Basic parameters of the static stability, loads and strength of the vital parts of the bucket wheel excavator’s slewing superstructure

Cite this as: Srđan M. Bošnjak, Nebojša B. Gnjatović, Sreten D. Savićević, Milorad P. Pantelić, Ivan Lj. Milenović, 2016. Basic parameters of the static stability, loads and strength of the vital parts of a bucket wheel excavator’s slewing superstructure. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 17(5):353-365. http://dx.doi.org/10.1631/jzus.A1500037

Abstract

- This paper presents a critical comparative analysis of the basic parameters of the static stability of the BWE 1600 superstructure, Fig. 1, the parameters being obtained by both analytical and experimental procedures.
- The procedure of superstructure 3D model mass correction, based on the results obtained by weighing conducted after the completion of the erection process, is presented.
- That way developed model provides enough accuracy in determining the superstructure’s COG in the entire domain of the bucket wheel boom inclination angle, and enables accurate load analysis of the superstructure’s vital parts.
- This fact becomes even more important considering that the procedure prescribed by standard DIN 22261 gives results which are not on the side of safety, as shown on the example of the strength analysis of the bucket wheel boom stays’ end eyes.

Key words: bucket wheel excavator, slewing superstructure, parameters of the static stability, loads, strength

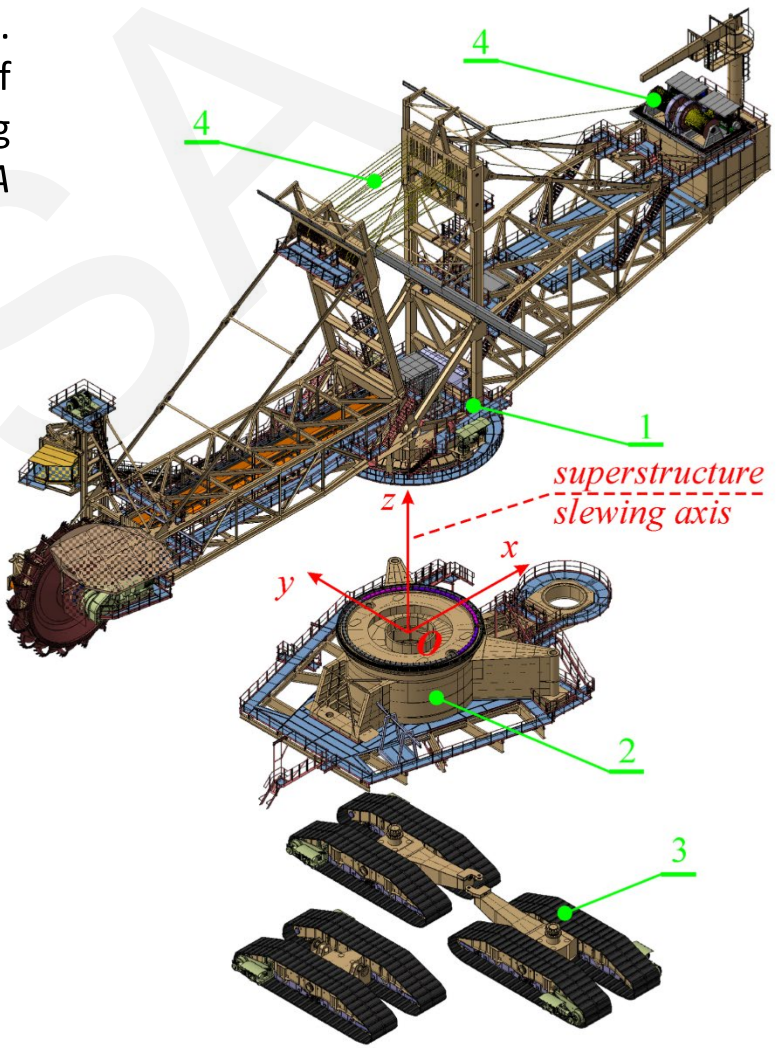

Fig. 1 Main parts of the BWE 1600: 1 – slewing superstructure; 2 – substructure; 3 – traveling mechanism; 4 – winches for BWB positioning

