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STRUCTURAL DESIGN AND SELECTED ASPECTS OF NUMERICAL SIMULATIONS OF A PROTOTYPE CONTAINER-PLATFORM FOR INTERMODAL TRANSPORT

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Abstract – The object of the research is a cheap, easy to build basic module with dimensions corresponding to typical railway containers. Such structures can be used to support the intermodal rail-road transport of wooden and metal logs. The basic structure and one assembled from two or more platforms with various longitudinal dimensions ensures high mobility resulting from the modular structure and the possibility of selecting transport configurations as well as the use of various forms of loading - unloading, including: typical crane operations, the use of forklifts or hook winches. The use of a platform-container will eliminate the need to repeat the operation of individual loading or unloading of each unit of the transported load e.g. a single block of wood, a bundle of bars, as a metal log, a single pipe, during each reloading operation - from the place of logging, production, storage, etc. The paper presents selected problems of the preliminary design and numerical strength tests of a single base module of the platform in a prototype version with dimensional equivalent of a 10'-foot railway container.

Key words – metal and wood logs, rail and road transport, prototype platform-container, FEM and MBS numerical tests

JEL Classification – Q55, O22, Q23

INTRODUCTION

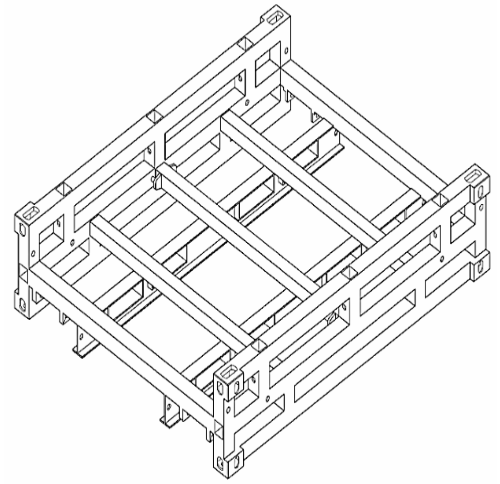
Various types of methods are used to facilitate the performance of loading and unloading operations and to support transport at different stages of log delivery [1-3]. Currently known and available solutions are mostly container structures [1] or a type of a fixed-length platform [4], designed and equipped mainly for one type of loading and unloading, most often of the hook type, for appropriately adapted vehicles [1, 5-7], including tractors and trucks. There are also solutions available on the market for loading and unloading operations as well as for transporting logs on roads in the unimpeded terrain and on public roads. There are also various solutions for loading and unloading logs at railway stations/terminals [1-3, 5-7]. The used methods are, among others, overhead crane loading and crane loading [1, 6] using typical rope slings and many others (e.g. with the use of various types of forklift trucks) [8-9]. Unfortunately, there is currently no universal system on the market for the organization of comprehensive long-distance transport of logs.

The object of research regarding this project is a cheap and easy to build basic 10'-foot module of a platform-container [10-11]. It can be used as a single platform or multi-platforms obtained by combining basic modules with dimensions corresponding to typical railway containers: 20'- and 30'-foot. Individual modules and sets can be used to support railway and road transport of wooden and metal logs, including pipes, products transported on pallets and loose materials. The use of such a structure will eliminate the need for multiple repetitions of individual loading and unloading operations for each unit of the transported load (e.g. a single block of wood, a bundle of bars as a metal log, a single pipe, etc.) during each reloading (from the place of logging, production, storage, etc.). The supporting set with the log load can be repeatedly reloaded (using four different types of loading and unloading techniques most commonly used in the transport of logs) from delivery vans to various types of railway wagons and vice versa without the need to empty the set. It is possible to move a platform, e.g. with a load of logs, using different means of close transport without the need to empty the set from the load. For this purpose, the following solutions can be used: typical rope slings and lifting with a self-propelled or stationary crane, overhead crane etc., forklifts, various types of forklift devices and standard hook lifting. The structure of the proposed platform-container for intermodal transport includes original solutions protected by national and European patent application [10-11].

