Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2024, № 2 (114) https://doi.org/10.33108/visnyk_tntu2024.02
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC 624.014

3D MODELING OF GRAIN UNLOADING STATION STEEL STRUCTURE BASED ON BIM TECHNOLOGY

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Summary. *Comparative analysis of two structural schemes for covering the car unloading station for one trip as part of the elevator complex for grain storage is considered in this paper. The first option is to use the same frame structures combined into a spatial scheme. The second option involves the structure with two types of frames and another approach to ensure lateral stiffness. Detailed descriptions of each structural scheme, their peculiarities, advantages and disadvantages are included in this paper. The stability and economic effects of each scheme are analyzed. This paper benefits engineers, designers and specialists in the field of construction and infrastructure operating in grain storage and logistics.*

Key words: *BIM, structural calculation, metal frame, stiffness, metal consumption.*

https://doi.org/10.33108/visnyk_tntu2024.02.141 *Received 13.02.2024*

Statement of the problem. The rapid development of the agricultural sector results in the increase of the number of metal structures in the construction or reconstruction of industrial facilities At the same time, the requirements for increasing efficiency, improving structural forms and calculation methods for this type of structures are growing. This, in turn, reduces the consumption of materials, the complexity of manufacturing and installation, and their cost in general. Software for quick and efficient modelling of the complex structures' behaviour is required for such structural calculations. At present, due to the clear course of European integration, software packages (SP) should comply not only with state building regulations (hereafter – «DBN»), but also with Eurocodes. Such flexible PCs using Building information modelling (BIM) technologies include Revit, Dlubal RFEM [1], Robot [2] and several other ones making it possible to carry out structural calculations [3].

Static and dynamic calculations of metal frames of high-rise buildings using SAP2000 PC were considered in the paper [4]. The method of dynamic calculations is presented, and differences, features and disadvantages of the applied methods are shown. It is shown that the nonlinear dynamic calculation from the point of view of the calculation of buildings in emergency situations is the most effective and enables to consider the processes of redistribution of forces and deformations in the structure in the most detailed way. At the same time, the disadvantage of the linear dynamic calculation is the impossibility of considering the development of plastic deformations, the corresponding angles of rotation of the beams and the lack of local effects consideration. [4].

In this article, a comparative analysis is carried out on the basis of the calculation results in the Dlubal RFEM 5 software package [5]. This complex is engineering software for analyzing building structures developed by Dlubal Software GmbH. RFEM 5 program is intended for calculations of engineering structures considering various loads, including static, dynamic [6], geometric and material nonlinearities. It provides wide opportunities for 3D modeling by BIM technologies [7–9], including various types of structures, materials and loads. RFEM 5 allows engineers to carry out strength, rigidity, stability, and sampling analyses to

Corresponding author: Volodymyr Iasnii; e-mail: v.iasnii@gmail.com ensure the safety and reliability of construction projects.[10]. The program has an intuitive user interface and many built-in tools for analysis and visualization of results.

The design and construction of elevator complexes [11] for grain storage with optimal choice of the structural scheme for covering car unloading stations [12] is an important area with practical applications. The car unloading station (CUS) aims to optimally unload grain crops with protection from atmospheric influences, such as rain, snow, sun, etc., ensuring the unhindered flow of cars for unloading.

The technological feature of CUS is the structure height, which is caused by dump truck body lifting (see Fig. 1).

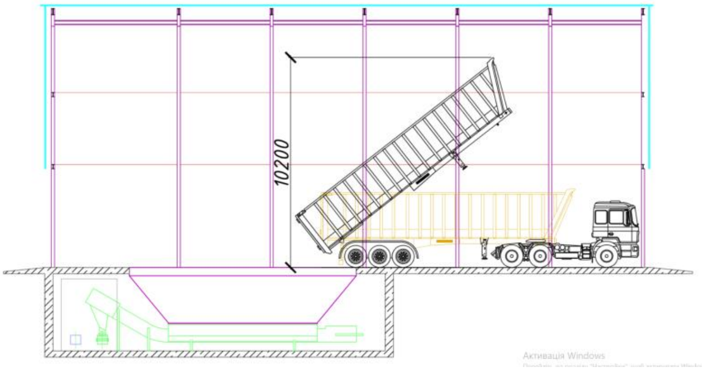


Figure 1. Technological scheme of unloading the dump truck with full cover

However, the height of the structure and its small dimensions in the transverse direction (Fig. 2) create technological complexity and increase the risk of the impact of strong wind loads on the structure For reasons of safety and operational efficiency, the solution to this problem requires the development of the optimal design of the station coverage that would ensure not only technological goals but also high resistance to wind loads.

