DE GRUYTER
OPEN

Arch. Min. Sci., Vol. 59 (2014), No 2, p. 297–306

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.2478/amsc-2014-0021

STANISŁAW WOLNY*

EVALUATION OF THE STATE OF STRESS IN LOAD-BEARING ELEMENTS IN CONVEYANCES

OCENA STANU WYTĘŻENIA W ELEMENTACH NOŚNYCH KONSTRUKCJI NACZYŃ WYDOBYWCZYCH

Evaluation is made of the state of stress in load-bearing elements in conveyances. Relying on the design loads of load-bearing elements in conveyances given by the proposed method (Wolny & Łowkis, 2012), the state of stress in those components is obtained (in the graphic form) by the FEM approach. The final results will be utilised to develop the guidelines for designing the load-bearing elements in conveyances in the aspect of their mass minimisation.

Keywords: mine hoists, conveyances, dynamics, stress

W referacie dokonano oceny wytężenia w elementach nośnych konstrukcji naczynia wydobywczego. Wykorzystując określone według zaproponowanej metody (Wolny i Łowkis, 2012) obliczeniowe wartości obciążeń konkretnych elementów nośnych naczynia wydobywczego, metodą elementów skończonych MES, wyznaczono (w formie graficznej) stan naprężenia panujący w tych elementach .Efektem końcowym tych analiz , będzie opracowanie wytycznych do projektowania elementów nośnych konstrukcji naczyń wydobywczych ze względu na minimalizację ich masy.

Słowa kluczowe: wyciąg górniczy, naczynia wydobywcze, dynamika, naprężenia

1. Introduction

In order that the FEM approach and the ultimate state method should be applicable to the dimensioning and safety analysis and the fatigue design approach should be used to find the service life of conveyance components, it is required that:

a) the dynamic analysis should be performed of their service conditions determined for all stages of the system operation and under the emergency conditions,

---

* AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-059 KRAKÓW, AL MICKIEWICZ 30, POLAND

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

b) the optimal loads acting upon the conveyance components should be determined as the functions of their constructional and operational parameters
c) the fatigue endurance of selected components and nodes should be determined in the function of their service time and the gear type

The results of analyses listed in items 1-3 will be utilise to determine the endurance redundancies of conveyance components, to develop a procedure aimed to find the real operational loads and to perform the endurance analysis of conveyance components, at the same improving the performance of mine hoists as well as their safety features.

Real loading of the pulley block is determined basing on the dynamic analysis of the pulley operation in the course of normal service, and under the regular braking and emergency braking conditions. The results are verified through measurements of:

- conveyance loading during all stages of the system operation
- conveyance- shaft steelwork interactions through the entire cycle of gear operation

Conveyance loads obtained for all stages of the gear operation will provide the backgrounds for the fatigue endurance analysis of its basic components.

2. Conveyance loading in a hoisting installation in normal operating conditions

The procedure applied to find the loads acting upon the conveyance's structural components and the deterministic approach underlying the safety analysis fails to conform to the state-of-the-art. methods of assessing the reliability of steel structures, widely adopted in Europe and based on Eurocodes 1-4. As the reliability check by the first level calculation procedure (a semi-probabilistic approach) is based mostly on design values of acting loads and fatigue endurance, it is required that the design loads and fatigue endurance of particular conveyance components should be duly determined.

As regards the acting loads, at the stage of dimensioning the magnitude and configuration of loads acting upon the designed structure should be precisely determined. For the lack of applicable standards and catalogues applicable to conveyances, the characteristic loads should be based on the analysis of real loads.

The real loads acting upon the conveyance components were obtained by the dynamic analysis of the gear operation under the normal operating conditions and under the emergency conditions (Wolny, 2009a, 2009b; Wolny & Matachowski, 2010).

