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# EXPERIMENTAL AND NUMERICAL TESTS OF SEPARATED SIDE LOCK OF INTERMODAL WAGON

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***Abstract***

*The object of the paper is to investigate the strenght of a separated subsystem of a wagon for transport of trucks semitrailers. The wagon designed in the Department of Mechanics and Applied Computer Science, Military University of Technology, allows easy and independent loading, transport and unloading without any special equipment or additional platform infrastructure. It is possible to utilize it for transport of various vehicles types such as tractors, cars, semitrailers, containers, heavy equipment. The tests presented in the paper concern a wagon separated construction element – a side lock. It is a key subsystem of the platform allowing transfer of its loads generated in the transport position (a wagon ready to go) to the form of longitudinal forces operating in the sides of the structure. The locks are simultaneously the most strained parts of the wagon. There were carried out the numerical analyses and experimental studies of a single lock were carried out. Owing to the application of Aramis non-contact optical system of strains measurement, the lock deformations as well as the areas of the minimum and maximum main deformations were defined.*

***Keywords:*** *intermodal transport, railway wagon, strength test, FE analysis, Aramis, experiment*

## 1. Introduction

A special wagon with a low rotatable loading floor (Fig. 1) for transportation of truck vehicles and semitrailers by rail was developed in Military University of Technology (MUT). The wagon allows quick and fast loading and unloading without any platform infrastructure or terminals.

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

- mass of a semitrailer with load up to 40 T, wagon weight up to 45 T,
- satisfying the requirements of GB 1 railway gauge,
- low- set rotatable loading floor for autonomous loading-unloading allowing individual loading-unloading of the wagon,
- application of standard biaxial bogies of Y25 type with allowed pressure on the axis equal to 22.5 T.

The wagon structure includes many innovative solutions confirmed by-acquisition of European patent “EP Application 12170915 (2012)” [1]. Using special side locks and appropriately shaped rotatable loading floor the effect of unload of the lowered wagon frame (Fig. 1) was obtained. Based on the conducted numerical analysis of wagon strength, it was verified that the most strenuous component of the wagon with a rotatable loading floor is the lock coupling the side of the rotatable platform with the over-bogie part of the frame of the special wagon (Fig. 2).

The design of the applied lock allows only transfer of the axial load in respect to the wagon side. Thus, rotation of the platform to the load-unload position (Fig. 1), after unblocking the locks, was possible. The elements of the lock, in the close configuration, are loaded mainly with longitudinal tensile and compressive forces. The purpose of the joint is also to relieve the central node, used mainly for positioning and rotation of the wagon loading platform. Taking into consideration the operation of complex functional and strength system of the complete wagon, the importance of these components is significant. Therefore, numerical and stand tests of the separated components of the side lock with the use of the experimental equipment at Strength of Materials Laboratory, the Department of Mechanics and Applied Computer Science, MUT were performed [3-5].

