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Innovative technology for making multilayerboards used in mobile systems of specialist transport

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Abstract. The paper presents the technology of production of multi-layer, large-size composite panels shaped by vacuum pressing. The advantages and possibilities of using composite panels as a modern material for the construction of special-purpose transport systems replacing traditional steel and aluminium are indicated. Examples of design solutions for mobile specialized transport systems are presented. For construction of walls, roofs, floors and doors, composite panels with specific strength, aesthetic and hygienic requirements were used. Thanks to the use of lightweight and durable composite panels and the technology used, their joining is resistant to extreme weather conditions, rigid, light and functional, free of all thermal bridges, thus we received mobile container systems with very good insulation parameters.
Key words: composite panel, vacuum press, mobile container system, digital model, innovativeness.

INTRODUCTION

Among the construction materials used to shape various products of engineering art, in addition to classic materials such as metallic materials and plastics, composite materials gain an increasingly stronger position. Their use is determined, among others, by aesthetic, mechanical and thermal features. Particular use has been found for composite panels, which are a modern material used for the construction of special-purpose transport systems replacing traditional steel and aluminium buildings These boards are used for building walls, roofs, floors, doors with high strength, impact, aesthetic and hygienic requirements, especially where lightness of the structure is required and its high resistance to changing and extreme climatic conditions. The advantages of composite panels as construction materials have influenced the growth of interest in the possibilities of configuring various usable space constructions, of such destinations, geometries and functional values that were not possible to obtain earlier, using conventional materials.

CHARACTERISTICS OF THE TECHNOLOGY FOR THE PRODUCTION OF MULTILAYER BOARDS BY VACUUM BONDING

The composite sandwich panel is made by means of vacuum pressing. The elements of the board are permanently joined with two-component polyurethane adhesives, and the production technology enables the production of all necessary reinforcements and insertions at the production stage. This ensures optimal strength of the panel, with a significant reduction in the weight of the building and increasing its aesthetics [1, 6, 10, 11].

The advantages of the vacuum bonding process [11]:

- the possibility of combining different materials,
- even distribution of stresses in the connection,
- the possibility of reducing the mass of glued elements (e.g. due to the fact that we do not connect elements pointwise, but on the whole surface - we can use a thinner skin material),
- simultaneous bonding and sealing,
- prevention of electrolytic corrosion (in the case of metals, the adhesive separates the elements - there is no galvanic connection between them),
- electrical and thermal insulation,
- absorption of vibrations,
- reducing of the finishing operation.

PROPERTIES OF MULTILAYER BOARDS

Composite, lightweight sandwich panel with hard extruded polystyrene core, polyurethane foam or specially prepared for this purpose mineral wool coated with polyester laminate reinforced with glass cloth, varnished with aluminium, steel or other composite, depending on the intended use.

An example of the order of arrangement of sandwich board composites is shown in Figure 1.

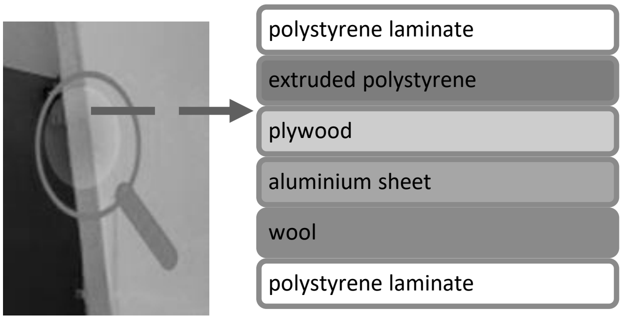

Fig. 1. Exemplary arrangement of multi-layer composite board

Composite boards manufactured by vacuum bonding show the following useful properties [10]:

- light weight,
- very good insulation,
- high mechanical resistance and strength,
- high aesthetic quality and durability of the surface,
- very good water resistance, and changing weather conditions,
- very good resistance to corrosion, ageing, and mould fungi,
- colour durability,
- easy assembly and simple repair technologies.

The modern adhesive system ensures high strength parameters and tightness of connections, eliminating thermal bridges of the structure.

