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ANALYSIS OF STRESS-STRAIN STATE AND LIFE PREDICTION OF NOTCHED STRUCTURAL COMPONENTS OF MINE HOISTS

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ABSTRACT
The goal of this paper is establishment the methodology for evaluation the residual life of structural elements of the mining machinery in the presence of initial damage which appears in the form of cracks. Before to experimental measurements, an analysis in structure of the mine hoist installation using the finite element method were done in order to establish the preliminary distribution of stress and strain as well as help to define the measuring points the measurement of strain. Experimental measurements were performed on a real system with a ganges measurements to determine whether the structure is uniformly loaded and whether the stress intensity reached a critical value. Also, it is shown how the results of the measurements may be used to evaluating the lifetime of structural elements of the two-storey hoisting cage. Knowing the conditions under which the particular construction operates and knowing the shape and dimension of the same, we can solidly calculate and assume the remaining life of exploration. Experimental data obtained by testing provide a substantial basis for better understanding and explanation of the phenomenon of material fatigue.
Keywords: mining hoisting, stress-strain state, structural integrity

1. INTRODUCTION
Structural complexity of deep mine hoists and other mining machinery (belt conveyors, loading platforms), their high prices and high costs of failures and maintenance, indicate the need to research and develop effective methodological approach for the assessment of their condition completely. Load of responsible parts of elements and constructions of deep mine hoists could not be expressed in form of sample mathematic function, and could not be presented by model where variables and parameters are changing uniformly in working conditions, because that kind of model must predict approximations, which are caused by real conditions of service [1]. Assessment of state of the hoists structure is possible only based on certain investigations in operating conditions.
In that sense experimental measurements are used to capture real values of relevant physical quantities, which can be used for correction of established theoretical models or validation of realized design solutions. The results of strain measurements of two-storey hoisting cage which were conducted in real conditions are presented in this paper. The measurements were performed during acceleration and deceleration of the cage when moving up and down. The strain rates and consequent stresses in hoisting equipment components change depending on the cage location in the shaft (height), hoisting speed (acceleration), freight weight, resistance force and so on.

For better understanding of crack occurrence and its growth effect in steel, applied in equipment for exposed to variable loads, it is necessary to quantify the parameters controlling the strain behaviour in crack tip vicinity and crack resistance.

2. STRUCTURAL ANALYSIS AND EXPERIMENTAL RESULTS

2.1. Numerical model

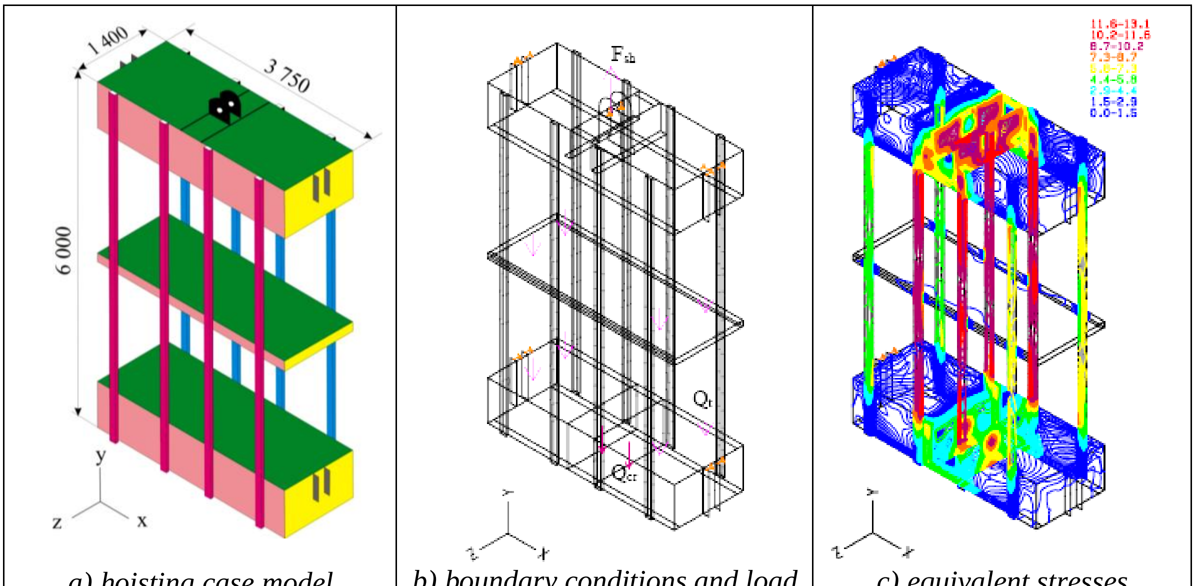
Using contemporary numerical methods, an ordinary preliminary design of the mine hoisting with two-storey hoisting cage has been analysed, respecting the prescribed boundary conditions. In addition to the analysis of the stress-deformation conditions, also applied has been the dynamic analysis of hoisting cage model structures, this being an efficient instrument in evaluating the structure behaviour under operating conditions. A two-storey hoisting cage having dimensions approx 3750 x 6000 x 1401 mm [2], in Coal Mine Zenica - excavation ″Raspotočje″, (Fig. 1.a) has been taken as a basic model for a numerical analysis of the behaviour of a real structure.