Introduction

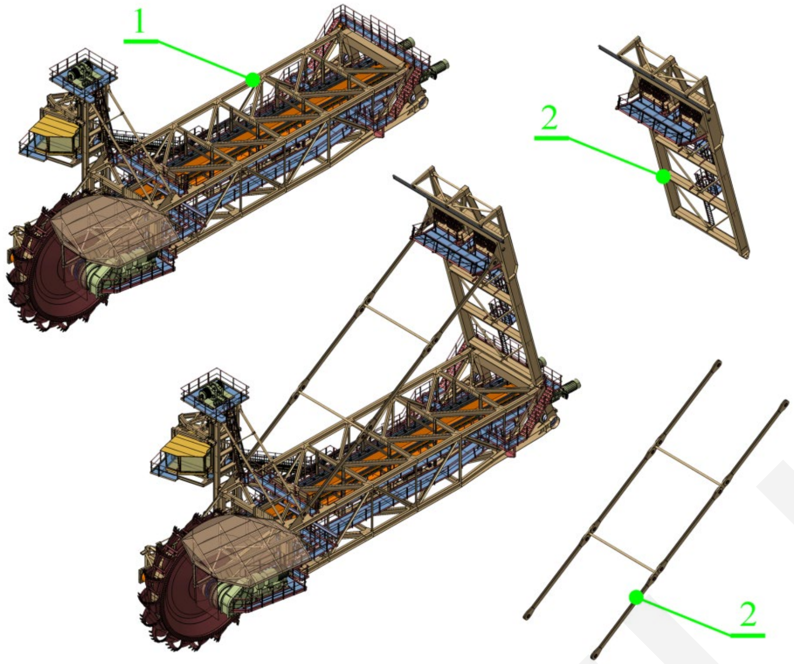

Fig. 2 Main parts of the SuS1: 1 – BWB; 2 – mast 1; 3 – BWB stays

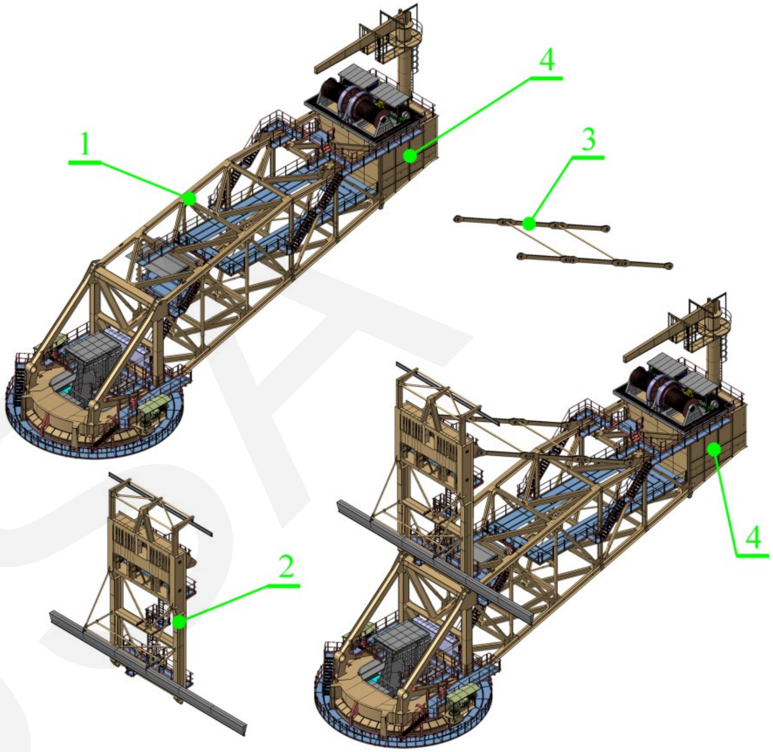

Fig. 3 Main parts of the SuS2: 1 – CWB with slewing platform; 2 – mast 2; 3 – CWB stays; 4 – CW box

