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STATIC CALCULATION OF CONTAINER STRUCTURE LOADED BY WIND AND SNOW USING THE FINITE ELEMENT METHOD

STATIČKI PRORAČUN NOSEĆE KONSTRUKCIJE KONTEJNERA OPTEREĆENE VETROM I SNEGOM PRIMENOM METODE KONAČNIH ELEMENATA

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Keywords
- static calculation
- container
- wind and snow
- equivalent stress
- finite element

Abstract

The paper describes analytical and numerical methodology analysing the stress state of structural elements of the special-purpose container. Research is based on the container supporting structure and the stress state under the effect of additional loads from wind and snow is determined. Numerical analysis is carried out using the finite element method in the ABAQUS® software package. After the numerical calculation, it is concluded that the designed container will not reach a critical condition due to additional loads. Some of the safety issues should be considered early in the container life cycle, already during design and manufacture. It is usually required to apply measures for safe and healthy work which are determined by regulations in the field of safety and health at work, and in connection with the work to be performed.

Ključne reči
- statički proračun
- kontejner
- vetar i sneg
- ekvivalentni napon
- konačni element

Izvod

Rad prikazuje analitički i numerički postupak za analizu naponskog stanja strukturnih elemenata konstrukcije kontejnera koji ima posebnu namenu. Istraživanje se zasniva na nosećoj konstrukciji kontejnera i razmatra se naponsko stanje pod dejstvom dodatnih opterećenja, koja podrazumevaju dejstva vetra i snega. Numerička analiza je izvršena metodom konačnih elemenata u programskom paketu ABAQUS®. Posle numeričkog proračuna zaključuje se da projektovani kontejner neće dospeti u kritično stanje usled dodatnih opterećenja. Neka od bezbednosnih pitanja treba razmotriti u ranoj fazi životnog ciklusa kontejnera, već u toku projektovanja i proizvodnje. Obično se zahteva primena mera za bezbedan i zdrav rad, koje su utvrđene propisima iz oblasti bezbednosti i zdravlja na radu, a u vezi poslova koji će se obavljati.

INTRODUCTION

Containers protect the stored equipment from effects of atmospheric precipitation and low temperatures, as well as from pollution and mechanical damage during operation. The equipment here concerns electronic communication and electrical energy equipment and devices. The purpose of the container is in accordance with the nature and technical requirements of the stored equipment, primarily the creation and maintenance of appropriate microclimatic conditions (temperature, air humidity), as well as the protection of power supply and control equipment from atmospheric pollution, mechanical damage, etc. Placing communication and power supply equipment, important for plant operation in the closed container space, is in accordance with legal regulations in the area of fire protection. Equipment in operation releases a certain amount of heat, so in accordance with legal regulations in the field of fire protection, the design and installation of appropriate devices for removing heat from the facility (air conditioning system), the cooling of the container is accomplished. In this sense, the supplier of key electronic-communication and electrical-energy equipment and devices should define the input data and conditions the container structure should satisfy in order for the stored equipment to function safely and reliably.

Wind loads imposed on structures are one of many loading conditions of steel structures. For a simulation, many approaches are available. In article /1/, a method is described based on the loading set by the EU standard, as well as on the simulation of air flow around the container by the finite element method.

Wind actions, forces and moments acting on the whole structure, or on individual elements, are correlated to the size of the structure, to the maximum pressure (generally strictly dependent on wind velocity) and to different coefficients correlated to the shape of the element. It is important to underline that the stress and displacement in structures due to wind actions, are directly proportional to the flexibility of structure or element (related to the natural frequencies of the structure). For instance, the maximal value of displacement is correlated to the intrinsic damping of the used material and to the different methodologies applied to join the elements together, such as welding or bolting. Usually, wind structural design is often carried out by a recourse to the concept of equivalent static wind loads. The main advantage of such loadings is to reproduce, with static analyses, the same extreme structural responses as those resulting from a formal buffeting analysis, /2-4/.

CONTAINER DIMENSIONS AND MATERIAL

The container has a prismatic shape, Fig. 1, with the following parts: 1-roof frame, 2-roof design/roof covering, 3-lifting points/lifting rings, 4-corner posts, 5-wall panels, 6-middle posts, 7-base frame, 8-front wall, and 9-base plates/false floor. Figure 2 shows the overall dimensions: 6058 × 2438 × 2591 mm.

