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STRENGTH ANALYSIS OF BUCKET WHEEL EXCAVATOR'S EIGHT WHEEL EQUALIZING SYSTEM

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Summary: *This paper presents the results of the study dedicated to the problem of the bucket wheel excavator equalizing system (ES) strength. Finite element analysis of two wheel (TWB), four wheel (FWB) and eight wheel (EWB) bogies were conducted in order to determine weak points in ES structure. Strength and carrying capacity of FWB and EWB structures might be jeopardized due to their insufficient strength under lateral forces acting during curve travel. Severe failure of similar TWB structure is also presented and certain paraleles were made.*

Keywords: *bucket wheel excavator, FEA, strength, two wheel bogie, four wheel bogie, eight wheel bogie*

1. INTRODUCTION

Different problems dealing with the strength of the open pit machines' travelling mechanisms and belonging substructures are in the scope of investigation of many researchers [1-7, 15]. This makes sense because failures of the mentioned travelling mechanisms are always followed by high financial losses and replacements of damaged parts are executed on site in hard working conditions. It is a well known fact that losses caused by machine downtime i.e. the system as a whole, may exceed direct material damage several times over. For instance, 1 hour of downtime for BWE, is estimated as a financial loss between 10,000 € and 15,000 €, depending on their capacity and types of material that are excavated (coal or overburden) [8].

This paper presents an attempt to determine possible week points of crawler equalizing construction (structure), to indicate zones of unacceptably high stress values and to underline problems which may ocure during exploitation of bucket wheel excavator (BWE) SchRs 1600/3x25. This studie was inspired by severe failure and redesign of BWE SchRs 1760 two wheel bogie structure [9,10] and was conducted according to saying "better safe than sorry".

Bucket wheel excavator SchRs 1600/3x25, which is used for overburden excavation, is the latest open cast mining machine purchased by "Kolubara" lignite basin - Serbia. This machine, with theoretical capacity of Q_{TH} = 6600 m^3/h, which was put in exploitation during year 2010., already represents back bone of coal excavation on "Tamnava - West Field", the most productive open pit mine in Serbia.

BWE-s traveling mechanism consists of three pairs of crawlers, two of wich are steerable. Every crawler is equipped with equalizing system (ES) which distribute the load statically determinate to the individual wheels and also provide the necessary freedom of movement of the travel wheels to adapt to undulating ground conditions in travel direction [11]. Single crawler ES is composed of two 8-wheel (EWB), four 4-wheel (FWB) and eight 2-wheel (TWB) bogies, Figure 1.