The hoisting cage is made of the structural steel S355 J2 plate with the following characteristics ultimate stress σ_m = 550 MPa, elastic modulus $E = 2.1 \cdot 10^5$ MPa and Poisson's coefficient υ = 0.3. The FEM analysis has been performed on 7706 2-D finite elements and 8162 nodes. The boundary conditions have been defined in such a way that the hoisting cages have been statically determined and the movement of the shaft guides system prevented.

The first stage of determining the actual stress and strain in the the the two-storey hoisting cage was carried out in several phases, in relation with the position of the cage in the shaft, [1]. Determination of deformation and stress state on steel structure a cage has been carried out for the sixth phase, i.e. the load by effective load position, Q_t = 84,366 kN, weight compensation ropes, Q_{cr} = 25,251 kN and real loading by up-movement a cage F_{sh} = 160 kN, (Fig. 1.b).

2.2. Results of FEM analysis

Based on the static and dynamic analyses of the model hoisting cage under consideration it is possible to make an overall analysis of the stress-deformation condition values obtained, and of the dynamic behaviour frequency values for the model. Primarily given are the model deflection values under the nominal load, and the hoisting cage with the compensating ropes weight, after which follow the stress condition values and in particular the values of the equivalent stresses, (Fig. 1.c), and Table 1.



a) hoisting case model *b) boundary conditions and load* *c) equivalent stresses*

Figure 1. Hoisting cage model and structural analysis

Table 1. Results of the stress- deformation analysis

Load (kN)	Attitude	Stress (MPa)					Deflection (cm)		
	Point:	SigEkv	Sig	Tau	Mem	Sav	Xi	Yi	Zi
Phase A6	7572	10,52	1,38	0,69	2,99	0.127	0.042	0.033	-0.012
	1034	6,54	0,78	0,35	4,9	0.045	0.0075	0.022	-0,008

2.3. Experimental set-up and procedure

The stress distribution obtained by the finite element method (FEM) and empirical data provides an arrangement of measuring gauges to determine stress and strain values that occur in the steel construction of the two-storey hoisting cage. Measurements were performed on two-storey hoisting cage in Coal Mine Zenica - excavation ″Raspotočje″, Fig. 2, which was designed for people and freight haulage. Measurements were performed using two strain-gauges LY 11-10/120 mounted on location MM1 and MM2 on hoisting cage construction. Measuring amplifier SPIDER-8 was used in "real-time" to record dynamic load of the two-storey hoisting cage.

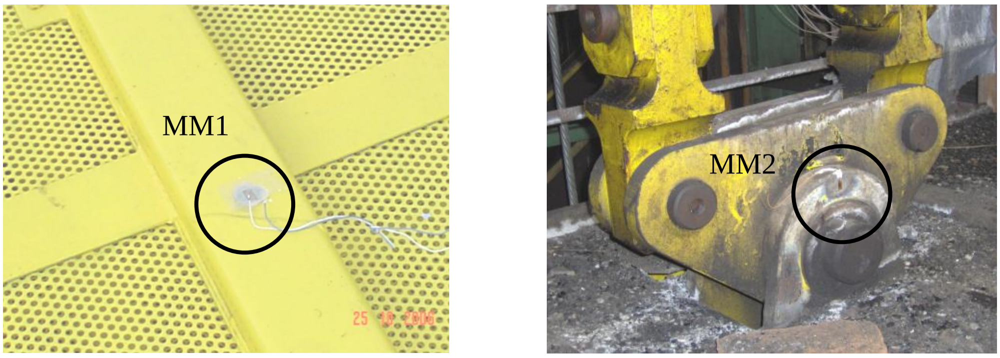


Figure 2. Experimental model with the installed strain-gauges on cage construction

Measurements on steel construction of the two-storey hoisting cage are made in order to:

- determine the real deformation and stress state of the two-storey hoisting cage steel construction loaded onli by its own weights, with different points on the cage during acceleration and deceleration when moving up and down,
- determine the real deformation and stress state of two-storey hoisting cage steel construction loaded by its own and freight weights and depending on the cage location in the shaft (height).

The aim of this study is evaluation of stress and its intensity in relation with construction's structural integrity. Based on the measured microstrains with a measuring gauge, normal stresses, σ_i, are calculate. At several points highest stress values were measured, $\Delta\sigma$ moving up to 32 MPa at the measuring point 1, where it was observed the emergence and growth of cracks. Cracks appeared relatively quickly, which creates doubt that in certain positions on the front side of elevation profil at the stage of digging, dynamic stress is even higher. Stress state of the measuring points 1 and 2 is the most critical as a result of low cyclic fatigue, which results in the appearance of cracks. These cracks are dangerous for the structural integrity of the two-storey hoisting cage.