Skin used in the production of composite sandwich panels [1, 21, 22]:

- polyester plate reinforced with glass cloth, 2-3.5mm thick,
- aluminium sheets lacquered 0.75 ÷ 1mm thick,
- epoxy laminate (melamine) board with a thickness of 1.5 ÷ 2mm, recommended for interiors requiring high hygienic requirements,
- "Farmacel" type plate, i.e. reinforced with polyester fibre, waterproof gypsum board,
- steel plate,

Materials glued into composite multi-layer boards, depending on the purpose of the final product:

- INOX steel sheets,
- aluminium sheets,
- EMI composites and fabrics,
- composites containing so-called honeycomb layers,
- radiological covers,
- reinforcements and steel structures,
- reinforcements and aluminium structures,
- made of polyester-glass composites,
- various types of plastics.

CHARACTERISTICS OF THE TECHNOLOGY FOR THE PRODUCTION OF MULTI-LAYER BOARDS

The composite sandwich panel is made by vacuum pressing on the vacuum press table on which the forming process takes place followed by gluing [4, 10, 14].

The gluing technology sets the following requirements [2, 3]:

- absolute compliance with cleanliness in rooms where gluing processes are carried out,
- care for proper temperatures in the rooms used, in accordance with the recommendations of the adhesive system manufacturer,
- strict adherence to included in the technical sheets the time of individual stages of gluing processes,
- the right choice of materials for preparing the surface of glued materials and composites,
- observance of the appropriate for each stage of gluing the ways and times of the gluing process - pressing in a vacuum press, clamping, technological twisting, etc.

Properly performed technological process ensuring obtaining a very rigid, and at the same time desired, flexible construction. Depending on the intended use of the final product, suitable materials are selected for both composite panels, as well as a supporting structure: steel, composite or aluminium.

Using the discussed technology, you can build mobile container systems: for refrigeration, social, storage, medical, and with sliding doors to increase the usable space.

After preparing the technical design of the sandwich panel, the technological design of the slab is prepared. It consists in specifying all components listed in the technical project with the specification of dimensions, specifying their tolerances. The technology design analyses the materials in terms of their physical and chemical properties and susceptibility to gluing. Glued surfaces must be cleaned of oxides and deposits, dry and clean. Prepared elements are laid starting from the outer skin, if it is designed as flat, or internal if the outer shell is designed as convex. The level of the current temperature and humidity in the room is recorded and the allowed times determined on the basis of the prepared diagram - mixing, opening and pressing of the adhesive at these specific conditions.

All elements prepared to fill the core of the sandwich panel are systematically covered with glue. After the automatic closing of the press, the appropriate vacuum level is set for the application, provided by the so-called "duty pump" that maintains the set vacuum values in the press.

The following parameters are important in the technology of gluing boards using a vacuum press [1, 10, 21, 22]:

- selection of the right type of glue depending on the opening time required for proper position of glued layers,
- selection of the appropriate ambient temperature for the process in the range from 16 ° C to 25 ° C, which directly determines the time of applying, opening and hardening the adhesive,
- maintaining relative humidity in rooms within 55%,
- providing a suitable machine park for precise formatting of glued elements,
- providing the right atmosphere in the rooms - air free of dust and pollution,

- ensuring proper internal transport of components of multi-layer boards and finished products.

The check of glued joints is carried out by non-destructive and destructive methods. Non-destructive test methods include: visual inspection, high voltage test, ultrasonic test, X-ray test, vacuum test, and determination of water and gas-tightness.

Simultaneously with the product being made, samples of it should be made, which should be assessed in accordance with existing standards.

There are three basic standards defining the quality of adhesives and glued joints, according to which the tests are conducted:

- determination of shear strength according to PN-69 / C-89300,
- determination of the tear-off strength of adhesives according to PN-69 / C-89302,
- determination of the tear-off strength of adhesives according to PN-65 / C-89301.

Joined elements should stay under the load recommended by the adhesive manufacturer. The appropriate load depends on the type of filling and construction of the inner plate. The joined elements should not be moved during pressing.

STRENGTH ANALYSIS OF THE MODULE USED TO BUILD SPECIALIZED MOBILE SYSTEMS

Constructions of specialized mobile systems are made in technology pasting into the steel frame of the structure, multilayer composite panels, which constitute the outer casing, acting as a thermal shield, increase the stiffness of the steel structure of the frame and improve the strength parameters Composite elements are also used to build self-supporting structures for various purposes.

