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LONGITUDINAL DYNAMIC LOADING OF A BUILDING STRUCTURE DURING SUDDEN STOP OF AN OVERHEAD BRIDGE CRANE

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Keywords: *overhead bridge crane, building structure, horizontal force, sudden stop, jerk function, braking distance*

ABSTRACT

The research in this paper focuses on issues related to determining the maximum horizontal inertial load transmitted from the bridge crane to the supporting structure of the building in the event of a sudden stop of the crane. The article begins by examining the generally accepted simplified relationships regulated in design standards, which are most often used by engineers to determine the maximum horizontal inertial loads from a bridge crane to the supporting structure of a building. For a more accurate determination of the horizontal inertial loads, a mechano-mathematical model was developed in this paper to study the dynamic behavior of the crane supporting structure and the suspended load in the event of a sudden stop of the crane. Example structures of bridge cranes with three different possible nominal speeds of movement of the crane were examined. For each of the considered examples, a numerical solution of the differential equations was performed, and results were obtained for the transmitted horizontal inertial load from the bridge cranes to the supporting structure of the building in the event of a sudden stop of the crane. Finally, a comparison of the maximum horizontal inertia force during braking obtained by the differential equations with the results obtained using the simplified dependencies from the design standards is made. The conclusions drawn may be useful for clarifying the cases when the realized horizontal inertia

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loads in the event of a sudden stop of the crane may be greater than those obtained using the methodology prescribed in the design standards.

1. Introduction

Overhead cranes are often used as a means of mechanizing loading and unloading, technological and assembly operations in the production workshops of construction companies (Fig. 1).

a) *b)*

Figure 1. Examples of overhead cranes operating in construction companies:
a) a crane with a grab for scooping bulk construction materials;
b) a crane with bucket for pouring concrete mixtures

When equipping overhead cranes with appropriate braking mechanisms, combined with the high capabilities of modern control and management systems for their driving electric motors, in most cases it is possible to ensure the most optimal possible smooth start/stop of the crane, as well as the most precise possible positioning of the suspended load (assembly unit) during the crane stop. The case is completely different, however, when in a real practical situation there are large lengths of the production workshops (Fig. 1), which impose the need for higher speeds of movement of the cranes in the longitudinal horizontal direction of the building (of the order of 30 – 50 m/min and more), and at the same time the existing technology for performing production operations with the crane requires less time (or shorter braking distance) to perform the process of stopping the crane, in order to more accurately position the load. Such a combination of "high nominal speed of movement – shortened time/distance for stopping the crane", implies the need to implement larger delays when stopping the movement of the crane bridge (the so-called abrupt braking of the crane), which in turn leads to larger horizontal inertial forces during the braking process.

There are many available works in our, European and world literature, which are devoted to the dynamic analysis of the movements of construction cranes. The issue of optimizing the working movements of a tower crane is considered in [1], in order to minimize electricity losses. There are also other works, which are devoted to the analysis of the transmitted loads from bridge cranes on building structures. The issue of the maximum longitudinal horizontal load from a bridge crane on the building, in the event of a crane bridge hitting the buffer, which is located at the end of the rail track, was mainly considered in [2]. At the same time, in other papers (such as: [3]) the issue of the maximum transverse load from a bridge crane on the building was analyzed.

This paper investigates the maximum longitudinal inertial force on the building during a sudden stop of the crane.

It is known that the maximum horizontal inertial load from the bridge crane on the building along the rail axis (the so-called longitudinal force) will occur when the bridge crane makes a sudden stop while moving at the nominal (maximum possible) operating speed. The purpose of this study is to analyze the actual value of the maximum horizontal load that can be transmitted by the bridge crane to the supporting structure of the building in the event of a sudden stop of the crane, by using a sufficiently accurate mechanical and mathematical model that takes into account the dynamic behavior of the main crane beams, as well as the swinging of the rope, during the process of stopping the crane. Additionally, this work aims to perform an engineering check of whether the specified mathematical dependencies for calculating the same "maximum longitudinal force when stopping the crane" in the generally accepted design standards [4] are conservative enough.