- The slewing superstructure of the BWE 1600, Fig. 1, consists of two main substructures: SuS1, Fig. 2 and SuS2, Fig. 3.
- The slewing superstructure parameters dominantly determine the basic BWE exploitation characteristics, its reliability and safety.
- They may be classified in three main groups: (a) parameters which determine the static stability of the superstructure; (b) parameters which determine the strength of the superstructure and (c) parameters which determine the dynamic behavior of the superstructure.
- The common denominator of all the above mentioned parameters is the mass of the superstructure and its distribution along the structure. That is the reason why the determination of the basic parameters of static stability (BPSS), above all the weight and the position of the center of gravity (COG), must be cautiously carried out in all phases of the BWE design.

Introduction

This paper presents:

- the results of an analytical–numerical investigations of BPSS at various stages of BWE 1600 project development. These investigations were based on:

(1) the preliminary stability calculation provided by the BWE manufacturer (Variant 1: V1);

(2) the final stability calculation provided by the BWE manufacturer (Variant 2: V2);

(3) a 3D model of the BWE superstructure (Variant 3: V3) (Figs. 1–3);

(4) a 3D model of the BWE superstructure, with the mass corrected according to the results of the first weighing (Variant 4: V4);

(5) a final stability calculation, with the mass corrected according to the results of the first weighing (Variant 5: V5);

- the results of the two weighings, made on site, after the first erection of the machine;
- the results of a strength analysis of the vital parts of the superstructure.

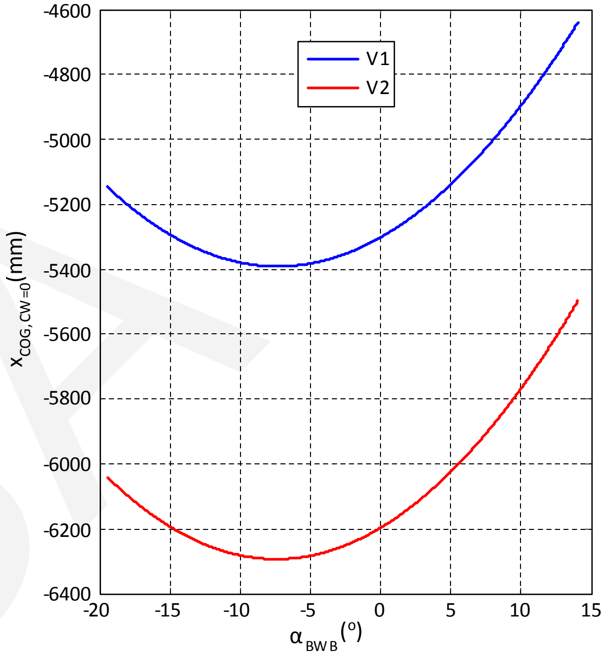

Fig. 4 The COG abscissas of the superstructure without the CW mass: V1 vs V2

Analytical determination of the BPSS: V1 vs V2

- The final shaping of the carrying structure and its adjustment with the mechanical subsystems and equipment, i.e. transformation from V1 to V2, causes a change in the superstructure BPSS.
- A relatively small difference in the calculated superstructure masses (1.5%) leads to a relatively large unfavourable shifting of its COG (902 mm towards the bucket wheel), Fig. 4, followed by a significant increase in the counterweight mass required for balancing (24 Mg), Fig. 5.

