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Many years of experience of standarding the medium component of wind load on building structures

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The article contains a systematic review of scientific and technical publications on the problems of wind load for the 90-year period from the 30s of the twentieth century to the present. It is emphasized that this load on the buildings has a complex physical nature and changeable nature. These features are reflected in the sections of design standards of building structures that contain codes of wind load. The main attention is paid to the analysis of the evolution of structural design codes in terms of changes in wind territorial zoning and design factors, the appointment of specified and design values of wind load. It is noted that most of the parameters of wind load codes are probabilistic in nature and require the use of statistical methods to justify them. There is a high scientific level of domestic standards DBN B.1.2-2006 "Loads and loadings", which have a modern probabilistic basis and are associated with Eurocode standards. Scientific results which can be included in the following editions of codes of wind loading are allocated

Keywords: wind observations, wind load, territorial zoning, specified load, design load.

Багаторічний досвід нормування середньої складової вітрового навантаження на будівельні конструкції

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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 вітрових навантажень. Ці навантаження мають досить складну фізичну природу і мінливий характер, що вимагають знання термодинамічних процесів в атмосфері, фізичних властивостей вітрових впливів, методики метеорологічних спостережень та кліматологічного опису місцевості, мінливості вітрових навантажень, характеру обдування вітром конструкцій та споруд. Такі особливості у певній мірі відображаються в розділах норм проектування будівельних конструкцій, що містять нормативи вітрового навантаження. Більшість параметрів норм вітрового навантаження мають імовірнісну природу і потребують для свого обґрунтування застосування статистичних методів. Ці методи постійно змінювалися і розвивалися разом з регулярним переглядом норм будівельного проектування. Тому аналіз еволюції вітчизняних норм вітрового навантаження разом з їх статистичними обґрунтуванням є актуальною задачею. Матеріали, присвячені вітровим навантаженням, опубліковані в різних науково-технічних журналах, збірниках статей, матеріалах конференцій. Стаття містить систематизований огляд норм проєктування та публікацій по проблемі вітрового навантаження за 90-річний період з 30-х років ХХ століття до теперішнього часу. Головна увага приділяється аналізу тенденцій розвитку норм проектування конструкцій в частині змін розрахункових коефіцієнтів, призначення нормативних і розрахункових значень вітрового 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 вітрового навантаження

Ключові слова: вітрові спостереження, вітрове навантаження, територіальне районування, нормативне навантаження, розрахункове навантаження.

Introduction

Ensuring the reliability and safety of buildings and structures largely depends on a proper understanding of the nature and quantitative description and regulation of loads on building structures, including wind loads. These loads on structures have a complex physical nature and changeable character, they require knowledge of thermodynamic processes in the atmosphere, physical properties of wind effects, methods of meteorological observations and climatological description of terrain, variability of wind loads, nature of wind blowing of structures. These features are reflected in the sections of design standards of building structures that contain codes of wind load. Most parameters of wind load codes are probabilistic nature and require the use of statistical methods. These methods are constantly changing and evolving along with the regular review of building codes. Analysis of the evolution of domestic wind load codes together with their statistical justification is an urgent task.

Review of research sources and publications

Regular wind observations have been conducted since the end of the 19th century. In the 1930s, their results were the basis for compiling the first normative document on wind load and the first publications on this issue [1-4]. This process was intensified by preparing for the transition of structural calculations to the method of limit states [5, 6]. In the following years, together with the regular revision of the codes of loads and loadings on the structures, the rationing of wind loads was improved. The evolution of wind codes has been covered in publications of leading scientific and technical journals, reviews of the development of wind standards, published as sections of monographs and theses on the loads on buildings and structures [7-31]. Since the 1990s, design codes have been developed by individual states that were formerly part of the USSR. In this regard, probabilistic studies of wind load on the territory of Ukraine were intensified [32-44], which resulted in the relevant section of DBN B.1.2-2006 “Loads and loadings”. In the following years, the study of wind load was continued together with the substantiation and refinement of calculated coefficients [45-48].

Definition of unsolved aspects of the problem

Materials on wind loading have been published in various scientific and technical journals, collections of articles, conference proceedings. Access to these publications is difficult, especially since some institutions have begun to destroy paper magazines of recent years, citing the transition to electronic publications. However, in reality, the transition into electronic form has taken place only for publications published after 2000. Published reviews of the development of wind load rationing are incomplete and do not include the research results of the past 15 - 20 years.

Problem statement

The article contains a systematic review of publications in leading scientific and technical editions on the problem of wind load for the 90-year period from the 30s of the twentieth century to the present. The main attention is paid to the analysis of the evolution of design codes in terms of changes in territorial zoning and calculated coefficients, the appointment of specified and design values of wind load and the involvement of experimental statistics. Scientific results which can be included in the following editions of codes of wind loads are allocated.

Basic material and results

The collection of information on wind effects has been carried out on the territory of pre-revolutionary Russia since the middle of the 19th century as part of general climatological work. This work was intensified when in 1849 the world's first Main Physical Observatory (later the Main Geophysical Observatory named after A.I. Voeikov) was created in St. Petersburg, which organized a network of meteorological stations throughhout the country and processed their observations. Along with other observations, weather stations made regular measurements of wind speed and direction. The beginning of domestic standardization of wind loads was laid in 1930, when the Committee for Standardization under the Council of Labor and Defense prepared and put into effect the first codes in the field of construction - "Uniform codes of construction design". The first normative document on wind load in the USSR was the “Uniform codes” OST/VKS 7626/a, introduced in 1933. There was already a certain scientific basis for substantiating the codes at that time: long-term meteorological wind observations (3 times a day); aerodynamic research conducted since pre-revolutionary times at the LIC, MSU, MHTU (Laboratory of Aerodynamics, prof. N.E. Zhukovsky) and TsAGI (Central Aerohydrodynamic Institute, founded in 1918); the first attempts to consider the wind effect as a load on construction objects [1].

