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NUMERICAL ANALYSIS OF COOLING TOWER SURFACE BASED ON WIND TUNNEL STUDIES IN TERMS OF AERODYNAMIC INTERFERENCE

ANALIZA NUMERYCZNA WPŁYWU INTERFERENCJI AERODYNAMICZNEJ NA KONSTRUKCJĘ CHŁODNI KOMINOWEJ

A b s t r a c t

Before the widespread use of computers, the only way to design a structure with complex shape was to build a prototype model and perform the necessary tests. Nowadays, designers are able to create an accurate and complex engineering design by effective mathematical models. The paper describes the numerical analysis of cooling tower carried out by a finite element method. The FEM analysis was performed with Lusas software. The cooling tower represents the real structure located in Kozienice, Poland. During the calculations, different load cases based on wind tunnel tests were taken into account. The evaluation of the influence of different wind directions and configuration of obstacles on internal forces and displacements were analyzed. Proper dimensions, material proprieties and method factors were applied to the model. In the further part, the dynamic evaluation was presented. The Eigen modes with corresponding values and shapes were created and described. Estimation of impact of dynamic wind action on the object will be also released. Time history of amplitude and displacements was attached. As a result of the dynamic studies, the dynamic evaluating indicator was calculated.

Keywords: *cooling tower, Finite Element Method, time variable analysis, Lusas*

S t r e s z c z e n i e

Przed rozpowszechnieniem komputerów, jedyną metodą projektowania obiektów o skomplikowanym kształcie, było zbudowanie modelu w celu przeprowadzenia niezbędnych badań. Obecnie, projektanci mogą tworzyć dokładne i złożone projekty poprzez dokładny model matematyczny. Referat opisuje analizę numeryczną chłodni kominowej metodą elementów skończonych przeprowadzoną w programie LUSAS. Chłodnia kominowa jest odzwierciedleniem obiektu zlokalizowanego w Kozienicach. Podczas obliczeń, wzięto pod uwagę wiele przypadków obciążenia wiatrem bazując na wynikach badań przeprowadzonych w tunelu wiatrowym. Zbadano ocenę wpływu różnych kierunków wiatru i lokalizacji sąsiadujących obiektów na siły przekrojowe i przemieszczenia. Odpowiednie wymiary, właściwości materiałowe i współczynniki zostały zastosowane. W następnej części przedstawiono oszacowanie efektu dynamicznego. Zaprezentowano wartości własne i odpowiadające im postaci własne. Przeprowadzono analizę czasową amplitudy i przemieszczeń. Jako podsumowanie badań dynamicznych oszacowano wskaźnik dynamiczny.

Słowa kluczowe: *chłodnia kominowa, Metoda Elementów Skończonych, analiza czasowa, Lusas*

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1. FEM model

1.1. Geometry, loading and mesh

The Finite Element Analysis was executed with LUSAS 14.7-10 software. Geometry of the cooling tower was performed by making the hyperbolical surface line (meridian). The meridian was divided into 4 elements: a column, from top of the column to the stiffening ring at the height of 15.86 m, between, the stiffening ring, and the upper platform (135.75 m), and the last fragment from the stiffening platform up to the top of the tower. The column is tangent to line and its extension. The surface of the tower is connected rigidly with columns. The thickness of the surface varies from 30 cm on the top, through 20 cm on, the narrowness, up to 110 cm on the bottom. At the height of 15.86 m a stiffening ring is placed (60 cm thick, 90 cm length). At the top, a stiffening platform is also located.

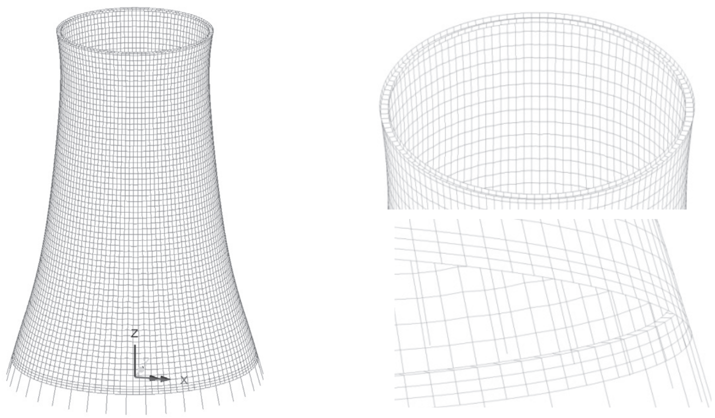


Fig. 1. FEM model and mesh [1]

For the shell of the cooling tower, quadrilateral shapes of elements with the quadratic interpolation order were adjusted (QTS8). The shell was divided into 120 horizontal and 64 vertical FEM elements. The mesh was refined on the base of the shell. Stiffening ring and stiffening platform were meshed with accurate density, adequate to the stiffness of the element. The columns are relatively short and stiff comparing to the cooling tower. Due to that fact, columns were divided only into three elements; three dimensional thick beams as a structural element type were selected. The linear interpolation order was applied. The elastodynamic analysis was performed.