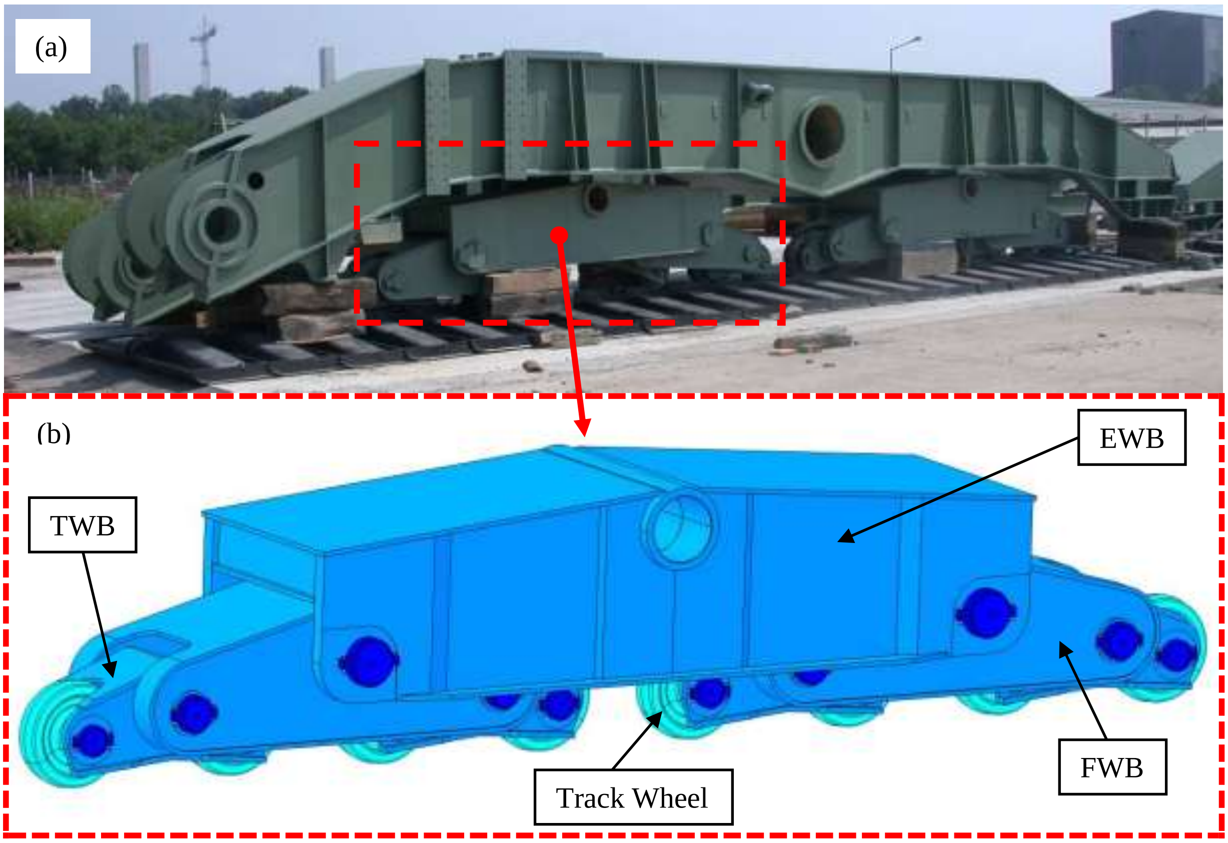

Figure 1: BWE 1600 crawler during erection process: (a) crawler bearing structure assembly; (b) 3D model of eight wheel equalizing assembly

2. LOAD ASSUMPTIONS

Load analysis of ES is carried out according to the recommendations given in the standard DIN 22261-2. The relevant loadcase considered herein is loadcase HZ including lateral forces from curve travelling [12]. Including the partial safety factor 1.33 for loadcase HZ, the design track wheel horizontal and vertical loads, as well as loads of TWB, FWB and EWB beddings are presented in Figure 2 and Table 1.

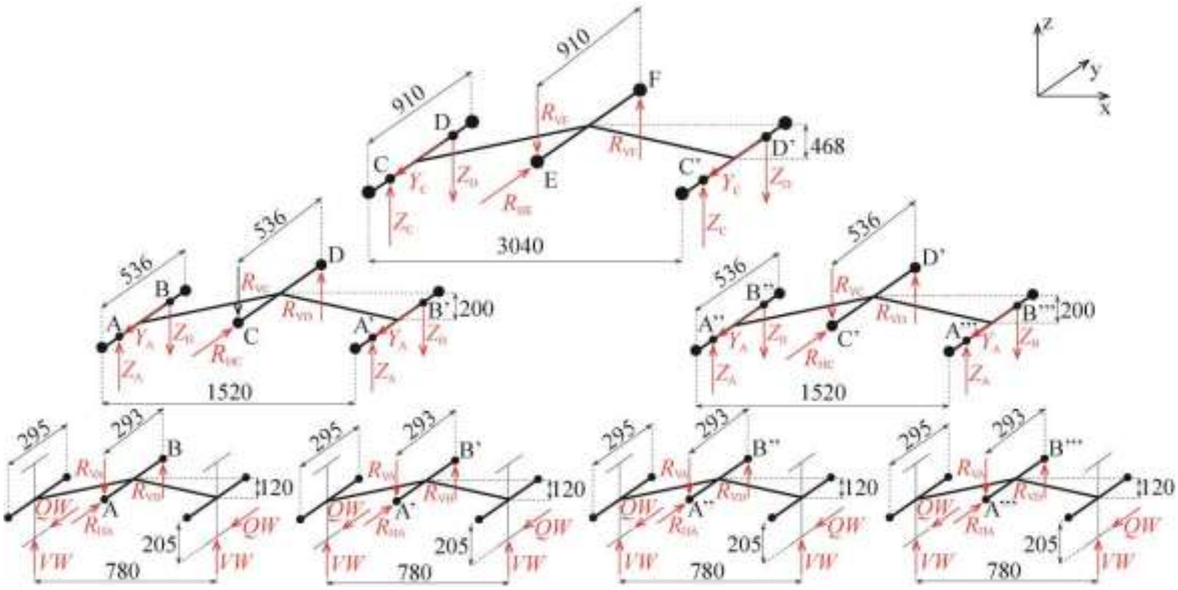

Figure 2: Loads acting on the eight wheel equalizing assembly

Table 1: EWB assembly loads

Nomenclature	Notation and value/kN
Vertical track wheel load	VW=710.0
Horizontal track wheel load	QW=425.0
Vertical loads of TWB beddings	Z_A=R_{VA}=1652.8
	Z_B=R_{VB}=232.8
Horizontal loads of TWB bedding	Y_A=R_{HA}=850.0
Vertical loads of FWB beddings	Z_C=R_{VC}=3085.1
	Z_D=R_{VD}=245.1
Horizontal loads of FWB bedding	Y_C=R_{HC}=1700.0
Vertical reactions of EWB beddings	R_{VE}=6550.1
	R_{VF}=870.1
Horizontal reactions of EWB bedding	R_{HE}=3400.0

3. FINITE ELEMENT MODELS

Finite element (FE) models of TWB, FWB and EWB structures are obtained on the basis of corresponding 3D models and with presumption that no faults were made during manufacturing and assembling process.

