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Development of crane load codes on the basis of experimental research

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The buildings and structures reliability and safety largely depend on a proper understanding of the nature and quantitative description and rationing of loads on building structures, including crane loads. Most of the parameters of the crane load codes have a probabilistic nature and require the use of statistical methods to substantiate them. These methods are constantly changing and evolving together with the regular revision of building design codes. Analysis of domestic codes' evolution of crane load together with their statistical substantiation is an urgent task, which is this article's purpose. Since the late 1930s, leading construction research institutes and universities have conducted research on crane loads, which results have been consistently incorporated into design codes. Giving an overall assessment of Ukrainian crane loads standards, it should be emphasized that they are compiled on a modern methodological basis, close to European standards Eurocode, based on representative statistics, more differentiated, and have a scientific probabilistic nature.

Keywords: building design codes, bridge crane, overhead crane, crane load, normative load, design load

Розвиток норм кранових навантажень на основі експериментальних досліджень

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Забезпечення надійності та безаварійності будівель і споруд у великій мірі залежить від правильного розуміння природи і кількісного опису та нормування навантажень на будівельні конструкції, в тому числі кранових навантажень. Ці навантаження на виробничі споруди мають досить складну фізичну природу і мінливий характер, що вимагають знання конструктивних відмінностей мостових та підвісних кранів, кінематичних та динамічних процесів, що реалізуються при роботі кранів, особливостей технологічних процесів, що відбуваються у виробничих цехах, які обслуговуються підйомними кранами. Такі особливості у певній мірі відображаються в розділах норм проектування будівельних конструкцій, що містять нормативи кранового навантаження. Більшість параметрів норм кранового навантаження мають імовірнісну природу і вимагає для свого обґрунтування застосування статистичних методів. Ці методи постійно змінювалися і розвивалися разом з регулярним переглядом норм будівельного проектування. Тому аналіз еволюції вітчизняних норм кранового навантаження разом з їх статистичним обгрунтуванням є актуальною задачею. Матеріали, присвячені крановим навантаженням, опубліковані в різних науково-технічних журналах, збірниках статей, матеріалах конференцій. Стаття містить систематизований огляд норм проєктування та публікацій по проблемі кранового навантаження за 90-річний період з 30-х років XX століття до теперішнього часу. Головна увага приділяється аналізу тенденцій розвитку норм проектування конструкцій в частині змін розрахункових коефіцієнтів, призначення нормативних і розрахункових значень кранового навантаження і залучення до цього дослідних статистичних даних. Відзначається високий науковий рівень вітчизняних норм ДБН В.1.2-2006 «Навантаження і впливи», які мають сучасний імовірнісний базис і асоціюються з нормами Єврокод. Виділяються наукові результати, що можуть бути включеними в наступні норми кранового навантаження.

Ключові слова: норми будівельного проєктування, мостовий кран, підвісний кран, кранове навантаження, нормативне навантаження, розрахункове навантаження

Introduction

Lifting and transport machines are indispensable elements of any sphere of the economy. The technological process of most manufacturing enterprises is associated with the need to mechanize operations for vertical and horizontal goods transportation with a wide range of weight. This mechanization, along with other vehicles, is carried out by means of a bridge (support) and overhead cranes, which are special devices that move with loads along and across the shop. Ensuring the reliability and safety of buildings and structures largely depends on a proper understanding of the nature and quantitative description and rationing of loads on building structures, including crane loads. Loads from cranes can be significant; they have a variable dynamic nature and have a significant force on the structure of industrial buildings. These features are reflected in the sections of building structure design codes that contain codes for crane load. Most of the crane load code parameters are probabilistic in nature and require the use of statistical methods to substantiate them. These methods are constantly changing and evolving together with the regular review of building design standards. Analysis of the evolution of domestic codes of crane load together with their statistical substantiation is an urgent task.

Review of research sources and publications

With approval the first domestic building codes, which included the section of crane loads, related publications of the 30s of builders and crane operators [1]. Subsequently, active studies of bridge cranes loads were performed in TSNIPS [2]. This process was intensified with the preparation of structural calculations for the limit states method. In the postwar years, the study of crane loads was restored by TSNISK [3-6]. In the 60-80s, a comprehensive study of crane loads was performed by the Test Station of the Moscow Civil Engineering Institute (MIBI) [7-29]. Since the '70s, research on crane loads has been conducted at the Poltava Civil Engineering Institute (now the National University "Yuri Kondratyuk Poltava Polytechnic") [30-40]. The conducted researches promoted regular revision of loading codes and improvement of crane loads rationing. Beginning in the 1990s, design codes were developed by individual countries that were formerly part of the USSR. In this regard, probabilistic studies of crane loads were intensified in Ukraine, which resulted in the relevant section of DBN B.1.2-2006 "Loading and effects". In the following years, the study of crane loads continued along with the justification and refinement of the calculated coefficients of design standards [41-43].

Definition of unsolved aspects of the problem

Field studies of bridge loads and overhead cranes have been performed for many years on a large scale, creating a significant array of statistical information. However, there is no common information database for this data. Some of them have been published in various scientific and technical journals, collections of articles, conference proceedings. Access to these publications is difficult, as the translation into electronic form has taken place only for publications published after 2000. The results of crane loads studies are partially included in the design codes, but several reasonable proposals remain outside the current regulations. There is no analysis of trends in crane codes and the allocation of further development issues of this important load rationing.

Problem statement is a systematic review of research results and scientific publications on the problem of crane loads for the 90-year period from the 30s of the twentieth century to the present. It is emphasized that these loads on buildings have a complex physical nature and changeable character. The main focus is on identifying the relationship between the crane loads and developing the results of experimental studies of these loads. Aspects of probabilistic substantiation of calculated coefficients, assignment of normative and calculated values of crane load are emphasized. Scientific results that can be included in subsequent editions of crane load standards are highlighted.

Basic material and results

The beginning of domestic standardization of crane loads was laid in 1930, when the "Uniform codes of construction design" were introduced. Given that at that time the relevant experimental work was not carried out in the USSR, the basis of the adopted codes were foreign standards, the work of crane operators, and reference books, for example [1]. There are the horizontal loads transmitted from the cranes to the crane tracks and directed along with the building and were defined as

$$H = 0.1\, P\, n\,, \tag{1}$$

where P - the calculated vertical pressure on the crane wheel;

n - the number of brake crane wheels located on the beam.

Formula (1) is obtained based on the law of friction $F = f\,N$, ie the friction force is equal to the normal pressure N multiplied by the coefficient of friction between the rails and wheels of the crane f, equal to 0.1.

In the late 1930s, a leading construction research organization, the Central Research Institute of Industrial Structures (CNIPS), organized large-scale field studies of the actual operation and bridge crane loads on steel frames of industrial buildings. The employees of TsNIPS N.E. Romanov tested 60, 125, and 220-ton foundry cranes [2]. Transverse loads when passing cranes past the measuring range were of different nature, but in all cases, they significantly exceeded the forces from the braking of the truck.

In 1940, the standard OST 90057-40 "Payloads" was adopted, in which crane loads were specified. In addition to the previous requirements, it emphasized that the transverse force should depend on the type of load suspension. For cranes with flexible suspension, this force was taken equal to 0.05 of the sum of load capacity and weight of the trolley, and for cranes with rigid suspension twice as much - 0.1 of the same sum.

