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OPTIMIZATION OF THE HOOD OF DIESEL ELECTRIC LOCOMOTIVE

OPTIMALIZACE KOSTRY KAPOTY DIESEL ELEKTRICKÉ LOKOMOTIVY

Abstract

The new construction of hood of diesel electric locomotive is analyzed in this paper. The whole construction is loaded by inertia effects caused by prescribed acceleration. The parts of the hood are subject to the standards for railway applications CSN EN 12663-1 [1]. Numerical analyses are performed by FEM computer program COSMOSWorks [2]. The original construction of hood is analyzed in first part of this paper. Structural changes are proposed in the next part of this article. Carrying capacity of the new construction of hood is verified by a numerical analysis. The results of the new construction are compared with the original construction of hood.

Abstrakt

Tento článek se zabývá výpočtem pevnosti nové konstrukce kostry kapoty železniční diesel elektrické lokomotivy. Kostra kapoty je zatížená setrvačnými účinky vyvolanými předepsaným zrychlením. Jednotlivé části kapoty podléhají ustanovením normy pro železniční aplikace ČSN EN 12663–1[1]. Numerické analýzy jsou provedeny v MKP programu COSMOSWorks [2]. V první části článku je analyzováno původní konstrukční řešení. V další části jsou na základě výsledků navrženy konstrukční úpravy. Únosnost nové konstrukce kostry kapoty je ověřena pomocí numerické analýzy. Výsledky nové konstrukce jsou porovnány s původní konstrukcí kapoty.

Keywords

limit state of plasticity, railway applications, FEM, hood

1 INTRODUCTION

The original structural design of hood was analyzed in paper [5]. The main aim of this paper is to suggest changes in the original construction. The changes are designed on the basis of the results of numerical analyses. The critical points were detected in locations of rectangular tubes with a low carrying capacity. Carrying capacity of the new construction of hood is verified by a numerical analysis in this paper. The results of the new construction are compared with the original construction of hood. The results are evaluated according to ČSN EN 12663-1 [1] and ČSN 73 1401 [3]. The new construction of the hood is evaluated by nonlinear numerical analysis GMNA (Geometrically and Materially Nonlinear Analysis). The influence of other loads is solved using the methods of modern science and technology

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2 COORDINATE SYSTEM AND LOADS

The coordinate system is taken from ČSN EN 12663-1 (see Fig. 1). Numerical models are subjected to acceleration in specified directions. Acceleration values are given in Tab. 1.

Fig. 1 Coordinate system according to ČSN EN 12663–1 [1]

Tab. 1 The limit value of acceleration according to ČSN EN 12663–1 [1] ($g=-9.81 m/s^2$).

Load Case LC	acceleration in the x-axis	acceleration in the y-axis	acceleration in the z-axis
3+	0	$1·g = - 9.81\ m.s^{-2}$	0
3 -	0	$-1·g = 9.81\ m.s^{-2}$	0
4+	$3·g = - 29.43\ m.s^{-2}$	0	$1·g = - 9.81\ m.s^{-2}$
4 -	$-3·g = 29.43\ m.s^{-2}$	0	$1·g = - 9.81\ m.s^{-2}$
5+	0	$1·g = - 9.81\ m.s^{-2}$	$1·g = - 9.81\ m.s^{-2}$
5 -	0	$-1·g = 9.81\ m.s^{-2}$	$1·g = - 9.81\ m.s^{-2}$

3 NONLINEAR ANALYSIS (GMNA) AND SAFETY FACTOR

Two nonlinearities (geometric and material) are considered in numerical analyses. Geometric nonlinearity (large displacements) allows for the detection the loss of stability of the structure. Material nonlinearity takes into account elastic - plastic material behavior (plasticity). The von Mises´s bilinear model of elastic - plastic material behavior with Young´s modulus $E=2E+5\ MPa$, Poisson´s number $\mu=0.3$, yield strength $f_y=235\ MPa$ and tangent modulus (isotropic hardening) $E_T=E/10000$ is used in the numerical analyses GMNA [4].

Local masses (contactors, cooling units) are prescribed by mass elements (computational model of original hood) or forces (computational model of the new hood). Different methods of placing of local masses were used to convergence of the numerical analyzes.

