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STRENGTH ANALYSIS OF THE FRAME OF A TRAILER

Summary. A trailer for carrying a small boat or water scooters was designed for a private sector company. It was a category O1 non-braked trailer with a gross weight up to 750 kg and a height-adjustable traction device. The frame must be designed and installed in such a way that, during its proposed lifetime, it will withstand all the loads and influences that may occur during construction and operation with an appropriate level of reliability. The designed frame of the trailer is a welded galvanized structure. The article is devoted to the problems related to the stress analysis of a trailer frame.
Keywords: trailer; frame; design; strength analysis; finite element method

1. INTRODUCTION

The design of a frame structure is based on the knowledge and experience that are commonly available at the time the design is proposed [7-8, 10, 11]. The supporting structure (frame) must be designed and installed in such a way that, during its proposed lifetime, it will withstand all the loads and influences that may occur during construction and operation with an appropriate level of reliability. Furthermore, the designed support (frame) structure must meet the relevant user requirements specified for the support structure or supporting element. The support (frame) structure must be designed to have the appropriate durability and usability.

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Possible damage to the steel structure (frame) must be eliminated or prevented by the appropriate choice of measures [6]. These include ensuring the integrity of the load-bearing structure and selecting a support structure that is considered to be capable of carrying an unforeseen loss of an individual element or enduring acceptable local damage.

It is also important to take appropriate diagnostics during operationalization into account, for example, by non-invasive methods [1-4, 9].

2. TRAILER FOR TRANSPORTING BOATS AND PERSONAL WATERCRAFT

A trailer was designed for a private sector company. It was a non-braked trailer (category O1, gross weight up to 750 kg) with a height-adjustable traction device for carrying small boat or water scooters. The designed trailer and its accessories are shown in Fig. 1.

The support (frame) structure must be designed to have the appropriate durability and usability.