The welded frame constitutes the main part of the platform module. Its two longer sides, to which the rope lifting slings were welded using e.g. mobile cranes, are equipped with lower skids constituting the support/base of the frame, together with container holders for mounting the set on the platform of wagons and road trucks, and upper handrails with built-in stanchion slots. They are locked in the frame slots with removable, loosely fitted bolts. A separate platform-container frame without stanchions is shown in Figure 1a.

The end carriage of the platform-container in the folded configuration and placed vertically at one end of the structure is shown in Figure 1b.

a)



b)

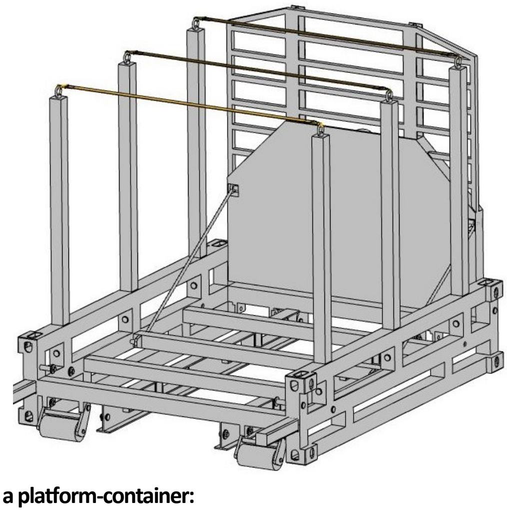


Fig. 1. The basic 10'-foot module of a platform-container:
a) Frame of the platform-container without stanchions,
b) End carriage mounted vertically on the platform frame for one-sided securing of the load with stanchions and two rails of a standard hook lifting mechanism visible under the floor ribbing

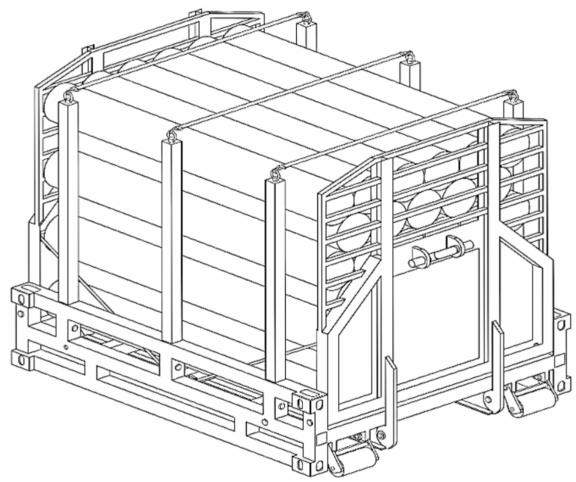
The complete single platform-container module in the structural design with two end carriages mounted vertically in the working position at both ends of the frame and in the configuration prepared for transport with the load of wooden logs is shown in Figure 2a.

In a single platform-container module, each end carriage is mounted to the platform's frame using side braces and special comb joints installed in the lower part of the end carriage wall. The purpose of this joint is to fix the end carriage to the rails of the standard hook lifting mechanism, attached to the bottom of the module frame.

Additionally, a single platform module can be equipped with removable metal or composite side walls and a roller shutter folding roof. Such a structure will enable the protection of loads, such as e.g. steel in coils or paper, against precipitation. A demonstrative view of the platform-container with side walls and unfolded roof is shown in Figure 2b.

The basic module of the platform-container with such a structure and intended use corresponds to the initial version of the structure protected in Poland and abroad by the patent and patent applications [10-11]. This concept requires thorough strength tests and formulating answers to a number of design questions, so that, on the basis of the collected results and data describing the strength of such a device in specific applications, a structural design of a single module of the 10'-foot platform-container can be developed.

a)



b)

Fig. 2. The complete single platform-container module:
a) Single platform module in the configuration with two end carriages, stanchions and the load of wooden logs,
b) View of the platform-container with side walls and unfolded roof

