European Research Studies Journal
Volume XXVIII, Issue 4, 2025

pp. 1836-1852

Applications of the Platform-Container System for Intermodal Transport of Goods – Concepts, Logistic and Strength Solutions

Submitted 11/10/25, 1st revision 13/11/25, 2nd revision 24/11/25, accepted 15/12/25

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Abstract:

Purpose: *This article provides a brief overview of solutions for attaching the rail/road-platform to the surface of a carrier-rail wagon or road vehicle using standard container connectors, solutions of using the container platform system with range of transported goods, including FEM and multibody simulations.*
Design/Methodology/Approach: *A platform-container for intermodal transport of goods is presented, including original methodology appropriately in numerical tests. An example solutions using container platform system is proposed, along with results of MBS simulation of the container platform during hook lifting.*
Findings: *Selected technical and logistical aspects of the use of platform-container with FEM and MBS simulation are discussed.*
Practical Implications: *The article highlights the solutions and concepts for using the container-platform system, selected possibility of expanding the range of transported goods, and selected results of multi-variant simulation tests of the container-platform.*
Originality/Value: *An innovative platform-container for intermodal transport of goods is proposed. The platform is cheap, easy-to-build bacis module and multiplatform sets, obtained by connecting basic modules with dimensions corresponding to typical rail containers 10-foot, 20-foot or larger wich can be used to support intermodal rail-road transport of wooden and metal logs, including pipes, products transported on pallets, sheet metal in coils and loose materials.*

Keywords: *Intermodal transport of various goods, prototype platform-container, additional platform equipment structures – structures platform installation, design and numerical strength tests, FEM and multibody analyses, simulation results.*

JEL codes: *O31, O36.*
Paper type: *Research article.*

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Funding: *"This research was funded by the Military University of Technology, grant number UGB 531-000008-W100-22-W112000/WAT/2025, and the APC was funded by the Ministry of Science and Higher Education of Poland".*

1. Introduction

Multiple technologies have been developed for reloading operations in intermodal transport, such as the use of various container cranes, container wagons with booms, container forklifts, terminal tractor units, container grips, the ACTS system, reloading devices manufactured by various companies and many other devices and accessories (Jacyna, 2012; Neider and Marciniak-Neider, 1997). Stationary cranes are often used to lift containers or truck trailers on ropes, but in most cases, e.g., for reloading wooden logs, especially in the field, mobile reloading cranes are used. Some of the above-mentioned, specialised reloading techniques are presented in Figure 1.

Figure 1. *View of the structural solution for attaching the rail/road platform to the surface of a carrier-rail wagon or road vehicle using standard container connectors: a) mast-type forklift for moving containers, b). view of container reloading with a mobile crane, c). container reloading with the ACTS system with hook-type equipment*

a) *b)* *c)*

Source: *Jacyna, 2012;Neider, and Marciniak-Neider, 1997; Bínová, 2018.*

Unfortunately, no universal reloading and transport system for organising comprehensive transport of goods, especially over long distances is currently offered on the market. This makes the transport of goods a proverbial "bottleneck" for various industry sectors, which is a serious problem not only in Poland, but also in other European countries (Jacyna, 2012; Neider and Marciniak-Neider, 1997; Rydzkowski, 2010). A system that would be adapted to transport bulk materials and food, for example including grain, would be a perfect solution to the problem of transporting/forwarding grain from Ukraine to Western Europe and other destinations.

The subject of the research is cheap, easy-to-build basic module and multiplatform sets, obtained by connecting basic modules with dimensions corresponding to typical rail containers: 10-foot, 20-foot or larger. They can be used to support intermodal rail-road transport of wooden and metal logs, including pipes, products transported on

pallets, sheet metal in coils and loose materials (Krasoń, Kędzierski, Sławiński, Stankiewicz, and Kiepura, 2022; Sławiński and Krasoń, 2022; Platforma z Kłonicami do Transportu Drewna, accessed on 24 November 2024).

The basic task in the design of an innovative structure is to develop technical assumptions and determine the data sets necessary to verify the structure at various stages of its creation. Industry standards, e.g. those applicable in the automotive industry or railway standards regarding railway platforms and containers (Platforma z Kłonicami do Transportu Drewna, accessed on 2024), and the requirements adopted on their basis are very helpful, especially in early stages of design.

To determine the reliable loads of the designed structures, mixed methods, also called multi-stage methods, can be used (Motrycz, Stryjek, Leski, and Kurdelski, accessed on 2024; Patent443294, 2024). Such methods use functional tests with e.g. different types of software and numerical models with various levels of simplification (Patent443294, 2024; Martin, Martin, and Lai, 2019).

2. Concepts for the Development of a Container Platform System

A single platform module for intermodal transport has the dimensions of a 10’ railway container. The base 10’ platform has a modular structure (Sławiński and Krasoń, 2022; Krasoń, Kędzierski, Sławiński, Stankiewicz, and Kiepura, 2021). The platform can be set in various configurations, depending on its application.

