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STANDARDS-BASED APPROACHES OF UKRAINE AND INDIA TO THE DETERMINATION OF WIND LOADS

Introduction. *The calculation of wind load on building structures is an indispensable component of modern building design, therefore, analyzing the experience of different countries of the world in this aspect is an important and relevant task.*

Problem Statement. *The main difficulty in taking wind load into account during design is the diversity of principles and approaches to its definition, which is based on national ideas and value system in different countries of the world.*

Purpose. *Comparison of applicable regulatory approaches to determining wind loads in Ukraine and India using the example of a low-rise industrial building with an analysis of the system of influencing factors and the degree of their consideration.*

Materials and Methods. *The research was conducted based on an analysis of the approaches of the applicable Ukrainian and Indian standards for determining wind loads. A low-rise industrial building of rectangular shape in plan with a gable roof was taken as the object of the study.*

Results. *It has been established that the applicable standards of Ukraine and India use a fundamentally similar model of wind load, which is supplemented by a system of correction factors to take into account local operating conditions. However, the Indian standard takes into account 12 factors of local conditions against 10 factors in the Ukrainian standard. The methodology for taking them into account differs qualitatively in these standards. At the same time, the value of the aerodynamic coefficient has a quantitative level of correlation within 50 % according to the standards of both countries. For a low-rise industrial building with a gable roof, the finally determined level of wind load according to the standards*

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of Ukraine and India differs by the amount for side facades — up to 25 %, for end facades — up to 40 %, for the roof — up to 30 %. The height wind profile for the Indian standard is flatter and has a quantitative correlation level within 50 % for heights up to 20 m above the ground.

Conclusions. The obtained results provide an opportunity to analyze the applicable national standards of Ukraine and should be used for their improvement.

Keywords: wind load, aerodynamic coefficient, low-rise building, Indian standard, Ukrainian standard.

Despite the exceptionally difficult circumstances Ukraine has faced in recent years, specialists across various sectors have continued to maintain cooperation with international partners. One of the increasingly common contemporary models of collaboration involves performing design work for new construction or reconstruction projects in one country, while their direct implementation takes place in another. This practice raises the issue of correctly and thoroughly accounting for all requirements of the relevant regulatory documents of both countries — and, not infrequently, the need to reconcile these requirements with the capabilities of the software tools used in developing design and engineering solutions. Such situations encourage preliminary analysis and comparison of the existing regulatory frameworks of partner countries, with the goal of identifying their specific features, shared principles, and key differences.

This issue is particularly critical in relation to the regulatory base governing the determination of loads on building structures, as this process represents the starting point of any design activity — whether new construction or repair and reconstruction. Errors at this stage often lead to severe consequences, as they “accompany” a structural asset throughout its entire life cycle. For example, one of the co-authors of this publication has illustrated this problem quite clearly using the case of steel tank structures [1]. This issue has also been examined in publications [2–4], which propose possible avenues for improvement. Additional recommendations for addressing similar challenges are provided in [5].

For most building structures, such as residential and industrial buildings, the primary acting loads are natural and climatic, with wind load be-

ing the most significant. Although wind load has been extensively studied in numerous classical works of Ukrainian scientific schools [5–11] and international research traditions [12–14], various countries still apply somewhat different approaches to its determination when developing design and engineering documentation [15–21].

The purpose of this study is to compare the applicable regulatory approaches to determining wind loads in Ukraine and India using the example of a low-rise industrial building.

A three-story industrial building, whose structural layout is described in detail in [22], has been selected as the object of investigation. The building is being designed for the city of Baddi (Himachal Pradesh), India.

Structurally, the study object is a rectangular building with overall dimensions of 52 m in length and 21 m in width. The first three stories have a reinforced-concrete frame and represent an existing structure. The fourth story is being added using a steel frame as part of a reconstruction project intended to convert the facility into a small-scale pharmaceutical production plant (Figs. 1 and 2). The roof is of a cold type and incorporates load-bearing steel trusses used as girders. The roof slopes have an inclination angle of 7°, although one of the reconstruction design options considers increasing this angle to 15°, which is more effective for drainage.