Thus, the braking force transmitted to the crane wheel with a flexible suspension of the load was defined as

$$T_k = \frac{0,05}{n_0}(Q_t + Q) \ , \qquad (2)$$

where Q_t is the weight of the crane trolley;
Q – load capacity of the crane;
n_0 – the number of wheels on each side of the crane bridge.

In 1942, instead of OST 90057-40, the state standard GOST 1645-42 was issued. In addition to the previous requirements, it specifies that when calculating crane structures, the vertical load is taken from the actual number of cranes, but not more than two cranes approaching for joint work in each span of the building and on each tier. In multi-span stores, the possibility of placing cranes in one line in adjacent spans is taken into account.

In the pre-war and first post-war years, the Gipromez Institute under the leadership of O.I. Kikin (later doctor of technical sciences) carried out large-scale studies of the operation mode and loads of bridge cranes in the shop of metallurgical production. O.I. Kikin divided the horizontal transverse loads of overhead cranes on the *lateral forces* arising from the movement of cranes on tracks, and the *braking forces* caused by braking of trolleys of overhead cranes. The measured lateral forces were significantly (up to 3… 5 times) more than the loads from trolley braking. The obtained results were used in the preparation of TU 104-53 "Technical conditions for the design of steel structures of buildings of metallurgical plants with a heavy mode of operation." They introduced lateral forces, which, however, it was recommended to take into account only for individual structures and components by multiplying the standard braking forces by an increase factor equal to 1.1 ... 2.5, when calculating the upper belts of crane girders and brake structures, and a coefficient equal to 2.2 ... 5.0, when calculating the attachment of the brake structures of the crane girders to the columns. This approach was selective and did not take into account the lateral forces when calculating the transverse frames. These coefficients then passed to NiTU 121-55 "Codes and technical conditions for the design of steel structures."

In the 50s of the last century, studies of the lateral bridge cranes were continued in the TsNIPS under the leadership of M.F. Barstein [3]. As a normative load, it was proposed to take the lateral forces arising from the movement of the wheel crane with normal factory tolerances, with crane rails, concluded with the usual installation deviations. In this case, the formula of lateral forces, taking into account the pseudo-slip and the skew angle of the wheel 0.001 was as follows:

$$H = 1,5\sqrt{F_{\max} \cdot d} \ \text{(kgs)}, \qquad (3)$$

where d is the diameter of the crane wheel.

The values calculated by the formula (3) were close to the results calculated by the formula $H = 0.1\ F_{max}$ that M.F. Barstein recommended determining the lateral forces.

The first edition of the State building codes and rules of SNiP II-B.1-54 "Loading and effects" kept the general recommendations of the previous codes concerning bridge cranes loadings, having noted that "... the influence of crane distortions has to be considered according to special codes and technical conditions". In connection with the transition to the method of calculating structures for limit states, for crane load, an overload factor of 1.3 was introduced.

Study of the lateral forces of bridge cranes continued, beginning in 1954, at the Institute VNIIPTMASH under the leadership of V.P. Balashov [4]. The research included a theoretical part, an experimental test, and concerned four-wheel and multi-wheel cranes with wheels on rolling bearings with central and separate drives. The design case was considered to be the skew of the crane during its movement, which is caused by numerous factors, among which the difference in diameters and skew of the wheel axes, as well as the displacement of the crane tracks in the horizontal and vertical planes. The work developed an idea of the mechanical nature of the lateral crane forces, but the derived formulas were not included in the codes due to their cumbersomeness.

A number of experimental studies of crane loads were conducted at the TsNIISK in 1954-1955 under the leadership of A.Kh. Khokharin [5]. The experiments were performed on an experimental frame equipped with a 10 tons capacity bridge crane, as well as in existing shops. Studies have confirmed that the main case of force interaction of the crane with the crane tracks should be considered the case of the crane skew with the contact of the wheel flanges. Based on the above experimental studies, a calculated formula for the lateral force transmitting the crane wheel was proposed:

$$T = \alpha\beta \frac{L_{cr}}{B} F_{\max} \ , \qquad (4)$$

where F_{max} is the maximum vertical pressure of the wheel;
L_{cr} – crane span;
B – crane base;
β – coefficient that takes into account the ratio of the stiffness of the crane bridge and the transverse stiffness of the shop frame;
α – coefficient taken depending on the load capacity of the crane and the mode of shop operation within 0.01 … 0.03 for the calculation of brake trusses and upper belts of crane girders and twice as much - for the calculation of fastening of brake trusses to crane girders and columns, rails to crane beam.

In the late '50s of last century, there was the first publication on the statistical study of crane loads, in which A.A. Bat (TsNIISK) cited the results of field studies of the crane girders load regime [6]. The research was carried out in 1956 - 1958 in 25 operating shops of 4 metallurgical factories, in total more than 8 thousand cycles of crane girders loading were recorded. The obtained experimental statistics on the mode of crane girders operation allowed to develop their calculation for endurance and gave an idea of the statistical variability of vertical crane loads.

In the 50-80s of the last century, the study of bridge crane loads was actively carried out at the Moscow Civil Engineering Institute (MISI) at the Test Station of the Department of Metal Structures. The results of these studies are summarized in collective monographs [7, 8], in which the author of this article took part. The first large-scale statistical study of vertical bridge cranes loads was conducted in the late 50s of the last century by B.N. Koshutin [9]. Observations were conducted in 23 spans of shops for various purposes. 52 experimental distribution polygons were obtained, which included 65535 cases of vertical loads on the columns and crane girders.

The polygons turned out to be symmetrical, single-vertex, and were reasonably replaced by curves of normal law. Developing a probabilistic approach to determining the overload factor, B.N. Koshutin drew attention to the misconception of the 50s of last century that the design load should be at a distance of three or four standards from the center of the distribution curve, ie the probability of exceeding it should not be more than $1.3 \cdot 10^{-3}$ or $3.1 \cdot 10^{-5}$. If we take into account that the vertical crane load can act on the columns, according to the obtained experimental data, $N = (0.6 \ldots 0.5)\ 10^6$ times during the 20-year service life, it becomes obvious that the above probabilities do not provide sufficient provision for the crane loads normalization. In view of this, the following expression was proposed for the overload factor

$$n = \left[1{,}1\left(\overline{X} + \beta\hat{X}\right) + 0{,}1\frac{F_K}{F_{M1}}\right]\frac{F_{M!}}{F_{M2}}, \qquad (5)$$

where $\overline{X}$ and $\hat{X}$ are the experimental average statistical value and standard;

F_K – load on the column from the weight of the bridge;
F_{M1} and F_{M2} - load on the column, respectively, from one and two cranes;
β – the number of standards corresponding to the probability of exceeding the design load F_R, $V = (F \geq F_R) = 1/N$, where N is the number of loads during the service life.

Based on the conducted statistical research the differentiated values (accepted with a stock) of overload coefficients of vertical crane loading of 1.0 … 1.2 were offered.

A.A. Bat and B.N. Koshutin in 1958 conducted a joint study of vertical crane loads at the Dniprospetsstal plant in the rolling shop and the pouring span of the electric steel shop [10]. Both methods gave the following main results, which coincide:

• distribution curves of vertical loads on columns have an approximately symmetrical look with the most probable size of 0,35 … 0,60 from standard loading of one crane without dynamic factor;

• cases of complete convergence of two cranes are rare and do not have a noticeable effect on the appearance of load distribution curves;

• the overload factor for the crane load can be reduced from 1.3 to 1.2.

