

Fracture Analysis of the Hydraulic Truck Crane ATLAS 3006

Mile Savković^{1*}, Milomir Gašić¹, Nebojša Zdravković¹, Goran Bošković¹, Goran Pavlović²

¹ University of Kragujevac, Faculty of Mechanical and Civil Engineering Kraljevo, Dositejeva 19, 36000 Kraljevo (Serbia)

¹ Colpart d.o.o-Beograd, Čirovljeva 5, 11030 Beograd, (Serbia)

This paper presents the analysis of a fracture due to the local increase in stress at the point of connection between the hydrocylinder and the first segment of the truck crane boom. The connection between the hydrocylinder support and the body of the first boom segment is accomplished by welding. The first part of the paper defines the relevant load for calculation of the hydrocylinder support, by using the manufacturer's data to perform analytical calculation of the critical section. It is followed by the FEM analysis and fatigue analysis, for the most unfavourable load case. It has been established that the critical value of stresses is at the point of connection between the hydrocylinder support and the structure of the first boom segment. Experimental testing has shown that the fracture did not occur due to an error in the material and that the material type is adequate for this type of structure. The superposition of negative influences: fatigue of the material and a pronounced difference in material thicknesses in the cross section at the point of fracture are the main causes of damage of the hydraulic truck crane structure.

Keywords: Hydraulic truck crane, Truck crane boom, Fracture analysis, FEM analysis

1. INTRODUCTION

The hydraulic truck crane ATLAS 3006 (Figure 1) is used for lifting and transportation of loads with the mass $Q_{min}=1120$ kg at the largest reach ($L_{max}=6080$ mm), i.e. $Q_{max}=3650$ kg at the smallest reach ($L_{min}=1920$ mm). The main structure of the crane consists of the crane column, two jointed segments and one telescopic segment. Another two telescopic segments can be added to the crane. The crane which is the subject of research in this paper does not have additional telescopic segments built-in. The mass of the crane ATLAS 3006, with the complete installation and oil in its hydrocylinders, is 1245 kg. The nominal pressure of the hydraulic installation is $p_n=175$ bar, and the maximum operating pressure can be $p_n=225$ bar. At the moment of damage of the mentioned crane, the operating pressure of the hydraulic installation was set to $p_n=170$ bar.



Figure 1. Hydraulic truck crane Atlas 3006

The hydraulic truck crane ATLAS 3006, which is the subject of research in this paper, is located at the Electricity Distribution Company Kruševac and is used for

work in very difficult conditions, for mounting and dismantling elements of power transmission lines and long distance lines so that it is mostly engaged for field work. The mentioned working conditions are difficult because it often lifts loads that are at the limit or exceed the values defined by the carrying capacity diagram. It is also used for tightening power lines, and there are no precise data about the values of forces that load the crane structure. The life and proper functioning of such a crane considerably depend on the operator himself, i.e. how much he adheres to the recommendations for its proper exploitation.

After more than 12 years of crane exploitation, during a regular overhaul, certain damages at the first jointed segment of the crane were noticed. This damage is at the point of connection between the hydrocylinder and the segment (detail "A" - Figure 2).



Figure 2. Point of the fracture initiation in the crane Atlas 3006

Hydraulic truck cranes mostly perform difficult operations and their loads are dynamic and stochastic, which is a frequent cause of failures that may have catastrophic consequences [1-6]. However, even when

they are not catastrophic, they certainly result in huge financial losses.

For the purpose of saving, the user himself, without any previous detailed analysis of the causes of damage, solved the problem of repairing the damage in the truck crane boom by welding at the point of cracking. The damaged

plates were connected by butt welding. After the repair, the crane was returned to exploitation.

After more than 3 years of exploitation of the repaired crane, a fracture (Figure 3) occurred at the point where it had been repaired.