STANDARD DBN V.1.2-2:2006. In Ukraine, the primary regulatory document governing the determination of wind loads on buildings of various types is the applicable standard [23]. Section 9 of this standard covers both civil and industrial buildings up to 200 m in height. In this context, wind pressure on building surfaces must

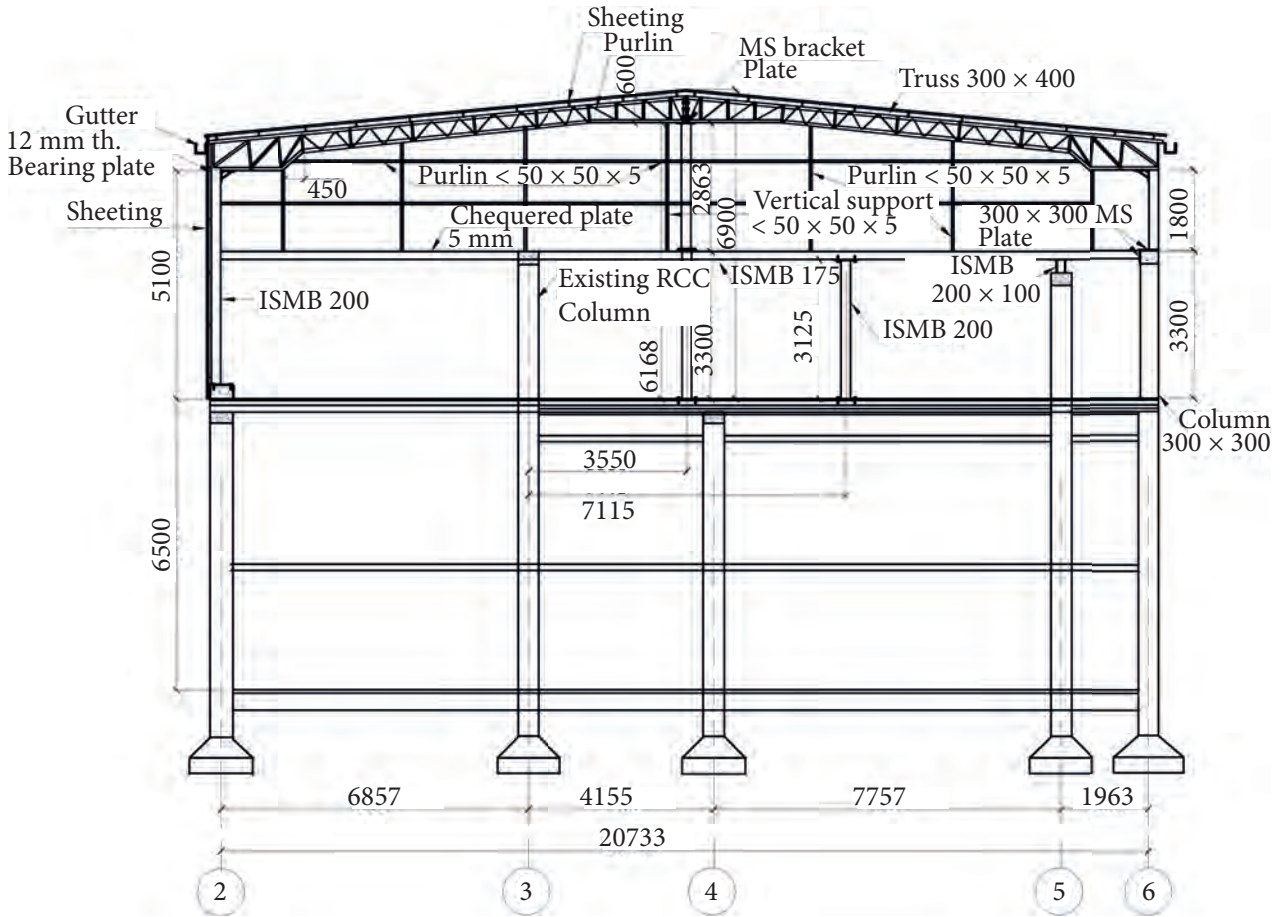


Fig. 1. Cross-section of the building

be determined in accordance with the following expression:

$$W_m = \gamma_{fm} \cdot W_0 \cdot C, \quad (1)$$

where γ_{fm} is the reliability factor for the ultimate value of wind load, which accounts for the intended service life of the building; W_0 is the characteristic value of the wind load, which depends on the geographical location of the building and is determined using a dedicated wind zoning map of Ukraine, expressed in kPa; C is the coefficient that reflects the building's operational conditions and is determined according to a separate prescribed expression:

$$C = C_{aer} \cdot C_h \cdot C_{alt} \cdot C_{rel} \cdot C_{dir} \cdot C_d, \quad (2)$$

where C_{aer} is the aerodynamic coefficient that accounts for the external configuration of the building;

C_h is the height coefficient, which reflects the variation of wind pressure along the height of the structure; C_{alt} is the coefficient that accounts for the elevation of the construction site above sea level; C_{rel} is the coefficient that reflects the local micro-terrain surrounding the construction area; C_{dir} is the coefficient that accounts for differences in wind intensity depending on wind direction; C_d is the coefficient that accounts for potential dynamic effects in the building structure induced by wind action.

