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PROBABILISTIC NUMERICAL CHARACTERISTICS OF OVERHEAD CRANES LOADS ON INDUSTRIAL BUILDINGS FRAMEWORKS

The article is dedicated to the development of analytical model of loads four-wheels travelling cranes loads. The design values of mathematical expectation, variance and standard for vertical and horizontal component of crane load were received. Numerical example has shown that the values of analytical numerical characteristics are very close to the experimental values of loads, and can be applied in the reliability estimation. Analytical numerical characteristics are used in the of steel framework one-storey industrial building columns calculation reliability. The time factor and the stochastic nature of the loads and the strength of steel were considered. The effect of different parameters (cranes capacity and the mode of travelling cranes, columns step, type of connection the column and girder, the type of roofing and the values of wind and snow loads) on the reliability of steel frameworks was considered.

Keywords: *probabilistic model, crane loads, four-wheel overhead travelling cranes, numerical characteristics.*

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ІМОВІРНІСНІ ЧИСЛОВІ ХАРАКТЕРИСТИКИ НАВАНТАЖЕНЬ МОСТОВИХ КРАНІВ НА КАРКАСИ ВИРОБНИЧИХ БУДІВЕЛЬ

Побудовано аналітичну модель навантажень чотириколісних мостових кранів. Отримано розрахункові значення математичного сподівання, дисперсії та стандарту для вертикальної й горизонтальної складової кранового навантаження. Числовим прикладом показано, що значення числових характеристик, отриманих аналітично, досить близькі до експериментальних значень навантажень, вони можуть застосовуватися при оцінюванні надійності. Аналітичні числові характеристики використано при розрахунку надійності колон сталевого каркаса ОВБ (одноповерхової виробничої будівлі) з урахуванням фактора часу та стохастичного характеру навантажень й міцності сталі. Досліджено вплив на надійність каркасів вантажопідйомності та режиму роботи мостових кранів, кроку колон, типу вузла з'єднання ригеля з колоною, типу покриття та значень вітрового й снігового навантажень.

Ключові слова: *ймовірнісна модель, кранові навантаження, чотириколісні крани, числові характеристики, надійність колон виробничих будівель.*

Introduction. Assessment of reliability of industrial buildings with overhead traveling cranes requires the use of probabilistic characteristics of crane loads. The process of obtaining these characteristics experimentally is lengthy, time consuming and technically difficult. Therefore, the crane loads mathematical model problem is relevant and justified.

Analysis of last research sources and publications. The results of extensive experimental investigations of crane loads nature are presented in the work [1]. Experimental data were processed in the technique of random variables and random processes and the probabilistic nature of crane loads were confirmed. Standardization and development of crane loads analytical models problems are considered in works [2]. Comparative analysis of the crane loads values defined according to national and international codes [3 – 5] is presented in [6]. The refined values of crane loads allow to get more accurate reliability of industrial buildings assessment [7 – 9]. The question of structures reliability is considered in [10 – 14]. The approaches to the reliability assessment were developed using probabilistic methods describing the structures conduct under external loads. Reliability assessment of one-storey industrial buildings with overhead cranes steel frames is described in [15 – 17], where the spatial nature of the frames was refined. Furthermore, the detailed analysis of loads and review of Codes [18, 19] which classify parameters of overhead traveling cranes were done.

Unsolved aspects of the problem. Notwithstanding, crane loads probabilistic model problem describing actual nature of the crane loads on industrial building structures is not solved.

Statement of the problem. Creating the probabilistic models of vertical and horizontal loads from influences of overhead travelling cranes on industrial buildings structures were done. Crane loads numerical characteristics values of crane loads were calculated.

Basic material and results. *Numerical characteristics of the vertical crane loads.* Vertical load (Fig. 1) on the structures of different rows (columns, crane girders) was defined as:

$$\tilde{F}_{max} = \left[\frac{G_B}{2} + (\tilde{Q} + G_{crab}) \frac{L_{cr} - \tilde{a}}{L_{cr}} \right] \frac{\tilde{y}}{n_0}, \quad \tilde{F}_{min} = \left[\frac{G_B}{2} + (\tilde{Q} + G_{crab}) \frac{\tilde{a}}{L_{cr}} \right] \frac{\tilde{y}}{n_0}, \quad (1)$$

where G_B , G_{crab} – weight of the bridge and the crab of crane;

\tilde{Q} – hoisting load;

L_{cr} – crane span;

\tilde{a} – approach of the crane hook;

\tilde{y} – sum of influence line ordinates;

n_0 – the number of wheels on one side of crane.

