Vol. 13, 2024, 237-245

DOI: 10.17512/bozpe.2024.13.24

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

The influence of aerodynamic effects on the supporting structure of high-rise buildings depending on their cross-sectional shape

Roman Gąćkowski[1]* (*orcid id: 0000-0002-4456-3011*)
Yvan Verbakel[2]
[1] Czestochowa University of Technology, Poland
[2] KU Leuven University, Belgium

Abstract: The influence of aerodynamic influences on the load-bearing structure of RC elements: columns, slabs and beams in high-rise buildings, is an important issue during the design of modern buildings, especially in the context of rapid urban development. Using the example of seven models of cross-sections of a building with a height of 75 meters, a detailed analysis of the work of eight selected reinforced concrete columns located in the central part of the building, was carried out. The analysed building models differed in the shape of the cross-sections. Static calculations with aerodynamic simulation were performed in Autodesk Robot Structural Analysis Professional 2024. Based on these, the final results of the selected one corner reinforced concrete column are presented, giving the maximum and minimum values of axial forces and displacements of the column axis over its entire height on the diagrams.

Keywords: high-rise buildings, wind load, aerodynamic simulations

Please, quote this article as follows:

Gąćkowski R., Verbakel Y., The influence of aerodynamic effects on the supporting structure of high-rise buildings depending on their cross-sectional shape, Construction of Optimized Energy Potential (CoOEP), Vol. 13, 2024, 237-245, DOI: 10.17512/bozpe.2024.13.24

Introduction

In general, high-rise buildings require highly qualified engineers, architects, constructors and engineers for various installations in the building. Advances in science and technology have made it possible to design taller and taller buildings around the world. In 1884-1885, the first tall Home Insurance Building was built in Chicago,

---

* Corresponding author: roman.gackowski@pcz.pl

designed by William LeBaron Jenney, which had eleven aboveground floors. The building was demolished in 1931, and in the years 1890-1994, the fourteen-storey Reliance Building, designed by Daniel Burnham, was also built in Chicago. Currently, the Burnham Hotel is located on the site. The beginning of the 20th century saw the designs of buildings over 300 meters high, an example of which was the first Chrysler Building skyscraper built in New York using a reinforced concrete frame structure with load-bearing elements in the form of columns, transoms, internal walls and bracing. The total height of the building is 318.9 m and it has 77 above-ground storeys. In 1931, the construction of the famous Empire State Building, a skyscraper with a total height of 443.2 m, began. The end of the 20th and the beginning of the 21st century saw the heyday of the construction of architecturally significant skyscrapers. Currently, the tallest building in the world is the Burj Khalifa located in Dubai, United Arab Emirates, measuring 827.9 meters high and has 163 floors. In Kuala Lumpur, Malaysia, there is the Merdeka building 118 rising 678.9 meters and containing 118 floors. In Shanghai, China, you can find the world's third tallest building, the Shanghai Tower, which is 632 meters high and has 128 floors (Gwozdowski et al., 2013). In total, there are 190 buildings in the world with a height of more than 250 meters (Gąćkowski, 2021; Pietrzak, 2015).

1. Characteristics of high-rise buildings

In Europe, buildings are classified as tall if their height is between 90 and 100 meters, while in the United States of America, only a building between 100 and 120 meters is considered high. The ratio of height to width of such a building should be between 4:1 and 7:1. In Poland, in accordance with (Dz.U. 2002) Section I, §8, the division of buildings into high-rise groups has been introduced:

- **N** – low-rise buildings, the height of which is up to 12 m (4 storeys above ground),
- **SW** – medium-high buildings, the height of which is from 12 to 25 m (from 4 to 9 storeys),
- **W** – high-rise buildings, the height of which ranges from 25 to 55 m (from 9 to 18 storeys),
- **WW** – high-rise buildings with a height of over 55 m (over 18 storeys).