With the use of the finite element method, strength and stiffness calculations [6] of selected variations of the container structure were made, constituting the main module used to build mobile specialist systems. Positive verification of the digital container model using numerical methods was the premise for the physical construction of a container structure with glued composite panels. Computer calculations were positively verified in laboratory research stands.

In the design process, constructions were assigned all geometrical, material and dynamic features, both in quantitative and qualitative form [1]. This made it possible to perform simulation calculations using the finite element method. Figure 3 presents digital models of selected container construction variants: skeletal version (traditional) and using new technologies with glued composite panels.

The MES calculation methodology was performed in the following steps [18, 20]:

- creating a geometric model of the object,
- selection of material properties,
- definition of the contact zone,
- defining the type of contact,
- creation of finite element mesh,
- introduction of boundary conditions,
- implementation of calculations,
- analysis of the obtained results of calculations.

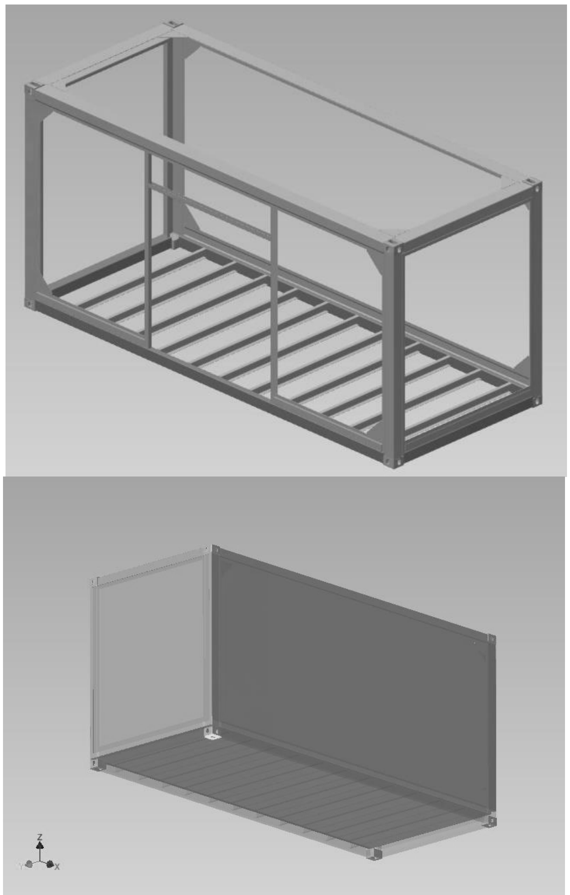

Fig. 2. Digital models of selected container construction variants

Four load variants were taken into account in the calculations, in line with the research methodology used at laboratory test stands. The forces in individual variants (except for the case of own load) were placed in the upper corners of the container structure. This corresponded to the methodology of laboratory tests performed with a real testing machine at the request of the manufacturer. The table below shows the values of loading forces:

Table 1. Values of forces loading the structure

Load case	The value of the force
Vertical force	318,000N
Transverse force	75,000N
Longitudinal force	75,000N
Own loading	------

Figure 4 presents three model load cases of the container structure. The way and point of applying of forces is in line with the standard test procedure carried out on certified measuring stations [5, 19].