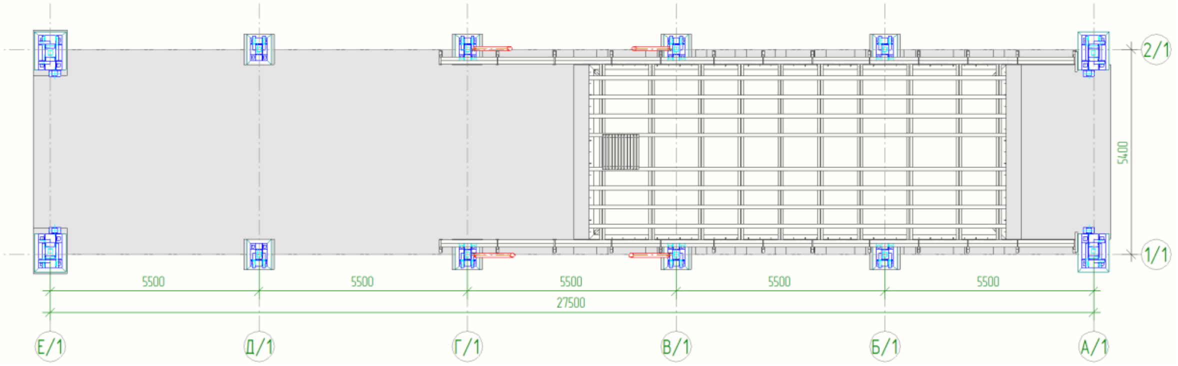


Figure 2. CUS schematic diagram for a single passage

Formation of the paper objectives. This paper aims to conduct a comparative analysis, using 3D modelling software and BIM technologies, of two design schemes covering the unloading station of CUS cars for one passage as part of a grain storage complex.

Main part. Let us consider the comparative analysis of the two above-mentioned structural schemes of CUS on the example of the structure with dimensions of 5.4 m x 27.5 m (see Fig. 2) and a height of 13.9 m. The structure is located in the I climatic region [13], with a standard snow load of 1450 Pa and wind load of 450 Pa [14].

Structural diagram No. 1

The scheme is the metal frame with plan dimensions of 5.4 m (width) and 27.5 m (length) and the structure height of 13.9 m. The transverse frames are columns made of two No. 33 channels welded into the box and No. 30 I-beams. The units of this frame are rigid, and the columns are fixed to the foundation rigidly. The step of the frames is constant and is 5.5 m. The frame rigidity in the transverse direction is ensured by rigid frame units in the longitudinal direction due to the elastic structure.

The main advantages of design scheme No. 1 include the simplicity of the frame structure and reduced metal content (provided that it is partially covered). Also, in this design scheme, it is possible to arrange the opening for the gate up to 12 m high at the end (since there are no plastic structures at the end of the structure, unlike the design scheme No. 2, and also to make coverage only over the bunker (see Fig. 3), where the absence of elastic structures at the end makes it possible to lift the dump truck)