In FE model of TWB structure, track wheel axles are loaded by vertical forces and bending moments (M_L) gained by a reduction of lateral forces, Figure 3. TWB structure model include track wheel axles. Lateral forces act on one vertical plate - annular surfaces of the holes' strengthenings, red colored surfaces in Figure 3, since, during curve travel, track wheels come in to contact with vertical plate which is in direction of lateral force. Connections between track wheel axles and vertical plates are defined to be contact frictionless [13].

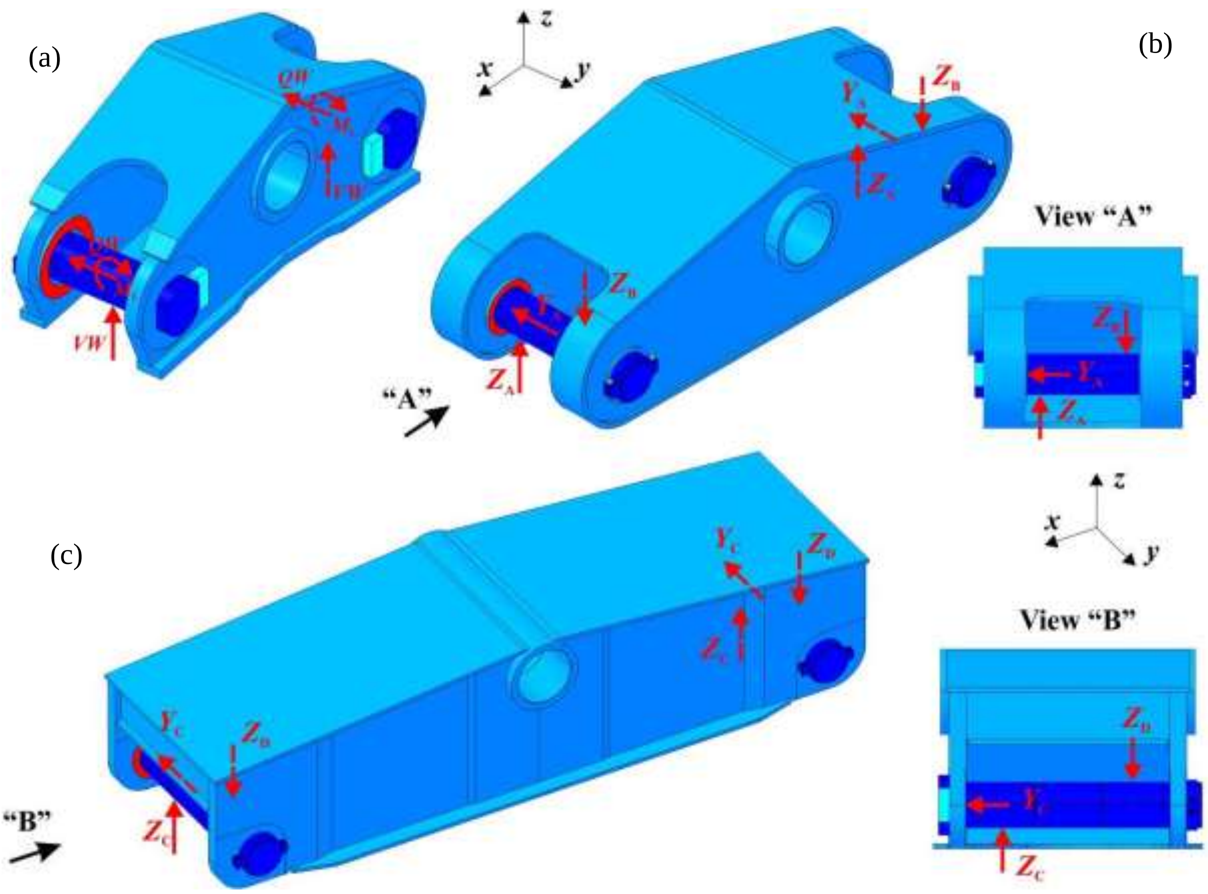

Figure 3: Analyzed structures loading: (a) TWB; (b) FWB; (c) EWB

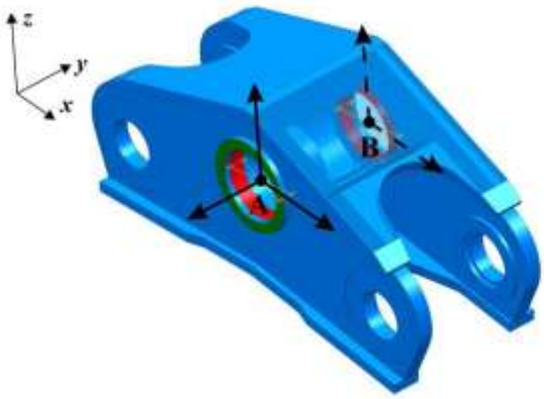

Figure 4: Leaning of the TWB structure

The TWB is supported by a FWB structure. The connection between them is realised by an axle which is not included in the presented TWB model. 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 Figure 4) which restrain displacements in the vertical plane i.e. in the directions of *x* and *z* axes, Figure 4. TWB lateral leaning on the FWB structure is modelled by a restraint of *y* displacements of nodes on the green colored surface in Figure 4. Same leaning (supporting) method was used for both FWB and EWB finite element models.
