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LIFETIME PREDICTION OF TOWERS WITH RESPECT TO LATERAL AND LONGITUDINAL WIND LOAD

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ABSTRACT

The paper deals with the theoretical lifetime prediction of telecommunication towers and antenna's cantilevers and the comparison with the measurements and numerical solution. A relatively simple and practical calculation method is presented. The wind load is described taking into account the probability distribution function of the mean velocity and corresponding mean mechanical stresses. The dynamic response of structure caused by the turbulence uses wind models for both longitudinal and lateral direction. Structural response takes into account the contribution of more vibration modes, measured or calculated if the structure is not accessible for any reason. Based upon this knowledge, the number of cycles for certain time period together with the residual life prediction of structure can be determined.

Keywords: *Lifetime prediction, towers, fatigue, wind load, spectrum*

1. INTRODUCTION

Slender structures like masts and towers are repeatedly exposed to pseudo-static and dynamic wind loading which is a subject of deep investigation for many years in many aspects, see e.g. [1-2]. The consequent response may cause cumulating damage, which sometimes leads to the collapse of a structure. The age and regular inspection often reveals that these structures or their components could be in danger with this respect. To prevent the breakdown by timely replacement or reconstruction, or to predict the expenses for further tower operation, one should determine its remaining lifetime.

There exists number of methods to determine the fatigue damage of a specimen, see e.g. [3-5] or the fatigue crack propagation both experimental and theoretical [6,7]. In the linear theory the damage analysis is based upon the assumption of the constant energy accumulated by one cycle and the characteristic amount of the energy in time. This approach is adopted here. In a case of existing measurement stress data the engineer can determine the number of cycles in theoretically every mechanical stress range and consequently he may assess if it complies with the damage criterion and/or determine the residual life of the structure.

In last years, the authors have carried out several measurements on broadcast towers in Czech Republic. The aim was to assess of the efficiency of damping absorbers and particularly the estimation of the remaining life of a structure. During these years, a method for the determination of remaining life of guyed masts and antenna cantilevers was developed. We call it the hybrid method, because it combines the theoretical approach, with the experimentally or numerically ascertained dynamic characteristics of the structures. It significantly extends the calculation proposal used in [8] while comparing the analysis of the vibration monitored during the measurements or calculated. The major enhancement is, that it takes into account the oscillations caused not only by the longitudinal turbulence, but also by the lateral wind turbulence, which in some cases of specific structural characteristics, becomes more important, see e.g. [9].

The paper demonstrates the use of this method on two examples of the broadcast towers selected especially because of their different character of the response. One is a monopole 30 m tall pipe tower with the dominating resonant part of the first mode of vibration. In the second example, treating the fiberglass antenna extension with the length of 16 m and the diameter of 1,9 m, the background response is more significant; because the resonant part is significantly damped by the high aerodynamic damping. The antenna is placed at the top of the lattice tower with the height of 70 m.

Both examples combine the dynamic analysis of the structure, the long-term data campaign on the site and numerical simulation of the wind events in the unique manner. For practical as well as analytical reasons the results and the life-time prediction obtained by this method have been compared with the Eurocode [10] (both cases) or with the measurement carried out at the site of a tower (second example).

2. DAMAGE MODEL AND DETERMINATION OF NUMBER OF CYCLES

The linear damage model has been adopted for the sake of practical engineering analysis. In this case the energy accumulation leads to the summation of partial damages notated as D_i:

$$D = \sum_i D_i = \sum_i \frac{n_i}{N_{i,f}} \tag{1}$$

where n_i is the number of completed cycles and $N_{i,f}$ is the total number of cycles to the failure at each stress level. Consequently, D is a sum of fractional damages at stress levels. For the total collapse it is taken the state when D=1, called Palmgren-Miner rule.

Major limitations of this rule represent omitting the sequence effects and considering the damage accumulation being independent of stress level. Some studies show, that in the case of cyclic loading with alternation of low and high amplitude cycles, the value D = 1 is very overrated and lead to the erroneous conclusion. Several modifications of the criterion (1) with the usage of non-linear equation for D involving the i-th level of the stresses can be found in [11]. However, for random loading histories as wind, correlation with the Palmgren-Miner rule is generally very good.