To the non-linear function (1) with three random arguments the procedure of statistical linearization was applied. In this case the mathematical expectations \bar{F}_1 and \bar{F}_2 were determined by substitution instead of random arguments the mathematical expectations of \bar{Q} , \bar{a} , \bar{y} . So accurate result was got because each second derivatives that define the mathematical expectation are zeros.

To calculate the dispersion of maximum crane load, the next coefficients were determined:

$$A_{1,max} = \frac{dF_{max}}{dQ} = \frac{L_{cr} - \bar{a}}{L_{cr}} \frac{\bar{y}}{n_0}; \quad A_{2,max} = \frac{dF_{max}}{da} = -\frac{G_{crab} + \bar{Q}}{L_{cr}} \frac{\bar{y}}{n_0};$$

$$A_{3,max} = \frac{dF_{max}}{dy} = \frac{1}{n_0} \left[\frac{G_B}{2} + (G_{crab} + \bar{Q}) \frac{L_{cr} - \bar{a}}{L_{cr}} \right]. \quad (2)$$

Using the obtained coefficients, the dispersion of vertical crane load was defined as follows:

$$\hat{F}_{\max} = \left(\frac{L_{cr} - \bar{a}}{L_{cr}} \frac{y}{n_0} \right)^2 \hat{Q}^2 + \left(\frac{G_{crab} + \bar{Q}}{L_{cr}} \frac{\bar{y}}{n_0} \right)^2 \hat{a}^2 + \frac{1}{n_0^2} \left[\frac{G_B}{2} + (G_{crab} + \bar{Q}) \frac{L_{cr} - \bar{a}}{L_{cr}} \right]^2 \hat{y}^2. \quad (3)$$

For the estimation the precision of dispersion the mixed derivatives are calculated:

$$\frac{d^2 F_{\max}}{dQ da} = -\frac{y}{L_{cr} n_0}; \quad \frac{dF_{\max}}{dQ dy} = \frac{L_{cr} - a}{L_{cr}} \frac{1}{n_0}; \quad \frac{d^2 F_{\max}}{dady} = -\frac{G_{crab} + \bar{Q}}{L_{cr} n_0}. \quad (4)$$

The dispersion precision of maximum crane load was determined using the linearization procedure:

$$\Delta \hat{F}_{\max} = \frac{1}{L_{cr}^2 n_0^2} \left\{ (L_{cr} - \bar{a}) \hat{Q} \hat{y} \right\}^2 + (\bar{y} \hat{Q} \hat{a})^2 + [(G_{crab} + \bar{Q}) \hat{a} \hat{y}]^2. \quad (5)$$