In the "Uniform codes" [2], the wind load was determined by the formula

$$P_a = k \cdot q \,, \qquad (1)$$

where P_a is the wind pressure in kg/m^2, normal to the perceived surface; this pressure is considered positive when it is directed inward of the structure, and negative when it is directed outward;

k is the flow coefficient, which depends on the shape and position of the object exposed to the wind;

q - the highest pressure in kg/m^2 when the direction of the air flow is normal to the surface. This pressure represents the magnitude of the wind pressure corresponding to the highest wind speed for a given location, and can be determined by the formula

$$q = \frac{\gamma}{g} \cdot \frac{v^2}{2} = \frac{v^2}{16} \,, \qquad (2)$$

where γ = 1.23 *kg/m³* is the weight of air (pressure 760 mm, temperature 15°C);

g = 9.81 m/s^2 - acceleration of gravity;

v is the design speed in m/s.

It should be noted that the first wind zoning was not sufficiently differentiated and regulated for the entire territory of the USSR (with few exceptions) only one value of the wind pressure of 45 kg/m^2. It was not statistically well-grounded. The zoning was established on the basis of wind speed measurements by the Wild weather-vane with a two-minute averaging. District values corresponded to open areas; for structures located in places partially protected from the wind by buildings or sparse vegetation, for example, in villages or on the outskirts of cities, the values were reduced by 30%; in places of large buildings or dense vegetation - decreased by 50%.

For structures up to 20 m high, the wind load was assumed to be constant, evenly distributed over the height. When the height h above ground level changed, the wind pressure was determined by the formula

$$q : q_0 = \sqrt{h} : \sqrt{h_0} \quad . \tag{3}$$

The power dependence (3) was supplemented by the velocity curves for the three geographical areas.

The first wind codes included detailed information on the flow coefficient in the form of a table with 16 variants of surfaces and cargo areas. For the main variant - vertical walls - the coefficient $k = +0.8$ for active pressure and $k = -0.4$ for suction was given (later this value was increased).

In the 1930s, a number of wind effects studies were conducted. Beginning in 1936, meteorological observations of wind and other climatic parameters began to be performed 4 times a day, which expanded the statistical basis of wind rationing. In 1931-37, construction aerodynamics was studied in the laboratory of the TsNIPS (Central Research Institute of Industrial Structures) under the direction of E.I. Retter. Here, the nature of the wind's effect on single-span and multi-span buildings with lanterns was studied by blowing models in a wind tunnel [3]. A number of experimental data of interest to builders were obtained at TsAGI, and also collected in the book by E.V. Krasnoperov [4].

In 1940, the standard OST 90059-40 "Wind Loads" was adopted. In it, the wind load was determined by a similar formula with changed designations

$$q_в = k\, q_0 \,, \tag{4}$$

where q_0 - high-speed wind pressure;
k - aerodynamic coefficient.

Wind zoning received small changes in shape, for the main territory of the USSR the wind speed was reduced from 45 kg/m^2 to 40 kg/m^2. The main aerodynamic coefficients were presented for vertical surfaces (+0.8 and –0.6) and in the form of a diagram for cylindrical surfaces. The code included some recommendations on the wind load on high-rise buildings (apparently in connection with preparations for the construction of a giant Palace of the Soviets). Subsequent editions of wind codes did not include these recommendations.

The development of methods for calculating building structures, especially to assess the safety margin of structures, required to objectively identify the parameters of loads and strength of materials [5]. Therefore, there is an increasing need to use statistical methods to describe wind loads that are clearly random. An example of statistical analysis of wind effects were the curves of wind speed distribution for the Eastern European region, built for the period from 1898 to 1937. These data allowed N.S. Streletsky to quantify the reliability of steel structures designed according to the codes in force at the time [6].

In the 1940s, the experience of applying load codes to buildings and structures was replenished, and the shortcomings of the current codes were revealed. In particular, G.A. Savitsky criticized the 1940 code in terms of wind loads on high-rise structures [7] and proposed the introduction of differentiated accounting for wind speed and dynamic coefficient. To some extent, these proposals have been taken into account in subsequent versions of the codes.

In 1954, the Construction Codes and Rules of SNiP II-B.1-54 "Basic Provisions for the Calculation of Building Structures" were introduced. These codes corresponded to the introduction of the structure's calculation by the method of limit states. When switching to this method, the values of the calculated wind load according to the previous standards were adopted as the specified load. Design wind loads, which began to be treated as the highest possible ones during the operation of the structure, began to be determined by multiplying by the overload factor. This coefficient, due to the lack of reliable data on the variability of wind maxima, was accepted as common to the whole area $n = 1.2$. The aerodynamic coefficients for the main surfaces were presented in a concise tabular form. Separate diagrams illustrated aerodynamic coefficients for buildings with pitched and cylindrical roofs, as well as with lanterns.

At the same time, the Main Geophysical Laboratory conducted statistical processing of wind speed data for 20 years, which showed that the design wind load for the first area, covering almost the entire territory of the USSR, has a security of 3%, ie possible once on average 30 - 50 years [8]. The need to identify a number of areas with increased specified wind speeds was justified, which was taken into account when clarifying the geographical wind zoning of the USSR in the development of subsequent editions of SNiP.