Reaction forces obtained by FE analysis of TWB structure were used, with opposite directions, as loads acting upon FWB model. TWB axles, which exist in FWB model are loaded by vertical forces which act in points previously defined as TWB structure supports. Similar method was used for determination of intensity and points of action of vertical and horizontal forces acting upon EWB structure.
3D models shown in Figure 3 are discretized by 4-node linear tetrahedron elements. Uniform meshes were generated for all elements of analyzed assemblies. Their accuracies are high and in that way the appearance of isolated unrealistic stress values was avoided.

4. RESULTS OF THE FINITE ELEMENT ANALYSES

The maximum calculated stress values appear in the lower stifftening plates (H plates) of all analized structures, red coloured surfaces in Figure 5.

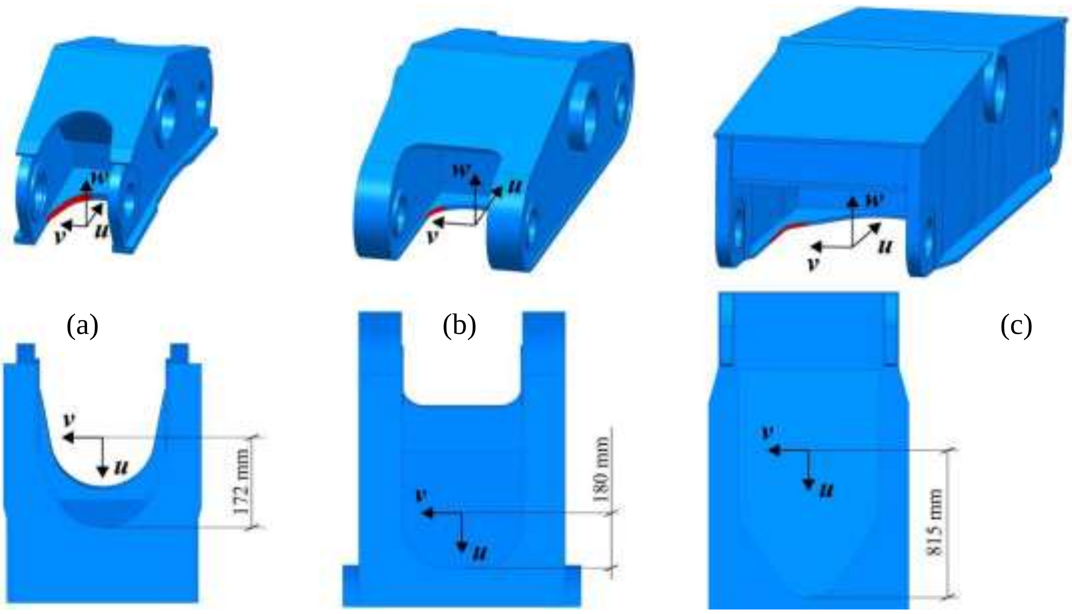

Figure 5: Zones (red colored) of maximum calculation stresses: (a) TWB; (b) FWB; (c) EWB

Distribution of von Misses stresses in the critical zones is shown in Figures 6, 7 and 8. Averaging of the calculation stress values along the H plate thickness is done by interpolation polynomials of higher order, as presented in [10], Figures 9, 10 and 11. The maximum averaged von Misses stress (MAvMS) values for boath factorized and working loads, as well as maximum calculated stress values (MACS) are presented in Table 2.