In the article, the author adopted models of high-rise buildings in which the total height is 75 meters (25 storeys above ground). When considering the load-bearing structure of high-rise buildings, a division can be made into structural systems used in high-rise buildings. At the design stage, the selection of the right construction system is very important. The higher the structure, the more advanced the construction system (Miari & Jankowski, 2022). In general, there are a few basic systems that are used in practice (Rębielak, 2012). These include:

- **A frame system** in which the main load-bearing elements are flat or spatial frames are connected to each other in a monolithic manner, which ensures rigidity at the nodes of these frames e.g. Bankers Trust Building, New York. Such a system is used in buildings up to 30 storeys. By using lattices in this system, buildings up to 60 storeys can be made.

- **A shaft system** in which the loads are mostly transferred through a centrally located shaft. The core also has a communication and installation function throughout the building. There are two types of shaft system: hanger e.g. Commercial Union Tower in London and cantilevered e.g. Ponte City Apartments Johannesburg. The hanging shaft system is characterized by the construction of a supporting structure attached to the shaft, which is where the tendons supporting the ceiling structure of the building are attached (Cała, 2021). On the other hand, the cantilevered stem system is characterized by the fact that the cantilevered structure supporting the ceilings and columns of the building rests on the shaft (Pawłowski, 1976; Pawłowski & Cała, 2013). The use of these types of systems in buildings allows the construction of a facility up to 45 storeys. In buildings with a core and frame system, buildings up to 60 storeys can be constructed.
- **A shaft-skeleton system**, in which the core and skeleton of the structure, consisting of mullions and transoms, cooperate with each other (Stefańska & Załuski, 2017). The reinforced concrete core of the building carries all the horizontal forces created by the aerodynamic action, while the columns carry the vertical loads e.g. HSB Turning Torso building in Malmö (Pawłowski, 2013).
- **A stem-to-stem system** provides a transitional solution between core and shell construction e.g. Central Plaza building, Hong Kong. High-rise buildings in which such a system is used can reach a height of 180 to 300 meters (up to 90 storeys).
- **A shell system** that is characterized by the main load-bearing structure in the form of an external shell, consisting of a dense network of columns monolithically connected to transoms e.g. building of Commercial Bank and Foreign Travel Headquarters, Warsaw. This type of system, used in the building, allows it to reach a height of over 300 meters (from 60 to 100 storeys).
- **Megastructures** are structures consisting of several shells on a modular grid, with a high level of rigidity e.g. Willis Tower building, Chicago (Youssef, 1991). The megastructures do not have internal shafts and the height of the buildings can reach over 400 meters (120 storeys).
- **A system of megacolumns**, which consists of a massive shaft and cooperating megacolumns, located on the external outline of the building e.g. Taipei 101 building, Taiwan. Megacolumns are steel boxes filled with reinforced concrete. The height of such buildings significantly exceeds 400 meters (over 120 storeys).
- **Unconventional systems** are systems that cannot be classified into any of the systems discussed above.

2. General characteristics of a high-rise building

The paper presents the results of the selected S-1 column located in the internal core of the building, in seven models of a high-rise building with different shapes of cross-section (Fig. 1). The height of the building is 75 meters. A core and skeleton system with 25 aboveground storeys was used (Padewska et al., 2015). To carry out a detailed analysis under the influence of wind aerodynamic forces, the author of the article differentiated the cross-section of the entire building to provide different side surfaces of the building (Ali & Moon, 2007). The main load-bearing elements of the building were 80 cm × 80 cm columns adopted over the entire height of the building and a 20 cm thick monolithic reinforced concrete floor slab connected to the columns (Kowalczyk et al., 1995).

The shaft is made of reinforced concrete walls with a thickness of 25 cm. Concrete class C30/37 and reinforcing steel class "C" B500SP EPSTAL were used throughout the building. The exposure class was XC4. The building is set on a 40 cm thick reinforced concrete slab foundation, made of C30/37 concrete from class "C" B500SP EPSTAL steel.

