UDC 624.042 **doi:10.31650/2707-3068-2023-27-19-27**

THE FEATURES OF DETERMINATION OF SEISMIC LOADS ON STEEL SILOS WITH A FLAT BOTTOM ACCORDING TO DBN V.2.6-221:2021

Makhinko A.V., ScD, Professor,
pasargada1981@gmail.com, ORCID: 0000-0002-9147-7087
Makhinko N.O., ScD, Associated Professor
nataliia.makhinko@npp.nau.edu.ua, ORCID: 0000-0001-8120-6374
National Aviation University

Abstract. The article is devoted to the peculiarities of determination of seismic loads on steel silos with a flat bottom according to newly introduced DBN B.2.6-221:2021, harmonized with the global system of European codification Eurocode. The main focus is on the general methods of specifying seismic action and the principles of schematizing seismic action for analysis silos. The parameters of the acceleration spectra of the horizontal and vertical components of seismic load and their influence on formation of silos reaction in these directions are analyzed. The recommendations are given for accurate evaluations the inertia-stiff characteristics of silos with a flat bottom in height based on the analysis of their design features and physical and mechanical characteristics of the particulate material.

Keywords. steel silo, particulate solid, seismic loads, failure probability, soil accelerations, importance coefficient, asymmetric seismic pressure, response acceleration.

Introduction. Over the past ten years, Ukraine has been harmonizing its regulatory framework with the European-wide system of codification of construction design Eurocode. During this period, hundreds of normative documents of various sectoral subordination have already been implemented in domestic design practice. Until recently, the state governing bodies of the construction industry showed a certain liberal approach to project organizations: to design the object according to the state construction regulations or according to the norms of the united Europe. However, over time, the project "window of opportunity" in certain directions of construction began to close, clearly orienting engineers to the European approach.

Analysis of recent research and publications. In the field of agricultural construction, the new DBN V.2.6-221:2021 "Steel silos for grain with a corrugated wall" became the most significant regulatory document of recent times [1]. It became iconic thanks to two things: firstly, it is probably the shortest DBN of Ukraine, secondly, it has almost no meaningful or constructive part. In terms of form, it is a collection of references to Eurocode norms on the subject of analysis and design of silos; in fact, it is a document that solved the problem of choosing between domestic and European regulatory practice. From now on, only Eurocode. For the most part researches in this field presented by foreign publications [2-6].

Formulation of the problem. The European approach in general turned out to be a surprise for the stakeholders of agricultural construction. As they say: the bottom (read as engineers) cannot, and the top (read as manufacturers) do not want. The reason for this dualistic problem is quite simple. For engineers, it is an unwillingness to understand several dozens of standards that regulate the calculation of steel silos, and for manufacturers, it is an unwillingness to spend additional funds on the transition to the European system of reliability of buildings and structures.

Purpose and tasks. This article is a part of the great engineering and educational work of the authors [7-9], aimed at overcoming this regulatory and economic nihilism among the engineering and production community of Ukraine. Subjectively, it concerns the analysis of silos with a flat bottom for seismic loads in accordance with the European Eurocode standardization system [10-13]. The main focus is on the general methods of normalizing seismic effects and the principles of schematizing seismic loads in silo calculations

The general description of seismic action. The analysis of seismic effects in accordance with section 2.1(1) DSTU-NB EN 1998-1 [11] is performed to comply with one of two main requirements: the no collapse requirement (abbreviated as NCR) and the damage limitation requirement (abbreviated as DLR). The seismic action is characterized by the probability P_R of its occurrence during the base period T_L expressed in years. The derivative characteristic of seismic impact is the average recurrence period T_R, which characterizes the frequency of earthquakes of the same intensity. These quantities are related by the following ratio:

$$T_R = \frac{T_L}{\ln\left(1-P_R\right)}. \tag{1}$$

The **no-collapse requirement** (NCR) needs that the silo shall be designed and constructed to withstand the design seismic action without local or global collapse, thus retaining its structural integrity and a residual load bearing capacity after the seismic events. The design seismic action is characterized by the expected probability of exceedance $P_{NCR} = 0.1$ over the $T_L = 50$ years. According to expression (1), this corresponds to expected recurrence period of $T_{NCR} \approx 475$ years.