In 1958-1960, at the request of the load laboratory of the TsNIISK (Central Research Institute of Building Structures) in the GGO named after A.I. Voeikova L. Anapolskaya and L. Gandin processed daily 4 urgent wind speeds (excluding the direction at 2-minute averaging) over a long period of time using statistical extrapolation to the range of velocities greater than 20 m/s [9]. Data on wind speeds at about 1,200 points in the Soviet Union were used, with a recurrence of once every 20, 15, 10, 5 years and 1 year. As an approximation function, the modified expression of the Weibull distribution was used (proposed by L. Gandin)

$$F(v) = P(V \ge v) = \exp\left[-(v/\beta)\right]^{\gamma} , \tag{5}$$

where $F(v)$ is the probability (or repeatability) that the wind speed V will reach or exceed the value v;
β and γ - parameters depending on the wind regime of

the area; β is close to the average value; γ characterizes the relative scattering of the series members.

At the suggestion of V.A. Otstavnov, to the data for wind speeds more than 20 m/s, obtained with the help of weather-vanes with a heavy board, a step-down correction (up to 10% for $v = 40$ m/s) was introduced, taking into account the systematic overestimation of wind speeds by observers [10].

According to the gradation of velocity pressures and repeatability of wind speeds set once every 5 years, the territory of the former USSR was zoned according to seven specified values of high-speed wind pressure [11]. A new map of more detailed zoning by wind load was included for the first time in SNiP II-A.11-62 "Loads and loadings". The district high-speed wind pressure for a height above the ground of 10 m (standard height of the weather-vane or anemometer) was in the range of 27 - 100 kg/m^2. It should be noted here that for network construction facilities located in different wind areas, there were certain difficulties in accounting for wind loads. To overcome them G.A. Savitsky developed a unified graph, on the abscissa axis of which the recurrence of velocity pressures was plotted on a bilogarithmic scale, and dimensionless velocity pressures were plotted on the ordinate axis [12]. For buildings located among the continuous construction, SniP II-A.11-62 allowed to reduce the wind speed by 30% - thus, approximately the roughness of the terrain was taking into account. The account of increase of wind loading with height was developed in comparison with the previous codes and was presented in the form of the table in which for heights in the range of 10…350 m correction factors of 1,0…3,0 were specified. The overload factor was left the same $n = 1.2$ for conventional buildings and structures, which provided a period of repetition of the design load $T = 10…15$ years; for tall structures, in the calculation of which the wind load is crucial (towers, masts, cooling towers, etc.) $n = 1.3$, which corresponds to $T = 20$ years. When checking the strength of structures for installation conditions, the overload coefficient of wind load was not entered.

In addition, TsNIISK (L.V. Klepikov) carefully analyzed the results of domestic and foreign studies in the field of aerodynamic coefficients and gave in the SNiP a fundamentally new table of their values for 17 cross sections of buildings and elements. This table was mostly preserved until the codes of 1985, that is, it was used for more than 20 years. Experimental-theoretical substantiation of normative aerodynamic coefficients is given in the book by G.A. Savitsky [12]. For high-rise structures, the SNiP introduced for the first time an increasing factor β, taking into account the dynamic effect of high-speed pressure pulsations caused by wind gusts, and gave a method for determining it.

Some researchers subsequently made suggestions for adjusting wind zoning. Due to the large-scale construction in Moscow, it was proposed to allocate it to a separate wind area and reduce the regulatory wind load for it [13]. This proposal was subsequently taken into account in the 1985 regulations.

In preparing the climatic parameters of wind loads for the next edition of SNiP L.V. Klepikov (TsNIISK) analyzed a large amount of material from 4 urgent observations on the weather-vane [14]. He found that a double exponential Humbell distribution (type I extremum distribution) is suitable for statistical smoothing of the extrapolation of the monthly and annual maxima of the wind speed modulus

$$F(v) = \exp\left[-\exp\left(-\frac{v-\alpha}{\beta}\right)\right], \qquad (6)$$

where α - position parameter;
β - scale parameter.

The obtained results were confirmed by the developments of climatologists [15], foreign results [16] and ended with the development of a new zoning of the USSR on high-speed wind pressures (in the former gradation of their specified values), which was included in the next edition of wind loads code.

An important aspect of wind impact on structures - the dependence of speed on altitude - has been constantly in the spotlight of climatologists and code developers. Baseline statistics to assess this dependence were obtained at 160 aerological stations, which measure wind speeds at different altitudes using radiosondes and radar stations such as Meteor and Meteorite. Wind observations were also regularly carried out at such high-altitude structures as the meteorological mast in Obninsk (300 m high), the 503 m high Shukhov Tower and other objects. As a result, vertical wind speed profiles [17] were constructed, described by the power law of the species

$$v(z) = v_{10}(z/10)^{\alpha}, \qquad (7)$$

where z is the height above the ground;
α - an indicator of the degree that depends on the terrain roughness.

Measurement data on masts in Kyiv, Novosibirsk, Leningrad and Obninsk were used to determine the effect of surface roughness on the wind profile. As a result, three types of terrain were identified depending on the degree of its protection [18].

In the next edition of SNiP II-6-74 "Loads and loadings" it was clearly stated that wind load is the sum of static and dynamic components. The static component corresponding to the steady-state pressure must be taken into account in all cases. The dynamic component caused by high-speed pressure ripples should be taken into account mainly for tall structures.

The definition of the specified value of the static component of wind load $q^н_c$ differed from the previous codes

$$q_c^н = q_0\, k\, c, \qquad (8)$$

where q_0 - the velocity pressure taken on the former regional values and a slightly modified map of the zoning of the USSR;
k - a new coefficient that takes into account changes in velocity pressure in altitude and terrain type;
c - aerodynamic coefficient.