1. Selected problems of designing the platform-container

Due to the modular structure of a single 10-foot platform solution, the expected high mobility of the structure of the platform for the transport of logs resulting from the possibility of its free configuration depending on the intended use, the range of goods to be transported and, at the same time, the possibility of folding the platform for stoppage/waiting and transport without load, the patent concept of the platform solution provides for numerous bolt and screw joints. Bolt joints are used to attach removable stanchions cooperating with the frame slots. Screw joints are designed to fix the lower part of the end carriage with the rails of the standard solution of the hook lifting mechanism mounted on the bottom of the frame. All these connections, due to the type of their loads, their variability depending on different operational variants and applications, require particularly precise verification of strength, especially in the initial phase of tests. Therefore, this project provides for the performance of simulation tests using analytical and numerical methods of the complete structure of a single platform-container, as well as detailed tests, also including separate bench models of connections essential for this type of construction for the above-mentioned reasons.

The following initial technical assumptions for the designed single platform-container module were adopted:

- strength criterion - structure safety factor n = 3 [12-13];
- construction material: weldable steel S355; R_{dop} = 120 MPa for n = 3;
- tare weight of the complete set of a single platform-container module $m_{max} \leq 2.500$ kg,
- log load/log weight of up to Q_{max} = 100 kN,
- maximum loads due to operational variants/cases of taking a load from the ground amounting to P_{max} = 100 kN,
- 1st kinematic criterion of structure safety – for operational load variants of lifting the platform using a rope sling (lifting devices, overhead cranes, etc.) and fork loading $W_{max} \leq 2$ mm [12-13],
- 2nd kinematic criterion of structure safety – for operational load variants of lifting the platform with a hook mechanism $W_{max} \leq 5$ mm (the biggest deformations of the end carriage and frame elements) [12-13].

The direct scientific goal of the discussed project will involve the development of the concept for a single module of a 10-foot platform-container that will meet the adopted design assumptions. The following research methodology is implemented for this purpose at the stage of initial works:

- preparing 3D documentation based on the patent concept and simplified geometric, analytical and numerical models[10-13];
- performing multi-variant numerical tests of the strength of the platform-container;
- preparing the initial design of the structure after considering the modification of the patent concept of the platform-container;
- preparing 3D documentation of the platform-container according to the completed patent concept.

2. Numerical tests of the platform-container strength in critical cases of operational loads

The use of original mathematical models, broadly understood numerical methods and computer simulations to solve contemporary transport problems, testing the strength and functionality of the rolling stock and delivery equipment, subassemblies or other elements of infrastructure and logistics systems, including rail and road transport, is more and more popular in scientific publications [14-16].

The mathematical model and selected aspects of computer simulations of a railway switch point are discussed, for example, in [14], taking into account the constant wheel load force in contact with the rail.

The paper [15] presents selected concepts, models and theories of safety that can be used in the field of transport. Research on the effectiveness of the selected Polish regional rail carriers in the years 2017-2020 is shown in [16]. Experimental and numerical tests of the strength of complex structural systems used in transport are presented, for example in [14, 18].

Design works and various aspects of pre-implementation studies of modern and innovative solutions in the field of rolling stock, road vehicles, as well as facilities of the broadly understood transport infrastructure are presented in numerous publications, among others, by authors. The use of different classes of deformable models (e.g. FEM-Finite Element Method [17]) and rigid models (e.g. MBS - Multibody Simulation) in design works and accompanying numerical analyses of strength, or in functional tests of vehicles and transport systems are discussed in detail in the works [14, 18].

Geometric models (Fig. 3) and simplified numerical models (Fig. 4) of the frame, end carriages, complete sets of a single module-container platform in the 10'-foot version and their numerous modifications are developed.