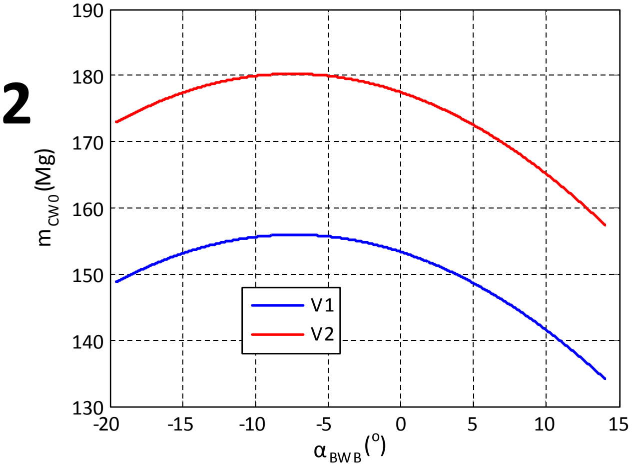

Fig. 5 Mass of the CW for balancing the superstructure deadweight: V1 vs V2

Weighing the superstructure

- The superstructure was weighed on site immediately after the first erection of the machine, Fig. 6. During the first weighing (W1), the CW mass was 177.017 Mg, which was supposed to be enough to balance the superstructure deadweight according to V2.
- After the first erection, the CW mass was corrected (54.96 Mg added), so the CW mass during the second weighing (W2) was 231.977 Mg.

Fig. 6 BWE during the first weighing on the erection site

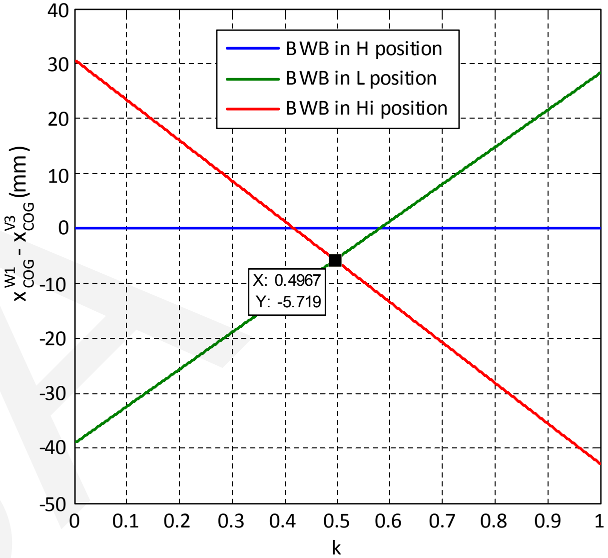

Fig. 8 Deviation of the COG abscissa

Correction of the mass of the superstructure models based on the results of the first weighing

- According to the results of the first weighing the average superstructure mass is ≈1172 Mg, while the mass of the 3D model superstructure (V3) with a CW of 177.017 Mg (CW mass during the first weighing) is ≈1155 Mg. Thus, the experimentally determined superstructure mass is greater by ≈17 Mg than the superstructure 3D model mass. Because the superstructure COG based on the weighing results is shifted towards the BW the excessive mass (the so called 'corrective mass'), is on the BWB side.
- To obtain a model which gives good approximations of the COG abscissas in both the low and high BWB positions simultaneously, Fig. 7, the applicate of the center of the corrective mass is determined by the expression $\zeta_C=k(\zeta_{C,L}+\zeta_{C,Hi})$ where k is the corrective factor. The influence of the k factor value on the difference between the superstructure COG abscissas obtained experimentally and by calculation (Δx_{COG}) for the characteristic BWB positions, is shown in Fig. 8.