3. FRACTURE MECHANICAL METHOD

If the structural component is continuously exposed to variable loads, fatigue crack may initiate and propagate from severe stress raisers if the stress intensity factor range at fatigue threshold, ΔK_{th}, is exceeded. Test performed in order to determine fatigue crack growth rate *da/dN* and fatigue threshold, ΔK_{th}, was performed with standard Charpy specimens, using the method of three-point bending, on resonant high-frequency pulsator CRACKTRONIC. On machined specimens, foil crack gauges RUMUL RMT A-5 of 5 mm measuring length were attached for monitoring of crack growth. The test itself was performed with sinusoidal cycle and stress ratio R = 0.4 by the mean load and amplitude were controlled. The standard ASTM E647, [3], defines testing of specimen for fatigue crack growth rate measurement, *da/dN*, and calculation of stress intensity factor range, ΔK. Two basic requirements in ASTM E647 are: the crack growth rate should be below 10^{-08} m/cycle to avoid fatigue threshold region and load should be of constant amplitude. Determination of the dependence of fatigue crack growth rate per cycle, *da/dN*, and range of stress intensity factor, ΔK, is reduced to determination of coefficient C and exponent m in Paris equation (1), [4]:

$$\frac{da}{dN} = C(\Delta K)^m \tag{1}$$

Calculated values for the Paris equation, presented in the form log *da/dN* on log ΔK, are shown in Fig. 3 and given in Table 2 for new and used steel that had been in service for approx. 45 500 hours.

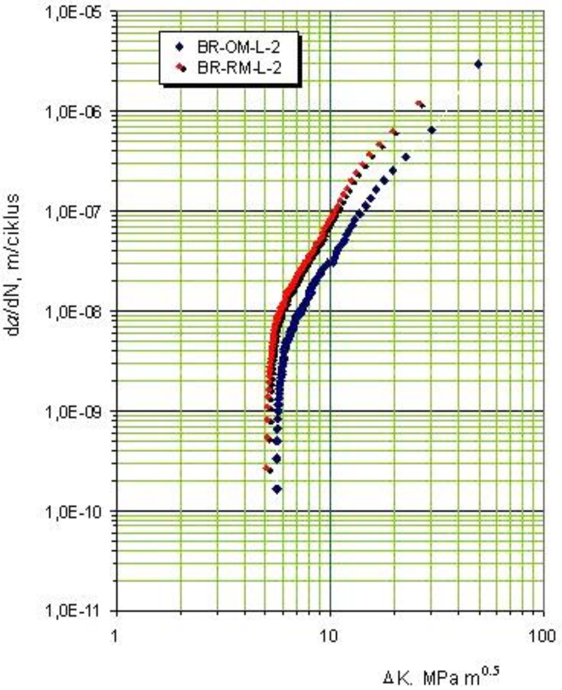


Figure 3. Relation da/dN–ΔK for specimens in new and used materials, tested at room temperature

Table 2 Fatigue Crack Growth Parameters for New and Used S355 J2 Steel at 20°C

	Simple mark	
	New BR_OM L 2	Old BR_RM L 2
Fatigue threshold ΔK_{th}, MPa m$^{1/2}$	5,7	5,1
Coefficient *C*, m/cycle	$1,13 \cdot 10^{-11}$	$7,84 \cdot 10^{-12}$
Exponent *m*	3.53	3.69
d*a*/d*N* with ΔK=10 MPa m$^{1/2}$	$3,14 \cdot 10^{-08}$	$7,85 \cdot 10^{-08}$

As one can see from the results presented in Tab. 2, service time significantly affect the values of fatigue threshold, ΔK_{th}, and parameters of fatigue crack growth. New steel S355 J2 has higher values of fatigue threshold, ΔK_{th}, i.e. better resistance of an already existing crack to propagation.
For the analysis fatigue crack growth rate, the value of ΔK = 10 MPa m$^{1/2}$ is taken. This value of the stress intensity factor range is located in the part of the curve where Paris law applies. Fatigue crack growth rate, *da/dN*, ranges from $3.14 \cdot 10^{-08}$ for the sample of new steel S355 J2 tested at room temperature to $7.85 \cdot 10^{-08}$ m/cycle for the sample tested for used steel.

5. CONCLUSION

Based on the presented consideration, one can conclude that:

- Dynamic measurements performed while driving provide additional insight into the stresses that occur during actual service conditions of export plant.
- Service times and crack initiation, influence values of fatigue threshold ΔK_{th} and fatigue crack growth parameters.

In spite of significant differences in fatigue crack growth rates, the obtained values are yet small and acceptable. This means that the level of fatigue crack growth resistance of the tested steel is acceptable and may be successfully applied in cases of detected crack-like defects, primarily for low-cycle fatigue.

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