TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
CIVIL ENGINEERING | BUDOWNICTWO

1-B/2016

DOI: 10.4467/2353737XCT.16.069.5418

KRZYSZTOF STAROWICZ*, TOMASZ MILEWSKI*, GRZEGORZ BOSAK*

WIND TUNNEL STUDIES OF COOLING TOWER SURFACE IN TERMS OF AERODYNAMIC INTERFERENCE

BADANIA MODELOWE WPŁYWU INTERFERENCJI AERODYNAMICZNEJ NA POWŁOKĘ CHŁODNI KOMINOWEJ

A b s t r a c t

The cooling tower can be classified as a special structure, both in terms of reliability and size. The collapse of such a large tower, located closely to other buildings, may result in very serious consequences. It seems that special attention should be paid during design process of this kind of structures. Despite the increase in cost, the additional analysis and studies are indicated and also may raise reliability. The article presents the influence of wind action on the cooling tower. It consists of the studies on the issue of aerodynamic interference performed in the wind tunnel. The attention was particularly focused on the influence of the wind pressure on the shell of cooling tower, and on variability of these pressures on the surrounding objects. Making an adequate scale model, configuration of measuring equipment and an execution of wind tunnel tests will be described in this paper. The research was concentrated on measuring the pressure coefficients on the cooling tower surface in single situation and interference situations.

Keywords: *cooling tower, wind tunnel, aerodynamic interference, power plant*

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

Chłodnię kominową można zakwalifikować do grupy konstrukcji specjalnych zarówno pod względem niezawodności jak i rozmiaru. Zniszczenie tak wielkiego obiektu zlokalizowanego w sąsiedztwie budynków elektrowni może skutkować poważnymi konsekwencjami. Projektowanie wymaga szczególnej uwagi. Pomimo większych kosztów, dodatkowe badania i analiza są zalecone ze względu na niezawodność. Artykuł zawiera informacje o badaniach przeprowadzonych w tunelu wiatrowym nad zagadnieniem działania wiatru na chłodnię kominową oraz zjawiska interferencji aerodynamicznej. Szczególną uwagę zwrócono na wpływ zmiennego ciśnienia wiatru, na powierzchnię chłodni kominowej. Poniżej opisano proces wykonania modelu w odpowiedniej skali, konfigurację aparatury pomiarowej i wykonanie badań w tunelu wiatrowym. Badania były skupione na pomiarze współczynników ciśnienia wiatru na powierzchni chłodni kominowej w sytuacji z otoczeniem i bez niego.

Słowa kluczowe: *chłodnia kominowa, tunel wiatrowy, interferencja aerodynamiczna, elektrownia*

* M.Sc. Krzysztof Starowicz, M.Sc Tomasz Milewski, Ph.D. Grzegorz Bosak, Faculty of Civil Engineering, Cracow University of Technology.

1. Wind tunnel studies

1.1. Model of cooling tower and its surrounding

The model of a cooling tower and surrounding objects are inspired by the new power plant unit in Kozienice, Poland. All the objects are not an accurate representation of this unit, however during the execution of models, similarity to the original was one of the most important goals.

Studies focused on the cooling tower – the biggest object in a new part of the power house. The cooling tower is 185 m height. The meridian located on the tower surface can be described by a hyperbolical equation:

$$\frac{x^2}{35^2} - \frac{(y-140)^2}{100^2} = 1$$

where:

$0 \le y \le 185$,

x – diameter.