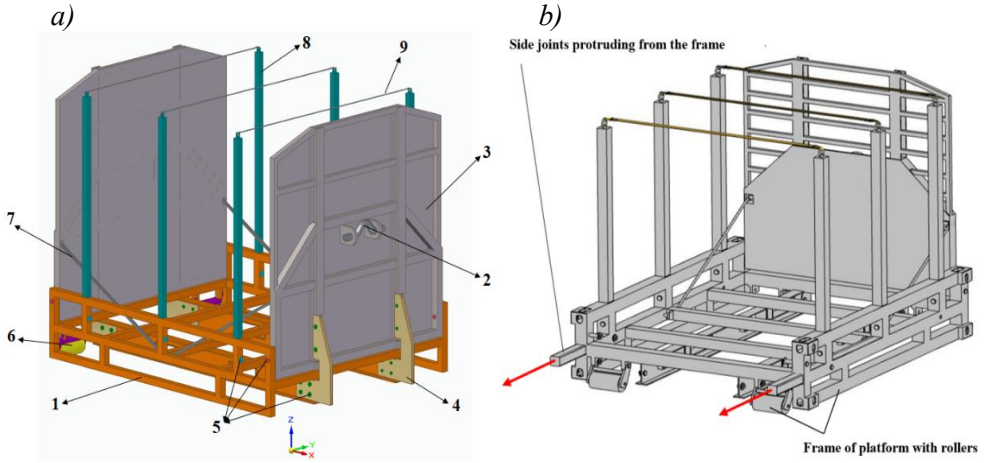
Complete module - a single platform consists of a steel frame (1 in Figure 1a), a rotating buffer beam (3 - Figure 2b) placed vertically at one end of the frame or at both ends and a set of removable stakes (8 - Figure 2a) with tie rods (1 in Figure 2a) clamping the load - Figure 2.

Additionally, a single module of the rail/road platform can be equipped with removable metal or composite side walls and a roll-out roof. Such a structure will protect loads such as sheet metal coils, paper bales and other materials that require isolation from the environment and the impact of moisture.

A set of two platforms-modules with dimensions of 20' is obtained by connecting two 10’ basic modules using stud side connectors. The 20' platform can be operated as integrally connected two 10' platforms - with permanent connections, i.e. without the use of stud side connectors. This integrated module has dimensions corresponding to typical 20’ railway containers – Figure 3a (PN-ISO 668:2013, 2018; PN-ISO 830, 2001).

The rail/road platform with a load weighing up to 10 tons can be attached to a wagon or installed on the platform of a tractor unit/trailer using conventional container connectors - Figure 3b.

Figure 2. *Platform-container for intermodal transport: a) 10-foot single module with joints in the prototype version, b) 10-foot basic module initial design concept with visible side joints for connecting into sets.*



Source: *Own study.*

The use of such a structure with various longitudinal dimensions, will eliminate the need to repeatedly repeat the operation of individual loading and unloading of each cargo unit, i.e. a single container with a structure for transporting bulk materials, including, for example, grain, etc. during each reloading, for example in the place of production of bulk materials or grain at the farm, drying facility, storage and other similar operations.

Thanks to its modular structure and flexible configuration, the platform can be used not only for transporting logs. Due to the current market demand, the possibility of using platform-containers for transporting metal coils and paper bales was tested.

Based on data received from potential recipients/users of rail/road platforms, preliminary analyses of the possibility of expanding the range of transported goods were performed. This part of the work presents selected results of such analyses. Figure 4 shows the arrangement of paper bales on a 20' platform-container (two 10' platforms bolted together).

In Table 1 the data and results of the preliminary analysis of possible expanding the range of transported goods using platform containers by the case of paper bales were discussed.

Additionally, a single module/platform can be equipped with removable metal or composite side walls and a roll-out roof. Such a structure will protect loads such as sheet metal coils, paper, etc. against precipitation. An illustrative view of the platform-container with installed side walls and a roll-out roof is shown in Figure 3c. while the roll-out is shown in Figure 4c.

The platform with side walls can also be successfully used to transport bulk goods in the the form of raw materials for various industry sectors, such as sawdust in the wood industry and many others.

Figure 3. *Solutions and concepts for using the container platform system: a) A set of two platforms-modules with dimensions of 20', b) Visualisation of the use of sets of two 20' multi-platforms with a load of wooden logs on a railway wagon, c) View of the container platform with installed side walls and rolled-out roof.*

a) *b)* *c)*

Source: *Own study*

The separate frame of the basic module (after dismantling the headstock together with the stakes) and the frames of the sets, obtained after connecting them using connectors, can function as pallets for temporary/ad hoc storage of logs of various longitudinal dimensions, for example in a difficult terrain: in wet landfills, areas periodically flooded with rainwater, etc.