To substantiate the coefficient k, the results of domestic wind observations at high-rise structures and foreign data were taken into account, and the power law of change in velocity pressure altitude was adopted (7). Two types of terrain with different degrees of protection were introduced into account this coefficient: type A - open areas; type B - areas with obstacles (cities, forests, etc.). The accounting of the dynamic component of the wind load, developed by M.F. Barshtein [18] taking into account the fundamental works of A.G. Davenport [19].

In the 70s and 80s of the last century, domestic and foreign research in the field of reliability of building structures was intensified [20,21]. An integral part of these works was a probabilistic description of random loads acting on buildings and structures, including wind loads (A.R. Rzhanitsyn [22], V.D. Raiser [23]).

In 1983, new additions and changes were made to Chapter SNiP II-6-74 "Loads and loadings", in which a new sub-district 1a was allocated for wind loads with a reduced speed pressure of 20 kgf/m^2 instead of 27 kgf/m^2 [24].

In the next edition of SNiP 2-01-07-85 "Loads and loadings", published 11 years later, wind load was widely interpreted as a combination of normal pressure applied to the outer and inner surfaces of buildings, and friction forces directed tangentially to the outer surface, or as the total normal pressure on the structure.

The specified value of the average component of wind load, marked w_m at a height z above the ground, was determined by a modified formula

$$w_m = w_0 \, k \, c \, , \tag{9}$$

where w_0 - the specified value of wind pressure;
k is the coefficient that takes into account the change of wind pressure in height;
c is the aerodynamic coefficient.

The specified value of wind pressure w_0 (Pa) was determined by formula (2), in which v - wind speed (m/s), at the level of 10 m above the ground for terrain type A, which corresponds to a 10-minute averaging interval and exceeds the average once in 5 years. The transition to a new averaging interval instead of the former two-minute interval led to a decrease in the specified wind pressure, which is approximately taken into account by multiplying by a factor of 0.92 [25]. Therefore, the adjusted district values of wind pressure were in the range of 0.23…0.85 kPa instead of 0.27…1.00 kPa according to previous codes. At the same time, the previous calculated values of loads were preserved, the coefficient, formerly called the "overload coefficient", was renamed "reliability factor for wind load" and was increased to γ_f = 1.4.

The list of types of terrain that are taken into account when determining the coefficient k was supplemented by type C for urban areas with buildings over 25 m high [25].

A number of researchers have identified the shortcomings of SNiP 2.01.07-85 in terms of wind loads rationing. Thus, proposals were made to reduce the design wind loads on the columns during the installation period [26]. This useful proposal, which did not receive support, was taken into account in essence in DBN V.1.2-2:2006 "Loads and loadings", which provides the design parameters of the wind load with a short return period.

Specialists also drew attention to the prospects of taking into account regional features of atmospheric loads, including wind effects. In particular, meteorological data were collected for 17 years on wind loads for 5 meteorological stations of the Lipetsk region (Gorev V.V.) [27]. The possibility of reducing the metal consumption of buildings by determining the loads according to local weather stations was shown.

With the collapse of the USSR, the opportunity opened up for the new states to move away from the rough Soviet wind regulation and develop their own, more differentiated wind zoning. Further development of wind standards on the territory of the CIS was realized in the form of national codes of individual states.

Russia has taken the path of gradual development of SNiP codes. The Code of Rules SP 20.13330.2011 "Loads and loadings", an updated version of SniP 2.01.07-85* was developed. The wind section of this SNiP is entitled “Wind Effects”, which include: the main type of wind load (hereinafter referred to as “wind load”; peak wind load values acting on fences; resonant vortex excitation; aerodynamic unstable oscillations such as galloping, divergence and flutter.

The specified value of the wind load w is determined, as before, as the sum of the average w_m and pulsation w_p components

$$w = w_m + w_p \, . \tag{10}$$

The formula for determining the specified value of the average component reflects the relationship of the coefficient k with the equivalent height z_e above the ground

$$w_m = w_0 \, k \, (z_e) \, c \, . \tag{11}$$

The coefficient $k\ (z_e)$ is determined by a table similar to that placed in the previous codes, or by a power formula [28]

$$k(z_e) = k_{10}\left(z_e/10\right)^{2\alpha} \, . \tag{12}$$

The specified value of wind pressure w_0 is determined by the previous 7 regional values and the map, adopted without changes. If necessary, this value w_0 (Pa) can be set on the basis of data from Roshydromet weather stations and calculated using the formula

$$w_0 = 0{,}43 v_{50}^2 \, , \tag{13}$$

where v_{50} is the wind speed, m/s, at a level of 10 m above the ground for terrain of type A, determined with a 10-minute averaging interval and exceeded on average once every 50 years.

In subsequent years, Russian scientists continued to study wind effects in the direction of assessing wind gusts [29] and taking into account the aerodynamic features of buildings of complex shape [30, 31].

Ukrainian specialists, in contrast to the Russian standards developers, prepared the State Codes of Ukraine

DBN B.1.2-2006 “Loads and loadings”, which are conceptually different from SNiP in terms of wind loads. The probabilistic representation of random loads on building structures, including wind loads, has been significantly developed. Mathematical models such as random processes, absolute maxima of random processes, independent test scheme, discrete representation, extrema, correlated random sequence of overloads have been developed [32]. This made it possible to substantiate a probabilistic model for the average component of the wind load in the form of a differentiable random process [33, 34]. The Weibull distribution, which well describes the experimental data, was used to describe the probabilistic wind load. This distribution has the following differential and integral distribution functions:

$$f(\gamma)=\frac{\beta}{\alpha}(X-\gamma)^{\beta-1}\exp\left[-\frac{(X-\gamma)^{\beta}}{\alpha}\right];$$
$$F(X)=1-\exp\left[-\frac{(X-\gamma)^{\beta}}{\alpha}\right], \tag{14}$$

where γ is the parameter of the distribution position, if $\gamma = 0$, then the distribution is possible only when $X > 0$;
$\alpha > 0$ - scale parameter that determines the elongation of the distribution;
$\beta > 0$ is the shape parameter on which the type of distribution depends.