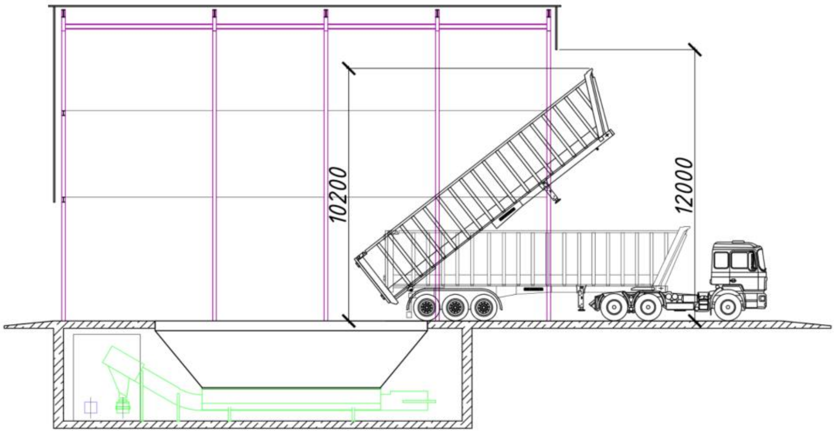
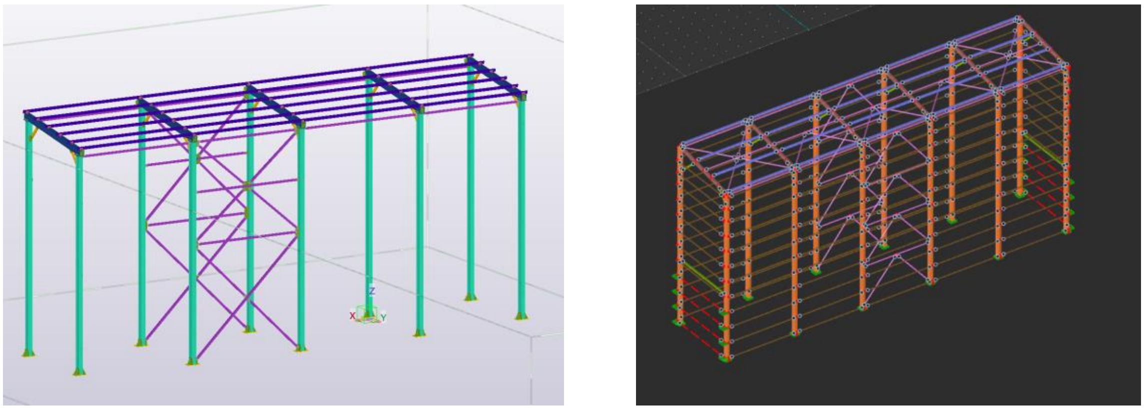


Figure 3. Technological scheme of unloading a partially covered dump truck

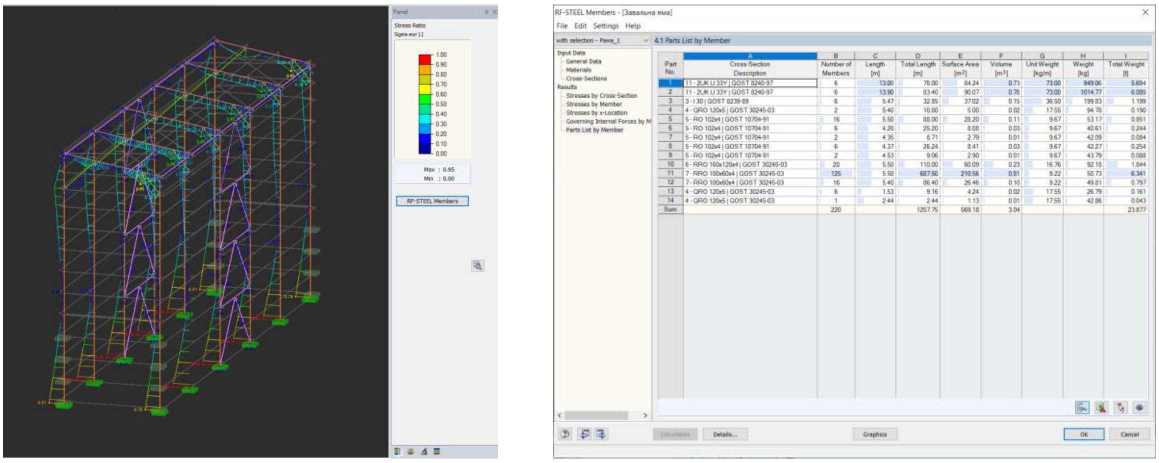
At the same time, this design makes it impossible to install dust removal (provided it is partially covered), and it has insufficient rigidity under the influence of wind loads, therefore, to ensure permissible horizontal movements[15] and to absorb large bending moments in the columns, larger metal content of the frame is required (provided full coverage);



a) b)

Figure 4. a) spatial model of the frame; b) calculation model of the frame

The structure was calculated and compared in the DlubalRFEM software package, and the equivalent stresses and metal content of the rod model were calculated in the RF-STEELMembers module (see Fig. 5).



