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IMPACT OF THE TRACK WHEEL AXLES ON THE STRENGTH OF THE BUCKET WHEEL EXCAVATOR TWO-WHEEL BOGIE

Srđan Bošnjak, Zoran Petković, Nebojša Gnjatović, Ivan Milenović, Boris Jerman

Original scientific paper
This paper presents the results of the study dedicated to the problem of the bucket wheel excavator two-wheel bogie (TWB) strength. Two variants of the TWB structure were analysed: the originally designed and the redesigned. Three calculation models for stress state identification were used for each of the variants. The first does not iclude the influence of the track wheel axle on the lateral loads distribution. The second model includes the mentioned influence while the third considers the track wheel axle as a structural part of the TWB. Validation of the FE models is done by FE simulation of the experiment carried out on an originally designed testing bench. The obtained results fully clarify the occurrence of cracks in the original TWB structure, as well as the considerable impact of the track wheel axles on the TWB structure stress state.

Keywords: *bucket wheel excavator, experiment, FEA, strength, two-wheel bogie*

Utjecaj osovina kotača na čvrstoću dvokotačnih kolica rotornog bagera

Izvorni znanstveni članak
U radu su prezentirani rezultati studije čvrstoće dvokotačnih kolica (DKK) pogona kretanja rotornog bagera. Analizom su obuhvaćene dvije varijante strukture DKK: izvorna i redizajnirana. Za svaku od varijanti formirana su po tri proračunska modela. Prvi model ne obuhvaća utjecaj osovina kotača na raspodjelu bočnih opterećenja, dok je u drugom modelu taj utjecaj uzet u obzir. U trećem modelu osovine kotača se posmatraju kao elementi strukture DKK. Validacija modela izvršena je usporedbom rezultata dobivenih MKE i rezultata dobivenih pokusom izvedenim na probnom stolu specijalno dizajniranom za tu namjenu. Dobiveni rezultati u potpunosti objašnjavaju pojavu prslina u izvornoj strukturi DKK i ukazuju na značajan utjecaj osovina kotača na naponsko stanje strukture DKK.

Ključne riječi: *čvrstoća, dvokotačna kolica, MKE, rotorni bager, pokus*

1 Introduction

Although the history of crawler design and manufacturing is very long [1], a relatively large number of researchers are even today occupied with different problems dealing with the strength of the open pit machines' travelling mechanisms and belonging substructures [2 ÷ 11]. It is important to note that failures of the mentioned travelling mechanisms are always followed by high financial losses [12]. Furthermore, the replacement of damaged parts is executed on site, often in hard working conditions, by that essentially prolonging the downtime of the complete surface mining system. Losses caused by machine downtime i.e. the system as a whole, may exceed direct material damage several times over [9, 10].

This paper presents a continuation of the investigations dealing with the problem of the crawler two-wheel bogie (TWB) strength [6], Fig. 1. Namely, the conclusion arrived at in the cited paper, shows that the main reason of the TWB structure failure, Fig. 2, is its insufficient strength under the lateral forces acting during curve travel. Beside that, the redesigned TWB structure is also presented, as well as the comparative test results of both the original and the redesigned TWB structure, Fig. 3.

Experimental results obtained on a test board especially designed for this purpose [6] as perennial exploitation with no failures, confirmed the validity of the TWB reconstruction design.

Bearing in mind that the FE models used in [6] do not include track wheel axles, the goal of the study presented in this paper is to quantify their influence on the stress–strain state of the TWB structure. The obtained results are important because of the wide usage of crawler traveling mechanisms in various types of earthmoving and conveying machines.