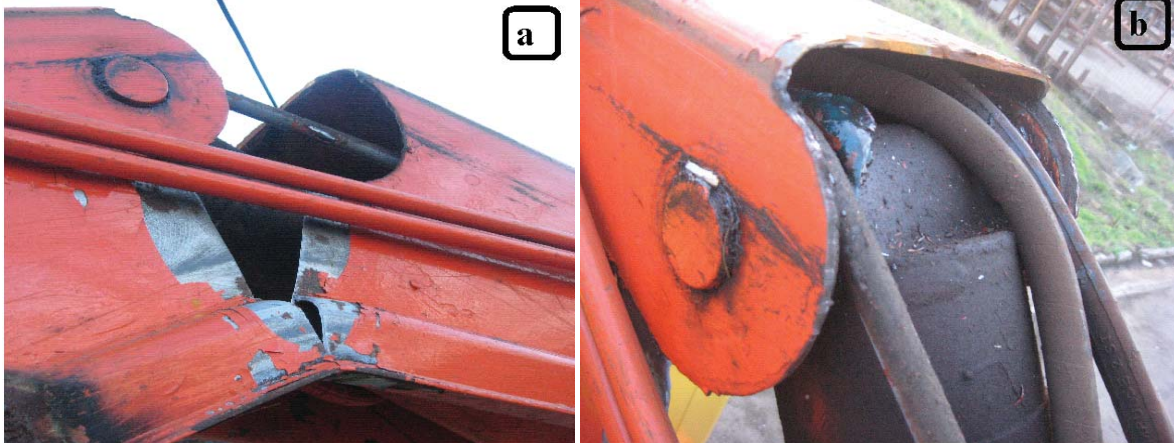


Figure 3. Point of the boom fracture in the telescopic truck crane ATLAS KRAN 3006 a) lateral side; b) upper side;

2. ANALYSIS OF THE MATERIAL USED FOR THE BOOM OF THE HYDRAULIC TRUCK CRANE ATLAS 3006

In the first phase, an experimental procedure was performed and it covered testing of the mechanical properties and chemical composition of the material as well as the visual examination of the fracture surface. The results of examination of the chemical composition of the samples taken at the point of fracture are presented in Table 1.

The results of examination of the samples taken at the point of fracture showed that the chemical composition and mechanical properties corresponded to the quality of steel NIOVAL 47 (P460NL1). For obtaining better mechanical properties and removal of residual stresses during welding, that material is subjected to the process of thermal treatment. More precise data about the type of material and its physical and chemical properties were obtained based on [7-9].

Table 1. Results of examination of the chemical composition of the samples taken at the point of fracture

Elements	%	C	Si	S	P	Mn
Prescribed values	from	max	max	max	max	max
NIOVAL 47 (P460NL1)	to	0.20	0.60	0.020	0.030	1-1.7
(DIN 1.8915)						
Values obtained by testing		0.14	0.41	0.013	0.011	1.08

Table 2. Results of examination (determination) of the mechanical properties of the material

Examined material		$R_{p0.2}$ (N/mm ²)	R_m (N/mm ²)	A_5 (%)
Prescribed values	from	510*	680*	min
	to	800*	975*	21
Sample 1		717	762	15.2
Sample 2		726	772	15.3
Sample 3		715	760	15.3

(*According to [7], for thermally treated steel)

The fracture analysis clearly shows the fatigue fracture initiation which occurred in the transition zone between the weld and the base material as well as at the point of joining the plates with a large difference in thicknesses (Figure 3).

The performed experimental procedure of testing the chemical composition and mechanical properties of the material, as well as the visual examination of the fracture

surface indicate that the fracture did not occur due to an error in the material.

3. ANALYSIS OF THE BOOM STRESS IN THE HYDRAULIC TRUCK CRANE ATLAS 3006

The analysis of the stress state of the hydraulic truck crane ATLAS 3006 was carried out by applying the finite element method (FEM). The model was formed on the basis of catalogue documentation and the additional measurements performed at the crane itself (Figure 4).

Papers [10-13] deal with damages of heavy-duty machines. In addition to metallographic examination, the FEM analysis is used for obtaining characteristic values of stresses and establishing the causes of damage..