With reference to the shaft steelworks – skip head interactions, the force spectral density becomes:

$$S_Q(\omega) = |W_0|^2 S_{X1}(\omega) \tag{1}$$

where

$$W_0 = -\frac{2k\left[m_A m_g (i\omega)^4 + \left(m_A + m_g\right) k_g (i\omega)^2\right]}{m_A m_g (i\omega)^4 + \left[m_g k_g + m_A\left(2k + k_g\right)\right]\cdot(i\omega)^2 + 2k\cdot k_g}$$

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

$$m_A = \frac{J + mb_2^2}{l^2} \quad ; \quad m_B = \frac{J + mb_1^2}{l^2}$$

m — mass of a loaded skip hopper,
J — inertia moment of a loaded skip hop,
m_g — mass of the skip head,
m_d — mass of the bottom frame,
$2h$, k — (linear) damping and elasticity factors of guide shoes,
$2h_g$, k_g — damping and elasticity factors of (lateral) flexible connector between the head and hopper,
b_1, b_2 — distance between the hopper centre of gravity (c.o.g) and front guides op on the tand at the bottom, respectively,
l — distance between the upper and bottom front guides,
$S_{x1}(\omega)$ — spectral density of the guiding string misalignment in the front plane, related to the skip head.

Spectral density of the interaction force between shaft steelwork – bottom frame is expressed as (Wolny & Matachowski, 2010):

$$S_{Qd}(\omega) = \left|W_{0d}\right|^2 \cdot S_{x2}(\omega) \tag{2}$$

where:

$$W_{0d} = -\frac{2k\left[m_B m_d (i\omega)^4 + (m_B + m_d) k_d (i\omega)^2\right]}{m_B m_d (i\omega)^4 + \left[m_d k_d + m_B (2k + k_d)\right] \cdot (i\omega)^2 + 2k \cdot k_d} e^{-i\omega\tau}$$

$S_{x2}(\omega)$ — spectral density of the guiding string misalignment related to the bottom frame,
$\tau = \frac{V_0}{l}$ — time of conveyance ride along the path equal to the distance between the roller guides at the bottom and on top.

Variance of the shaft steelwork – skip head interaction force is expressed as:

$$\sigma^2_{SQ(\omega)} = 2\int_0^\infty \left|W_0\right|^2 \cdot S_{x1}(\omega) d\omega \tag{3}$$

The value of the integral (3) is computed numerically in a sufficiently wide finite range. The standard deviation of the shaft steelwork – skip head interaction force is given as

$$\sigma_{SQ(\omega)} = \sqrt{\sigma^2_{SQ(\omega)}} \tag{4}$$

Table 1 summarises the values of variance $\sigma^2_{(SQ)}$ and standard deviation $\sigma_{(SQ)}$ of spectral densities of shaft steelwork – skip head interaction force obtained by solving Eq (4) analytically, for the conveyance whose structural components are subject to the fatigue endurance analysis.

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

TABLE 1

Process variance $\sigma^2_{(SQ)}$ and standard deviation $\sigma_{(SQ)}$ of spectral densities of the interaction force for the analytical solution

	V = 12 m/s	**V = 16 m/s**	**V = 20 m/s**
Process variance [N^2]	$20{,}5\cdot10^6$	$26{,}2\cdot10^6$	$31{,}7\cdot10^6$
Standard deviation [kN]	$4{,}5\cdot10^3$	$5{,}1\cdot10^3$	$5{,}6\cdot10^3$

3. Numerical (FEM 3D) models of conveyances

Underlying the fatigue endurance analysis of selected components of a conveyance are numerical models particular components and applied loads. Within the scope of the endurance analysis, the dynamic testing data were compared to the results obtained from the applicable calculation procedure based on relevant mining regulations that remained in force at the time and complied in (*Obniżenie masy*..., 2011). The numerical FEM models were utilised in the analysis of the state of stress and strain in the entire volume of the investigated structural components of a conveyance.

The developed model (Fig. 1) is a beam-surface model, and the beams were used to model the load-bearing ropes. The remaining load-bearing components are modelled by surface elements of the thickness equivalent to that specified in the technical documentation. The skip components that do not carry any load (loading and unloading hatches, hopper lining) are modelled by adding a relevant mass at their attachment points. The guiding elements (roller guides) are modelled as elements having the elasticity equal to that of the roller guides. The payload is modelled as a distributed mass.

The entire model encompasses about 35.5 thousand of finite elements in the size range 20-100 mm.