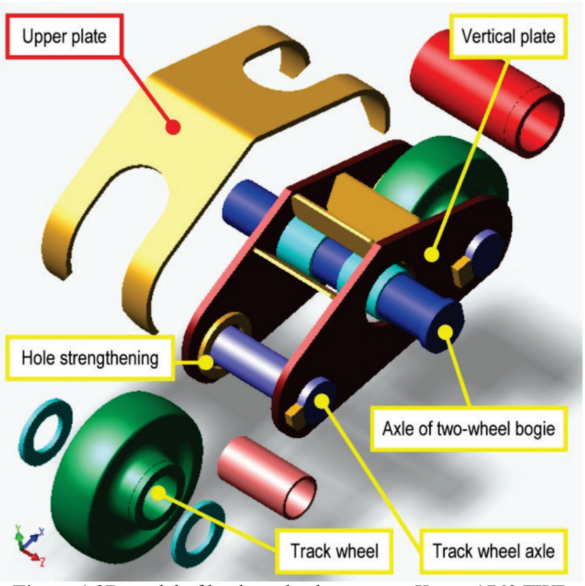


Figure 1 3D model of bucket wheel excavator Krupp 1760 TWB

Figure 2 Typical failure of the TWB structure

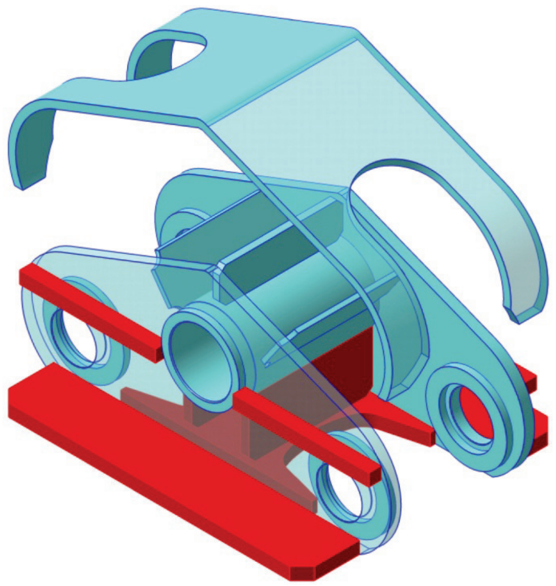


Figure 3 Redesigned TWB structure
(added elements are red colored) [12]

2 Load assumptions

Load analysis of the TWB structure, Fig. 4 and Tab. 1, is carried out according to the recommendations given in [13, 14, 15].

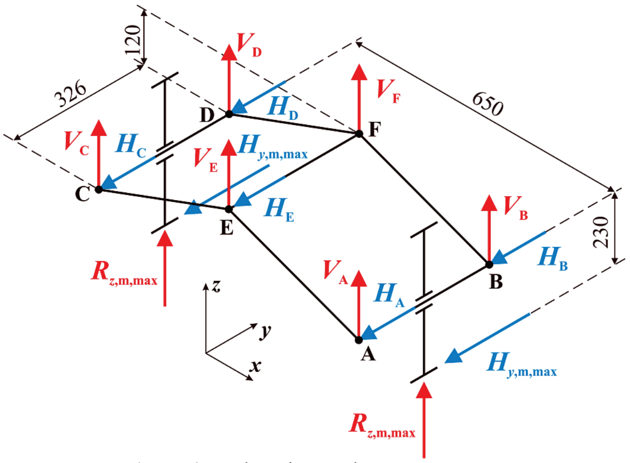


Figure 4 Loads acting on the TWB structure

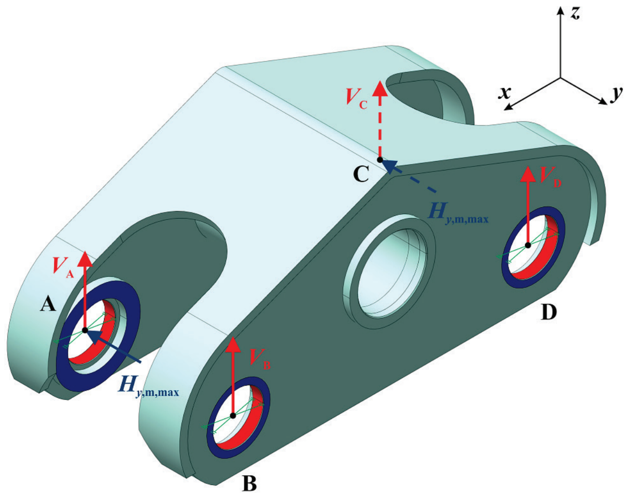
Table 1 TWB loads

Nomenclature	Notation and value, kN
Average vertical wheel load for maximum load on the crawler track	$R_{z,m,max}$=384,3
Horizontal wheel load	$H_{y,m,max}$=230,6
Vertical loads of track wheel axles' beddings	V_A=354,8
	V_B=29,5
	V_C=354,8
	V_D=29,5
Horizontal loads of track wheel axles' beddings	H_A=H_B=H_C=H_D=115,3
Vertical loads of TWB beddings	V_E=879,4
	V_F=110,8
Horizontal loads of TWB bedding	H_E=461,2

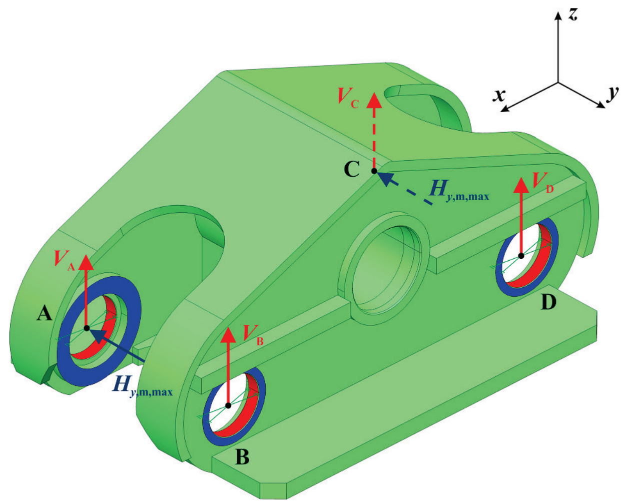
3 Finite element models

Finite element (FE) models of the original and redesigned TWB structure are obtained on the basis of corresponding 3D models.