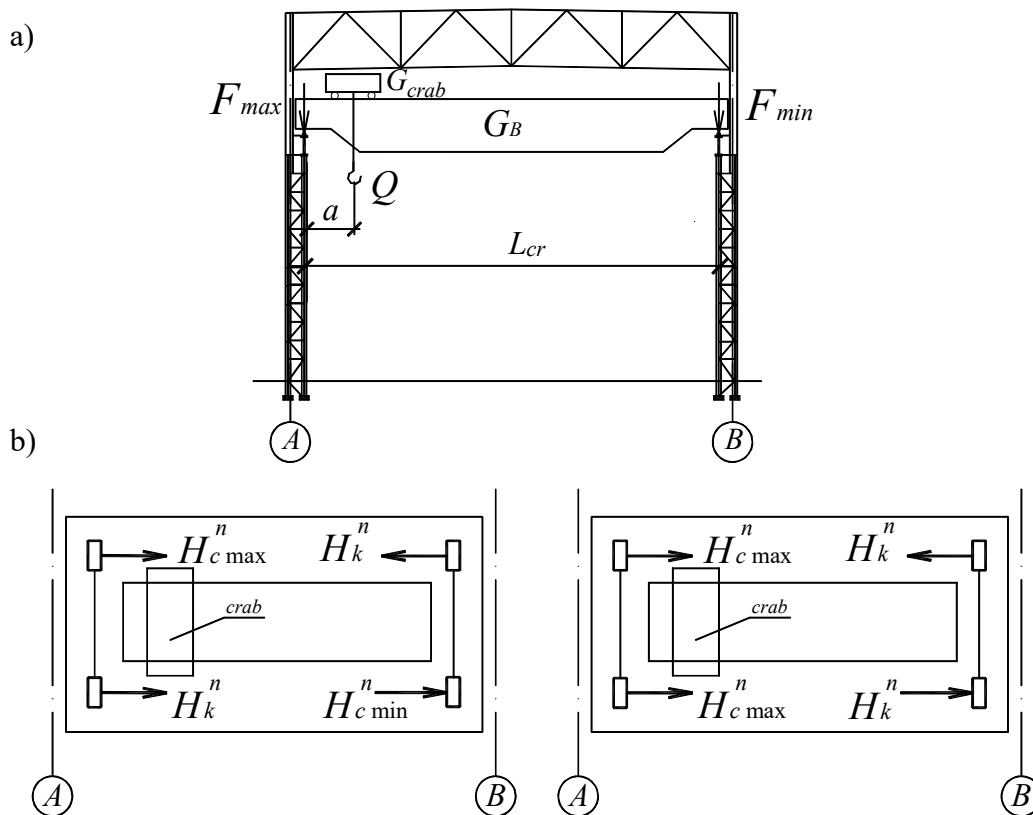


Figure 1 – Schemes of crane loads:

- a – application of vertical load to the transverse frames;
- b – application of horizontal loads to the crane wheels

The precision of minimum crane loads dispersion can be defined similarly.

For the numerical evaluation the crane with lifting capacity $Q = 50/10$ t was taken. The weight distribution was taken as normal with variation coefficient $V_Q = 1/3$ $V_{\bar{Q}} = 1/3$, distribution y – uniform. The obtained precision of dispersion was very low (2,2% \hat{F}_{\max}). The obtained numerical characteristics were used to construct a graph of load normal distribution on the column. This graph well corresponds to experimental polygons of loads.

Obtained formulas allow to use simple random arguments \tilde{Q} , \tilde{a} i \tilde{y} instead of complicated experimental study of vertical crane loads. Furthermore, the available experimental data and priori reasons followed by analytical determination of the crane loads characteristics can be used.

Numerical characteristics of horizontal crane loads. To calculate the dispersion of minimum crane load coefficients are determined:

$$A_{1,min} = \frac{dF_{min}}{dQ} = \frac{\bar{a} \bar{y}}{L_{cr} n_0}; A_{2,min} = \frac{dF_{min}}{da} = -\frac{G_{crab} + \bar{Q} \bar{y}}{L_{cr} n_0};$$

$$A_{3,min} = \frac{dF_{min}}{dy} = \frac{1}{n_0} \left[\frac{G_B}{2} + (G_{crab} + \bar{Q}) \frac{\bar{a}}{L_{cr}} \right]. \quad (6)$$

Then the dispersion of minimum crane load can be defined as:

$$\hat{F}_{min} = \left(\frac{\bar{a} \bar{y}}{L_{cr} n_0} \right)^2 \hat{Q}^2 + \left(\frac{G_{crab} + \bar{Q} \bar{y}}{L_{cr} n_0} \right)^2 \hat{a}^2 + \frac{1}{n_0^2} \left[\frac{G_B}{2} + (G_{crab} + \bar{Q}) \frac{\bar{a}}{L_{cr}} \right]^2 \hat{y}^2. \quad (7)$$

The mathematical expectation of lateral forces on the wheels of four-wheel crane (Fig. 2) can be found using formula (8). These forces are limiting skewing of the bridge:

$$\bar{H}_k^n = 0,1\bar{F}_{max} + \frac{\alpha(\bar{F}_{max} - \bar{F}_{min})L_{cr}}{B}. \quad (8)$$

To determine the dispersion of lateral forces also linearization process can be applied and the necessary coefficients can be defined. Then the dispersion of maximum lateral forces will be:

$$\hat{H}_k^n = \left[\left(0,1 + \frac{\alpha L_{cr}}{B} \right) \hat{F}_{max} \right]^2 + \left(\frac{\alpha L_{cr}}{B} \hat{F}_{min} \right)^2. \quad (9)$$

On the other crane side lateral forces with the following numerical characteristics appear:

$$\bar{H}_c^n = 0,1\bar{F}_{max} \text{ або } \bar{H}_c^n = 0,1\bar{F}_{min}; \text{ or } \hat{H}_c^n = 0,1\hat{F}_{min}. \quad (10)$$

The obtained formulas allow to use the numerical characteristics of horizontal crane loads in calculations and to use these characteristics for estimation reliability of industrial buildings structures.