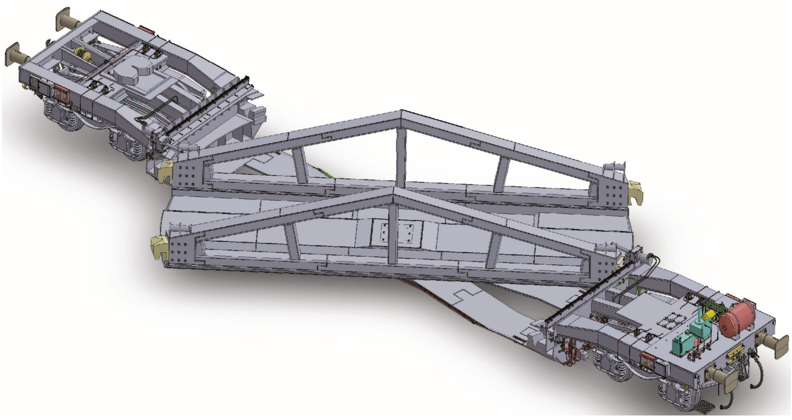

*Fig 1. Prototype version of the wagon with open loading platform*

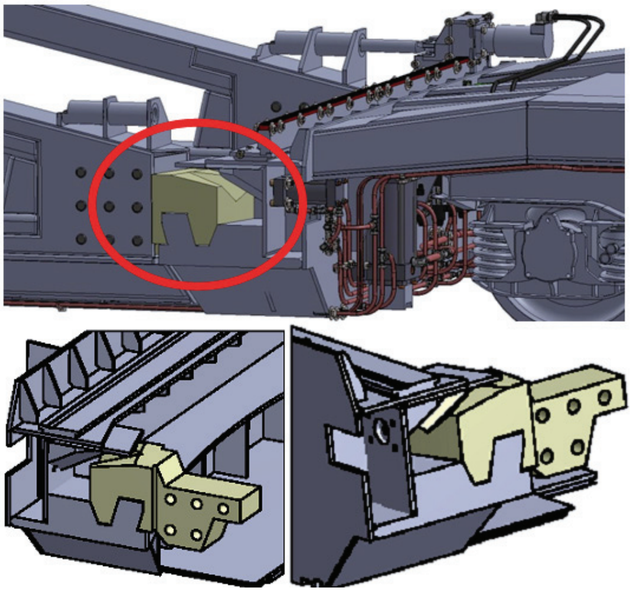

*Fig. 2. Side lock between rotatable platform and over-bogie part of the railway wagon for intermodal transport*

## 2. Numerical and experimental investigations

### 2.1. Experimental investigations

In the strength tests, a component of the lock in a 1:1 scale, with real dimensions of the connector made of heat-treated steel 40H (Fig. 3), was used. Owing to the large size and considerable mass of these elements, it was decided that the elements used for the experimental research would be the plates, with a shape of a real lock, which are the clippings with thickness of 30 mm, what corresponds to 1/10 of the width of the actual lock (300 mm). Static compression and tensile tests of a separated rail connector were performed on the hydraulically driven device INSTRON SATEC 1200 kN. In the research, Aramis optical measurement system of deformation was used. Owing to this system, deformation of the side lock, and areas of minimum and maximum principal strain were determined.

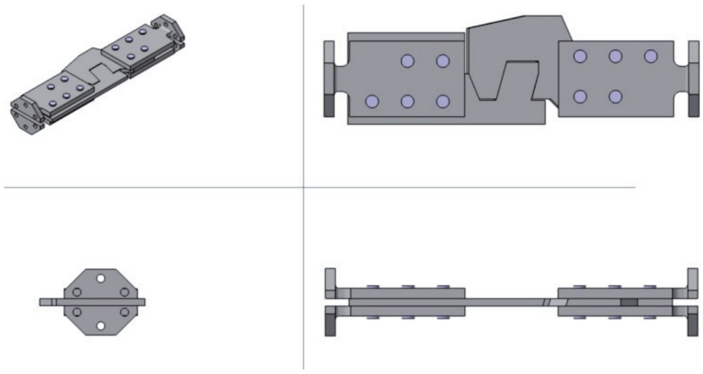

*Fig. 3. 3D view of the tested system of the side locks along with the mounting elements in the strength machine*

Aramis is an optical system designed for non-contact measurement of complex deformation and strain of different materials and structures under load. This utility uses two CCD cameras with resolution of 2358x1728 pixels to obtain a three-dimensional image, which is subsequently processed by a digital correlation (digital image correlation – DIC). Owing to contrasting random surface texture of the side lock elements (pattern random point's paint to the test object), the system divides the image into the working areas called facets, which can be correlated with the corresponding areas on the successive captured images. Subdivisions are of the several pixels size. The optical deformation measurement system compares successive images to the photo taken before the initial application of load. Subsequently, three-dimensional maps of displacements and deformations for all facets are computed. A set of halogen lamps lighting the test object was applied (Fig. 4).

