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STRENGTH TESTING OF SIDE CONNECTOR OF RAILWAY WAGON FOR SEMITRAILERS TRANSPORT

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Abstract

A prototype railway wagon with a rotatable platform for an intermodal system is developed in Military University of Technology. The special railway wagon is equipped with a rotatable low flat loading floor. It can be used for transporting various types of vehicles, for example, tractors, trucks, trailers, semitrailers, cargo containers. The special wagons allows quick and convenient self-loading and unloading of vehicles and containers (no cranes needed); no platform infrastructure is required, only hardened flat surface; there is no need for hubs, terminals or special logistics; each wagon can be operated separately. A considered wagon consists of the following elements: chassis with biaxial standard Y25 bogies, frame, platform body, pneumatic systems, buffer devices, other external devices, electric equipment and hydraulic systems. A mechanism blocking rotation of a rotatable platform during transport of the load (typical semitrailers) is very important from a functionality and strength point of view of the considered wagon. Construction of such a lock allows only transmission of longitudinal load. Based on the performed FE analysis and strength tests of the wagon, it was verified that the most strenuous component of the wagon with a rotatable loading platform is a connector (lock) coupling the side of the rotatable platform with the over bogie part of the frame wagon. The selected aspects of numerical and experimental studies of the prototype railway wagon and its components are presented in the paper. FE analyses of the side lock element separated from the wagon structure are discussed as well.

Keywords: *intermodal railway wagon, strength test, FE analysis of the side connector (lock)*

1. Introduction

An intermodal wagon [5, 9] with a low rotatable loading floor (Fig. 1) for transportation of truck vehicles by rail is the subject of consideration. This structure consists of light and lowered bottom of the frame, rotatable floor of the body for a transported load and standard railway bogies [6, 7]. The wagon allows quick and fast loading and unloading without any platform infrastructure or terminals.

The following constructional assumptions are adopted in the project of a special wagon for intermodal transport:

- mass of a semitrailer with load up to 40 tons, wagon weight up to 45 tons,
- meeting the requirements of GB 1 railway gauge,
- lowly placed rotatable loading floor for autonomous loading-unloading allowing individual loading-unloading of the wagon,
- application of standard biaxial bogies of Y25 type with allowed 22.5 tons pressure on the axis,
- the structure can be used for transportation of different types of vehicles, such as tractors, trucks, trailers, semitrailers and cargo containers [6, 7, 10, 13, 14].

The idea of building and construction details of the wagon with a rotatable platform for intermodal transport have been presented in authors' other papers [3, 4, 8, 11, 12]. Therefore, a prototype version of the wagon with a rotatable load platform is discussed shortly in the paper and it presents only selected aspects of research on the prototype railway wagon [6, 7]. Separated subassemblies (4 in Fig. 1a, b) of the connectors/joints (called locks) connecting a rotatable platform with an immovable over bogie part of the wagon for intermodal transport are considered in the paper.