2. Calculation of horizontal inertial loads from a bridge crane on a building structure according to Eurocode and the current European Crane Standards

According the current European standard EN 1991-3:2006 [4], horizontal loadings from overhead cranes on building structures can be considered as "variable actions", but also as "accidental actions". The group of "accidental horizontal actions" includes only the buffer force from the impact of the crane on a buffer, which are not a subject of analysis in the present paper. The group of "variable horizontal actions" in longitudinal direction of the rail includes the horizontal inertial forces, caused by starting/stopping the crane bridge travel mechanism, which are the main subject of analysis in the present paper.

According to standard EN 1991-3 [4], the longitudinal force on the crane supporting structure H_L, caused by acceleration and deceleration of the crane motion can be calculated as follows:

$$H_L = \frac{1}{n_r}\varphi_5 K, \tag{1}$$

where: φ_5 is a dynamic factor, the value of which is assumed to be φ_5 = 2,00 in cases where sudden changes in loads are expected; n_r is the number of runway beams, on which the crane moves. The present paper considers the total (summary) loading from the bridge crane on the building structure. Therefore, it is assumed n_r =1; K is the driving force. According to the standard [4], when no crane wheel control system is used, the driving force K can be expressed as follows:

$$K = K_1 + K_2 = \mu \sum Q^*_{R,\min}, \tag{2}$$

where K_1 and K_2 are the driving forces from the crane that are transmitted to the two runway beams; $\sum Q^*_{R,\min}$ is the sum of the minimum loads on the driving crane wheels, which are transmitted to the two runway beams; μ is the coefficient of friction between the rail and the wheel.

The value of $\sum Q^*_{R,\min}$ is equal to that part of the crane's own weight (without suspended load on the hook) that loads the driving crane wheels. For the present analysis, an overhead crane with 8 rail wheels, 2 of which are drive wheels, is considered. In this situation, the value of $\sum Q^*_{R,\min}$ can be conservatively assumed as: 2/8 i.e. 25 % of the total dead weight of the crane (without suspended load on the hook). According to standard [4], the recommended value μ = 0,20 is taken for a steel wheel on a steel rail.

The final mathematical expression by which the total (sum) longitudinal force H_L acting on the crane supporting structure according to standard [4] caused by acceleration and deceleration of the crane movement is calculated takes the following form:

$$H_L = \varphi_5 \mu \sum Q^*_{R,\min} . \tag{3}$$

The specific method of mounting a bridge crane in a building structure (via steel wheels freely standing on a rail track) assumes that the longitudinal force from the crane is transferred to the supporting structure by means of friction forces between the crane wheel and the rail. There are many articles that are dedicated to the study of the actual values of the coefficient of friction between two steel parts. For example: in work [5], based on detailed studies, the following values for the coefficient of friction between two sliding steel parts (with coating) were obtained: μ = 0,20 ÷ 0,42. In another paper [6] it is obtained that the friction coefficient for mild steel can vary from 0,44 to 0,53 for different operating conditions, etc.

3. Modeling the dynamic behavior of a bridge crane in case of sudden stop

For the purposes of this article, an overhead crane is considered that moves at a nominal speed V_0, which appears as the initial velocity before the sudden stop. The used denotations for masses of crane structural components are shown on Fig. 2.

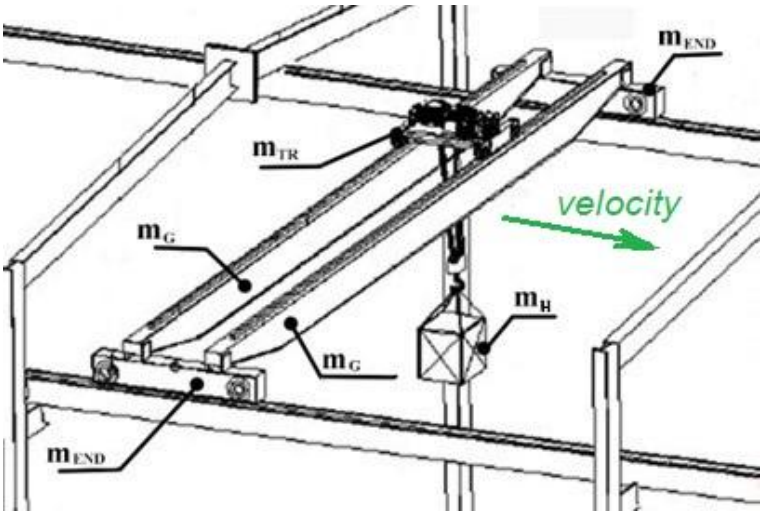

Figure 2. Used designations for the masses of the individual components

Figure 2 uses the following denotations of own masses:

- m_H – mass of hoist load (which is hanged on the hook);
- m_G – mass of one crane main girder;
- m_{END} – mass of crane end beam;
- m_{TR} – own mass of crane trolley.