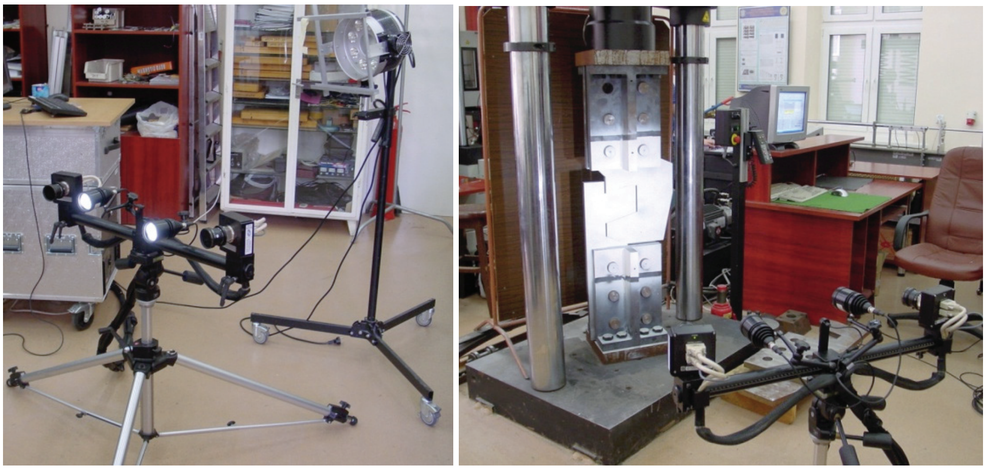

*Fig. 4. Cameras of the system for deformation measurement placed in front of the test stand*

The optical system was calibrated to measurements using a calibration plate with dimensions of 350x280 mm before performing the test, what enabled obtainment of the measurement area of dimensions 500x370x500 mm, in which there were the tested elements of the side lock. The lenses with a focal length of 50 mm were used. Cameras, distanced from the lock front surface by 1590 mm, registered images with a frequency of 2 frames per second. In the analysis, the facets of 20x20 pixel size (about 3.5x3.5 mm) were employed.

The results of strain measurements in Aramis system were synchronized in time with displacement and force signals from the testing machine (SATEC). A graph of the force-displacement during stretching of the side lock ($F_{max}$ = 200 kN) is shown in Fig. 5. The photos of the side lock taken during tension of the area of the optical measuring deformation system marked green is shown in Fig. 6. A map of modules displacements values in the side lock elements and a map of the Huber-Mises-Hencky reduced strains, on which the locations of the largest strain are marked with red eclipses, is shown in Fig. 7 and 8.

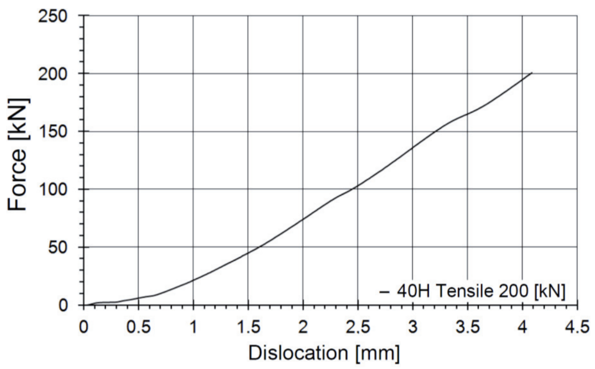


*Fig. 5. A graph of the force-displacement during tension of the side lock to the value of 200 kN*