Ukraine is divided into five wind zones with characteristic wind pressures ranging from 400 to 600 Pa, with a recurrence period of 50 years. In terms of wind speed, these values correspond to 25.6 to 31.4 m/s, respectively. According to the

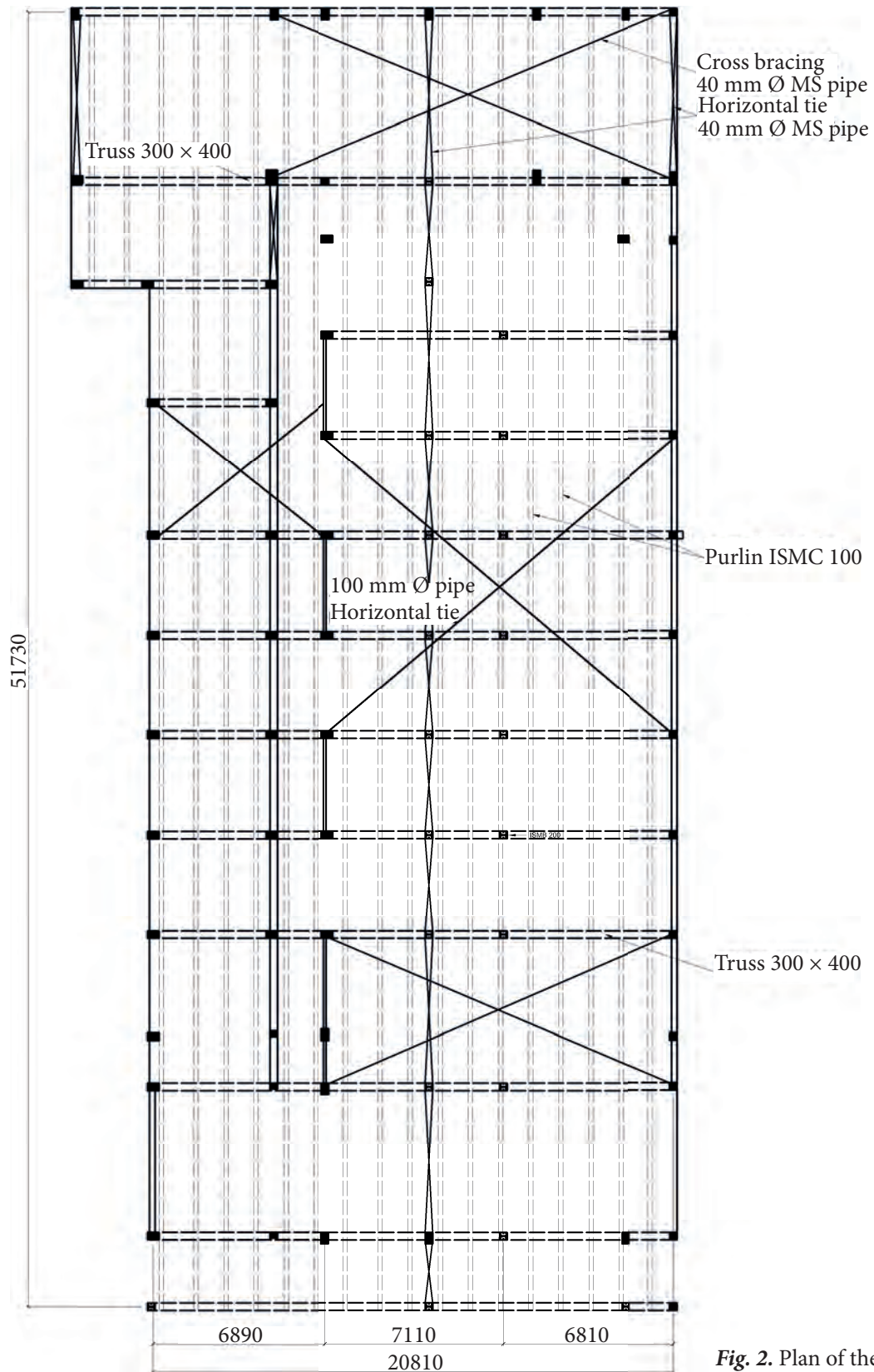


Fig. 2. Plan of the building

refined 12-point Beaufort scale, such wind speeds correspond to levels 11 and 12, respectively, which in practice are associated with severe and devastating destruction [24].

The standard **SNiP 2.01.07-85***. According to the previous version of the standard [25], which remained in force in Ukraine until 2006, the territory of Ukraine was divided into two wind zones with wind pressures of 300 and 380 Pa, taken as the *normative load* (with a recurrence period set at 5 years). Converted into wind speed, these values correspond to 22.2 and 25.0 m/s, respectively. According to the refined 12-point Beaufort scale, such wind speeds correspond to level 10, which in practice is associated with substantial destruction [24].