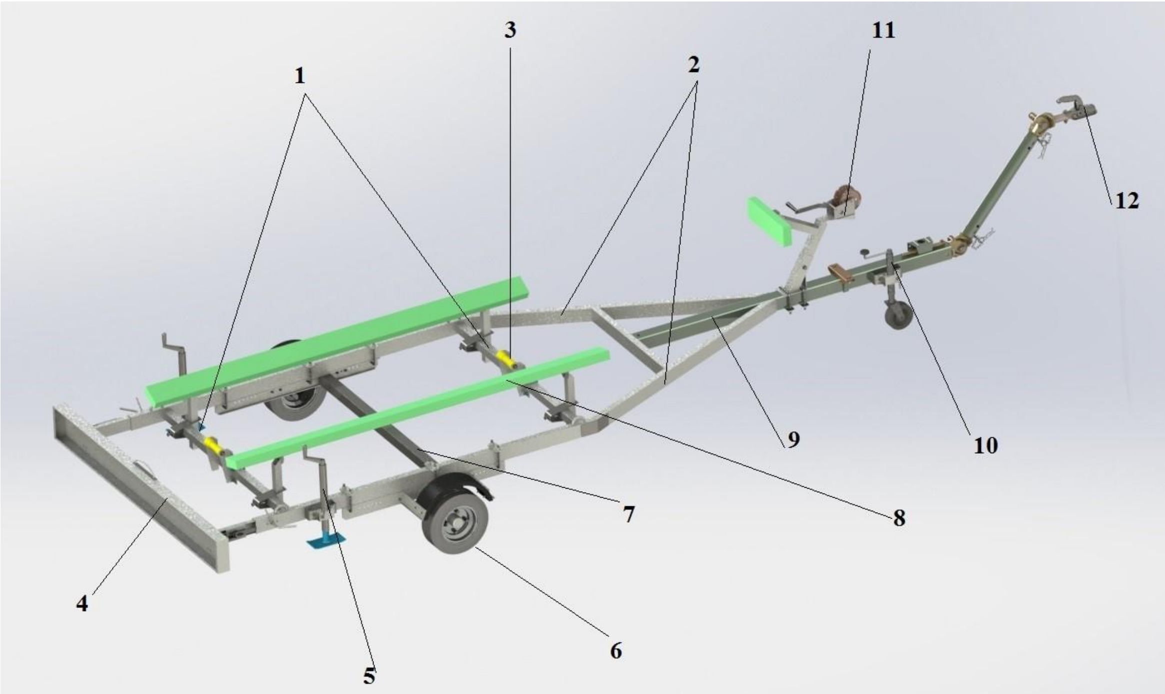

Fig. 1. The designed trailer with accessories

The descriptors for Fig. 1 are as follows: 1) a cross beam; 2) longitudinal beam; 3) guide rollers; 4) a draw-out light panel; 5) supporting leg with holder; 6) wheel; 7) axletree; 8) guide skis; 9) height-adjustable lift device; 10) supporting wheel with holder; 11) height-adjustable reel; 12) connecting hinge.

The axle (position 7 in Fig. 1) is mounted under the frame and fulfils the function of the intermediate transverse beam. Between the axle (position 7 in Fig. 1) and the trailer frame are two cross beams (position 1 in Fig. 1), which reduce stress and deformation on the frame of the trailer. When loading and unloading a boat or water scooter, it is necessary to immerse the trailer in the water. The trailer truck is designed to have a total weight of not more than

750 kg. This means that the maximum weight can be 450 kg because the weight of the separate trailer is 240 kg.

An important component is the boat carrier for the transport of boats. It is attached to the frame by means of a boulder clamp. The designed holder for the guide rail is shown in Fig. 2. Position 1 is the top of the guide rail, which comprises 4 mm of thick sheet metal. The centre holder of the cam chain guide is in position 2. The bottom holder of the cam chain guide (position 3) also comprises 4 mm of thick sheet metal. In position 4 is a screw with a washer, while a boat carrier is located in position 5.

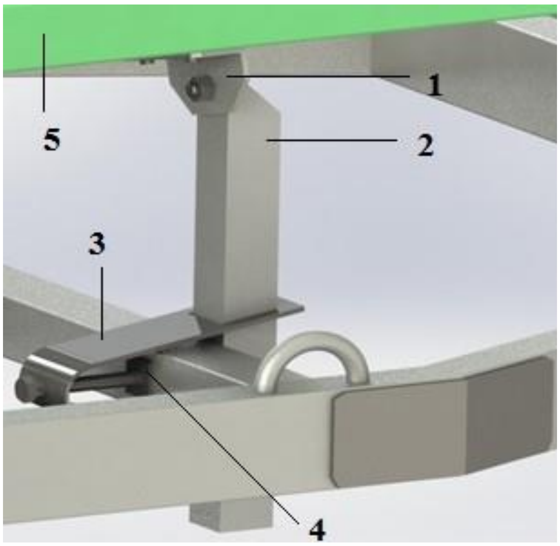

Fig. 2. The designed holder for the guide rail

3. DESIGN OF A TRAILER FRAME

The designed frame of the trailer is a welded galvanized structure. The frame consists of two longitudinal beams (position 1), two cross beams (position 2) and one shorter cross beam (position 3), as shown in Fig. 3.

These elements are joined together by welded joints. The overall frame dimensions are 5,200 mm x 1,950mm. The longitudinal beams (position 1 of Fig. 3) are made of the profile 80 x 40 x 4 mm (h x b x t in Fig. 4). The cross beams (position 2 of Fig. 3) are made of the profile 50 x 50 x 4 mm (5 x b x t in Fig. 4) and the shorter cross beam (position 3 of Fig. 3) is made of the profile 80 x 40 x 4 mm (h x b x t in Fig. 4).

All parts of the frame are made of material W. Nr. 1.0039. This material has guaranteed weldability.

