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DESIGNING FOLDING WALL BOX PALLETS

ABSTRACT

Designing of modern box pallets with folding walls, which are used for example to transport tires, requires fulfilment of a number of performance requirements. Such pallets, adapted to be moved by forklifts, are stored or transported without loading with walls folded, and during operation they are put together in the piles of a few pieces and braced by the transport belts. Difficult operating conditions are related to necessity to provide resistance of construction of a pallet or their pile on: bending, piling, stability, hitting in case of a free-fall, lifting by forklift, as well as the resistance to horizontal strokes by both edges and legs. In order to meet the above mentioned requirements, it is necessary to implement the relevant tensile FEM analyses, which are then reviewed by the relevant experimental testing. The paper discuss the requirements specified by standards for designing of the above mentioned pallets and presents FEM results in the process of pallets' designing.

Keywords: *loading pallet, FEM, strength, design*

PROJEKTOWANIE PALET ŁADUNKOWYCH SKRZYNIOWYCH ZE SKŁADANYMI ŚCIANKAMI

Projektowanie nowoczesnych palet skrzyniowych ze składanymi ściankami, wykorzystywanych np. do transportu opon samochodowych, wymaga spełnienia szeregu wymagań eksploatacyjnych. Palety takie przystosowane do przemieszczania wózkami widłowymi, przechowywane są lub transportowane bez ładunku w stanie ze złożonymi ściankami, a w trakcie eksploatacji zestawiane są w stosy po kilka szt. oraz stężane pasami transportowymi. Trudne warunki eksploatacji związane są z koniecznością zapewnienia odporności konstrukcji palety lub ich stosu na: zginanie, piętrzenie, stateczność, uderzenie przy swobodnym spadku, unoszenie za pomocą wózka widłowego oraz odporność na uderzenia poziome obiema krawędziami i nóżkami. W celu spełnienia w/w wymagań, konieczne jest wykonanie odpowiednich analiz wytrzymałościowych MES, które weryfikowane są następnie odpowiednimi badaniami eksperymentalnymi. W pracy omówiono wymagania normowe dotyczące projektowania w/w palet oraz przedstawiono wyniki wykonanych analiz MES w procesie projektowania palet.

Słowa kluczowe: *palety ładunkowe, MES, wytrzymałość, projektowanie*

1. INTRODUCTION

Certain materials, e.g. car tyres, are transported in special box pallets with folding walls, designed for forklift handling. During their use, such pallets are stacked several units high and braced with tie-down straps. Empty pallets are stored or transported with their walls folded.

Difficult conditions in which pallets are used result from the need to meet operational requirements, such as easy moving of mobile components, easy access to fixing and protection fittings during the storage and transport, easy replacement of damaged or wearable parts, all of which must be done while meeting the applicable strength requirements laid down in standards (PN-M-78205:1988 and PN-EN 614-1:2007). During design work, it is necessary to fulfil strength requirements that guarantee the appropriate integrity of the pallet or a stack of pallets making them resistant to: bending, stacking, free-fall impact, horizontal impacts with two edges and legs as well as lifting with a forklift truck and ensuring their stability.

2. STRENGTH CALCULATION ASSUMPTIONS

To obtain the appropriate operational characteristics of pallets their dimensions and projected operating conditions must be defined. In the case of specialised pallets for transporting and storing passenger car tyres under consideration here, the nominal load-bearing capacity of a single pallet was assumed at 10 kN while the dimensions of the base are 2.400 mm × 1.250 mm and the height 2.200 mm (Ładecki and Matachowski 2008). A stack of three was assumed as the maximum number of pallets stacked, but it was assumed that empty pallets should not be stored open and the maximum number of empty pallets folded close and stacked for storage is 12. In the case of truck transport, it is permitted to transport either one loaded pallet or five empty, folded down ones. For pallet storage and transport it is necessary to use a top plate on each uppermost pallet in the stack to prevent the excessive deformation of rack uprights during storage and wheeled transport, regardless of the number of pallets in a stack. The top plate may be replaced with bracing tie-down straps of the appropriate load capacity fixed at the level of 150 cm above the pallet base. S235JR steel (according to PN-EN 10025:2007), for which the yield point of elements ≤ 16 mm thick is $f_y = 235$ MPa, was adopted as the material for research. The minimum load capacity parameters of the floor were adopted as B20 concrete at least 150 mm thick.