The **damage limitation requirement** (DLR) stipulates that the silo shall be designed and constructed to withstand a seismic action having a larger probability of occurrence than the design seismic action, without the occurrence of damage and the associated limitations of use, the costs of which would be disproportionately high in comparison with the costs of the silo itself. The seismic action to be taken into account for the "damage limitation requirement" has a probability of exceedance, $P_{DLR} = 0.1$ in $T_L = 10$ years. This corresponds to a recurrence period $T_{DLR} \approx 95$ years.

As a general rule, a **no-collapse requirement** (NCR) is adopted in silo seismic analysis, although a **damage limitation requirement** (DLR) may also be imposed for some storage, especially those located near critical infrastructure sites. The normative intensity of seismic effects in points of the macroseismic scale for the construction area is adopted in accordance with section NB. 2.5 of the National Appendix [13] based on a set of general seismic zoning maps of territory of Ukraine ZSR-2004. The set includes three main maps ZSR-2004-A, ZSR-2004-B and ZSR-2004-C, which are characterized by the following indicators of the probability of an earthquake of a given intensity:

- **ZSR-2004-A:** the probability of exceedance the normative seismic intensity during the $T_L = 50$ years − $P_R = 0.1$; corresponds to the average recurrence period $T_R \approx 475$ years;
- **ZSR-2004-B:** the probability of exceedance the normative seismic intensity during the $T_L = 50$ years − $P_R = 0.05$; corresponds to the average recurrence period $T_R \approx 1000$ years;
- **ZSR-2004-C:** the probability of exceedance the normative seismic intensity during the $T_L = 50$ years − $P_R = 0.01$; corresponds to the average recurrence period $T_R \approx 5000$ years.

The choice of a specific card depends on the class of consequences of the silo:

- ZSR-2004-A: silos of class consequence CC1 and CC2 at silo limit height 73.5 meters;
- ZSR-2004-B: silos of class consequence CC2 at a silo height from 73.5 to 100 meters;
- ZSR-2004-C: silos of class consequence CC3.

Taking into account that height of all currently known silos does not exceed 73.5 m, the ZSR-2004-B map is not used for structures of this class and maps A and C remain for seismic intensity. In addition, guided by our experience in assessing the class of silo consequences in accordance with norms [1, 14, 15], it can be asserted that the majority of silos of various sizes and structures belong to the class of consequences CC1, which allows us to limit ourselves only to the ZSR-2004-A map.

In addition, the construction site on which the silo will be installed must be classified according to the type of soil base. According to section 3.1.2 of the norms [11], seven types of soils are distinguished. The soil classification is performed according to the data of engineering and geological investigations based on the average speed of propagation of seismic waves $v_{s,30}$ or the total sum of shock pulses during a standard penetration test. If the upper 30-meter soil layer is heterogeneous, then the average speed of the seismic wave is estimated by the expression:

$$v_{s,30} = 30 \Big/ \sum_i h_i / v_i , \tag{2}$$

where h_i and v_i denote the thickness (in meters) and shear-wave velocity (at a shear strain level of 10^{-5} or less) of the i-th formation or layer ($i = 1 \ldots N$), in a total of N, existing in the top 30 m.

For sites with ground conditions matching either one of the two special ground types S1 or S2 (see classification [11]), special studies for the definition of the seismic action are required. For these types, and particularly for S2, the possibility of soil failure under the seismic action shall be taken into account.

The normative seismicity, expressed in points I_p, determines the calculated level of maximum accelerations a_{gR} of the base on which the silo is located. The value a_{gR} are used to determine inertial seismic loads, which are entered into the calculation of seismic resistance as static. The quantities I_p and a_{gR} are related by the following ratio:

$$a_{gR} / g = \alpha_g = 0.1 \cdot 2^{I_p - 7}, \tag{3}$$

where $g \approx 9.81$ м/с^2 – is the acceleration of gravity; α_g − is the coefficient, which express the acceleration of the base of the silo in portions of acceleration of gravity (see table 1).

Table 1.

The relationship of base accelerations with seismicity, which is expressed in points

I_p	5	6	7	8	9	10
α_g	0.025	0.05	0.1	0.2	0.4	0.8
a_{gR}, m/s^2	0.245	0.491	0.981	1.962	3.924	7.848

The design acceleration of the soil a_g, for seismic analysis of the silo and all its structural elements, is determined by the product:

$$a_g = a_{gR} \cdot \gamma_I , \tag{4}$$

where γ_I − importance factor, which is accepted depending on the importance class of buildings in accordance with section 4.2.5 [11] and section NB. 2.13 of the National Annex [13], see table 2.