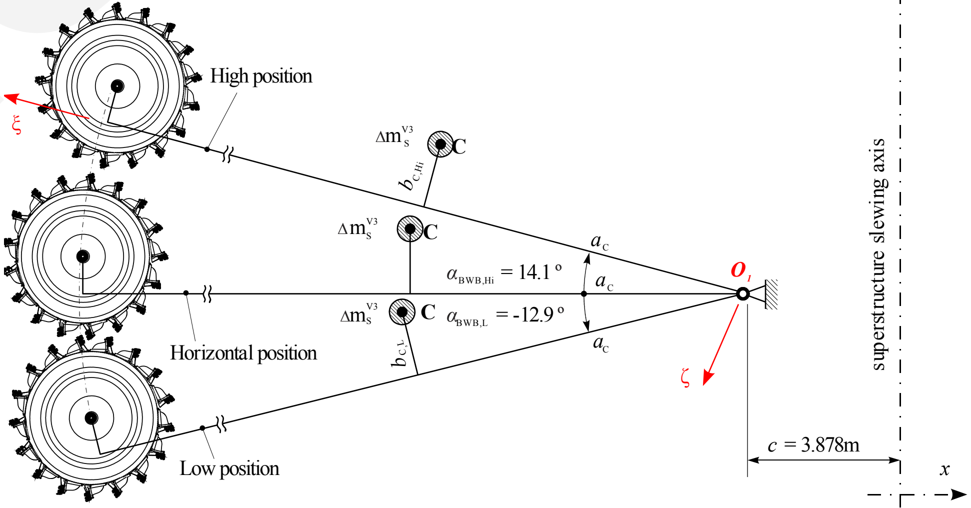

Fig. 7 Determination of the corrective mass center position

Comparative analysis of analytical and experimental results

- V4 gives the best approximation of the superstructure COG abscissa in relation to the first weighing results, Figs. 9 and 10. Nevertheless, it is important to note that the intensities of the winch rope forces, and of the BWB stay forces, are highest specifically for V4, Figs. 11 and 12. This is a consequence of the less favorable final deadweight distribution with respect to V1, which was the basic BWE design. Otherwise, the V4 results are in good agreement with the second weighing results, Fig. 13 and, therefore, V4 was adopted for further analyses and determination of the stress states of the vital superstructure parts.