3. PALLET STRENGTH ANALYSIS

The FEM Femap/NE Nastran suite was used to analyse the strength. A beam model fully reflecting the pallet geometry was

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used in FEM calculations. The model consists of 2000 beam elements (CBEAM) 25 mm long on the average and of rigid elements (RBE2) connecting the side frame with the bottom frame (bolts). The geometric characteristics of beam elements correspond to the dimensions of structural elements identified using the FEM analysis. The pallet strength analysis includes checking the integrity of the pallet in the strength cases presented below in accordance with standard (PN-M-78205:1988) requirements, but the calculation does not account for a top plate, because a uniform distribution of mass over the pallet is assumed.

3.1. Flexural strength

A pallet should not be damaged or permanently deformed when weighed with a mass equal to the product of its nominal load capacity multiplied by the coefficient of 1.25. The elastic deflection should not be greater than 1/200 of the longer dimension of the pallet side between the supports if the load is distributed evenly. The distribution of normal stresses in a transverse bend stress is shown in figure 1.
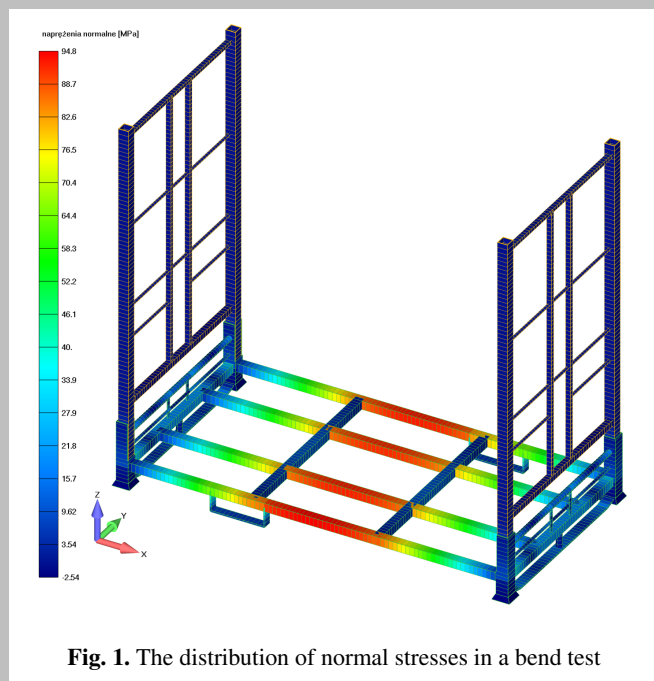

Fig. 2. The maximum vertical sag of the bottom pallet when three pallets are stacked

Fig. 1. The distribution of normal stresses in a bend test
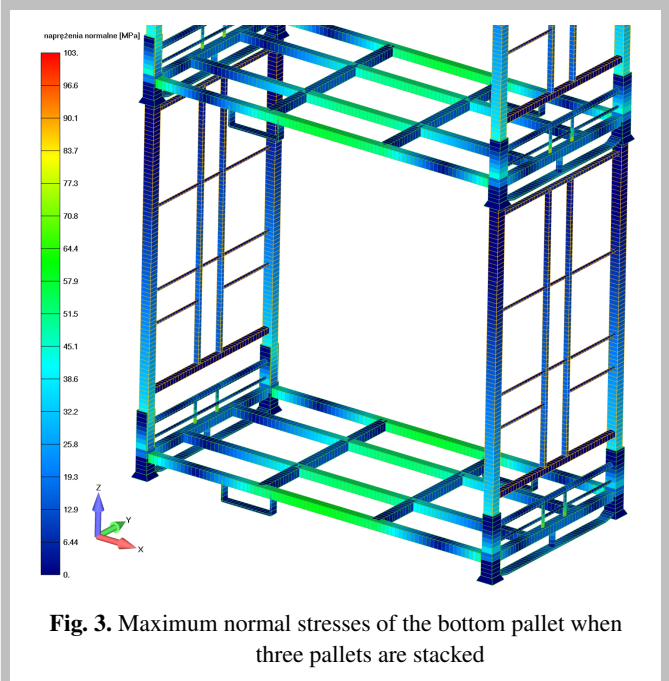
Fig. 3. Maximum normal stresses of the bottom pallet when three pallets are stacked