Figure 4. *Selected results of the analysis of the possibility of expanding the range of transported goods on the example of paper bales: a) Variant I, b) Variant II c) roller blind based load securing on a rail/road 10' platform.*

a) *b)* *c)*

Source: *Own study.*

Table 1. *Dimensions and weights of variants*

Variant of the analysis	**Cargo data**	**Results**
I	- diameter of 1 bale = 1500 mm, - length of 1 bale = 2800 mm, - weight of 1 bale = 3.300 kg	- weight of 1x complete 20' set with the above load = 6.600 + approx. 4,000 kg = **approx. 10.500 kg** - weight of 2x 20' sets (i.e. 40' set - for one railway wagon) = **21.000 kg**

II	- diameter of 1 bale = 1500 mm, - length of 1 bale = 1600 mm, - weight of 1 bale = 2.800 kg	- weight of 1x complete 20' set with the above load = 8.400 + approx. 4.000 kg = **approx. 12,400 kg** - weight of 1x complete 20' set with the above load – 5 bales = 14.000 + approx. 4.000 kg = **18.000 kg –** unacceptable - stacking bales on top of each other

Source: *Own calculations.*

3. Concept of Using a Container Platform System for Intermodal Transport of Various Goods: Additional Platform Equipment

Each 10’ or 20’ platform can be equipped with additional structures to enable transporting a wide range of goods. Such a structure may, for example, adapt a road-rail platform to transport bulk materials, including cereals, crushed earth products, fertilisers, sawdust and other similar products – Figure 5.

The structure of the road-rail platform is made of connected upper cover - 1, side walls - 2 and bottom – 3 (in Figure 5c) that create a closed loading chamber with access from the top in the form of a pouring/discharging opening located at the bottom of the chamber. The structure formed in this way, without any load, can be attached to the frame of the rail/road platform using stakes during a crane operation, hereinafter referred to as assembly.

The top cover has a covering formed in line upwards from four flat trapezoidal sections rigidly connected to each other and ending at the top with a vertical flange forming a centrally located rectangular pouring opening. The trapezoidal sections are rigidly connected at the bottom to a frame consisting of two identical sections of a flat bar rigidly mounted on two opposite ends of the cover in a vertical position and two identical sections with a closed tetrahedral section, rigidly mounted on two opposite sides of the cover.

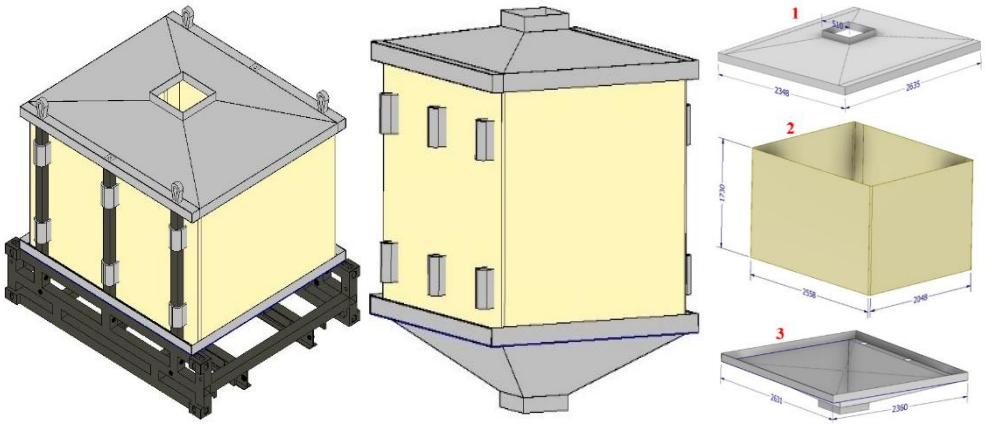
Both shapes have three rectangular blind holes, located symmetrically on both sides of the lower wall of the cover frame. All holes end at the bottom with flanges lowered vertically down with the upper ends of the stakes inserted into them (Figure 5).

Similarly, the bottom of the structure is built convergent downwards, ending with a centrally located chute opening, which is also mounted through appropriate holes on the stakes of the rail/road platform (Figure 5c)

The structure of road/rail platforms for transporting bulk materials also has four rectangular walls: two side walls with the same dimensions and two front walls installed crosswise to the longitudinal axis of the structure, also with the same dimensions (Figure 5).

Figure 5. *Suggestions for the construction of a platform intended for the transport of bulk materials: a) 3D view of the set with a structure for transporting bulk materials mounted on a platform frame with stanchions, b) 3D view of a set with a structure for transporting bulk materials without a platform and stanchions, c) components of the structure for the transport of bulk materials: 1 - top cover with hopper, 2 - side walls with stanchion holders, 3 - bottom with chute*

a) *b)* *c)*



Source: *Own study.*

Six bows are rigidly fixed to the side walls in three pairs of two bows each placed one above the other with through vertical holes, attaching the walls of the structure to the platform stakes.

