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Supporting structure for transportation of damaged dump cars by railway

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Abstract. The publication is devoted to the analysis of the static and dynamic work of the developed structural solution of the supporting beam for transporting the bodies of damaged dump cars of the model 2VS-105 manufactured in Poland. The overall dimensions of the supporting structure are determined by the dimensions of the selected universal transporting flat car of the model 13-401. The analysis was performed by the finite element method using the computer-aided design complex SCAD. As a result of the static analysis, the minimum permissible thickness of steel sheets for the supporting structure was determined to be 20 mm. The dynamic analysis resulted in a spectrum of forced frequencies, which turned out to be discrete and higher than the resonant values of the transportation platform - from 18.45 Hz. The obtained vibration forms allow the use of reliable fastening of the dump car body during its transportation.

1. Introduction

The transportation of various types of bulk cargo has been and remains a special area in the transportation industry [1, 2]. This is due to a number of significant features of bulk material as a type of mechanical medium. In particular, bulk materials have such specific characteristics as porosity, moisture, external and internal friction, arrangement of particles, etc. [3, 4]. At the physical level, this manifests itself in such unusual properties of bulk material as the ability to form hills during storage, the ability to uneven discharge from storage containers in the form of flow arrays, and the ability of large volumes to suddenly collapse in case of loss of spatial stability.

For long-term or temporary storage of various volumes of bulk materials, bunker tanks are used in practice [5-7]. Their operation is distinguished by a number of significant features and is generally associated with the need to ensure appropriate conditions for high-quality and reliable unloading of bulk materials.

To enable the transport of bulk materials, movable bunker tanks are used, which are placed on the moving parts of machines and mechanisms. Railway transport, as the cheapest, fastest and most reliable at the present time [8-12], uses special wagons - dump trucks. They are equipped with a self-unloading body and can be operated for a long time without additional maintenance. Currently, there are a significant number of sizes and models of dump cars, but all of them have rather similar operational characteristics and can be used for a fairly wide range of bulk cargo.

The main problem in their operation is the process of unloading bulk material. Due to the features listed above, bulk material can lead to car overturn and its damage as a result (figure 1). This often results in the destruction of the bogie attachment point to the car body. This creates a separate problem of transporting the dump car body to a repair facility, which requires separate research and development of a special design solution. It should also be noted that such an accidental destruction of dump cars is partly a consequence of the wear and tear of the domestic car fleet [13].

The purpose of this publication is to present the results of the development of a constructive solution for transporting dump car bodies and the research justification of this solution.

Figure 1. Overturn of a dump car during unloading of bulk material.

2. Methods

Object of investigation. The model 2VS-105 dump car manufactured in Poland was taken as the object of transportation (figure 2). Its main technical characteristics are given in table 1.

The current standards that regulate the design and operation of dump cars in Ukraine are [14-17]. According to their guidelines, the properties of materials were determined and loads were set during the analysis.

Figure 2. Appearance of the model 2BC-105 dump car.

Table 1. Technical characteristics of the model 2BC-105 dump car.

No.	Characteristic	Value
1	Carrying capacity, t	105
2	Tare weight, t	50
3	Body volume, m^3	55
4	Body material - steel grade	09G2
5	Car length along the coupling axles, mm	15040 ± 15
6	Wheel base, mm	9340 ± 5
7	Maximum body length, mm	13430 ± 15
8	Maximum body width, mm	3190 ± 15
9	Bogie type	UVZ-7
10	Number of axles	6
11	Track gauge, mm	1520
12	Body tilt angle when unloading, °	45
13	Number of unloading cylinders	6
14	Maximum design speed, km/h	100

The dump car body is to be transported on the universal 13-401 model flat car - figure 3. For this purpose, two steel beams with supporting pedestals are installed along the edges of the flat car. The pedestals serve as bases for attaching supporting cones to them, which in turn are mounted on recesses in the dump car body. All static and dynamic loads from the dump car body during its placement on the flat car and transportation are transferred through the cones to the supporting pedestals and then to the beams. The beams are bolted to the wooden deck of the universal flat car.

After a series of preliminary studies, the following design option was chosen for the steel beam: a box structure with a trapezoidal cross-section, welded from individual steel sheets. The overall dimensions of the beam: length - 2400 mm, width along the bottom chord - 600 mm, width along the upper chord - 400 mm, total height - 600 mm. The beam has a maintenance hatch and is supported by vertical stiffeners.

