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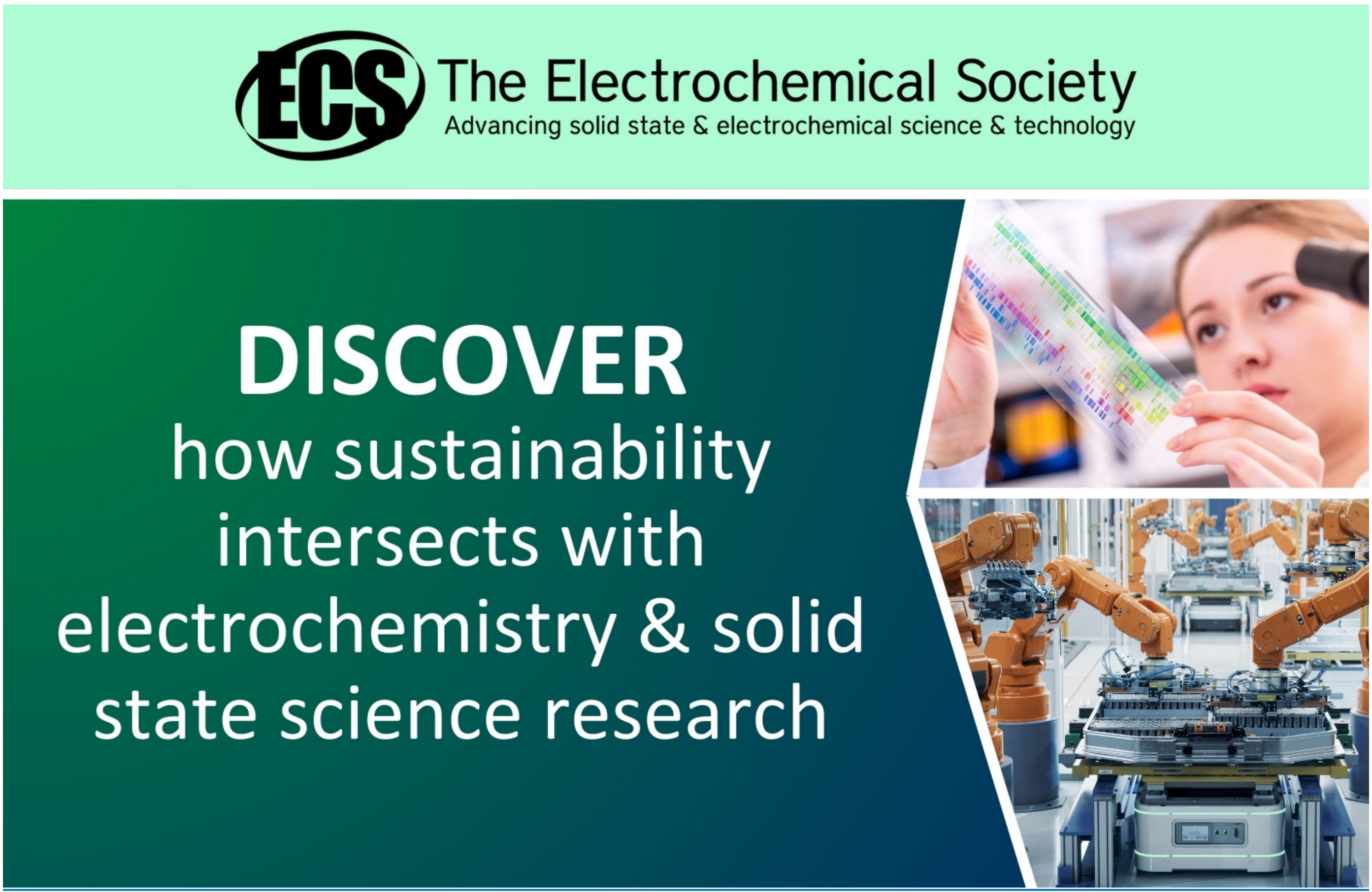

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Controlling the dynamic characteristics of steel bunker containers for bulk materials