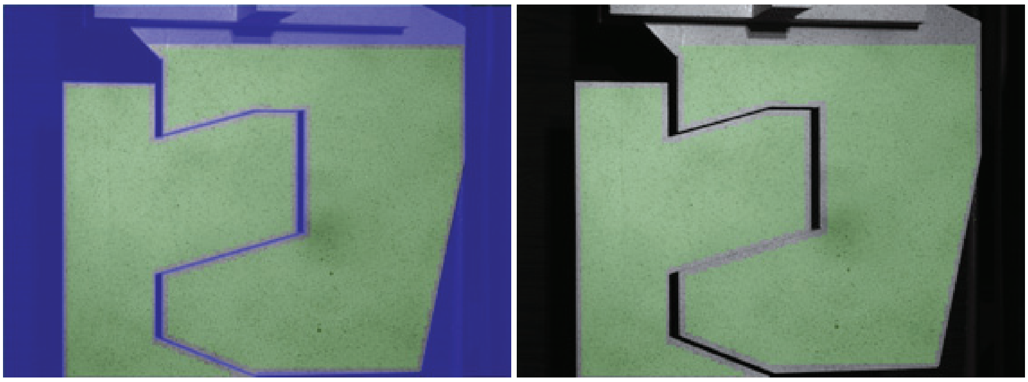

*Fig. 6. Photos taken during tension of the side lock_to the value of 200 kN with Aramis measurement system area marked: unloaded lock (left) and maximally loaded (right)*

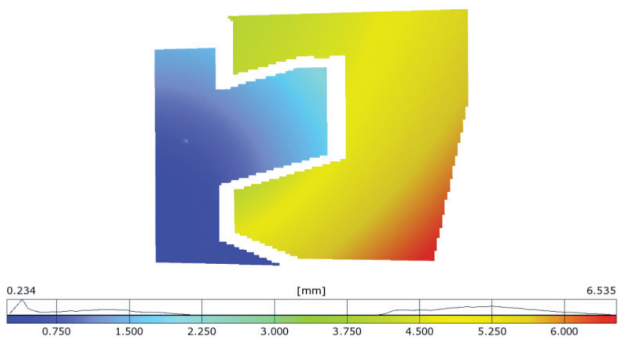


*Fig. 7. Map of strains modules values in elements of the lock subjected to tension within the range of 200 kN*

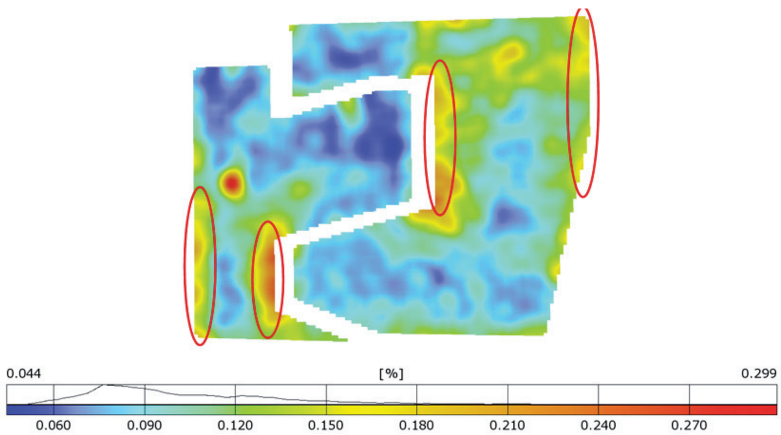


*Fig. 8. Map of HMH reduced strains in elements of the lock subjected to tension within the range of 200 kN. Red eclipses depict locations of the largest strains*

The same results are shown for a compression test:

- a graph of compression of the side lock to the value of 200 kN, in the coordinates of force versus displacement of the testing machine travers (Fig. 9),
- a photo of side locks loaded and unloaded during the test, with deformation measurement area of the optical system marked green (Fig. 10),
- a map of displacements modules of in the lock elements and a map of Huber-Mises-Hencky reduced strains, on which the locations of the largest strain are marked with red eclipses (Fig. 11 and 12).