Figure 3. Appearance of the universal 13-401 model flat car.

The supporting pedestals are also made of steel sheets and have geometric dimensions of 380 × 360 mm with a total height of 160 mm. The cones have a complex cross-section with an average thickness of approx. 16 mm and a total height of 165 mm. During transportation, a cone-shaped nozzle made of elastomeric material is placed on top of them to reduce the dynamic component of the loads and to be used as a damping agent.

The geometric dimensions of the supporting structure are determined by the dimensions of the dump car body and the transporting flat car. During the research, it was necessary to select the thickness of the steel sheets of the structure. According to the customer's terms, it had to be the same for all supporting elements.

Materials. According to the customer's specifications, the following materials were to be used for the supporting structure: sheet steel and cast steel. The strength characteristics of the accepted materials were determined according to the existing standards [14, 15] for a 1520 mm railway gauge and are presented in table 2.

Table 2. Strength characteristics of the supporting structure steels.

Structural element	Steel	Yield strength σ_t, MPa	Permissible stress, MPa			
			Combination I		Combination II	
			formula	value	formula	value
Beam	St3 (S275JR)	245	$0.9 \cdot \sigma_t$	Beam	–	245
Cone	20L (GC20)	216	$0.9 \cdot \sigma_t$	Cone	–	216

Calculation model. The finite element method [18, 19] based on the domestic computer-aided design complex SCAD was chosen as a method for analysing the operation of the supporting structure. In contrast to analytical approaches in the field of railway vehicle design, for example [20], the finite element method allows obtaining solutions for more complex problems. Its capabilities have been repeatedly tested for various problems in the theory of building structures, for example [21], and mechanical engineering structures, for example [22, 23]. The finite element method is considered to be more suitable for practical calculations in specific production situations, especially connected with railway tracks, such as those in [24, 25].

The simulation model of the steel beam together with the supporting pedestals is shown in figure 4. The modelling was performed with plate finite elements, and the placement of the supporting cones was modelled with rods of equivalent stiffness, assuming equality of linear displacements from the design model of the supporting cone. The simulation model of the supporting cone is shown in figure 5. The modelling was carried out using volumetric finite elements.

Loads. The loads during the transport of the dump car body were set in accordance with the existing standards of the 1520 mm railway gauge. Two combinations of loads were considered. The load values calculated for them are shown in table 3. The loads were applied at the level of the top of the supporting cone. The approaches given in [26, 27] were used to adjust the loads.

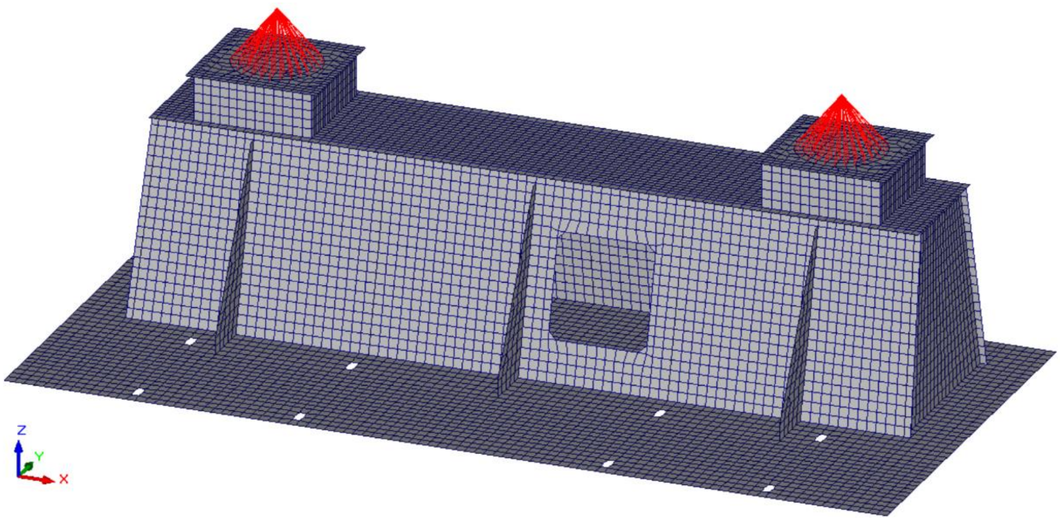

Figure 4. Finite element model of the supporting beam.