In the performed analysis only dead and wind loads were taken into account. The dead load was applied to the structure automatically by the software, based on material properties. Both internal and external wind pressures were taken from the wind tunnel studies describes in [1]. Due to the fact that studies were focused on the influence of wind direction and location of obstacles on internal forces, the cracking of concrete and its impact on stiffness of structure was omitted.

2. Results of static analysis

2.1. Dead load

In the following pictures the N_x, N_y forces and M_x moments are presented, N_x means meridians forces, and the N_y means parallel forces, the notation of moments is identical. The wind pressure consists of internal pressure and external pressure. Characteristic design values were taken into calculations. All the safety factors in load combination are equal to 1. The internal forces calculated only for dead loads (see Fig. 2) are fully symmetrical. The results show, that the shell is close to the membrane state. The moments are relatively small, and are not significant. Disorders of the membrane state can be caused the stiffening elements located on the surface. According to [2] such a size of disturbance is natural in hyperbolical shells with these kinds of loads.

An enormous increase of values appears near the columns. Assuming the FEM theory; the values may tend up to infinity. It can be noticed in all kinds of forces. It is caused by the connection of bar elements to the surface. The values located in that areas are invalid and should be omitted during design process. Enlargement of values caused by stiffening rings is also visible near the top of the tower.

2.2. Dead load and Wind loads

The results are presented in such a way that wind direction is parallel with axis *X*. (see Fig. 2). As it was noticed before the wind pressure come from wind tunnels studies [1]. The analysis of all wind directions was performed, however only two directions are presented in this paper. The wind acting on single cooling tower without any objects in neighborhood, and the second case when the tower is surrounded by power house facilities .In single situation (without surroundings) the increase of negative values of N_y up to –95 kN/m in upper windward section in comparison to leeward section is visible. The maximum negative values of N_y are reached for the lowest vertical division (left, right, windward), maximum value about 300 kN/m. On the sides in upper division the positive values appear, however the values are close to zero. When it comes to the N_x forces the biggest positive forces are reached for the whole windward section 150 kN/m, in this part only positive values are observable. In both upper sides, the values are positive (maximum 130 kN/m). However, in the lower rings the maximum negative values appears – up to 1.3 MN/m. In the leeward section situation is similar to sides, but in the lower rings the absolute negative values are much smaller – maximum 700 kN/m. Interference situation (I_{135}) is characterized by significant differences in comparison to the previous one. Differences are noticeable in all kinds of forces and displacements. In N_y forces, the biggest changes are observable in windward section. There is a significant decrease of absolute values both negative and positive. Even the change of sight in upper part, from negative to positive is visible; however the positive values are close to zero. Leeward section in upper part is characterized by the increase of positive values up to 35 kN/m. Also the change of signs from positive to negative in the middle of leeward section is visible. In the other sections of tower, rather the decreases of the absolute values are visible, while the distribution of forces is unchanged.