For the purposes of this study, the following simplifying assumptions are adopted:

- the crane trolley is located exactly in the middle of the crane bridge;
- the crane moves at a constant nominal speed V_0 (from the initial moment of time $t_{INITIAL} = 0$);
- during the uniform movement of the crane, the rope swing angle φ is equal to zero;
- at the initial considered moment of time, the crane undertakes a "hard stop", which is characterized by a constant deceleration during the entire braking distance of the crane;
- the manufacture technology in the workshop requires the maximum crane brake duration to be within 2,50 seconds ($t_{BRAKE} \leq$ 2,50 seconds).

For the bridge crane shown in Fig. 2, a simplified mechanical-mathematical model with two degrees of freedom has been developed, which is presented in Fig. 4.

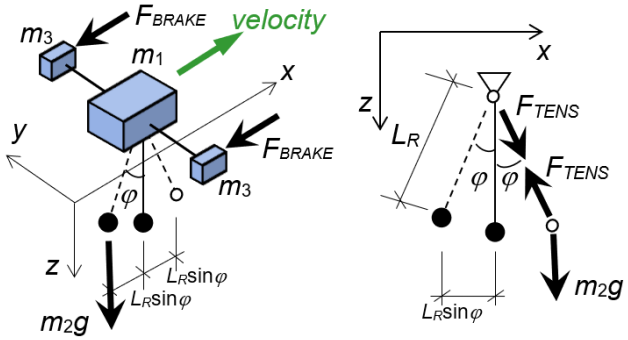

Figure 3. General 3-D and 2-D views of the dynamic system

Figure 3 uses the following notations:

- m_1 – mass of crane bridge structure lumped to the middle of crane span (it includes mass of crane trolley plus mass of crane main girders);
- m_2 – mass of hoist load $\left(m_2 = m_G\right)$;
- m_3 – mass of crane bridge structure lumped to the crane end beam (it includes mass of end beam plus mass of main girder);
- φ – swing angle of crane hoist rope;
- $F_{TENS} = \dfrac{m_2 g}{\cos\varphi}$ – tensile force in the hoist rope;

- $F_H = m_2 g \tan\varphi$ – horizontal loading force, caused by hoist rope swinging;
- L_R – length of hoist rope;
- c_3 – damping constant of crane steel structure in a horizontal direction;
- c_4 – damping constant in a hoist rope connection, during load swinging in horizontal direction;
- k_3 – stiffness coefficient of crane steel structure in horizontal direction. It is determined for a bridge crane with hoist capacity Q on the basis of the requirements, which are described in standard [7];
- x_1 – horizontal displacement of a point, which is located in the middle of crane span;
- F_{BRAKE} – the external braking force applied to the crane in the horizontal direction (along the *X*-axis) caused by a sudden activation of the crane's braking system.

According to the guidelines of the standard [8], the approximate value of the dead mass of the crane supporting structure, brought to the middle of the crane span (including the two main girders and trolley) could be calculated from the relationship:

$$m_1 = \frac{17}{35}\left(m_G + m_G\right) + m_{TR}\,. \tag{4}$$

The rest of crane own mass, lumped to end beam (end beam plus main girder) in the present paper is assumed to be equal to:

$$m_3 = \left(1 - \frac{17}{35}\right) m_G + m_{END}\,. \tag{5}$$

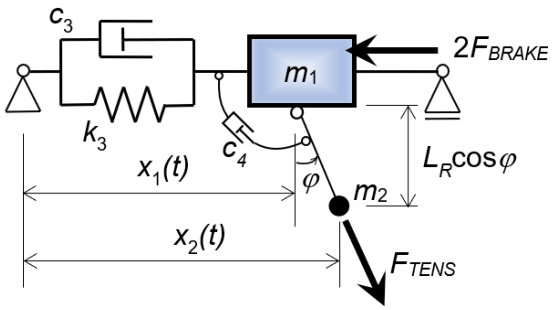

Figure 4. Simplified mechanical mathematical model with a two DOF system

The damping constant c_4 is determined based on the Kelvin – Voigt model (damper and purely elastic spring connected in parallel), which is adopted for the crane as a system with one degree of freedom. The hoist rope with a swinging load on the hoist can be modelled as a simple gravity pendulum. If the amplitude is limited to small swings the eigen period T of the simple pendulum is:

$$T = 2\pi\sqrt{\frac{L_R}{g}}\,, \tag{6}$$

where L_R is the length of the pendulum and g = 9,81 m/s^2 is the acceleration of gravity. Taking into account the damping effect, the equation of motion for free oscillations of a pendulum is:

$$\varphi = \varphi_{\mathrm{MAX}} e^{-\gamma t} \cos(\omega t), \tag{7}$$

where φ_{MAX} is the maximum angle; ω is the eigenfrequency; γ is the damping coefficient. In SDOF systems, the expression for the damping constant is $c = 2m\gamma$ or $c = 2m\omega\xi$, where $\omega = 2\pi / T$ is the eigenfrequency, ξ is the damping ratio. In fluid dynamics, drag, is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid. To account for the damping of oscillations in the pendulum, the drag equation is used, the authorship of which is attributed to Lord Rayleigh. In this paper, damping constant c_4 is determined based on the hoist load swinging movement through air.

The differential equations of motion of the system under forced oscillations in the horizontal direction (transmission of an input horizontal disturbance caused by a sudden stop of the crane) are derived according to the principles of theoretical mechanics. The differential equations of motion of the system are derived based on the use of Lagrange's equations.

The Lagrangian function L for a system is defined as the difference between kinetic and potential energy, expressed as a function of positions and velocities, and its expression is:

$$L = E_K - E_P, \tag{8}$$

where E_K is the kinetic energy of the system, E_P is the potential energy of the system. The general form of the Lagrange's equations of the second kind or the Euler – Lagrange equations of motion is [9]:

$$\frac{\partial L}{\partial q_k} = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_k}\right), \tag{9}$$

where q_K are the generalized coordinates of the dynamic system. The Euler – Lagrange formulation is completely equivalent to Newton's second law. For the dynamic system with two degrees of freedom (x_1 and φ) shown in Fig. 4, two differential equations of motion are obtained in the following form:

$$\left(m_1 + m_2\right)\ddot{x}_1 + m_2 L_R \ddot{\varphi} + c_3 \dot{x}_1 + k_3 x_1 = F_{TOTAL}(t). \tag{10}$$

$$m_2 L_R \ddot{x}_1 + m_2 L_R^2 \ddot{\varphi} + c_4 \dot{\varphi} + m_2 g L_R \varphi = 0. \tag{11}$$

On the right side of equation (8) is the total braking force $F_{TOTAL} = 2F_{BRAKE}$ which is applied to crane travelling structure while it is moving with an initial speed V_0.

4. Solving a numerical example for an exemplary bridge crane with rated hoist capacity Q = 32 tons and crane span L = 26 meters

For the purposes of this paper, three overhead cranes with a span of L = 26 meters and a hoist capacity of Q = 32 tons, operating in the manufacture workshop of a construction factory, are examined. The length of hoist rope is L_R = 5 meters. The cranes have different

nominal travel speeds V_{RATED}, 30, 50 and 70 meters/min respectively. Each of the three bridge cranes has 8 rail wheels (for bridge travelling), of which two wheels are driven, and the remaining 6 wheels are idle. The masses of the individual components of the three overhead cranes are as follows: m_H = 32 tons; m_G = 16 tons; m_{END} = 4,771 tons; m_{TR} = 10,457 tons. It is specified that the manufacturing technology in the workshop (where the overhead crane is operated) requires a maximum brake duration of no more than 2,50 seconds, i.e. $t_{BRAKE} \leq 2{,}50$ s. According to the relationships given in the standard [8], the following lumped masses are determined for the dynamic model (Fig. 4): m_1 = 26 tons; m_2 = 32 tons; m_3 = 13 tons.