Table 2.

Importance classes for buildings

Class	Building descriptions	γ_I
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.	0.8
II	Ordinary buildings, not belonging in the other categories	1.0
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.	1.2
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.	1.4

According to the guidelines [12], the values of the importance factor can be set in National Annex to DSTU-EN [5]. However, the Ukrainian version [13] of these appendices does not contain any recommendations on the normalization of the factor γ_I. In this regard, for silos of different classes, in our opinion, it is possible to accept the importance class "I" with the value $\gamma_I = 0.8$.

The design acceleration a_g of the construction site soil on which the silo is located provokes the appearance of dynamic effects on the silo itself. The magnitude of these impacts depends on the inertia-stiffness characteristics of the silo and is characterized by the design spectrum of accelerations of the horizontal and vertical components of the seismic action. The horizontal reaction spectrum is described according to section 3.2.2.5 of the norms [11]:

$$S_d(T) = a_g \cdot S \cdot \begin{cases} \dfrac{2}{3} + \dfrac{T}{T_B} \cdot \left(\dfrac{2.5}{q} - \dfrac{2}{3} \right), & if \quad 0 \le T < T_B; \\ \dfrac{2.5}{q} & if \quad T_B \le T < T_C; \\ \dfrac{2.5}{q} \cdot \dfrac{T_C}{T}, \quad but \ \ge \dfrac{\beta}{S} & if \quad T_C \le T < T_D; \\ \dfrac{2.5}{q} \cdot \dfrac{T_C \cdot T_D}{T^2}, \quad but \ \ge \dfrac{\beta}{S} & if \quad T \ge T_D, \end{cases} \qquad (5)$$

where T – is the fundamental period of vibration of the silo for lateral motion in the direction considered; T_B, T_C, T_D – characteristic periods on the curves of the acceleration spectrums on Figure 1 and 2 with values according to the table 3; S – is the soil factor (see table 3); $\beta = 0.2$ – is the lower bound factor for the horizontal design spectrum; q – is the behavior factor (see below).

The values of periods T_B, T_C, T_D and the soil index S, which unambiguously describe the design spectrum of accelerations, depend on the type of soil and could be given in the national appendix [13]. However, there is no information on their rationing in the national annex. Instructions of section NB. 2.8 of the appendix [13] do not resolve the issue of normalization of parameters T_B, T_C, T_D, S and, moreover, contradict section NB. 2.9 and NB. 2.10 of the appendix [13]. In view of this, in the calculations of silos, it is necessary to accept the basic recommendations of norms [11]. According to these recommendations, two sets of parameters T_B, T_C, T_D, S should be considered, corresponding to type I and type II spectra. For earthquakes with a magnitude of surface waves less than 5.5, the spectrum of type II is adopted, for other cases - the spectrum of type I (see Table 3).

Table 3.

Parameters of horizontal spectra of soil response under seismic action

Ground type	Type 1 spectrum				Type 2 spectrum			
	S	T_B, s	T_C, s	T_D, s	S	T_B, s	T_C, s	T_D, s
A	1.0	0.15	0.4	2.0	1.0	0.05	0.25	1.2
B	1.2	0.15	0.5	2.0	1.35	0.05	0.25	1.2
C	1.15	0.20	0.6	2.0	1.5	0.1	0.25	1.2
D	1.35	0.20	0.8	2.0	1.8	0.1	0.30	1.2
E	1.4	0.15	0.5	2.0	1.6	0.05	0.25	1.2

Taking into account the set of seismic zoning maps of the territory of Ukraine, it is recommended to use type 1 for the design spectrum of the horizontal response of the ground. For the vertical component of the seismic action, the design spectrum $S_{vd}(T)$ is given by expression (5) when the acceleration a_g is replaced by the acceleration a_{vg} of the ground in the vertical direction, and the soil factor S is taken equal to 1.0. Other parameters a_{vg}, T_B, T_C, T_D of the vertical reaction spectrum are taken according to the data in Table 4.

Table 4.