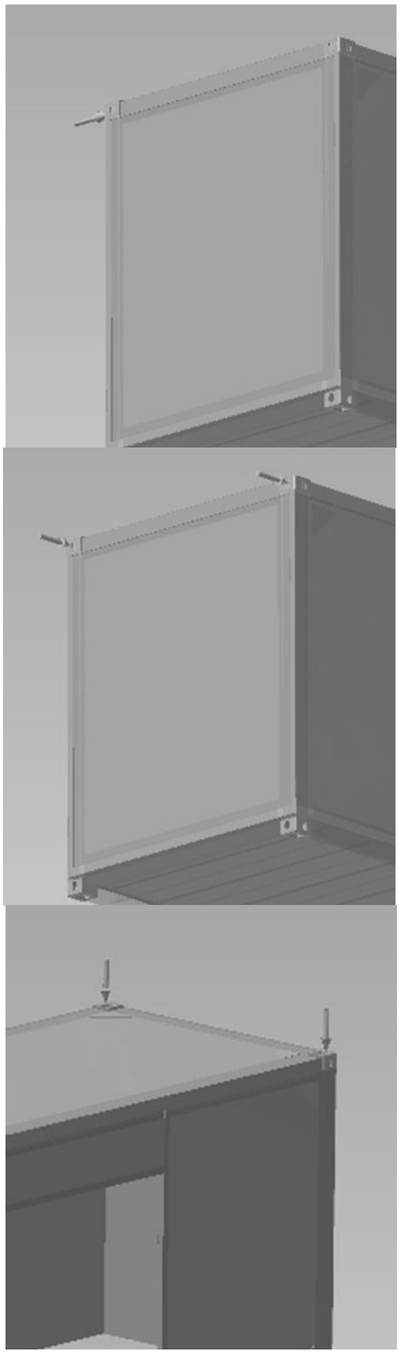

Fig. 3. Scheme of applying forces on a measuring stand

In the digital model of the container with the plates [14, 18, 20], 782 pairs of contacts were generated between the elements constituting the skeleton and the skin. In order to effectively carry out the analysis of the assembly (container with plates), 46 elements being thin bodies were simplified. This is how calculations in case when there are elements of very different dimensions in the structure can be carried out. Subsequently, the analysis area was divided into a finite element grid. Using the "solver" module of the MES system, digital displacement maps were generated for the tested container versions. Figure 5 shows displacements of the container structure without composite panels and with glued composite panels subjected to vertical forces in the upper corners of the frame.

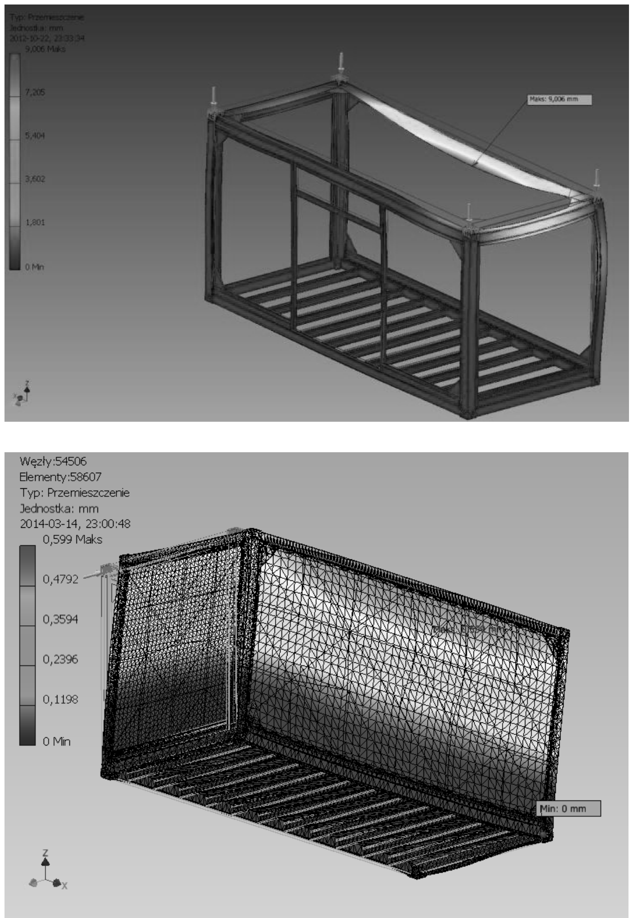

Fig. 4. The deformation map of the container without composite plates and with glued composite panels

Table 2. Compilation of the obtained calculation results

Type of load	Container without plates	Container with composite plates	Relative deformation decrease [%]
vertical	9.01 mm	0.85 mm	90.57
longitudinal	63.00 mm	0.44 mm	99.30
transverse	63.92 mm	0.60 mm	99.06
own	5.58 mm	0.08 mm	98.57

The calculations prove that the deformations of the container structure with glued multi-layer composite panels are much smaller than in the case of classic structural solutions. A decrease in the value in the range (90% - 99%) was recorded. The results of numerical calculations have been confirmed in tests at certified laboratory stands.