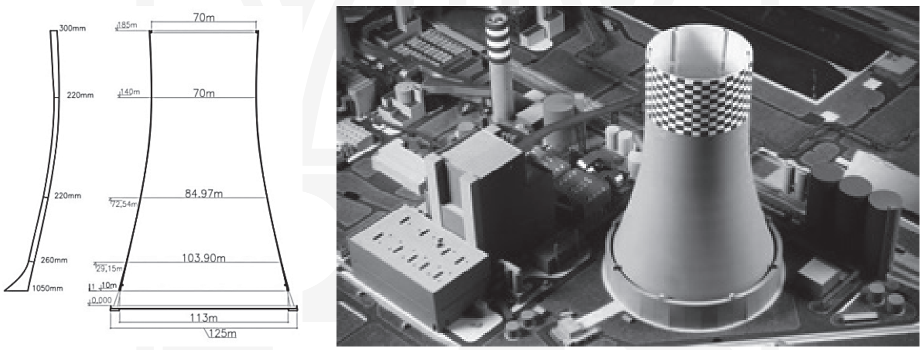


Fig. 1. Dimensions of the cooling tower (left), model of a new power plant unit in Kozienice (right)

Buildings located in a distance of 400 m from the cooling tower were taken into consideration. The second highest object in the area is a steam generator building with a height of 107 meter and it is situated 124 meters from the center of the tower. Surrounding consists of 20 different types of structures (see Table 1).

The scale of models is 1:400. It is equivalent to 46.3 cm height for the tower and 25 cm for steam generator building.

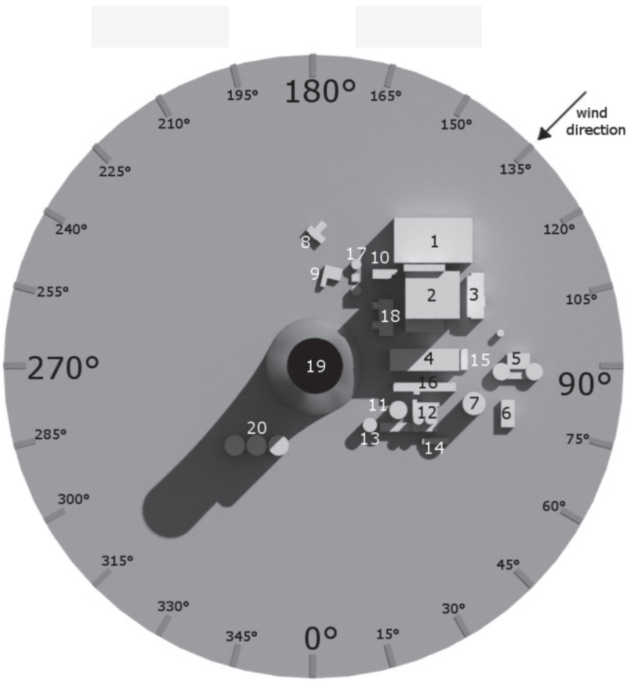
1.2. Measuring points

To achieve the assumed level of accuracy and due to limited number of measuring sensors available in the wind tunnel, the measuring points were located on 4 meridians of the cooling tower (0°, 90°, 180°, 270°). There are 13 sensors on each meridian located along its length. Willed total number of points is 312 (24 meridians). Taking advantages of the fact that geometry of the cooling tower is rotationally symmetrical, it is possible to rotate the cooling tower to reach the desired number of points. Due to, the predicted lower variability of internal pressure, the measuring points located on internal surface of the cooling tower are spaced more rarely. The total number of internal measuring points is equal to 65.

Table 1

List of surrounding objects with location from center of the cooling tower [1]

#	Height [m]	Distance [m]
1	42.6	165
2	107	124
3	22.9	201
4	29.25	96
5	14.65	230
6	10	242
7	57.45	194
8	9.15	156
9	7	100
10	38.77	134
11	37.7	108
12	33.6	107
13	23.4	93
14	7.8	163
15	7.6	187
16	20	105
17	11.4	103
18	60	97
19	185	–
20	66.6	95