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Abstract. The article presents the main results of research devoted to the definition and analysis of the dynamic characteristics of steel small-sized bunker containers for storing bulk materials. All studies were carried out using the finite element method with the use computer complex SCAD. The object of research was a bunker of a bypass track for feeding bulk materials with a total volume of up to 70 m^3. The study analysed the natural partial frequency spectrum and the partial oscillation modes of individual load-bearing elements of the bunker. Based on the results of the data analysis, a rather high quantitative density of the natural frequency spectrum was determined. At the same time, its lower limit is about 25-30 Hz for an empty bunker capacity and decreases to 3-5 Hz when the bunker is fully loaded, which is dangerous from the point of view of the possibility of resonance phenomena. In order to qualitatively and quantitatively control the dynamic characteristics, it was proposed to change the steel strength of the structure, which made it possible to change the natural frequencies by about 15% for every 100 MPa change in steel strength for the bunker containers of the considered type.

1. Introduction

Steel bunkers are widely used today for the long-term or short-term storage of various bulk materials in both industry and transport. During their operation, one of the main types of loads is various dynamic loads. They can arise primarily due to the movement of bulk material during the process of loading or unloading of the container. Quite often, both of these processes are accompanied by impact loads from falling or sudden movement of massive lumps of bulk material. Another aspect of steel containers is the long-term cyclic dynamic loads that accompany the operation of special unloading devices such as vibrating feeders.

Despite the rather widespread distribution of these loads, their study has received little attention in domestic practice, which is primarily due to the high complexity of the theoretical description of such processes. Thus, the author's research on this issue was carried out in the early 2000s and allowed for the first time to obtain a spectrum of the natural dynamic characteristics of steel capacity structures. Modern domestic research is rather narrow and fragmentary [1-3]. At the same time, modern foreign research on this issue is even more limited [4-6]. In both cases, there are solved partial analytical problems of determining dynamic parameters for space enclosures that only approximately resemble real bunker containers.

Meanwhile, one of the most important practical problems that has not yet been solved is the need to control the natural dynamic characteristics of steel bunker containers. This task is connected with two practical aspects. Firstly, practical experience shows that higher frequencies are more likely to lead to the failure development in the steel structural elements, as they contribute to the development of fatigue defects more quickly, which results in emergencies and failures of such structures [7]. Therefore, it is advisable to reduce the values of the natural frequency spectrum, which also reduces the noise level during the operation of the structure. Secondly, there is a need to avoid resonance during the operation of vibrating unloading devices.

Thus, the purpose of the study is to develop a methodology for controlling the dynamic characteristics of steel bunker containers for bulk materials.

2. Methods

To achieve the purpose of the study, the use of steels with improved mechanical characteristics is proposed. One of their modern types is heat-treated steel with a fine-grained structure. They are increasingly used both in Ukraine [8] and in the world [9], especially for structures operating in difficult conditions [10], including under dynamic loads.

A steel bunker of a bypass track for feeding bulk materials in a blast furnace complex was taken as the object of research [11]. Structurally, the bunker is a steel container of the pyramidal-prismatic type with a total height of about 4.5 m with overall dimensions in plan of 6.0×5.2 m, angles of inclination of the faces of the pyramidal part of 59 ° and 63 °, respectively, and a total volume of 68 m^3.

The bulk material (slag scrap) loaded into the container has a density of 3 t/m^3 with an internal friction angle of 45º. The process of its loading is provided by dump trucks according to a fairly simple process flow diagram (figure 1) with a single unloading of bulk material in the amount of 50 tons. This creates certain dynamic loads, as this volume is approximately a quarter of the total capacity of the bunker. The bulk material is discharged using a vibrating feeder with a round-the-clock operation and a working frequency of 50 Hz.

One of the modern widespread numerical methods of structural mechanics, the finite element method, was chosen as a research method [12]. This is due to the combination of significant advantages of this method, the relative simplicity of its computer implementation and the ability to analyse rather complex structures. The domestic product SCAD, which is construction-oriented by its specificity, was adopted as a computational complex [13, 14].