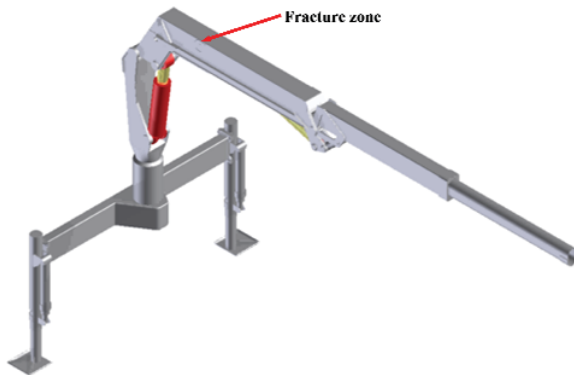


Figure 4. Model of the hydraulic truck crane ATLAS 3006

The 3D model of the hydraulic truck crane was built by synthesis of all structural parts (Figure 4). The model represents a continuum discretized by 10-node tetrahedral elements for the purpose of creating an FEM model (64036 nodes and 33060 elements). The first segment of the jointed boom of the truck crane was particularly taken out and analysed (Figure 5).

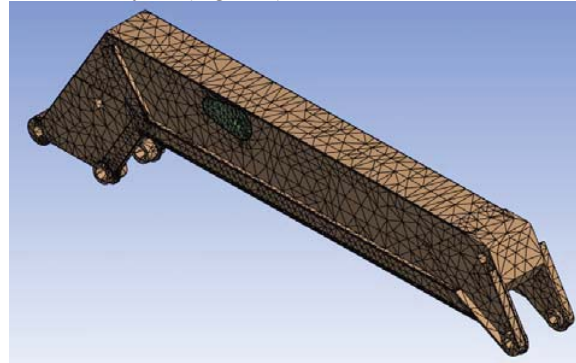


Figure 5. First segment of the boom of the hydraulic truck crane ATLAS 3006

The manufacturer's data about the value of maximum load and the data about the mass of crane elements were used for the analysis of loads of the hydrocylinder support for lifting the second segment. The scheme of loading of the first segment of the crane boom is shown in Figure 6.

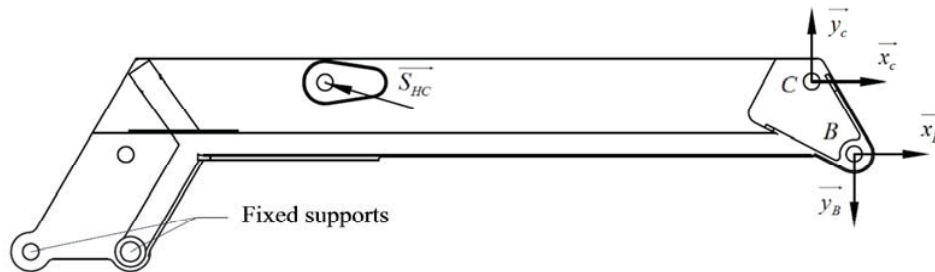


Figure 6. Scheme of loading of the first segment of the boom in the hydraulic truck crane ATLAS 3006

The analysis of stresses of the jointed segment of the boom was carried out for two load cases:

- case I - the telescope is extended to the maximum, the reach is maximum, the payload $Q = 11.2 \text{ kN}$
- case II - the telescope is extended to the maximum, the reach is minimum, the payload $Q = 36.5 \text{ kN}$

The loads due to the dead weight are the same in both cases, i.e.:

$Q_{s1} = 1,12 \text{ kN}$ - the load due to the weight of the boom extension and the telescopic segment

$Q_{s2} = 1,15 \text{ kN}$ - the load due to the boom weight.

The stress state for case I is more unfavourable than for case II.

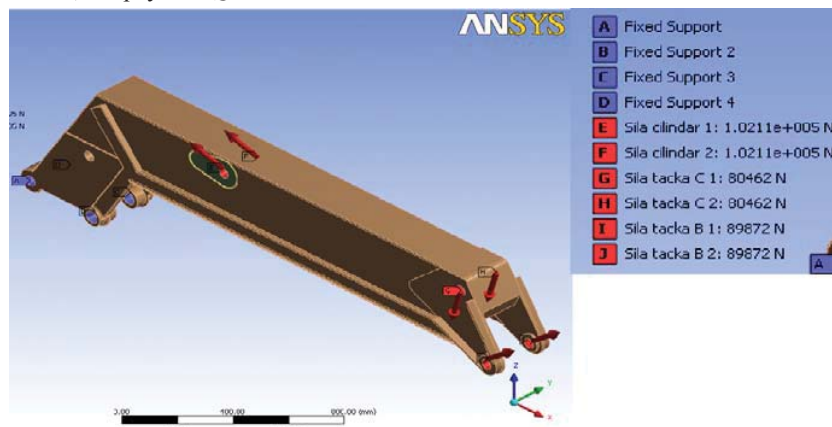


Figure 7. Scheme of loading of the first segment of the boom in the hydraulic truck crane ATLAS 3006