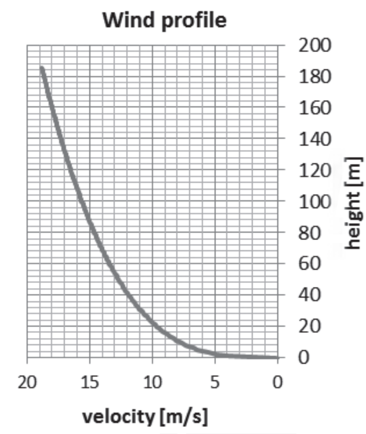
1.3. Wind tunnel properties

Reynolds number is a dimensionless quantity that is used to help predict similar flow patterns in different fluid flow situations. For the model of the cooling tower the value of Reynolds number for $u = V_{ref} = 18.8$ m/s lies between $2.2 \cdot 10^5$ and $3.76 \cdot 10^5$ (for the smallest and the biggest diameter). As a result, the critical and supercritical regime $R_e \in (10^5; 3.5 \cdot 10^5)$ is achieved for the small and medium velocity of flow. In this range, the flow in front of the tower is unsettled, turbulent, vertical and asymmetrical. The number and size of vortexes behind the tower is random and unpredictable. For the real structure of the cooling tower the R_e value is between $8.8\cdot10^7$ and $1.5\cdot10^8$ which gives transcritical regime. Taking into account that the purpose of the studies was to look into the changes of the wind pressure acting on cooling tower in case of aerodynamic interference, this kind of simplification is possible, because precise values of wind pressure are not the most important but the changes of those [2, 3].

All of the wind tunnel properties such as: configuration of adjustable ceiling, ejection of floor blocks, RPM of the fan, type of circulation, settings of barrier and spires had been optimized for the size of the model, its scale, external shape, roughness of the terrain and type of performance. Experience gained during previous studies executed at Cracow University of Technology wind tunnel, was taken into consideration during adjustment of wind tunnel properties.

Table 2

Vertical wind profile and wind tunnel properties

	Reference velocity	$V_{ref} = 18.8 \frac{m}{s}$
	Reference pressure	$q_{ref} = 220$ Pa
	Intensity of wind turbulence	$I_v = 20\%$
	Kinematic viscosity of air	$\mu = 10 \cdot 10^{-6}$

1.4. Execution of results

The first part of the experiment was focused on measuring the wind pressure acting on cooling tower without any influence of facilities located in the neighborhood of the tower. This situation is called single.

The second part of the experiment measured the change of wind pressure acting on the cooling tower, which was caused by the influence of power plant facilities. This part is much more complex. Occurrence of surrounding buildings significantly complicated the studies. Direction of wind is not the only one variation. Location of surrounding buildings must have been additionally taken into consideration. This part is called an interference situation. Also the wind pressure acting on internal surface of the cooling tower was measured in the third part of the experiment.