The two side walls and both front walls of the structure are tightly connected to each other in the four corners along the height of the walls, and additionally, all walls of the structure are tightly and rigidly connected to the edges of the top cover frame and to the edges of the bottom frame along their internal surfaces.

Such a structure is mounted on the rail/road platform frame equipped with stakes and at least one buffer beam (Figure 5a). Once installed, the bottom surface rests with the lower surface of the frame on the upper surfaces of the transport platform frame sides, so that the conical surface of the bottom and the drain hole enabling emptying the cargo chamber of bulk materials are located between the sides of the transport platform frame.

The lower sections of the stakes are mounted vertically in the sockets of the rail/road platform frame, which are inserted using the six through holes in the frame made of the tetrahedral section of the bottom, so that they fix it symmetrically on both sides together with the load, not only in the vertical direction, because the lower faces of the stakes are based on the bottom of blind slots in the platform, but also in the horizontal plane.

The solution of the structure, which uses through holes in the shape frame of the bottom and blind holes in the frame of the upper cover, enables the assembly of the empty structure, its loading as well as the positioning and holding of the chamber with the load of bulk materials during transport using typical stakes that constitute the equipment of road/rail platforms.

A load of bulk materials enclosed in a waterproof, tight and ventilated chamber created by converging coverings of the bottom, side walls and the top cover is suspended on stakes and rests with the bottom on the frame of the rail/road platform. As a consequence, this solution allows adapting the openwork structures of the rail/road platforms frames with stakes for intermodal transport and storing bulk materials while maintaining transport requirements, safety conditions and structural strength.

Platforms of this type, together with an appropriately selected structure for transporting bulk materials, can therefore function as a mobile warehouse in which, for example, a farmer cam temporarily store and collect grain in the appropriate amount after harvesting and then transport it with his own means of short-haul transport (various types of wheeled vehicles for transporting containers) to a railway siding, where such cargo can again wait for railway transport using appropriate freight wagons, e.g. containers adapted to transport and other similar types of platform wagons.

For intermodal transport of coiled sheet metal, it is necessary to equip, for example, a 10-foot platform with an additional structure that will secure the coiled sheet metal to the platform during loading and unloading operations and during various transport phases – Figure 6.

The structure design should be tested for strength. If a prototype of such a structure has not been built for experimental testing, a special hybrid MBS and FEM simulation methodology (Krasoń, Sławiński, and Dobrowolski, 2024) can be used for this purpose, using rigid and flexible models. Figure 6a shows the design of a structure for the transport of coiled sheet metal, and Figure 6b shows selected FEM test results of such a structure mounted on an intermodal platform with a selected operating load.

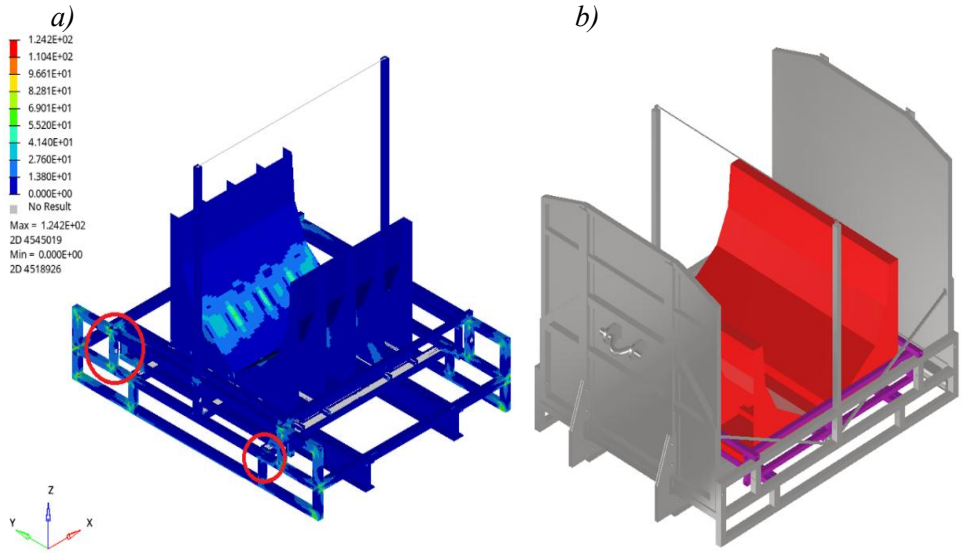
4. Functional Tests and MBS Simulations of Rail/Road Platforms

4.1 Initial Design Assumptions

Based on applicable industry standards (PN-ISO 668:2013, 2018; PN-ISO 1161, 2018), preliminary technical assumptions were made on the designed single module of the 10' and 20’ platform:

- strength criterion - structure safety factor n = 1.75;
- construction material: weldable S355 steel, Re=420MPa;