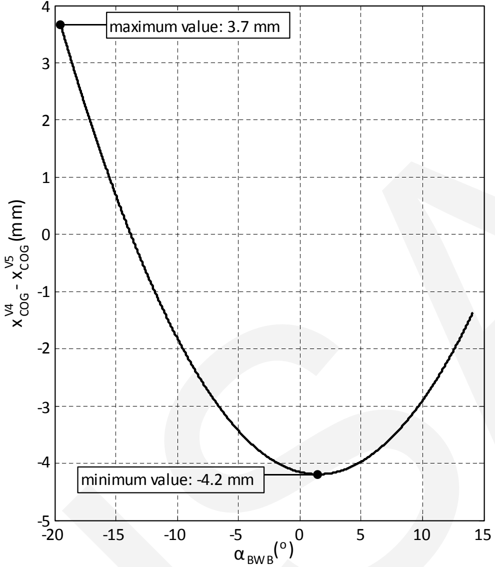

Fig. 10 Difference in the COG abscissas for V4 and V5

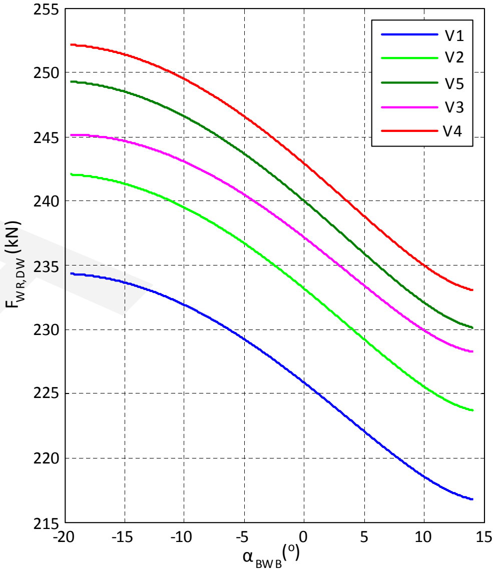

Fig. 11 Winch rope forces caused by deadweight

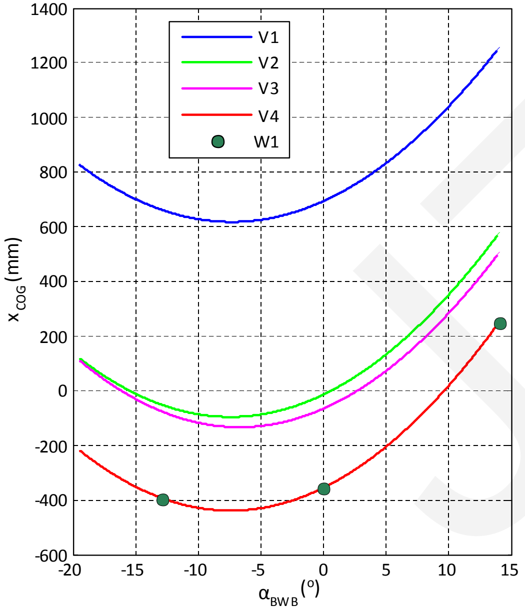

Fig. 9 Abscissas of the superstructure COG

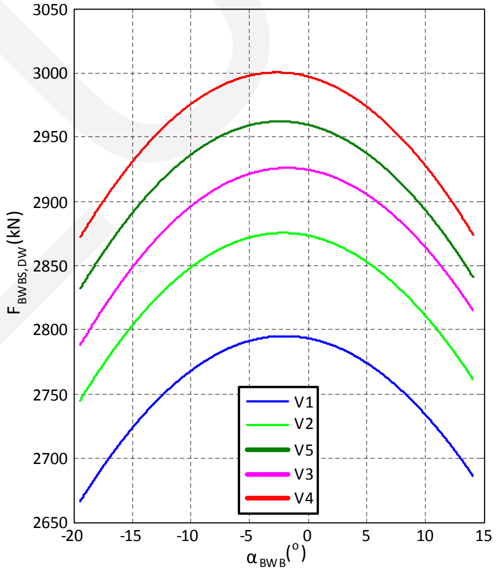

Fig. 12 BWB stay forces caused by deadweight

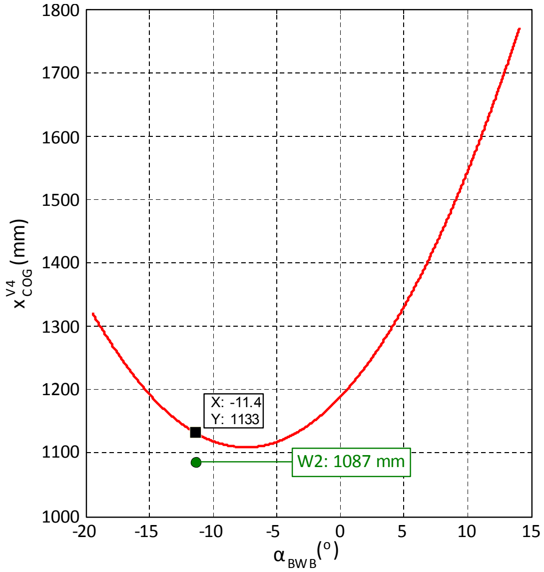

Fig. 13 V4 vs W2: Abscissa of COG

Working load analysis

- Load analysis of the vital superstructure parts was carried out according to code DIN 22261-2 (2014) for load case (LC) H1.2 (BWE in normal operation) (Figs. 14 and 15) using our original, in-house software “EXLOAD”.