The dynamic and fatigue endurance analyses were performed for the full conveyance being hoisted from the bottom station to the top station in the course of a typical duty cycle.

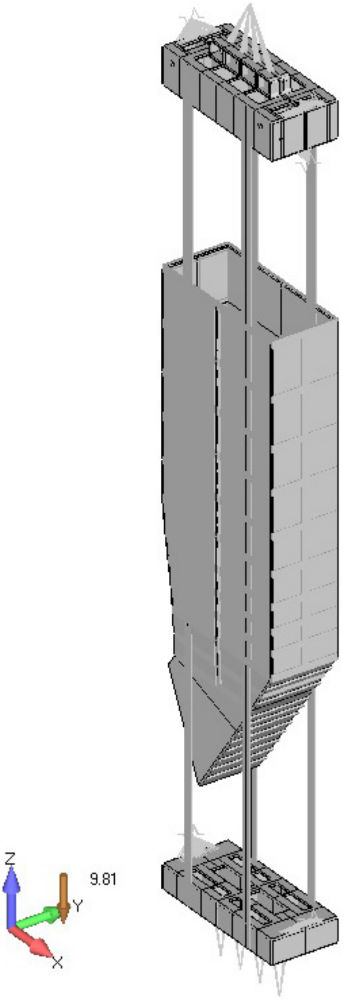

Fig. 1. 3D FEM model of a conveyance, with the view of upper strings (connecting the skip head to the skip hopper) and the bottom strings (connecting the hopper to the lower frame)

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

The initial conditions were assumed:

- $a_1 = 1$ m/s^2 – acceleration during the start-up phase,
- $a_2 = 1{,}2$ m/s^2 – deceleration during the braking phase,
- $V = 16$ m/s – hoisting velocity (stabilised).

The dynamic analysis of fatigue endurance of structural components in a conveyance takes into account the following loads:

- weight of a conveyance,
- payload weight,
- weight of tail ropes,
- kinematic loading due to misalignment of the guiding string,
- dynamic loading generated in the course of a typical duty cycle (start-up from the bottom station with acceleration a_1, the braking phase near the top station with the deceleration a_2).

Loads to be carried by the suspension elements include the dynamic loads due to the start-up of the conveyance, moving upward from the bottom station with the acceleration a1 and due to the braking action when approaching the top station with the deceleration a_2, as summarised in section 2.

3. Dynamic analysis of fatigue endurance

The dynamic and fatigue endurance analysis of the of the full conveyance being hoisted upwards from the bottom to the top stations gives us an insight into the state of stress and strain experienced in all structural components of the conveyance.

Fig. 2 shows the reduced stress distribution (stress contours) in the skip head operated in a hoist installation, registered when the full conveyance is being hoisted upward from the bottom station at the steady velocity $V = 12$ m/s.

The maximal reduced stress approached $\sigma_2 \approx 45$ MPa in longitudinal beams, at points where their cross-section area would change (Fig. 2, top view).

Fig. 3 shows the reduced stress variations in the beams profiles (the stress concentration zones) registered whilst the full conveyance is being hoisted from the bottom to the top station at the steady velocity $V = 12$ m/s. The maximal amplitude of the stress variation $\Delta\sigma_{\max}$ does not exceed 35 MPa.

Fig. 4 shows the reduced stress distribution in the skip hopper lining registered while the full conveyance is being hoisted from the bottom to the top station at the steady velocity $V = 12$ m/s. The reduced stress concentration $\sigma_z = 35$ MPa is registered in the upper section of the skip hopper, at points where the lead-bearing strings are attached.

Fig. 5 shows the reduced stress distribution (stress contour lines) in the bottom frame of the conveyance hoisted upward from bottom loading station at the steady velocity $V = 12$ m/s. The maximal reduced stress approaching $\sigma_z \approx 35$ MPa are registered in the longitudinal beams, at points where their cross-section area should be altered. The location of points where the maximal reduced stress are experienced is indicative of an undesired change of the beam profile height (the notch effect).