The damage assessment requires the identification of the stress peak-to-peak amplitudes and corresponding individual cycles. There are several causes of the dynamic response of slender structures and consequently the sources of cyclic stresses. In the observed structures four sources are identified:

a) cycles caused by the fluctuation component of the wind acting in the direction of mean wind speed, notated as $n_{i,fl,long}$ (treated in part. 2.1);

b) cycles caused by lateral turbulent wind loads in the direction perpendicular notated as $n_{i,fl,lat}$ (part. 2.2);

c) cycles caused by the changes in mean wind speed and mean wind direction notated $n_{i,m}$ (part. 2.3);

d) cycles caused by the shed vortices known as the Strouhal's effect notated as $n_{i,St}$ (part. 2.4).

The total number of cycles n_i is then total sum of cases a) – d):

$$n_i = n_{i,fl,long} + n_{i,fl,lat} + n_{i,m} + n_{i,St} \tag{2}$$

2.1 Number of the cycles caused by longitudinal turbulence of wind

The number of cycles $n_{i,fl,long}$ with the amplitude of fluctuation component of the stresses $\sigma_{a,fl,long,i}$ can be formed according to the practical formula, expressing the cumulative probability of mutually independent phenomena. We may write:

$$n_{i,fl,long} = \sum_{v_m} P_1(v_m) \cdot P_{2i}(v_m) \cdot P_3 \cdot d_t \cdot \psi(v_m) \tag{3}$$

where P_1, P_{2i} and P_3 are the relevant probabilities of individual phenomena. These probabilities are described and analyzed in the following text. The quantity d_t is the desired (projected) lifetime of the structure and ψ is the frequency determined from the spectral density of the response and/or by the following formula:

$$\psi = \sqrt{\frac{\int f^2 \cdot S_{\sigma\sigma}(f) \cdot df}{\int S_{\sigma\sigma}(f) \cdot df}} \approx \sqrt{\frac{\sum_k f_k^2 \ \sigma^2_{rms,k}}{\sigma^2_{rms,b} + \sum_k \ \sigma^2_{rms,k}}} \tag{4a,b}$$

where f denotes the frequency, f_k is the k-th natural frequency, $S_{\sigma\sigma}(f)$ is stress power spectral density, $\sigma_{rms,b}$ is the standard deviation of stress in the section produced by the background response and finally $\sigma_{rms,k}$ is the standard deviation of stress by the resonant response for k-th vibration mode. The probabilities P_1, P_{2i} as well as the frequency ψ varies with the mean wind speed. If the tower vibrates with one frequency, the value of ψ will equal to this one. It is advised to use this frequency ψ in the cases of the more complex power spectral density of the response.

One can use also the alternative formula respecting the calculation of the significant individual frequency components of the response, i.e. the background and the resonant parts. The formula (2) can be then written:

$$n_{i,fl,long} = \sum_{f_k}\sum_{v_m} P_1(v_m)\cdot P_{2i,fk}(v_m)\cdot P_3\cdot d_t\cdot f_k + \\ +\sum_{v_m} P_1(v_m)\cdot P_{2i,fb}(v_m)\cdot P_3\cdot d_t\cdot f_b \tag{5}$$

where f_b is the equivalent frequency assumed for the background response and f_k is the k-th resonant frequency of the response. Background frequency f_b can be calculated from the spectral density of the background response using the formula (4a).

2.1.1 Probability P_1

We call P_1 the probability of occurrence of the mean wind speed, i.e. that the mean wind speed will lie in certain interval. This probability is based upon the knowledge of probability density function p. Here we use the Weibull distribution with parameters $k = 2$ and $c = 0.35\cdot v_{m,max}$, applicable for most locations in the Czech Republic. It is written as:

$$p_1(v_m) = \frac{k}{c}\cdot\left(\frac{v_m}{c}\right)^{k-1}\exp\left[\left(-\frac{v_m}{c}\right)^k\right] \tag{6}$$

where v_m is the ten-minutes wind speed according to [10]. Dividing the whole band into several intervals and integrating the curve in these intervals, we obtain the probability that the mean wind speed will lie in that interval:

$$P_1\left(v_m \in \langle a,b\rangle\right) = \int_a^b p_1(v_m)\cdot dv_m \tag{7}$$