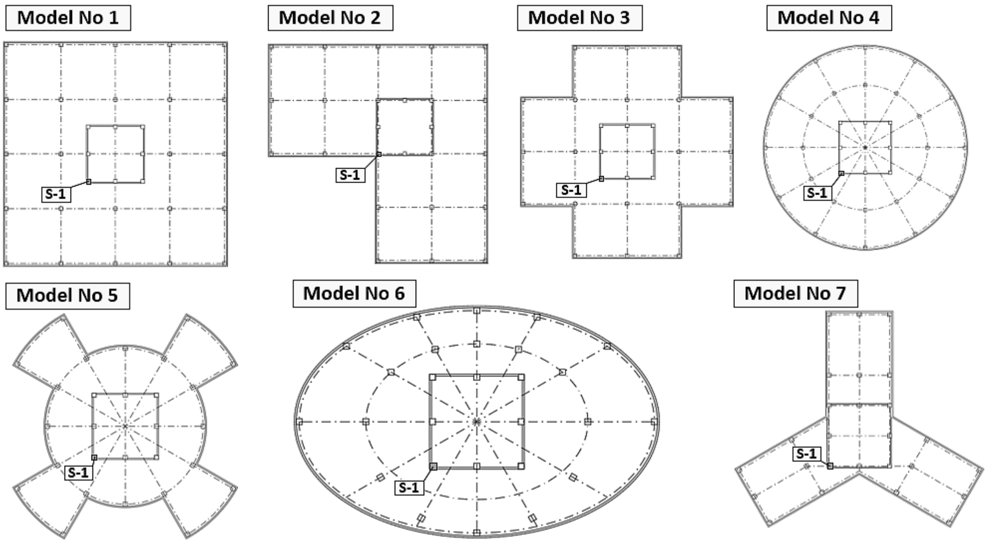


Fig. 1. Cross-sections of a high-rise building with the use of various cross-section models. The reinforced concrete internal core of the building with columns is marked. The S-1 column is distinguished, the detailed analysis of which is presented in the article (*own research*)

3. Structural analysis of a high-rise building

The article analyses seven models of buildings with different cross-sections (Fig. 1). 3D numerical models were made of each building using the Autodesk Robot Structural Analysis Professional 2024 calculation program and on this basis an analysis was carried out due to the ultimate and serviceability limit states of load-bearing elements, i.e. columns, floor slabs and walls of the internal core of the building (Fig. 2) (Rychter, 2013). For example, a corner column of the internal core of the building was selected and the results of the analysis were presented, taking into account the aerodynamic actions in all wind directions (Paruch, 2016). The maximum wind speed was 22 m/s (PN-EN 1991-1-4:2008).

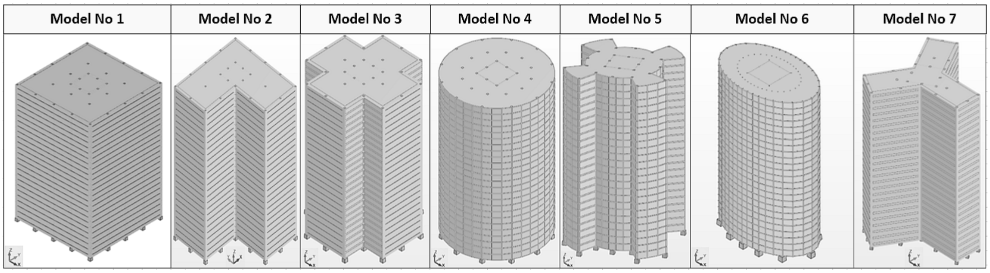


Fig. 2. Computational models of a 25-storey building and a height of 75 meters and various cross-sections (*own research*)