4.1 Parts List by Member

Part No.	A Cross-Section Description	B Number of Members	C Length [m]	D Total Length [m]	E Surface Area [m²]	F Volume [m³]	G Unit Weight [kg/m]	H Weight [kg]	I Total Weight [t]
1	11 - 2UK U 33Y | GOST 8240-97	6	13.00	78.00	84.24	0.73	73.00	949.06	5.694
2	11 - 2UK U 33Y | GOST 8240-97	6	13.90	83.40	90.07	0.78	73.00	1014.77	6.089
3	3 - I 30 | GOST 8239-89	6	5.47	32.85	37.02	0.15	36.50	199.83	1.199
4	4 - QRO 120x5 | GOST 30245-03	2	5.40	10.80	5.00	0.02	17.55	94.78	0.190
5	5 - RO 102x4 | GOST 10704-91	16	5.50	88.00	28.20	0.11	9.67	53.17	0.851
6	5 - RO 102x4 | GOST 10704-91	6	4.20	25.20	8.08	0.03	9.67	40.61	0.244
7	5 - RO 102x4 | GOST 10704-91	2	4.35	8.71	2.79	0.01	9.67	42.09	0.084
8	5 - RO 102x4 | GOST 10704-91	6	4.37	26.24	8.41	0.03	9.67	42.27	0.254
9	5 - RO 102x4 | GOST 10704-91	2	4.53	9.06	2.90	0.01	9.67	43.79	0.088
10	6 - RRO 160x120x4 | GOST 30245-03	20	5.50	110.00	60.09	0.23	16.76	92.18	1.844
11	7 - RRO 100x60x4 | GOST 30245-03	125	5.50	687.50	210.56	0.81	9.22	50.73	6.341
12	7 - RRO 100x60x4 | GOST 30245-03	16	5.40	86.40	26.46	0.10	9.22	49.81	0.797
13	4 - QRO 120x5 | GOST 30245-03	6	1.53	9.16	4.24	0.02	17.55	26.79	0.161
14	4 - QRO 120x5 | GOST 30245-03	1	2.44	2.44	1.13	0.01	17.55	42.86	0.043
Sum		220		1257.75	569.18	3.04			23.877

Figure 5. Equivalent stresses and metal content of the rod model, RF-STEELMembers

From this diagram, it can be concluded that the columns, in this case, are 95% stressed, and the metal content is 23.877 tons. The maximum horizontal displacements under wind loads are 89.6 mm (see Fig. 6). In accordance with the standard [15], we determine the limit values of deflections f_u:

$$f_u = {}^{h_s}/_{150} = {}^{13900}/_{150} = 92{,}7\ \text{mm}; \tag{1}$$

where h_s is structure height ($h_s = 13900$ mm).

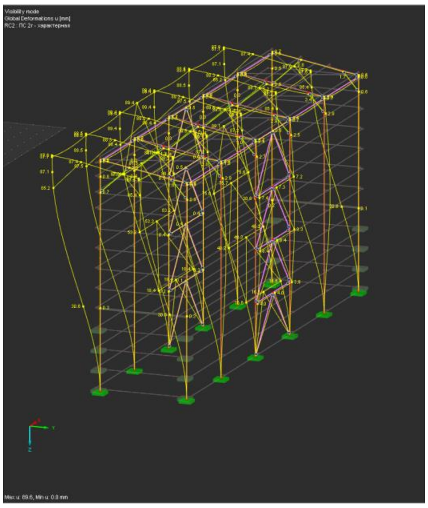
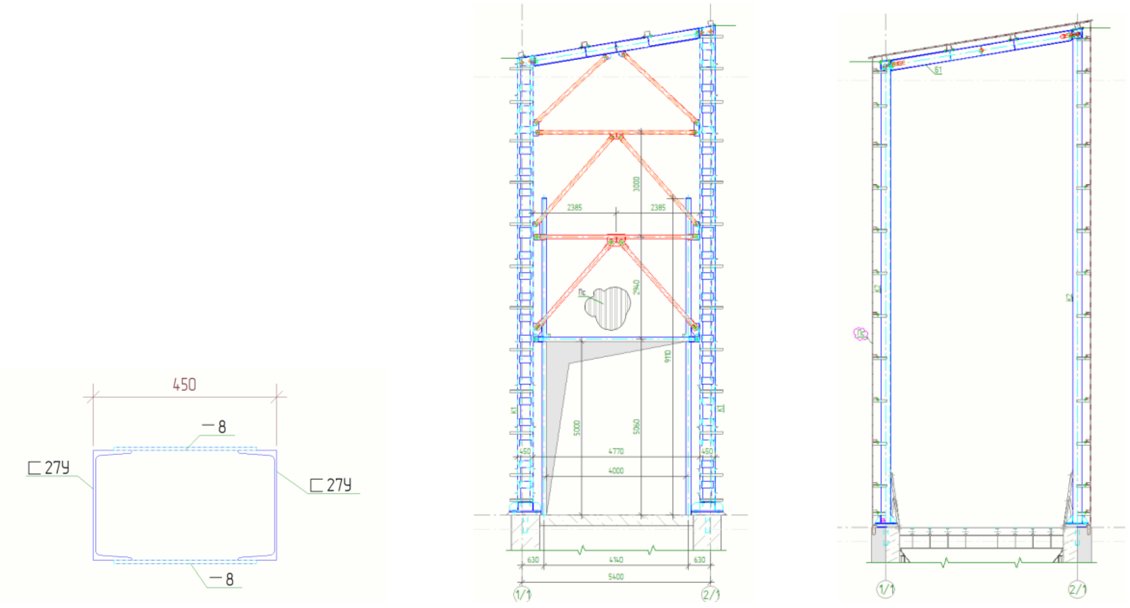