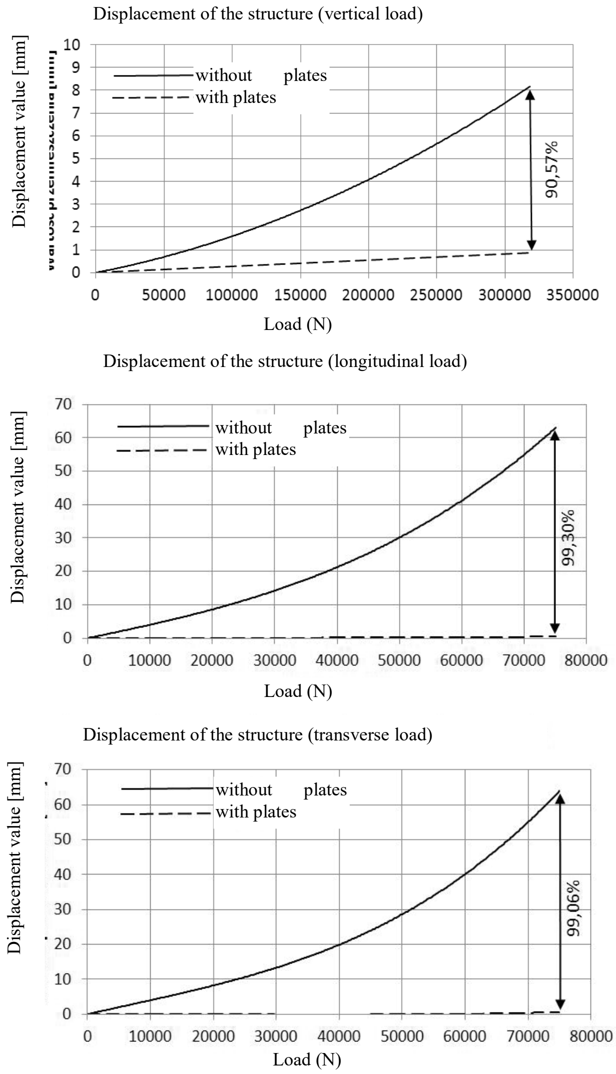

Fig. 5. Displacement dependencies from load types (no own load)

CONSTRUCTION SOLUTIONS FOR MOBILE SPECIALIZED TRANSPORT SYSTEMS

The technology of making multi-layer and large-size composite panels has been used in many practical applications [4, 13, 17]. The physically realised mobile constructions in which composite panels are used are described below.