Calculation of crane loads numerical characteristics. For the crane loads numeric characteristics definition the industrial building (with a span of 24 m and a columns step 6 m) with four-wheels traveling cranes was chosen. The cranes with operating mode 6K and the separate drive base were considered. Crane span $L_{cr} = 23,0 m$ and a crane base is $B = 4,4 m$. The mathematical expectations of maximum and minimum loads on crane wheels $\bar{F}_{max} = 124,63 kN$, $\bar{F}_{min} = 67,87 kN$ were calculated by substituting in (1) the numerical characteristics of all parameters. The mathematical expectations of lateral forces on the wheels of the crane were calculated using formulas (8) and (10): $\bar{H}_k^n = 15,43 kN$; $\bar{H}_c^n = 12,46 kN$.

The mathematical expectations of horizontal load on a column from lateral forces are: $\bar{H} = \bar{H}_k^n \cdot y_1 + \bar{H}_c^n \cdot y_2 = 23,32 kN$. Expectation and standard of lateral forces with $0,1F_C^{WW}$ are expressed:

$$\bar{X} = \frac{\bar{H}}{0,1F_C^{WW}} = 1,843, \hat{X} = \frac{\hat{H}}{0,1F_C^{WW}} = \frac{2,94}{0,1 \cdot 126,583} = 0,232,$$

where F_C^{WW} is load on the crane column without weight.

The obtained numerical characteristics of horizontal crane load correspond to the experimental values. For the further calculations of the industrial buildings columns reliability the numerical characteristics of vertical and horizontal crane loads were worked out.

The numerical reliability evaluation of industrial buildings columns. The analytical model of crane loads was used in the calculation of columns reliability on the example of multispan industrial building to design the three-span industrial building with columns of constant cross section. The spans of building are 24 m, the top elevation mark of the column is +14,000.

The building columns were designed on the resistance of structures in the plane and out of the plane of dead and variable compatible effect loads action defined by DBN V.1.2-2: 2006 [7]. The structures were uploaded by random vertical loads: dead and snow loads were applied with eccentricity, the vertical crane loads and horizontal loads were distributed with wind loads. The results of probabilistic reliability calculation are shown in Fig. 2 – 4 as the probability of structures no-failure during 50 years. It was expressed in bells $P_L = -\lg[1 - P(t)]$.

The main objective of the reliability estimation was to identify the various parameters which effect on no-failure probability of structures. In particular, two types of coverings for buildings: «heavy» – prefabricated concrete panels and «light» – profiled steel (Fig. 2) were considered.