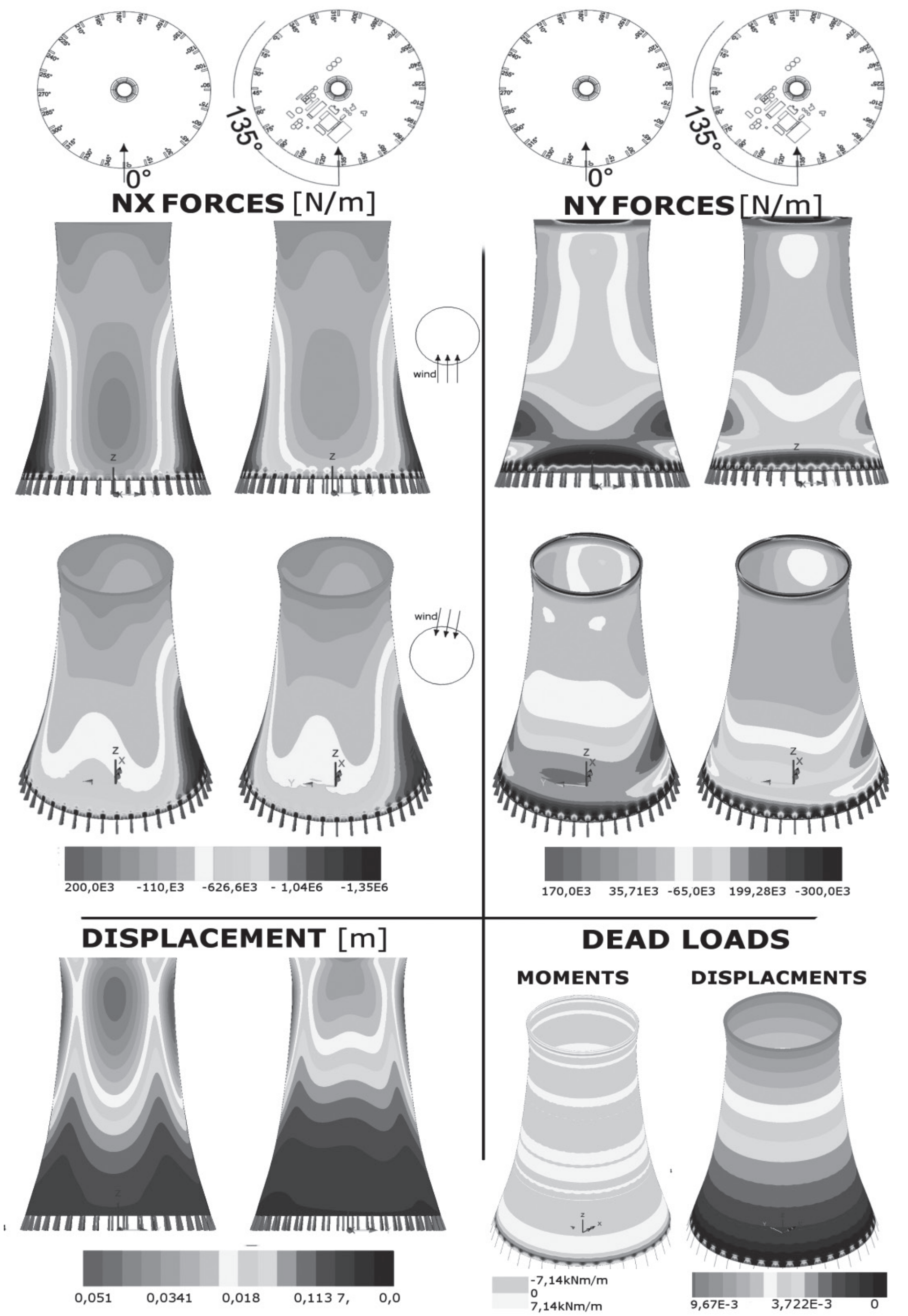


Fig. 2. Internal forces and displacements [1]

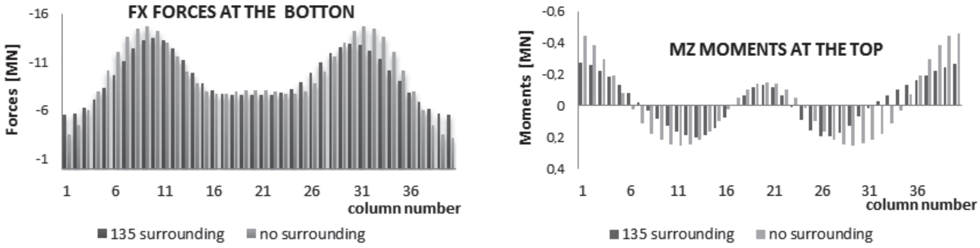
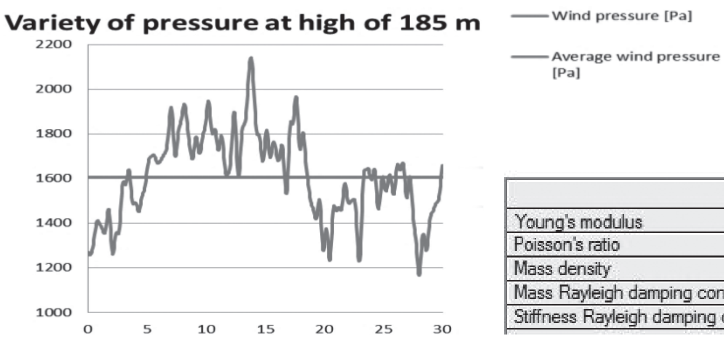


Fig. 3. Internal forces in columns [1]

When it comes to the N_x there are no big changes, the decrease of absolute values with the same distribution of forces occur. There are no significant disturbances in the line symmetry of N_x forces, only the disturbances of displacements are observable. The longitudinal forces are presented in Fig. 3, F_x notation means longitudinal forces which cause the compression of columns (sign –), the values are gathered in the base of the columns. The windward direction is located between 20 and 21 column, while the leeward orientation is near the column 1 and 40.

