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DETERMINISTIC AND PROBABILITY ANALYSIS OF THE STEEL CHIMNEY UNDER WIND LOADS

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Abstract: *This paper describes the static and dynamic analyses used for welded steel chimneys expertise according to European standard EN 1991 and EN 1993. More details are concerned with wind loading determination and its using for static analysis and lateral resonance analysis. On the base of the VEAB chimney model with and without the pendulum mass damper the wind load effect is presented. The deterministic and probability analysis were performed. The simple spring and damper model and the FEA model under system ANSYS using shell elements are presented. The effect of the wind cycle loading to the fatigue evaluation of the chimney is discussed.*

Keywords: ***Chimney, wind, dynamic, pendulum mass damper, probability, FEM, ANSYS.***

1. Introduction

The frameless welded steel chimneys are modern and economic solution for the transmition of the smoke gas from the plants. The steel chimneys are constructed in dependency on the plant powers with diameter more than 5 m and 150 m of the height. The steel chimney consist two pipes – the structural pipe and the inner pipe. Furthermore there is the thermal insulation. The structural pipe can be constructed from one or more segments connected by the flanges and bolts. The chimney is anchored in the concrete block. The design of the chimney can be optimized by static and dynamic analysis considered various load effects. The critical load of the chimneys is the wind impact. For slender structures subjected to wind loading there are three main actions to consider, gust wind, vortex shedding and ring oscillation ovalling. Assessment of the design chimney due to wind effect is defined in standard ENV 1991-2-4. The previous standard was STN 730035 in Slovakia. Pirner, M., Fischer, O. (2003) and Szabo, G. Gyorgyi, J. (2010) prezent the new methodology to design of the chimneys. In the case of the design of the chimneys the german standard DIN 4133 is recommended.

Fig. 1: VEAB steel chimney.

In this paper the VEAB steel chimney (Travnik, 2002) of the height 90 m is considered. The behavior of the steel chimney was investigated in the real plant. The experimental and numerical analyses were published in report of the Sweden Company (Travnik, 2002).

2. Deterministic contra probability reliability analysis

Most problems concerning the reliability of building structures (Králik, 2009) are defined today as a comparison of two stochastic values, loading effects *E* and the resistance *R*, depending on the variable

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material and geometric characteristics of the structural element. In the case of a deterministic approach to a design, the deterministic (nominal) attributes of those parameters R_d and E_d are compared.

The deterministic definition of the reliability condition has the form

$$R_d \geq E_d \tag{1}$$

And in the case of the probabilistic approach, it has the form

$$RF = R - E \geq 0 \tag{2}$$

The probability of failure can be defined by the simple expression

$$P_f = P\left[R < E\right] = P\left[\left(R - E\right) < 0\right] \tag{3}$$

3. Uncertainties of input data

The uncertainties of the input data – action effect and resistance are for the case of the probabilistic calculation of the structure reliability defined in JCSS and Eurocode 1990.

Tab. 1: Probabilistic model of input parameters.

Name	Quantity	Charact. value	Variable paramet.	Histogram	Mean	Stand. deviation	Min. value	Max. value
Material	Young's modulus	E_k	e_{var}	Normal	1	0,120	0,645	1,293
Load	Dead	G_k	g_{var}	Normal	1	0,010	0,755	1,282
	Live	Q_k	q_{var}	Gumbel	0,60	0,200	0	1
	Earthquake	$A_{E,,k}$	a_{var}	Gama(T.II)	0,67	0,142	0,419	1,032
	Wind extrem	$A_{W,k}$	w_{var}	Gumbel	0,30	0,150	0,500	1,032
Resistance	Steel strength f_{sk}	F_k	f_{var}	Lognormal	1	0,100	0,726	1,325
Model	Action uncertaint	θ_E	Te_{var}	Normal	1	0,100	0,875	1,135
	Resistance uncert.	θ_R	Tr_{var}	Normal	1	0,100	0,875	1,135

The stiffness of the structure is determined with the characteristic value of Young's modulus E_k and variable factor e_{var}. A load is taken with characteristic values G_k, Q_k, $A_{E,k}$, $A_{W,k}$ and variable factors g_{var}, q_{var}, a_{var} and w_{var}. The resistance of the steel is delimited by the characteristic values of the strength f_{sk} and the variable factor f_{var}. The uncertainties of the calculation model are considered by variable model factor θ_R and variable load factor θ_E for Gauss's normal distribution.