Parameters of vertical spectra of soil response under seismic action

Type spectrum	a_{vg} / a_g	T_B, s	T_C, s	T_D, s
Type 1	0.90	0.05	0.15	1.0
Type 2	0.45			

The examples of calculated design spectra of accelerations of horizontal and vertical components of seismic action, on the basis of which the silo analysis is performed, are shown below in Figure 1 and 2. The figure also shows the characteristic periods T_B, T_C, T_D which correspond to the places of changes in the shape of the spectra.

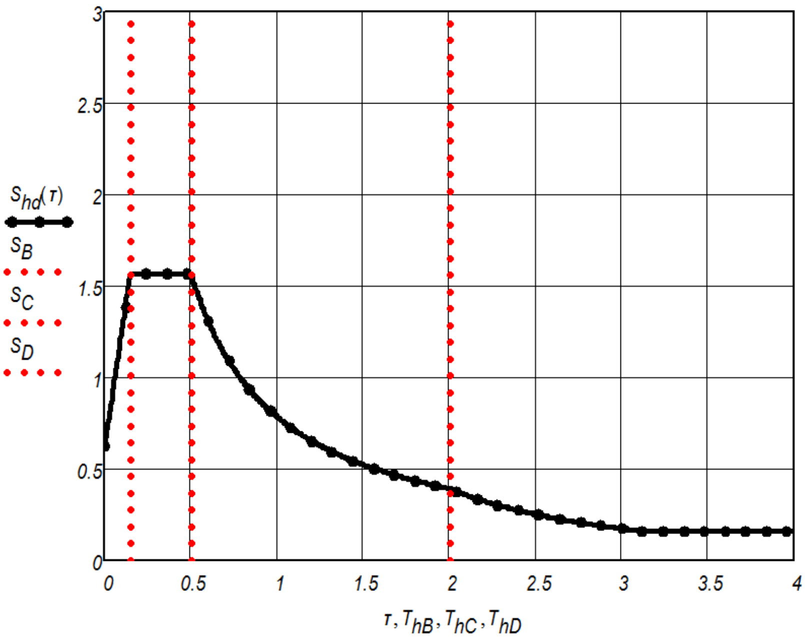

Fig. 1. The example of design spectrum of accelerations of the horizontal component of seismic action

The behavior factor q is an approximation of the ratio of the seismic forces that the structure would experience if its response was completely elastic with 5 % viscous damping, to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the silo. The Values of the behavior factor with appropriate justification can be determined individually for each direction of seismic action. According to section 3.4 of the norms [6] and section 3.2.2.5(6) of the norms [5], the behavior factor for all directions of seismic action can be taken equal to 1.5.

With the accepted parameters of the reaction spectrum, design value of horizontal displacement of the base on which the silo is placed is determined according to section 3.2.2.4 of the norms [5]:

$$d_g = 0.025 \cdot a_g \cdot S \cdot T_c \cdot T_D . \tag{6}$$

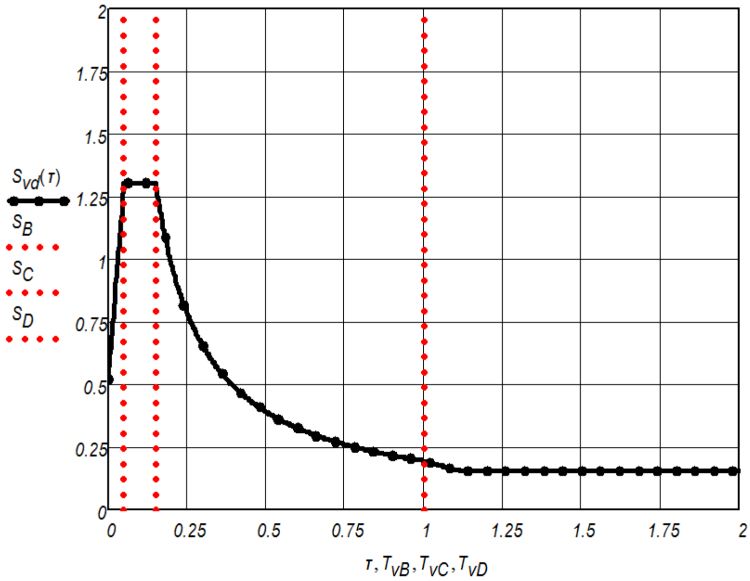

Fig. 2. The example of design spectrum of accelerations of the vertical component of seismic action