In order to realize a "hard stop" for a required time not greater than $t_{BRAKE} \leq 2{,}50$ seconds with a constant deceleration a_{DEC}, in the present work the braking force is set in the form of an external kinematic disturbance, which varies in time according to the following nonlinear law, as follows:

$$F_{TOTAL} = k_3 V_0 \left(t - \frac{t^2}{2t_{BRAKE}} \right) + c_3 V_0 \left(1 - \frac{t}{t_{BRAKE}} \right). \tag{12}$$

For the time $t = 0 \div t_{BRAKE}$, where t_{BRAKE} = 2,50 seconds is the required maximum time for braking duration, whose expression is:

$$t_{BRAKE} = \frac{V_0}{a_{DEC}} \ . \tag{13}$$

In the calculations, the maximum permissible value of t_{BRAKE} = 2,50 seconds is assumed, and the deceleration is calculated by:

$$a_{DEC} = \frac{V_0}{t_{BRAKE}} . \tag{14}$$

For the time after the end of the braking duration, the state of free oscillations is considered.

According to (6), the eigen period of the simple pendulum is: T = 4,4857 s. The mass moment of inertia about the pivot point is I_m = 800 ton.m^2. The damping constant in the hoist rope connection is: c_4 =16 kN.m.s., where γ is the damping coefficient. According to the recommendations in paper [10], the present research article for the crane ropes swinging accepts the value for logarithmic decrement δ = 0,10. The damping ratio of the steel structure of the crane in the horizontal direction is assumed to be ξ = 4 %. Therefore, the damping constant of the steel structure of the crane is: $c_3 = 2\xi\sqrt{m_1 k_3}$ = 43,028 kN.m.s. Based on the results obtained from the solution of the two differential equations, the maximum horizontal longitudinal force (horizontal load) is calculated, which is transferred from the bridge crane to the building structure below during a sudden stop of the crane. For the purposes of this study, the maximum horizontal longitudinal force (horizontal load) is assumed to be as follows:

$$F_{HOR.MAX} = k_3 x_1 + c_3 \dot{x}_1 + 2m_3 a_{DEC} . \tag{15}$$

The stiffness of the crane bridge in the horizontal direction for the present research paper, according to [7], is as follows k_3 = 11 126,081 kN/m. The initial conditions that are set in the differential equations at the initial moment (t = 0) are respectively:

$$\begin{matrix} x_1 = 0 & \dot{x}_1 = V_0 \\ \varphi = 0 & \dot{\varphi} = 0 \end{matrix} . \tag{16}$$

After substituting the sample values, the system of two differential equations was solved with [11]. Eigenvalue analysis reveals the values of the two periods $T_1 = 4{,}498$ s. and $T_2 = 0{,}303$ s. The first is almost equal to the eigen period of the pendulum, considered as a SDOF system. The second natural frequency is $f_2 = 3{,}302$ Hz and it corresponds to the vibrations in the crane after the braking force is applied.

The results for "Crane 1" (with a nominal speed of $V_{RATED} = 0{,}50$ m/s) are shown in Fig. 5. The velocity function $\dot{x}_1$ on Fig. 5(c) corresponds to the initial velocity value and allowed deceleration set as input.

The maximum acceleration from the graph in Fig. 5(b) is 0,374 m/s^2, i.e. greater than the absolute value of the maximum allowable deceleration set for the input impact ($a_{DEC} = 0{,}200$ m/s^2 for crane 1).

The jerk itself is defined as the time derivative of acceleration. In modern engineering design, limits on accelerations and jerks are assumed. The jerk function should be limited to a reasonable range to extend engine life. In the design of cranes, practical constraints are given for the jerk, usually around $j_{LIMIT} = 5$ m/s^3.

In the example shown with an initial speed of 30 m/min., the maximum value of the jerk function is: $j_{MAX} = 3{,}88$ m/s^3, see Fig. 5(d). At higher speeds, such as those of crane 2 and crane 3, this value is exceeded.