2.1.2 Probability P_2

The probability of the fluctuating stress component at certain mean wind speed is P_2. We use the assumption of the Gaussian distribution around the mean stress according to the standard [12]. It can be seen on the Fig. 1. The stress probability density at certain cross-section of the structure may be expressed as follows:

$$p_2(\sigma,v_m) = \frac{1}{\sigma_{rms}(v_m)\sqrt{2\pi}}\exp\left(-\frac{\left(\sigma-\sigma_m(v_m)\right)^2}{2\sigma_{rms}^2(v_m)}\right) \tag{8}$$

where σ is the mechanical stress, σ_m is the mean stress value in the structural element. The mean stress is calculated employing the mean wind speed from each interval. For the reference wind speed in order to calculate the mechanical stresses we selected the upper limit of each interval. The value σ_{rms} is the total standard deviation of the fluctuating part of the response. The mean stress value as well as the standard deviation values can be obtained from the numerical analysis of the mathematical model of the structure or from the measurement on the real tower.

For the determination of the total number of cycles by the formula (3) following formula for σ_{rms} is used:

$$\sigma_{rms,tot} = \sqrt{\sigma_{rms,b}^2 + \sum_k \sigma_{rms,k}^2} \tag{9}$$

In case of using Eq. (5) one can determine the σ_{rms} related to the i-th resonant frequency by the given formula:

$$\sigma_{rms,i} = \sqrt{\sum_{k\geq i}\sigma_{rms,k}^2} \tag{10}$$

For the number of cycles related to the background response, Eq. (9) should be used.

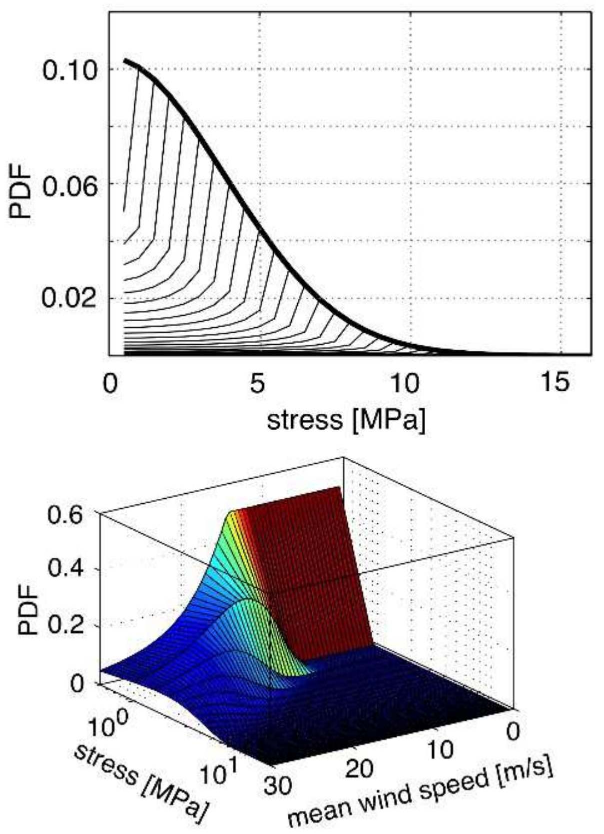

Figure 1: *Top: Half part of the probability density function p_2 of the mechanical stress and partial probability density functions p_h (thin lines) associated with the harmonic components with the amplitudes $\sigma_{a,fl,long,i}$. Bottom: Probability density function as the function of mean wind speed. The halves of the functions are shown*

Assuming the Central Limit Theorem one can conclude, that the stress fluctuation response distribution in Eq. (8) is composed from the harmonic components with the amplitudes $\sigma_{a,fl,long,i}$ and probability density function given by the following formula, combining infinite sinusoidal wave with limiting time interval:

$$p_{h,i}\left(\sigma, v_m\right) = \frac{1}{\pi\sqrt{\sigma_{a,fl,long,i} - \sigma^2}} \cdot \gamma \tag{11}$$

Coefficient γ (expressing the time limitation) should be determined numerically from the condition that $p_2(\sigma_{a,fl,long,i}, v_m)$ from Eq. (8) equals to the $p_{h,i}(\sigma_{a,fl,long,i}, v_m)$, see Fig. 1. For each of these amplitudes we calculate the probability P_{2i} as individual component of total probability P_2 corresponding to the certain mean wind speed.