The seismic loads on the silo body. The loads from the action of seismic influences, described in the previous section, cause additional tensile forces in the sheets of the silo body due to the inertial interaction of the particulate material with the shell. The quantitative assessment of these loads is carried out in accordance with the general instructions of section 3 of DSTU-NB EN 1998-4 [12], by applying additional pressure in the places of contact of the stores contents with the shell sheets according to the trigonometric dependence:

$$\Delta_{ph,s}(y,\theta) = \Delta_{ph,so}(y) \cdot \cos\theta, \tag{7}$$

where θ − is the angle between the radial line to the point of interest on wall and the direction of the horizontal component of the seismic action; $\Delta_{ph,so}(y)$ − is the reference pressure:

$$\Delta_{ph,so}(y) = \alpha_y(y) \cdot \min\{\min[H_a, 0.5d_c], 3y\}, \tag{8}$$

where H_a − is the silo body height; $\alpha_y(y)$ − is the ratio of the response acceleration $a_g(y)$ of the silos at a vertical distance y to the acceleration of gravity.

To determine accelerations, you can use the lateral force method, which is given in section 4.3.3.2.2 of DSTU-NB EN 1998-1 [11]. The possibility of its application involves the satisfaction of two requirements: the inertia-stiffness characteristics of the building are uniformly distributed along the height; the fundamental period of building vibration does not exceed 2.0 s or the product $4T_C$, where T_C is one of the characteristics of the design spectrum of accelerations of the horizontal component of seismic action, see above table 3. Taking into account that the storage product uniformly fills the volume of the silo in height, and the fundamental period of self-vibrations of the filled silo rarely exceeds 2.0 s, we can always consider these conditions satisfied a priori. Then the acceleration of any silo point located at the y level can be estimated assuming a linear dependence for the fundamental mode of self-vibrations:

$$a_g(y_i) = \mathrm{A}_i \cdot F_b, \qquad \mathrm{A}_i = i \Big/ \sum_i i, \tag{9}$$

where i − is the ordinal number of the layer of sheets of the silo body (counting from the top) with their total number n_c; F_b − is the seismic base shear force:

$$F_b = S_d(T_1) \cdot \mathrm{M} \cdot \lambda, \tag{10}$$

where $\lambda = 0.85$ − is the correction factor (the factor accounts distribution of modal mass of silo); $S_d(T_1)$ − is the ordinate of the design spectrum (5) with an argument value equal to the fundamental period T_1 of natural vibrations of the filled steel silo; M − is the total weight of the filled silo, which is easily expressed by the weight of one layer M_0 according to the formula (neglecting the own weight of the steel structures of the silo body):

$$M = M_0 \cdot n_c, \qquad M_0 = 0.25 \cdot \gamma_{gu} \cdot \pi \cdot d_c^2 \cdot l_c \tag{11}$$

where γ_{gu} – is the upper characteristic value of the specific gravity of the particulate material in silo; l_c – is the height of one layer of silo; d_c – is the silo diameter.

The estimation of the total weight M is performed on the assumption that the equivalent surface of the storage product passes over the top of the silo body, i.e. without taking into account the equivalent height of the bulk cone h_0. This was done in accordance with the provisions of section 3.3(4) of the norms [12], which recommend taking the weight of particulate material in the silo when it is subjected to seismic influences equal to 80% of its total weight. The volume of the storage product corresponding to the height h_0 is less than 20% of the weight of the silo when fully loaded, so the proposed assumption provides a result that is commonly called "safety margin".

The distribution of additional pressures $\Delta_{ph,s}(y,\theta)$ along the perimeter of the silo is shown in Fig. 3. It should be noted that this pressure is not considered a separate load, as its appearance is caused by the inertial characteristics of the storage product, which exerts static axisymmetric pressure $p_h(z)$ on the silo body. At any point on the silo body, the sum of the static pressure $p_h(z)$ of the particulate material and the effect of the seismic action $\Delta_{ph,s}(z,\theta)$ cannot be negative. In cases where the algebraic sum of the pressures $p_h(z)$ and $\Delta_{ph,s}(z,\theta)$ is negative, it is necessary to redistribute the additional pressure in such a way that its sum with the pressure of the particulate material is not negative while maintaining the uniform force according to the pressure diagram in Figure 3 within the given height level z.