4. Static and dynamic calculation of the chimney

The most importance parameters for the static design of the steel chimneys by EN 1991-1-4 are the mean wind velocity v_m. The mean wind velocity depends of the roughness factor $c_r(z)$ and the orography factor $c_o(z)$, $v_m = c_r\left(z\right).c_o.v_b$, where v_b is the basic wind velocity. The dynamic analysis of the steel chimneys must be realized in accordance of the ENV considering the across resonance vibration due to buffering effects, galloping, divergence and fluttering. The base of the dynamic analysis is the calculation of the first mode of the chimney. The critical wind velocity and pressure at vortex shedding is calculated as

$$v_{cr} = \frac{f.d}{St}, \qquad p_{cr} = 0.5.\rho.v_{cr}^2 \tag{4}$$

where f is the natural frequency of the chimney, d is the diameter, St is the Strouhal number (= 0.2) at ordinary vortex, ρ is assumed equal to 1.25 kg/m^2

Tab. 2: Critical wind velocity.

	Critical wind velocity v_{cr} [m/s]		
	first mode	second mode	third mode
At chimney shell d = 2.3 m	3.24	16.6	44.4
At damper shell d = 2.8 m	3.95	20.2	54.0

The equivalent load during vortex shedding may be calculated as

$$w_{eq} = \mu_{tr} \cdot p_{cr} .d \left(\pi / \delta_m \right), \tag{5}$$

where μ_{tr} is the shape factor, p_{cr} is the wind velocity pressure, d is the diameter, δ_m is the logarithmic decrement (= 0.7).

5. Computational model of the steel chimney with damper

The tuned pendulum damper is one from the effective damper. This damper was tested on the VEAB chimney (Travnik, P. Alpsten, G., 2002). The damper consists of a pendulum mass ring hinged in three chains, located in 120 degrees direction, connected to the damper house roof. The damping is achieved by friction between the friction mass and the damper house floor. The manufacturer calculated the generalized mass to Mgen = 12460 kg. The pendulum mass was defined as 10% of the generalized mass.

The generalized mass is defined as

$$M_{gen} = \int_0^H m(x). \left(\frac{u(x)}{u_{top}} \right)^2 .dx \,, \tag{6}$$

where *m(x)* is the mass per length at height *x*, *u(x)* is the deflection at height (*x*), u_{top} is the top deflection and *H* is the chimney height. The horizontal force necessary to accelerate the friction masses into motion by an inclination of the pendulum damper is

$$F_H = \mu .m_f .g \,, \tag{7}$$

where μ is the friction coefficient (= 0.15 - 0.30), m_f is the friction mass.

The calculation model of the chimney with damper can be defined as the system of the springs and damping elements (Fig. 2). The following differential equations describes this model

$$M_{gen} \frac{d^2 u_1}{dt^2} + k_1 u_1 + k_2 \left(u_1 - u_2 \right) + c_1 \frac{du_1}{dt} + c_2 \left(\frac{du_1}{dt} - \frac{du_2}{dt} \right) = F.\sin\left(\omega t \right), \tag{8}$$

$$m \frac{d^2 u_2}{dt^2} + k_2 \left(u_2 - u_1 \right) + c_2 \left(\frac{du_2}{dt} - \frac{du_1}{dt} \right) = 0 \,,$$

where *F* is the amplitude for vortex shedding force determined from the condition of the equivalent deflection of the chimney as from the distributed vortex load along the chimney corp. The top deflection of the chimney with and without damper was calculated from the equations (8) in dependency of the frequency (Fig. 3).

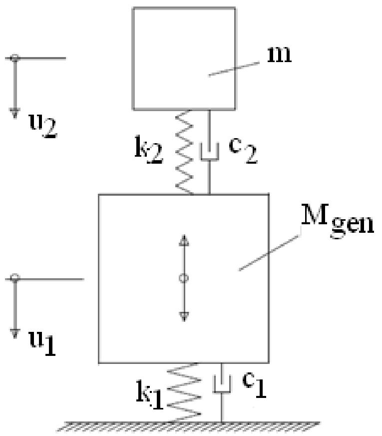

Fig. 2: Model of the chimney damper.

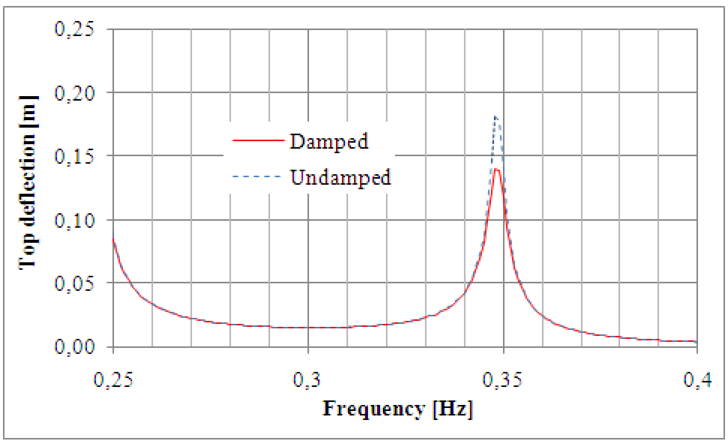

Fig. 3: Top deflection with and without damper.