Variations of reduced stress in sections experiencing the highest stress whilst the fully loaded conveyance is hoisted upward from the bottom station to the top station at the steady velocity

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

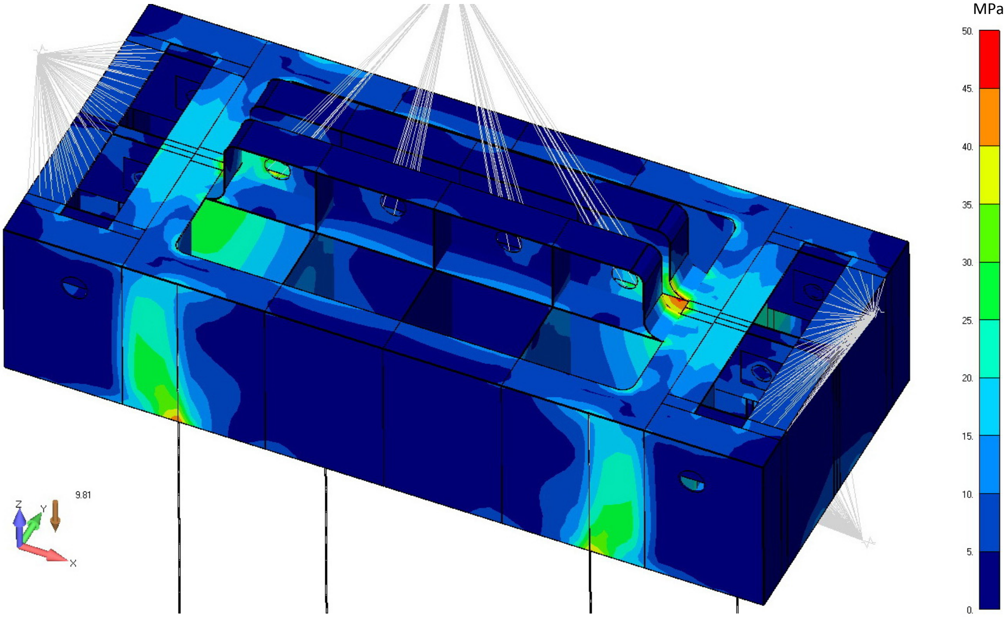

Fig. 2. Contour lines of reduced stress in the skip head (top view), $V = 12$ m/s

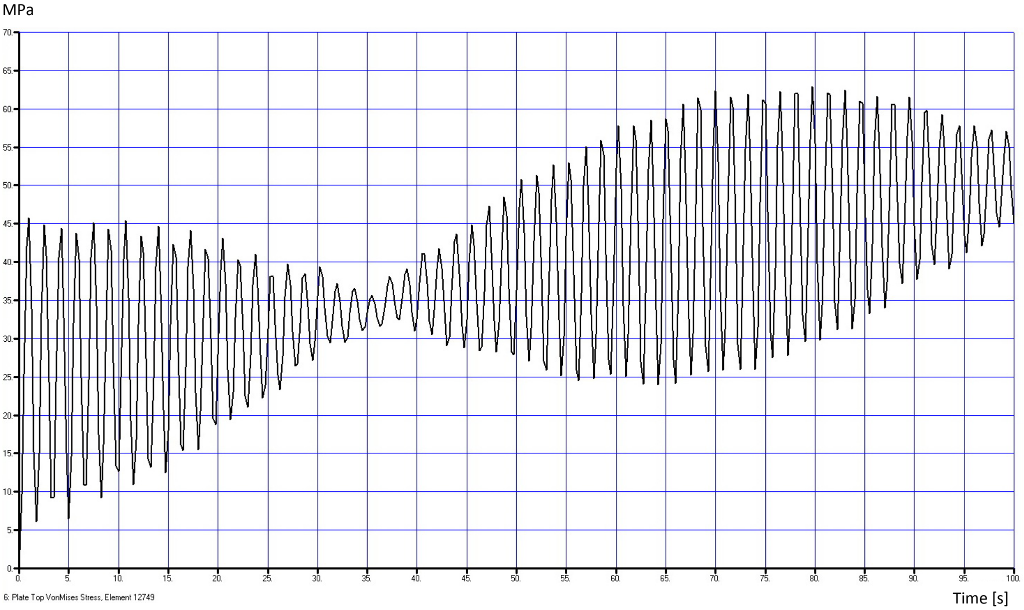

Fig. 3. Reduced stress change in the most stressed regions in the skip head while the full conveyance is being hoisted at the steady velocity $V = 12$ m/s