The developed finite-element model of a steel bunker is shown in figure 2. It is a plate system that uses a shell isoparametric 4-node element with high calculation accuracy as a finite element, which allowed to slightly reduce the problem dimension. The dimensions of the finite element mesh were chosen in such a way as to ensure the required accuracy of the results obtained for static calculations. However, according to available research, this is sufficient to ensure the required accuracy for dynamic calculations as well. In general, the calculation model consisted of about 70,000 elements and about 70,000 nodes, which created an order of stiffness matrices of about 450,000 equations.

The research was a modal analysis for the following combination of the studied parameters:

1) loading level of the bunker container – 1/4, 1/2, 3/4 of the container volume and its full loading;

2) strength level of steel - grades C255, C345 and C440.

Modelling of the bulk material was performed by applying pressure to the inner surface of the bunker structure, which was interpreted as the application of additional masses using a specially developed technology [15]. In addition, some developments in the field of transport, presented in works [16-18] and in the field of seismic resistance of building structures according to works [19, 20] were used.

For each design variant of the parameters under study, a static analysis and selection of cross-sections of the main structural elements - wall thickness and cross-section of horizontal stiffening ribs - were previously performed. In all cases, the bunker beam remained an unchanged structure.

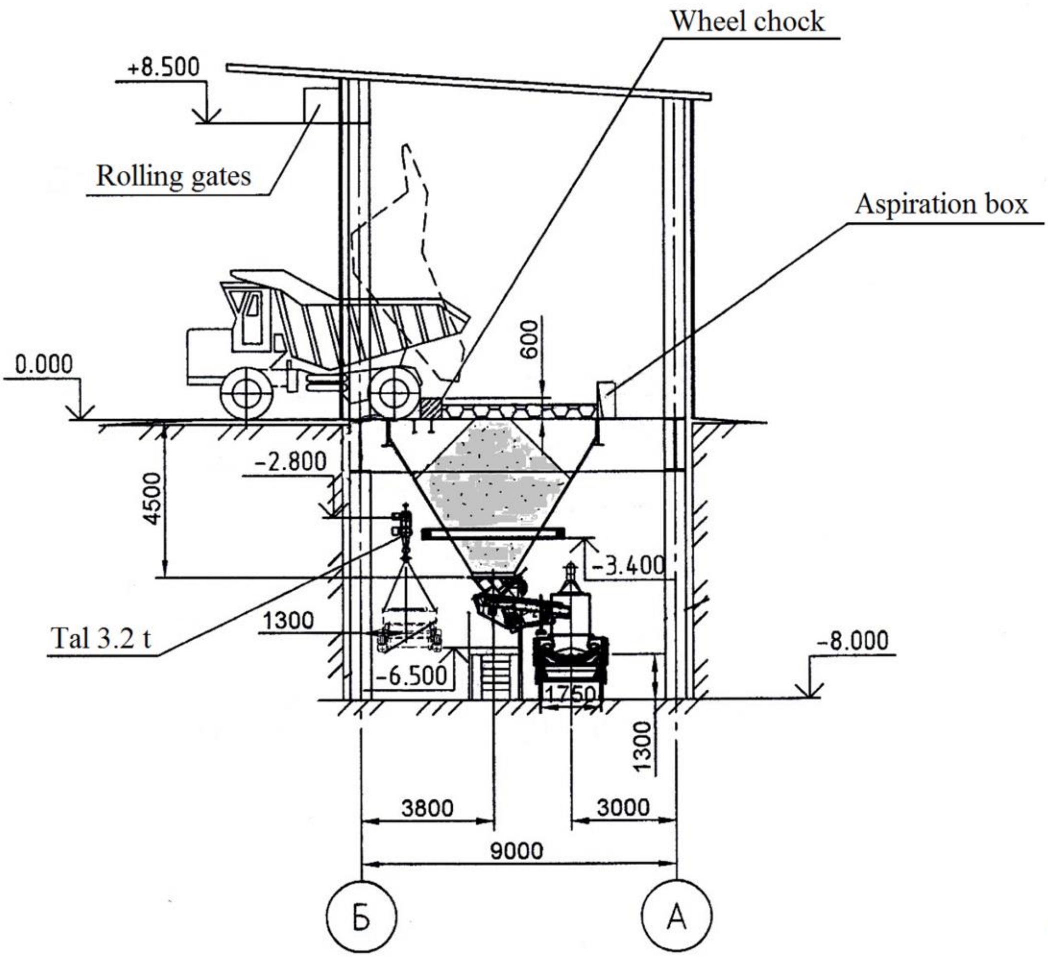

Figure 1. Process flow diagram of steel bunker container operation.