Manufacturing and assembling faults caused the appearance of a relatively great axial gap (≈4 mm) between the TWB vertical plates and the track wheel axles subassemblies. That is the case considered in [6], where FE models were created by supposing that the lateral forces act only on one vertical plate, while the second is the support in the corresponding direction. In the models shown in Fig. 5, lateral forces act on the annular surface of the holes' strengthenings (blue colored surfaces).



(a) original TWB structure - model 1 (M 1)



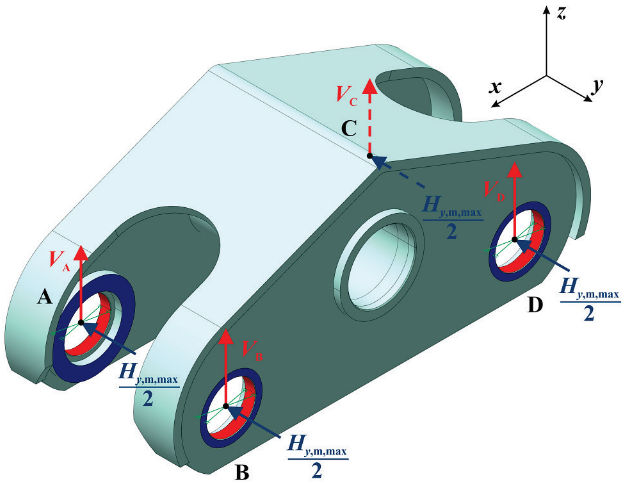
(b) redesigned TWB structure - model 2 (M 2)

Figure 5 TWB structure loading in case of an axial gap between the vertical plate and the track wheel axles subassemblies

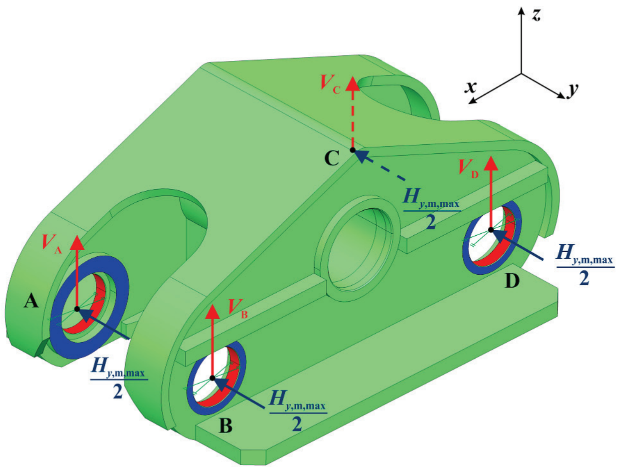
According to the project documentation, the mentioned axial gaps do not exist, and by the track wheel axles subassemblies, lateral forces equally load both vertical plates, blue colored surfaces in Fig. 6.

In FE models which include track wheel axles subassemblies, lateral forces act on one vertical plate - annular surfaces of the holes' strengthenings, blue colored surfaces in Fig. 7.

In order to obtain a reliable model of the contact connection between the track wheel axles and vertical plates i.e. to enable correct input of vertical loads into the corresponding holes in vertical plates of the models 1, 2, 3 and 4, contact virtual parts are implemented [16], red coloured surfaces in Figs. 5 and 6.



(a) original TWB structure - model 3 (M 3)



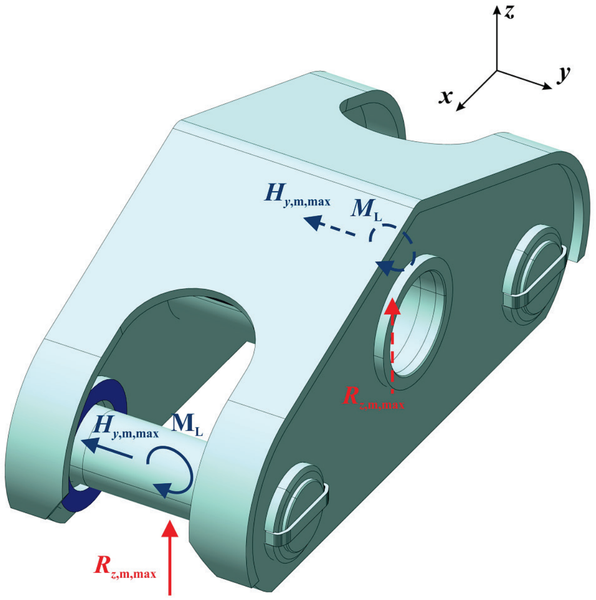
(b) redesigned TWB structure - model 4 (M 4)