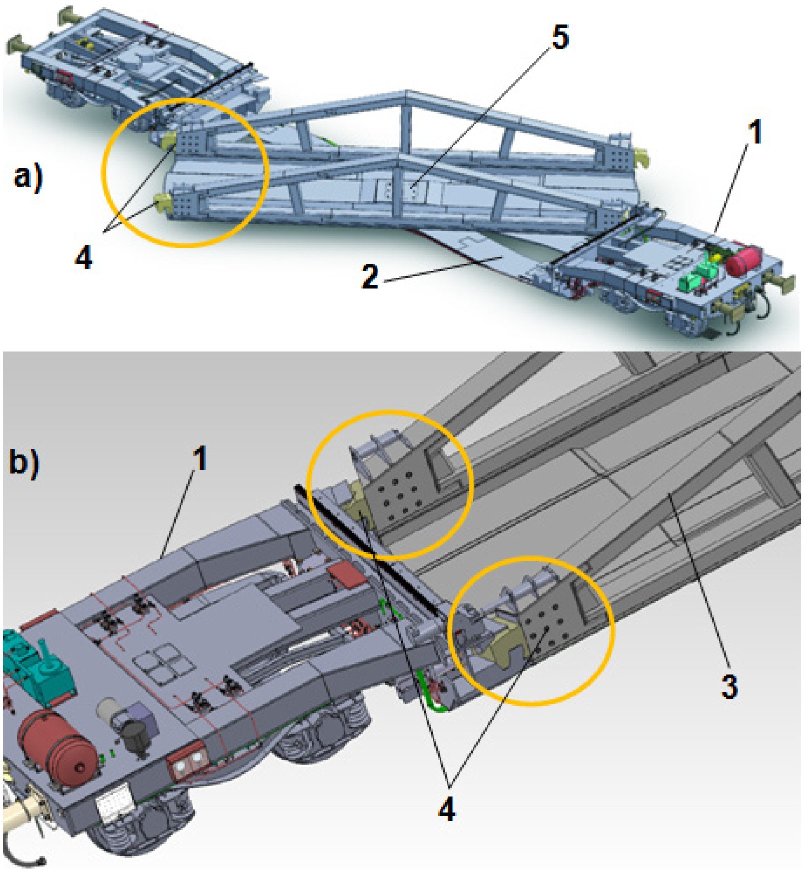

Fig. 1. Prototype version of the wagon [6, 7] with: a) open loading platform, b) closed loading platform with the view of lock components: 1 – over-bogie part of the wagon, 2 – lowered fixed frame of the wagon, 3 –side of the moving loading platform, 4 – hook shape locks with the support area, 5 – central node of the rotatable platform

The side locks (4 in Fig. 1a, b) are part of a mechanism blocking rotation of a rotatable platform with load during transport. A construction of such a lock allows only transmission of longitudinal load; therefore, it does not block rotation of the platform during loading/unloading operations. Based on the performed FE analysis and strength tests [4] of the wagon, it was verified that the most strenuous components of the wagon with a rotatable loading platform are the side connectors. Therefore, numerical models and analyses of a complete wagon and the most effort parts of the wagon are applied. Different variants of the lock components configurations and boundary conditions are considered during the tests. The results of the stand investigation are used to verify the numerical model and the methodology applied for computer simulations. The selected strength assessments based on the analysis of numerical and experimental results are included in the paper.

2. Numerical investigations of the complete wagon

Different variants of a complete railway wagon models are developed for numerical analysis. Simulation of the tests of the wagons in motion with mapping of the appropriate conditions of the track formation was carried out using multibody analyses and MSC Adams software [10]. A model of the railway wagon for a multibody simulation (Fig. 2a) is built of rigid solids based on the design documentation and PN-EN standards [13, 14]. The main components of the wagon and contact connections between them are taken into account.

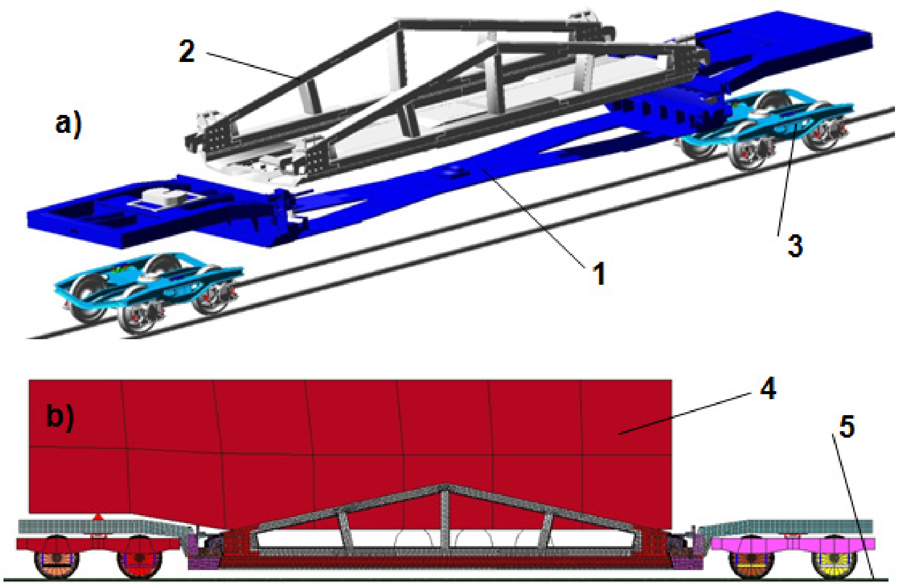

Fig. 2. A View of 3D numerical model [3, 8]: a) multibody model with main subsystems, 1 – chassis frame of the wagon, 2 – rotatable platform, 3 – Y25 type bogie with the suspension [12]; b) FE model of the complete wagon for dynamic simulation [3, 8], 4 – semitrailer with load, 5 – railway track

Forces of reaction and forces in contact connectors (Fig. 3) of the most strenuous parts of the wagon are estimated as a result of multibody analyses [12]. The loads values determined in this manner are used in the experimental tests of the wagon components, including a side lock (the subassembly operating between the rotatable platform and the wagon frame). The selected FE numerical simulations corresponding to the experimental tests of this wagon subassembly are presented in the further parts of the paper.