3.2. Stacking strength

A pallet should resist the load of a mass equal to the pallet load capacity times the coefficient of 2.12 when three pallets are stacked upright, while the elastic deflection should be below 1/200 of the dimension of the longer side of the pallet between supports if the load is distributed evenly. Based on the calculations completed, it was found that the maximum deflection and normal stresses occur in the bottom pallet and do not exceed the permissible values of the adopted pallet geometry – figures 2 and 3.
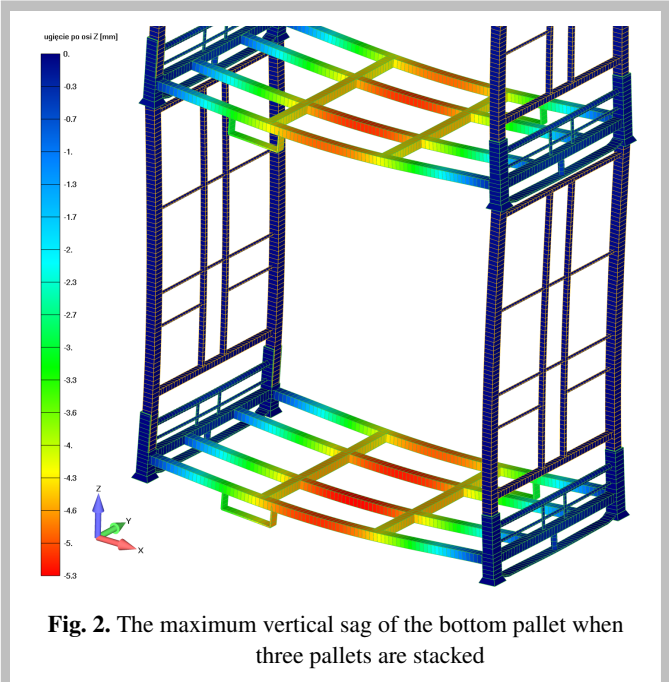
3.3. Stability

A stack of pallets should be stable when built on a smooth, level surface. Stability control can be carried out in accordance with standard (PN-EN 1993-1-1:2006), adopting no more than three evenly loaded pallets in a stack and taking into account the loading coefficient $\gamma_F = 1.25$. In that case there is not needed to calculate critical load for buckling. Figures 4 and 5 show, respectively, the flexural and the torsional form of buckling for the bottom pallet of the stack, which is the loaded most.
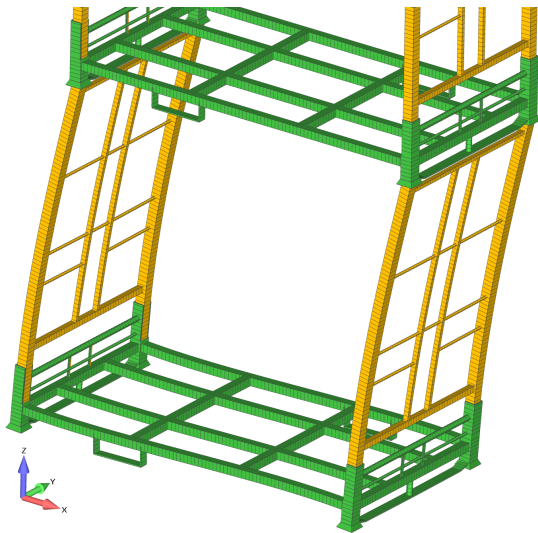
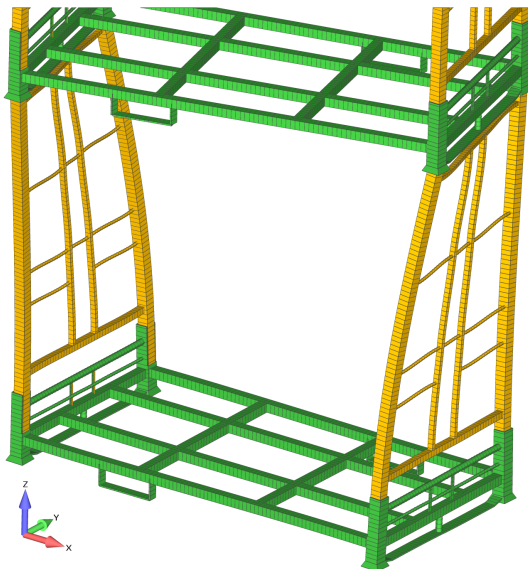**Fig. 4.** Elastic buckling – flexural