In 1962 the second edition of SNiP II-A.11-62 "Loading and effects" was published. In a publication [11], the drafters list the new aspects of the publication related to crane loads. The value of the overload factor has been reduced from 1.3 to 1.2 for vertical and horizontal loads from cranes with a capacity of 5 tons and more (than taking into account the above results of statistical studies). This version of SNiP, as before, distanced itself from the specifics in determining the lateral forces of bridge cranes: "Horizontal transverse loads arising from the movement of the crane due to its skew and non-parallel crane tracks should be determined and taken into account in the calculation in accordance with the provisions of the design codes of structures of buildings and structures for various purposes." According to this installation, for steel structures, the coefficients α_1 and α_2 taking into account the action of lateral forces on individual structures and assemblies were preserved.

In the same years, the MIBI Test Station actively studied the lateral forces of bridge cranes. Chronologically, the first studies were realized by I.B. Izosimov at the Cherepovets Metallurgical Plant [12]. Four-wheel cranes on rolling bearings were investigated in order to identify the factors influencing the lateral forces. Noting the number of factors influencing the lateral forces, and the difficulty of taking them into account by calculation, it was decided to determine the lateral force as a function of the vertical pressure on the wheel:

$$H_k = f_p F_k, \qquad (6)$$

where H_k and F_k – respectively, the lateral and vertical load on the wheel;
f_p – the coefficient of proportionality, called the "realized friction coefficient of the transverse slip", which must be determined according to field tests.

The latter term cannot be considered successful, because f_p is essentially a generalization that establishes the relationship between horizontal and vertical loads. Setting the task in this form oversimplifies the problem, while making it difficult to assign f_p. The experimental values of the realized coefficients of friction were summarized in graphs of their dependence on the vertical pressure on the wheel and described by power functions. Received by I.V. Izosimov empirical dependences for the lateral forces cannot be considered sufficiently substantiated due to the insufficiency of the original statistical material and the depersonalization of a number of factors.

More profound field studies of the transverse loads of bridge cranes were conducted by A.V. Figarovsky (MISI, Test Station), with whom the author has long and fruitfully collaborated in joint work. In 1962-1963 years in one of the machine-building plant shops, it was conducted experimental force effects studies of a four-wheeled bridge crane of medium mode with a separate drive, with a capacity of 15/3 ts [13,14]. Simultaneous measurements of vertical and horizontal crane loads were performed. The used integrated methodology was a significant step forward in comparison with the crane loads studies of previous years, it was unique in its complexity and thoroughness of preparation and application. Based on the tests, A.V. Figarovsky derived the formula for the values of the largest lateral forces on the wheels of four-wheeled cranes:

$$H_{\kappa} = 0{,}1F_{\max} + \alpha(F_{\max} - F_{\min})\frac{L_{cr}}{B}, \qquad (7)$$

where F_{max} and F_{min} – the average pressure of the wheels, respectively, more or less loaded side of the crane;

α – coefficient equal to 0.01 for cranes with a separate drive of the movement mechanism and 0.03 – for cranes with a central drive.

In the above formula, the first term gives the transverse force from the skew of the wheel, the second - the horizontal component on the wheel flange, which limits the bridge skew. On other wheels can act only friction forces, approximately equal $0.1F$. This formula provides a fairly close coincidence with the experimental values.

A.V. Figarovsky also conducted a comprehensive field experiment in the pouring span of the open-hearth shop of the metallurgical plant [15]. A multi-wheeled foundry crane with a capacity of 175 tons with a central drive was tested. Unlike a four-wheel crane, a multi-wheel crane is less prone to skew and tends to keep the initial angle of skew constant. This is due to the smaller ratio of the crane span to its base and the presence on each side of the bridge balancing carts that allow some rotation in the vertical plane. Lubrication of the side surface of the rail head significantly (1.7 ... 2.0 times) reduced the magnitude of the lateral forces and their dynamics. The magnitude and nature of changes in the lateral forces of multi-wheel cranes are significantly affected by deviations in track width that exceed the total clearances of the flanges. It was found that in places of narrowing and widening of the track, the lateral forces increase by 2.0 ... 2.5 times.

In 1963-1965 years in the laboratory of dynamics of CNDIBK the researches of lateral forces were carried out by A.N. Zubkov under the direction of M.F. Barstein [16]. The theoretical development of the question was based on the idea of the bridge crane movement on the crane track, which has random deviations in the horizontal plane. The continuous contact of the rail with the flange of one wheel or with the flanges of two wheels located on one end beam was considered. Differential equations of crane motion were formed, and it was considered that the track deviation in the horizontal plane is a stationary normal process, the correlation functions of which were calculated from the materials of a geodetic survey of crane tracks in existing shops. Based on the research, a formula to determine the calculated values of the transverse forces acting on the wheels of the crane when limiting the skew by the flanges of the wheels on one side of the crane was proposed:

$$R = 15(\alpha\frac{L_{cr}}{b} \pm \beta)\sqrt{F} \text{ (in kgf)}, \qquad (8)$$

where L_{cr} – the crane flight;

b is the distance between the end crane wheels;

F – average vertical wheel pressure;

α, β – coefficients accepted for four-wheel, eight-wheel, and sixteen-wheel cranes equal to [0,4, 0,8, 1,6] and [1, 3, 7].

In the same years, probabilistic studies of bridge crane loads were carried out at the MISI Test Station. The first attempt to obtain and process statistical data on horizontal loads of bridge cranes was made by B.N. Koshutin in the open-hearth shop of the Cherepovets Metallurgical Plant [17]. Lateral forces were recorded on the columns in the normal operation of the shop in the pouring and furnace spans. The experimental values of the overload coefficient had a large variance, and for the furnace, span exceeded the normative value equal to 1.2 (according to the variant SNiP valid at the time of testing).

In 1964-1966 years S.F. Pichugin conducted complex field studies of vertical and horizontal loads of bridge cranes for various purposes [13, 15, 18]. Statistical material was collected as a result of continuous registration of crane loads of normal operation in existing shops. Crane loads were presented in the form of random variables. The following features of statistical distributions of crane loadings were revealed:

• rapid stabilization, i.e. detection of these distributions taking into account the relatively small amount of statistical material, further increase of which does not change the picture either qualitatively or quantitatively;

• reasonable opportunity of applying the normal law to describe the ordinate distributions of vertical and horizontal crane load is substantiated;

• close connection of cranes work and crane loadings with the production technology of shops in which cranes are operated, stability of trajectories of movement of cranes and trolleys, the technological features influence on probabilistic characteristics of crane loadings (actual location of crane work areas, unequal loading of different rows structures, restriction of crane trolleys approach);

• a specific feature of some crane loads with flexible suspension (for example, foundries), which consists in the allocation in their distributions of the extreme "tail" parts, corresponding to operations with loads close to the load capacity; these parts should be considered separately [19,20].

Based on the analysis of statistical distributions of lateral crane loads for different purposes for 14 spans of 12 shops of three metallurgical plants, formulas were proposed to determine the normative values of these loads and the values of the overload coefficients of lateral bridge cranes forces.