Analysis of the stochastic nature of wind load allowed to present it as a quasi-stationary random process with relatively slowly changing numerical characteristics and the ordinate distribution during the annual cycle, with a constant frequency structure. Based on the above provisions, using the generalized research data of 77 meteorological stations of Ukraine and an additional 10 meteorological stations of other CIS countries, the calculated parameters of the probabilistic wind load model were substantiated [35-37].

The development and publication of the State Code of Ukraine DBN B.1.2-2006 "Loads and loadings" in terms of wind load was preceded by many years of work by foreign and Ukrainian researchers, including A. Perelmuter and M. Mikitarenko (UkrNII-Proektstalkostruktsiya), V. Pashinsky, S. Pichugin, A. Makhinko (National University «Yuri Kondratyuk Poltava Polytechnic»), R. Kinash (Lviv Polytechnic State University) and others [38-41].

For statistical research and normalization of wind load, the results of term measurements of wind speed performed by anemorumbometers at 195 meteorological stations of Ukraine during 1970-990 were used, a total of more than 12 million results of term wind observations.

According to the DBN, wind load is a variable load for which limit and operational design values are set. The limit design value of wind load is defined as

$$W_m = \gamma_{fm} W_0 C, \tag{15}$$

where γ_{fm} is the reliability factor for the maximum calculated value of wind load;
W_0 - characteristic value of wind pressure (in Pa);
C is the coefficient determined by formula (16).

The characteristic value of wind pressure W_0 is equal to the average (static) component of wind pressure at a height of 10 m above the ground, which can be exceeded, in contrast to SNiP, on average once every 50 years (similar to Eurocodes). We will note that wind zoning of the territory of Ukraine according to DBN considers territorial variability of wind loading that considerably differs from its too generalized rationing of SNiP, according to which almost the entire territory of Ukraine belonged to the II (specified load $W_0 = 0.3$ kPa, design load 0.42 kPa) and III ($W_0 = 0.38$ kPa, design 0.53 kPa) wind areas. More detailed territorial zoning of Ukraine according to the characteristic values of wind load includes five territorial districts with characteristic values from 0.4 to 0.6 kPa. The lowest values of wind load are observed in the central and north-western regions of Ukraine, as well as in Transcarpathia. High wind loads are realized in the Carpathians and coastal areas. The territorial zoning of Ukraine according to the characteristic values of the wind pressure was carried out according to the methodology developed by V.A. Pashinsky [40]. The regional values of the design wind load were set so that the excess reserves of the territorial zoning were minimal. Comparison of wind zoning according to DBN with SNiP reveals a relatively small difference in the calculated velocity pressures. On average in Ukraine, zoning according to the DBN underestimates the wind load by 4%. At the same time, for 34% of observation points the wind load was reduced by 15… 25%, and for 12% of points - increased by 25… 65%.

Coefficient C is determined by a detailed formula similar to the Eurocode formula

$$C = C_{aer} C_h C_{alt} C_{rel} C_{dir} C_d, \tag{16}$$

where C_{aer} is the aerodynamic coefficient;
C_h - coefficient of building height;
C_{alt} - coefficient of latitude;
C_{rel} - relief factor;
C_{dir} - direction factor;
C_d - dynamic coefficient.

The height coefficient of the structure C_h takes into account the increase in wind load with height. In contrast to the SNiP, which used the degree dependence of wind speed on height (7), the DBN introduced a logarithmic dependence, as in European standards

$$\bar{v}(z)=\bar{v}_{10}\frac{\ln(z/z_0)}{\ln(10/z_0)}, \tag{17}$$

where $\bar{v}(z)$ and $\bar{v}(10)$ - average wind speeds at a height of z and 10 m, respectively;
z_0 - the parameter of the roughness of the underlying surface, which is determined depending on the type of surrounding area; unlike the three SNiP types, the DBN includes four terrain types.

The reliability factor γ_{fm} for the limit design value of wind load is determined depending on the specified average return period T in the range of 0.55… 1.45 for

$T = 5\ldots$ 500 years. the transition from the base return period $T = 50$ years to other values of T (in years) the dependence for the reliability coefficient on the limit design value of wind load is substantiated [40]

$$\gamma_{fm} = 0{,}56 + 0{,}12\ln T \quad . \tag{18}$$

The operational design value of wind load is determined by the formula

$$W_e = \gamma_{fe} W_0 C \quad , \tag{19}$$

where γ_{fe} is the reliability factor according to the operational design value of wind load.

For the first time, the DBN codes stipulate that the operational design value of wind load depends on the proportion η of time during which it may be exceeded. According to the data of 195 meteorological stations of Ukraine, the operational design values of wind load were calculated, depending on the geographical area and the share of the service life of the structure [40]. This made it possible to justify the corresponding coefficient

$$\gamma_{fe} = 0{,}358\left[-\lg(\eta)\right]^{3/2}. \tag{20}$$

For objects of mass construction it is allowed to accept $\eta = 0.02$.

Giving a general assessment of the Ukrainian codes DBN V.1.2-2006 "Loads and loadings" in terms of wind load, it should be emphasized that they are compiled on a modern methodological basis, close to the European Eurocode standards and are based on representative statistical material. DBN are more differentiated and have a scientific probabilistic basis that is deeper developed than in the codes of previous years.