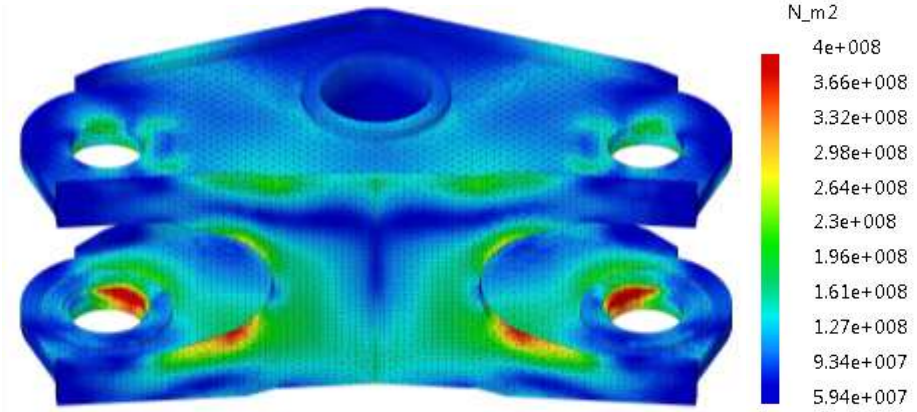

Figure 6: Two wheel bogie body - von Misses stress field

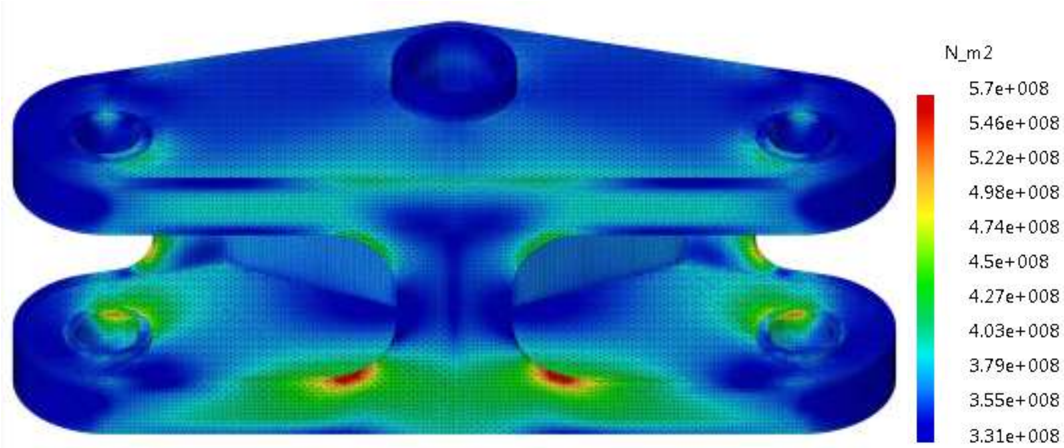

Figure 7: Four wheel bogie body - von Misses stress field

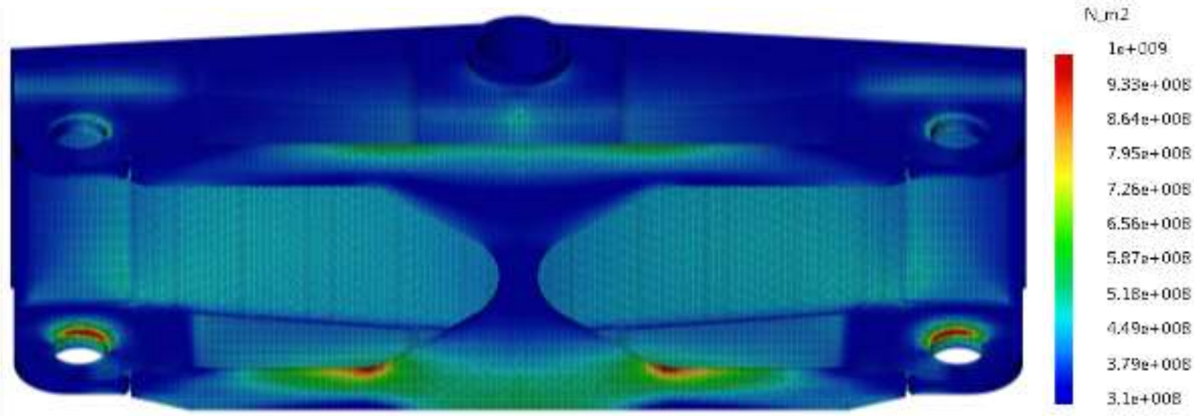

Figure 8: Eight wheel bogie body - von Misses stress field

High stresses (stress values) which appear in zones of axle beddings on all analyzed structures, Figures 6, 7 and 8, are contact stresses and are not subject of this investigation.

It is important to note that H plates of TWB and EWB structures are made of steel quality grade S420N with yield stress value of $\sigma_{YS,S420N}$=420MPa, while the H plate of FWB is made of steel quality grade S355J2+N with yield stress value of $\sigma_{YS,S355J2+N}$=355MPa.

Table 2: Maximum stresses

Model	MACS/MPa	MAvMS/MPa (for factorized loads)	MAvMS/MPa (for working loads)
TWB	400	348	262
FWB	570	554	417
EWB	1000	926	696