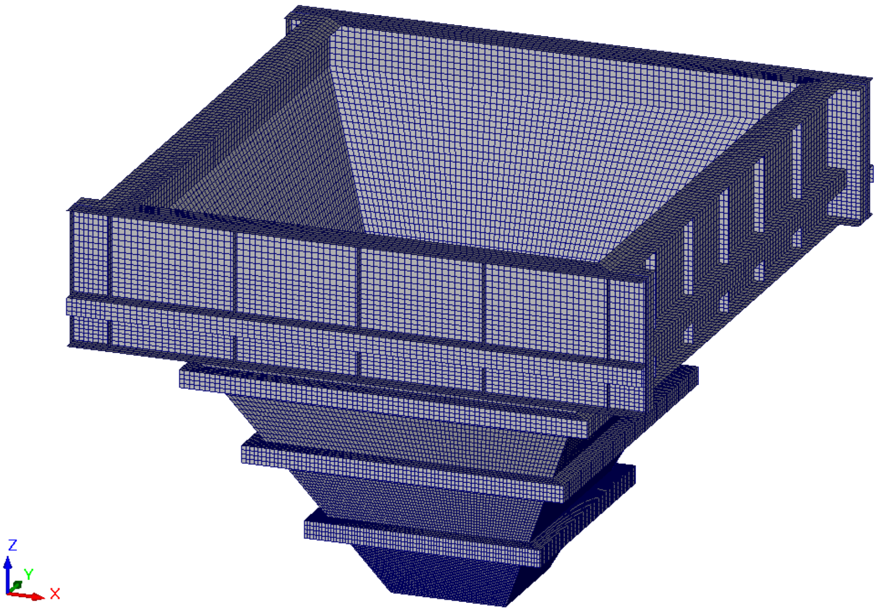

Figure 2. Calculation model of steel bunker container.

3. Results and discussion

First of all, it should be noted that the frequency spectrum of both empty and loaded steel bunkers at different levels is quite dense. This somewhat complicates the analysis of the partial characteristics for various elements of the container structure, as it is necessary to track the change in each of them with sufficient accuracy, separating them from the total mass. This situation applies to the use of steels of any strength level. At the same time, the qualitative change in the frequency spectrum remains approximately the same for different steels.

Table 1 shows, as an example, the quantitative data obtained for C345 steel (the numbering for the stiffening ribs and the corresponding sections of the bunker container wall starts from the top of the structure). The graphs (figure 3) demonstrate more clearly the change in the frequency spectrum for the steels of the three strength levels analysed (the numbering of the rows corresponds to that in table 1).

Table 1. Partial frequencies of natural oscillations of a steel bunker container made of C345 steel.

No.	Container element	Partial frequency (Hz) at the container loading level, %				
		0	25	50	75	100
1.	Bunker beam	36.31	36.31	34.83	32.31	29.76
2.	Horizontal rib No. 1	28.47	28.47	25.97	11.13	7.58
3.	Horizontal rib No. 2	37.31	36.89	13.54	9.61	8.33
4.	Horizontal rib No. 3	55.03	53.54	33.94	27.00	21.73
5.	Wall section No. 1	38.95	36.43	36.10	20.18	11.61
6.	Wall section No. 2	33.33	30.15	26.86	12.03	8.30
7.	Wall section No. 3	38.64	37.72	15.19	10.67	8.63
8.	Wall section No. 4	49.70	22.51	15.64	12.91	11.02

Figure 4 graphically combines the dependences of changes in the values of partial frequencies for different structural elements of the considered steel bunker container at different levels of strength of the steel used. There are presented three typical cases of container loading - empty container (level 0), half-loaded container (level 50 %) and fully loaded container (level 100 %). The numbering of the structural elements corresponds to that shown in table 1.