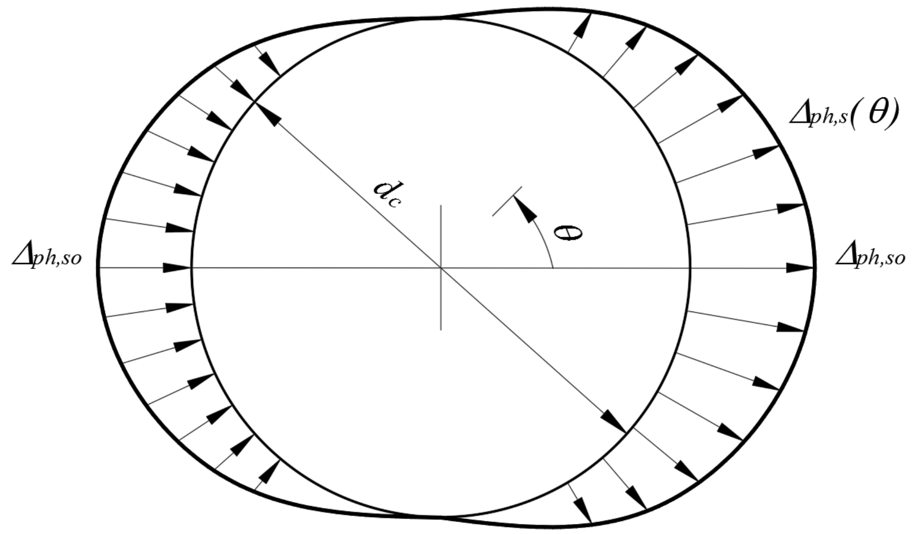

Figure. 3. The diagram of additional pressure distribution from seismic action along the silo body

Conclusion. The article examines the peculiarities of determining seismic loads on silos with a flat bottom in accordance with the newly introduced DBN B.2.6-221:2021, harmonized with the European Eurocode codification system. The main attention was paid to the methods of normalization of seismic actions and the principles of schematization of seismic loads on silos. The parameters of the spectra of soil accelerations for the horizontal and vertical components of the seismic action and their influence on the formation of reactions of silos in these directions were analyzed. The recommendations for evaluation the inertia-stiffness characteristics of silos with a flat bottom in height based on the analysis of their design features and physical and mechanical characteristics of the storage product are provided.

References

1. DBN V. 2.6-221: 2021. Structures of silos with a corrugated wall for grain. – K.: Minregion, 2022. – 7p.

2. Demir A. D. Simplified seismic response model for a bulk solid- silo-embedded foundation/soil system / A. D. Demir, R. Livaoglu // Soil Dynamics and Earthquake Engineering. − 165 (2023). − 107664.

3. Yang J. Seismic performance of column-bearing silo structure with granular materials considering SSI effect // J. Yang, F. Zhang, P. Li, H. Jing // Structures. − 47 (2023) . – PP. 595-606.

4. Mehretehran A.M. Seismic response and failure modes of steel silos with isotropic stepped walls: The effect of vertical component of ground motion and comparison of buckling resistances under seismic actions with those under wind or discharge loads / A.M. Mehretehran, S. Maleki // Engineering Failure Analysis. − 120 (2021) . − 105100.

5. H. Jing, X. Wang, J. Yang, H. Chen, Static and seismic pressure of cylindrical steel silo model with granular materials / H. Jing, X. Wang, J. Yang, H. Chen // Journal of Constructional Steel Research. − 198 (2022) . − 107515.

6. Wang M. Probabilistic seismic fragility assessment of vertical storage tank with a floating roof / M. Wang, Z. Sun, J. Sun, L. Cui, Y. Wu // Structures. − 48 (2023) . – PP. 318-330.

7. Makhinko A. Steel silos for grain storage / A. Makhinko, N. Makhinko. − Kyiv, Stal, 2021. − 356 p.

8. Lapenko O.I. Features of silos calculations at asymetric wind load by using momentless theory / O.I. Lapenko, A. Makhinko, N. Makhinko // Tehnički glasnik. − 13 1 (2019) . – PP. 12-15.

9. Makhinko A. Resource-saving steel hopper for loading of railway cars / A. Makhinko, N. Makhinko. − IOP Conf. Series: Materials Science and Engineering, 2021. − Vol. 1021. − 012021.