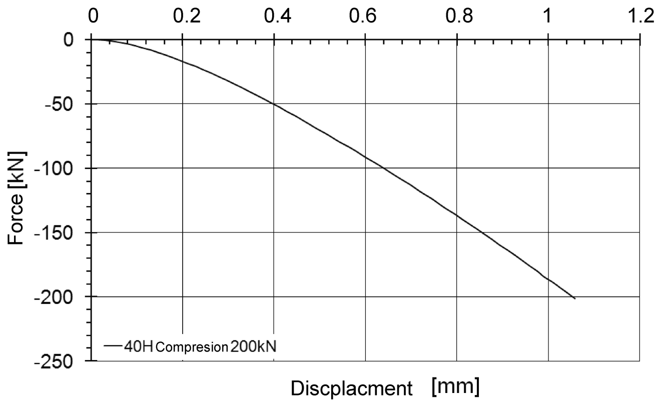


*Fig. 9. Graph illustrating compression test of the rail lock/side lock to the value of 200 kN*

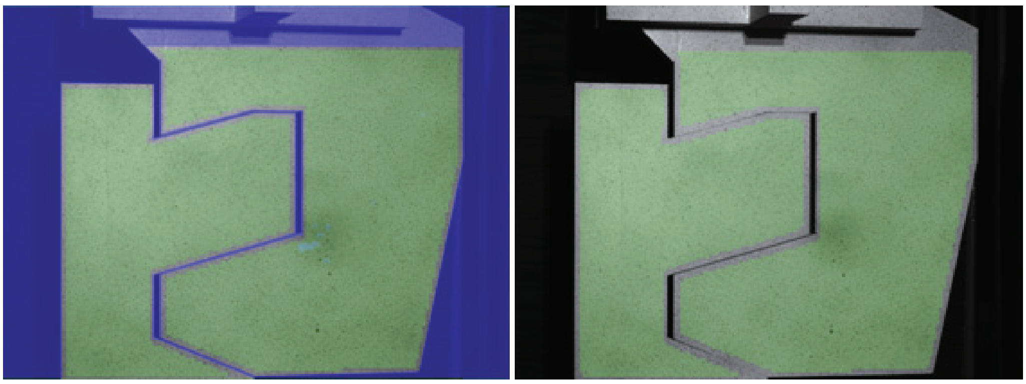

*Fig. 10. Photos taken during compression test of the side lock_to the value of 200 kN with Aramis measurement system area marked: unloaded lock (left) and maximally loaded (right)*

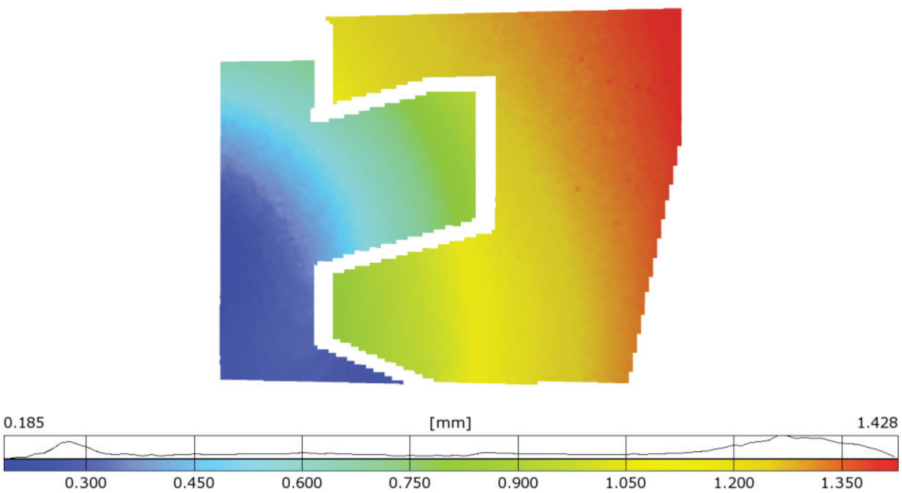


*Fig. 11. Map of strains modules values in elements of the lock subjected to compression within the range of 200 kN*