According to the previous version of the standard [25], the wind pressure acting on building surfaces should be determined using the following expression:

$$W_m = \gamma_f \cdot W_n \cdot k \cdot C, \quad (3)$$

where γ_f is the reliability factor for wind load; W_n is the normative wind load value that depends on the geographical location of the building and is determined from a special zoning map of the territory of Ukraine, in kPa; k is the coefficient accounting for the variation of wind pressure along the height of the building; C is the aerodynamic coefficient reflecting the external configuration of the building.

Standard IS 875-3. In India, the principal normative document regulating the determination of wind loads on buildings of various types is the applicable standard [26]. Part 3 covers both civil and industrial buildings without any specific height limitation. In this case, the wind pressure on their surfaces shall be determined using the following expression:

$$p_d = 0,6 \cdot K_d \cdot K_a \cdot K_c \cdot (C_{pe} - C_{pl}) \cdot V_z^2, \quad (4)$$

where K_d is the wind directionally factor; K_a is the area averaging factor; K_c is the combination factor; C_{pe} is the external pressure coefficient; C_{pl} is the internal pressure coefficient; V_z is the design wind

speed at height z , which is determined by the expression:

$$V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4, \quad (5)$$

where V_b is the basic wind speed that depends on geographical location of the building. It is determined from a special wind-zoning map of India, in m/s; k_1 is the probability factor; k_2 is the terrain roughness and height factor; k_3 is the topography factor; k_4 is the importance factor for the cyclonic region.

The territory of India is divided into six wind zones with wind speeds ranging from 33 m/s to 55 m/s (with a recurrence period set at 50 years). According to the refined twelve-point Beaufort scale, such speeds already significantly exceed the minimum threshold corresponding to force 12 (29.0 m/s) and fall within the hurricane category [24].

It should also be noted that in recent decades substantial work has been carried out to refine the distribution of wind speeds across India. As a result, the number of wind zones remained unchanged, but their layout was qualitatively revised [27]. Therefore, the object of study shall be located in a somewhat different wind zone, with a basic wind speed $V_b = 50$ m/s (Fig. 4) instead of 47 m/s (Fig. 3). Thus, in qualitative terms, the applicable methodologies for determining wind loads on building structures in Ukraine and India are practically similar. The fundamental difference lies only in the zoning principle: by wind speed V_i (India) or by wind pressure $W_i = 0.61 \cdot V_i^2$ (Ukraine). For the considered building, with a wind speed $V_b = 50$ m/s according to the updated Indian zoning data, the characteristic (normative) wind-load value according to Ukrainian standards would equal $W_{o(n)} = 0.61 \cdot V_b^2 = 0.61 \cdot 50^2 = 1525$ Pa.

Regarding the quantitative set of correction factors supplementing the expressions for determining wind pressure in the Ukrainian and Indian standards, these factors differ both in purpose and in magnitude. This aspect is analyzed below.

Wind Load According to Standard DBN V.1.2-2:2006. The recommended service life for an industrial building under the applicable Ukrai-