2. Results of internal pressure

2.1. Introduction

The results are submitted in matrix form, where the columns represent the meridians, and the rows represent the height. Data is arranged in such a way, that the windward meridian is always in 1st column (and 25th – which is always the copy of 1st one). 25th column is placed only to achieve visualization of symmetry of results. The 13th column always represents the leeward meridian. The change of wind direction is counterclockwise (see Table 1).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0,3	0,24	0,04	-0,23	-0,5	-0,67	-0,73	-0,67	-0,51	-0,4	-0,4	-0,33	-0,3	-0,33	-0,4	-0,4	-0,51	-0,67	-0,73	-0,67	-0,5	-0,23	0,04	0,24	0,3
2	0,36	0,29	0,03	-0,31	-0,66	-0,9	-0,97	-0,88	-0,52	-0,37	-0,39	-0,36	-0,36	-0,36	-0,39	-0,37	-0,52	-0,88	-0,97	-0,9	-0,66	-0,31	0,03	0,29	0,36
3	0,4	0,3	0	-0,4	-0,82	-1,09	-1,14	-0,91	-0,51	-0,36	-0,37	-0,35	-0,37	-0,35	-0,37	-0,36	-0,51	-0,91	-1,14	-1,09	-0,82	-0,4	0	0,3	0,4
4	0,44	0,33	-0,01	-0,47	-0,95	-1,25	-1,32	-1,05	-0,55	-0,4	-0,4	-0,38	-0,37	-0,38	-0,4	-0,4	-0,55	-1,05	-1,32	-1,25	-0,95	-0,47	-0,01	0,33	0,44
5	0,49	0,35	-0,03	-0,54	-1,07	-1,4	-1,47	-1,13	-0,59	-0,42	-0,41	-0,4	-0,39	-0,4	-0,41	-0,42	-0,59	-1,13	-1,47	-1,4	-1,07	-0,54	-0,03	0,35	0,49
6	0,55	0,39	-0,04	-0,61	-1,21	-1,56	-1,61	-1,23	-0,63	-0,45	-0,44	-0,42	-0,41	-0,42	-0,44	-0,45	-0,63	-1,23	-1,61	-1,56	-1,21	-0,61	-0,04	0,39	0,55
7	0,6	0,41	-0,08	-0,72	-1,38	-1,75	-1,78	-1,3	-0,63	-0,44	-0,43	-0,42	-0,41	-0,42	-0,43	-0,44	-0,63	-1,3	-1,78	-1,75	-1,38	-0,72	-0,08	0,41	0,6
8	0,64	0,45	-0,04	-0,7	-1,37	-1,77	-1,86	-1,43	-0,71	-0,48	-0,46	-0,45	-0,44	-0,45	-0,46	-0,48	-0,71	-1,43	-1,86	-1,77	-1,37	-0,7	-0,04	0,45	0,64
9	0,68	0,47	-0,04	-0,73	-1,43	-1,84	-1,88	-1,55	-0,8	-0,51	-0,49	-0,47	-0,48	-0,47	-0,49	-0,51	-0,8	-1,55	-1,88	-1,84	-1,43	-0,73	-0,04	0,47	0,68
10	0,71	0,54	0,05	-0,63	-1,31	-1,73	-1,87	-1,53	-0,85	-0,55	-0,52	-0,49	-0,5	-0,49	-0,52	-0,55	-0,85	-1,53	-1,87	-1,73	-1,31	-0,63	0,05	0,54	0,71
11	0,75	0,58	0,12	-0,54	-1,19	-1,6	-1,73	-1,41	-0,86	-0,62	-0,58	-0,52	-0,51	-0,52	-0,58	-0,62	-0,86	-1,41	-1,73	-1,6	-1,19	-0,54	0,12	0,58	0,75
12	0,8	0,63	0,2	-0,4	-0,98	-1,32	-1,43	-1,13	-0,85	-0,72	-0,64	-0,54	-0,5	-0,54	-0,64	-0,72	-0,85	-1,13	-1,43	-1,32	-0,98	-0,4	0,2	0,63	0,8
13	0,76	0,64	0,27	-0,25	-0,75	-1,03	-1,13	-0,97	-0,82	-0,72	-0,65	-0,54	-0,51	-0,54	-0,65	-0,72	-0,82	-0,97	-1,13	-1,03	-0,75	-0,25	0,27	0,64	0,76