Fig. 5. Elastic buckling – torsional

3.4. Impact strength in free-fall

A pallet loaded with a mass equal to its nominal load capacity should withstand the impact of a free fall from a height of 0.2 m onto the surface pressing on its legs. Assuming an even fall of the pallet (all legs of the pallet are displaced equally), the stresses within their cross-section at the moment they hit the floor after the pallet has fallen from the height of 0.2 m amount to (Kaliski *et al.* 1966):

$$\sigma = -\frac{1}{4}\rho a v_0 \qquad (1)$$

where

$\rho = 7850$ kg/m^3 – steel specific weight,

$E = 2.05 \cdot 10^5$ MPa – longitudinal elasticity (Young) coefficient,

$a = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{2.05 \cdot 10^{11}}{7.850 \cdot 10^3}} \cong 5.1 \cdot 10^3$m/s – the propagation rate of the elastic deformation wave,

$v_0 = \sqrt{2gh} = \sqrt{2 \cdot 9.81 \cdot 0.2} = 1.98$m/s – the speed at the moment a pallet free-falling from the height of $h = 0.2$ m hits the floor.

Having substituted numerical values in equation (1), we obtain what follows:

$$\sigma = -\frac{1}{4}7850 \cdot 5.1 \cdot 10^3 \cdot 1.98 \cong -20.0 \text{ MPa}.$$

After the impact caused by the fall, the pallet should show no permanent deformations - and this was confirmed by the FEM simulations run for the predefined pallet geometry: figure 6 – forced by the normal stresses in the legs of the pallet structure.
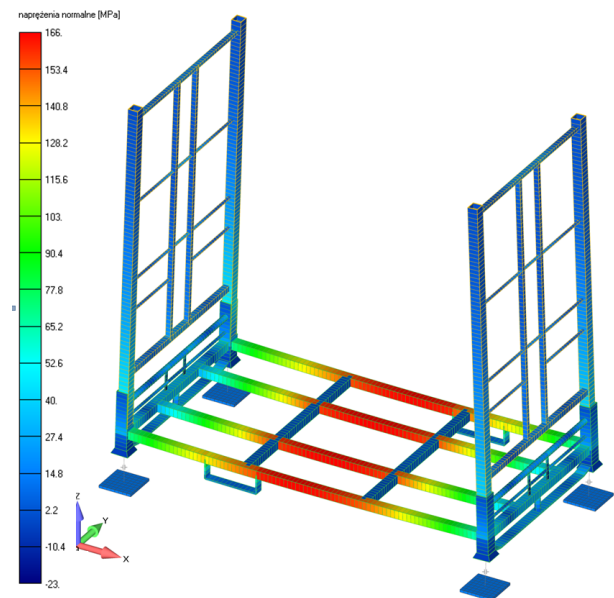

Fig. 6. The distribution of normal stresses at impact after a free fall

3.5. Horizontal impact strength

Horizontal impact strength is checked according to the requirements of standard (PN-EN ISO 2244 2007), pursuant to which a pallet moving horizontally at a defined speed should be stopped by hitting a vertical crash wall. The crash wall should be so rigid that a load of 160 kg/cm^2 applied at any point of its surface should not bend it by more than 0.25 mm. The two most unfavourable and at the same time most likely distributions of points of pallet contact with the wall during the crash (the bottom horizontal edge and the vertical edge) are assumed in the calculations, and so is the speed of $v = 2.2$ m/s at the moment of the crash, which is the maximum permissible driving speed of forklift trucks.

The horizontal edge impact strength is modelled as the case in which the pallet hits the crash wall with its bottom edge and then the mass of the load causes it to hit the wall with the upper edge.

If the lower edge of the pallet hits the crash wall, the stresses in the zone of contact between the crash wall and the pallet are as follows (Kaliski *et al.* 1966):

$$\sigma = -\rho \frac{a}{2} v. \tag{2}$$

Having substituted numerical values in equation (2), we obtain what follows:

$$\sigma = -7850 \cdot 5.1 \cdot 10^3 \cdot 0.5 \cdot 2.2 \cong -44.0 \text{ MPa}.$$

This is based on the assumption that when the upper edge hits the crash wall, the stresses in the pallet/crash wall contact zone are distributed evenly (in all four zones). Thus, one pallet/crash wall contact zone carries stresses equal to $\sigma/2 = -22.0$ MPa if it is the horizontal edge that hits the wall.