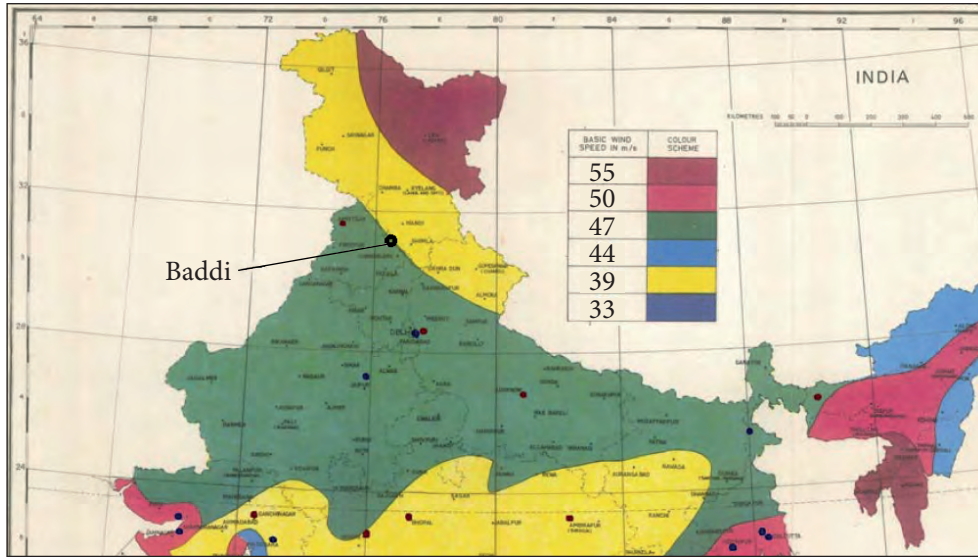


Fig. 3. Location of the study object according to the standard wind map of India

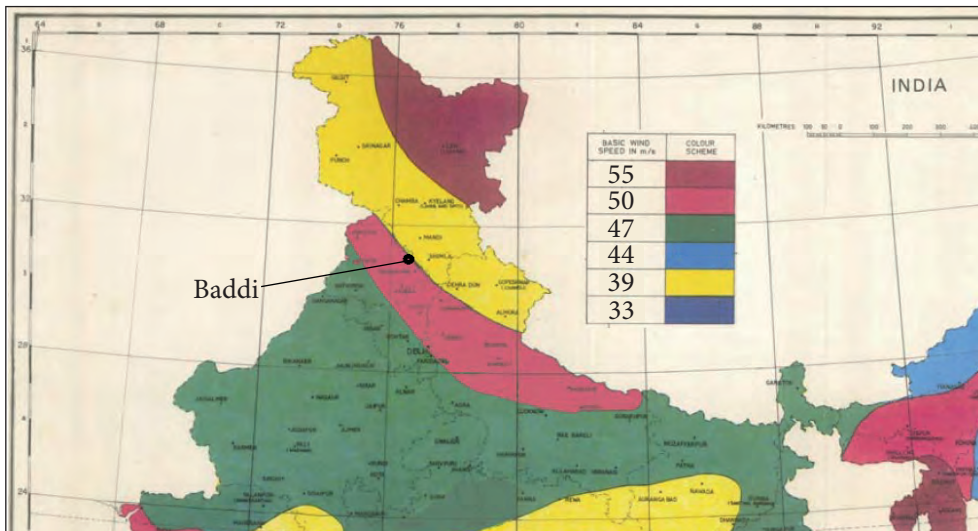


Fig. 4. Location of the study object according to the updated wind map of India

nian standard is 60 years. Therefore, the reliability factor for the ultimate wind load, which depends on this parameter, is $\gamma_{fm} = 1.04$.

The height coefficient C_h depends on the type of terrain surrounding the construction site. According to the geographical location of the studied object (Fig. 1), the surrounding area is a suburban zone with low-rise development and forested areas.

Under the applicable Ukrainian standard, this corresponds to Terrain Category III. In this case, the coefficient C_h varies with the height above the ground surface as follows:

$$z \leq 5 \text{ m, } C_h = 0.90;$$

$$z = 10 \text{ m, } C_h = 1.20;$$

$$z = 20 \text{ m, } C_h = 1.55.$$

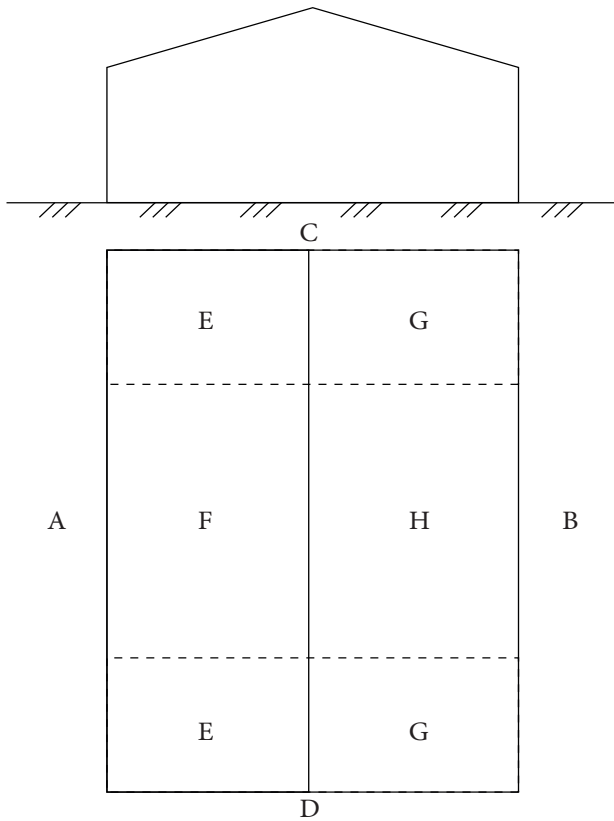


Fig. 5. Surfaces for determining the aerodynamic coefficient

Table 1. Aerodynamic Coefficient Values According to the Applicable Ukrainian Standard

Surface	Wind effect on the facades			
	Side Façade A		End Façade C	
	7°	15°	7°	15°
A	+0.80	+0.80	-0.40	-0.40
B	-0.52	-0.52	-0.40	-0.40
C	-0.52	-0.52	+0.80	+0.80
D	-0.52	-0.52	-0.40	-0.40
E	-0.56	-0.49	-0.70	-0.70
F	-0.56	-0.49	-0.70	-0.70
G	-0.42	-0.42	-0.70	-0.70
H	-0.42	-0.42	-0.70	-0.70

The altitude coefficient C_{alt} , which accounts for the elevation of the construction site above sea level, equals 1.0 for altitudes not exceeding 0.5 km.