Regarding the partial oscillation modes of individual elements of the steel container structure, it should be stated that in general, regardless of the level of strength of the steel used, the qualitative oscillation modes in all the considered calculation cases remained the same. Figures 5 and 6 show the most characteristic and important modes of natural oscillations for the main structural elements of the considered steel bunker container. They are spatial in nature, but to simplify their visual perception, the modes are presented in a flat image. The mode numbers correspond to an empty container without additional masses added by the loaded bulk material.

Thus, based on the analysis of the study results presented in table 1 and figures 3-4, we can clearly observe the pattern of reducing the quantitative value of the natural frequency spectrum with increasing the level of steel strength of the bunker container in the range from 15 to 45 %. On the other hand, an increase in the level of loading of the bunker container leads to a significant decrease in natural frequencies, which quantitatively reaches 5 times for individual structural elements of the bunker container. Such regularities make it possible to control the dynamic characteristics of steel bunker containers in the practice of their operation.

4. Conclusions

Based on the analysis of the natural dynamic properties of steel bunkers for bulk materials with little capacity (up to 100 m^3), the following should be stated:

1. The spectrum of the natural dynamic characteristics of such containers is quite dense and changes quite significantly with changes in the main structural and technological parameters of the structures.

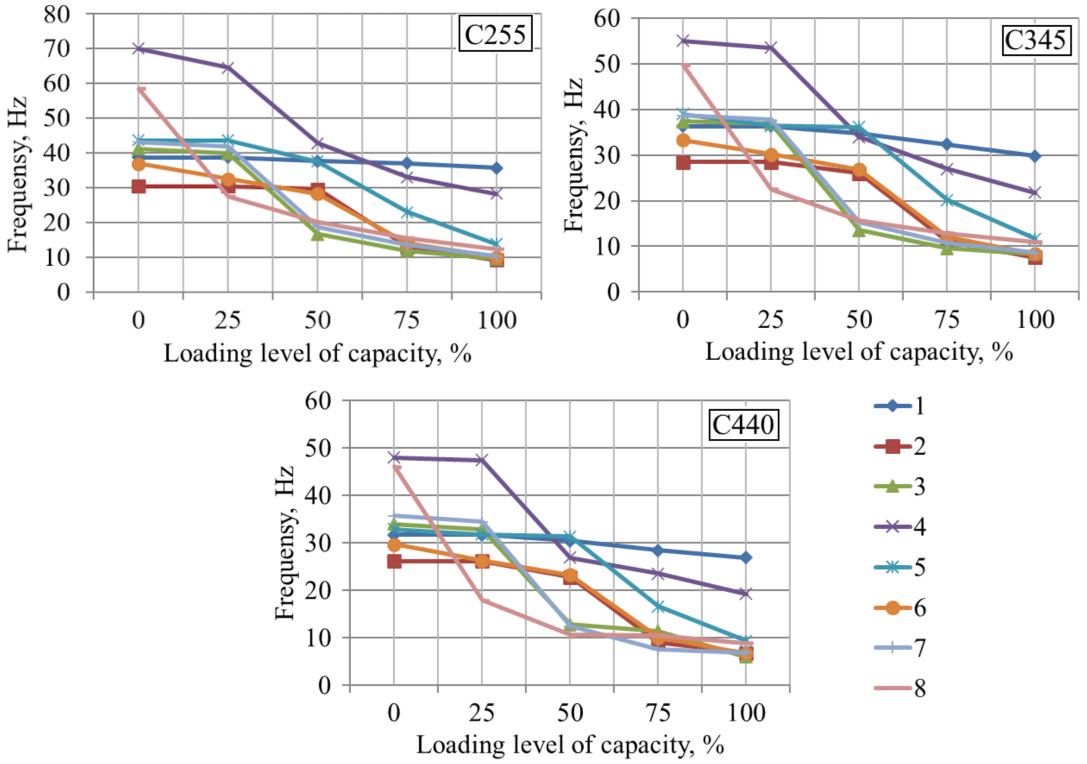

Figure 3. Partial frequencies of natural oscillations of the steel bunker container made of steel C255, C345 and C440: 1-8 – container elements (table 1).