In 1967-1968 years, the MISI Test Station (Y.S. Kunin) carried out large-scale field measurements of crane loads in the shops of metallurgical plants. The main results of this work are presented in a publication [21], which illustrates the transition from the representation of crane loads in the form of random variables to a probabilistic model of random processes. It was confirmed that crane loads are normal stationary random processes of ergodic nature. The obtained statistical data allowed estimating the overload factor of the vertical crane load based on the theory of random processes outliers

$$n = \overline{X} + \gamma\hat{X} \ , \tag{9}$$

where $\overline{X}$ and $\hat{X}$ – mathematical expectation and standard,

γ – the number of standards, which is determined taking into account the accepted service life of the structure and the specified probability of not exceeding $[P(T)]$ or exceeding $[Q]$ the calculated value of the crane load:

$$\gamma(T) = \sqrt{2\ln\frac{T\cdot\overline{n}_0}{-\ln[P(T)]}} = \sqrt{2\ln\frac{\omega T}{2\pi[Q(T)]}} \ , \tag{10}$$

Here, on the left part, a variant of the formula is given, in which the frequency characteristic includes the average number $\overline{n}_0$ of excess of the average level per unit time; the left part of the formula includes the effective frequency of the crane load – this option was used in further crane loads studies.

According to the formula (9), the overload coefficient n = 0.45 … 1.08 for the service life T = 50 years and the probability of trouble-free operation $[P(T)]$ = 0.999 was obtained, which in all cases turned out to be less than the normative one.

Operators and researchers, including those mentioned above, have repeatedly noted that the actual vertical pressures on individual wheels of bridge cranes can differ significantly from the passport values. Such differences are called "uneven pressure of crane wheels". It is known that the bridge crane is a redundant spatial system that has fairly high rigidity in the vertical direction. Therefore, for example, a real 4-wheel crane while driving on real roads at certain times can rely on the rails at three or even two points (located on the diagonal of the bridge). As a result, the load on the wheels of bridge cranes can change both upwards and downwards. The non-uniformity of wheel pressures was studied in detail by V.N. Val (MISI, 1966-1969) [22], who used the method of weighing in tests of 26 cranes with a capacity of 5 ... 225 tons. He proposed to take into account the increase in wheel pressure of the bridge crane by the *coefficient of non-uniformity*

$$n_н = 1 + \Delta F / F_n \ , \tag{11}$$

where ΔF – increase in wheel pressure;

F_n – maximum normative wheel pressure.

Based on the performed research, values of coefficient of non-uniformity of pressures on separate wheels of cranes were received in the range 1.3 ... 1.1 for cranes with a loading capacity of 5 ... 200 ts.

Another source of increasing the pressure of individual crane wheels is their dynamic nature, which is taken into account by the local dynamic coefficient $k_{d,loc}$, which depends on the stiffness of the crane girders, the speed of the cranes, and especially on the condition of the crane tracks. Experimentally obtained values $k_{d,loc}$ = 1.0 ... 1.5 depends on the type of load suspension and lifting capacity of cranes.

Taking into account the above values of the non-uniformity coefficient of pressure on the wheel n_n and the local dynamic coefficient $k_{d,loc}$, V.N. Val proposed (not yet implemented) to increase the total coefficient to the following values: γ_{f1} = 1.8 – for cranes with rigid suspension; γ_{f1} = 1.5 for cranes with the flexible suspension of heavy rate (groups of modes 7K and 8K); γ_{f1} = 1.3 for other cranes [22].

The next statistical research stage of the MISI Test Station was the study in 1970-1973 combinations of vertical crane loads by A.T. Yakovenko [23]. Statistical data were obtained for vertical loads of 17 cranes operating in 7 spans of metallurgical plants. The actual combination coefficients of crane loads were determined by a formula suitable for any random loads:

$$\psi = [S_\Sigma] \Big/ \sum_{i=1}^{n} [S_i] \ , \tag{12}$$

where $\sum_{i=1}^{n}[S_i]$ – the sum of loads (efforts) at unfavorable loading of a line of influence by the approached cranes provided that pressures of separate wheels of each crane can be exceeded with probability $Q(T)$;

$[S_\Sigma]$ – design load (effort) taking into account the actual random process of crane load, which is determined from the condition of the same probability of exceeding the service life $Q(T)$ according to formulas (9) and (10).

Of the thus obtained combination coefficients, the largest was the experimental values for cranes of groups of modes 8K (ψ = 0.75 … 0.85), which regularly lift loads close to the nominal and have high speeds. Slightly smaller, within ψ = 0.58 … 0.73, the obtained composition coefficients for cranes of groups of modes 7K. The lowest values ψ = 0.38 … 0.40 were observed in cranes of groups of modes 4K… 6K. These cranes are less loaded, rarely lift loads close to the nominal, approach relatively rarely.

In 1974 the next edition of SNiP II-6-74 "Loading and effects" was published in which the load codes of overhead cranes were combined with the load standards from overhead cranes. Long-term loads (without experimental justification) included the load from one crane, multiplied by 0.6 for cranes of medium mode and by 0.8 for cranes of heavy and very heavy modes. Taking into account large-scale studies of crane loads conducted in the '60s and '70s at MISI (as described above), the overload factor for loads of all cranes was assumed to be 1.2. For the first time, a scale of lowering combination coefficients for vertical loads from two and four cranes in the range of 0.70 ... 0.95, depending on the modes of operation of the cranes, was included. A lateral force standard equal to 0.1 of the normative vertical load on the wheel was introduced for each running wheel. However, as before, it was inconsistently regulated that "... this load should be taken into account when calculating only the beams of crane tracks and their attachments to columns in buildings with cranes of very heavy mode, with foundries and other cranes of the heavy mode of metallurgical production." For the endurance calculation of crane track beams, it was indicated that the normative load from one crane should be multiplied by a factor of 0.6 for cranes of medium mode and a factor of 0.8 for cranes of heavy and very heavy modes.

In the 70's the Dnepropetrovsk Institute of Railway Engineers (DIIT, Yu.A. Zdanevych [24]) continued a study initiated earlier by a number of researchers to assess the impact on the crane load of the technological process features. The recommendation to reduce the overload factor to $n = 1.1$ was substantiated for the payload of steel ladles (taking into account the wear of the lining) in determining the vertical loads of foundry cranes. For an open-hearth shop with 10 furnaces with a capacity of 220 ... 450 t, the following composition coefficients for vertical crane loads in the interval $\psi = 0.70 \ldots 0.90$ were substantiated.

In the same period, the features of the technological process of rolling shops were also identified by S.A. Nischeta (MISI Test Station) during experimental studies on seven heavy-duty bridge cranes with a capacity of 10 ... 20 tons with a flexible suspension traverse and a separate drive [25]. The obtained experimental statistics, together with the results of previous studies [8, 21], as well as the provisions of the design standards of bridge cranes [26], allowed the recommendation to reduce the overload factor of the crane load to $n = 1{,}1$.

The maximum values of horizontal loads that exceeded the braking forces by 2.5 ... 3.0 times were obtained. Based on these data, the following formula of lateral force on the wheel of a crane with a separate drive was proposed

$$H_k^n = 0{,}04 \frac{L_{cr}}{B} F_{\max}^n , \qquad (13)$$

S.A. Nischeta also studied the coefficients of forces composition from vertical crane loads for crane girders and columns of the extreme and middle rows by statistical modeling (Monte Carlo). Coefficients of the combination of vertical crane influences on columns from two bridge cranes located on one crane way, and four cranes - on different ways, were defined by the formula

$$\psi = S / \left(n S_i^n \right) , \qquad (14)$$

where S is the value of the vertical loads on the column from two or four bridge cranes, corresponding to the probability of realization $P = 0.95$ per time $T = 40$ years;

nS_i^n – the sum of the products of the loads on the column from each of the "k" cranes wheels (with unfavorable loading of the influence line of the crane girders support reactions) on the corresponding actual values (for each of the spans) of the overload coefficients n.

It was found that the combination coefficients significantly depend on the line length of corresponding force influence and the ratio of the crane span to its base.