Figure 6 TWB structure loading in case of no axial gap between the vertical plate and the track wheel axles subassemblies

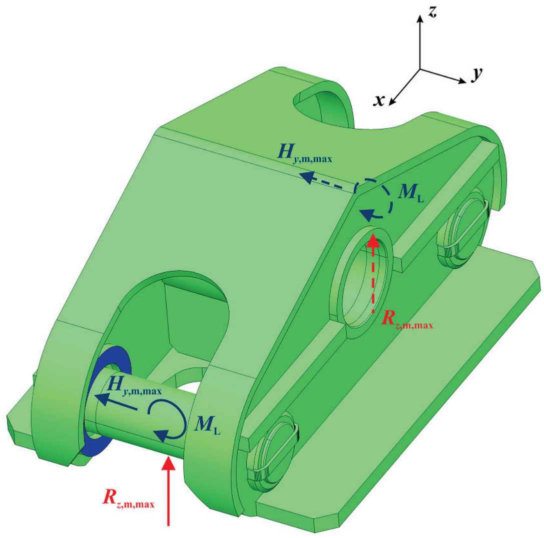
In models 5 and 6, track wheel axles are loaded by vertical forces and bending moments (M_L) gained by a reduction of lateral forces, Fig. 7. Connections between track wheel axles and vertical plates are defined to be contact frictionless [16].

The TWB is supported by a four-wheel bogie (FWB) structure. The connection between them is realised by an axle which is not included in the presented models. It was presumed to be absolutely rigid and immovable. Connections between the mentioned axle and the TWB structure are modelled by two virtual contact elements (placed on red colored surfaces in Fig. 8) which restrain displacements in the vertical plane i.e. in the directions of x and z axes, Fig. 8. TWB lateral leaning on the FWB structure is modelled by a restraint of y displacements of nodes on the blue colored surface in Fig. 8.

3D models shown in Figs. 5, 6 and 7 are discretized by 4-node linear tetrahedron elements. Uniform meshes were generated, Fig. 9, in order to provide full comparability of the FE analyses results. Their accuracies are high and in that way the appearance of isolated unrealistic stress values was avoided.



(a) original TWB structure - model 5 (M 5)



(b) redesigned TWB structure - model 6 (M 6)

Figure 7 Loading of TWB structure models which include track wheel axles subassemblies

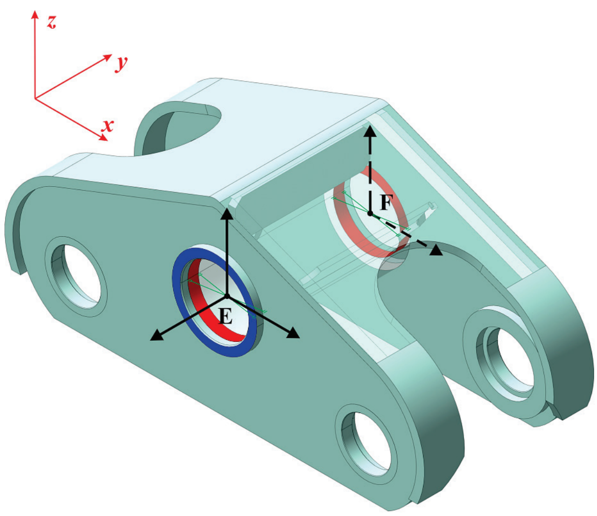


Figure 8 Leaning of the TWB structure

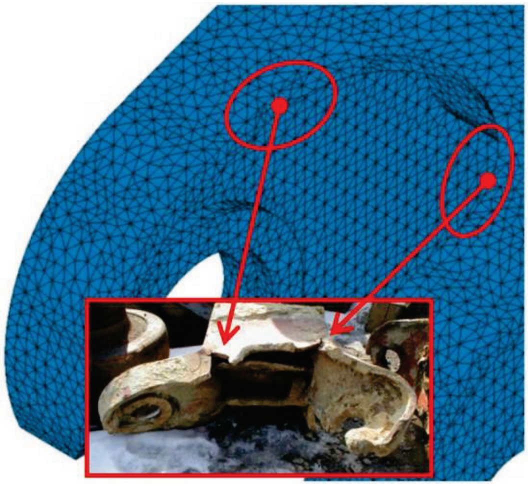


Figure 9 Detail of mesh in the cracks occurring zone

4 Validation of the finite element models

Validation of the models which include track wheel axles subassemblies (models 5 and 6) is done by linear FE simulation of the experiment described in [6], Figs. 10 and 11.