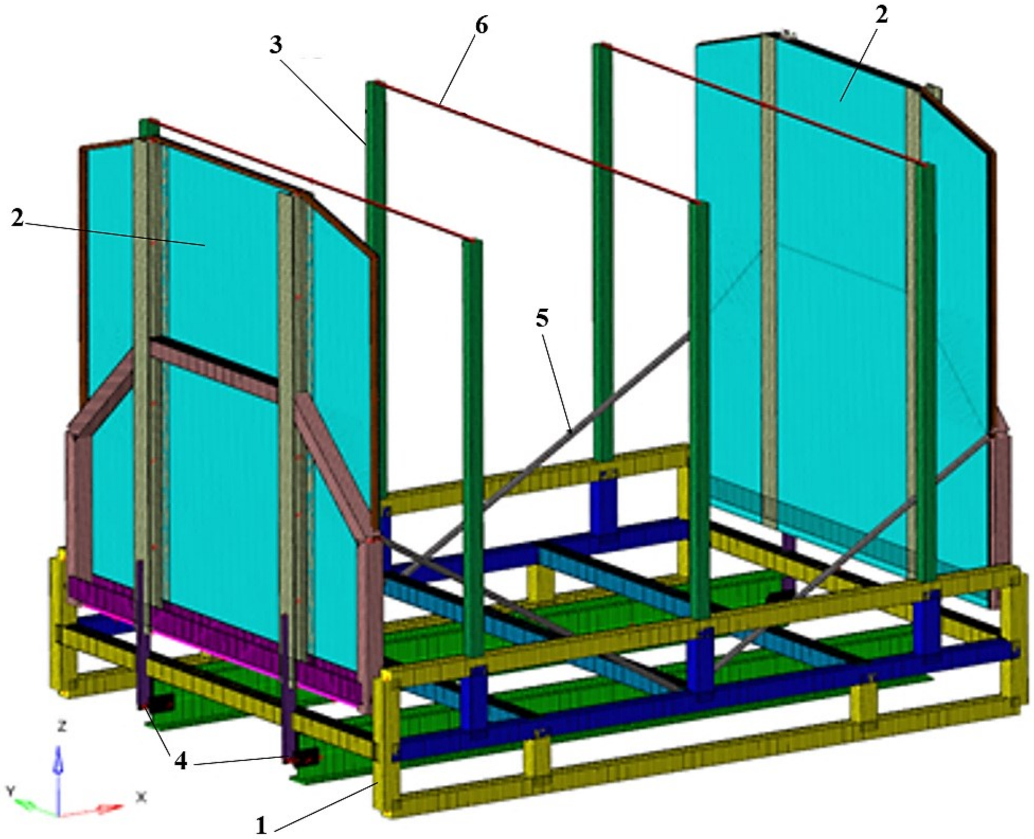


Fig. 3. 3D model of the platform-container with the mapping of the basic components:
1 - frame, 2- end carriage, 3 - stanchion, 4-lower joint of the end carriage, 5 - side brace,
6 - strap strapping - covering the stanchions with the load

Multivariate FE analyses are performed in the field of linear statics [17, 19-20]. The case of a load with a maximum log weight of 100 kN is represented in them. The tests also simulated the impacts occurring in the platform in various variants of loading logs with the use of a rope sling and a crane, in the case of using a forklift and with the use of a hook device.

The most effort load case is established on the basis of preliminary numerical tests of the platform-container strength. It corresponds to the option of loading logs with a weight of 100 kN using a standard hook device. Therefore, a numerical FE model is built to simulate such an extreme variant of loading the transport platform. The 3D numerical model of the platform-container with constraints and loads applied in the hook loading variant is shown in Figure 4a. The non-sliding articulated constraints 1 - Figure 4a are modelled on the lower surface of the sides on one - right side of the platform frame. The vertical rockers modelling the impact of the rollers of the hook mechanism based on the ground, i.e. the horizontal support surface of the platform, are also mapped.

Movable connections between the lower and side parts of the end carriages are modelled using simplified models of complex nodes, kinematic elements and typical beam elements. The construction of the rotary connection model of the end carriage wall in the side of the frame is shown schematically in Figure 4b. The pin is mapped in the model by means of beam elements with equivalent stiffness. The connection of the ends of the beam elements with the nodes of the adjacent discrete FE elements modelling the joined areas of the end carriages and the frame are replaced with the kinematic RGB2 elements [17, 19-20].