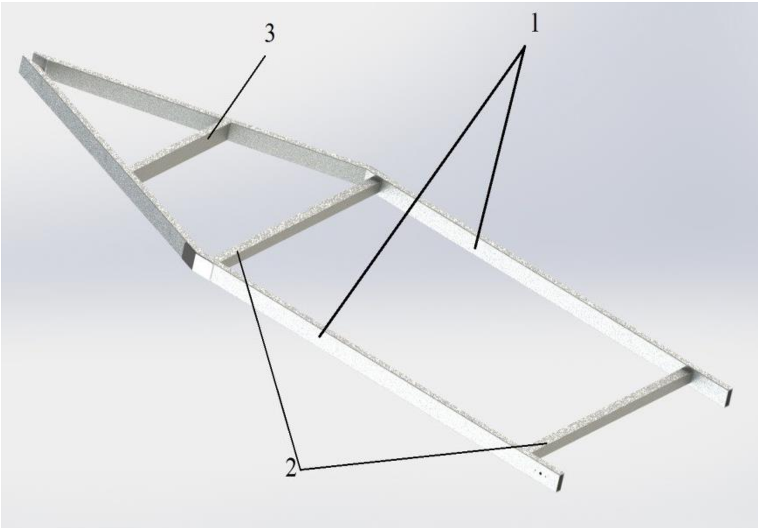

Fig. 3. The frame of the designed trailer

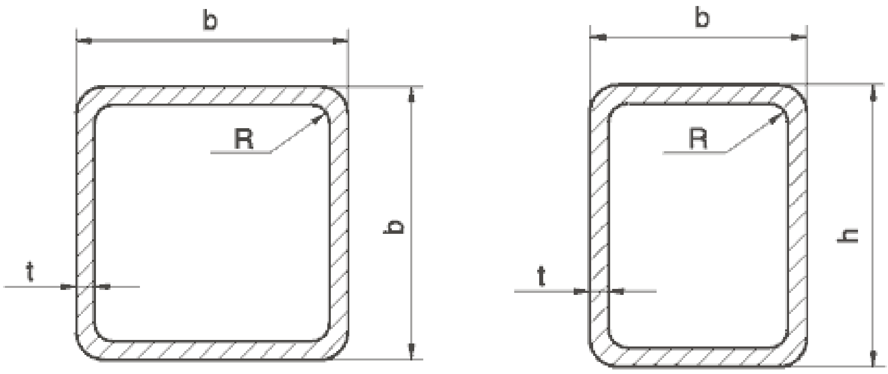

Fig. 4. The profile of the frame beams

4. CALCULATION OF FILLET WELD ACCORDING TO STN EN 1993-1-8

Welds are checked to connect the cross beams (position 2 of Fig. 3) with the profile of the frame of the trailer. The fillet weld is made around the circumference. The size of the filled weld is a = 2.1 mm (z = 3 mm). According to STN EN 1993-1-8, the design resistance of the fillet weld is checked. Design resistance to fillet welding is sufficient when conditions (1) and (2) are met.

$$\left[\sigma_{\perp}^{2} + 3.\left(\tau_{\perp}^{2} + \tau_{II}^{2}\right)\right]^{0,5} \leq \frac{f_u}{\beta.\gamma_{M2}}, \tag{1}$$

$$\sigma_{\perp} \leq 0,9.\frac{f_u}{\gamma_{M2}}, \tag{2}$$

where:

$\sigma_{\perp}$ – normal stress perpendicular to the plane of the weld [MPa]

τ_{II} – shear stress (in the plane of welding) parallel to the welding axis [MPa]

$\tau_{\perp}$ – shear stress (in the plane of welding) perpendicular to the welding axis [MPa]

f_u – nominal tensile strength of the weaker of the joined parts [MPa]

γ_{M2} – partial reliability factor [-]

β_u – relevant collector factor [-]

The calculation follows:

$$\left[\sigma_{\perp}^{2} + 3.\left(\tau_{\perp}^{2} + \tau_{II}^{2}\right)\right]^{0,5} = 9.31MPa \leq \frac{f_u}{\beta.\gamma_{M2}} = 360MPa,$$

$$\sigma_{\perp} = 82.94MPa \leq 0,9.\frac{f_u}{\gamma_{M2}} = 259.2MPa.$$

Since the two conditions are met, the weld is compliant.