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

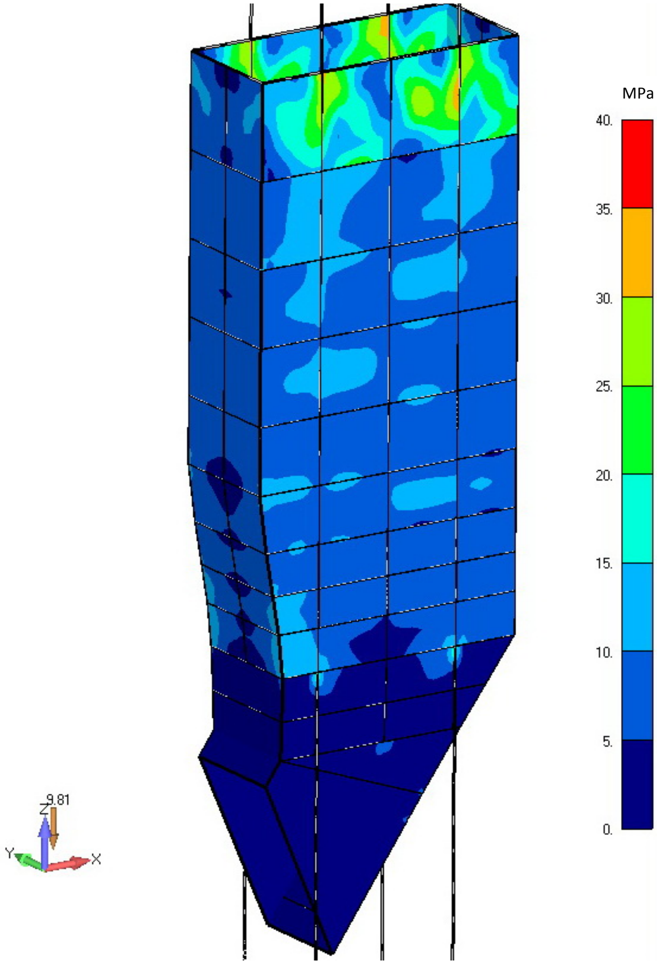

Fig. 4. Contour lines of reduced stress in the skip lining ($V = 12$ m/s)

$V = 12$ m/s are shown in Fig. 6. In this case the change in the reduced stress level is attributable to mostly to the increased weight of tail ropes and is nearly linear. The maximal registered stress level becomes 33 MPa.

Fig. 7 shows the variations of maximal normal stresses in the cross- profiles of the string connectors:

- cross- profile 1 (continuous line) this cross-profile,
- cross-profile 2 (broken line)

at the attachment points to the skip head and skip hopper, respectively and for the steady hoisting velocity $V = 12$ m/s.

The maximal stresses of the order of 45 MPa are registered in the two cross-profiles 1 and 2. Such state of stress is suggestive of uniform loading of the two string connectors.