The vertical edge impact strength is modelled as the case in which the pallet hits the crash wall with the vertical edge at angle $\beta_2 = 26.4^\circ$, which is the relative angle of the upper edge of the pallet to the impact axis (the pallet diagonal). In this case, normal stresses in the pallet/crash wall contact zone are as follows:

$$\sigma = -\rho \frac{a}{2} v \sin \beta_2. \tag{3}$$

Substituting v = 2.2 m/s in relationship (3) yields:

$$\sigma = -7850 \cdot 5.1 \cdot 10^3 \cdot 0.5 \cdot 2.2 \cdot \sin 26.4^\circ \cong -19.5 \text{ MPa}$$

At the moment of impact, stresses must not exceed the yield point of the material. The loading diagram presenting the values of maximum normal stresses when the pallet hits the wall with the horizontal and the vertical edges is shown in figures 7 and 8.
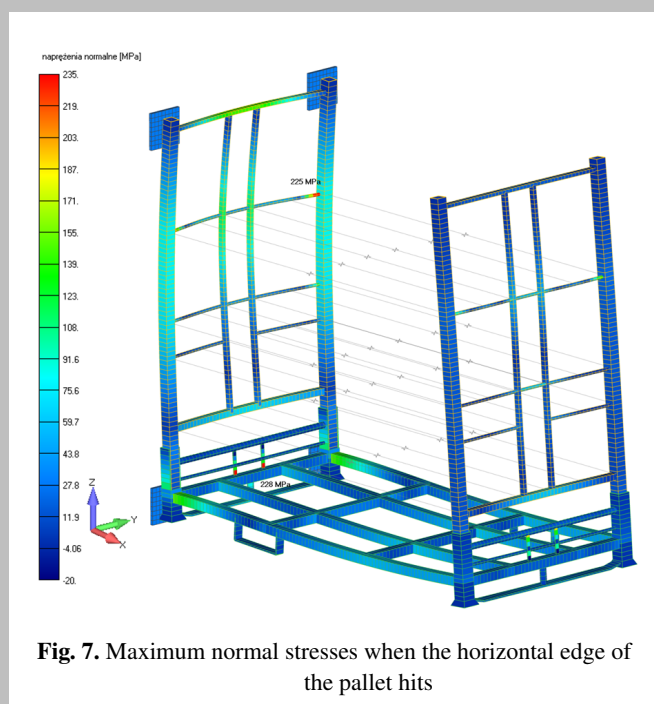

Fig. 7. Maximum normal stresses when the horizontal edge of the pallet hits
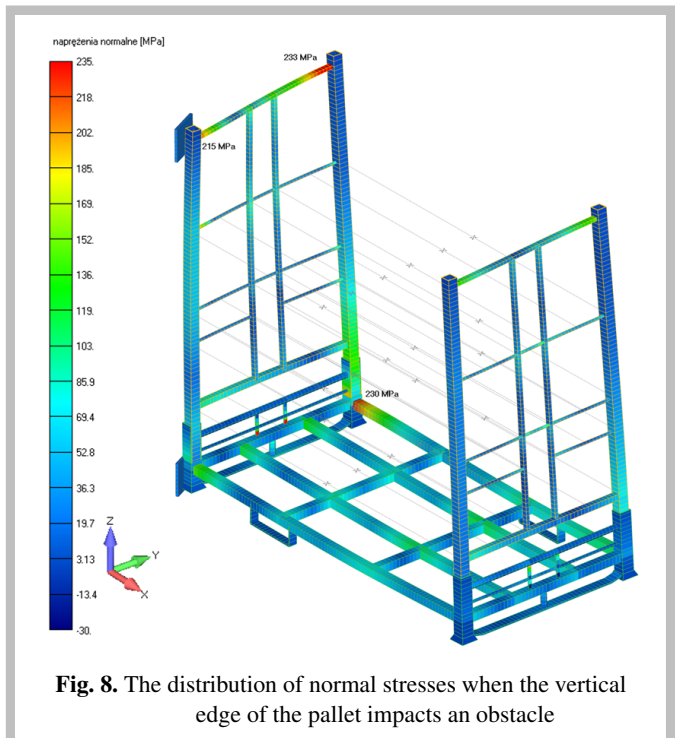

Fig. 8. The distribution of normal stresses when the vertical edge of the pallet impacts an obstacle

3.6. Leg impact strength

The pallet should be loaded evenly and its legs should impact against a support beam while the wall leaves are folded. It can be assumed when it impacts, a pallet loaded with a nominal load with the loading coefficient $\gamma_F = 0.1$ has travelled the distance of 1 m along a slope angled at $\alpha = 10^0$, which corresponds to the impact speed of $v_1 = 0.59$ m/s at the moment of impact.

