranes as a whole.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Огляд і аналіз пошкоджень та існуючих систем захисту баштових кранів під впливом вибухової хвилі

Анотація. Проблема. *Актуальною є проблема оцінки технічного стану стаціонарних баштових кранів різних типів експертними організаціями з метою визначення можливості їх подальшої експлуатації та методів здійснення капітального ремонту. Разом з тим, слід враховувати характер наслідків ураження металоконструкцій та вид ремонту, якщо він взагалі можливий. Тематика статті носить практичний характер. Здійснена спроба зробити первинне уявлення та візуальний аналіз стану різних типів баштових кранів при умовах вибухових повітряних ударних хвиль в залежності від відстані до кранів. В статті зроблена спроба обґрунтувати наслідки руйнувань металоконструкцій, механізмів чи систем захисту та вказати на деякі закономірності, що вимагають пильної уваги під час експлуатації баштових кранів та їх подальших досліджень.* ***Мета.*** *Метою робо є зробити огляд пошкоджень баштових кранів різних типів, що зазнали ураження та їх існуючі системи захисту. Надати припущення для подальших досліджень стійкості баштових кранів в умовах повітряних ударних хвиль.* ***Методологія.*** *Прийняті в роботі підходи до вирішення поставленої мети базуються на умовному розділенні на категорії пошкодження стаціонарних баштових кранів під дією повітряних ударних хвиль.* ***Результати.*** *Отриманий аналіз пошкоджень баштових кранів, дасть змогу в подальшому враховувати при розробці згідно технічної документації типових проектів щодо їх демонтажу-монтажу, видах ремонту тощо.* ***Оригінальність.*** *Дослідження стійкості баштових кранів в умовах повітряних ударних хвиль є рідкісним і специфічним напрямом в області інженерних досліджень. Тому результати цього дослідження дозволять заповнити прогалини в науковій літературі та інженерній практиці.* ***Практичне значення.*** *Результати дослідження можуть призвезти до розробки нових підходів та рекомендацій для проектування баштових кранів з урахуванням можливих повітряних ударних хвиль. Це дозволить інженерам створювати більш безпечні та надійні кoнструкції для роботи в небезпечних умовах.*

Ключові слова. *ураження; баштові крани; вибухова хвиля; повітряна ударна хвиля; відновлення; експлуатація*

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