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	-0,2	-0,21	-0,15	-0,16	-0,25	-0,4	-0,49	-0,49	-0,37	-0,26	-0,22	-0,19	-0,18	-0,2	-0,22	-0,3	-0,35	-0,41	-0,4	-0,36	-0,28	-0,29	-0,2	-0,2	-0,2
2	-0,2	-0,19	-0,1	-0,18	-0,32	-0,55	-0,68	-0,66	-0,42	-0,24	-0,23	-0,2	-0,2	-0,21	-0,24	-0,35	-0,43	-0,52	-0,5	-0,42	-0,26	-0,2	-0,18	-0,2	-0,2
3	-0,16	-0,14	-0,05	-0,2	-0,42	-0,71	-0,83	-0,8	-0,55	-0,24	-0,25	-0,21	-0,23	-0,23	-0,27	-0,38	-0,51	-0,61	-0,57	-0,46	-0,27	-0,19	-0,15	-0,16	-0,16
4	-0,1	-0,08	-0,03	-0,15	-0,42	-0,73	-0,91	-0,89	-0,59	-0,27	-0,27	-0,24	-0,25	-0,26	-0,31	-0,43	-0,62	-0,77	-0,73	-0,58	-0,34	-0,21	-0,11	-0,1	-0,1
5	0	-0,01	-0,01	-0,15	-0,51	-0,85	-1,07	-1,03	-0,72	-0,39	-0,32	-0,32	-0,31	-0,36	-0,36	-0,47	-0,72	-0,96	-0,95	-0,78	-0,45	-0,22	-0,05	0,01	0
6	0,15	0,12	0,07	0	-0,61	-1,02	-1,29	-1,22	-0,83	-0,44	-0,39	-0,36	-0,35	-0,38	-0,42	-0,5	-0,79	-1,16	-1,21	-1,04	-0,64	-0,29	0,01	0,14	0,15
7	0,31	0,27	0,11	-0,15	-0,78	-1,23	-1,48	-1,39	-0,91	-0,51	-0,43	-0,43	-0,4	-0,45	-0,44	-0,5	-0,81	-1,35	-1,5	-1,36	-0,9	-0,35	0,05	0,26	0,31
8	0,44	0,37	0,1	-0,21	-0,91	-1,4	-1,66	-1,55	-0,95	-0,55	-0,47	-0,49	-0,45	-0,49	-0,46	-0,49	-0,8	-1,43	-1,65	-1,54	-1,06	-0,45	0,05	0,34	0,44
9	0,55	0,44	0,1	-0,41	-1,05	-1,56	-1,8	-1,64	-0,95	-0,54	-0,46	-0,48	-0,45	-0,48	-0,45	-0,49	-0,8	-1,44	-1,7	-1,6	-1,13	-0,54	0,04	0,41	0,55
10	0,64	0,5	0,12	-0,43	-1,08	-1,57	-1,79	-1,6	-0,95	-0,58	-0,5	-0,5	-0,48	-0,5	-0,48	-0,52	-0,78	-1,36	-1,61	-1,52	-1,07	-0,55	0,06	0,47	0,64
11	0,7	0,55	0,15	-0,36	-1	-1,46	-1,65	-1,48	-0,93	-0,64	-0,58	-0,53	-0,5	-0,52	-0,55	-0,6	-0,78	-1,28	-1,52	-1,45	-1,01	-0,45	0,14	0,54	0,7
12	0,78	0,65	0,26	-0,26	-0,8	-1,21	-1,34	-1,13	-0,79	-0,7	-0,65	-0,55	-0,49	-0,54	-0,6	-0,67	-0,74	-1	-1,24	-1,22	-0,85	-0,37	0,21	0,62	0,78
13	0,77	0,64	0,3	-0,15	-0,64	-0,99	-1,1	-0,98	-0,79	-0,72	-0,64	-0,55	-0,49	-0,55	-0,6	-0,68	-0,73	-0,91	-1,06	-1,02	-0,7	-0,24	0,28	0,63	0,77

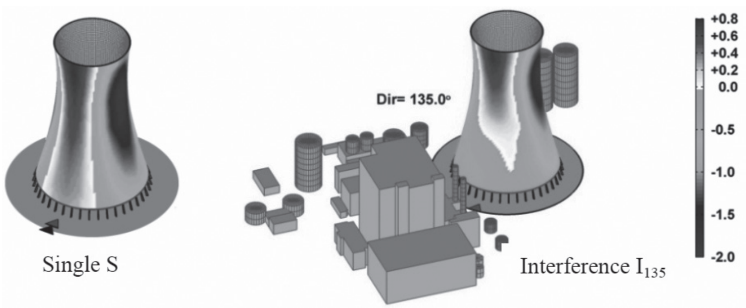
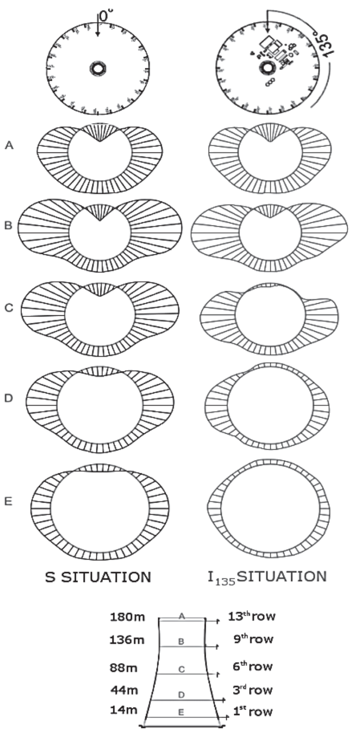
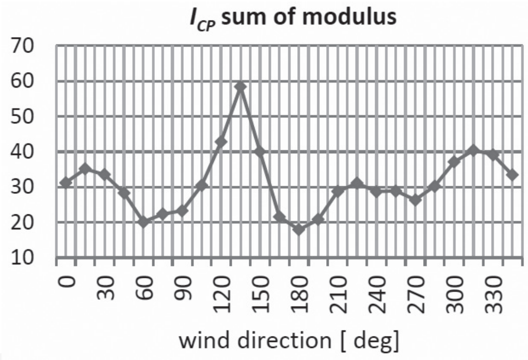