The micro-terrain coefficient C_{rel} is also equal to 1.0, since the studied building is located on a flat plain without hills or slopes.

The wind directionality coefficient C_{dir} is taken as 1.0 in the absence of specific meteorological data.

The dynamic coefficient C_d , according to the applicable Ukrainian standard, depends on the building's plan dimensions and height. For a steel-concrete frame, and for both roof-slope angles (7° and 15°), this coefficient takes the same value of 0.93.

The aerodynamic coefficient C_{aer} for a dual-pitch building depends on its geometric dimensions. According to the applicable Ukrainian standard, for wind acting on the side façades A (B) and the end façades C (D), at roof-slope angles of 7° and 15° (Fig. 5), the corresponding coefficient values are shown in Table 1.

Wind Load According to Standard SNiP 2.01.07-85*. The reliability factor for wind load is a constant value and equals $\gamma_f = 1.4$.

The building-height coefficient k depends on the type of terrain surrounding the construction site. Under the withdrawn Ukrainian standard, the terrain at the location of the studied object corresponds to Category B. In this case, the coefficient k varies with the height above the ground surface as follows:

$$z \leq 5 \text{ m}, k = 0.50;$$

$$z = 10 \text{ m}, k = 0.65;$$

$$z = 20 \text{ m}, k = 0.85.$$

The values of the aerodynamic coefficient C are identical to the previous case and fully correspond to the values of the coefficient C_{aer} presented in Table 1.

Wind Load According to Standard IS 875-3. The wind directionality factor K_d for buildings with flat surfaces, in accordance with the Indian standard, is taken as 0.9.

The pressure coefficient K_a , which accounts for the non-uniform distribution of wind pressure over a building surface, depends on the area of the corresponding surface according to the Indian

standard. For the considered case, it takes the following values for different surfaces (Fig. 5):

- ◆ for side façades A and C, each with an area of approximately 630 m², $K_a = 0.8$;
- ◆ for end façades B and D, each with an area of approximately 255 m², $K_a = 0.8$;
- ◆ for roof slopes E and F, each with an area of about 550 m², $K_a = 0.8$.

The combined pressure coefficient K_c is taken as 1.0, since no additional internal pressure — either positive or negative — is present inside the building.

The coefficient k_1 accounts for the design life of the building. According to the applicable Indian standard, the design life for industrial buildings is 50 years; therefore, $k_1 = 1.0$.

The coefficient k_2 reflects the terrain category around the construction site. According to the applicable Indian standard, the site corresponds to Terrain Category 3. In this case, the coefficient k_2 varies with height z above ground level as follows:

$$z = 10 \text{ m}, C_h = 0.91;$$

$$z = 15 \text{ m}, C_h = 0.97;$$

$$z = 20 \text{ m}, C_h = 1.01.$$

The micro-relief coefficient of the terrain surrounding the construction site, k_3 , equals 1.0, since the facility is located on a flat plain with no hills or slopes. The coefficient k_4 may also be taken as 1.0, because the facility is located more than 60 km away from the shoreline.

To determine the internal pressure coefficient C_{pi} , it is necessary to calculate the ratio of the total area of openings (windows and doors) to the total area of all building walls. For the case under consideration, this ratio equals $340/1770 = 0.19$, or 19%. According to the applicable Indian Standard, such a building is classified as one with a medium level of openings. Therefore, the coefficient $C_{pi} = \pm 0.5$.

The external pressure coefficient C_{pe} essentially represents the aerodynamic coefficient. According to the applicable Indian Standard, for wind action on the side façades A (C) and the end façades B (D), and for roof slopes of 7° and 15° (Fig. 5), the cor-

responding values of this coefficient are provided in Table 2.

By comparing the data in Tables 1 and 2, it is possible to state that there is a rather high degree of correlation in terms of the overall qualitative pattern, since the aerodynamic coefficient describes the physical process of interaction between the wind flow and an obstacle and therefore cannot differ across countries. Quantitatively, however, the correlation is not very strong, although the maximum difference between the values of this coefficient remains within 50%.

Comparison of Results. Let us compare the calculated wind-pressure results according to the different standards of Ukraine and India. This will be done in parts, which allows for a more accurate and detailed analysis. For this purpose, the following general expression for determining wind pressure W will be used:

$$W = W_v \cdot C_{aer}, \tag{6}$$

where W_v is the equivalent wind pressure, calculated based on the wind speed corresponding to the zone where the studied object is located; it takes into account the system of operational coefficients. According to the adopted data, the values of this quantity, calculated according to different standards for the various surfaces of the studied building, are presented in Table 3.