Figure 6. Deformed diagram of structural scheme No. 1

Structural diagram No. 2

The scheme is the metal frame with dimensions of 5.4 m (width) and 27.5 m (length), and structure height of 13 m. The transverse frames are of two types: 1) the first ones are located at the ends and are K_1 double-branched columns made of channels No. 27 (see Fig. 7 a), connected by plates with a certain step, and B1 are I-beams No. 30, with plastic structures between the columns (see Fig. 7 b), which provides rigidity in the transverse direction. K_1 have rigid joints to the foundations, and the rest connections, such as columns to the beam and joints to the beam, are hinged; 2) Intermediate frames are columns K2 made of two channels No. 27 welded into a box and beams B1 of I-beam section No. 30 (see Fig. 7 c). The units of this frame are hinged, and the columns are fixed to the foundation with rigid joint. The step of the frames is constant and is 5.5 m.

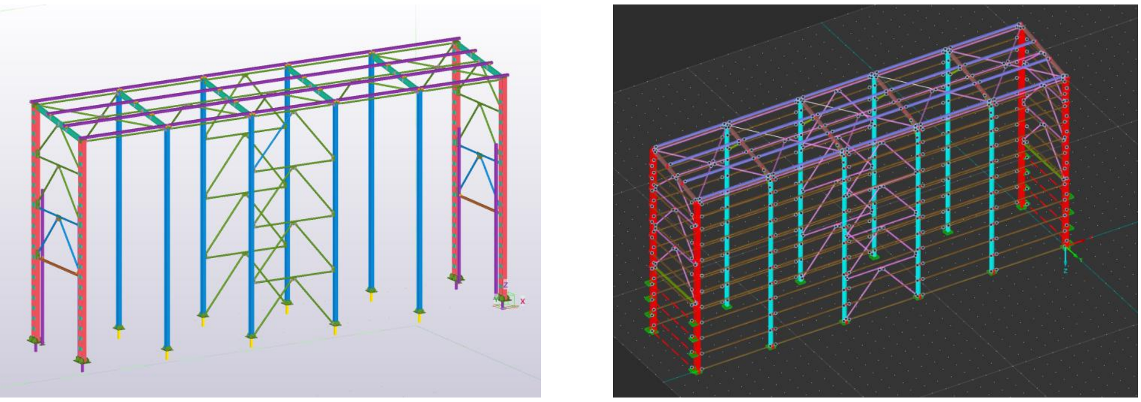
The rigidity of structural scheme No. 2 in the transverse direction is provided by the end frames, which have great rigidity in this direction, and the hard disk of the coating, in the longitudinal direction, by the plastic structure.