The dependence on the length of the working area and the structure position (column, crane beam) is also noted. The actual combination coefficients obtained in the range $\psi = 0.60 \ldots 0.95$ were lower (especially taking into account the four cranes) than those set in the SNiP, which indicates that under operating conditions, the maximum convergence of two (and even more so four) cranes with a maximum load is an exceptional phenomenon. Therefore, there was (and now is) the possibility of differentiation and further reduction of the crane load combination coefficients.

In the following years, a number of changes in the part of crane loads were introduced in SNiP II-6-74 [27], which were included in SNiP 2.01.07-85 "Loading and effects", which came out after 11 years. Based on statistical data obtained by A.A. Bat, the long-term parts of the loads from the bridge and overhead cranes were reduced: from 0.6 to 0.5 from one medium mode crane and from 0.8 to 0.7 from a heavy and very heavy mode crane. It was indicated that instead of taking into account two cranes, the check of deflections of crane track beams should be performed from one crane - on the basis of research by M.Ya. Kouzin (MISI [28]).

The reliability factor for the load (which replaced the former overload factor) for crane loads began to be taken equal to $\gamma_f = 1.10$ (justification is given above). A long-overdue addition was made - the coefficient of increase of concentrated load on a single wheel of the bridge crane was transferred from SNiP for steel structures to SNiP for loads in the range $\gamma_{f1} = 1.10 \ldots 1.60$ depending on the groups of operation modes of cranes and cargo suspension. The scope of the lateral force standard, which is caused by the skew of bridge cranes and non-parallelism of crane tracks, was slightly changed – now it concerning the calculation of durability and stability of crane tracks beams and their fastenings to columns in buildings with cranes of operating modes groups 7K, 8K.

The latest field tests, aimed at a study of crane loads, were conducted by V.A. Plotnikov in the 90s of the twentieth century in the shops of the Magnitogorsk Metallurgical Plant [29]. Experimental values of lateral forces from multi-wheel cranes in all cases did not exceed the normative values according to SNIP 2.01.07-85. This work significantly supplemented the idea of the nature and magnitude of the lateral forces of multi-wheel cranes. However, the probabilistic coefficients remained undefined in the proposed formulas, and no comparison of the obtained theoretical formulas with experimental data was performed. Investigation of horizontal loads of four-wheel cranes V.A. Plotnikov performed on an open scrap yard overpass. It was found that the values of the experimental loads correspond quite closely to the values determined by the formula (13), proposed by S.A. Nischeta for overhead cranes of industrial buildings.

Researchers, designers, and operators have identified significant shortcomings of SNiP 2.01.07-85 in terms of crane loads normalization.

1. Double approach to determining the horizontal transverse effects of the bridge and overhead cranes. On the one hand, when calculating the transverse frames of buildings and beams of crane tracks, it is proposed to take into account the load caused by trolley

braking - the transverse braking force. On the other hand, when calculating the strength and stability of crane track beams and their attachments to columns in buildings with cranes of operating modes 7K, 8K, it is proposed to take into account much larger lateral forces directed across the crane track and caused by skew electric cranes and non-parallel crane tracks.

2. Lack of explicit connection of the crane load standard with the period of its recurrence, which does not allow to take into account the service life of buildings.

3. Disadvantages in the rationing of the reduced component of the crane load, which refers to long-term loads and is also intended for the calculation of structures for endurance.

With the collapse of the USSR, the new states had the opportunity to move away from the rude Soviet rationing and develop their own, more adequate codes for crane loads. Further development of crane codes in the CIS was realized in the form of national codes of individual states.

Russia has followed the path of gradual development of SNiP. The Code of Rules of SP 20.13330.2011 "Loading and effects" and the updated version of SNiP 2.01.07-85* were developed. They do not differ in principle from the previous version of SNiP 2.01.07-85 and include the following changes:

• the multiplier of 0.1 is replaced by 0.2 for determination of the lateral loads;

• the coefficient of reliability on loading is increased to γ_f = 1.2 for cranes of all groups of operating modes;

• the increased factor taking into account local and dynamic action of vertical loading from one wheel of the crane, to γ_f = 1.2 … 1.8 (in accordance with the above recommendations of V.N. Val).

Ukrainian specialists, in contrast to Russian standards developers, have prepared the State Codes of Ukraine DBN B.1.2:2006 "Loading and effects", conceptually different from SNiP in terms of crane loads. The publication of these codes was preceded by the systematization of the results of many years of work in the field of crane loads, described above, by the combined efforts of MISI (B.N. Koshutin, Y.S. Kunin) and PoltISI (National University "Yuri Kondratyuk Poltava Polytechnic", V.A. Pashinsky, S.F. Pichugin) [30, 31].

83 processes of crane loading were generalized, from which 8 concerned cranes with a rigid suspension of cargo, and the rest - to cranes with a flexible suspension with a loading capacity of 5 ... 650 ts of various groups of operating modes. As a result, a generalized probabilistic model of vertical crane load in the form of a normal stationary random process was created. Determined with the necessary security, the mathematical expectation $\overline{X}$, standard $\hat{X}$ and effective frequency ω fully described this random process. Mathematical models of crane loads such as absolute maxima of random processes, a scheme of independent tests, a discrete representation, extremes, and a correlated random sequence of overloads have also been developed [32]. This allowed the development of the combining random loads issue, including the participation of crane loads [33-35].

Codes DBN B.1.2-2: 2006 for loads, including crane loads, are conceptually built similarly to European standards Eurocode [36]. They are based on the characteristic values of loads (previously they were called normative). The calculated values of loads are determined by multiplying the characteristic values by the coefficient of reliability for the load, which depends on the type of load. DBN considers crane load as a variable load with four calculated values of the vertical component: limit F_m, operational F_e, cyclic F_c and quasi-constant F_c [37,38]:

$$F_m = \gamma_{fm}\psi F_0 \ , \quad F_e = \gamma_{fe}F_{01} \ , \qquad F_c = \gamma_{fc}F_{01} \ , \quad F_p = \gamma_{fp}F_{01} \ , \tag{15}$$

where F_{01}, F_0 – the characteristic values of the vertical load, respectively, from one or two of the most unfavorable for the impact of cranes (determined similarly to the normative load according to SNiP);

ψ – composition coefficient of crane loads, which passed in the range of 0.70 ... 0.95 from the previous codes.

The reliability coefficient of the crane load limit value γ_{fm} was determined, according to the general concept of DBN, depending on the average return period of load *T*. Its maximum value was taken equal γ_{fm} = 1.1 based on the statistical results of a number of researchers, discussed above. This coefficient corresponds to the base return period *T* = 50 years and does not change with increasing *T* due to the small variability of the crane load maxima. For units with a service life of fewer than 50 years, reduced reliability coefficients in the range of 0.97 ... 1.10, determined by the formula

$$\gamma_{fm}(T) = \frac{1 + V\gamma(T)}{1 + V\gamma(T = 50\,years)}, \tag{16}$$

where $V = \hat{X} / \overline{X}$ is the coefficient of crane load variation;

$\gamma(T)$ – normalized deviation from the mathematical expectation of the maximum calculated value of the crane load at a given probability of its exceeding *Q(T),* determined by the formula (10).

The reliability coefficient of the operational design value of the crane load was assumed to be equal γ_{fe} = 1. Thus, for the calculations of structures at the second limit state (deflections, displacements, etc.), the characteristic load from one crane is used, based on the operating experience, which shows the validity of such SNiP recommendation.