The real limit state (loss of stability, limit state of plasticity) is the result of non-linear numerical analysis. The strength of construction is evaluated from the limit load, when it occurs the real limit state. This method is commonly used for the design of restricted equipment (e.g. pressure vessels, steel structures, etc.) in the energy, chemical, nuclear and transportation industries [5].

The following safety factors are indicated in EN 12663-1 [1]:

- $S_1 = 1.15$ – Safety factor for yield strength,
- $S_2 = 1.50$ – Safety factor for ultimate strength,
- $S_3 = 1.50$ – Safety factor for loss of stability.

The standard ČSN EN 12663–1 [1] recommends the use of increased levels safety factor S_1 for evaluating the results of nonlinear analysis (GMNA). Safety factor S_1 is determined for evaluating strength of construction on the basis of the pseudo - elastic stress. Limit state is determined by allowable elastic stress σ_{ALL}.

$$\sigma_{ALL} = \min\left(\frac{R_{p0.2}}{S_1}; \frac{R_m}{S_2}\right) \tag{1}$$

where

$R_{p0.2}$ - yield strength [MPa]

R_m - ultimate strength [MPa]

The real limit state of plasticity occurs after the establishment of a sufficient number of plastic hinges. Then the construction behaves as kinematic mechanism. The real limit state is the result of non-linear numerical analysis GMNA. Safety factor $S = 1.5$ is used to evaluate the structural strength for the limit state of plasticity. Safety factor $S = 1.5$ is based on increased levels of safety factor S_1. But the safety factor $S = 1.5$ does not include affect thin wall of rectangular tubes on the limit state of plasticity.

The ratio between the elastic and plastic cross section modulus in bending is $\eta_1 = 1.5$ for solid rectangular cross-section.

$$\eta_1 = \frac{w_{pl1}}{w_{el1}} = 1.5 \tag{2}$$

where

w_{pl} - plastic cross section modulus in bending [mm^3]

w_{el} - elastic cross section modulus in bending [mm^3]

The ratio between the elastic and plastic cross section modulus in bending is $\eta_2 = 1.15 \div 1.18$ for thin wall rectangular tubes.

$$\eta_2 = \frac{w_{pl2}}{w_{el2}} = 1.15 \div 1.18 \tag{3}$$

Safety factor $S = 1.5$ should be added to the influence of thin wall rectangular tubes. Fictitious safety factor S_f takes into account low reserve of carrying capacity of thin wall profile. Fictitious safety factor S_f is based on safety factors $S = 1.5$ and it is determined by the following equation.

$$\boldsymbol{S_f} = S \cdot \frac{\eta_1}{\eta_2} = 1.5 \cdot \frac{1.5}{1.15} = 1.956 \tag{4}$$

$$\boldsymbol{S_f \cong 2}$$

Fictitious safety factor $S_f = 2$ and nonlinear numerical analysis GMNA are not anchored in EN 12663-1 [1]. Application of nonlinear analysis GMNA together with fictitious safety factor S_f for the evaluation of the hood is based on current knowledge of science and technology.

4 ORIGINAL CONSTRUCTION OF HOOD

The original structural design of hood was analyzed in paper [5]. Limit and allowable loads for all load cases are given in Tab. 2. A brief description of the calculation for selected load case LC 4- follows. Example of evaluation is given in the Chapter 5.

The computational model is shown in Fig. 2. FEM mesh is created by shell element SHELL3T (Fig. 3). The numerical model is exposed to acceleration $a_z=3\cdot g=29.43\ m.s^{-2}$ and $a_x=9\cdot g=88.29\ m.s^{-2}$. Limit state of plasticity is reached in the 55th step. The value of limit load factor is LF_L = 0.60 (see equilibrium curve in Fig. 4). Deformed model with drawn reduced stress von Mises on the top surface is shown in Fig. 5.