a b c

Figure 7. a) column K1; b) end frame; c) Intermediate frames

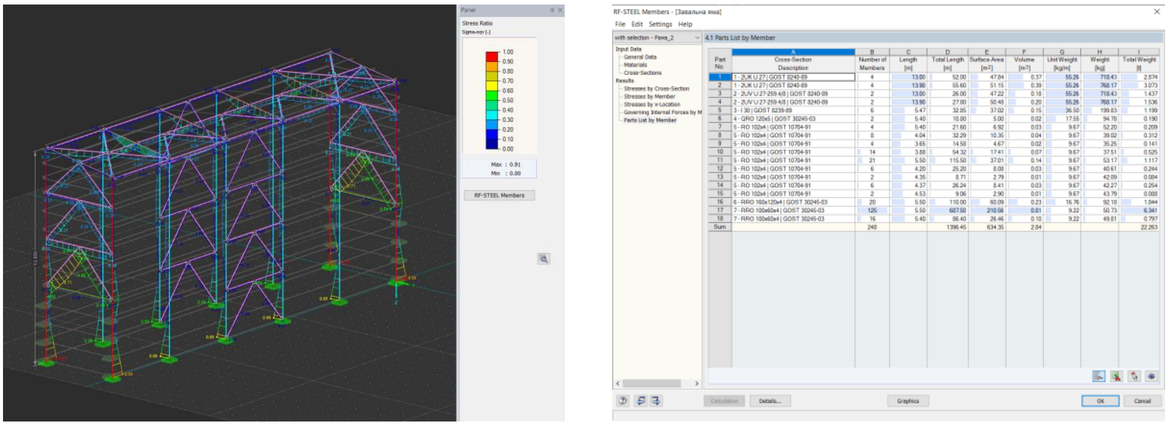
The main advantages include high frame rigidity and low metal content. At the same time, the complexity of the structure (two types of frames are used) and the impossibility of a technological scheme with partial coverage (Fig. 3) are certain disadvantages.



a b

Figure 8. a) spatial model of the frame; b) calculation model of the frame

The calculation and comparison of the structure were carried out in the DlubalRFEM software package [16], and the equivalent stresses and metal content of the rod model were calculated in the RF-STEELMembers module [17] (see Fig. 9).



	A	B	C	D	E	F	G	H	I
Part No.	Cross-Section Description	Number of Members	Length [m]	Total Length [m]	Surface Area [m²]	Volume [m³]	Unit Weight [kg/m]	Weight [kg]	Total Weight [t]
1	1 - 2UK U 27 | GOST 8240-89	4	13.00	52.00	47.84	0.37	55.26	718.43	2.874
2	1 - 2UK U 27 | GOST 8240-89	4	13.90	55.60	51.15	0.39	55.26	768.17	3.073
3	2 - 2UV U 27-259.4/8 | GOST 8240-89	2	13.00	26.00	47.22	0.18	55.26	718.43	1.437
4	2 - 2UV U 27-259.4/8 | GOST 8240-89	2	13.90	27.80	50.48	0.20	55.26	768.17	1.536
5	3 - I 30 | GOST 8239-89	6	5.47	32.85	37.02	0.15	36.50	199.83	1.199
6	4 - QRO 120x5 | GOST 30245-03	2	5.40	10.80	5.00	0.02	17.55	94.78	0.190
7	5 - RO 102x4 | GOST 10704-91	4	5.40	21.60	6.92	0.03	9.67	52.20	0.209
8	5 - RO 102x4 | GOST 10704-91	8	4.04	32.29	10.35	0.04	9.67	39.02	0.312
9	5 - RO 102x4 | GOST 10704-91	4	3.65	14.58	4.67	0.02	9.67	35.25	0.141
10	5 - RO 102x4 | GOST 10704-91	14	3.88	54.32	17.41	0.07	9.67	37.51	0.525
11	5 - RO 102x4 | GOST 10704-91	21	5.50	115.50	37.01	0.14	9.67	53.17	1.117
12	5 - RO 102x4 | GOST 10704-91	6	4.20	25.20	8.08	0.03	9.67	40.61	0.244
13	5 - RO 102x4 | GOST 10704-91	2	4.35	8.71	2.79	0.01	9.67	42.09	0.084
14	5 - RO 102x4 | GOST 10704-91	6	4.37	26.24	8.41	0.03	9.67	42.27	0.254
15	5 - RO 102x4 | GOST 10704-91	2	4.53	9.06	2.90	0.01	9.67	43.79	0.088
16	6 - RRO 160x120x4 | GOST 30245-03	20	5.50	110.00	60.09	0.23	16.76	92.18	1.844
17	7 - RRO 100x60x4 | GOST 30245-03	125	5.50	687.50	210.56	0.81	9.22	50.73	6.341
18	7 - RRO 100x60x4 | GOST 30245-03	16	5.40	86.40	26.46	0.10	9.22	49.81	0.797
Sum		248		1396.45	634.35	2.84			22.263

Figure 9. Equivalent stresses and metal content of the rod model, RF-STEELMembers

From this diagram, it can be concluded that the columns in this case are 95% stressed, and the metal content is 22.263 tons. The maximum horizontal displacements under wind loads are 35.0 mm (see Fig. 10). According to the State Standard B V.1.2-3:2006 «Deflections and Displacements», the limit values of deflections f_u for our case are 92.7 mm. It can be concluded that the displacements of 35 mm are much smaller than the limit value of f_u 92.7 mm.