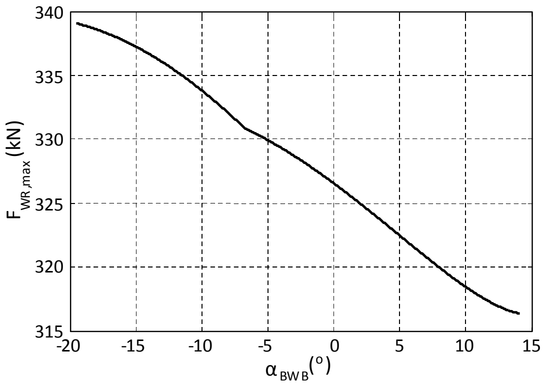

Fig. 14 Maximum winch rope force in LC H1.2

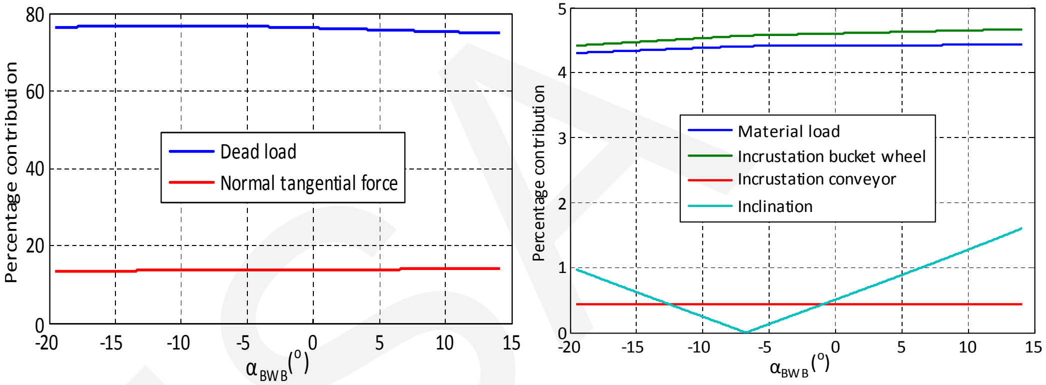

Fig. 15 Percentage contribution to maximum winch rope force

Stress state of the BWB stay

- According to DIN 22261-2 (2014), the value of nominal stress caused by the tension force is 180 MPa, while the value of nominal stress caused by the frictional moment is 41.6 MPa.

- The stress state of the lamella was also identified by applying the linear finite element method (FEM), neglecting the influence of the frictional moment. In the critical eye plate cross section, the maximum value of the stress tensor component in the tension force direction is σ_{max}=496 MPa (Figs. 16 and 17).