The cyclic design value of the vertical crane load, which is used in the calculations of crane structures for endurance, was included in the DBN at the suggestion of V.A. Pashinsky [39]. Since the real crane load processes are random and therefore cannot be directly included in endurance calculations, the cyclic design value is determined based on a schematic load process of the simplest type – a harmonic process with a given frequency equivalent to the actual load process. The cyclic calculated value characterizes the "average" load mode and therefore should not depend on the service life of the object. In DBN the cyclic design value is presented in the unified form of the product of characteristic vertical loading from one crane and reliability coefficients $\gamma_{c\ max}$, $\gamma_{c\ min}$. The duration of the cyclic load is taken into account by the number of cycles (per day) n_c = 270…820 depending on the groups of modes of crane operation.

The quasi-constant design value of the vertical crane load, adopted in the calculations, which takes into account long processes in structural materials (creep, etc.), is proposed to be equal to the vertical load of one crane without load (empty) F_{01}^{Π} with the introduction of the reliability coefficient $\gamma_{fp} = F_{01}^{\Pi} / F_{01}$ in formula (15).

In the development of DBN in terms of horizontal crane loads, it was taken into account the main provisions relating to the actual nature and magnitude of the lateral forces of bridge cranes. For these loads, the characteristic values were the values of loads from two cranes H_0 or one crane H_{01} which are determined differently for four-wheel and multi-wheel cranes.

For four-wheel cranes, the lateral force from one crane is determined by the formula (7) proposed by A.V. Figarovsky. The lateral forces H_{01} calculated by this formula can be applied:

• to the wheels of one side of the crane and directed in different directions (inside or outside the considered span of the building), which corresponds to the limitation of the skew of the crane wheels of one side;

• to the wheels on the crane diagonally and also directed in different directions (inside or outside the considered span of the building), which corresponds to the case of limiting the skew of the crane by wheels located on the diagonal of the crane.

At the same time to other wheels the forces $0.1F_{\max}^{n}\left(0.1F_{\min}^{n}\right)$, directed in the most unfavorable direction (inside or outside of the considered run) are applied.

For multi-wheel cranes, a new lateral force standard has been introduced based on the results of many years of testing such cranes. The characteristic value of the lateral force on the wheel of multi-wheeled cranes with the flexible suspension of the load H_k^n is taken equal to 0.1 of the vertical load on the wheel, calculated at the location in the middle of the bridge of the trolley with a load equal to the passport capacity of the crane. For multi-wheel cranes with rigid suspension, the load H_k^n is assumed to be equal to 0.1 of the maximum vertical load on the wheel.

When determining the characteristic values H_k^n, it is taken into account that the lateral forces from the two multi-wheel cranes are transmitted to both sides of the crane track. On each side of the crane, the lateral forces have one direction - outwards or inwards, on different tracks, they are directed in opposite directions (both inwards or both outwards). On one of the tracks, the full lateral force is accepted, on the other track, half of the lateral force is accepted. In contrast to the SNiP, the above-mentioned lateral forces of bridge cranes are proposed to be taken into account when calculating the strength and stability of beams of crane tracks, frames, columns, and foundations.

The assumption of vertical loads reduction from cranes with constant restrictions of wheelchair approximations introduced by the DBN is based on a fairly representative experimental and statistical material [40] and makes it possible to take into account the reduction factors K_y = 0.94 … 0.76.

Giving a general assessment of the Ukrainian code DBN B.1.2-2006 "Loading and effects" in terms of crane load, it should be emphasized that they are compiled on a modern methodological basis, close to European codes Eurocode [36], based on representative statistics, more differentiated and have scientific probabilistic substantiation, more deeply developed than in the codes of previous years

An analysis of the consequences of the implementation of the recommendations of DBN B.1.2-2: 2006 "Loading and effects" in terms of bridge cranes loads were carried out [41]. The excess of horizontal loads on the wheel of four-wheel bridge cranes, determined by DBN, is up to 1.3… 9.6 times, compared with the loads calculated in accordance with SNiP. In the transition to determining the force of four-wheel bridge cranes by DBN, bending moments in the columns of the transverse frames of single-story industrial buildings from the lateral forces increase 1.9… 6.9 times, compared with the forces from the braking forces of SNiP. Bending moments in the structures of crane girders increase 1.2… 7.8 times. As a result, there is a slight increase in material consumption of crane girders, which averages 1.1%, as well as an increase in material consumption of up to 24% of crane parts of columns of buildings equipped with four-wheeled cranes.

Under the action of multi-wheel bridge cranes, the load on the wheel according to DBN exceeds the load according to SNiP by 1.3… 1.7 times. It was found that the bending moments in the transverse frames increase by 1.1… 1.2 times and up to 1.6 times in the crane girders.

Based on inspections of the load-bearing capacity of structures, it was found that in the case of equipping buildings with multi-wheeled bridge cranes, the transition to determining the loads according to DBN does not increase the cost of materials for crane girders and columns.

To neutralize the consequences of the introduction into the practice of design codes, it is recommended to use such a reserve of steel frames as its spatial operation. It is established that taking into account the effect of spatial work when calculating the transverse frames on the crane loads according to DBN B.1.2-2: 2006 allows to approximate the results of calculations of frames for loading according to SNiP 2.01.07-85 and to avoid additional costs of materials.

As can be seen from the above, the study of crane loads on the structures of industrial buildings has a long history, and most of the work performed on this topic is based on the results of field observations in industrial buildings with the most intensive work of cranes. Numerical statistical modeling was also used in some studies. However, the computational capabilities of the time were limited, and the number of randomized trials in each task was relatively small. In view of these circumstances, A.V. Perelmuter performed a statistical study of crane loads, which involved modern computational capabilities [42] and methods of mathematical modeling [43]. As a result, it was clearly shown that the values of crane loads and combination coefficients of these loads, presented in the design codes, are somewhat overstated. Therefore, it is relevant and real in the current conditions to perform research aimed at clarifying the codes of crane loads, using modern methods of statistical modeling.

Conclusions

It is shown that during the last ninety years the domestic codes of building structures design in terms of crane loads normalization have undergone significant changes and expanded their statistical bases. There is a high scientific level of domestic codes DBN B.1.2-2006 "Loading and effects", which have a modern statistical basis, are associated with Eurocode and provide the required level of building structures reliability. The modified account of bridge cranes lateral forces is developed and included in these codes; the substantiation of normative (characteristic) and design values of crane loading is developed. For further research such tasks are allocated: the further statistical analysis of random crane loadings combinations, in-depth consideration of the physical nature of crane loads, an estimation of the technological processes' influence on bridge crane loading.