To compare the results, this weld was also checked using the standard calculation procedure according to the following equation:

$$\tau_S = \sqrt{\left(\frac{\tau_{II}}{\alpha_{II}}\right)^2 + \left(\frac{\tau_{\perp}}{\alpha_{\perp}}\right)^2} \leq \beta.\frac{R_e}{k}, \tag{3}$$

where:

τ_S – result stress in the weld [MPa]

τ_{II} – shear stress (in the plane of welding) parallel to the welding axis [MPa]

$\tau_{\perp}$ – shear stress (in the plane of welding) perpendicular to the welding axis [MPa]

α_{II} – welding factor for the given load direction [-]

$\alpha_{\perp}$ – welding factor for the given load direction [-]

R_e – yield stress [MPa]

β – coefficient of the thickness of the filled weld [-]

k – coefficient of security measure [-]

The calculation follows:

$\tau_S = 87,31MPa \leq \tau_{DS} = 169,4MPa.$

Since the two conditions are met, the weld is compliant.

5. STRENGTH ANALYSIS OF THE FRAME BY FEM

Recently, given ever-faster evolving computer technology and the available literature, we can encounter modern numerical methods, such as the finite element method (FEM) [5, 13]. It is one of the most widely used numerical mathematical methods for solving the problems of elasticity and strength, the dynamics of pliable bodies, heat transfer, fluid flow, electromagnetism, and many other problems in engineering.

An important part is the definition of boundary conditions. The three-dimensional model of the trailer was divided into four parts in order to create the so-called nodule point. Nodule points serve as load points for load definition. The second part of the longitudinal beam represents the start and end of the axle of the trailer. At these two nodule points, binding was defined using the "fixed geometry" function, which prevented movement in every direction. The cross beams were divided into three sections. The nodule points on the cross beams make up the places where the guide skates are held. At the nodule points of the cross beams, the binding was defined using the "external loads" function, which represents the total load force applied to the cross beams. The wearing force acting on the cross beams had to be calculated.

Load force is calculated from the weight of:

- the transported boat (450 kg)
- the cam chain guide (position 8 of Fig. 1)
- upper holder of the cam chain guide (position 1 of Fig. 2)
- centre holder of the cam chain guide (position 2 of Fig. 2)
- screw and self-locking nut
- bottom holder of the cam chain guide (position 2 of Fig. 2)

The total load on the frame is determined by the calculation F_C = 4,645 N. Stress analysis by the FEM of the frame of the designed trailer is shown in Fig. 5.

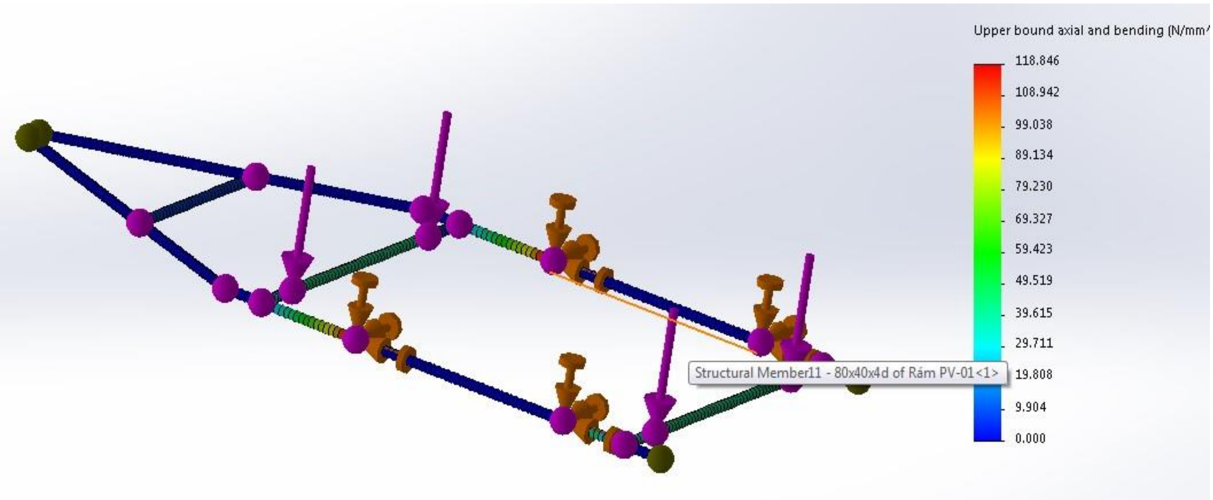

Fig. 5. Trailer frame stress (reduced stress according to HMH strength theory)