Comparative analysis pointed out a high agreement between the experimental and FEM results, Fig. 12, Tab. 2.

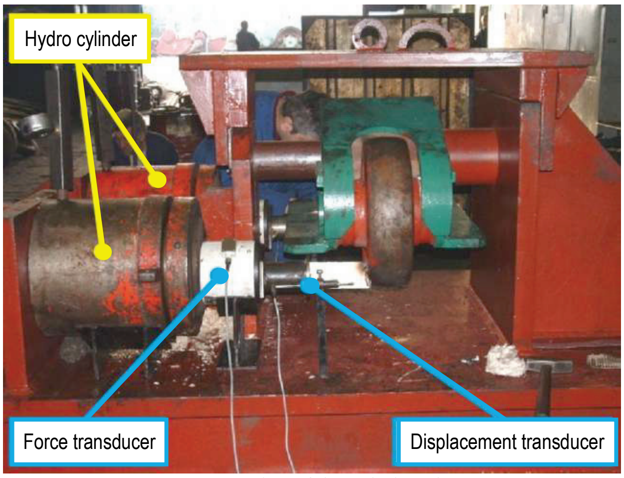


Figure 10 Testing of the redesigned TWB

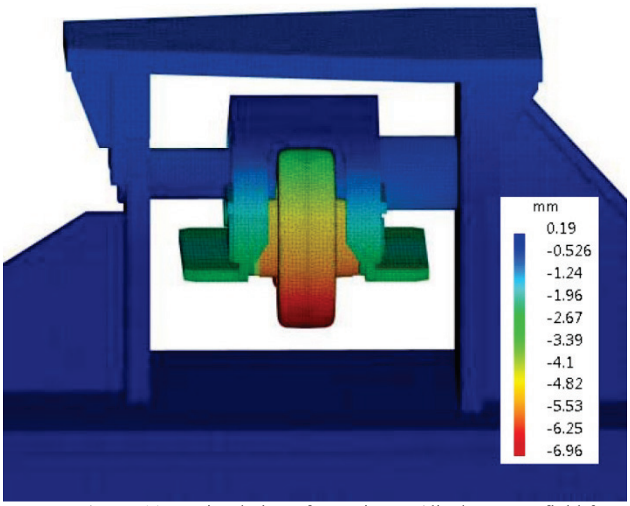


Figure 11 FE simulation of experiment (displacement field for hydro cylinder force F_{HC}=1000 kN)

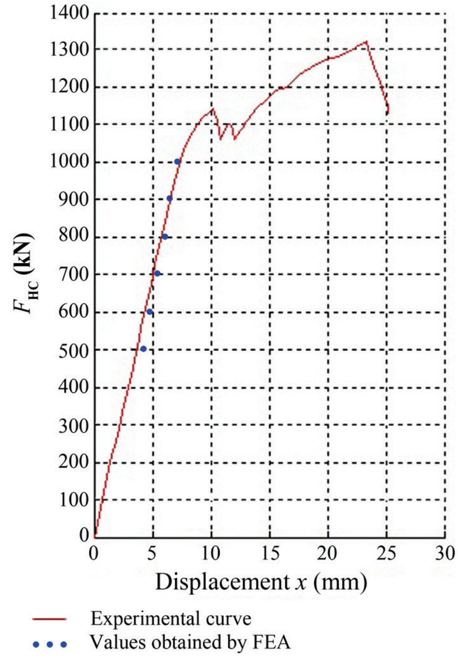


Figure 12 Experimental VS FEM results

Table 2 Comparison of the results obtained by experiment and FEM

Lateral force F_{HC} / kN	Displacement/mm		Percentage difference
	experiment	FEM	
500	3,8	4,2	9,5
600	4,4	4,7	6,4
700	5,2	5,4	3,8
800	5,8	6,0	3,4
900	6,5	6,5	0,0
1000	7,2	7,0	2,8

5 Results of the finite element analyses

The maximum calculated stress values appear in the upper plate of the TWB structure, red coloured surface in Fig. 13. Distribution of von Misses stresses in the critical zone is shown in Figs. 14 and 15. Averaging of the calculation stress values along the upper plate thickness is done by the 5th order interpolation polynomial with high values of the factor of determination (greater than 0,9). The maximum averaged von Misses stress (MAvMS) values are presented in Tab. 3.