References

1. Левенсонъ А.А. (1905). *Справочная книга для архитекторовъ, механиковъ и студентовъ* («HÜTTE»). Часть I. – Москва: Товарищество СКОРОПЕЧ

2. Романов Н.Е. (1938). Исследование поперечных горизонтальных крановых нагрузок кольцом. *Исследование действительной работы стальных конструкций промышленных зданий*, 164-175

3. Барштейн М.Ф. (1951). Экспериментальное определение горизонтальных поперечных сил, возникающих при движении мостовых кранов прокатного цеха завода «Азовсталь». *Труды института ЦНИИПС*,16-51

4. Балашов В.П. (1957). Поперечные силы при движении мостовых кранов с центральным приводом механизма передвижения. *Сборник научных трудов ВНИИПТМАШ*, №18, 24-59

5. Хохарин А.Х. (1961). О боковых воздействиях мостовых кранов на каркас промышленного здания. *Промышленное строительство*, № 9, 38-45

6. Бать А.А. (1959). О расчете на выносливость. *Строительная механика и расчет сооружений*, №5, 24-28

7. Кикин, А.И., Васильев А.А., Кошутин Б.Н. (1969). *Повышение долговечности конструкций промышленных зданий*. Москва: Стройиздат

8. Кикин А.И., Васильев А.А., Кошутин Б.Н., Уваров Б.Ю., Вольберг Ю.Л. (1984). *Повышение долговечности конструкций промышленных зданий*. Москва: Стройиздат

9. Кошутин Б.Н. (1966). Статистическое определение коэффициентов перегрузки вертикальных крановых нагрузок. *Металлические конструкции (Работа школы Н.С. Стрелецкого)*. Москва: Стройиздат, 195-210

10. Бать А.А., Кошутин Б.Н. (1960). Статистическое изучение крановых нагрузок. *Строительная механика и расчет сооружений*, №2, 1-5

11. Клепиков Л.В., Отставнов В.А. (1962). Определение нагрузок при расчете строительных конструкций. *Строительная механика и расчет сооружений*, №5, 39-45

12. Кикин А.И., Изосимов И.В. (1966). Изучение факторов, влияющих на величины боковых сил мостовых кранов в цехах металлургического завода. *Известия вузов. Строительство и архитектура*, №12, 1-8

13. Изосимов И.В., Фигаровский А.В., Пичугин С.Ф., Валь В.Н. (1966). Исследование силовых воздействий мостовых кранов. *Металлические конструкции (Работа школы профессора Н.С. Стрелецкого)*. Москва: Стройиздат, 164-176

1. Levenson A.A. (1905). *Reference book for architects, mechanics and students ("HÜTTE") Part I.* Moscow: SKOROPECH Partnership

2. Romanov N.E. (1938). Investigation of transverse horizontal crane loads by a ring. *Research of the actual work of steel structures of industrial buildings,* 164-175

3. Barshtein M.F. (1951). Experimental determination of horizontal shear forces arising from the movement of overhead cranes in the rolling shop of the Azovstal plant. *Proceedings of the Institute TsNIIPS*, 16-51

4. Balashov V.P. (1957). Cross forces during the movement of bridge cranes with a central drive of the movement mechanism. *Collection of scientific works of VNIIPTMASH*, 18, 24-59

5. Khokharin A.Kh. (1961). On the lateral loads of bridge cranes on the frame of an industrial building. *Industrial construction*, 9, 38-45.

6. Bat A.A. (1959). On the calculation of endurance. *Building mechanics and calculation of structures*, 5, 24-28.

7. Kikin A.I., Vasiliev A.A., Koshutin B.N. (1969). *Increasing the durability of industrial buildings structures.* Moscow: Stroyizdat

8. Kikin A.I., Vasiliev A.A., Koshutin B.N., Uvarov B.Yu., Volberg Yu.L. (1984). *Increasing the durability of industrial buildings*. Moscow: Stroyizdat

9. Koshutin B.N. (1966). Statistical determination of the overload coefficients of vertical crane loads. *Metal structures (Work of the school of N.S. Streletsky)*. Moscow: Stroyizdat, 195-210

10. Bat A.A., Koshutin B.N. (1960). Statistical study of crane loads. *Building mechanics and calculation of structures*, 2, 1-5

11. Klepikov L.V., Otstavnov, V.A. (1962). Determination of loads in the calculation of building structures. *Building mechanics and calculation of structures*, 5, 39-45

12. Kikin A.I., Izosimov I.V. (1966). Study of the factors affecting the magnitude of the lateral forces of overhead cranes in the shops of a metallurgical plant. *Izvestiya vuzov. Construction and architecture,* 12, 1-8

13. Izosimov I.V., Figarovsky A.V., Pichugin S.F., Val V.N. (1966). Investigation of the power effects of bridge cranes. *Metal structures (Work of the school of NS Streletsky)*. Moscow: Stroyizdat, 164-176

14. Фигаровский, А.В. (1970). Исследование боковых сил четырехколесных кранов с гибким подвесом груза. *Металлические конструкции: Сборник трудов*, № 85, 41-52

15. Кикин А.И., Фигаровский А.В., Пичугин С.Ф. (1967). Экспериментальные данные о поперечных горизонтальных силах от разливочных кранов. *Промышленное строительство*, №12, 8-13

16. Барштейн М.Ф., Зубков А.Н. (1966). Статистический анализ боковых сил, возникающих при движении мостового крана. *Строительная механика и расчет сооружений*. №2

17. Кошутин Б.Н. (1963). О коэффициенте перегрузки боковых сил от мостовых кранов. *Методика определения нагрузок на здания и сооружения: Сборник статей ЦНИИСК*, 81-88

18. Пичугин С.Ф. (1970). Результаты статистического экспериментального исследования горизонтальных и вертикальных нагрузок мостовых кранов на. конструкции промышленных зданий. *Исследование и расчет стр. конструкций: Сб. научных трудов МГМИ*, 59, 8-16

19. Пичугин С.Ф. (1972). К исследованию крайних частей статистических распределений (на примере нагрузок мостовых кранов). *Проблемы надежности в строительном проектировании*, 169-175

20. Пичугин С.Ф., Леванин Ю.П. (1974). Результаты экспериментального изучения вертикальных нагрузок мостовых кранов на колонны мартеновских цехов. *Известия вузов. Строительство и архитектура*, №12, 31-35

21. Кунин Ю.С., Эглескалн Ю.С. (1969). Исследование статистических свойств режимов нагружения подкрановых конструкций. *Промышленное строительство*, №9, 36-39

22. Валь В.Н., Эглескалн Ю.С. (1969). Влияние дефектов подкрановых путей на силовые воздействия мостовых кранов. *Промышленное строительство*, №4, 36-38

23. Васильев А.А., Кунин Ю.С., Яковенко А.Т. (1974). Об уточнении расчетных вертикальных нагрузок от мостовых кранов. *Промышленное строительство*, №6, 31-33

24. Зданевич Ю.А. (1974). О некоторых резервах нагрузок на подкрановые конструкции действующих сталеплавильных цехов. *Труды ДИИТ*, 159

25. Кошутин Б.Н. Кунин Ю.С., Нищета С.А. (1979). Исследование вертикальных и горизонтальных воздействий от мостовых кранов методом статистического моделирования. *Облегченные конструкции покрытий зданий*, 195-199

26. Бать А.А. (1969). О согласовании норм нагрузок для расчета кранов и подкрановых конструкций. *Промышленное строительство, 10,* 46-47

27. Отставнов В.А., Бать А.А., Клепиков Л.В. (1983). О новых дополнениях и изменениях главы СНиП II-6-74 «Нагрузки и воздействия». *Промышленное строительство*, №9, 9-10

28. Кунин Ю.С., Кузин Н.Я. (1972). О нагрузках при расчёте жёсткости подкрановых балок, *Промышленное строительство*, 6, 26-27

29. Плотников В.А. (1990). Исследование горизонтальных силовых воздействий от мостовых кранов. *Межвузовский сборник научных трудов*, 122-125

30. Кошутин Б.Н., Кунин Ю.С., Пашинский В.А. (1985). Обобщенная математическая модель вертикальной крановой нагрузки. *Вопросы надежности железобетонных конструкций*, 40-51