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

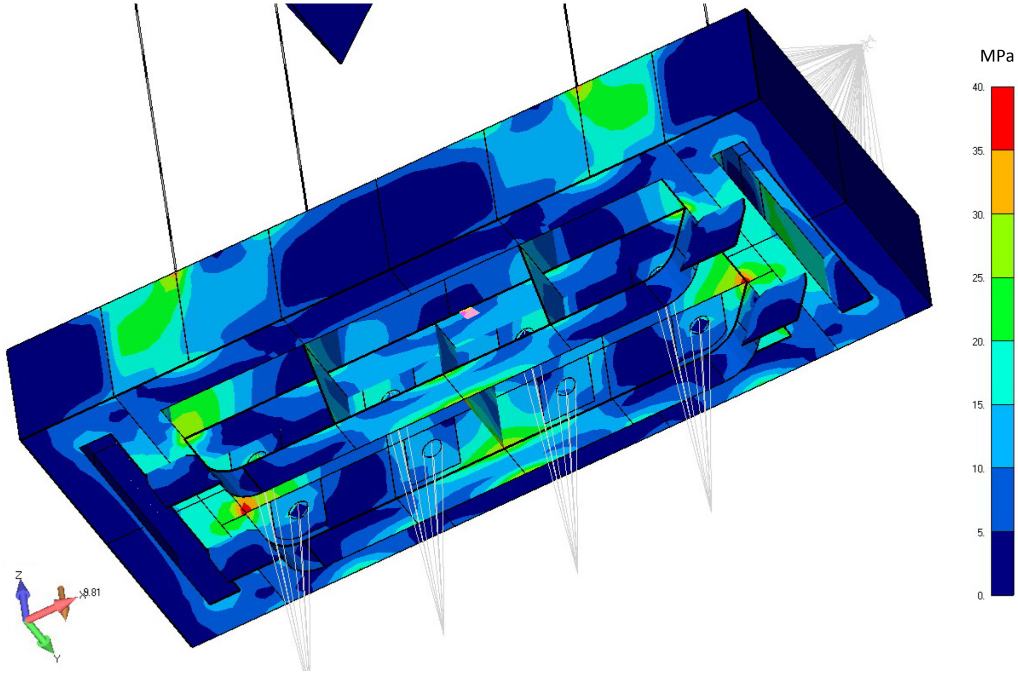

Fig. 5. Contour lines of reduced stress in the bottom frame of the conveyance (bottom view), $V = 12$ m/s

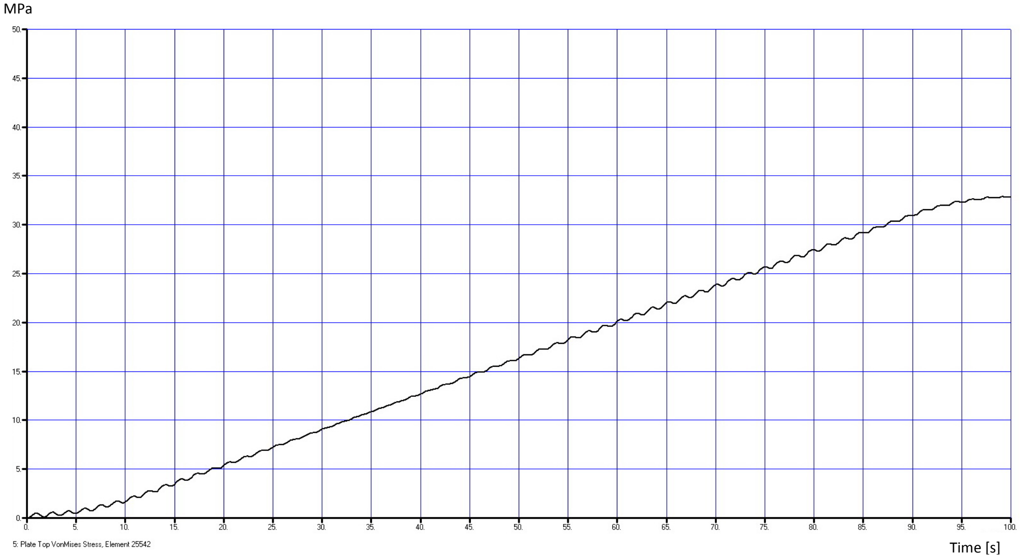

Fig. 6. Reduced stress change in the most stressed regions in the bottom frame while the full conveyance is being hoisted at the steady velocity $V = 12$ m/s