$$P_{2i}\left(\sigma_{a,fl,long,i} \in \left\langle \sigma_{i-1}, \sigma_i \right\rangle, v_m\right) = \\ = \int_{-\sigma_{a,fl,long,i}}^{\sigma_{a,fl,long,i}} \left(p_{h,i-1} - p_{h,i}\right) \cdot d\sigma \tag{12}$$

The peak-to-peak stresses related to the determined number of cycles $n_{i,fl,long}$ equal to

$$\Delta\sigma_i = 2\sigma_{a,fl,long,i} \tag{13}$$

2.1.3 Probability P_3

Alternatively we should consider also the occurrence frequency of the mean wind speed in one direction. This we may call P_3. It is given by the fraction of the area bellow the relevant part of a histogram (usually taken from the meteorological observations; wind rosette) and the area below the whole curve.

2.2 Number of the cycles caused by lateral turbulence of wind

The calculation of the number of the cycles and the range of the stress is performed in the same way as for the longitudinal direction of the wind but with the use of different parameters. The probability P_3 is in this case determined from the wind roses in the perpendicular direction. However, in the majority of the cases it may be simply assumed that $P_{3,lat}$ = 1-$P_{3,long}$.

The probability P_{2i} and the value of the equivalent frequency ψ can be determined from the spectral density or the standard deviation of the response generated by the turbulence in the lateral direction. However, numbers of the cycles due to lateral fluctuation of the wind is often minor and some simplifications can be used. For example, the standard deviations of the background response can be in a simplified way assumed to be 0.4 times the standard deviation for longitudinal wind direction. Moreover, the standard deviation of the resonant part can be assumed as $\lambda=\lambda_1/\lambda_2=\sqrt{(1/3)}/\sqrt{(1/2)}=0.82$ times the standard deviation for the along-wind direction. The coefficient λ_1 expresses the approximate amplitudes of the fluctuating wind contribution of the lateral and longitudinal components of the wind in the resonant part of the response. Moreover, it is considered, that the aerodynamic damping for the lateral response is half of the aerodynamic damping in the longitudinal direction expressed by λ_2. More detailed explanation of this simplification can be found in [13].

2.3 Number of cycles caused by the changes in the mean wind speed and mean wind direction

For the determination of the stress range spectra, caused by changes of the mean wind speed and the wind direction, following simplifications are used. It is assumed that the change of the mean velocity or direction occurs every 10 minutes, i.e. the period (integration time) during which is the mean component of the wind velocity is considered as a constant. The stress range (hereafter labeled $\Delta_{\sigma,m}$) which occurs after this time is equal to the difference between the maximum or minimum value of the stress decrease in the ten-minute interval and the minimum or maximum value of the stress increase in the previous interval:

$$\Delta_{\sigma,m} = \left|\sigma_{\max,j} - \sigma_{\min,j-1}\right| \tag{14a}$$

respectively

$$\Delta_{\sigma,m} = \left|\sigma_{\min,j} - \sigma_{\max,j-1}\right| \tag{14b}$$

where j is the counter of the ten-minute intervals. The maximum and minimum values of the stress increase $\sigma_{max,j}$ and $\sigma_{min,j-1}$ are defined as:

$$\sigma_{\max,j} = \sigma_{m,j} + k_{p,j} \cdot \sigma_{fl,j} \tag{15}$$

$$\sigma_{\min,j-1} = \sigma_{m,j-1} - k_{p,j-1} \cdot \sigma_{fl,j-1} \tag{16}$$

Where σ_{fl} is the standard deviation of the fluctuation component response in the corresponding interval and k_p is the peak factor, which can be found in the reference [13]. The maximal and minimal stresses as the function of the wind velocity are shown at Fig. 2 and demonstrated on one of the examples – tower Vraní vrch.

The mean stresses can obtained from the numerical calculation of the response, see Fig. 3.