In subsequent years, probabilistic studies of wind load were continued in Ukraine, the practical results of which were recommendations for improving design codes. Scientific School of Reliability of Building Structures of National University «Yuri Kondratyuk Poltava Polytechnic»developed the probabilistic calculation of elements for wind load [42,43], supplemented the probabilistic description of the static component of wind load [44,45].

R. Kinash proposed an alternative method of zoning wind loads for the territory of Ukraine [39]. Proposals were developed for a more detailed wind zoning of the mountainous Carpathian region (within the boundaries of the Transcarpathian region) with the introduction of additional 4 regions (from the 6th to the 9th) with characteristic wind loads in the range of 0.6...1.9 kPa [46]. I. Dobryansky and colleagues obtained results to verify the provisions of the DBN on wind pressure profiles for high-rise buildings in urban areas [47]. V. Pashinskiy developed a new method of administrative-territorial districting of wind tunnels on the building constructions [48].

Conclusions

It is shown that over the past ninety years, domestic codes for the design of building structures in terms of normalizing wind loads have undergone significant changes and expanded their statistical foundations. Territorial wind zoning has developed, the number of wind regions has increased, especially on the territory of Ukraine. The substantiation of the specified (characteristic) and design values of the wind load was modified on the basis of an increased return period. A statistical justification for the operational value of the wind load was received. The high scientific level of domestic codes DBN V.1.2-2006 "Loads and loadings" is noted, which have a modern statistical basis, which are associated with Eurocode standards and provide the necessary level of reliability of building structures. New scientific results are highlighted, which can be included in subsequent editions of the wind load standards.

References

1. Лебедев С.И. (1931). *Ветер как нагрузка сооружений*. Техника управления

2. *Справочник инженера-проектировщика промсооружений.* (1934). Том II. Расчетно-теоретический. Госстройиздат

3. Реттер Э.И. (1936). *Ветровая нагрузка на сооружения*. Госстройиздат

4. Красноперов Е.В. (1935). *Экспериментальная аэродинамика.* ОНТИ ИКТП

5. Стрелецкий Н.С. (1932). Об исчислении запасов прочности сооружений. *Труды МИСИ*, 1, 4-32

6. Стрелецкий Н.С. (1947). *Основы статистического учета коэффициента запаса прочности сооружений*. Стройиздат

7. Савицкий Г.А. (1945). О нормах ветровой нагрузки на высокие сооружения. *Строительная промышленность*, 10-11, 15-16

8. Барштейн М.Ф. (1959). Воздействие ветра на высокие сооружения. *Строительная механика и расчет сооружений*, 1, 19-32

9. Анапольская А.Е., Гандин Л.С. (1958). Методика определения расчетных скоростей ветра для определения ветровых нагрузок на строительные сооружения. *Метеорология и гидрология*, 10, 9-17

1. Lebedev S.I. (1931). *Wind as a load of structures*. Management Technique

2. *Handbook of industrial engineer-designer*. (1934). Volume II. Calculation-theoretical. Gosstroyizdat

3. Retter E.I. (1936). *Wind load on structures*. Gosstroyizdat

4. Krasnoperov E.V. (1935). *Experimental aerodynamics*. ONTI IKTP

5. Streletsky N.S. (1932) On the calculation of the safety margins of structures. *Proceedings of the MCEI*, 1, 3-32

6. Streletsky N.S. (1947). *Fundamentals of statistical accounting for the safety factor.* Stroyizdat

7. Savitsky G.A. (1945). About norms of wind loading on high constructions. *Construction Industry*, 10-11, 15-16

8. Barshtein M.F. (1959). The effect of wind on tall buildings. *Structural Mechanics and Calculation of Structures,* 1, 19-32

9. Anapolskaya A.E., Gandin L.S. (1958). Methods for determining the calculated wind speeds to determine the wind loads on buildings. *Meteorology and Hydrology*, 10, 9-17

10. Керимов А.А., Исраимов А.А. (1970). Сравнение результатов измерения скорости ветра, осуществленных различными приборами. *Метеорология и гидрология,* 11, 102-104

11. Клепиков Л.В., Отставнов В.А. (1962). Определение нагрузок при расчете строительных конструкций. *Строительная механика и расчет сооружений*, 5, 9-45

12. Савицкий Г.А. (1972). *Ветровая нагрузка на сооружения*. Стройиздат

13. Никитин Н.В., Травуш В.Н. (1969). Об определении ветровых нагрузок в Москве. *Строительная механика и расчет сооружений*, 2, 62-64

14. Клепиков Л.В. (1975). О статистическом распределении скорости ветра. *Металлические конструкции*, 119, 31-40

15. Заварина М.В. (1976). *Строительная климатология*. Ленинград: Гидрометеоиздат

16. Duchene-Marullar Ph. (1972). Etudes des vitesses maximales annuelles de vent pour le calcul des surcharges. *Cahier du CSTB*, 131

17. Борисенко М.М. (1974). *Вертикальные профили ветра и температура в нижних слоях атмосферы. Труды ГГО, 220*. Гидрометеоиздат

18. Барштейн М.Ф. (1978). *Руководство по расчету зданий и сооружений на действие ветра*. Стройиздат

19. Davenport A.G. (1967). The dependence of wind loads on meteorological parameters. *Jut. Reseach Seminar on Wind Effects on Building and Structures, Ottava*

20. Soize C. (1986). Approache aléatoire des effets du vent et de la houle sur les structures. *Cont. specialisée sur la securité probabiliste des structures,* CT1OM

21. Wianecki J. (1985). Securité des structures sous l'action du vent. *Annales JIBTP*, 434, 69-100

22. Ржаницын А.Р. (1978). *Теория расчета строительных конструкций на надежность*. Стройиздат