The maximum stress is located in the points of attachment of the axle to the trailer frame. The maximum stress achieved has a value σ_{max} = 118.8 MPa. The maximum stress value does not exceed the permitted stress of σ_D = 210MPa. The results show that the designed frame of the trailer meets the strength conditions.

6. FRAME DEFLECTION

The deflection of the trailer frame by the FEM is showed in Fig. 6. The maximum deflection occurred at the front of the trailer frame; its size is 7.67 mm. In practice, the deflection is much smaller at this point because the front part of the trailer is coupled with the trailer drawbar by the welded joint.

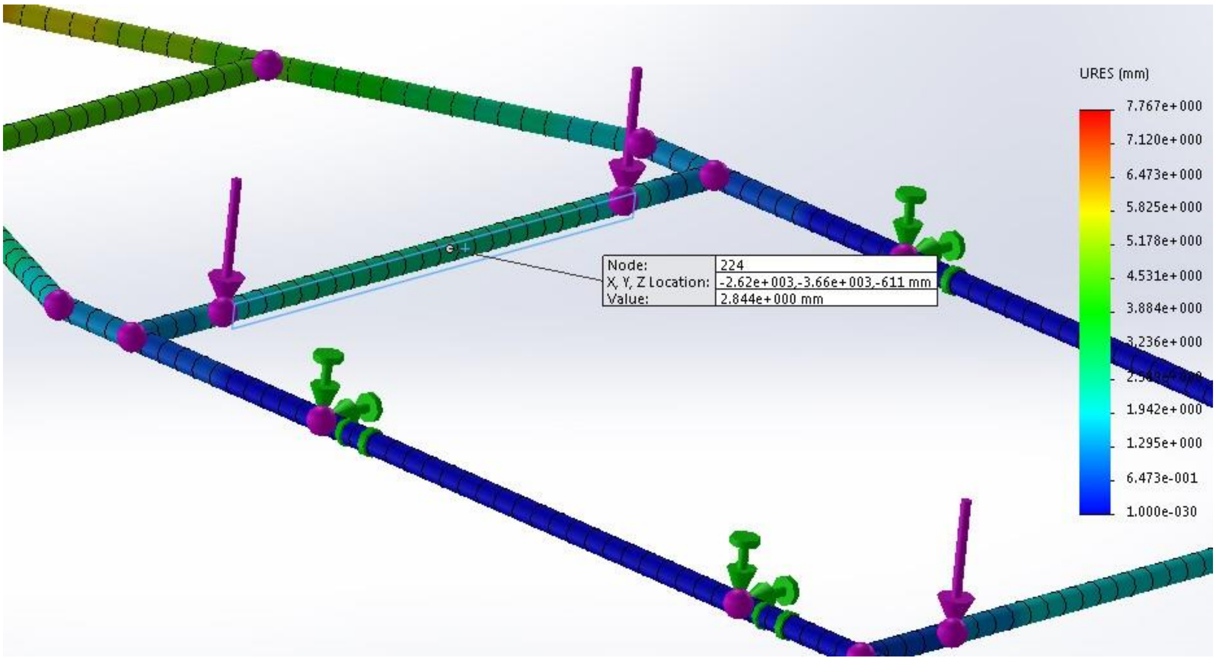

Fig. 6. Deflection of the trailer frame

After loading the boat or water scooter, most of the cross beams are loaded. The deflection in the centre of the cross beams is 2.84 mm (Fig. 6). When designing similar types of trailers for the transport of boats or water scooters, the greatest attention must be paid to the cross beam. These elements carry most of the load.