The obtained values of loads at the characteristic points (Figure 5) are:

$$x_B = 139,44 \text{ kN}; \quad y_B = -113,42 \text{ kN}; \quad x_C = -41,8 \text{ kN};$$

$$y_C = -155,4 \text{ kN}; \quad S_{HC} = 204,22 \text{ kN};$$

The obtained values of loads were used in the calculation model created in the software package ANSYS (Figure 7).

The uniaxial stress field, according to the Huber-Hencky-von Mises hypothesis, for load case I, is presented in Figs. 8 and 9.

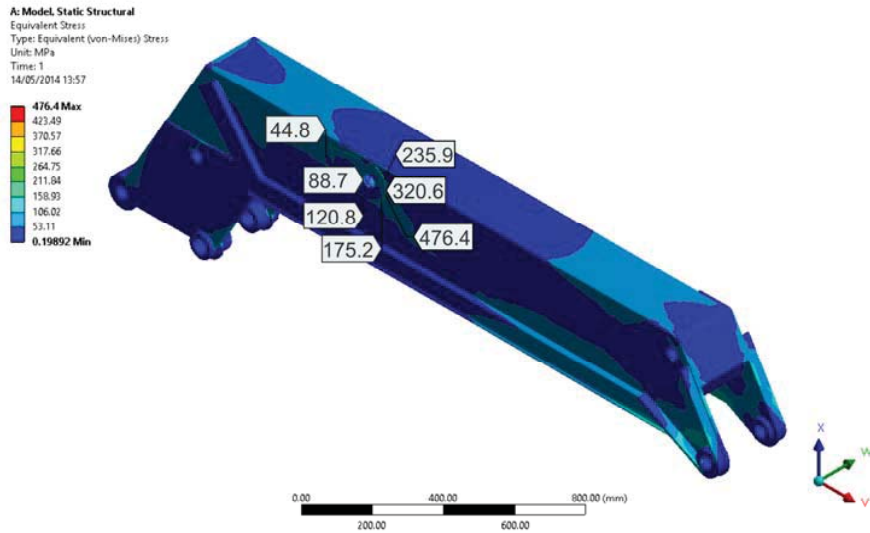


Figure 8. Stress state of the first segment of the boom with characteristic values