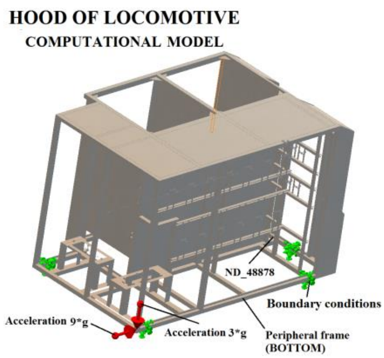

Fig. 2 Numerical model – LC 4-

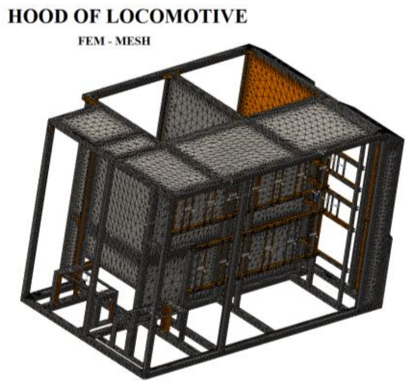

Fig. 3 FEM mesh – LC 4-

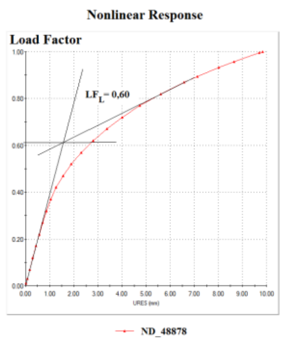

Fig. 4 Equilibrium curve

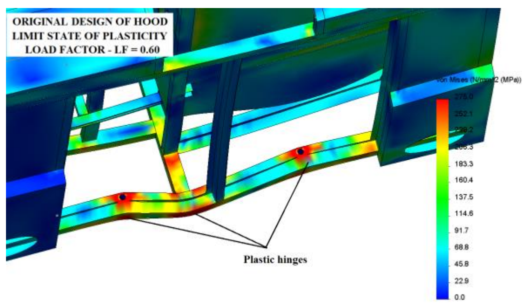

Fig. 5 Detail of plastic hinges–LC 4-

Tab. 2 Limit and Allowable acceleration – original construction of hood.

Load Case LC	Limit acceleration a_L (m/s^2)	Allowable acceleration a_{ALL} (m/s^2)	-	Computational acceleration a (m/s^2)
LC 1+	$a_{zL} = 51.22$	$\boldsymbol{a_{zALL} = 25.61}$	$\ngeq$	$a_z = 29.43$
LC 4-	$a_{xL} = 52.98$	$\boldsymbol{a_{xALL} = 26.49}$	$\ngeq$	$a_x = 29.43$
LC 5-	$a_{yL} = 25.9$	$\boldsymbol{a_{yALL} = 12.95}$	$\geq$	$a_y = 9.81$

The original construction of the hood was composed of many types of rectangular tubes. All loads were carried only massive peripheral frame at the bottom of the hood (see Fig. 2). Limit state of plasticity occurred after the creation of plastic hinges in a massive peripheral frame. The next part of hood is not involved in the carrying capacity. Strength conditions were not fulfilled.

5 NEW CONSTRUCTION OF HOOD

The new construction of the hood is composed by single type of square tube 60x60x4. New square tube has a lower carrying capacity than the peripheral frame (see Fig. 2) of the original hood, but it has a higher carrying capacity than other parts of the original hood. Then the whole structure is involved in the carrying capacity (see Fig. 6). Limit state of plasticity occurs to the creation of more plastic hinges than the original construction. A brief description of the calculation for selected load case LC 4- is shown in this Chapter. Limit and allowable loads for all load cases are given in Tab. 3 on the next page.

The computational model is shown in Fig. 6. FEM mesh is created by shell element SHELL6T. The numerical model is exposed to acceleration $a_z=1\cdot g=9.81\ m/s^2$ and $a_x=3\cdot g=29.43\ m/s^2$. Limit state of plasticity is reached in the 16^{th} step. The value of limit load factor is LF_L = 3.19 (see equilibrium curve in Fig. 7). Deformed models with drawn reduced stress von Mises on the top surface are shown in Fig. 8 and Fig. 9. The location of plastic hinges is clearly visible (the area where reduced stress reached the yield stress of material). Evaluation of the results follows.