The probability analysis of the chimney with damper was considered in 200 simulations of the LHS method in system ANSYS. The simulated top deflections of the chimney are presented in the Fig. 4. The sensitivity analysis of the influence of the variable input parameters to the reliability of the structures depends on the statistical independency between input and output parameters. The variability of the wind load, the stiffness and masses of the chimney has the most significant influence on the top deflection (Fig. 5).

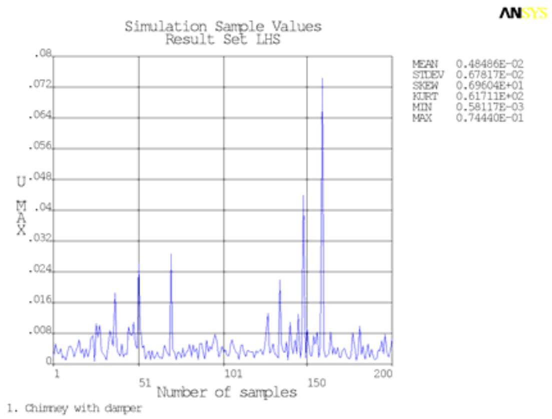

Fig. 4: The simulated top deflection.

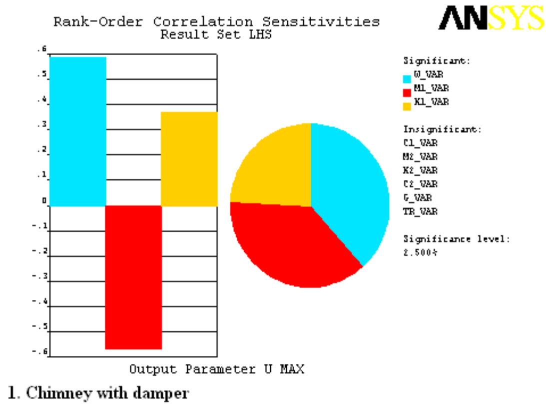

Fig. 5: The sensitivity analysis of the deflection.

The sensitivity analysis gives the valuable information about the influence of uncertainties of input variables (load, material, model and other) to engineer for optimal design of the structures.

6. Conclusions

This paper presents that a detailed analysis of top deflection of the chimney with and without the damper. The damper consists of a pendulum mass ring hinged in three chains, located in 120 degrees direction, connected to the damper house roof. The damping is achieved by friction between the friction mass and the damper house floor. The affectivity of the tuned pendulum damper depends on the frequency of the vortex load and the eigenvalue of the chimney. The stochastic methods give us the possibility of the complex analysis of the influence of uncertainties of input variables (load, material, model and other) to engineer for optimal design of the structures.

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References

EN 1991-1-4 Eurocode 1 (2005) Actions on structures-Part 1-4: General actions-Wind actions.

JCSS-OSTL/DIA/VROU (2000), Probabilistic Model Code, Part 1 Basis of Design, Working material, http://www.jcss.ethz.ch/, 2001.

Králik, J. Králik, J. jr. (2009) Deterministic and Probabilistic Analysis of Nonsymmetrical Wind Effects to Symmetrical High Rise Buildings. In proc. *European Safety and Reliability Conference, ESREL 2009, Reliability, Risk and Safety, Theory and Applications*, CRC Press/A.Balkema Book, Prague, CR, 7-10 September, Vol.2, p.1393-1396, Full in CD.

Králik, J. (2009) *Reliability Analysis of Structures Using Stochastic Finite Element Method*, Published by STU Bratislava, 2009, 143pp. ISBN 978-80-227-3130-0.

Pirner, M., Fischer, O. (2003) *Zatížení staveb vetrem.* ČKAIT, Praha, 256 strán, ISBN 80-86769-10-0.

Szabo, G. Gyorgyi, J. (2010) Application of the ANSYS Software to Fluid-Structure Interaction Analysis, In proc. of the *Seventh International Conference on Engineering Computational Technology*, Civil-Comp Press, Stirlingshire, Scotland. 19pp, in CD.

Travnik, P. Alpsten, G. (2002) *Dynamic Behaviour under Wind Loading of a 90 m Steel Chimney*, Alstom Power Sweden AB, Report S-01041.