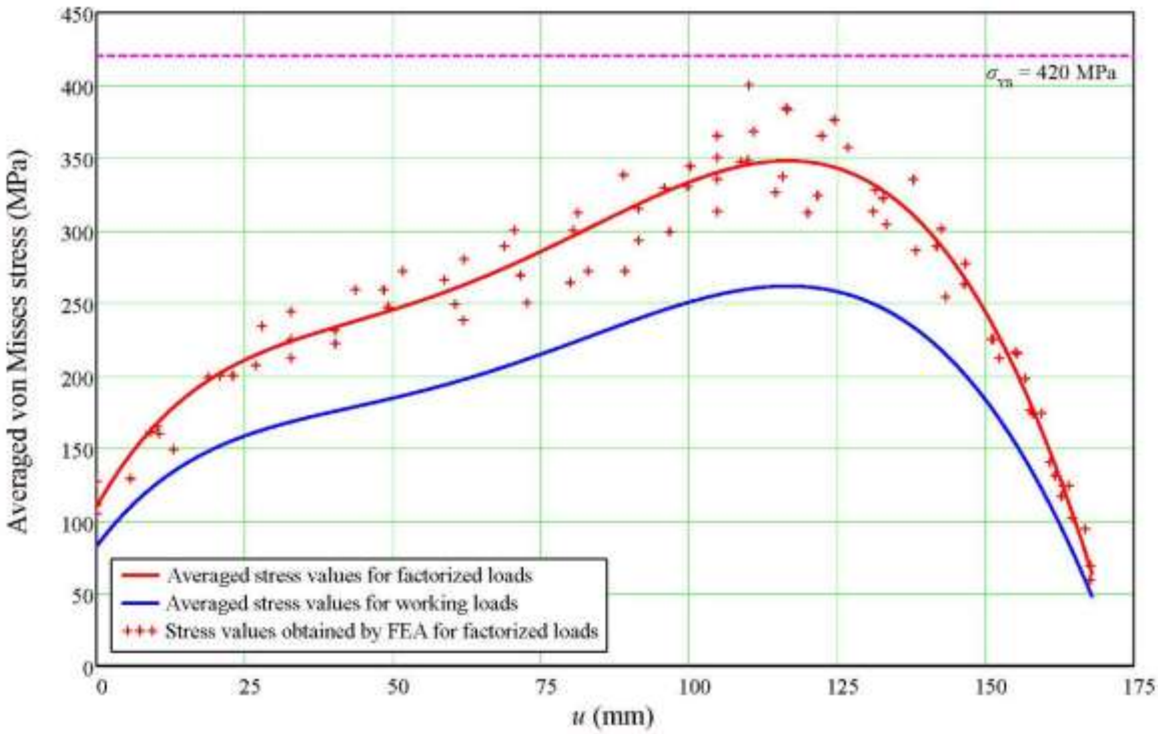

Figure 9: Distribution of averaged von Misses stresses in the critical zones - TWB

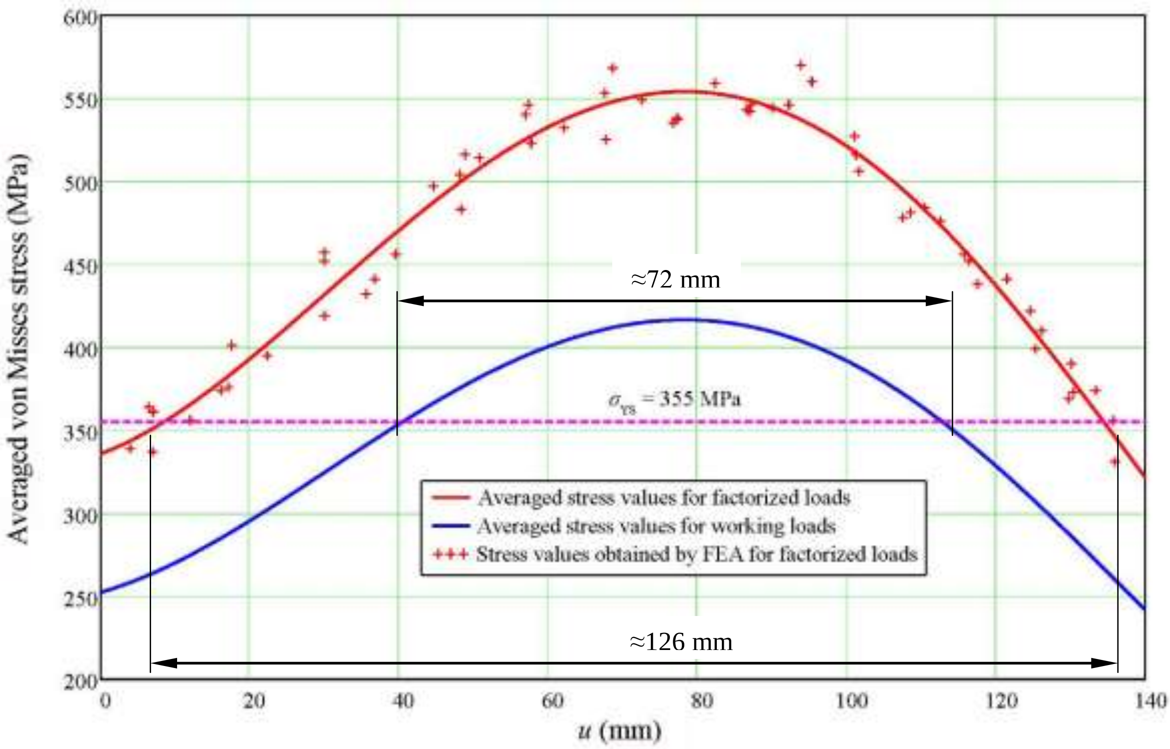

Figure 10: Distribution of averaged von Misses stresses in the critical zones - FWB