10. DSTU-N B EN 1990:2008. Eurocode. Basis of structural design (EN 1990:2002, IDT). - K.: Мінрегіон, 2009. – 105 p.

11. DSTU-N B EN 1998-1:2010. Eurocode 8. Design of structures for earthquake resistance. Part 1: General rules, seismic actions, rules, structures. (EN 1998-1:2004, IDT). − K.: Minregion, 2014. – 304 p.

12. DSTU-N B EN 1998-1:2010. Eurocode 8. Design of structures for earthquake resistance. - Part 4. Silos, tanks and pipelines (EN 1998-4:2006, IDT). − K.: Minregion, 2014. – 103 p.

13. DSTU-N B EN 1998-1:2010 (Amendment №1). Eurocode 8. Design of structures for earthquake resistance. Part 1. General rules, seismic actions, rules, structures (EN 1998-1:2004, IDT). − K.: Minregion, 2014. – 37 p.

14. DBN V. 1. 2-14:2018. General principles of ensuring the reliability and structural safety of buildings and structures. – K.: Minregion, 2018. – 30 p.

15. ДСТУ 8855:2019. Buildings and structures. Determining the class of consequences (responsibility). – K.: DP "UkrNDNC", 2019. – 13p.

ОСОБЛИВОСТІ ВИЗНАЧЕННЯ СЕЙСМІЧНИХ НАВАНТАЖЕНЬ НА СТАЛЕВІ СИЛОСИ ІЗ ПЛОСКИМ ДНИЩЕМ ВІДПОВІДНО ДО ДБН В.2.6-221:2021

[1]**Махінько А.В.**, д.т.н., професор
pasargada1981@gmail.com, ORCID: 0000-0002-9147-7087
[1]**Махінько Н.О.**, д.т.н., доцент
nataliia.makhinko@npp.nau.edu.ua, ORCID: 0000-0001-8120-6374
[1]*Національний авіаційний університет*

На протязі останніх десяти років Україна гармонізує свою нормативну базу із загальноєвропейською системою нормування розрахунків конструкцій Eurocode. За цей

період у вітчизняну практику проєктування вже імплементовано сотні нормативних документів різної галузевої підпорядкованості. Державні керівні органи будівельної галузі до недавнього часу проявляли до проєктних організацій певний ліберальний підхід: проєктувати об’єкт за державними будівельними нормами або за нормами об’єднаної Європи. Проте з часом, проєктне «вікно можливостей» по окремим напрямкам будівництва почало зачинятися, однозначно орієнтуючи проектувальників на європейський підхід. В галузі сільськогоспо-дарського будівництва найбільш знаковим нормативним документом останнього часу став новий ДБН В.2.6-221:2021 «Сталеві силоси для зерна із гофрованою стінкою». Знаковим він став завдяки двом речам: по-перше, це, мабуть, самий короткий ДБН України, по-друге, він майже немає, ані змістовної, ані конструктивної частини. По суті − це сукупність посилань на норми Eurocode за тематикою розрахунку та проєктування силосів; по факту − це документ, який вирішив проблему вибору між вітчизняною та європейською нормативною практикою. Від нині, тільки Eurocode. Європейський підхід загалом виявився несподіванкою для стейкхолдерів сільськогосподарського будівництва. Як говориться: низи (вони же проєктувальники) не можуть, а верхи (вони же виробники) не хочуть. Причина цієї дуалістичної проблеми доволі проста. Для проєктувальників − це неготовність осягнути декілька десятків норм, які регламентують розрахунок сталевих силосів, а для виробників – небажання витрат додаткових коштів на перехід до європейської системи надійності будівель та споруд. Дана стаття є частиною великої інженерно-просвітницької роботи авторів, спрямованої на подолання цього нормативно-економічного нігілізму серед інженерно-виробничої спільноти України. Предметно вона торкається розрахунку силосів із плоским днищем на сейсмічні навантаження відповідно до європейської системи нормування Eurocode. Основна увага фокусується на загальних методах нормування сейсмічних впливів та принципах схематизації сейсмічних навантажень при розрахунку силосів.

Ключові слова. сталевий силос, сейсмічні навантаження, ймовірність руйнування, спектр прискорень ґрунту, коефіцієнт важливості, асиметричний сейсмічний тиск.