Another simplification can be applied by taking into account that the minima of the stress $\sigma_{min,j-1}$ or $\sigma_{min,j}$ are approximately the same low values (near zero) for all mean wind velocities, see Fig. 2. If we apply this simplification, the peak-to-peak value of

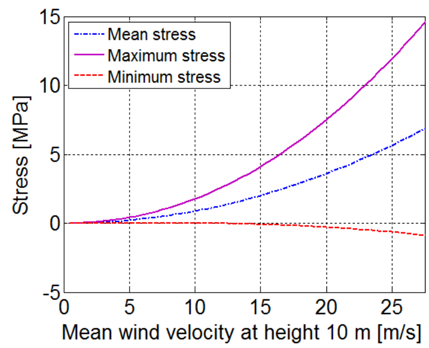

Figure 2: *Maximal and minimal stresses as the function of the mean wind speed (tower Vraní vrch)*

the stress will depend on the mean wind speed of the related 10-minutes interval and not on the unknown time sequence of mean wind speeds. Peak to peak value of the stress can be then stated as:

$$\Delta_{\sigma,m} = 2 \cdot k_{p,j} \cdot \sigma_{fl,j} \tag{17}$$

This stress change can be included into the cycles count as one half of a cycle. It is important to know however, before to carry out this step, whether after the minimal value of $\sigma_{min,j-1}$ in the previous interval (or after the maximum $\sigma_{max,j-1}$) follows $\sigma_{max,j}$ or rather $\sigma_{min,j}$. In the first case, the peak-to-peak stress $\Delta_{\sigma,m}$ occurs in the instant of the mean wind speed change. In the latter case, it occurs already during the 10-minutes time interval and thus it is included into $n_{i,fl,long}$. At the end, it is therefore considered that the half of the cycle with the peak-to-peak stress amplitude $\Delta_{\sigma,m}$ occurs only in the half number of changes of the mean wind speed.

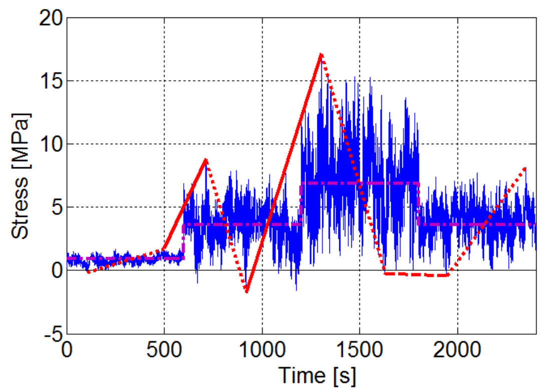

Figure 3: *Example of stress sequence (Vraní vrch) of simulated time history with the mean wind speeds changes (v_m = 10, 20, 27,5 and 20 m/s). The red lines connect the minima and maxima of ten minutes intervals*

Finally, the number of cycles $n_{i,m}$ is calculated as:

$$n_{i,m} = \sum_{v_m} 0,25 \cdot P_1(v_m) \cdot P_3 \cdot d_{10} \tag{18}$$

where d_{10} is the number of the ten-minute intervals in the total lifetime of the structure.

2.4 Number of cycles caused by vortex shedding

The last case is the number of the cycles caused by the vortices shed at the structure and possible lateral dynamic response due to Strouhal effect. It can be determined for example from the methodology in the code and according to the equation:

$$n_{i,St} = 2 \cdot d_t \cdot f_k \cdot \varepsilon_0 \cdot \left(\frac{v_{crit}}{v_0}\right)^2 \cdot \exp\left(-\left(\frac{v_{crit}}{v_0}\right)^2\right) \tag{19}$$

where d_t is the lifetime of the structure, f_k the k-th natural frequency and further quantities are described in [10]. The number of the cycles is then determined for all the important critical wind speeds considering constant amplitudes of the lateral vibration.

3. DETERMINATION OF NUMBER OF CYCLES USING NUMERICAL SIMULATION AND DIRECT INTEGRATION

The random sample of the wind speed at different levels of structure using a second order autoregressive process by Iwatani [14] was simulated. This procedure shows very good agreement between the desired and simulated wind characteristics, in particular the spectral densities of the wind speed and the coherence between the different nodes of the structure. Because Iwatani's method is not suitable for the numerical simulation of the process with high sampling, time step Δt=0.2 s has been selected. Then, the wind speed history was resampled using the step Δt=0.05 s and the direct Newmark method was used for the integration and determination of the response. The total time used for the simulated event was T=1000 s. The evaluation of the steady response was however carried out for a period of 600 s (range 400-1000 s). This corresponds to the ten-minute integration time considered in the previous calculations.