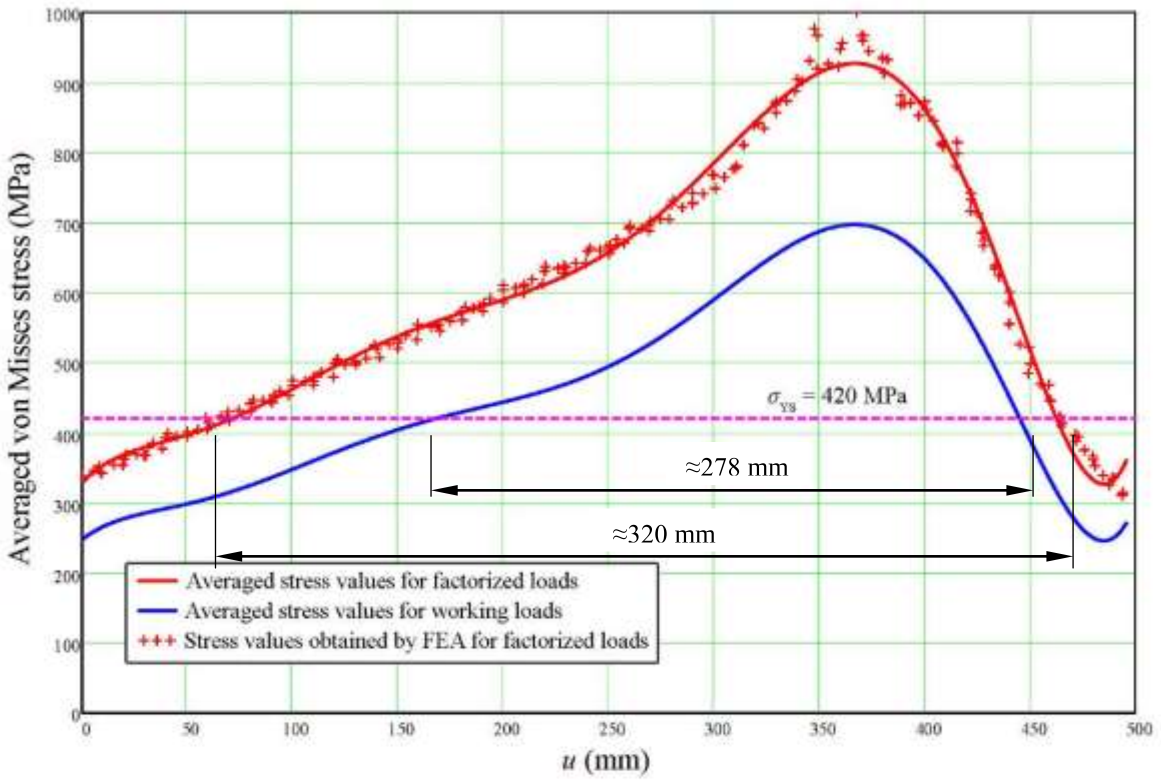

Figure 11: Distribution of averaged von Misses stresses in the critical zones - EWB

5. DISCUSSION

The results presented in Section 4 pointed out the following:

- Maximum averaged von Misses stress (MAvMS) value of TWB structure obtained for factorized loads (348 MPa) is lower than permissible stress which is equal to yield stresss (σ_{YS}=420MPa) of steel quality grade S420N. MAvMS value of TWB structure obtained for working loads (262 MPa) is considerable lower than yield stress value. Even the maximum calculated stress value (MACS) obtained for factorized loads (400 MPa) is lower than permissible stress, Figure 9.
- MavMS value of FWB structure obtained for factorized loads (554 MPa) is 1.6 times higher than permissible stress which is equal to yied stresss (σ_{YS}=355MPa) of steel quality grade S355J2+N. MAvMS value of FWB structure obtained for working loads (417 MPa) is 1.2 times higher than yield stress value. MACS obtained for factorized loads (570 MPa) is 1.6 times higher than permissible stress, Figure 10.
- MAvMS value of EWB structure obtained for factorized loads (926 MPa) is considerable, even 2.2 times, higher than permissible stress which is equal to yield stresss (σ_{YS}=420MPa) of steel quality grade S420N. Moreover, MAvMS obtained for working loads (696 MPa) is 1.7 times higher than yield stress. MACS obtained for factorized loads (1000 MPa) is 2.4 times higher than permissible stress, Figure 11.
- Zone of MAvMS values, alonge *u* axis, higher than permissible stress for FWB structure and factorized loads is ≈126 mm long. While MAvMS values, for working loads, higher than yield stress spred over ≈72 mm alonge *u* axis, Figures 10 and 12.
- The situation is far worse when eight wheel bogie is considered. Namely, zone of MAvMS values, alonge *u* axis, higher than permissible stress for factorized loads is ≈320 mm long and MAvMS values, for working loads, higher than yield stress spred over ≈278 mm, Figures 11 and 12.