Limit acceleration

$$a_{xL} = LF_L \cdot a_x = 3.19 \cdot 29.43 = 93.88\ m.s^{-2} \tag{5}$$

Allowable acceleration

$$a_{xALL} = \frac{a_{xL}}{S_f} = \frac{93.88}{2} = 46.94\ m.s^{-2} \tag{6}$$

Strength condition

$a_x = 29.43\ m.s^{-2}$ $\leq$ $a_{xALL} = 46.94\ m.s^{-2}$ -----> Fulfilled

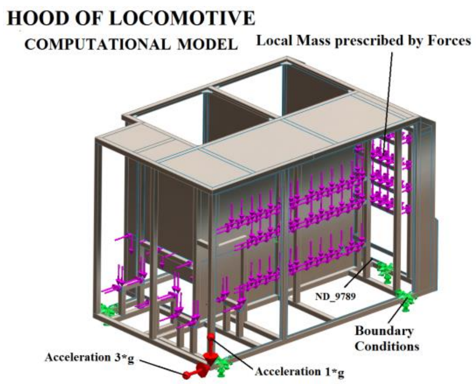

Fig. 6 Numerical model – LC 4-.

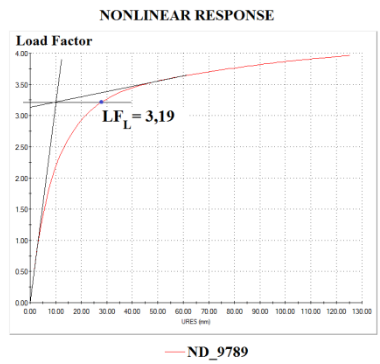

Fig. 7 Equilibrium curve.

Tab. 3 Limit and Allowable acceleration – new construction of hood.

Load Case LC	Limit acceleration a_L (m/s^2)	Allowable acceleration a_{ALL} (m/s^2)	-	Computational acceleration a (m/s^2)
LC 1+	$a_{zL} = 98.3$	$\mathbf{a_{zALL} = 49.15}$	≥	$a_z = 29.43$
LC 4-	$a_{xL} = 93.88$	$\mathbf{a_{xALL} = 46.94}$	≥	$a_x = 29.43$
LC 5-	$a_{yL} = 52.39$	$\mathbf{a_{yALL} = 26.20}$	≥	$a_y = 9.81$

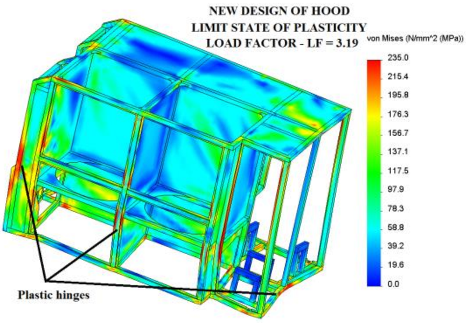

Fig. 8 Detail of plastic hinges–LC 4-.

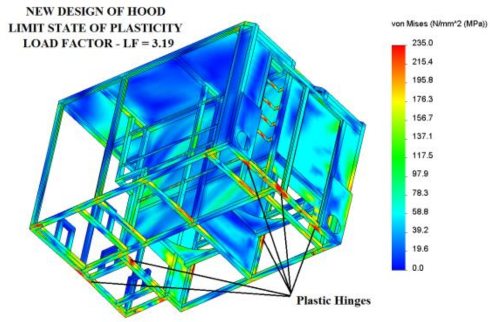

Fig. 9 Detail of plastic hinges–LC 4-.

6 CONCLUSIONS

Fictitious safety factor $S_f = 2$ and nonlinear numerical analysis GMNA were used to evaluate the strength of the hood. The original construction of the hood was composed of many types of rectangular tubes. The new construction of the hood is composed by single type of square tube 60x60x4. Then the whole structure is involved in the carrying capacity. Limit state of plasticity occurs to the creation of more plastic hinges than the original construction. Carrying capacity of the new construction of hood was verified by a numerical analysis. The carrying capacity of the new construction is higher than the original construction of hood (see Limit and allowable loads in Tab. 2 and Tab. 3).

Fictitious safety factor $S_f = 2$ and nonlinear numerical analysis GMNA are not anchored in EN 12663-1 [1]. Application of nonlinear analysis together with fictitious safety factor for the evaluation of the hood is based on current knowledge of science and technology.

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