7. CONCLUSION

The frame of the trailer must be designed to have the appropriate durability and usability. The design of the frame is based on the knowledge and experience that are commonly available at the time the design is proposed. The designed trailer frame is designed as a welded structure. In our case, all welds were by checked for strength according to STN EN 1993-1-8 [12]. Stress analysis of trailer frame was made using the FEM. When designing similar types of trailers for the transport of boats or water scooters, the greatest attention must be paid to the cross beam. These elements carry most of the load. The results obtained show that the designed trailer frame meets the strength and deformation conditions and can fulfil its function.

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References

1. Czech Piotr. 2012. "Diagnosis of industrial gearboxes condition by vibration and time-frequency, scale-frequency, frequency-frequency analysis." *Metalurgija* 51(4): 521-524. ISSN: 0543-5846.
2. Czech Piotr. 2012. "Identification of leakages in the inlet system of an internal combustion engine with the use of Wigner-Ville transform and RBF neural networks." In: Jerzy Mikulski, ed., *12th International Conference on Transport Systems Telematics.* Katowice Ustron, Poland. 10-13 October 2012. *Telematics in the Transport Environment. Book Series: Communications in Computer and Information Science* Vol. 329: 414-422. DOI: http://doi.org/10.1007/978-3-642-34050-5_47. ISSN: 1865-0929. ISBN: 978-3-642-34049-9.
3. Figlus Tomasz, Marcin Stańczyk. 2016. "A method for detecting damage to rolling bearings in toothed gears of processing lines." *Metalurgija* 55(1): 75-78. ISSN: 0543-5846.
4. Figlus Tomasz, Marcin Stańczyk. 2014. "Diagnosis of the wear of gears in the gearbox using the wavelet packet transform." *Metalurgija* 53(4): 673-676. ISSN: 0543-5846.
5. Gąska Damian, Tomasz Haniszewski, Jerzy Margielewicz. 2017. "I-beam girders dimensioning with numerical modelling of local stresses in wheel-supporting flanges." *Mechanika* 23(3): 347-352. ISSN 1392-1207.
6. Kim Jung-Seok. 2006. "Fatigue assessment of tilting bogie frame for Korean tilting train: analysis and static tests." *Engineering Failure Analysis* 13(8): 1326-1537. ISSN 1350-6307.
7. Lotte Berghman, Roel Leus. 2015. "Practical solutions for a dock assignment problem with trailer transportation." *European Journal of Operational Research*. 246(3): 787-799. ISSN 0377-2217. DOI: http://doi.org/10.1016/j.ejor.2015.05.057.
8. Lučanin Vojkan J., Simić Goran Ž., Milković Dragan D., Ćuprić Nenad, Golubović Snežana D. 2010. "Calculated and experimental analysis of cause of the appearance of cracks in the running bogie frame of diesel multiple units of Serbian railways." *Engineering Failure Analysis* 17(1): 236-248. ISSN 1350-6307.
9. Madej Henryk, Czech Piotr. 2010. "Discrete wavelet transform and probabilistic neural network in IC engine fault diagnosis." *Eksploatacja i Niezawodnosc – Maintenance and Reliability* 4(48): 47-54. ISSN 1507-2711.
10. Manesis Stamatis. 1998. "Off-tracking elimination in road trains of heavy duty trucks with multiple semi-trailers." *IFAC Proceedings Volumes* 31(20): 355-359. DOI: http://doi.org/10.1016/S1474-6670(17)41820-9.
11. Mathissen Marcel, Scheer Volker, Kirchner Ulf, Vogt Rainer, Benter Thorsten. 2012. "Non-exhaust PM emission measurements of a light duty vehicle with a mobile trailer." *Atmospheric Environment* 59: 232-242. ISSN 1352-2310.
12. Standard STN EN 1993-1-8: Eurokód 3 Design of Steel Structures. Part 1-8: Design of Nodes. Bratislava: STUN, 2007.

13. Wittek Adam Marek, Damian Gąska, Bogusław Łazarz, Tomasz Matyja. 2014. "Automotive stabilizer bar – stabilizer bar strength calculations using FEM, ovalization of radial areas of tubular stabilizer bars." *Mechanika* 20(6): 535-542. ISSN 1392-1207.

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