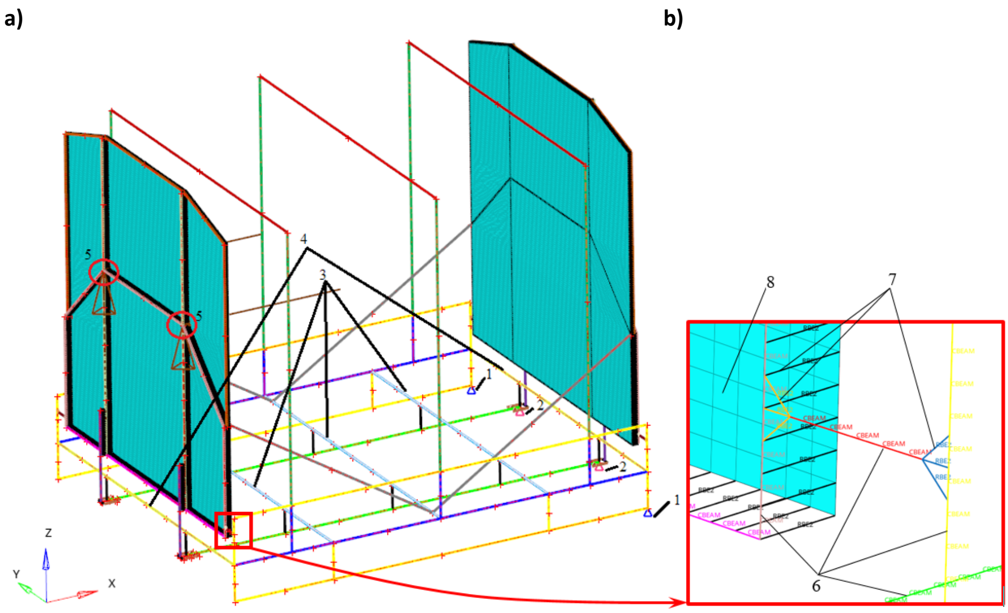


Fig. 4. 3D numerical model of the container-platform:
a) Boundary conditions: 1 - supports – articulated non sliding constraints, 2 - vertical rockers; 3 and 4 - model of the equivalent load of the structure with its own weight and from a log with a weight of 100 kN distributed continuously on the cross-members of the frame bottom; 5 - reduced loads modelling the action of the hook,
b) Discrete model of the rotary joint of the end carriage wall in the side of the frame: 6- beam elements, 7 - kinematic RGB2 elements, 8 - 2D shell elements

Continuous force models designated as 3, 4 in Figure 4a, operating on the cross-members of the bottom of the frame, are used to map the external loads in the platform. For this purpose, reduced concentrated forces 5 (Fig. 4a) are applied diagonally in the form of two identical sets of vertical and horizontal component forces symmetrically located in the nodes of end carriage stiffeners.

The values of these two sets of concentrated forces are the same and correspond to half of the resultant force acting on the hook of the end carriage while lifting the load of the log with the platform. The resultant values of these loads are determined in separate dynamic simulations using a simplified 2D model consisting of rigid bodies replacing the movable subassemblies of the platform.

The operational cases of picking up with the use of a hook device, in which the extreme friction forces between the platform rollers and the rigid ground surface from which the platform with the load of logs is loaded are taken into account and mapped in MBS simulations.

The values of these component forces obtained for the minimum μ_{min} and maximum friction coefficient μ_{max} are given in Table 1. The load model also takes into account the self-weight of the platform structure. The self-weight of the platform is mapped using the inertial load by gravity option [19-20].

Table 1. Hook load components estimated in MBS numerical tests

Friction μ	F_X [N]	F_Y [N]
μ_{min}	27602	61337
μ_{max}	36802	61337

The comparison of the displacement maps determined in the platform-container with the deformation image enlarged 50x for the maximum stress variant of the FEM analysis and for two extreme cases of friction between the rollers and the ground from which the platform is loaded: μ_{min} and μ_{max} is shown in Figure 5 and Figure 6. The greatest displacements occur in the upper part of the left end carriage and are, respectively, 3,32 mm and 4,83 mm.