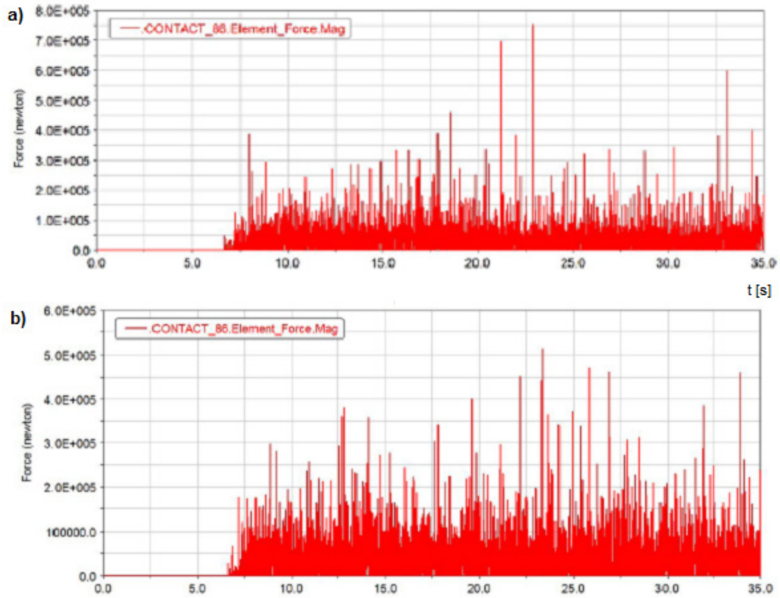

Fig. 3. The chart of contact forces in the selected lock as a result of 3D multibody analysis: a) during passage of the wagon on the curved track at a speed of 60 km/h, b) during passage of the wagon on the curved track at a speed of 80 km/h [12]

Numerical FE analyses of a complete wagon [3, 8, 11] are carried out as well. The deformation strain and stresses (Fig. 4) of particular elements of such a construction in different configurations of the wagon platform and side locks are determined. Boundary and initial conditions corresponding to strength tests of cargo wagons and specified in the standard EU-PN were taken into consideration [13, 14]. The most strenuous and vulnerable to damages area of the railway wagon structure is identified based on the FE numerical results. For this purpose, a numerical 3D model (Fig. 2b) of the complete wagon is used.