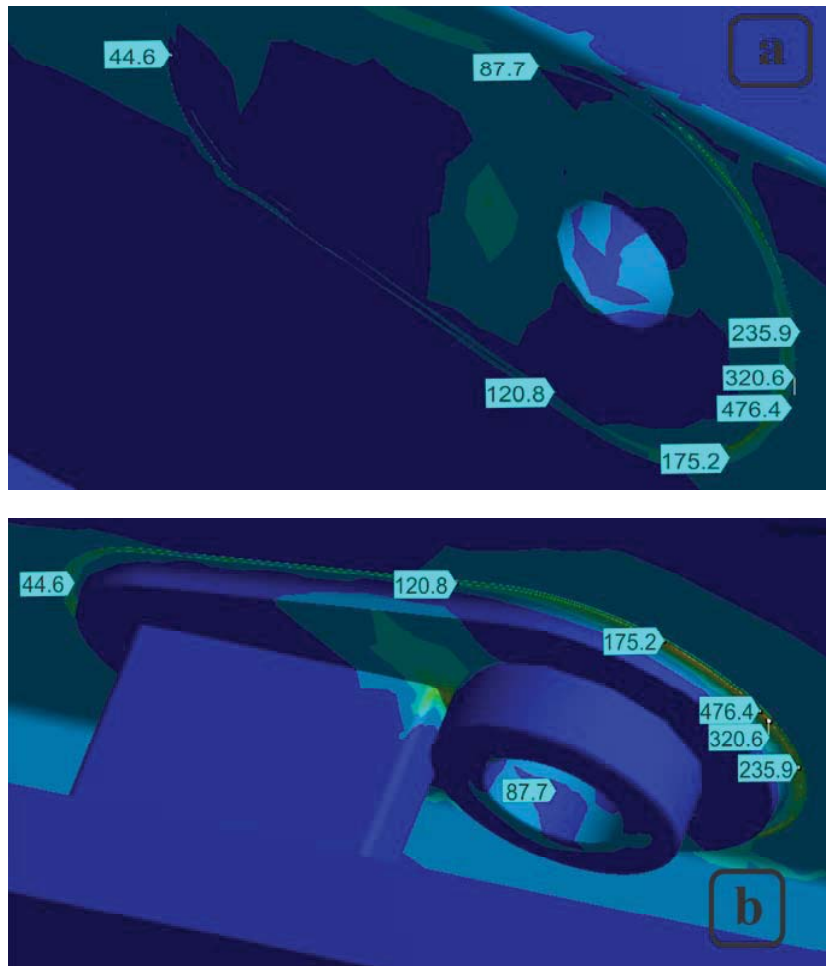


Figure 9. Stress state at the point of connection between the hydrocylinder and the first segment:
a) outer side b) inner side

The characteristic values of the analysed segment of the truck crane boom obtained by the finite element method are shown in Table 3 and Table 4.

Table 3 – Characteristic values of stresses in the weld zone

Measuring point	1	2	3	4	5	6	7
$s_{i,max}$ (MPa)	476.4	320.6	235.9	175.2	120.8	87.7	44.6
$s_{i,min}$ (MPa)	428.8	288.5	212.3	157.7	108.7	78.9	40.1
s_{mean} (MPa)	381.1	256.5	188.7	140.2	96.6	70.2	35.7
s_a (MPa)	47.6	32.1	23.6	17.5	12.1	8.8	4.5

Table 4 – Characteristic values of stresses in the zone of base material

Measuring point	1	2	3	4	5	6	7
$s_{i,max}$ (MPa)	350.4	309.3	286.8	218.6	94.5	81.2	68.5
$s_{i,min}$ (MPa)	315.3	278.4	212.3	196.7	85.1	73.1	61.6
s_{mean} (MPa)	280.2	247.5	188.7	174.8	75.7	65.0	54.7
s_a (MPa)	35.1	30.9	28.7	21.9	9.4	8.1	6.9

The analysis of fatigue fracture was carried out by using the Goodman diagram. Based on the results of chemical and mechanical testing of samples of the material in the zone of fracture of the first segment of the boom, the values of tensile strength of the weld material are read and then written on the abscissa of the Goodman diagram.

The value of yield stress of the weld material is calculated as follows: $R_e = 0.66 \cdot R_m = 0.66 \cdot 772 \approx 509 \text{ MPa}$

In Figs. 9 and 10, the yield limit is represented by the line E-F. For the weld, the value of yield stress is $R_e = 509 \text{ MPa}$, and for the base material, based on the results of testing, it is $R_e = 726 \text{ MPa}$.

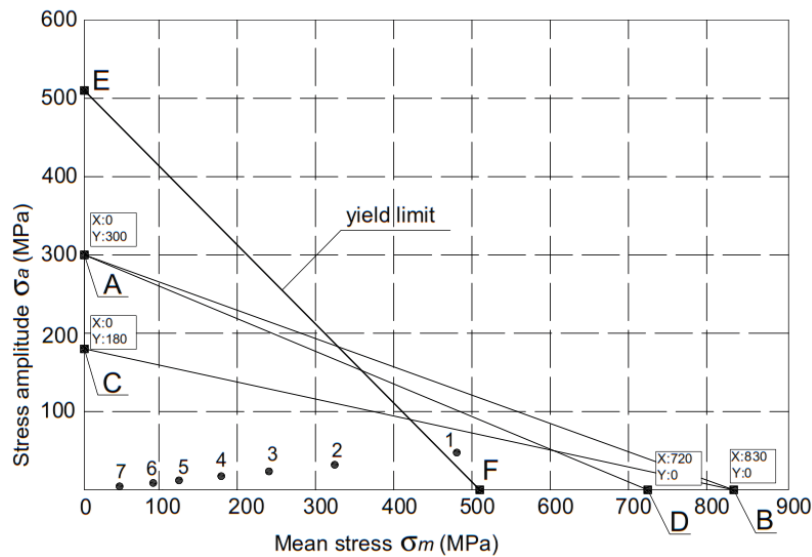


Figure 9. Goodman diagram in the weld zone

The characteristic values of the working stresses obtained by the finite element method are presented in Table 3 and Table 4. The minimum recommended value of the stress amplitude is $\sigma_a = 300 \text{ MPa}$ [9,14-15], where the minimum value of tensile strength in the weld is $\sigma_m = 830 \text{ MPa}$ [7], and in the base material, based on the