Fig. 2. Results of external pressure coefficient C_{Pe} for single situation S (above) and interference situation I_{135} (below)

a)



b)



$$I_{Cp} = C_{Pe}(\mathrm{S}) - C_{Pe}(\mathrm{I}_{135}) \qquad (1)$$

c)

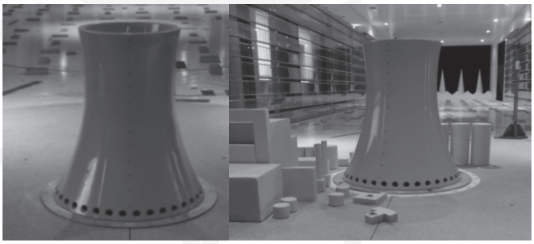


Fig. 3. a) Distribution of external pressure coefficient C_{Pe} in cross sections; b) Diagram of sum of modulus; c) Pictures of cooling tower in wind tunnel

The numeration of meridians is also counterclockwise. The following data show the C_{Pe}^{I} (interferences situation) and C_{Pe}^{S} (single situation) coefficients (according to EC1-4). The coefficients are not the values of the pressure on the surface; they only show the distribution of the pressure.

Due to the amount of data, only the single situation S (wind acting one the cooling tower without surroundings) and Interference situation I_{135} (wind acting on the cooling tower with surroundings from the angle 135°; see Table 1) are presented.

2.2. Comparison between single S and interference I_{135} situation

In single situation the distribution of pressure is line-symmetric with respect to 13th meridian. In the area starting from meridian 4th up to 22nd only negative wind pressure appears with maximum values reached for the sides of tower. The biggest values of positive pressure are located on the 1st windward meridian, near the top of the tower.

When it comes to the I_{135} situation, significant changes in comparision to the single situation are visble. The most observable phenomen is a change of sign from positive to negative pressure. It results in occurance of negative pressure on the whole lower part of circumference otower.

2.3. Conclusions

The main aim of the issue was concerned with interference of wind load acting on a surface of the cooling tower. Disorder of distribution of pressure was affected by power plant facilities located in the surroundings of cooling tower. The greatest differences are related with angle 135°, at which the structure of the tower is obstructed by adjacent power generator building. Detailed results are released in [1] written by the same authors.

References

[1] Starowicz K., Milewski T., *Wind Action on cooling tower surface in terms of aerodynamic interference*, master's thesis, Cracow University of Technology, 2014.
[2] Flaga A., *Inżynieria wiatrowa, podstawy i zastosowania*, Arkady, Warszawa 2008.
[3] Kramer C., *Advances in wind engineering*, Elsevier Publishers, Amsterdam 1988.
[4] Mungan I., Wittek U., *Natural Draught Cooling Tower*, Taylor & Francis Group, London 2004.
[5] Ledwon J., Golczyk M., *Chlodnie Wiatrowe i Wentylatorowe*, Arkady, Warszawa 1967.