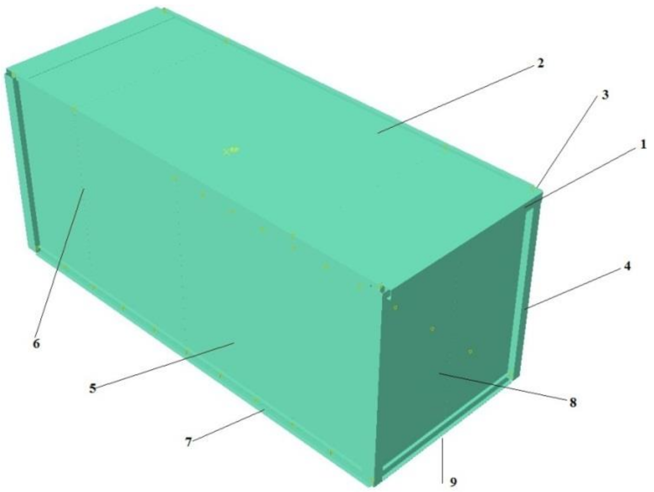

Figure 1. Container model.

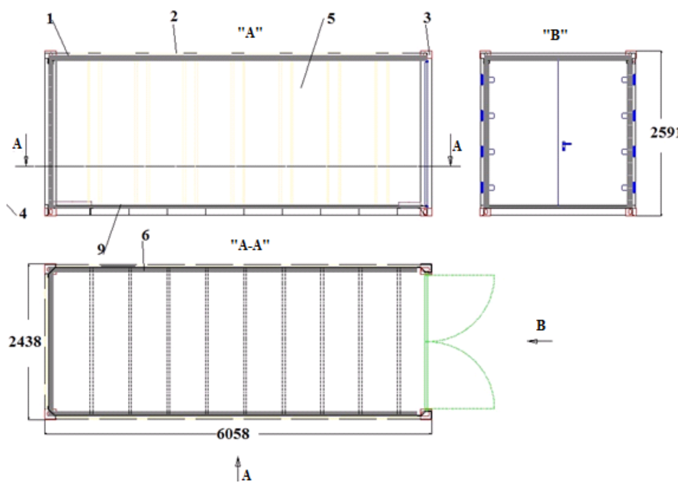

Figure 2. Container dimensions.

According to EN 10025-2/2019, steel S355J2 /5/ is selected as the basic material of the container supporting structure. This material has good mechanical properties for the intended loads and operating conditions.

STRUCTURAL LOADS

The permanent load on a structure is a load that changes very little or not at all over a short period of time. It includes the container's own weight and permanent load - the load of equipment on the floor. The permanent load of the container under consideration is:
- empty container weight: 4000 kg, and
- floor load (equipment weight): 3900 kg.

The effect of snow and wind on the structure represents an additional load. Additional loads from wind and snow are prescribed by Eurocode 1 standard, SRPS EN 1991-1-4: 2012, Part 1-4: General effects - Wind effects and SRPS EN 1991-1-3:2017, Part 1-3: General effects - Snow loads, /6/. The calculation is made on the basis of the structural strength settings, /7-11/.

The safety factor represents a reserve that includes unknowns in the process of creating the calculation model. According to Gašić /12/, different load combinations are relevant for different structural elements. The following table shows safety factor values for three load cases that are defined by professional regulations.

Table 1. Safety factor for three load cases, /12/.

Load case	Safety factor
I Load case (basic)	$\nu_{I} = 1.5$
II Load case (basic + additional)	$\nu_{II} = 1.33$
III Load case (basic + additional + exceptional)	$\nu_{III} = 1.2$

The first load case includes loads that occur continuously during the use of a structure, i.e., basic loads that occur when achieving the purpose of the designed structure (e.g., permanent load, weight, etc.).

The second load case used in this paper, in addition to the basic one, includes loads that may occur during exploitation (i.e., wind, braking forces, temperature effects, etc.).

The third load case, in addition to the basic and additional loads, also includes exceptional loads such as mechanical shocks.

To prove the strength of the structure, the allowable normal, Eq.(1), and shear stress, Eq.(2), are /12/:

$$\sigma_0 = \frac{f_v}{\nu} = \frac{355}{1.33} = 266.9 \text{ MPa}, \tag{1}$$

$$\tau_0 = \frac{f_v}{\sqrt{3}\cdot\nu} = \frac{355}{\sqrt{3}\cdot 1.33} = 154.4 \text{ MPa}, \tag{2}$$

where: $f_v = R_e = 355$ MPa is the yield stress for the given material.