The resulting stress waveform was analyzed by the rain-flow method; see e.g. [15] that effectively sorts the stresses and counts the cycles. Because the load is random the resulting histogram was determined as the average of several samples. In order to compare the results with the number of cycles calculated in the Section 2.1, the number of cycles corresponding to each mean wind speeds are multiplied by the occurrence frequency of that wind speed, i.e. the next formula is used:

$$n_{i,fl,long} = \sum_{v_m} P_1(v_m) \cdot P_3 \cdot d_{10} \cdot n_i(v_m) \tag{20}$$

where P_1, P_3 , and d_{10} were defined in the previous section and n_i (v_m) is the number of cycles of the mean wind speed v_m.

4. DAMAGE ASSESMENT OF EXISTING STRUCTURES

In the period 2005-2011, the authors carried out several measurements on broadcast towers with the aim to provide the customers with the assessment of the efficiency of dampers and particularly with the estimation of the remaining life of a structure. Strain measurement was carried out and the numbers of cycles was determined by the system SANWELL1 RE-49/4SG-2, developed at ITAM. It uses the rain-flow method and sifts and consequently groups the strains (and thus also stresses) into 32 classes including the mean values. As stated in the introduction, the efficiency of the method is demonstrated by two typical examples, shown in Fig. 4.

Figure 4: *Photo of monopole of height 30 m (left) and of TV tower Vraní vrch with GRP antenna cantilever (right)*

4.1 Example 1 – monopole tower

Tubular shaft with sections ranging from TR920x16 to TR508x16 forms this tower. The upper part is made of the sections TR324x12, see Fig. 4. It was considered that the location of the tower is in the wind zone III, terrain category II, see code [12]. The detail at the heel of the tower was analyzed. It is connection of foot plate stiffener by category detail 71 N/mm^2. The assessment is made for the life of 50 years and partial safety factors for fatigue γ_{Ff} =1,0 *a* γ_{Mf}=1,35 given in [16] and [17].

For this type of tower equipped with ladder, antennas and other equipment the shed vortices do not occur. Therefore, the lateral vibration due to Strouhal's effect has been not assessed. The logarithmic decrement of structural damping was determined as δ=0.012. The first four natural frequencies of the structure were calculated: f_1=0.94 Hz, f_2=4.41 Hz, f_3=10.22 Hz and f_4=17.26 Hz. The levels of total logarithmic decrement at the maximum mean wind speed were determined as δ_1=0.11, δ_2=0.03, δ_3=0.02 and δ_4=0.018 respectively. The probabilities $P_{3,long}$ = 0.57 and $P_{3,lat}$ = 0.43 were evaluated from the wind rosette relevant for the site of the structure.

The partial damages due to individual causes are tabulated in Tab. 1-2 and corresponding number of cycles are shown in Figs 5-7.

Table 1: *Damage related to individual cases*

	Equation	Damage
Long. turb.	3, 4a	D = 0,217
Long. turb.	3, 4b	D = 0,247
Long. turb.	5	D = 0,144
Long. turb.	Integration	D = 0,119
Lat. turb.	3, 4a	D = 0,025
Dir. changes	18	D = 0,002

Table 2: *Total cumulative damage*

	Equation	Damage
Total	3, 4a	D = 0,245
Total	3, 4b	D = 0,275
Total	5	D = 0,172
Total	Integration	D = 0,146
Total	EN1991-1-4 [10]	D = 1,070

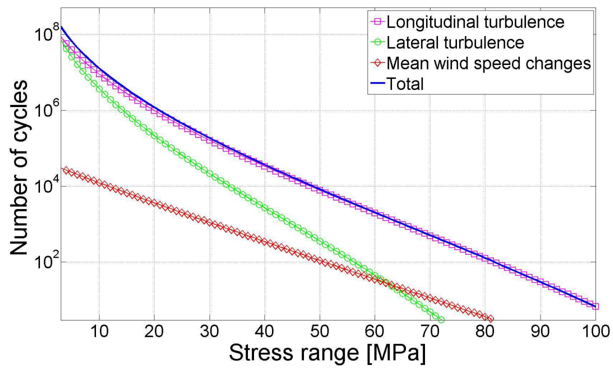

Figure 5: *The contribution of individual components to the total number of cycles according to Section 2. The number of cycles caused by the longitudinal turbulence was established according to Eq. (3)*