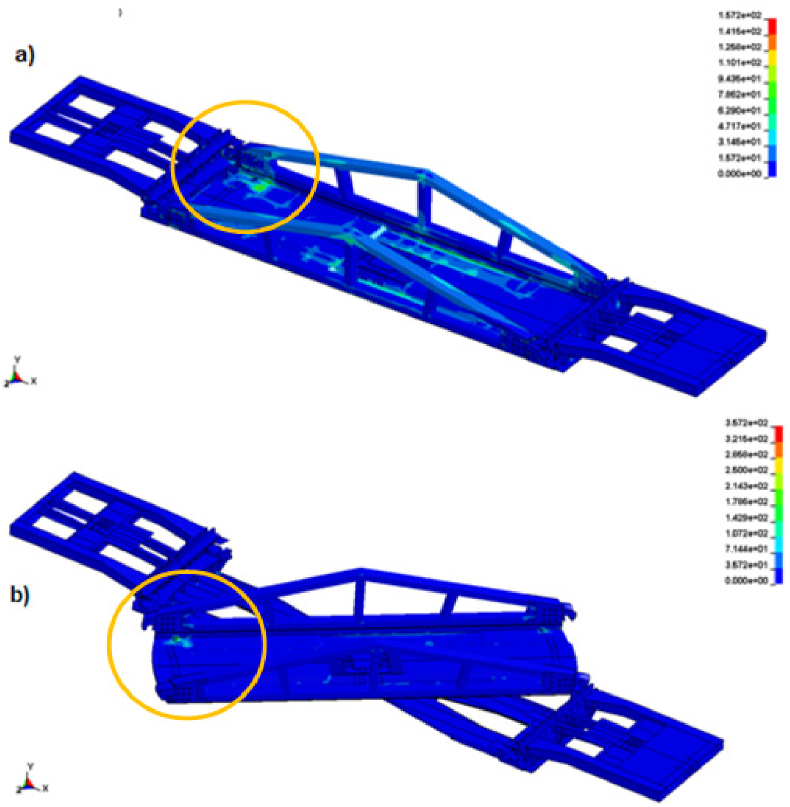

*Fig. 4. FE numerical result – HMH stress of the lock components areas in the special wagon with 1.95*Q load and: a) closed platform after unblocking the side locks – σ_{max} = 157 MPa, b) opened platform with load and rotated by an angle of 50° – σ_{max} = 357 MPa*

3. Object of investigations and stand tests

The locks (4 in Fig. 1a, b) coupling the side of the rotatable platform with the over bogie part of the frame of the special wagon (Fig. 1) are identified as the most strenuous component of the wagon with a rotatable loading floor [8-11]. Therefore, stand tests and numerical analysis of the separated components of the side lock are performed.

The parts of the lock, in the close configuration of the wagon (Fig. 1b), are loaded mainly with longitudinal tensile and compressive forces. The design of the applied lock allows only transmission of axial load in respect to the side of the wagon. The purpose of the joint is also to relieve the central node, which is used mainly for positioning and rotation of the wagon-loading platform. Rotations of the wagon platform to the load-unload position (Fig. 1a, 4b) are possible after unblocking the locks (4 in Fig. 1a, b).

One of the solids of such locks areas is the over bogie part (1) connected with the lowered fixed frame (2) of the wagon – Fig. 1. The other part of the lock area is the side of the moving loading platform (3) connected with the use of nine screws. Components of the lock (4) constitute a connection between the raceway on the over bogie frame in the rotation process of the floor in respect to the central node (5). The side locks (4), according to preliminary design assumptions, should relieve the area of the central node positioning the rotatable platform over the lowered part of the wagon frame. The central node (5) is used mainly for rotation of the loading platform in respect to the wagon frame and the platform ramp.

The stand tests of the separated components of the side lock with the use of the experimental equipment of Strength of Materials Laboratory at Military University of Technology were performed. Components of the side lock (Fig. 5, 6) with real dimensions of the connector (1:1 scale) are used during the strength tests. Owing to a large size and considerable mass of the lock subassemblies, it has been decided that the elements used for the experimental research will be the plates of a real solids shapes (Fig. 5, 6), which are the clippings with thickness of 30 mm -corresponding to 1/10 of the width of the actual lock (300 mm) [4]. Two different shapes of the connector are used in the stand tests. The hook shape connector (Fig. 5a, 5b) was used for an initial version of the side lock. The stand test results of the initial hook-shape locks will be discussed in the paper. The separated components of the side lock in a modified form of the dovetail joint are tested in the next stage. Static compression and tensile tests of the separated lock connectors are performed on a hydraulically driven machine INSTRON SATEC within a range of forces up to 1200 kN (Fig. 6).

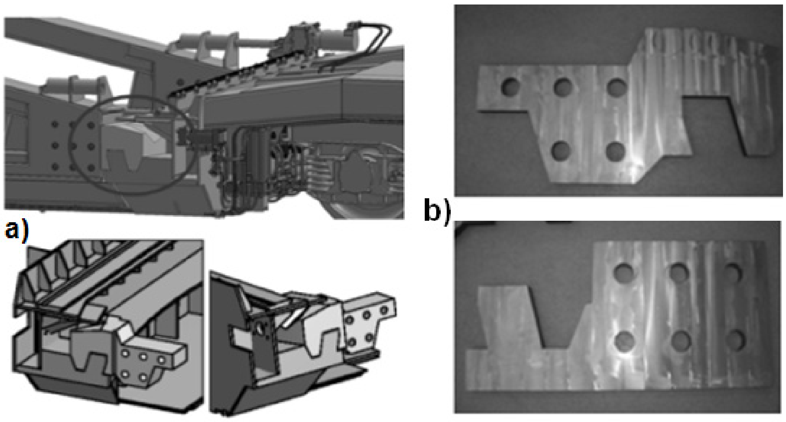

Fig. 5. Views: a) side lock area between rotatable platform and over bogie part of the intermodal wagon, b) separated hook-shaped connector prepared for tests