When the container is standing one on top of the other the wind load is obtained based on following expressions:
- wind speed based on wind maps is $v_{b,0} = 30$ m/s;
- air density is $\rho = 1.25$ kg/m^3;
- basic aerodynamic wind pressure is:

$$q_b = \frac{1}{2}\rho v_{b,0}^2 = \frac{1}{2}1.25\cdot 30^2 = 562.5 \ \frac{\text{kg}}{\text{ms}^2}; \tag{3}$$

- area of the container side that is exposed to the wind is:

$$A_{ref} = (6.058\cdot 2.591)\cdot 2 = 31.4 \text{ m}^2, \tag{4}$$

- wind load:

$$Q_w = A_{ref} q_b = 31.4\cdot 562.5 = 17662.5 \ \frac{\text{m}\cdot\text{kg}}{\text{s}^2}. \tag{5}$$

When calculating the impact of snow on the stability of the container, an extreme load is taken. The snow load on the roofs is calculated using the characteristic value of the snow load on the ground as s_{Ad} = 1.5 kN/m^2, multiplied by appropriate conversion factors (roof shape, exposure and thermal coefficient).

RESULTS

Analytically, according to the mentioned standards, the load intensity value is reached, that is later entered into the numerical calculation. Numerical calculation is done using the finite element method in the ABAQUS® software. The numerical model of the container is shown in Fig. 3. As can be seen in the figure, at the location where the containers are placed, the requirement is such that two containers stand on top of each other. This is a disadvantageous case because the surface that is loaded by wind (side surface) increases. The snow load of the container roof is:

$$Q_v = A_{roof} \cdot s_{Ad} = 14.8 \cdot 1.5 = 22.2 \text{ kN} .$$

During exploitation of the container in practice the notes would be: do not lift the container in strong, i.e., stormy wind. If there is snow, before lifting the container the snow should be cleared from the roof (do not lift the container with snow on the roof). The distributions of equivalent, normal and shear stresses are shown respectively in Figs. 4, 5 and 6. On given corresponding scales it can be seen that all stresses are within the permissible limits.

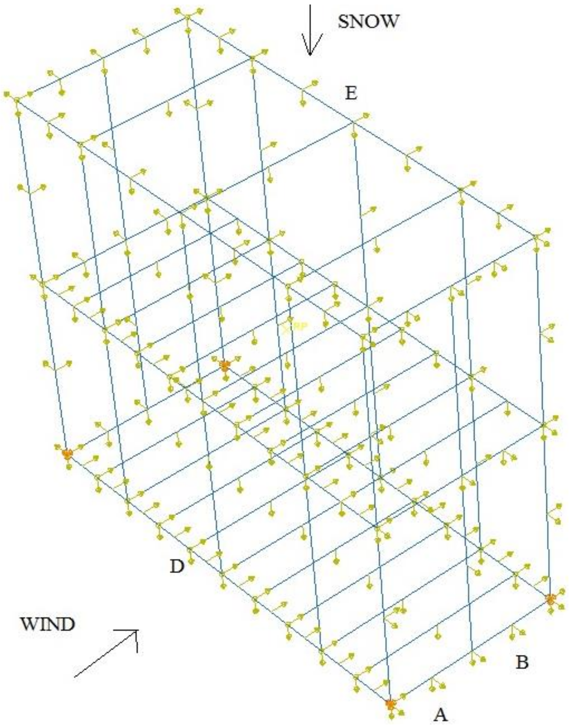

Figure 3. Numerical model of the container.

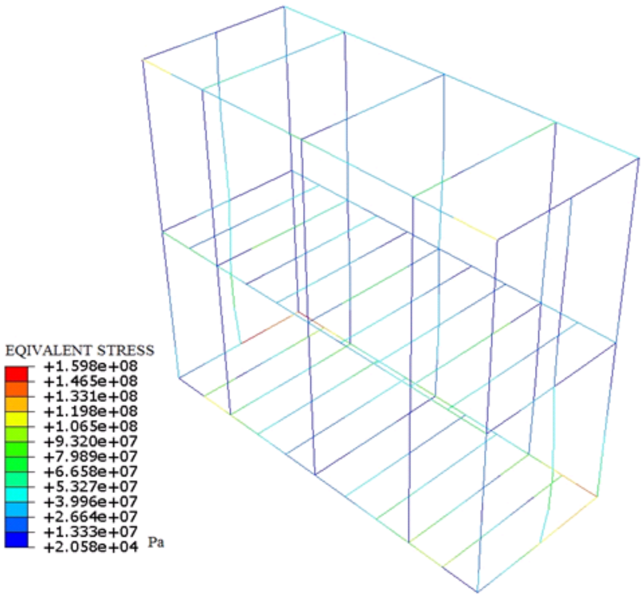

Figure 4. Equivalent stress distribution - von Mises.