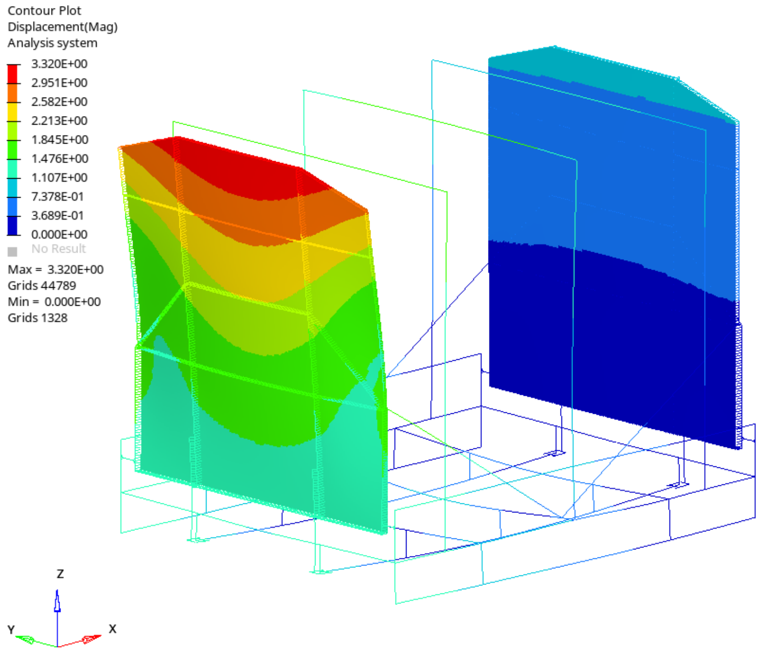


Fig. 5. Displacement maps with a deformation image magnified 50 times for the maximum stress variant for the friction variant μ_{min} - the maximum value of the displacement V = 3,3 mm

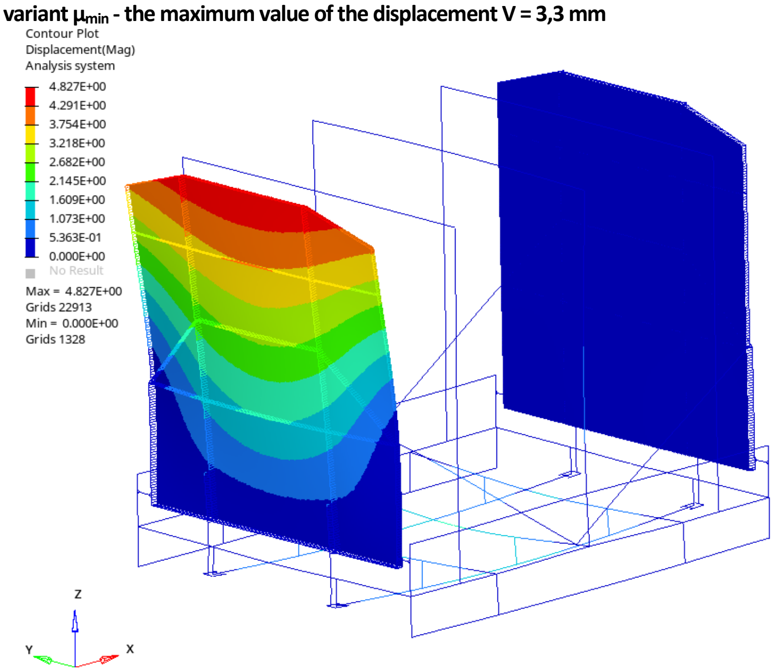


Fig. 6. Displacement maps with a deformation image magnified 50 times for the maximum stress variant for the friction variant μ_{max} - the maximum value of the displacement V = 4,8 mm