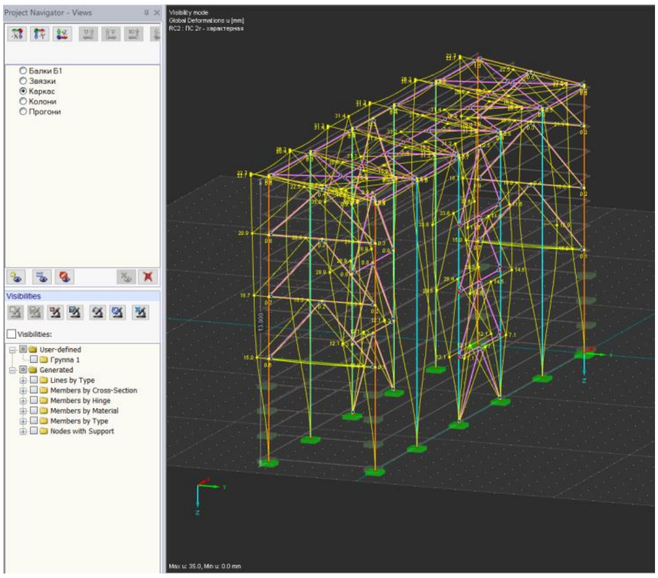


Figure 10. Deformed diagram of structural scheme No. 2

Conclusion. The overview of 3D software systems for finite element calculations is carried out. From the comparative analysis, structural solution No. 2 makes it possible to optimize the consumption of metal up to 6.8% and also reduces the deformability of the frame by 61%, providing much greater rigidity of the structure. It is reasonable to use the described structural solution No. 2 in the design of the car unloading station with full coverage.

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УДК 624.014

3D МОДЕЛЮВАННЯ МЕТАЛОКОНСТРУКЦІЇ ЗЕРНОРОЗВАНТАЖУВАЛЬНОЇ СТАНЦІЇ НА ОСНОВІ БІМ-ТЕХНОЛОГІЇ

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Резюме. *Присвячено детальному порівняльному аналізу двох конструктивних схем накриття станції вивантаження автомобілів у складі елеваторного комплексу для зберігання зерна. Роботу виконано за допомогою програмного комплексу Dlubal RFEM 5, а також допоміжного модуля RF-STEEL Members. Основна проблема, розглянута у цьому дослідженні, полягає в технологічній необхідності, зумовленій підйомом кузова автомобіля, мінімальної висоти конструкції 12 метрів, що, в свою чергу, викликає значні вітрові навантаження, які можуть негативно впливати на безпеку та ефективність експлуатації. Два різних варіанти конструктивних схем були ретельно проаналізовано, з розглядом переваг і недоліків з точки зору конструктивних та технологічних аспектів. Перший варіант споруди, з однаковим типом поперечних рам, відрізняється простотою конструкції, але вимагає додаткових заходів для забезпечення стійкості й деформативності до вітрових навантажень. Другий варіант, з двома типами поперечних рам, які за допомогою горизонтальних та вертикальних в'язей утворюють жорсткий просторовий блок. Даний тип споруди хоча складніший, але виявився ефективнішим з точки зору жорсткості та металоємності, за рахунок перерозподілення вітрових навантажень в об'ємно-стрижневій конструкції. Порівняльний аналіз обох розрахункових споруд станції автомобільного виванження на один автомобільний проїзд дозволяє зробити висновок щодо вибору оптимальної конструктивної схеми для конкретних умов експлуатації. Проаналізовано випадки використання кожного із варіантів будівлі під певні умови експлуатації й технологічних вимог. Робота важлива для підвищення безпеки та ефективності елеваторних комплексів і може бути використана як основа для подальших досліджень у цій області. Отримані результати є важливим внеском у розвиток даної галузі та можуть бути використані для вдосконалення проектування та експлуатації станції вивантаження автомобілів.*

Ключові слова: *BIM, конструктивний розрахунок, металевий каркас, жорсткість, металоємність.*

https://doi.org/10.33108/visnyk_tntu2024.02.141 *Отримано 13.02.2024*