Figure 6. *Suggestions for the construction of a platform intended for the transport of sheet metal in coils: a) geometric model of the structure integrated with the intermodal platform, b) selected FEM test results - map of reduced H-M-H stresses – σmax = 124MPa*



Source: *Ziniewicz, 2024.*

In the numerical tests, only the linear-elastic range of changes in stresses allowed in the structure up to the limit value was assumed Rdop_n = Re/n = 240MPa, for the safety factor determined on the basis of applicable standards (PN-ISO 830, 2001; Krasoń, and Małachowski, 2015) n = 1.75:

- the empty weight of the complete set of a single platform-container module mmax ≤ 2,500 kg,
- maximum log load/weight of the log Qmax = 100 kN,
- maximum loads due to operational variants/cases of lifting the load from the ground Pmax = 100 kN,
- kinematic criterion of structure safety - for the operational load variants of lifting the platform using a rope sling and fork loading, Wmax ≤ 2 mm, and for lifting the platform using a hook mechanism, Wmax ≤ 5 mm.

4.2 Functional Variants of Loading/Unloading the Platform Adopted for Testing

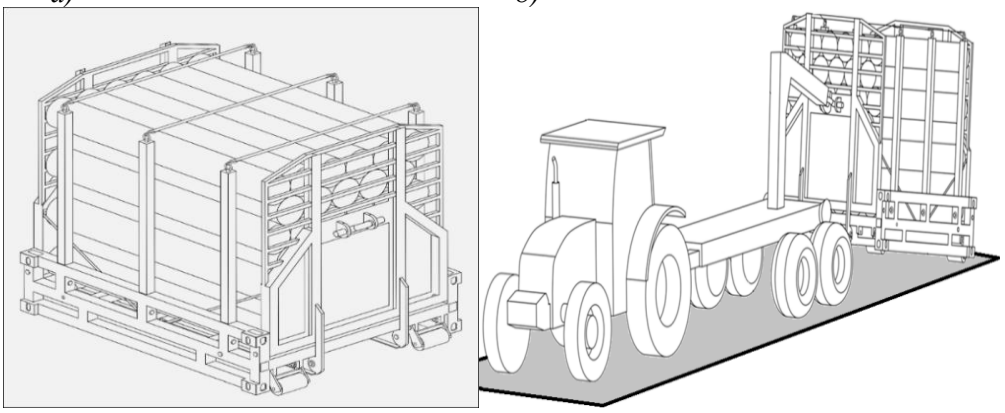
Various methods of loading/unloading the platform ensure high mobility of a single platform. It is possible to move the platform, e.g. with a load of logs (Figure 7a), using various means of short-haul transport, various types of loading and unloading techniques, from delivery trucks to various types of railway wagons and vice versa, without the need to empty the set of cargo. For this purpose, you can use: a typical

rope sling and lift with a self-propelled crane (Figure 7b) or a stationary crane, an overhead crane, etc., trolleys and various classes of forklifts (Figure 7a) , as well as standard hook lifting (Sławiński, and Krasoń, 2022) (Figure 7b).

This type of loading and unloading operations with the unit of maximum load - the weight of the log - P_{max} = 100 kN are the basic operating configurations platforms adopted as functional variants in simulation studies.

Figure 7. *10' intermodal platform: a) with a load of logs weighing P_{max}, b) during a loading and unloading operation using a hook lifting device.*

a) *b)*



Source: *Own study.*

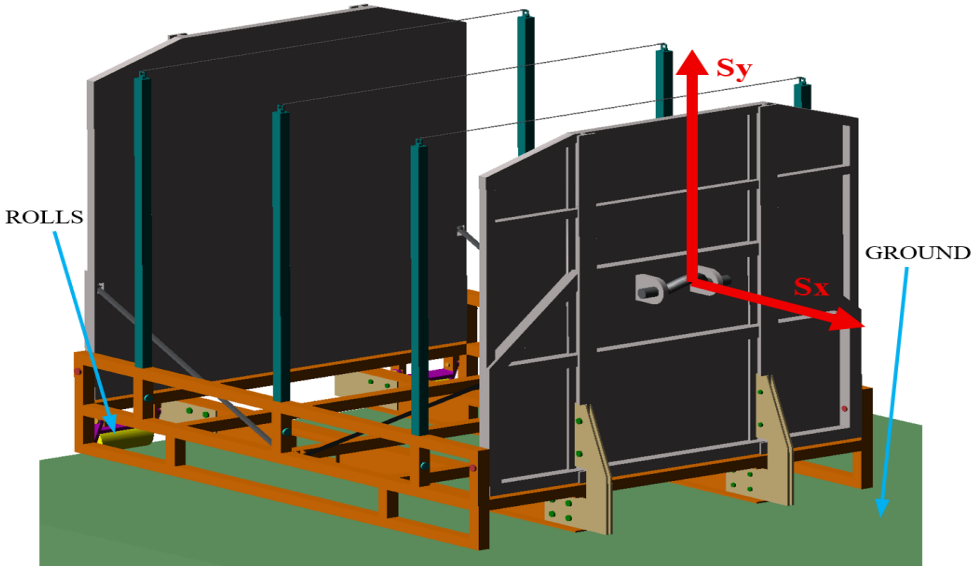
The direct goal of the MBS dynamic analysis is to determine the limit component forces (Figure 8) in the hook lifting operation of the platform-container module for rigid and rotating rollers at the minimum and maximum friction coefficient. The analysis was carried out using a multibody dynamics simulation environment into which a 3D geometric model of the 10' alloy platform module was imported. Based on this model, in the Multibody program environment, a multi-body model of the platform was created, consisting of rigid bodies connected by appropriate external and internal constraints - movable connections between the individual components of the platform were mapped.