23. Райзер В.Д. (1986). *Методы теории надежности в задачах нормирования расчетных параметров строительных конструкций.* Стройиздат

24. 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

25. Цейтлин А.А., Бернштейн А.С., Гусева Н.И., Попов Н.А. (1987). Новая редакция раздела «Ветровые нагрузки» главы СНиП «Нагрузки и воздействия». *Строительная механика и расчет сооружений*, 6, 28-33

26. Лукьянов К.И., Карманов Ю.В., Костин В.С. (1987). Определение расчетных ветровых нагрузок на колонны в период монтажа. *Промышленное строительство и инженерные сооружения*, 3, 24-25

27. Горев В.В., Огневой В.Г. (1995). Обеспечение надежности стальных колонн с учетом региональных особенностей. *Известия вузов. Строительство и архитектура*, 12, 13-19

28. Popov N.A., Travoush V.I. (2006). Wind Speed Profile. *Problems of the Technical Metheorology. Proc. of 3rd Int. Conf., 22-26 May 2006.* 104-108

29. Хлыстунов М.С., Прокопьев В.И., Могилюк И.Г. (2014). Высокоразрешающие исследования закономерностей формирования порывов ветра. *Промышленное и гражданское строительство*, 11, 44-47

30. Попов Н.А., Лебедева И.В., Богачев Д.С., Березин М.М. (2016). Воздействие ветровых и снеговых нагрузок на большепролетные покрытия. *Промышленное и гражданское строительство*, 12, 71-76

31. Чурин П.С., Грибач Ю.С. (2016). Экспериментальное исследование ветрового и снегового воздействия на проектируемый аэропортовский комплекс. *Промышленное и гражданское строительство*,11, 24-27

10. Kerimov A.A., Israimov A.A. (1970). Comparison of wind speed measurement results performed by different instruments. *Meteorology and Hydrology*, 11, 102-104

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

12. Savitsky G.A. (1972). *Wind load on structures*. Stroyizdat

13. Nikitin N.V., Travush V.N. (1969). On the determination of wind loads in Moscow. *Structural Mechanics and Calculation of Structures*, 2, 62-64

14. Klepikov L.V. (1975). On the statistical distribution of wind speed. *Metal constructions*, 119, 31-40

15. Zavarina M.V. (1976). *Building climatology*. Leningrad: Gidrometeoizdat

16. Duchene-Marullar Ph. (1972). Etudes des vitesses maximales annuelles de vent pour le calcul des surcharges. *Cahier du CSTB*, 131

17. Borisenko M.M. (1974). *Vertical wind profiles and temperature in the lower atmosphere. Proceedings of GGO, 220*. Gidrometeoizdat

18. Barstein M.F. (1978). *Guidance for the calculation of buildings and structures for the action of the wind*. Stroyizdat

19. Davenport A.G. (1967). The dependence of wind loads on meteorological parameters. *Jut. Reseach Seminar on Wind Effects on Building and Structures, Ottava*

20. Soize C. (1986). Approache aléatoire des effets du vent et de la houle sur les structures. *Cont. specialisée sur la securité probabiliste des structures,* CT1OM

21. Wianecki J. (1985). Securité des structures sous l'action du vent. *Annales JIBTP*, 434, 69-100

22. Rzhanitsyn A.R. (1978). *Theory of calculation of building structures for reliability*. Stroyizdat

23. Raiser V.D. (1986). *Methods of the theory of reliability in the problems of normalizing the design parameters of building structures.* Stroyizdat

24. Ostavnov 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

25. Zeitlin A.A., Bernshtein A.S., Guseva N.I., Popov N.A. (1987). New edition of the section "Wind loads" of the chapter SNiP "Loads and loadings". *Structural mechanics and calculation of structures*, 6, 28-33

26. Lukyanov K.I., Karmanov Yu.V., Kostin B.C. (1987). Determination of the calculated wind loads on the columns during the installation period. *Industrial construction and engineering structures*, 3, 24-25

27. Gorev V.V., Ognevoi V.G. (1995). Ensuring the reliability of steel columns, taking into account regional characteristics. *Proceedings of Universities. Building and Architecture*, 12, 13-19

28. Popov N.A., Travoush V.I. (2006). Wind Speed Profile. *Problems of the Technical Metheorology. Proc. of 3rd Int. Conf., 22-26 May 2006.* 104-108

29. Khlystunov M.S., Prokopiev V.I., Mogilyuk I.G. (2014). High-resolution studies of patterns of wind gust formation. *Industrial and Civil Engineering*, 11, 44-47

30. Popov N.A., Lebedeva I.V., Bogachev D.S., Berezin M.M. (2016). The impact of wind and snow loads on large-span coatings. *Industrial and Civil Engineering,* 12, 71-76

31. Churin P.S., Gribach Yu.S. (2016). Experimental study of wind and snow impact on the projected airport complex. *Industrial and Civil Engineering*, 11, 24-27

32. Пичугин С.Ф. (1995). Вероятностное представление нагрузок на строительные конструкции. *Известия вузов. Строительство*, 4, 12-18

33. Pashinski V.A., Pichugin S.F. (1994). Wind Load Probabilistic Description and Value Computation Procedure Adopted for Building Code of Ukraine. *Preprints EECWE΄94 (Warsaw, Poland)*, Part 1, Vol. 3, 49-52

34. Пичугин С.Ф. (1997). Вероятностный анализ ветровой нагрузки. *Известия вузов. Строительство*, 12, 13-20