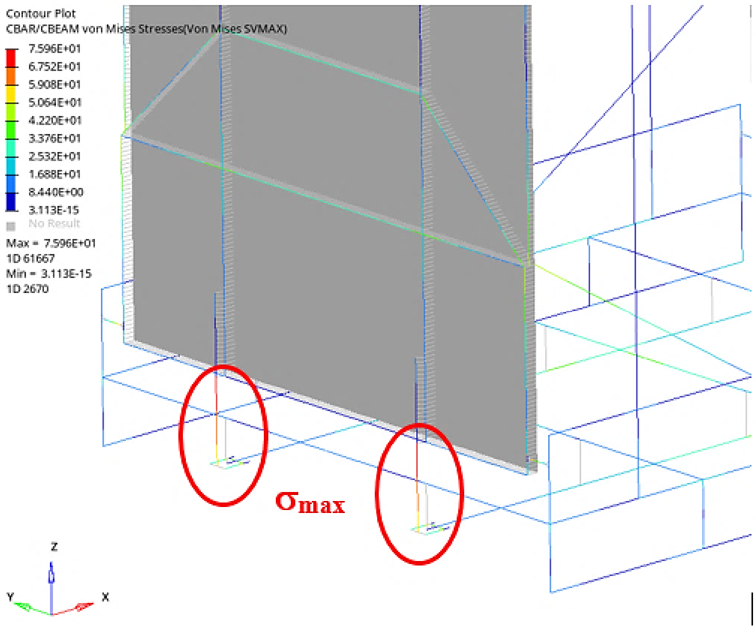


Fig. 7. Visualization of H-M-H stress distributions in beam elements used to model the front part of the platform for the maximum effort variant - $\sigma_{H\text{-}M\text{-}H}$ = 75,9 MPa

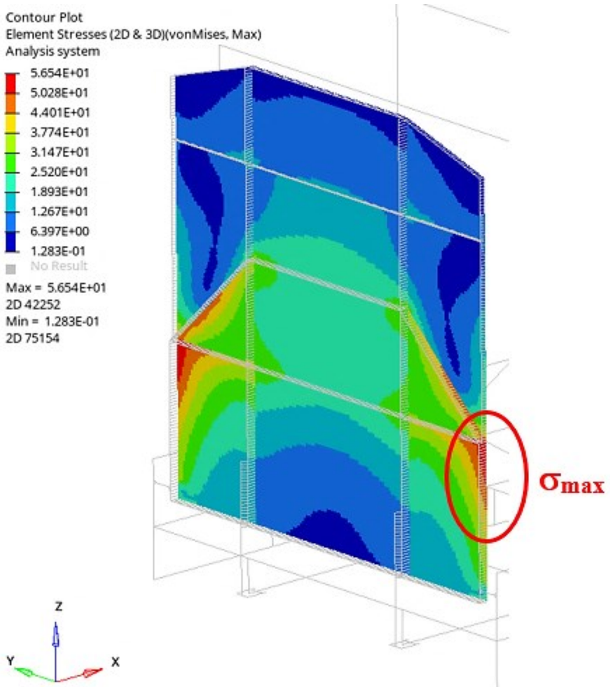


Fig. 8. Map of H-M-H stresses in 2D elements used to model the front part of the platform with the vertical wall of the left end carriage - $\sigma_{H\text{-}M\text{-}H}$ = 56,5 MPa

The greatest deformations occur in the considered variant of the maximum platform effort for both load and support conditions. They concern the upper part of the end carriage wall and consist in bending in the direction of the action of the horizontal load component (Table 1). This directly influences the most unfavorable increase in the values of the determined displacements during hook lifting of the container-platform.

The visualization of the H-M-H stress distributions in beam elements used to model the front part of the platform with a fragment of the structure of the frame, stanchions, stiffeners of the left end carriage with the applied equivalent load from hook lifting is shown in Figure 7. The maximum values of H-M-H stresses in beam type elements are $\sigma_{H\text{-}M\text{-}H}$ = 75,9 MPa for the maximum effort variant and with the maximum friction μ_{max}.

The map of H-M-H stresses in 2D elements used mainly for modeling the front part of the platform with the wall of the left end carriage, with the equivalent load from hook lifting applied, is shown in Figure 8. The maximum H-M-H stresses occur in the cross-sections of the pin models in the side struts connecting the vertical walls of the left end carriage with the sides of the frame. They are respectively $\sigma_{H\text{-}M\text{-}H}$ = 56,5 MPa.

The comparison of the analyzes results in numerical models for the variant of the maximum load of the platform with the mapping of the load during hook loading under the conditions of extreme friction forces between the soil surface and the rollers of the hook device is summarized in Table 2.