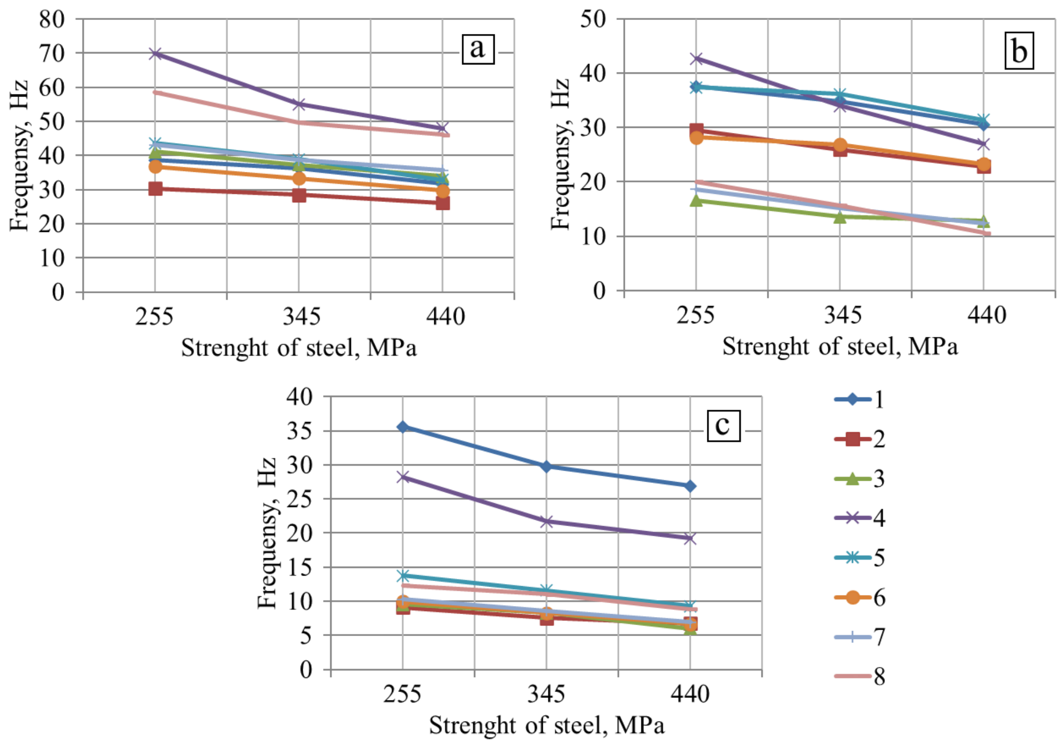

Figure 4. Partial frequencies of natural oscillations of the steel bunker container: a – for an empty container (loading level – 0); b – for a half-loaded container (loading level – 50 %); c – for a fully loaded container (loading level – 100 %); 1-8 – container elements (table 1).