3. Estimation dynamic wind action impact on cooling tower

In order to facilitate the analysis, several simplifying assumptions have been implemented. Without these assumptions, it would be impossible to evaluate the vulnerability of the structure due to the dynamic wind load. Wind field applied to the model has a stationary nature, when in the reality; the wind acting on the tower is strongly inhomogeneous and variable in time and space. The variability of the wind field in time is implemented in model by multiplying the C_{Pe} coefficients by a corresponding values of the wind pressures – only the multiplier is time variable. Values of wind pressure were achieved from the Wind_Sym software for the height of 185 m.



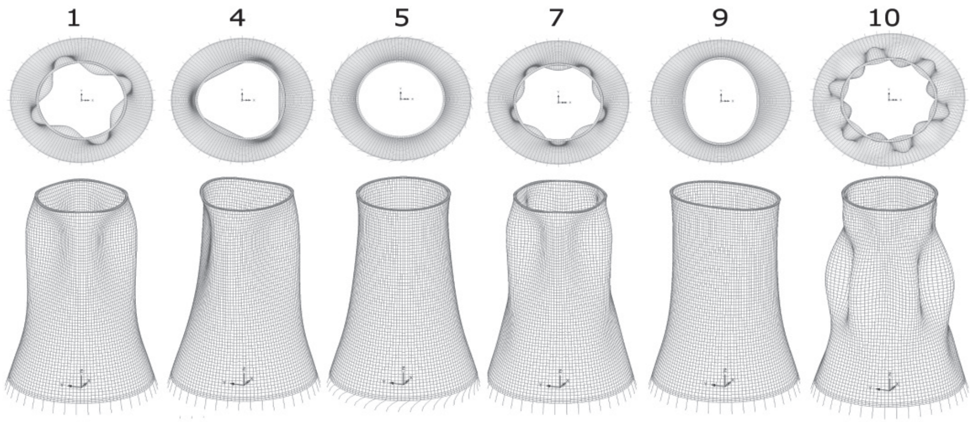
	Value
Young's modulus	37,0E9
Poisson's ratio	0,2
Mass density	2,54842E3
Mass Rayleigh damping constant	0,03
Stiffness Rayleigh damping constant	0,02

Fig. 4. Diagram of variety of pressure at reference and material properties [1]

The software imitates the wind field velocity adequately, however in nature the variations occur also in respect to height. In dynamic analysis the same C_{Pe} coefficients as in static analysis were used. Lusas software has been used to carry out the dynamic analysis.

The geometric and FEM models have remained unchanged in comparison to the static analysis. Through the entire procedure, only the wind load was taken into the account, model has been released from the dead load. Again, only two situations were taken into consideration, the single situation without surrounding and the interference situation (I_{135}). However, the different values of the wind pressure were used, so there is no correlation between dynamic and static results included above.

Procedure has been based on processing the structure to the action of time variable wind load in strictly defined period of time. The period was 35 seconds long and the sampling rate was equal to 20 per second, what gives 700 samples with the 0.05 second long of each one. Additionally the time constant analysis was implemented to estimate response time of construction in the initial phase of dynamic analysis. Respecting the fact that only the wind loads are applied into the model, as an indicator of the dynamic vulnerability, solely the displacements of individual nodes were used.



MODE	EIGENVALUE	FREQUENCY	PERIOD
1	23,377	0,770	1,300
2	23,378	0,770	1,299
3	35,563	0,949	1,054
4	35,565	0,949	1,054
5	44,029	1,056	0,947
6	46,039	1,080	0,926
7	46,039	1,080	0,926
8	46,307	1,083	0,923
9	46,309	1,083	0,923
10	58,487	1,217	0,822

Fig. 5. Natural modes with corresponding eigenvalues and frequency, Lusas [1]

3.1. Eigenmodes and shapes

Totally ten eigenmodes have been created. Nonetheless only 6 of them have been published, because of the fact that some of shapes are equivalent to another, only the rotation appears. From the tables presented below, it is visible that the second mode is similar to first, third to fourth, sixth to seventh and eighth to ninth. The fifth mode has a torsion nature. The simpliest is decidedly mode number 9.