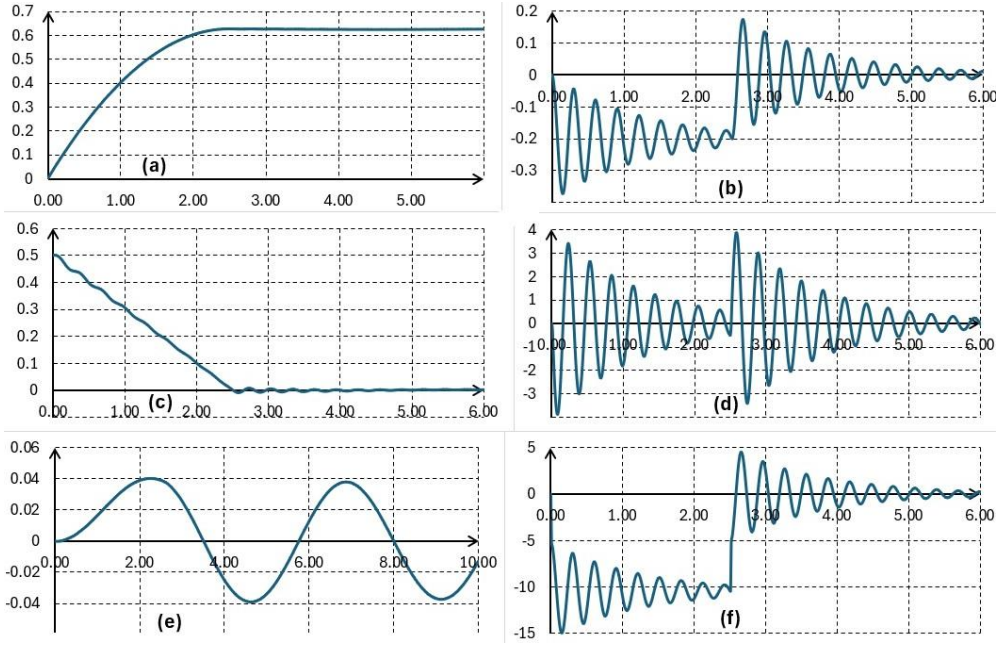

Figure 5. Time history results obtained during sudden stop of crane 1:

a) displacement function x_1 in m; b) acceleration function $\ddot{x}_1$, in m/s^2; c) velocity function $\dot{x}_1$ in m/s; d) jerk function $\dddot{x}_1$, in m/s^3; e) rope swing angle φ, in rad; f) force transmitted to the structure F_{TOT}, in kN

Similar studies, as for "Crane 1", were also carried out for the other two cranes considered (Crane 2 and Crane 3), and the results obtained are summarized and presented in Table 1.

The maximum horizontal inertial force transmitted from the crane to the building structure is limited by the maximum possible friction force between the running wheel and the rail, i.e. the horizontal force transmitted from the crane to the building cannot be greater than the maximum possible friction force, i.e.

$$F_{HOR.\mathrm{MAX}} \le F_{FR.\mathrm{MAX}}. \tag{17}$$

Using the maximum specified coefficient of friction μ = 0,42 in the development [5], it is possible to calculate the limiting value (maximum possible) of the friction force:

$$F_{FR.\mathrm{MAX}} = 0,42\frac{4,771+4,771+16+16+10,457}{4}9,81 = 53,56 \text{ kN}. \tag{18}$$

If we compare the obtained maximum values of the horizontal inertial forces during a sudden stop of the crane (from Table 1) with the limit value, it can be seen that the obtained maximum values of the horizontal inertial forces during a sudden stop for crane 1 ($F_{HOR.\mathrm{MAX}}$ = 25,61 kN) and crane 2 ($F_{HOR.\mathrm{MAX}}$ = 42,70 kN) can be realized, since they are lower than the limit value $F_{FR.\mathrm{MAX}}$ = 53,56 kN. For crane 3, the obtained maximum value of the horizontal inertial force during a sudden stop ($F_{HOR.\mathrm{MAX}}$ = 59,83 kN) cannot be realized in reality, since it is higher than the limit value, i.e. during a sudden stop of crane 3, the crane is expected to slip on the rail.

Table 1. Result in case of sudden stop of the three cranes

Considered option of an overhead bridge crane	**Nominal velocity V_0, m/min**	**Corresponding constant deceleration a_{DEC}, m/s²**	**Maximum rope swing angle φ_{MAX} when braking, rad**	**$F_{HOR.\mathrm{MAX}}$ (maximum horizontal force transmitted to the building structure), kN**
Crane 1	30	0,2000	0,0404	14,92
Crane 2	50	0,3333	0,0673	24,87
Crane 3	70	0,4667	0,0943	34,82

If the maximum value of the total (sum) longitudinal force H_L (acting on the two crane girders of the building structure) caused by the acceleration or deceleration of the crane is calculated according to the established formula from the design standard [4], the following value will be obtained:

$$H_L = \varphi_5 \mu \sum Q^*_{R.\mathrm{MIN}}, \tag{19}$$

$$H_L = 2.0,2\frac{4,771+4,771+16+16+10,457}{4}9,81 = 51,011 \text{ kN}. \tag{20}$$

The value of H_L calculated in this way according to the design standard [4] is about 5 % lower than the maximum possible limit value of the friction force, obtained by using the

maximum friction coefficient from the development [5]. On the other hand, for the specific case considered (overhead crane $Q = 32$ tons; $L = 26$ meters), maximum brake duration $t_{BRAKE} = 2{,}50$ seconds is exceeded at rated crane speeds about: $V_0 \geq 85$ m/min. i.e. when realizing a braking deceleration greater than 0,55 m/s^2, calculated by formula (14).