35. Pichugin S.F. (1997). Probabilistic Analysis on Wind Load and Reliability of Structures. *Proc. of the 2 EACWE.– Genova (Italy)*, 2, 1883-1890

36. Pichugin S.F. (1998). Probabilistic Specification of Design Wind Load Coefficients. *2nd East European Conference on Wind Engineering*, 511-515

37. Пичугин С.Ф. (2001). Случайные параметры ветровой нагрузки. *Вісник ДонДАБА, випуск 2001-4(29). Будівельні конструкції, будівлі та споруди. Том 1. Вплив вітру на будинки і споруди,* 45-50

38. Пичугин С.Ф., Махинько А.В. (2005). *Ветровая нагрузка на строительные конструкции*. Полтава: АСМІ

39. Кінаш Р.І., Бурнаєв О.М. (1998). *Вітрове навантаження і вітроенергетичні ресурси в Україні*. Львів: Видавництво науково-технічної літератури

40. Пашинський В.А. (1999) *Атмосферні навантаження на будівельні конструкції.* Київ: Сталь

41. Simiu E., Scanlan R.H. (1996). *Wind Effects on Structures: Fundamentals and Applications to Design*. New York: John Wiley

42. Пічугін С.Ф., Северин В.О. (2001). Особливості імовірнісного розрахунку елементів на вітрове навантаження. *Вісник ДонДАБА, 2001-4(29),* 91-96

43. Sergiy P., Vitaliy S. (2002). Certain Problems and Probabilistic Modelling of Wind Loads. *Proceedings of 3rd East European Conference on Wind Engineering,* 58-60

44. Пічугін С.Ф., Северин В.О. (2002). Імовірнісні моделі атмосферних навнтажень. *Proc. of 2rd International Conf. "Problems of the Technical Meteorology",* 113-118

45. Пічугін С.Ф., Махінько А.В. (2003). Імовірнісний опис статичної складової вітрового навантаження у техніці абсолютних максимумів випадкового процесу. *Вісник ДонДАБА, 2003-2 (39)*, 76-82

46. Кінаш Р.І., Гук Я.С. (2010). Районування території Закарпатської області за вітровим навантаженням. *Збірник наукових праць Українського науково-дослідного та проектного інституту сталевих конструкцій імені В.М. Шимановського*, 5, 117-123

47. Добрянський І.М., Лопатка С.С. (2002). Актуальні проблеми дослідження профілів змінного з висотою тиску на будівлі і споруди. *Вісник Національного університету "Львівська політехніка"*, 462, 41-46

48. Пашинський В.А. (2016). Методика адміністративно-територіального районування кліматичних навантажень на будівельні конструкції. *Ресурсоекономні матеріали, конструкції, будівлі та споруди*, 32, 387-393

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

33. Pashinski V.A., Pichugin S.F. (1994). Wind Load Probabilistic Description and Value Computation Procedure Adopted for Building Code of Ukraine. *Preprints EECWE΄94 (Warsaw, Poland)*, Part 1, Vol. 3, 49-52

34. Pichugin S.F. (1997). Probabilistic analysis of wind load. *Proceedings of Universities. Construction,* 12, 13-20

35. Pichugin S.F. (1997). Probabilistic Analysis on Wind Load and Reliability of Structures. *Proc. of the 2 EACWE.– Genova (Italy)*, 2, 1883-1890

36. Pichugin S.F. (1998). Probabilistic Specification of Design Wind Load Coefficients. *2nd East European Conference on Wind Engineering*, 511-515

37. Pichugin S.F. Probabilistic Parameters of Wind Load. *Bulletin of DonDABA, issue 2001-4 (29). Building structures, buildings and constructions. Volume 1. The effect of wind on houses and buildings,* 45-50

38. Pichugin S.F., Makhinko A.V. (2005). *Wind Load on Building Structures*. Poltava: ASMI Publishing House

39. Kinash R.I., Burnaev O.M. (1998). *Wind Load and Wind Energy Resources in Ukraine.* Lviv: Publishing House of Scientific and Technical Literature

40. Pashinsky V.A. (1999). *Atmospheric loads on building structures*. Kyiv: Stal Publishing House

41. Simiu E., Scanlan R.H. (1996). *Wind Effects on Structures: Fundamentals and Applications to Design*. New York: John Wiley

42. Pichugin S.F., Severin V.O. (2001). Features of Probabilistic Calculation of Elements for Wind Load. *Bulletin of DonDABA, 2001-4 (29),* 91-96

43. Sergiy P., Vitaliy S. (2002). Certain Problems and Probabilistic Modelling of Wind Loads. *Proceedings of 3rd East European Conference on Wind Engineering,* 58-60

44. Pichugin S.F., Severin V.O. (2002). Probabilistic Models of Atmospheric Loads. *Proc. of 2rd International Conf. "Problems of the Technical Meteorology",* 113-118

45. Pichugin S.F., Makhinko A.V. (2003). Probabilistic Description of the Static Component of Wind Load in the Technique of Absolute Maxima of a Random Process. *Bulletin of DonDABA, 2003-2 (39),* 76-82

46. Kinash R.I., Guk J.S. (2010). Zoning of the Transcarpathian Region by Wind Load. *Collection of scientific works of the Ukrainian Research and Design Institute of Steel Structures named after V.M. Szymanowski,* 5, 117-123

47. Dobryansky I.M., Lopatka S.S. (2002). Current Problems of Research of Pressure Profiles Variable with Height on Buildings and Constructions. *Bulletin of the National University "Lviv Polytechnic"*, 462, 41-46

48. Pashinsky V.A. (2016). Methods of Administrative-territorial Zoning of Climatic Loads on Building Structures. *Resource-saving materials, structures, buildings and structures*, 32, 387-393