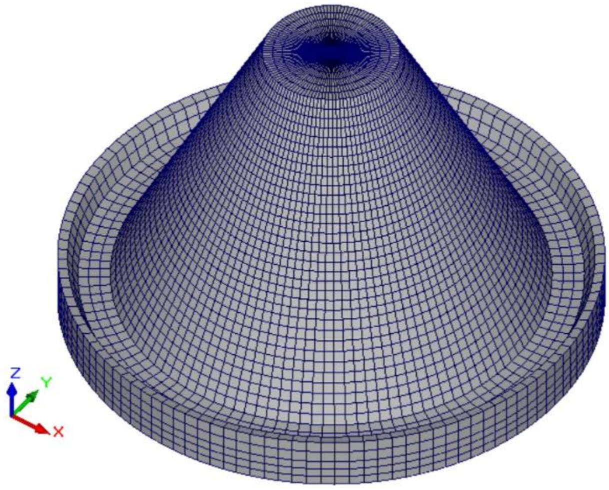

Figure 5. Finite element model of the support cone.

Table 3. Loads on the supporting cone.

Force	Combination I	Combination II
Vertical, kN	98.1	98.1
Longitudinal, kN	30.9	–
Transverse, kN	–	21.6

3. Results and discussion

Static studies. As a result of the numerical analysis, it was found that the qualitative picture of the static stress distribution is quite similar for both design load combinations.

For the steel beam, two zones of stress concentration were observed (zones A and B in figure 6). The values of the static stresses obtained in the analysis for both load combinations are given in table 4. The equivalent stresses according to the 4th strength theory (von Mises stress) are presented depending on the thickness of the steel sheet. The increase in stress level corresponds to the colours of the rainbow, starting with blue, which has the lowest stress level. For clarity, the data is illustrated in figure 7. According to the analysis, the final thickness of the steel sheets for the beam was taken to be 20 mm.

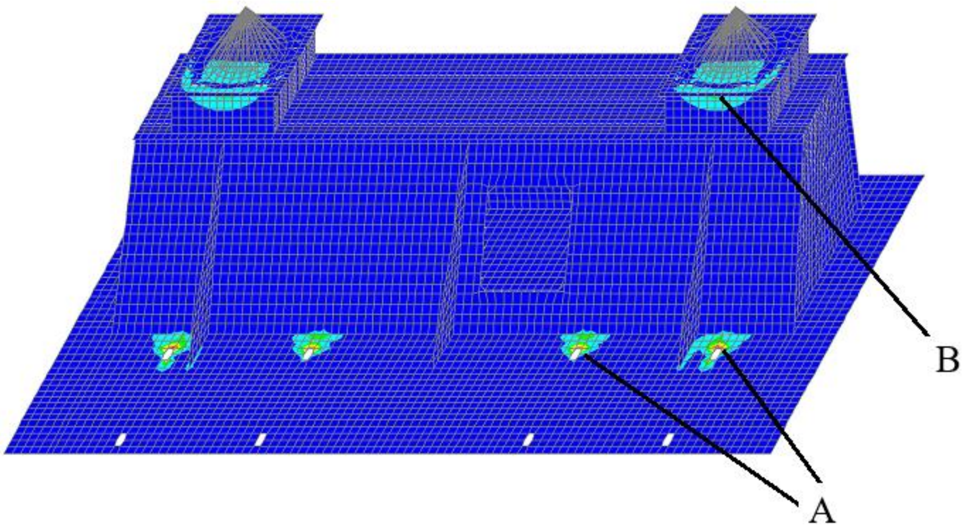

Figure 6. Static stress distribution for the steel beam:
A and B – stress concentration zones.

Table 4. Static stresses in the steel beam (MPa).