31. Pichugin S. (1998). Analysis of bridge crane loads on industrial buildings. *XLIV Konferencja Naukowa KILiW PAN i KN PZITB. Poznan-Krynica*, 172-179

14. Figarovsky A.V. (1970). Study of the lateral forces of four-wheel cranes with flexible load suspension. *Metal structures: Collection of works of MISI*, 85, 41-52

15. Kikin A.I., Figarovsky A.V., Pichugin S.F. (1967). Experimental data on transverse horizontal forces from casting cranes*. Industrial construction*, 12, 8-13

16. Barshtein M.F., Zubkov A.N. (1966). Statistical analysis of lateral forces arising from the movement of an overhead crane. *Building mechanics and calculation of structures*, 2

17. Koshutin B.N. (1963). On the coefficient of overload of lateral forces from bridge cranes. *Methodology for determining loads on buildings and structures: Collection of articles of TSNIISK*, 81-88

18. Pichugin S.F. (1970). The results of a statistical experimental study of horizontal and vertical loads of overhead cranes on. structures of industrial buildings. *Research and Calculation of Structural Structures: Collection of Scientific Papers of MGMI*, 59, 8-16

19. Pichugin S.F. (1972). On the study of the extreme parts of statistical distributions (for example, the loads of overhead cranes). *Problems of reliability in construction design*, 169-175

20. Pichugin S.F., Levanin Yu.P. (1974). Results of experimental study of vertical loads of overhead cranes on columns of open-hearth shops. *Izvestiya vuzov. Construction and architecture*, 12, 31-35

21. Kunin Yu.S., Egleskaln Yu.S. (1969). Study of the statistical properties of loading modes for crane structures. *Industrial construction*, 9, 36-39

22. Val V.N., Egleskaln Yu.S. (1969). The influence of crane runway defects on the power effects of bridge cranes. *Industrial construction*, 4, 36-38

23. Vasiliev A.A., Kunin Yu.S., Yakovenko A.T. (1974). On the clarification of the calculated vertical loads from bridge cranes. *Industrial construction*, 6, 31-33

24. Zdanevich, Yu.A. (1974). On some reserves of loads on crane structures of operating steel-making shops. *Proceedings of DIIT*, 159

25. Koshutin, B.N., Kunin, Yu.S., Nyscheta, S.A. (1979). Investigation of vertical and horizontal impacts from overhead cranes by the method of statistical modeling. *Lightweight Building Coating Structures*, 195-199

26. Bat, A.A. (1969). About coordination of codes of loads for calculation of cranes and crane structures. *Industrial construction, 10,* 46-47

27. Oststavnov V.A., Bat A.A., Klepikov L.V. (1983). On new additions and changes to the chapter of SNiP II-6-74 "Loads and loadings". *Industrial construction*, 9, 9-10

28. Kunin Yu.S.. Kuzin N.Ya. (1972). About loads when calculating the rigidity of crane beams. *Industrial construction*, 6, 26-27

29. Plotnikov V.A. (1990). Investigation of horizontal force effects from bridge cranes. *Interuniversity collection of scientific papers*, 122-125

30. Koshutin B.N., Kunin Yu.S., Pashinsky V.A. (1985). Generalized mathematical model of vertical crane load, *Questions of the reliability of reinforced concrete structures,* 40-51

31. Pichugin S. (1998). Analysis of bridge crane loads on industrial buildings. *XLIV Konferencja Naukowa KILiW PAN i KN PZITB. Poznan-Krynica*, 172-179

32. Пичугин С.Ф. (1995). Вероятностное представление нагрузок, действующих на строительные конструкции. *Известия вузов. Строительство*, №4, 12-18

33. Пичугин С.Ф., Пашинский В.А. (1982). Методика вычисления коэффициентов сочетаний нагрузок. *Вопросы надежности железобетонных конструкций*, 94-97

34. Пичугин С.Ф. (1995). Вероятностный расчет стальных элементов на совместное действие нагрузок. *Известия вузов. Строительство*, 5,6, 23-29.

35. Pichugin S. (1995). Reliability estimation of steel elements under variable loads. *XLI Konferencia Naukowa KILIW PAN i KN PZITB, Krakow-Krynica,* 151-156

36. Eurocode 1 EN 1991-3.: Actions on structures – Part 3: Actions induced by cranes and machinery. – Brussels: CEN, Sep. 2006. – 42 p.

37. Pichugin S.F. (1994). Calculation coefficients of design codes based on the analysis of the reliability of steel structures. *Construction of Ukraine*, 1, 18-20

38. Пічугін С.Ф. (2007). Кранові навантаження в ДБН В.1.2-2:2006 «Навантаження і впливи». *Будівельні конструкції: Збірник наукових праць*, 67, 691-702

39. Пашинський В.А. (1999). Циклічні розрахункові значення навантажень на будівельні конструкції. *Вибрации в технике и технологиях*, №2, 15-17

40. Pichugin S. (1997). Probabilistic description of crane load on building structures. *XLIII Konferencja Naukowa KILiW PAN i KN PZITB, Poznan-Krynica,* 171-178

41. Pichugin S., Patenko Iu., Maslova S. (2018). Comparative analysis of loads from the travelling cranes of different producers. *International Journal of Engineering &Technology*. 7 (3.2), 36-39

42. Perelmuter A.V. (2017). Statistical simulation of crane loads and calculated force combinations. *International Journal for Computational Civil and Structural Engineering,* 13(2), 136-144

43. Pasternak H., Rozmarynowski B., Wen Y.-K. (1996). Crane load modeling. *Structural Safety,* 17, 205-224

32. Pichugin S.F. (1995). Probabilistic representation of loads acting on building structures. *Izvestiya vuzov. Construction*, 4, 12-18

33. Pichugin S.F., Pashinsky V.A. (1982). Methodology for calculating the coefficients of combinations of loads. *Questions of the reliability of reinforced concrete structures*, 94-97

34. Pichugin S.F. (1995). Probabilistic calculation of steel elements for joint action of loads. *Izvestiya vuzov. Construction*, 5,6, 23-29

35. Pichugin S. (1995). Reliability estimation of steel elements under variable loads. *XLI Konferencia Naukowa KILIW PAN i KN PZITB, Krakow-Krynica,* 151-156

36. *Eurocode 1 EN 1991-3.: Actions on structures – Part 3: Actions induced by cranes and machinery.* (2006). Brussels: CEN, Sep.

37. Pichugin S.F. (1994). Calculation coefficients of design codes based on the analysis of the reliability of steel structures. *Construction of Ukraine*, 1, 18-20

38. Pichugin S.F. (2007). Crane loads in DBN B.1.2-2: 2006 "Loads and iloadings". *Building constructions: Collection of scientific works of NDIBK*, 67, 691-702

39. Pashinsky V.A. (1999). Cyclic calculated values of loads on building structures. *Vibrations in technology and technology*, 2, 15-17

40. Pichugin S. (1997). Probabilistic description of crane load on building structures. *XLIII Konferencja Naukowa KILiW PAN i KN PZITB, Poznan-Krynica,* 171-178

41. Pichugin S., Patenko Iu., Maslova S. (2018). Comparative analysis of loads from the travelling cranes of different producers. *International Journal of Engineering &Technology*. 7 (3.2), 36-39

42. Perelmuter A.V. (2017). Statistical simulation of crane loads and calculated force combinations. *International Journal for Computational Civil and Structural Engineering,* 13(2), 136-144

43. Pasternak H., Rozmarynowski B., Wen Y.-K. (1996). Crane load modeling. *Structural Safety,* 17, 205-224