Von Misses stress values were obtained using linear finite element method so it is obvious that results higher than yield stress values for corresponding materials are not exact and don't give realistic picture of state in the material (material strength). Regardless, values higher than yield stresse point out that structure strength and carrying capacity are jeopardized.

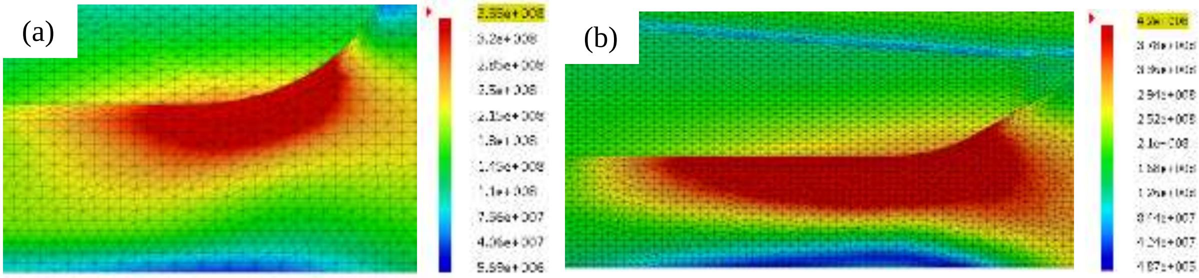

Figure 12: Zones of high von Misses stress values: (a) FWB structure; (b) EWB structure (values higher than corresponding permissible stresses are red colored)

6. CONCLUSION

Two wheel bogie structure wholly meets the strength criterion. This is not the fact with four and eight wheel boogies. The main reason for appearance of stress values higher than permissible ones in critical zones of lower stiffening plates of FWB and especially EWB structure is their insufficient strength under lateral forces acting during curve travel.
What makes the case worse is the fact that presented investigation was done under the presumption that no unforeseen loads will appear during BWE exploitation what is quite possible having in mind the extremely hard working conditions.
Presented problems led to appearance of a relatively great axial gap (≈4 mm) between the TWB vertical plates and the track wheel axles subassemblies in TWB structure of another BWE SchRs 1760 also operating on "Kolubara" lignite basin – Serbia. The fact that complete lateral force was acting upon one vertical plate resulted with severe failure of mentioned structure, Figure 13.

Figure 13: Typical failure of the TWB structure [14]

Large scope investigation was carried out. TWB body strength of original and redesigned construction was analyzed under the influence of lateral force acting on one vertical plate, the equal distribution of lateral force on both vertical plates and finally finite element analysis of models which include track wheel axles subassemblies were conducted.
As it can be observed, Figure 14, MAvMS obtained for working loads acting upon original TWB structure, for model which include track wheel axles subassemblies (M5 curve) is considerable lower than yield stress value, and yet failure occured.
According to zones of high stress values, especially pronounced in FWB and EWB structures of BWE SchRs 1600 and presented failure of similar construction it can be concluded that analyzed structures strength and carrying capacity might be jeopardized.
Authors of this paper suggest conservative approach to calculating the substructures of BWE crawlers equalizing systems, using FE models which do not include track wheel axles, since that is the way of providing sufficient carrying capacity even in the case of unforeseen loads.
The presented results have wider significance because the same or similar concept of equalizing systems and their vital subassemblies are frequently used in other types of excavators and earthmoving machines as well as mobile cranes.

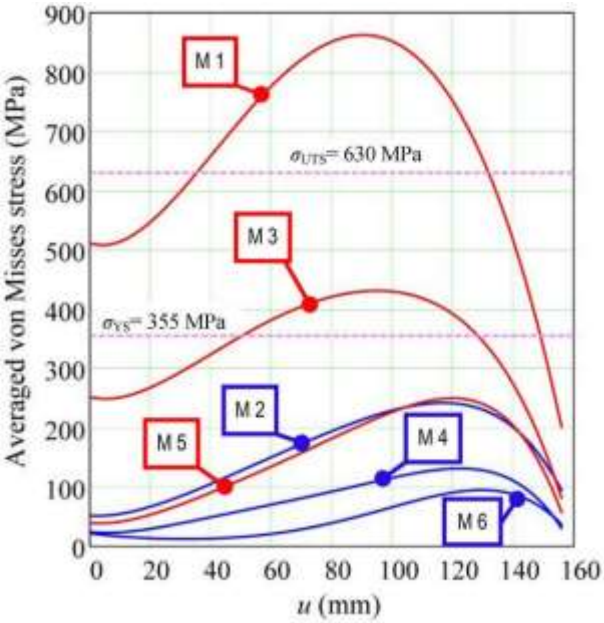

Figure 14: Comparative distribution of MAvMS in the critical zones of TWB – BWE SchRs 1760: M1 curve – original TWB in case of existence of axial gap; M2 curve - redesigned TWB in case of existence of axial gap; M3 curve - original TWB, no axial gap; M4 curve - redesigned TWB, no axial gap; M5 curve - original TWB which include track wheel axles subassemblies; M6 curve - redesigned TWB which include track wheel axles subassemblies [10]

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