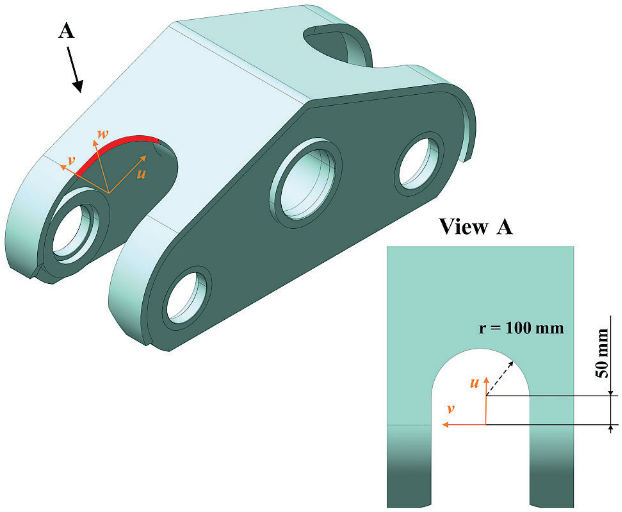


Figure 13 The zone (red colored) of maximum calculation stresses

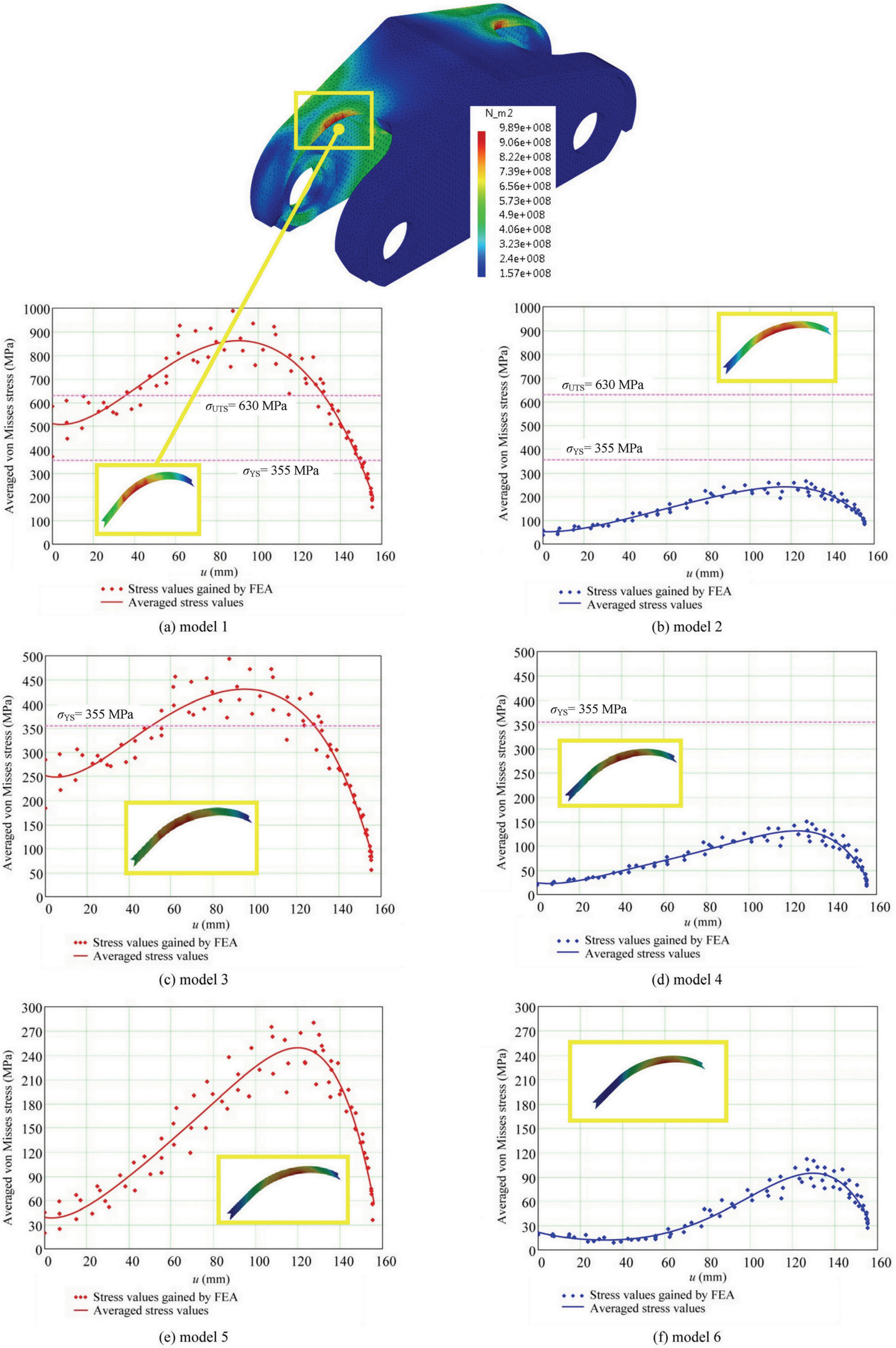


Figure 14 Distribution of averaged von Misses stresses in the critical zones

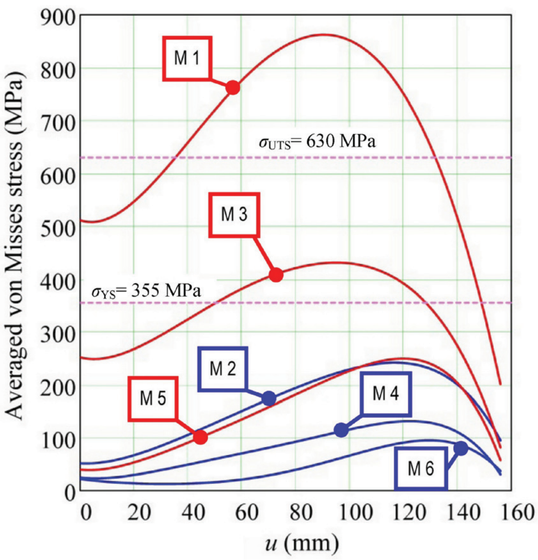


Figure 15 Comparative distribution of averaged von Misses stresses in the critical zones

Table 3 Maximum averaged von Misses stresses

Model	Stress value / MPa
1	862
2	242
3	431
4	133
5	249
6	95

6 Discussion

The results presented in Section 5 pointed out the following:

- In all cases the maximum averaged von Misses stresses (MAvMS) are considerably greater for the original TWB structure than the redesigned TWB structure i.e. 3,6 times in the case of the axial gap between the TWB structure and the track wheel axles subassemblies (models 1 and 2); 3,2 times if it is supposed that the track wheel axles distribute lateral loads equally to both vertical plates (models 3 and 4) and 2,6 times when the track wheel axles subassemblies are considered as structural parts (models 5 and 6);
- If track wheel axles do not distribute the lateral loads (models 1 and 2, Fig. 5), MAvMS (862 MPa) for the original TWB structure (model 1) are considerably greater than the ultimate tensile strength (σ_{UTS}=630 MPa for steel quality grade S355J2G3). This fact fully explains the occurrence of cracks in the case of an axial gap between the TWB structure and the track wheel axles subassemblies. Even in that case, MAvMs (242 MPa) for the redesigned TWB structure (model 2) are lower than the minimum yield stress value (σ_{YS}=355 MPa) (in ISO $\sigma_{UTS}=R_m$, $\sigma_{YS}=R_{p0,2}$);
- If it is supposed that the track wheel axles distribute the lateral loads equally to both vertical plates (models 3 and 4, Fig. 6), MAvMS (431 MPa) for the original TWB structure (model 3) are considerably greater than the minimum yield stress value (σ_{YS}=355 MPa), while MAvMS (133 MPa) for the redesigned TWB structure (model 4) are also lower than the minimum yield stress value. Beside that, MAvMS for model 3 are 2 times lower than MAvMS for model 1, while MAvMS for model 4 are 1,8 times lower than MAvMS for model 2;
- If track wheel axles are included in the models of TWB structures (models 5 and 6, Fig. 7), MAvMS for both the original (249 MPa) and the redesigned (95 MPa) TWB structure are lower than the minimum yield stress value, while MAvMS for model 6 are 2,6 times lower than MAvMS for model 5. Beside that, MAvMS for model 5 are 1,7 times lower than MAvMS for model 3 which does not include track wheel axles. Analogously, MAvMS for model 6 are 1,4 times lower than MAvMS for model 4 which does not include track wheel axles.

Based on the fact that the results of the FE analyses indicate a considerable influence of track wheel axles on the TWB structure stress state, the impact of their diameter was investigated on model 5, Figs. 16 and 17.