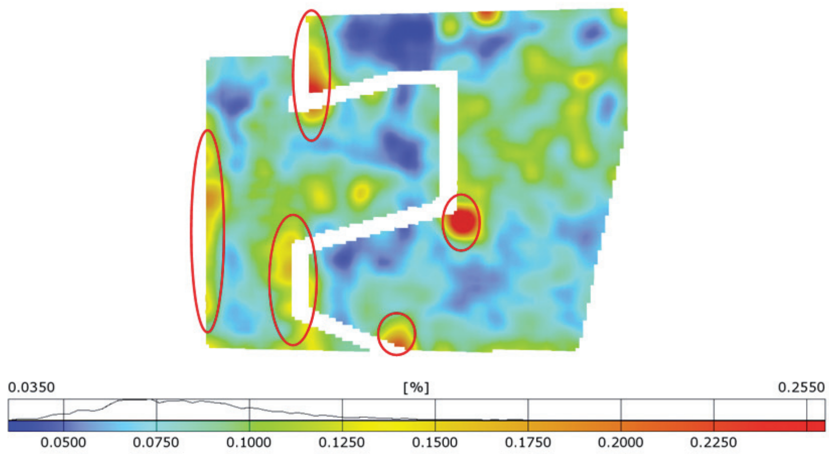


*Fig. 12. Map of HMH reduced strains in elements of the lock subjected to compression within the range of 200 kN. Red eclipses depict locations of the largest strains*

Maximum deformations (global displacements) of the lock elements under tension are much larger than in the case of the compression test. The upper element deforms more during interaction with the lower element, both during tension and compression tests. The upper element of the lock displaced maximum by 6.5 mm during the tension test. In test 2, the maximum deformations of this element were equal to 1.4 mm. The locations of maximum deformations for the tested types of loads are different. In the tension test, the lower outer corner of the upper element displaced the most (Fig. 6).

The highest values of reduced strains on the surface of the lock elements occurred in both the tests in the areas neighbouring to the places of direct contact with the other element of the lock. Particularly, it took place in the corners of two neighbouring surfaces of direct contact (interaction), where the phenomenon of stress concentrations occurred and near the outer edge of the lock lower element.

## 2.2. Numerical tests

A numerical model of a side lock along with the grip was built. The model maps the stand for experimental research (Fig. 13). In the contact area of the hooks, which were described as a deformable solids, there was given contact of friction coefficient equal to $\mu=0.2$. In the numerical model, the contact was defined also between the modelled bolts and the grip. The side lock was loaded with the force of 200 kN applied to the one of the grip ends. After determining the appropriate boundary conditions, non-lineal tension and compression analyses of the joint were carried out (Figs. 14 and 15). A discrete model of a side joint includes 76 090 elements [6]. Fig. 15 presents a map of displacements. The accuracy of the model was verified based on the results of measurements of displacements of joints elements in the selected measurement points with the use of time sensors during tension and compression stand tests [2]. Fig. 5 presents a general view of reduced stresses in the tensile test of the joint subjected to force of 200 kN value. The biggest concentrations of stresses occur in the contact area between two hooks (the area of locks elements bending) and are equal to approximately 498 MPa. Fig. 14 illustrates a map of resultant displacements for this test and in the measurement point; they are equal to 10 mm.

## 3. Conclusions

The areas, indicated in the experimental measurements, in which the highest values of reduced strains on the joint elements surfaces occur, correspond to those identified on the maps developed based on the results of numerical simulations.

Based on the conclusions drawn from the tests, the following modifications in the construction of the side joints were proposed:

– application of corners curvatures, especially in the areas of joint elements interaction and removing constructional cuttings,
– modifications of the shape and outline of the interaction surfaces of joint elements in which there were taken into consideration the strains state and the areas of occurrence of increased strains determined based on the results map from the numerical and stand tests.