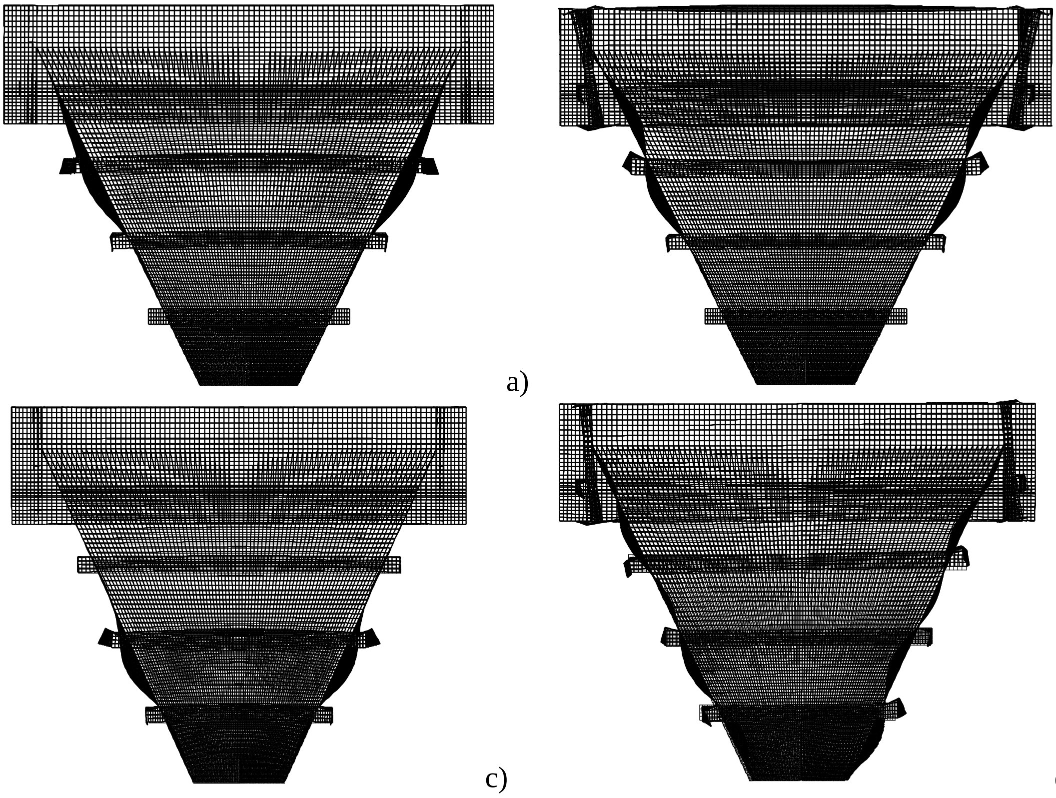

Figure 5. Partial modes of natural oscillations of the stiffness elements of the steel bunker container: a – horizontal rib No. 1 (1st mode); b – bunker beam (6th mode); c – horizontal rib No. 2 (8th mode); d – horizontal rib No. 3 (16th mode).

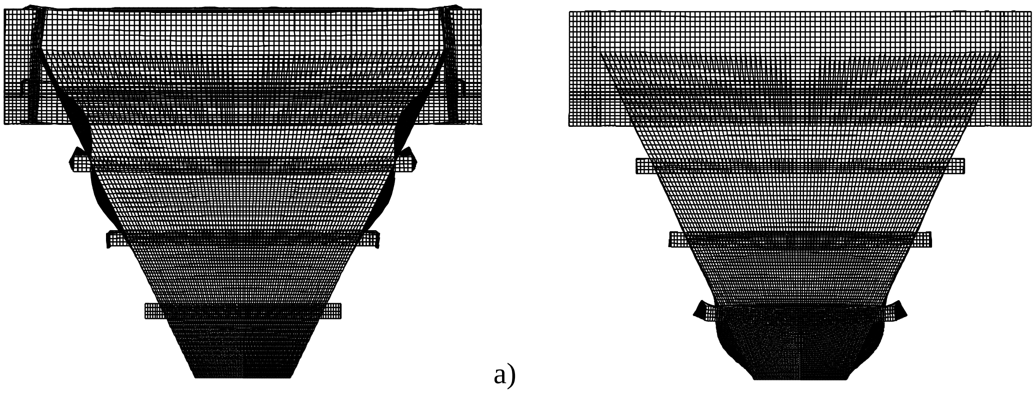

Figure 6. Partial modes of natural oscillations of the steel bunker container wall: a – wall section No. 1 (11th mode); b – wall section No. 4 (25th mode).

2. The spectrum of partial frequencies of the structural elements of the container depends significantly on the level of loading of the bunker and at full level starts with values of about 5 Hz. For an empty container, the spectrum begins with values of about 65-70 Hz.

3. Increasing the strength of steel for the container structure reduces the value of natural frequencies by an average of 15 % for every 100 MPa increase in strength.

4. In practice, in order to increase the efficiency of the container unloading, it is recommended to perform a smooth change in the frequency of the vibrating feeder instead of its operation with a constant fixed frequency. Such a change can be implemented automatically under the guidance of a special control program that adjusts the frequency depending on the loading level of the bunkers.

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