Thickness of steel sheet, mm	Combination I		Combination II	
	Zone A	Zone B	Zone A	Zone B
10	760	254	571	203
12	534	192	401	154
14	397	152	298	123
16	307	126	231	101
18	246	106	184	85
20	202	91	151	73
22	168	78	126	63
24	143	69	108	55

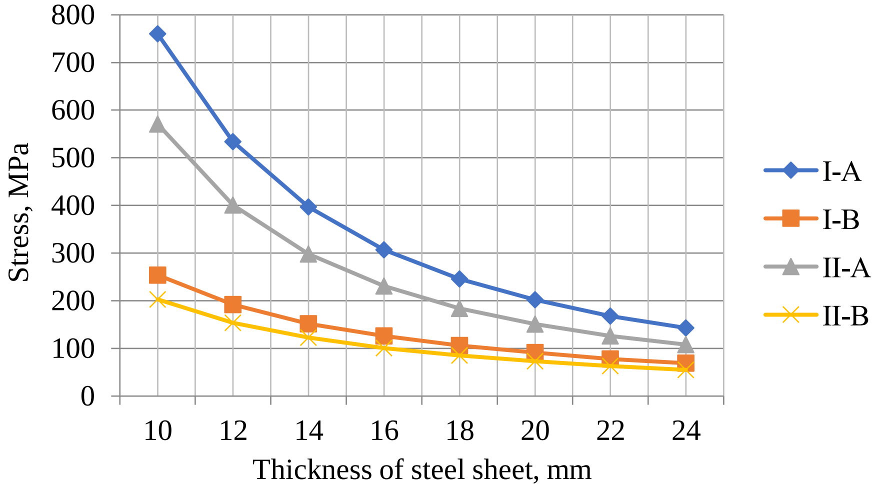

Figure 7. Static stress distribution for the steel beam.

The stress state of the supporting cone under static loads is shown in figure 8. The maximum stresses are associated with the upper part of the cone and according to the analysis were 189 MPa for load combination I and 148 MPa for load combination II.

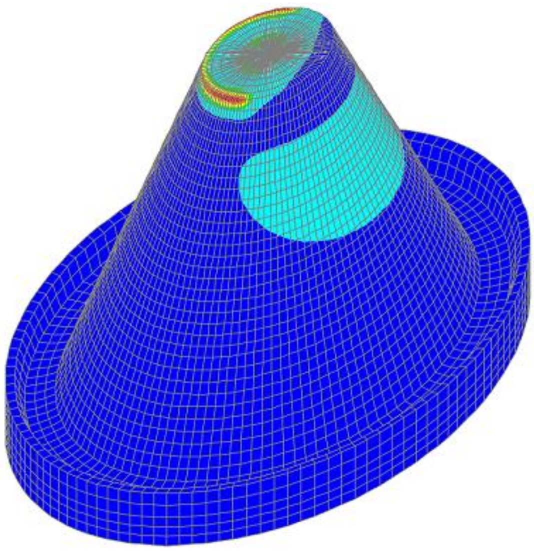

Figure 8. Static stress distribution for the support cone.

Dynamic studies. To avoid resonance phenomena during the movement of the transporting flat car with the dump car body located on it, a modal analysis of the supporting structure was performed. The obtained values of the lowest frequencies are given in table 5. The frequency spectrum is quite discrete. It does not contain frequencies in the resonance range of the transporting flat car, which is 1-12 Hz. Figure 9 shows the main lowest obtained vibration modes (the numbers correspond to the frequencies given in table 1).