A model of a horizontally oriented, perfectly rigid substrate was also built and the platform model was placed on it. The contact phenomenon and various friction conditions between the platform and ground models were determined, which simulated the boundary effects of ground resistance forces during the simulation of the platform's movement during hook lifting operations. Figure 8. presents the model with the ground in the MSC Adams program.

Dynamic analyses were performed for two variants of cooperation between the platform model and the ground:

- Variant I - introduction of rotational constraints in relation to the longitudinal axis of the hook mechanism rolls - rigidly dragged rolls when moving the platform along the ground in the representation of the hook lifting operation (Figure 7b).
- Variant II - rolls with the possibility of rotation relative to the longitudinal axis of the rolls of the hook mechanism - the rolls rotate by rolling on the surface of a rigid substrate (Figure 8) when moving the platform along the ground in the mapping of the hook lifting operation.

Figure 8. *Platform module model – force during hook lifting operation.*



Source: *Own study.*

Dynamic MBS simulations of the platform with self-load and maximum load weight P_{max} = 100kN in the conditions of movement initiation with the mapping of the platform movement initial phase during hook lifting were made by defining different sets of component forces on the buffer beam lock (Figure 8), varying in individual cases of the analysis from zero to the limit values determined analytically (Krasoń and Małachowski, 2015; Rahnejat, 1998; Rusiński, Czmochowski, and Smolnicki, 2000; Rakowski and Kacprzyk, 2016; Zienkiewicz, Taylor, and Zhu, 2005; Flexible multibody systems in Adams, accessed on 16 december 2024), respectively reduced by the value of 50 N and increased by the value of 50 N.

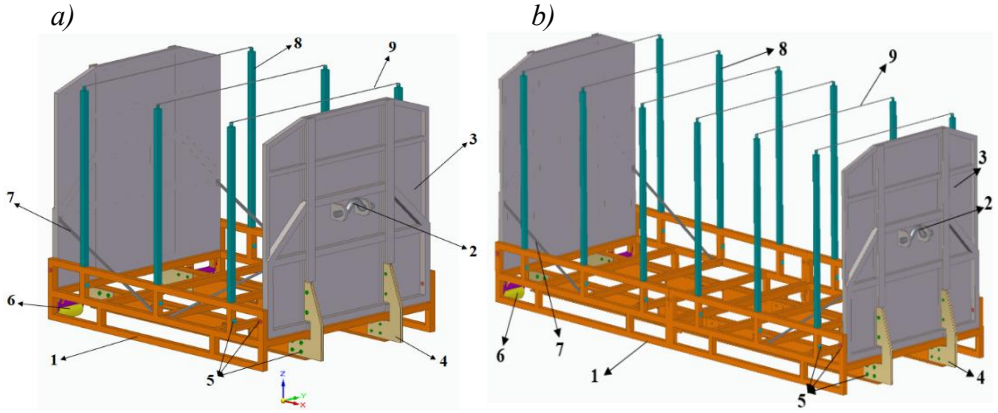
Therefore, a complete dynamic analysis was performed for all variants presented in Tables 1 and 2, i.e. with variable conditions of contact between the platform and the ground (described in variants I and II with different friction coefficients μ_{max} and μ_{min}) and under the influence of various sets of forces initiating the movement of the platform relative to the ground. In the functional test variants performed, the

displacement curves and changes in the values of the platform-ground contact forces were analysed - Figure 8.

To perform dynamic analyses, platform-container models for intermodal transport were created as shown in Figure 9.

The 10' foot platform model consists of the following components: 1-Frame, 2-Hook holder, 3-Headlamp, 4-Connector, 5-Pins, 6-Handles with rollers, 7-Brackets, 8-Stakes, 9-Lashing chains/straps – strapping the load

Figure 9. *Model of a platform-container module for intermodal transport of goods: a) the 10' foot platform, b) the 20' foot platform*



Source: *Own study.*

The aim of the dynamic analysis is also to determine the forces occurring when lifting the platform-container module with a hook for the minimum and maximum coefficient of friction of the platform in contact with the ground. The focus was on the loading operation using a hook device, because this type of loading and unloading operations lead to the greatest effort on the rail/road platform components.