Table 2. Comparison of the maximum displacements V and maximum stresses in the 1D beam and 2D shell elements in the maximally effort numerical models of the platform with the hook loading mapping

Extremely effort case of analysis	**Displacement - V [mm]**	**H-M-H stress - $\sigma_{H\text{-}M\text{-}H}$ [MPa]**	
		1D	**2D**
μ_{min}	3,3	71,6	52,6
μ_{max}	4,8	75,9	56,5
Δ [%]	Δ_1 = 46 %	Δ_2 = 6 %	Δ_2 = 8 %

Relative Δ differences presented in Table 2 are determined according to the relationship (1) and (2) on the basis of the maximum results of the analyzes in numerical FE models of the platform with the mapping of the hook loading. The largest relative differences for the displacements are, respectively, about 46 % and 6 % for the stresses determined in the beam 1D elements and about 8 % in the 2D elements.

$$\Delta_1 = \left(\frac{|V_{max}|-|V_{min}|}{|V_{min}|}\right)\cdot 100\% \qquad (1)$$

$$\Delta_2 = \left(\frac{|\sigma_{H\text{-}M\text{-}H\ max}|-|\sigma_{H\text{-}M\text{-}H\ min}|}{|\sigma_{H\text{-}M\text{-}H\ min}|}\right)\cdot 100\% \qquad (2)$$

where:

V_{max} - the maximum value of the displacement from Table 2,

V_{min} - the minimum value of the displacement from Table 2,

$\sigma_{H\text{-}M\text{-}H\ max}$ - the maximum value of the H-M-H stress from Table 2,

$\sigma_{H\text{-}M\text{-}H\ min}$ - the minimum value of the H-M-H stress from Table 2.

SUMMARY AND CONCLUSIONS

The methodology of numerical strength tests of the platform-container has been defined. It allows for the initial shaping of the strength of the prototype platform structure within the adopted design assumptions.

Models of a complete single platform-container module for the transport of logs are selected based on multivariate FE analyzes performed in the field of linear statics. The numerical models adopted for research accurately mapped the actual operating conditions of the platform, including the most effort variant corresponding to the hook loading of the platform.

It was found that the 3D models of the platform-container used in the presented simulations illustrate the greatest sensitivity of end carriage displacements to simplifications in mapping various stiffeners and movable joints between platform components.

The lower joints of the end carriage with the hook device rails attached to the bottom of the frame, and the strut joints of the side stiffeners of the end carriage with the sides of the platform frame require additional tests with the use of more precise 3D numerical models, built of solid elements and taking into account the contact phenomena. The greatest stress concentrations have been identified in these areas of the platform structure.

As a result of the project implementation in accordance with the platform-container test methodology presented above, prototype variants of the structure will be built and the necessary qualification tests will be conducted, preparing for the implementation of the proposed platform-structure.

At the moment, there are pending construction works at the stage of developing detailed design solutions, including the joints of the target module of the basic platform-container, and obtaining European patent protection.

ABBREVIATIONS

1. **MBS** – Multiobody Simulation;
2. **FEM** – Finite Element Method.

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PROJEKT KONSTRUKCYJNY I WYBRANE ASPEKTY SYMULACJI NUMERYCZNYCH PROTOTYPOWEJ PLATFORMY-KONTENERA DO TRANSPORTU INTERMODALNEGO

W pracy przedstawiono wybrane problemy wstępnego projektowania pojedynczego modułu bazowego platformy, odpowiednika wymiarowego 10' stopowego kontenera kolejowego w wersji prototypowej. Badania wytrzymałościowe innowacyjnej konstrukcji wspomagane są metodami numerycznymi. Omówiono metodykę takich badań z wykorzystaniem MES i metod multibody MBS, zastosowane modele numeryczne oraz wybrane wyniki symulacji komputerowych odpowiadających krytycznym, najbardziej wytężonym wariantom eksploatacyjnym zastosowań platformy np. do załadunków hakowych.

Słowa kluczowe: dłużyca metalowa i drewniana, transport kolejowy i drogowy, prototypowa platforma-kontener, testy numeryczne MES i MBS

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