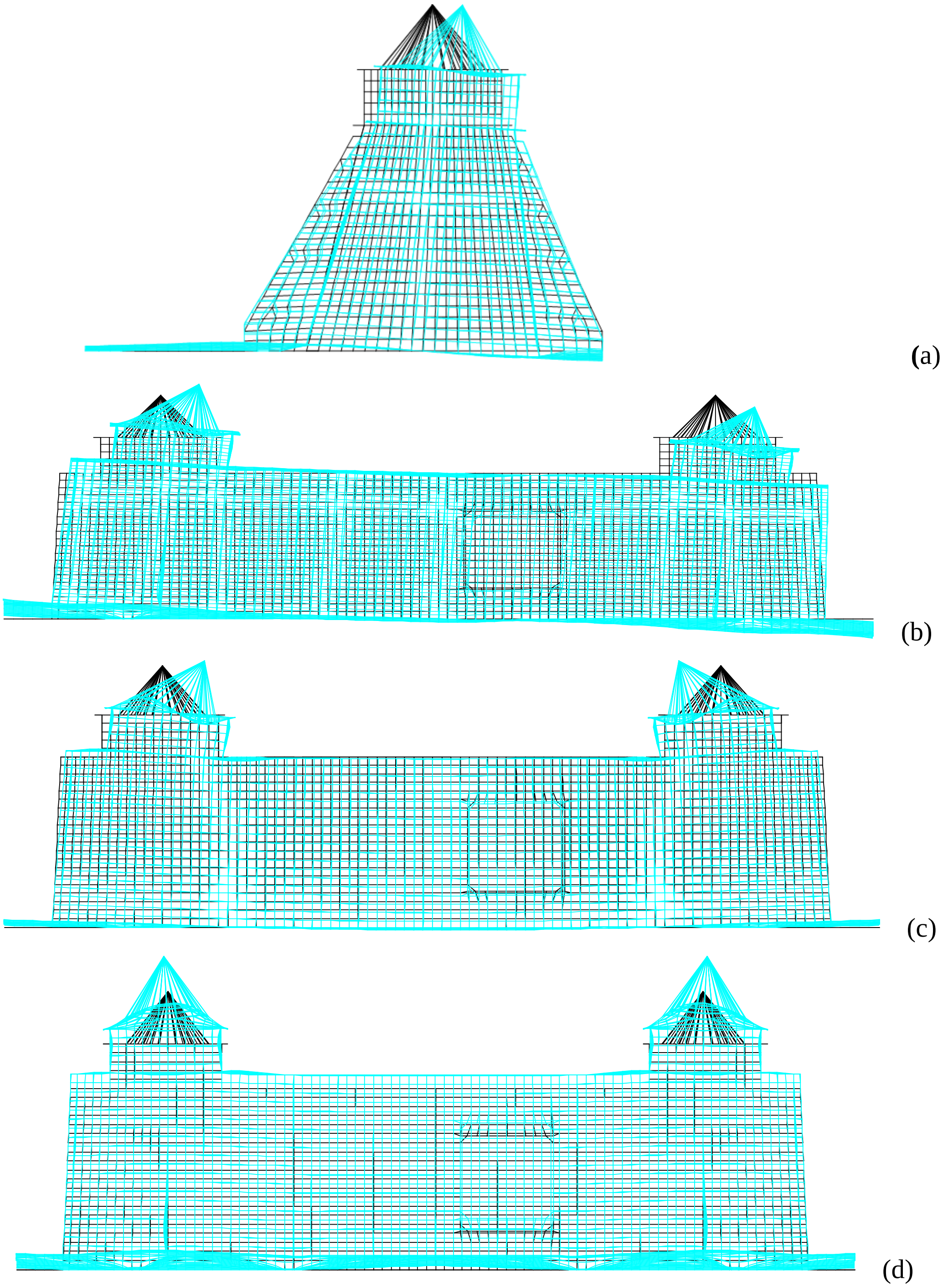

Figure 9. Forms of forced vibrations of the supporting structure:
a – No. 1; b – No. 2; c – No. 4; d – No. 5.

Table 5. Frequencies of forced vibrations of the supporting structure (Hz).

Frequency No.	Frequency value	Frequency No.	Frequency value
1	18.45	9	163.29
2	22.11	10	268.22
3	24.16	11	287.07
4	26.74	12	302.06
5	36.29	13	318.31
6	38.38	14	336.00
7	144.74	15	362.86
8	144.78	16	366.98

4. Conclusions

Based on the numerical analysis of the developed supporting structure for transporting bodies of damaged dump cars of the model 2BC-105 (manufactured in Poland), the following should be stated:

1. Due to the imperfection of the study of the bulk medium during the unloading of dump cars, there is a risk of their overturning, which results in the destruction of the bogie attachment unit to the machine body. This makes self-moving of the dump car to a repair facility impossible and requires its forced transportation.
2. A special supporting structure has been developed for transporting on the universal 13-401 model flat car. It consists of a 600 mm high box beam and a 160 mm high supporting cone. These dimensions ensure that the dump car body can be transported in a position close to the structural position.
3. Based on static analysis, the thickness of the steel sheets for the support beam should be at least 20 mm. This value ensures the required level of strength if the supporting structure is made of St3 steel.
4. The accepted overall dimensions of the width of the support beam - 600 mm along the bottom chord and 400 mm along the upper chord - provide a discrete spectrum of forced vibrations during transportation of the dump car body. The spectrum starts at a frequency of 18.45 Hz, which is higher than the potential resonance spectrum of the transporting flat car in 12 Hz.
5. The obtained forms of forced vibrations of the developed structure allow the use of a reliable fastening of the dump car body, which is capable of providing the possibility of its transportation.

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