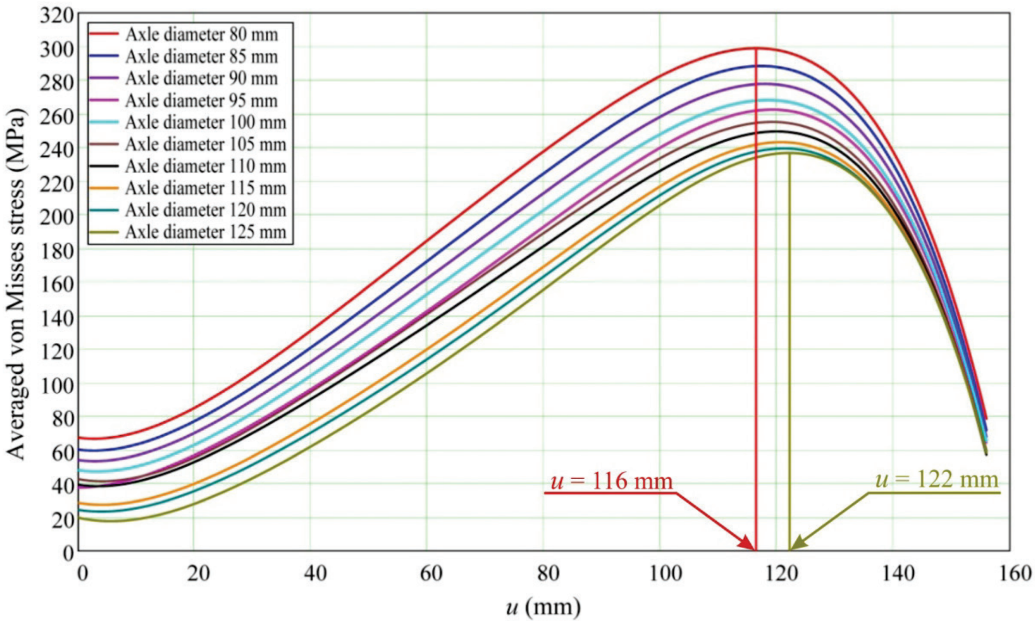


Figure 16 Dependence of the averaged von Misses stresses on the track wheel axle diameter (model 5)

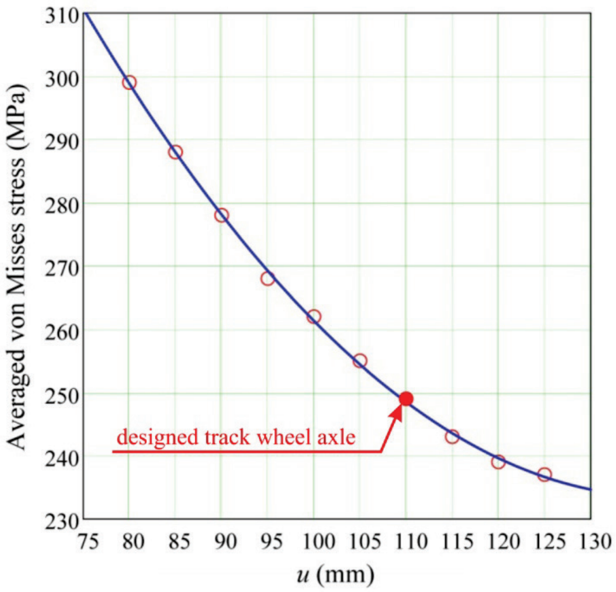


Figure 17 Dependence of maximum averaged von Misses stresses on track wheel axle diameter (model 5)

Obviously, Figs. 16 and 17, increasing of track wheel axle diameter leads to decreasing of the MAvMS values. If the MAvMS value for designed track wheel axle diameter d = 110 mm is accepted as a base for comparison, it can be concluded that MAvMS value for d = 80 mm is greater by 20 %, while MAvMS value for d = 125 mm is lower by 5 %, Tab. 4. Besides, it can be seen, Fig. 16, that increasing of the track wheel axle diameter leads to shifting of the locations of MAvMS values deeper in the TWB structure (from u = 116 mm for d = 80 mm to u = 122 mm for d = 125 mm).

Table 4 Influence of track wheel axle diameter on MAvMS

Track wheel axle diameter / mm	MAvMS/MPa	Relative MAvMS*
80	299	1,20
85	288	1,16
90	278	1,12
95	269	1,08
100	262	1,05
105	255	1,02
110	249	1,00
115	243	0,98
120	239	0,96
125	237	0,95

*The accepted base for comparison is the MAvMS value in the case of the designed track wheel axle with a diameter of d = 110mm.

7 Conclusion

The results of the FEA fully explain the occurrence of cracks in the case of the axial gap between the original TWB structure and the track wheel axles subassemblies. Even in that case, the integrity of the redesigned TWB structure is not jeopardized. In all of the studied cases, the stress state in the redesigned TWB structure is considerably lower than that in the original TWB structure.

Track wheel axles greatly influence the load distribution and, consequently, the stress state as well. Beside that, their introduction into the models of the TWB structure leads to considerable reducing of stress levels. Nevertheless, the conservative approach to calculating the TWB structure, using models which do not include track wheel axles, provides sufficient TWB carrying capacity even in the case of unforeseen loads, the appearance of which is quite possible having in mind the extremely hard working conditions.

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