Table 2. Values of the Aerodynamic Coefficient According to the Applicable Indian Standard

Surface	Wind effect on the façades			
	Side Façade A		End Façade B	
	7°	15°	7°	15°
A	+0.70	+0.70	-0.50	-0.50
B	-0.30	-0.30	-0.50	-0.50
C	-0.70	-0.70	+0.70	+0.70
D	-0.70	-0.70	-0.10	-0.10
E	-0.98	-0.90	-0.86	-0.80
F	-0.98	-0.90	-0.60	-0.60
G	-0.60	-0.55	-0.86	-0.80
H	-0.60	-0.55	-0.60	-0.60

As can be seen from the data, the highest values are obtained according to the applicable Ukrainian standard. On average, these values are 25—30% higher than those calculated according to the withdrawn Ukrainian standard and 1.5—2 times higher than those calculated according to the applicable Indian standard.

However, for a final conclusion, a comparison of the total wind pressures calculated using expression (6) according to different standards for the various surfaces of the studied building has been performed, with values rounded to the nearest 5 Pa (Table 4). As noted above, according to the applicable Indian standards, the external aerodynamic

Table 3. Values of the Equivalent Wind Pressure (Pa)

Surface	Altitude, m	Standard		
		DBN V.1.2-2:2006	SNiP 2.01.07-85	IS 875-3
A, B, C, D	5.0	1327	1068	894
	10.0	1770	1388	894
	12.7	1903	1495	954
E, F, G, H	13.4 (7°)	1947	1537	975
	15.0 (15°)	2035	1601	1016

Table 4. Full Values of the Wind Pressure (Pa)

Surface	Altitude, m	Standard					
		DBN V.1.2-2:2006		SNiP 2.01.07-85		IS 875-3	
		Wind effect on the facades					
		A	C	A	C	A	C
A	5.0	1060	-530	855	-425	1075 (180)	0 (-895)
	10.0	1415	-710	1110	-555	1075 (180)	0 (-895)
	12.7	1520	-760	1195	-600	1145 (190)	0 (-955)
B	5.0	-690	-530	-555	-425	180 (-715)	0 (-895)
	10.0	-920	-710	-720	-555	180 (-715)	0 (-895)
	12.7	-990	-760	-775	-600	190 (-765)	0 (-955)
C	5.0	-690	1060	-555	855	-180 (-1075)	1075 (180)
	10.0	-920	1415	-720	1110	-180 (-1075)	1075 (180)
	12.7	-990	1520	-775	1195	-190 (-1145)	1145 (190)
D	5.0	-690	-530	-555	-425	-180 (-1075)	360 (-535)
	10.0	-920	-710	-720	-555	-180 (-1075)	360 (-535)
	12.7	-990	-760	-775	-600	-190 (-1145)	380 (-570)
E	13.4 (7°)	-1090	-1365	-860	-1075	-470 (-1445)	-350 (-1325)
	15.0 (15°)	-1000	-1425	-785	-1120	-405 (-1420)	-305 (-1320)
F	13.4 (7°)	-1090	-1365	-860	-1075	-470 (-1445)	-100 (-1075)
	15.0 (15°)	-1000	-1425	-785	-1120	-405 (-1420)	-100 (-1120)
G	13.4 (7°)	-820	-1365	-645	-1075	-100 (-1075)	-350 (-1325)
	15.0 (15°)	-855	-1425	-670	-1120	-50 (-1065)	-305 (-1320)
H	13.4 (7°)	-820	-1365	-645	-1075	-100 (-1075)	-100 (-1075)
	15.0 (15°)	-855	-1425	-670	-1120	-50 (-1065)	-100 (-1120)

coefficient must additionally be adjusted by a special internal coefficient (C_{pi}). This allows for the determination of not only the maximum wind-pressure values but also the minimum ones shown in parentheses in the table. In practice, this requires engineers to perform structural calculations for a greater number of possible combinations, taking into account the likelihood of strongly asymmetric loading.

According to the obtained results, the total wind load calculated according to the applicable standards of Ukraine and India exhibits a high qualitative correlation.

Quantitatively, for the building walls, the correlation decreases to approximately 30% with increasing height, due to the less pronounced vertical wind profile in the applicable Indian standard. For the roof, the quantitative correlation is similar; however, higher values for the windward slope are reported according to the Indian standard, while for the leeward slope, higher values are obtained according to the Ukrainian standard.

Wind-pressure values based on the withdrawn Ukrainian standard are approximately 1.5 times lower than those calculated using the applicable standards of Ukraine and India. One of the main factors explaining this difference is the consideration of roughly half as many influencing factors in the withdrawn Ukrainian standard compared to the modern Ukrainian and Indian standards (Table 5). In this regard, the latter two standards are roughly equivalent.