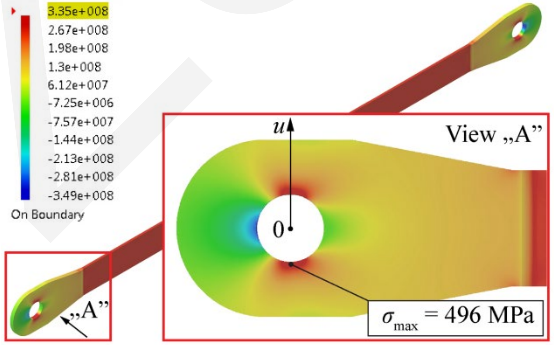

Fig. 16 Stress tensor component in the direction of the tension force

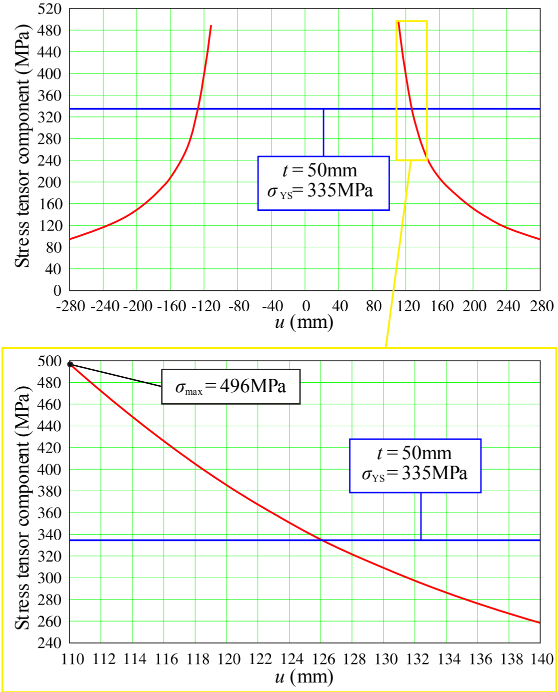

Fig. 17 Distribution in the eye plate critical cross section

Load and stress analyses results

- Based on the results presented in Fig. 15, the dead load has most influence on the load of the winch rope. In LC H1.2 its minimum percentage contribution to the maximum winch rope force is 74.8%, whilst the maximum contribution of the normal tangential force is 14.1%. The contribution of the other factors is considerably lower: material load – maximum 4.4%, bucket wheel incrustation – maximum 4.7%, conveyor incrustation – maximum 0.4% and inclination – maximum 1.6%. These findings underline the importance of a precise identification of the weight and COG of all parts, as well as of the entire superstructure.
- In terms of the nominal stress values in the critical eye plate cross section and applying the procedure prescribed in DIN 22261-2 (2014), **1.4 σ_n=1.4(σ_{nZ}+ $\sigma_{n\mu}$)= 310.2 MPa<σ_{YS}=335 MPa**, we conclude that the eye plate satisfies the strength criterion.
- However, values of the corresponding stress tensor component in the critical eye plate cross section, caused by the factored tension force, are greater than the yield stress value up to a depth of 16 mm, measured from the edge of the hole (Fig. 17).
- The value of the geometric stress concentration factor is **α_K=σ_{max}/σ_{nZ}=496/180=2.76**.
- This value of α_K is in full agreement with values given in the literature. The diagram shown in Fig. 18 (Petersen, 1990) gives **α_K≈2.9**.
- Therefore, according to the results of the linear FEM and published data, the geometric stress concentration factor value is about twice as great as the factor **1.4** prescribed by DIN 22261-2 (2014).
- **Keeping in mind that tension stresses are dominant in the critical zone, we conclude that the considered eye plate is the weak point in the superstructure and presents a potential danger to its integrity, although it satisfies the strength criterion prescribed by DIN 22261-2 (2014).**

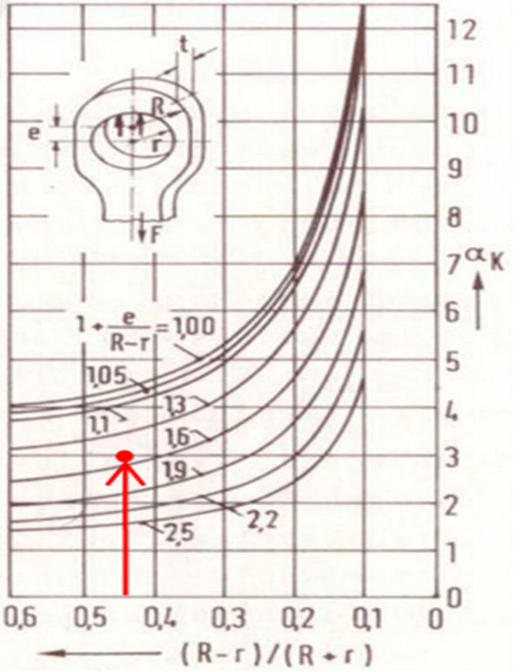

Fig. 18 Geometric stress concentration factor (Petersen, 1990)

Conclusions

The deadweight is a dominant load of the vital parts of a bucket wheel excavator's superstructure, such as stays and winch ropes. Also, due to its nature, from the entire set of BWE superstructure's loads, only the deadweight does not have the character of assumption. Therefore, its identification should be conducted with the utmost care during the BWE design, as well as during the first erection.

Based on the presented investigation results we conclude the following:

1. A relatively small difference in the calculated superstructure masses (1.5%) leads to a relatively large unfavourable shifting of its COG (902 mm towards the bucket wheel), followed by a significant increase in the counterweight mass required for balancing (24 Mg).

2. The 3D model of the superstructure enables a very precise determination of its weight and COG position.

3. By merging the results obtained from the superstructure 3D model and the weighing conducted after the completion of the erection process (first weighing), the distribution of superstructure masses can be fully identified, and a corrected 3D model created. The validity of the model is confirmed by the results of the second weighing, conducted after the correction (increase) of the counterweight mass. The 3D model developed in such a manner provides enough accuracy in determining the superstructure COG in the complete domain of the bucket wheel boom inclination angle, and enables accurate load analysis of the superstructure's vital parts.

4. In LC H1.2 (BWE in normal operation) the minimum percentage contribution of the SuS1 deadweight to the maximum winch rope force is 74.8%.

5. The procedure for the proof of the eye plates' stress prescribed by code DIN 22261-2 (2014), gives results which are not on the side of safety, as demonstrated by the example of the bucket wheel boom stay's eye plate.