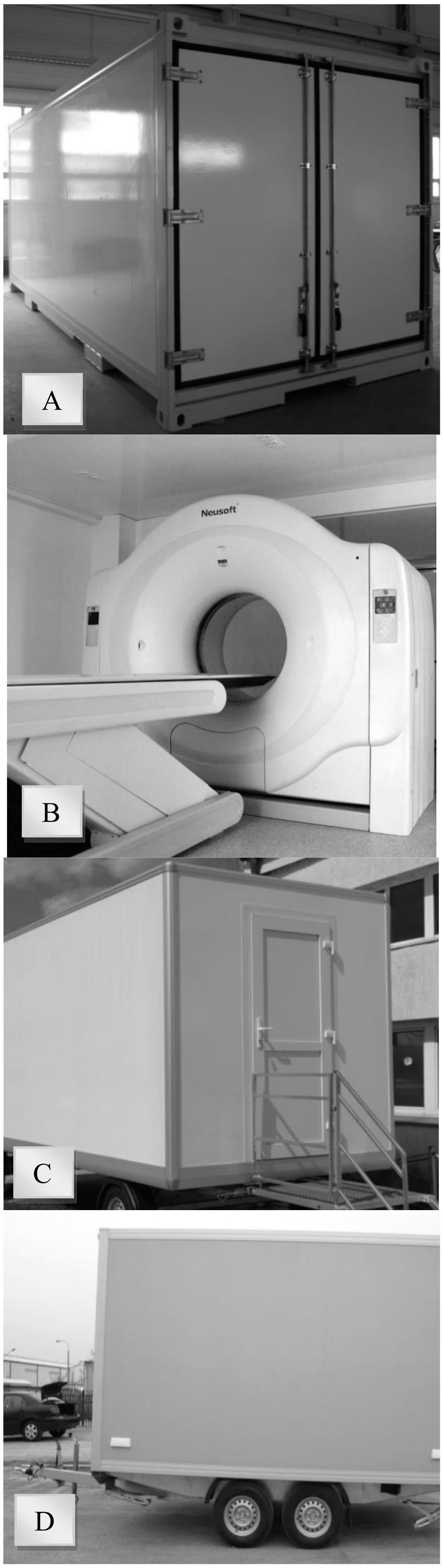

Fig. 6. Examples of use of multi-layer boards in mobile constructions

Refrigeration container (A) intended for transporting and storing various types of food. The presented solution uses a lightweight steel structure, into which the tightly fitting composite panels were glued, with all necessary reinforcements glued into them, intended for mounting the internal equipment of the container (fixing loads, ANCRA floor structures, etc.), and distributing the electrical installation. The construction of a light under-floor frame allows the unloading of a container from the vehicle with a forklift or (if the vehicle is suitable for transporting removable containers), putting the container on the legs with which the container is equipped.

Thanks to the use of lightweight and durable composite panels and the unique technology used, container gluing has been made resistant to extreme weather conditions rigid, light, functional, free of all thermal bridges with very good insulation parameters. Product with a load capacity exceeding steel containers with traditional construction - thus a product of a load capacity exceeding steel containers of traditional design has been obtained.

Using the discussed technology of creating entire composite structures, innovative sliding containers (B) are made, in which the floor of the main container is always available, and the equipment of the sliding parts is fixed on the walls. Thanks to this, the basic heavy elements of equipment for operating rooms, operating rooms or diagnostic rooms, such as a computer tomograph, X-ray machine or dental unit can be permanently attached to a specially designed composite floor. This ensures safe transport and quick access to devices after the container is opened. This provides the necessary comfort of the medical team and treated patients. Thanks to the use of composite panels for the production of this type of containers, a system of completely automatic unfolding and folding of containers based on electric motors supplied with 24V voltage from accumulators which are in equipment was created.

The surfaces of walls, ceilings and floors are easy to clean, resistant to disinfectants, and easy to repair in case of an accidental damage.

Social containers (C) are designed for various types of spaces, such as barracks, toilets or watchtowers. Their use is pretty various and can adapted to very diverse climatic conditions (from -50 ° C to + 50 ° C).

Containers can be equipped with sanitary, air-conditioning, heating with electric or oil-fired furnaces. Depending on the purpose of the object, the façade can be made of low profile facade sheets, PVC, or aluminium or steel siding.

Containers of this type, made in the technique of gluing multi-layer composite panels are used for the construction of mobile barracks, sanitary facilities and warehouses. The applied construction and technological solutions ensure high rigidity and stability of the objects. Elimination of thermal bridges, thanks to the gluing technique, greatly increases the insulation parameters of objects.

Technology of manufacturing containers by technology of bonding multilayer composite panels has been used to build mobile service trailers (D). The advantages of the construction and technological solutions used include: lightness of the object, no occurrence of corrosion phenomena, the possibility of using in extreme climatic conditions, high stability and rigidity of the structure.

CONCLUSIONS

The technology of shaping multilayer, large-size composite panels due to the presented functional advantages qualifies for the category of innovative solutions. Using the discussed technology, you can build mobile container systems: refrigerated, for social, storage, medical uses, sliding etc., as well as modular building systems with the possibility of configuring various usable spaces of them, with such destinations, geometries and functional values that were difficult or impossible to obtain, using conventional steel supporting structures.

The implementation of production technology developed by NTContruction technology for the shaping of large-size composite panels has been crowned with the development of new mobile structures of considerable originality and usability. This technology enables shaping not only large-size but also boards and other elements with smaller overall dimensions with proven high-quality qualities.

Stiffness calculations show that the deformations of structures in which composite panels are used are smaller than those in which the basic support element is the frame structure. Multilayer composite panels that are the walls of the container receive an additional function in a significant way increasing the stiffness of the analysed structure.

Structures in which composite panels are used are ideal for multi-storey building systems, container storage, for example: transport ferries or warehouses in which the utilisation of space is particularly important. The developed digital models for which simulation studies were conducted were verified by experimental research carried out on the test stand consisting in loading the actual structure with normalized force values, in accordance with the research methodology [14, 16]. Empirical studies confirmed the results of numerical calculations. The design met the assumed stiffness and strength criteria. Deformations of structures with glued composite panels did not exceed the admissible values. As a result of empirical research, the modelled object (a container with composite plates) received the PRS certificate.

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