Thus, the scientific novelty of this study lies in the systematic qualitative and quantitative assessment of methodologies for calculating wind loads on structural elements of single-story buildings, performed for the first time. The evaluation has been carried out based on the applicable standards implemented in the design practice of Ukraine and India. From a practical perspective, this provides opportunities to optimize the scope of structural load calculations by incorporating international experience, and it also outlines directions for improving the regulatory frameworks of Ukraine and India in this area.

Table 5. Factors Considered in the Standards

No.	Factor	Standard		
		DBN V.1.2-2:2006	SNiP 2.01.07-85	IS 875-3
1	Wind speed depending on natural and climatic conditions	+	+	+
2	Variation of wind power by direction	+		+
3	Variation of wind speed with altitude	+	+	+
4	Elevation of the building site above sea level	+		
5	Presence of obstacles to the wind flow on the ground surface around the building	+	+	+
6	Micro-relief of the ground surface around the building	+		+
7	Service life of the building	+	+ (implicitly)	+
8	Building shape in plan	+	+	+
9	Building profile	+	+	+
10	Area of solid building surfaces			+
11	Area of building openings			+
12	Additional internal pressure in the building			+
13	Effect of the pulsation component of wind load	+	+ (at an altitude over 36 m)	
14	Cyclones and storms			+

CONCLUSIONS

Based on the analysis of wind pressure on a low-rise industrial building according to Ukrainian and Indian standards, the following conclusions can be drawn:

1. In principle, the approaches of the Ukrainian and Indian standards to determining wind pressure on building surfaces are quite similar. The main difference lies in the zoning principle: India uses wind speed for zoning, whereas Ukraine uses wind pressure.

2. The Indian standard incorporates a milder wind profile with height. This results in progressively lower wind-pressure values compared to the applicable Ukrainian standard, starting from a height of 10 m.

3. The aerodynamic coefficient, which meaningfully describes the interaction between the wind flow and the building, shows a high qualitative cor-

relation between the applicable Ukrainian and Indian wind standards, while the quantitative correlation is about 50%. However, unlike the Ukrainian standard, the Indian standard allows this coefficient to take two values (maximum and minimum). This requires performing structural calculations for a larger number of possible combinations, considering the probability of sharply asymmetric loading.

4. The values of total wind pressure on different parts of the building, calculated according to the applicable Ukrainian and Indian standards, exhibit a very high qualitative correlation, with a quantitative correlation of about 40%.

5. Wind-pressure values under the withdrawn Ukrainian standard are approximately 1.5 times lower than those under the applicable Indian and Ukrainian standards. This difference is mainly due to the consideration of only half as many influencing factors.

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НОРМАТИВНІ ПІДХОДИ УКРАЇНИ ТА ІНДІЇ З ВИЗНАЧЕННЯ ВІТРОВИХ НАВАНТАЖЕНЬ

Вступ. Розрахунок вітрового навантаження на будівельні конструкції є невід’ємною складовою сучасного будівельного проектування, тому аналіз досвіду різних країн світу в цьому аспекті є важливим та актуальним завданням.

Проблематика. Основною складністю урахування вітрового навантаження під час проектування є різноманітність принципів та підходів до його визначення, яка ґрунтується на національних засадах різних країн світу.

Мета. Співставлення чинних нормативних підходів з визначення вітрових навантажень України та Індії на прикладі малоповерхової виробничої будівлі з аналізом системи факторів впливу та ступеня їх урахування.

Матеріали й методи. Дослідження проведено на основі аналізу підходів чинних стандартів України та Індії з визначення вітрових навантажень. Об’єктом досліджень прийнято малоповерхову виробничу будівлю прямокутної форми в плані з двоскатним покриттям.

Результати. Встановлено, що у чинних стандартах України та Індії використовується принципова схожа модель визначення вітрового навантаження, яка доповнюється системою поправочних коефіцієнтів для врахування місцевих умов експлуатації. Проте стандарт Індії враховує 12 факторів місцевих умов, тоді як у стандарті України взято до уваги лише 10 чинників. Методика їх врахування якісно різниться в цих стандартах. При цьому значення аеродинамічного коефіцієнту має кількісний рівень кореляції в межах 50 % за стандартами обох країн. Для малоповерхової виробничої будівлі з двоскатною покрівлею остаточно визначений рівень вітрового навантаження за стандартами України та Індії відрізняється. Так для бічних фасадів різниця показників становить до 25 %, для торцевих фасадів — до 40 %, для покрівлі — до 30 %. Висотний вітровий профіль для стандарту Індії є більш пологим та має кількісний рівень кореляції в межах 50 % для висоти до 20 м над поверхнею землі.

Висновки. Отримані результати дають можливість аналізу чинних національних стандартів України та можуть бути використані для їхнього удосконалення.

Ключові слова: вітрове навантаження, аеродинамічний коефіцієнт, малоповерхова будівля, стандарт Індії, стандарт України.