In this impact case as well, the stresses in the legs/support beam contact zone can be determined from the following equation (Kaliski *et al.* 1966):

$$\sigma = -\rho \frac{a}{2} v_1 \tag{4}$$

If numerical values are substituted in relationship (4), this yields:

$$\sigma = -7850 \cdot 5.1 \cdot 10^3 \cdot 0.5 \cdot 0.59 \cong -11.8 \text{ MPa}.$$

The distribution of normal stresses when the legs hit the beam are shown in figure 9, in which it is apparent that the stresses do not exceed the yield point of the material.
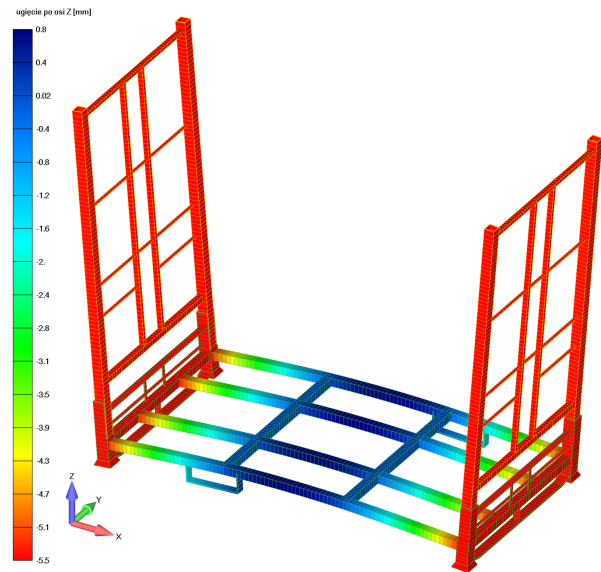
3.7. Forklift truck lifting strength

The resistance to being lifted using a forklift truck is checked for a pallet without the upper plate, lifted by a forklift truck while the weight is evenly distributed.

The maximum deflection of the pallet while it is being raised by a forklift truck should be lower than the maximum permissible flexural elastic deflection of the pallet and no permanent deformation of the pallet should occur. Pallet deflection during its raising with a forklift truck is shown in figure 10.
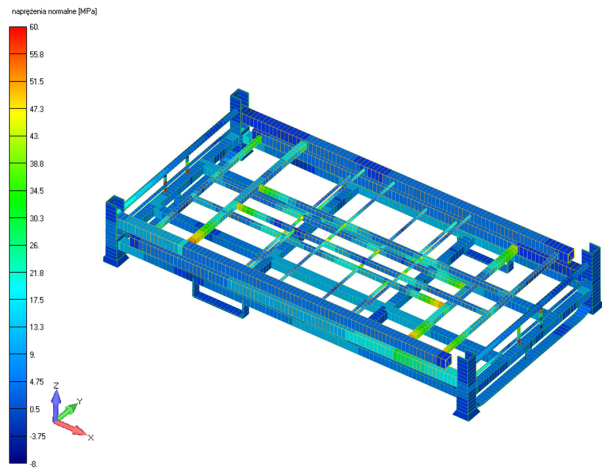
Fig. 9. The distribution of normal stresses when legs impact an obstacle

Fig. 10. The pallet deflection in the axial direction when lifted by a forklift truck

4. SUMMARY

Strength modelling with the use of the FEM analysis usually represents the first stage in design work, at which the appropriate usage, strength, ergonomic and environmental engineering requirements are accounted for. A structure thus designed should be verified by conducting the appropriate experimental research on real-life units.

Several years' operation of several hundred pallets whose structure had been designed while meeting the requirements described above has shown that the right assumptions had been made using strength analyses of the considered pallet to determine its resistance to complex conditions of its operation, and in particular that the pallet structure or the stack of pallets has been made resistant to bending, stacking, free-fall impacts, lifting by forklift truck, horizontal impacts to both edges and legs and ensures its stability.

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