4.1.1 Example 1 – discussion of the results

All the theoretical (hybrid) methods give relatively good estimate of total damage. For this particular example, when the first modal shape dominates the tower response, the use of Eq. (4b) gives the most conservative prediction of the total damage from all the methods including the numerical integration of the equation of motion. In comparing to the results by EN 1991-1-4, this gives more reliable results, while the EN method is very conservative. As expected the most important part of the total damage was caused by the longitudinal turbulence. The contribution of other causes of the damage was minimal.

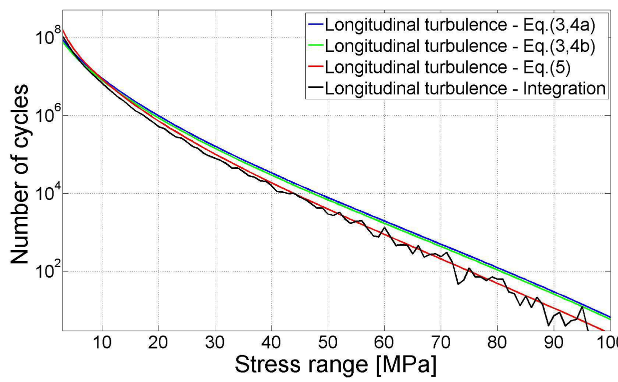

Figure 6: *Comparison of the number of cycles due to longitudinal turbulence according to different procedures*

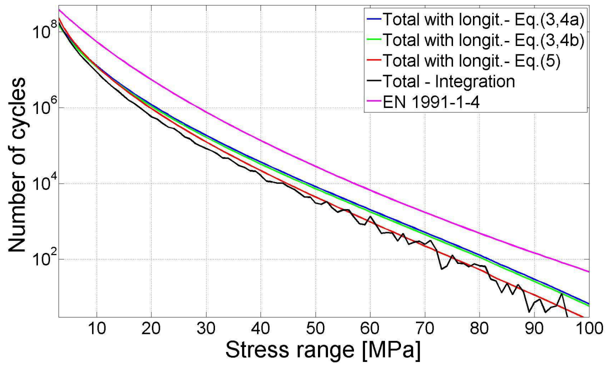

Figure 7: *Comparison of the total number of cycles under different procedures. The brown curve represents number of cycles according to [10]*

4.2 Example 2 – prediction of life time of antenna cantilever

The second example illustrates the use of the proposed method on the tower with fiber-glass reinforced cantilevers that is about 20 m tall. It is made with the diameter of 1.9 m and with the wall thickness 12÷16 mm. The properties of the fiber-glass elements were taken from the experiments made at elder extensions, see [18]. Their characteristics, describing the limit stress values for certain number of cycles, were closest to the characteristics of the laminates under examination and they were made in the same time period and with similar fabrication procedure. The so-called cut off limit of the SN curve was measured to be 10 MPa, so that the stress peak-to-peak amplitudes up to 5 MPa caused for example by the vortex shedding have only minor influence on the total damage of the antenna extension.

Table 3: *Cumulative damage related to individual cases assuming cut off limit*

	Equation	Damage
Long. turb.	3, 4a	D = 0,155
Long. turb.	3, 4b	D = 0,447
Long. turb.	5	D = 0,156
Long. turb.	Integration	D = 0,548
Lat. turb.	3, 4a	D = 0,001
Dir. changes	18	D = 0,007
Vortex shedding	19	D = 0

The logarithmic decrement of the structural damping has been determined as δ=0.03. The first four natural frequencies of the structure are f_1=0.61, f_2=1.47, f_3=3.09 and f_4=3.49. The levels of total logarithmic decrement of the damping at the maximum mean wind speed were determined as δ_1=0.196, δ_2=0.086, δ_3=0.056 and δ_4=0.043 respectively. Identical values of the probability P_3 as in the first example were used.

The numbers of cycles related to individual components of the wind load are shown in Figs 8-10. The corresponding partial damages are tabulated in Tab. 3-4.