5. Conclusions

This paper proposes a methodology for analyzing the maximum horizontal inertial load transmitted by a bridge crane to the supporting structure of the building in the event of a sudden stop of the crane. From the results obtained for the specific model of overhead crane $Q = 32$ tons, $L = 26$ meters, considered in the paper, the following important conclusions can be drawn:

1. The calculated value of the longitudinal force $H_L = 51{,}01$ kN on the building structure according to the design standard [4] is lower than the maximum possible limit value of the friction force $F_{HOR.MAX} \leq F_{FR.MAX} = 53{,}56$ kN, obtained by using more conservative possible values for the coefficient of friction between the running wheel and the rail;

2. The established dependence in the design standard [4] for calculating the maximum design value of the longitudinal force H_L on the building structure seems to be sufficiently conservative, but only under relatively stricter regulations for short brake duration. In this particular case, the condition is that the rated speed of the crane V_0 be less than 85 m/minute, which results in a deceleration $a_{DEC} \leq 0{,}55$ m/s^2.

The authors recommend that in the presence of higher values of the deceleration a_{DEC} than 0,50 m/s^2 during the stopping of a bridge crane, to obtain the design value of the maximum longitudinal inertial force on a building structure, not only the design standard [4] should be used, but also a more accurate approach such as that described in this paper. The values obtained by the two approaches should be compared with each other in order to select the more conservative possible value of the longitudinal force H_L, which should be used for the design calculations.

3. In the example, the peak values of the accelerations and the force transmitted to the structure appear at the same time ($t = 0{,}15$ s and $t = 2{,}66$ s), and the peak value of the jerk function appears shortly before them (at time $t = 0{,}08$ s and $t = 2{,}59$ s). This lead time is actually the phase lag and is equal to one quarter of f_2. This fact gives reason to investigate the possibility of developing a methodology for predicting maximum braking force by observing the extrema of the jerk function. To achieve this goal, special equipment is required.

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ХОРИЗОНТАЛНО ДИНАМИЧНО НАТОВАРВАНЕ НА СТРОИТЕЛНА КОНСТРУКЦИЯ ПРИ ВНЕЗАПНО СПИРАНЕ НА МОСТОВ КРАН

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Ключови думи: *мостов кран, строителна конструкция, хоризонтална сила, рязко спиране, джърк функция, спирачен път*

РЕЗЮМЕ

Изследването в тази статия се фокусира върху въпроси, свързани с определяне на максималното хоризонтално инерционно натоварване, предавано от мостовия кран към носещата конструкция на сградата в случай на внезапно спиране на крана. Статията започва с разглеждане на общоприетите опростени зависимости, регламентирани в стандартите за проектиране, които най-често се използват от инженерите за определяне на максималните хоризонтални инерционни натоварвания от мостов кран към носещата конструкция на сграда. За по-точно определяне на хоризонталните инерционни натоварвания в тази статия е разработен механо-математически модел за изследване на динамичното поведение на носещата конструкция на крана и окачения товар в случай на

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внезапно спиране на крана. Разгледани са примерни конструкции на мостови кранове с три различни възможни номинални скорости на движение на крана. За всеки от разгледаните примери е извършено числено решаване на диференциалните уравнения и са получени резултати за предаденото хоризонтално инерционно натоварване от мостовите кранове към носещата конструкция на сградата при внезапно спиране на крана. Накрая се прави сравнение на максималната хоризонтална инерционна сила по време на спиране, получена чрез диференциалните уравнения, с резултатите, получени с помощта на опростените зависимости от проектните стандарти. Направените изводи могат да бъдат полезни за изясняване на случаите, когато реализираните хоризонтални инерционни натоварвания при внезапно спиране на крана могат да бъдат по-големи от тези, получени по методиката, предписана в стандартите за проектиране.