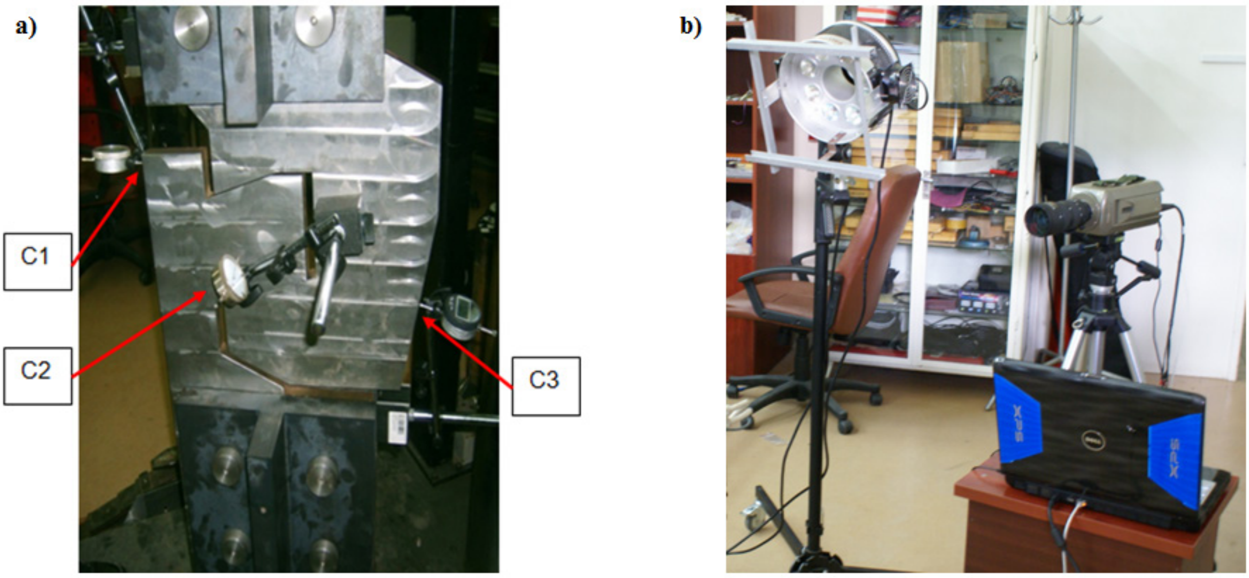

Fig. 6. Photos of the tested components of the side lock and the test stand view with INSTRON SATEC machine: a) hook-shaped connector with the measuring equipment, b) additional stand equipment: black-and-white camera to high-speed and high-resolution images Phantom V12 with halogen lamps

An experimental force – displacement curve, the map of displacements from Aramis system [1] and photographs of the connector deformations before and during the load test, presented in Fig. 7a, b, c, are recorded during the stand test of the hook-shape lock.