data from testing of the material, $\sigma_m = 730 \text{ MPa}$. These values are presented by points A and B, and they represent the fatigue boundary line. However, for real exploitation conditions, this line must be corrected.

The minimum recommended value of the stress amplitude [7] is: $\sigma_a = 300 \text{ MPa}$. For real exploitation

conditions, in compliance with the recommendations [7,8], the corrected minimum value of the stress amplitude ($\sigma_{a,m} = 180 \text{ MPa}$) was defined, whereas the minimum value of tensile strength was established experimentally (Table 2) and it is $\sigma_{m,m} = 730 \text{ MPa}$.

These values are denoted with points C and D (Figs. 9 and 10) and they define the modified boundary of the Goodman diagram.

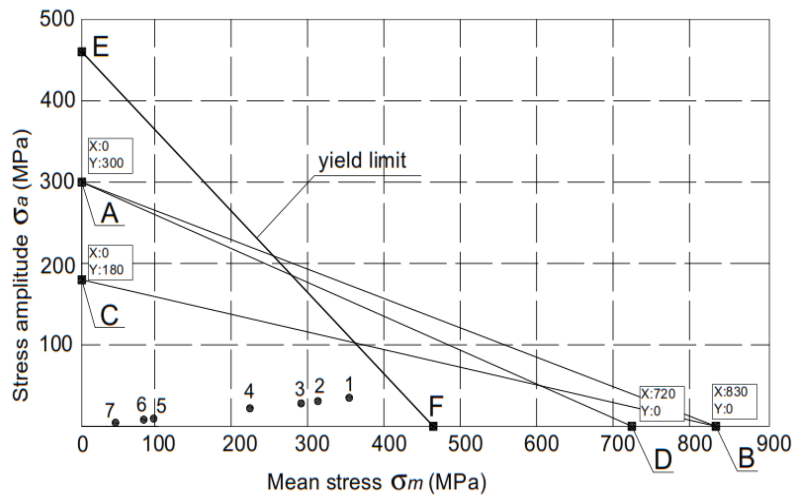


Figure 10. Goodman diagram for the base material

The characteristic values for testing the boom of the telescopic truck crane for fatigue are denoted with numbers from 1 to 7 in the diagrams. All values of the corresponding working stresses were obtained by the finite element method – by using the software package ANSYS.

In Fig. 9, the mentioned points (1-7) are below the line A-B, which represents the fatigue boundary, while in Fig. 10 the point 1 exceeds the fatigue boundary and thus fatigue safety is not provided.

The line C-D was chosen to be the relevant fatigue line and in the first diagram in Figure 3.9 the point 1 does not exceed this boundary, but in the diagram in Fig. 10 this boundary is already exceeded in terms of the position of the point 1 in the diagram.

4. CONCLUSION

On the basis of the presented research results, the following conclusions can be made:

- The chemical composition and mechanical properties of the material of the truck crane structure correspond to the steel NIOVAL 47 (P460NL1, DIN 1.8915).
- The chemical composition and mechanical properties of the material of the boom are within the prescribed limits, so it can be concluded that the cause of damage is not an error in the material.
- Based on the results of the FEM analysis, it can be concluded that the highest values of stresses are at the point of connection between the hydrocylinder and the boom.
- The safety factor of the truck crane boom in the characteristic section for the most unfavourable load case is:

$$S = \frac{\sigma_y}{\sigma_{eq,max}} = \frac{730}{476.4} = 1.53$$

- The critical value of stresses in the weld exceeds the fatigue boundary line. Therefore, fatigue failure

safety is not provided, which was proved by the FEM analysis.

- The truck crane boom was not repaired in a prescribed and adequate manner. Such jobs should be entrusted to the companies which are specialized for that type of activity.

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