4. Dynamic Results

Scrupulous dynamic analysis is presented for points, in which maximum resultant displacement in static analysis occurred. Control of response of structure were executed by applying a constant load in time. It was necessary to estimate the time in which dynamic results would be uncontaminated by natural response of the structure. For further analyzis of dynamic results, time from 0 to 12 seconds were omitted.

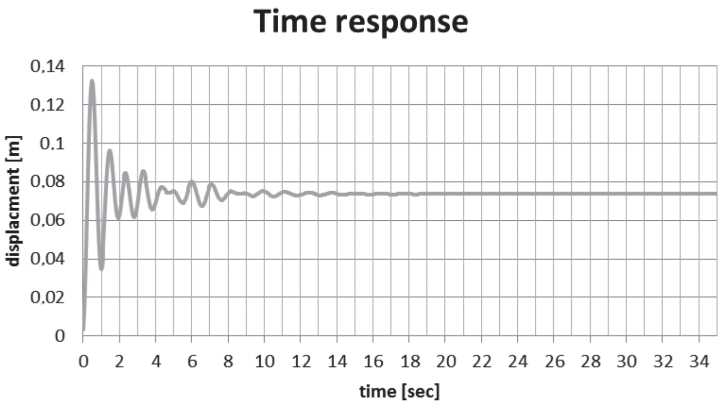


Fig. 6. Response of structure diagram and material properties [1]

The diagrams of amplitudes (A) were performed with formula:

$$A(t) = U(t) - U^{d}_{avg} \tag{1}$$

$$U_{avg} = \frac{\sum_{t=12}^{t=35} U(t)}{n} \tag{2}$$

where:

U_{avg} – average value of displacement from 12 to 35 second,
$U(t)$ – value of displacement in time,
n – number of time steps (460).

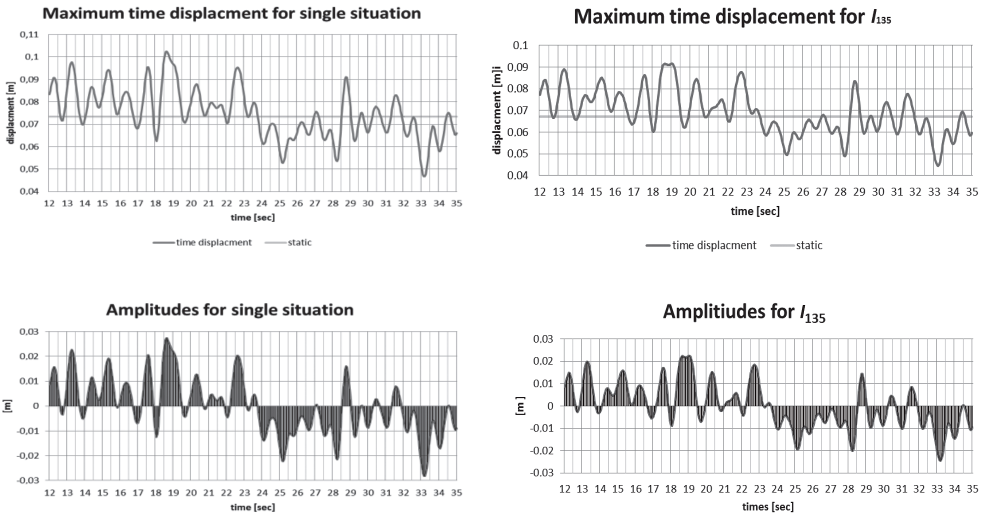


Fig. 7. Time history graphs [1]

The dynamic evaluating indicator ψ is equal to:

$$\psi_{I_{135}} = \frac{\max|A_{I_{135}}(t)|}{U^{s}_{I_{135}}} = 36.66\% \qquad \psi_{single} = \frac{\max|A_{single}(t)|}{U^{s}_{single}} = 38.48\%$$

5. Conclusions

By the application of such a powerful engineering tool like Lusas, the dynamic analysis was possible. It is easy to perform a multiple number of additional structure behavior analysis including complex non- linear problems. It is possible to solve multitude of problems like: large deformations, high levels of nonlinearity and complicated boundary conditions. The results show that location of obstacles, in surrounding of cooling tower, has a significant impact on internal forces and displacements. However, in dynamic analysis the changes are slightly smaller but still visible. It seems that an individual and detailed analysis may be very helpful in further design of cooling towers. Finally, it can result in different spacing and sizes of concrete reinforcement.

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