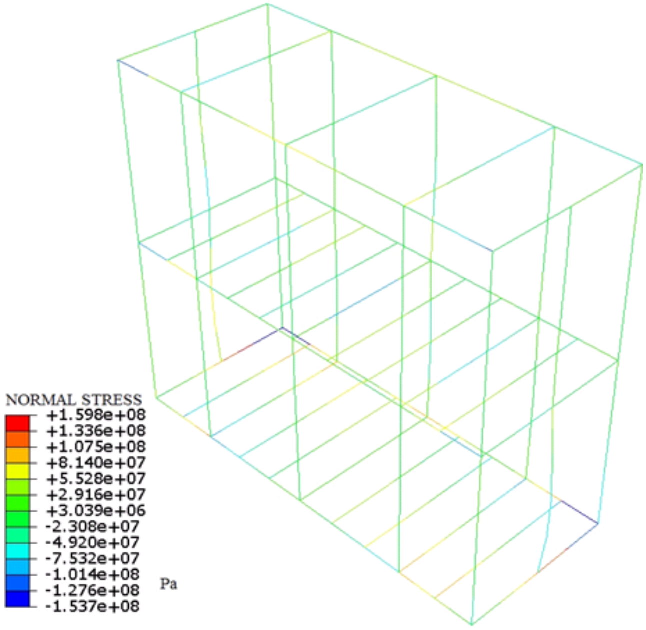

Figure 5. Normal stress distribution.

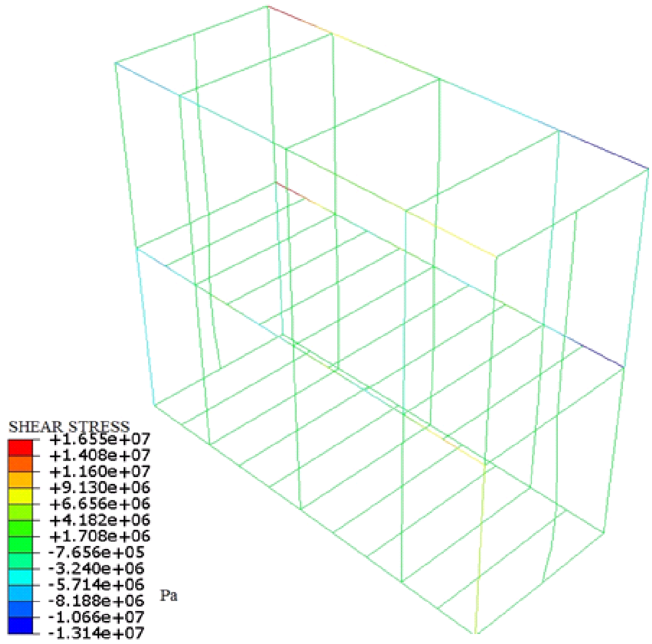

Figure 6. Shear stress distribution.

SAFETY AT WORK WITH CONTAINERS

Already during the design and manufacture of the container, the following stages of its life cycle should be taken into account, among other things, transportation, that is, the possibility of its safe, efficient and reliable transportation.

It is usual to demand the application of measures for safe and healthy work established by regulations in the field of occupational safety and health in relation to the work to be performed, then measures prescribed by technical regulations and Serbian standards that govern the matter of occupational safety and health in relation to the work performed, whereby corresponding standards are largely ignored. For example, it is well to mention the standard SRPS ISO 1161: Corner fittings, which sets specifications for corner joints used on transport containers. Corner fittings are essential for the safe lifting, stacking and handling of containers during transport. The standard defines dimensions, strength and performance requirements for different types of angle fittings, ensuring container compatibility and safe handling in different operations.

The employer is obliged to provide the employees who will handle the transport of containers with instructions for safe and healthy work, in accordance with the regulations on safety and health at work for the tasks they perform, but also in accordance with the technical regulations specified in the regulations regarding technical requirements for products and conformity assessment, which states the manufacturer's obligation to prepare the appropriate instructions. Reference is made here to standard SRPS ISO 3874: Handling and securing, which focuses on safe handling and securing of shipping containers. The standard prescribes methods for lifting, transporting and stacking containers in order to avoid damage and ensure stability during the various stages of handling. It also looks at specific loading scenarios, container types and potential hazards, promoting safe and efficient container handling practices.

CONCLUSION

Analytical and numerical calculation is made due to the request that two containers stand on top of each other. Thus, the side surface that is loaded by wind is increased. Based on the results shown in Figs. 4-6, it can be concluded that the calculation model is good and can be used to solve problems in practice. It can be seen on the scales that all stress values are within permissible limits when compared with values obtained by Eqs. (1) and (2) for allowable stresses. The inclusion of requirements from the next phases of the container's life cycle (transportation, use, maintenance) in the design and manufacturing phase will contribute to a more comprehensive (including safe) solution to an engineering problem.

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