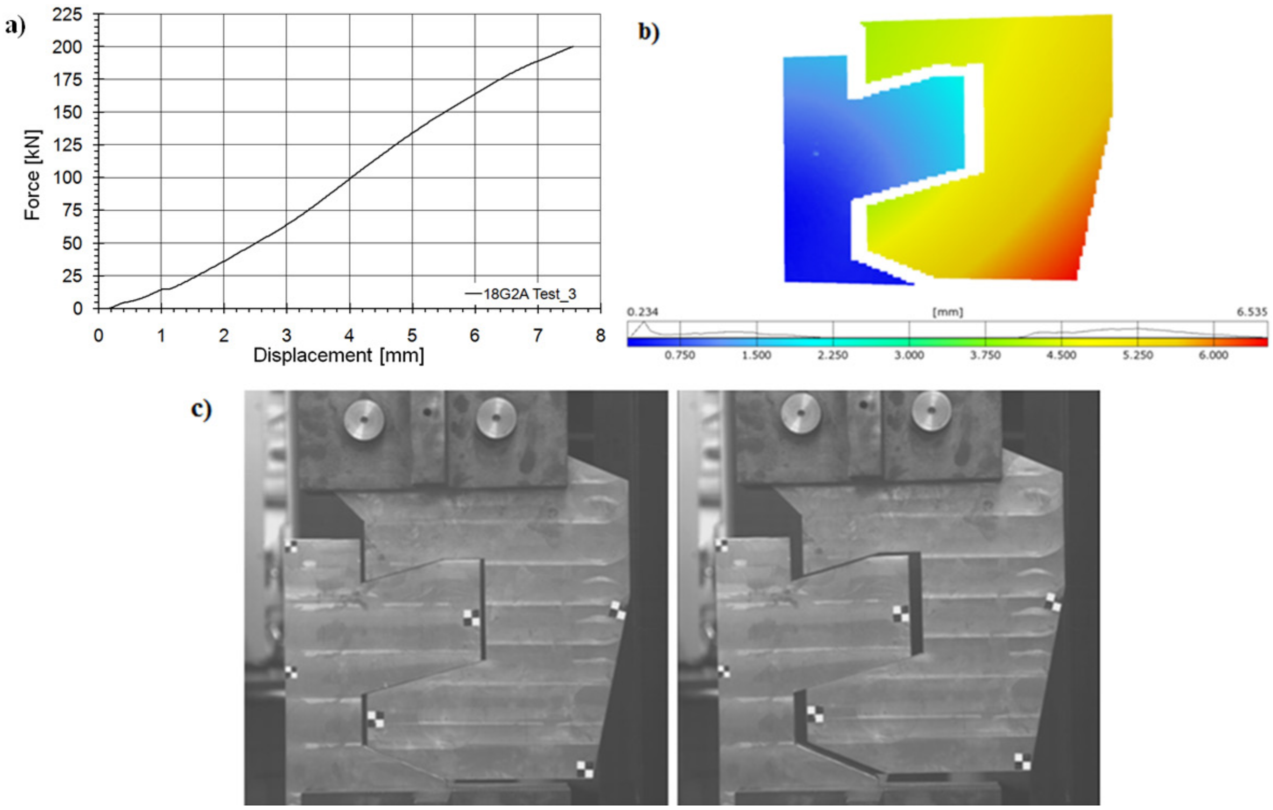

Fig. 7. Selected results of stand test: a) force – displacement curve, b) displacement map of the hook-shape connector, c) photographs of the connector deformations before and during the load test

4. Results of the numerical study

This part of the paper presents the selected aspects of numerical research on the separated subassembly of a lock. Separated components of the side lock mapping a hook shape of the connector (as in the experimental tests described in chapter 3 of the paper – Fig. 5 and 6) are used in numerical FE models as well. The selected results from experimental tests (Fig. 7b) of the side lock components are used to verify a numerical model and an FE methodology used for simulations. An FE model (Fig. 8) and numerical analysis of the most effort part of the lock are applied. A comparison of the results of both bench and numerical tests is shown in Tab. 1. Numerical analyses of lock tensile within a nonlinear range are performed using MSC software [11]. Load was defined as the reduced force linearly increasing to the value of $S_{\max} = 200$ kN for Variant I of the FE model. The kinematic extortion load is defined in Variant II of FE the presented analysis. A comparison of the results is shown in Tab. 1. Displacements and H-M-H stresses are recorded during the numerical tests using FE models and a suitable variant of the load models. Fig. 9 and 10 show a result maps of lock plates determined numerically in FE models with different load conditions (for Variant I and II). The displacement map and H-M-H stress obtained for the joint initial shape from Variant I of load are presented in Fig. 9a, 9b. Analogous results maps for Variant II of load conditions are shown in Fig. 10a, 10b.

Tab. 1. Comparison of the FE and stand test results

Measuring points (Fig. 6a)	Aramis [mm]	Sensor (Fig. 6a) [mm]	FE analysis [mm]
C1	3	10	12
C3	6.5	5.6	6.13

Tab. 2. Comparison of the FE results

FE models	FE results for initial hook-shape connector	
	$V_{\max}$ [mm]	σ_{max} [MPa]
I variant	12	365
II variant	8.5	350

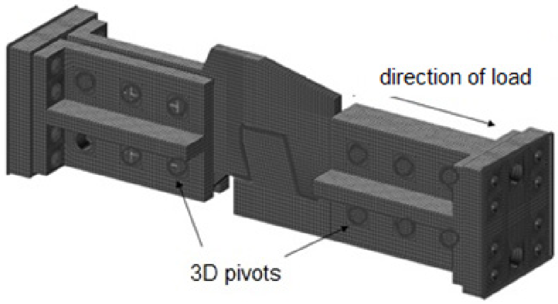

Fig. 8. FE models mapping two different shapes of lock connectors (as in the experimental tests): initial hook-shape lock