The analysis was carried out using the MSC Adams program, into which a geometric model of the platform module was uploaded along with the geometric model of the ground and the hook in order to determine the forces occurring when lifting the platform-container module using a hook. The models of 10-foot and 20-foot platforms with the ground and a simplified hook device used in the Adams program are shown in Figure 9 and 10.

Figure 11 shows various intermediate positions recorded during the simulation of hook loading of the: a) 10' and b) 20' foot platforms. Dynamic analyses were performed for four variants of model construction:

- Variant 1 – fixing the hook holder,

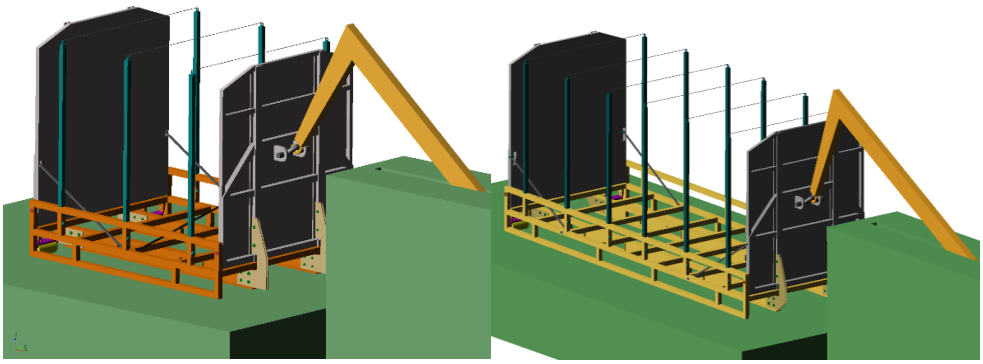
- Variant 2 – hook holder with the option of rotation in the Y axis,

Due to the friction on the ground and conflicts with the ground of the frame-to-frame connections, it was decided to change the dimensions of the buffer beam to frame connectors to eliminate these conflicts. The following simulation variants were obtained:

- Variant 3 - modified connectors - fixing the hook holder,
- Variant 4 - modified connectors - hook holder with the option of rotation in the Y Axis.

Figure 10. *Model of the: a) 10' foot platform, b) the 20' foot platform with the ground and the hook device before starting the loading simulation.*

a) *b)*



Source: *Own study.*

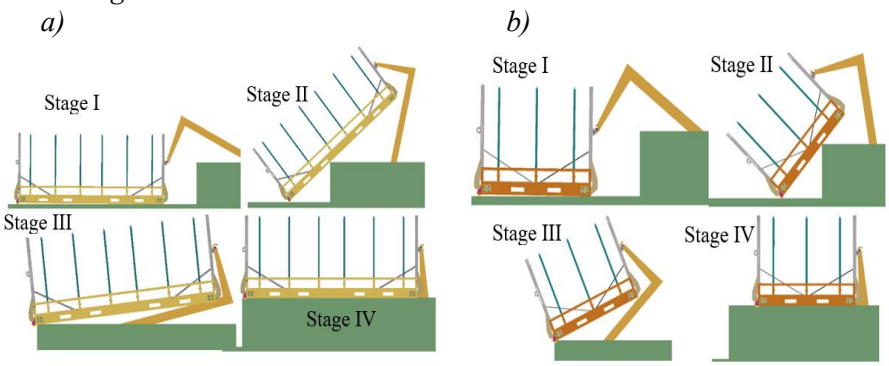
The following assumptions were made to perform the analysis:

- The ground has been fixed (all degrees of freedom removed),
- The rolls can be rotated in the Y axis,
- Contact has been established between the ground and the frame, as well as between the ground and the rollers (for friction coefficients: 0.45 and 0.6),
- Contact was created between the hook holder and the hook in order to determine the forces during the hook lifting operation (steel-steel friction coefficient of 0.15),
- The remaining components of the platform module have been attached to each other,
- Lifting height of the container from the ground to the rolls - 1,400 mm (according to ACTS solutions).

Multibody simulations of lifting 10-foot and 20-foot platforms with loads were performed. They were used to map various methods of lifting a platform with a load of 10 tons and 20 tons, respectively.