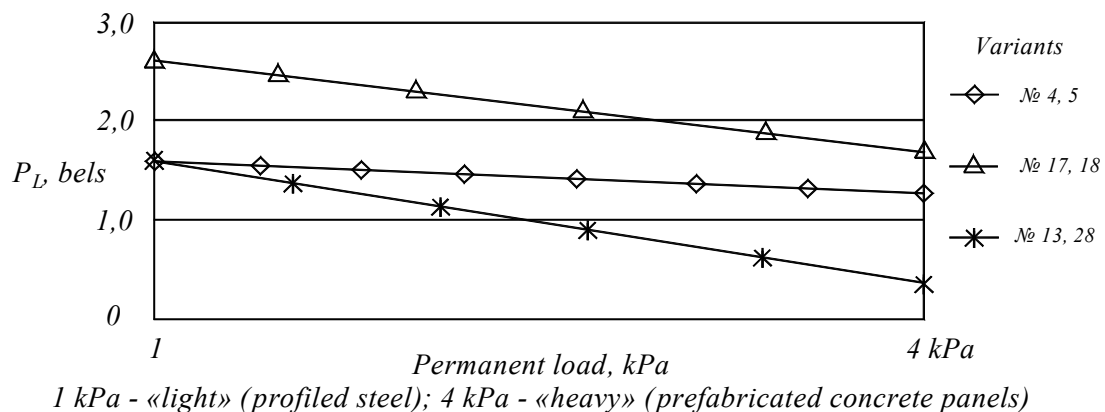


Figure 2 – The probability of columns no-failure dependence on the coverage type

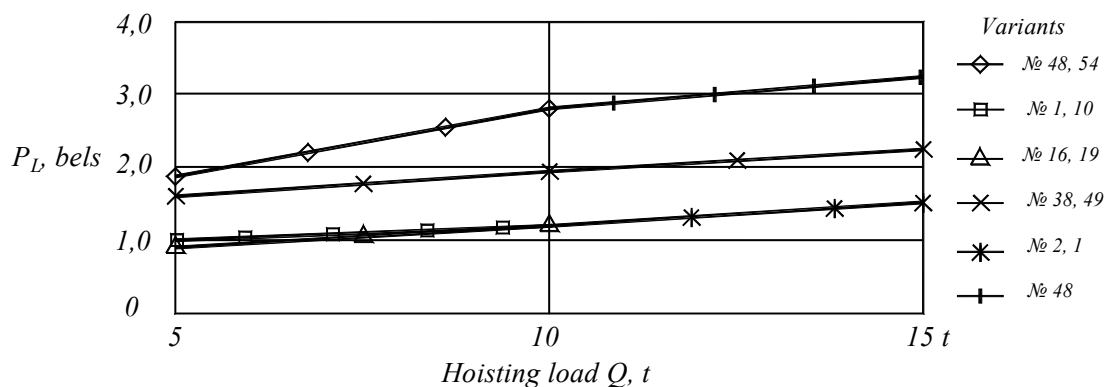


Figure 3 – The probability of columns no-failure of duty overhead cranes dependence

For each variant of covering the various ranges of building columns (Fig. 3) and types of column and girder connection (Fig. 4) were considered. In addition, the varied climatic loads were calculated (by considering the building, located in the II, III, V, and VI snow area and II, III and V wind area). Since the extreme wind load effect on the outer columns, the parameters of middle and outer columns were analyzed separately (for such columns different loading surfaces were considered). In total 56 variants of columns were worked out.

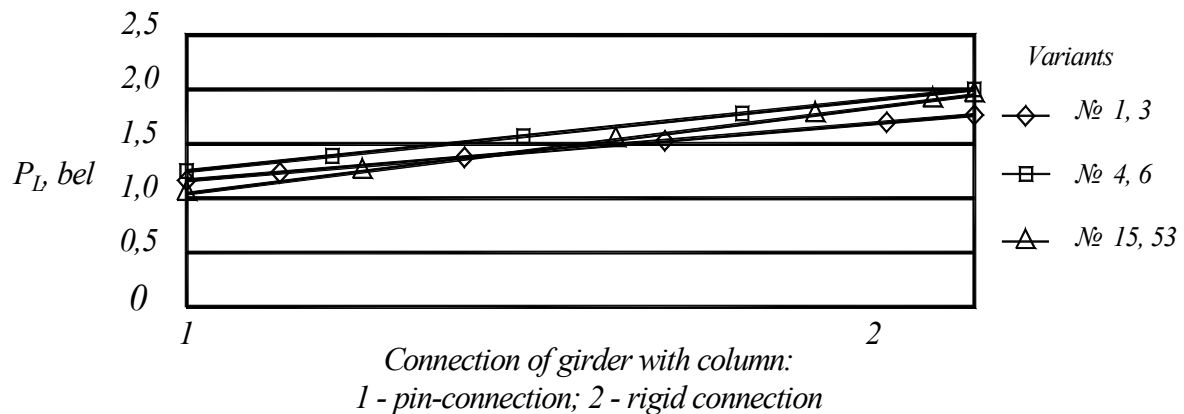


Figure 4 - The probability of columns no-failure dependence on the type of girder and column connection

Conclusions. The probabilistic model of vertical and horizontal crane loads was constructed. This model can be used for obtaining analytical stochastic loads characteristics of overhead traveling cranes and the following use of this characteristics in assessing the reliability of industrial buildings structures with overhead cranes. The obtained numerical characteristics of vertical and horizontal crane loads correspond to the experimental values, therefore characteristics can be used for reliability estimation of industrial buildings structures with crane equipment.

The numerical industrial buildings columns reliability evaluation was done considering the time factor and the stochastic loads nature and steel strength. For the investigation of the different factors as for frameworks reliability influence, the next parameters were considered: capacity and mode of overhead cranes, columns spacing, the type of column and girder connection, the coverage type and the wind and snow loads values. The tendency to increase the no-failure probability of structures with overhead cranes capacity increasing was detected. Such character of probability change can be explained by reliability stress ratio decrease of one and two overhead cranes and the growth of weight characteristic (ratio of hoist load and own crane weight). The growing of columns no-failure probability with permanent cross section of the industrial building was detected after increasing the coverage weight (due to the part of permanent load growing and reducing the part of high-frequency component of strength reserve). The redistribution of internal forces and components of columns reserve was detected by changing pin-connection to the rigid connection of column with girder. Herewith the increasing of permanent and snow loads parts and the reduction of wind and crane loads parts provide the reliability columns enhancement.

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