Table 4: *Total cumulative damage*

	Equation	Damage
Total	3, 4a	D = 0,162
Total	3, 4b	D = 0,454
Total	5	D = 0,163
Total	Integration	D = 0,555
Total	Measurement	D = 0,112
Total	EN 1991-1-4 [10]	D = 1,770

4.2.1 Example 2 –discussion of the results

In this example, the background response is dominant. This may explain why the results of individual procedures Eq. (3, 4a) and Eq. (3, 4b) differ and why Eq. (4b) gives the results close to numerical integration. Also in this case, it gives the conservative prediction of the total damage and may be used for the calculation instead of EN method giving extremely conservative estimation of the number of cycles n_i. This is proved by the measured values. Since the measurement was carried out only limited time (up to several weeks) it is impossible to record high speeds with the low probability of the occurrence. Thus, limited numbers of the cycles with the high peak-to-peak amplitudes is present in the data and also in the projection on the whole lifetime of the tower, see Fig. 10.

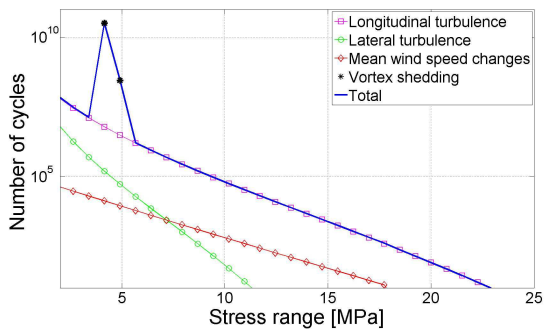

Figure 8: *The individual components of the total number of cycles. The number of cycles caused by the longitudinal and lateral turbulence was determined using the Eq. (3)*

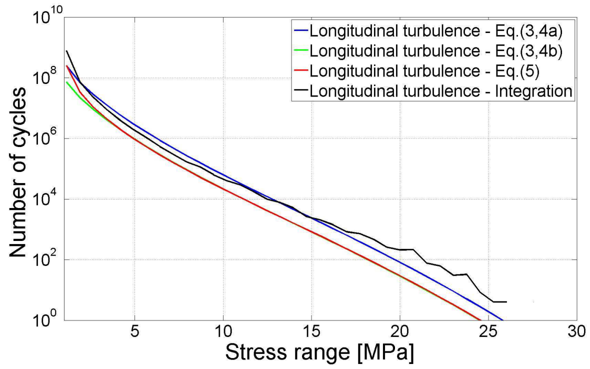

Figure 9: *Comparison of the number of cycles in the longitudinal direction according to different procedures*

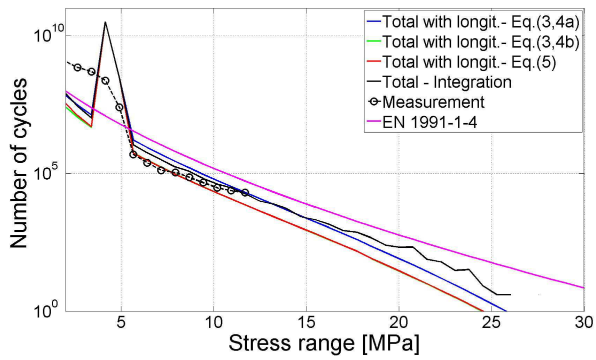

Figure 10: *Comparison of the total number of cycles under different procedures*

5. CONCLUSIONS

The paper presented the analysis focused on the prediction of theoretical lifetime of towers and antenna cantilevers. The method based on the numerical calculation and supplemented by the measurement data was suggested. The proposed method was applied in case of two towers subjected to the turbulent wind. The wind load has been described by relatively simple formulas and the number of cycles during certain period was determined.

The accuracy of the results was verified using the comparison with data from measurements on the real structures or from the direct numerical integration of the response. The comparison showed that the theoretical number of cycles is higher than measured ones. This deviation may be caused by some conservative assumptions especially for lower wind speeds, which includes wide range of excitation. Also the time-limited measurements do not cover the higher stresses with low number of cycles, i.e. low probability of the occurrence. In any case, the proposed method, gives the much more realistic life-time prediction than method in the code, which seems to be too conservative. It offers to the clients a better estimation of the service life of towers and their parts and facilitates better organization of the maintenance work.

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