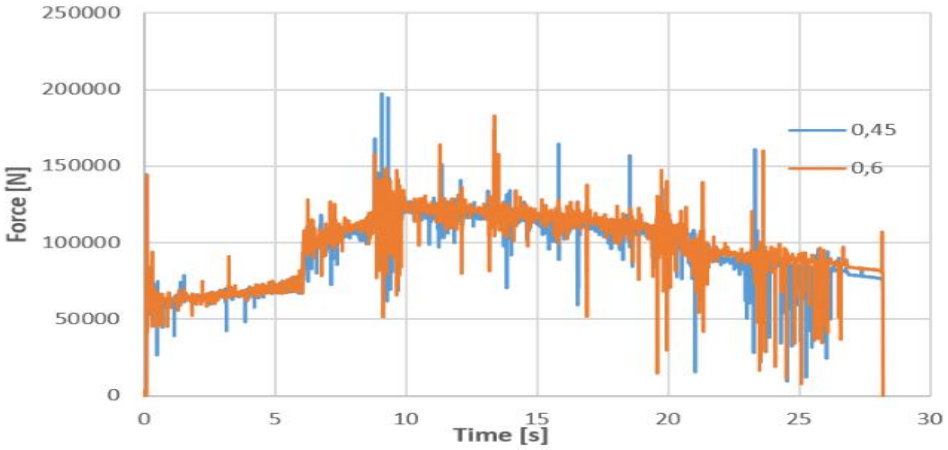
The courses of reaction forces on the ground and on the hook device were recorded during the simulation of the platform loading operation - Figure 12 and 13.

Figure 11. *Various intermediate positions recorded during the hook-loading simulation for: a) the 10' platform and b) the 20' platform. Stage I presents the platforms prior to the start of the loading simulation. Stage II illustrates the first phase of pulling the platforms into the loading area, while Stage III shows the second phase of this process. Stage IV depicts the platforms fully pulled into and positioned within the loading area.*



Source: *Own study*

Figure 12. Changes in reaction forces on the ground in the hook lifting operation for variant 2

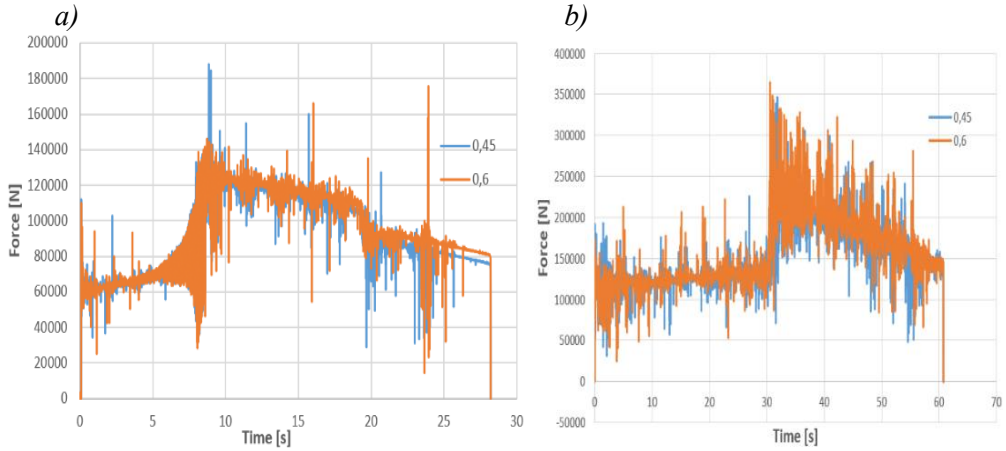


Source: *Own study.*

5. Summary and Conclusions

Numerical tests of the base platform 10’ and the 20’ set were performed in order to obtain design data, but also to build and certify prototypes of the container platform with its structure. For this purpose, an original methodology of multi-stage numerical research was used. Multibody MBS simulations were used to determine the loads in critical operational variants.

Figure 13. *Graphs of contact forces on the arm of the hook device during the hook loading simulation operation of the following platforms (Variant 4): a) 10' foot platform with a load of 10 tons, b) 20' foot platform with a load of 20 tons.*



Source: *Own study.*

Preliminary tests of the 10' foot platforms without side joints in simplified numerical models and subjected to limit loads have shown that it is possible to meet the adopted technical assumptions. Detailed conclusions from the performed numerical tests:

- MBS dynamic analyses make it possible to determine the forces occurring for given variants of hook lifting operation of the platform-container module,
- In the results read from the charts, it can be seen that for variants 1 and 3 the results during hook lifting are less stable than for variants 2 and 4, i.e. for variants with the possibility of rotating the hook holder,
- Approximately in the 6th seconds of the lifting operation, the force increases due to the tilt angle of the platform-container module,
- In the 9th seconds of the lifting operation, the average value of the forces reaches its maximum value and then decreases due to the platform-container module being pulled along the edge of the raised loading platform,
- From the diagrams of forces occurring during hook lifting, it can be seen that the forces are on average higher for a friction coefficient of 0.6 than for a friction coefficient of 0.45,
- In order to verify the results of functional analyses, experimental tests should be carried out using a 1:1 scale prototype of the platform and structure.

Based on the results of the platform strength tests in the MBS and FEM solid models, in which the most important areas of movable connections of the components of the tested structure were represented in detail, separate models of movable joints are built, which will be tested in laboratory conditions.

The results of these tests will be used to collect validation data to improve the numerical models of the platform and to develop final structural and detailed design

documentation for the construction of prototype structures and certification of platforms for intermodal transport.

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