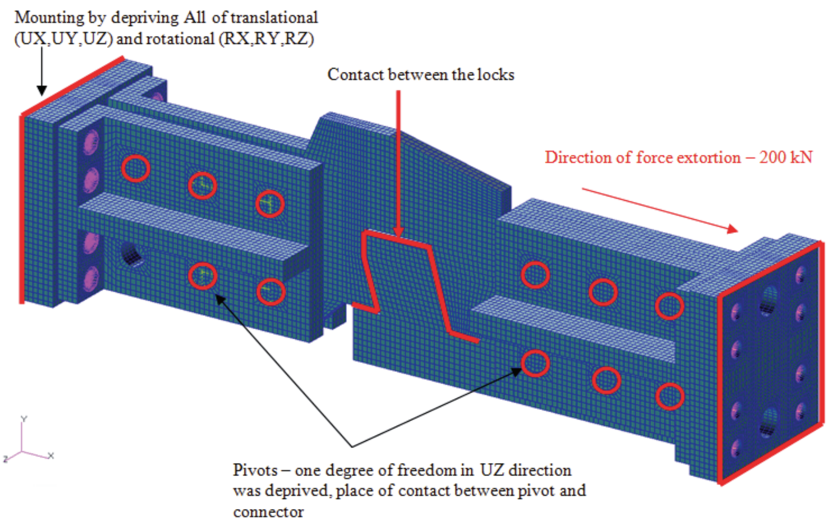


*Fig. 13. Numerical model of the joint*

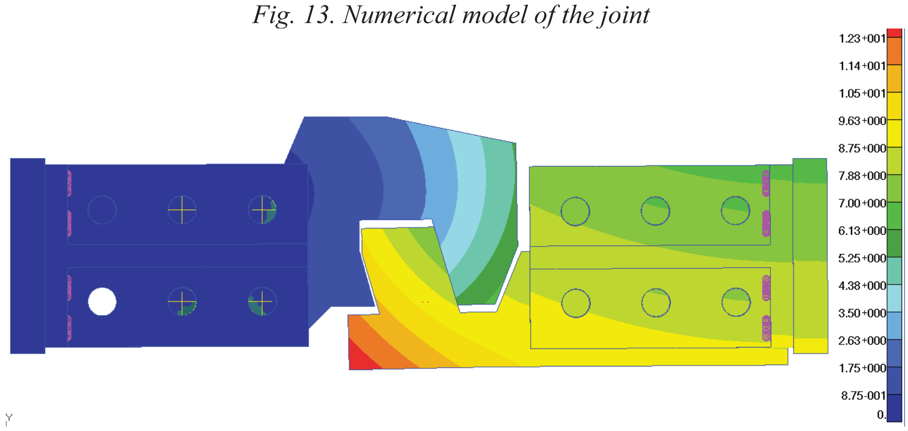


*Fig. 14. Map of displacements of FEM joint elements*

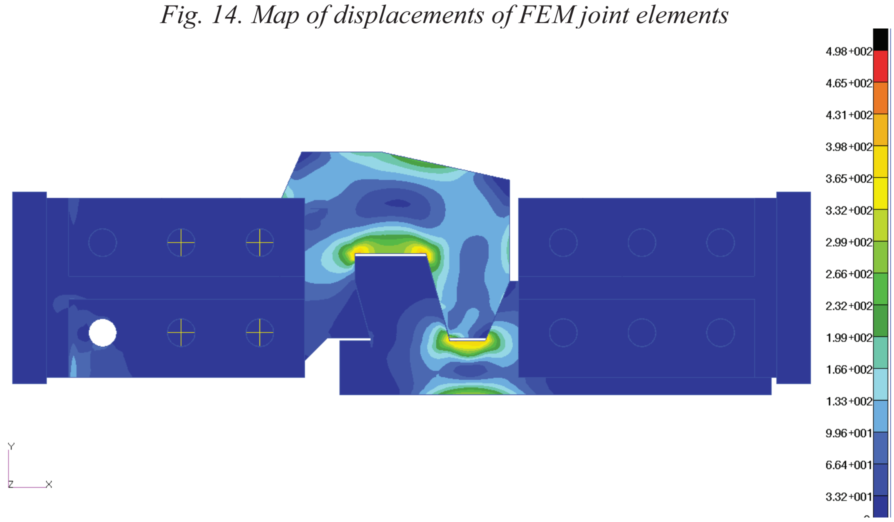


*Fig. 15. Map of reduced stresses – side view – maximum stresses equal 498 MPa*

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