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

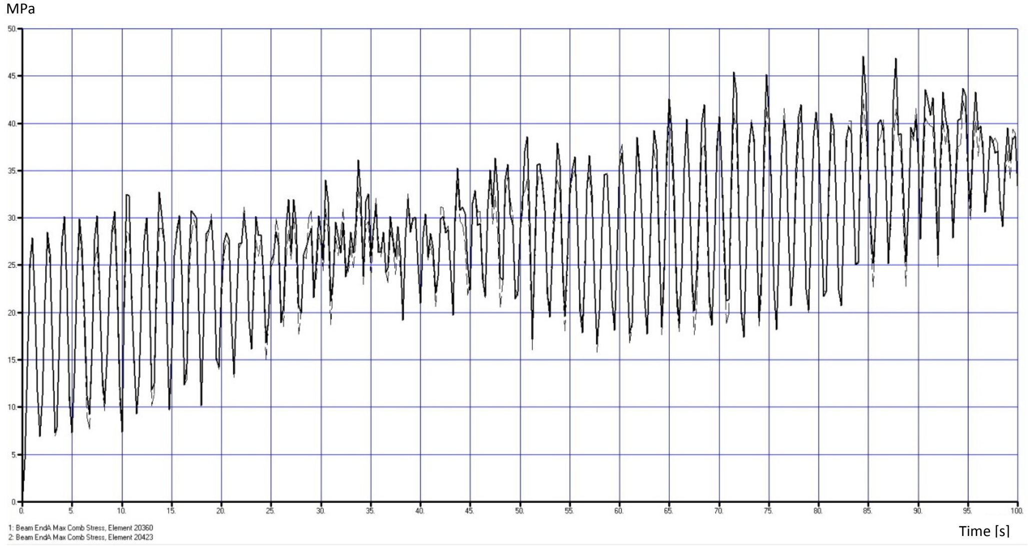

Fig. 7. Maximal normal stresses in cross-profiles of the string connectors 1 (continuous line) and 2 (broken line) at their attachment points to the skip head and the bottom frame for a full conveyance being hoisted upwards from the bottom station at the steady velocity $V = 12$ m/s

4. Conclusions

Results of the dynamic and fatigue endurance analyses of the state of stress in structural components of conveyances reveal the potentials of their load-bearing capacity to be fully and effectively utilised.

In order to enhance the load-bearing capacity of the conveyance's structural components, at the same time minimising their mass, it is required that:

- the beams of the skip head and bottom frame should be re-designed, in particular those elements which are responsible for stress concentration at points where their cross-section area is changed (the notch effect),
- the connections between the skip head and the bottom frame should be re-profiled to mitigate for the additional bending effect,
- the load-bearing capacity of the entire components should be as uniform as possible,
- the load-bearing capacity of all structural components should be as uniform as possible.

According to the Authors, reliability of structural components of a conveyance should be assessed by the ultimate state method, with the main focus on the ultimate load-bearing capacity. As the reliability check by the first level calculation procedure (a semi-probabilistic approach) is based mostly on design values of acting loads and fatigue endurance, it is required that the design endurance of particular materials of the conveyance components should be duly determined.

In relation to admissible stresses and the safety factors, there is still some safety redundancy left as regards the design fatigue endurance levels. The design endurance is related to the yield point of the component material and the material coefficient γ, falling in the range $\gamma_S = 1.15 – 1.25$.

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM

Reference

Obniżenie masy własnej naczyń wyciągowych w celu ograniczenia kosztów eksploatacji związanych ze zużyciem energii. Praca naukowo-badawcza zrealizowana w grudniu 2011 w Katedrze Wytrzymałości, Zmęczenia Materiałów i Konstrukcji AGH WIMiR – niepublikowana

Wolny S., 2009a. *Assessmemt of Hoist Control to Ensure Conveyance Guiding in a Motion Sequence other than Trapezoidal*. Arch. Min. Sci., Vol. 54, No 4, p. 623-640.

Wolny S., 2009b. *Dynamic Loading of the Pulley Block in a Hosting Installation in Normal Operating Conditions*. Arch. Min. Sci., Vol. 5, No 2, p. 261-284.

Wolny S., Łowkis Z., 2012. *Propozycje nowych metod wyznaczania obciążeń i naprężeń w elementach nośnych naczynia i zbrojenia w aspekcie poprawy bezpieczeństwa eksploatacji górniczych wyciągów szybowych. Innowacyjne techniki i technologie dla górnictwa*. ITG KOMAG.

Wolny S., Matachowski F., 2010. Operating loads of the shaft steelwork – conveyance system due random irregularities of the guiding strings. Arch. Min. Sci., Vol. 55, No 3, p. 589-603.

Received: 15 September 2013

Unauthenticated | 10.248.254.158
Download Date | 9/16/14 4:22 PM