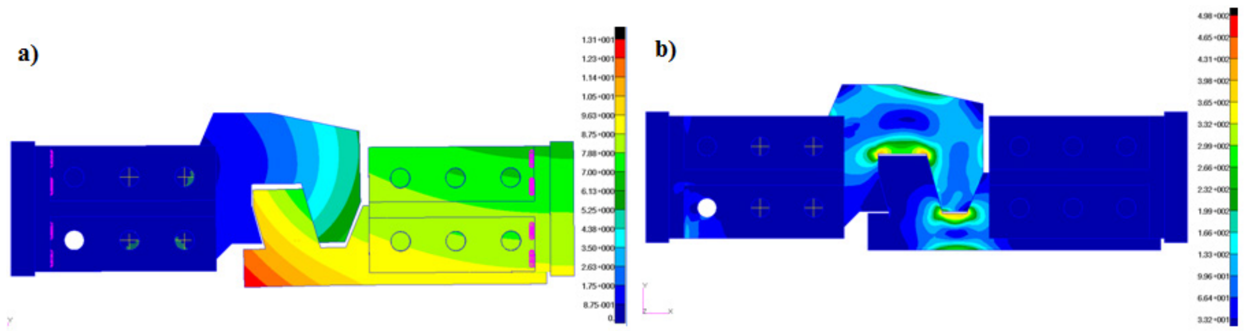

Fig. 9. Results maps for Variant I of load: a) displacement – V_{max} = 12 mm, b) H-M-H stresses – σ_{max} = 365 MPa

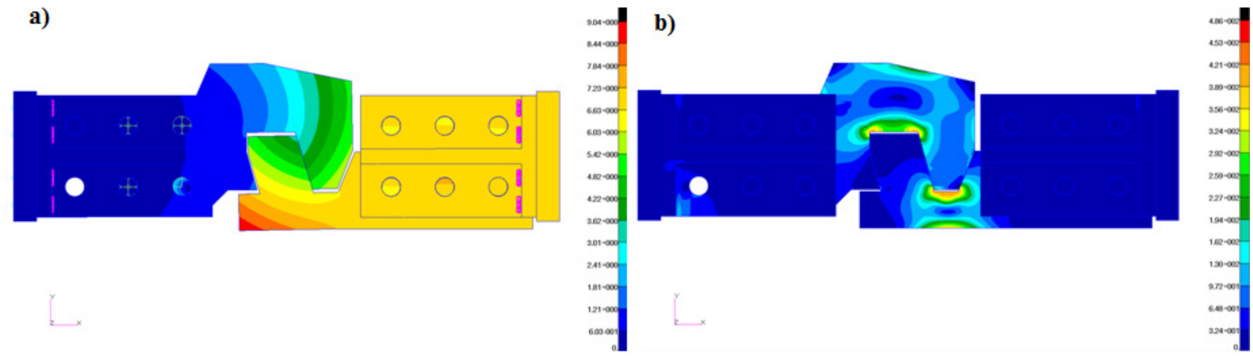

Fig. 10. Results maps for Variant II of load: a) displacement – V_{max} = 8.5 mm, b) H-M-H stresses – σ_{max} = 350 MPa

5. Conclusions

Based on a comparison of displacements from the numerical analysis and the ones measured experimentally, it was verified that both of the discrete models of the tested set with a non-linear material model and load boundary conditions properly and sufficiently reflect the actual construction of the side locks system and the applied holders. It was found that deformability of the initial hook-shape joint is higher than in the case of the modified shape-dovetail lock, presented in Fig. 11.

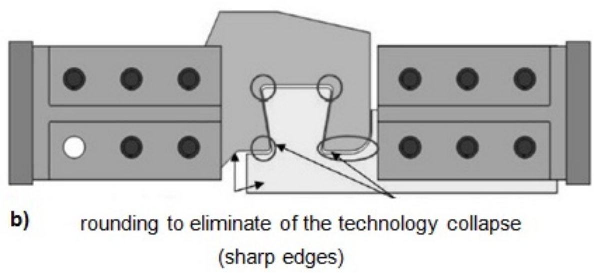

Fig. 11. View of numerical model mapping a modified shape of the lock connectors – dovetail joint without sharp edges

Maximal longitudinal displacements of two type connectors differ up to 25% [2]. Both types of numerical models (the initial hook shape and with the modified shape join) and computer simulations, presented in the paper, can be used for further strength tests of the wagon side locks with the use of more complex load states and mapping of dangerous, from the point of view of their exploitation, conditions.

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