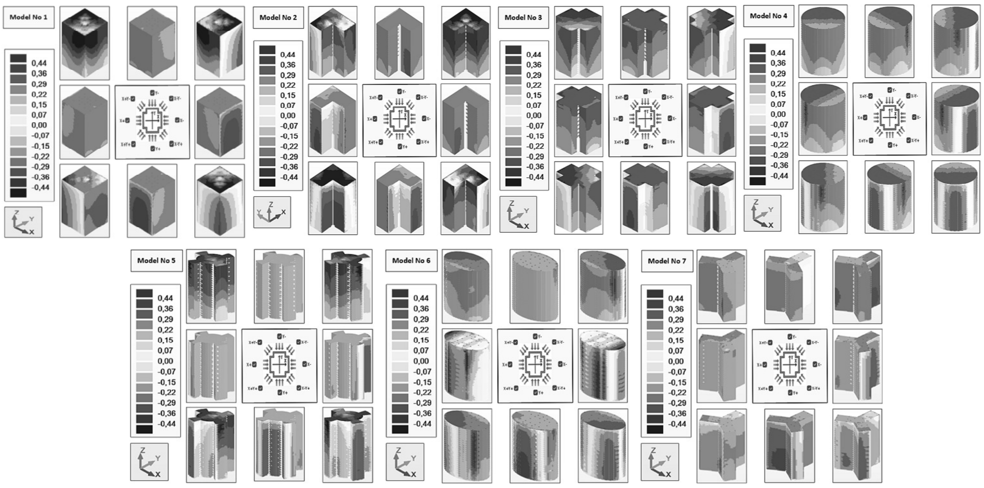


Fig. 3. Computational models of a 25-storey building and a height of 75 meters and various cross-sections (PN-EN 1991-1-4:2008)

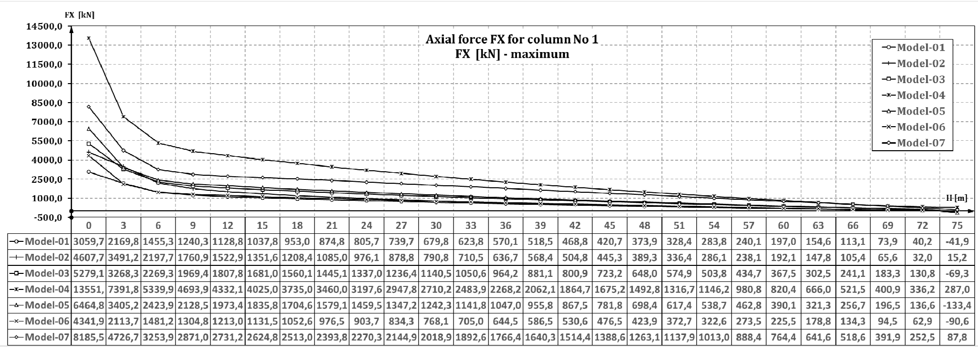
In the static calculations in the numerical models, the following was assumed: permanent structural load (generated automatically by the program); non-structural permanent load (weight of non-structural layers of the ceiling of 3.0 kN/m^2); live load according to Eurokode 1 (PN-EN 1990:2004) assuming use category C1, for which the load value is assumed to be 3.0 kN/m^2; aerodynamic load from wind in all directions; load from shrinkage and creep of concrete, assuming appropriate coefficients in accordance with Eurocode 2 (PN-EN 1992-1-1:2008; Rawska-Skotniczy, 2014); foundation conditions and a subsoil operation model due to the low height of the analysed building (75 meters for the above-ground part). The building was erected directly on a 40 cm thick reinforced concrete foundation slab (Taranath, 1988).

A homogeneous subsoil was assumed and classified as medium sand with $I_D = 0.70$. The presence of the groundwater table was omitted. The foundation slab was modelled as an element on an elastic foundation. The columns and walls of the building were connected to the foundation slab in a monolithic manner. The foundation level of the foundation slab was taken to be at a depth of 1.5 m. The elastic coefficient K_z was taken as 3800.0 kN/m^3 (PN-EN 1997-1:2008). A detailed aerodynamic analysis of wind load and the aerodynamic analysis of wind impact on the structure of individual digital models of the buildings was performed in the Autodesk Robot Structural Analysis Professional 2024 calculation program. The program generated eight wind load variants for each direction. These variants were included in the load combinations in the static design when calculating the ultimate and serviceability limit states. Figure 3 presents the results of the wind impact on the external walls of the building (wind pressure map) depending on the cross-section of the building and the direction of wind action (Lipiecki, 2013).

4. Strength analysis of the structure of a high-rise building

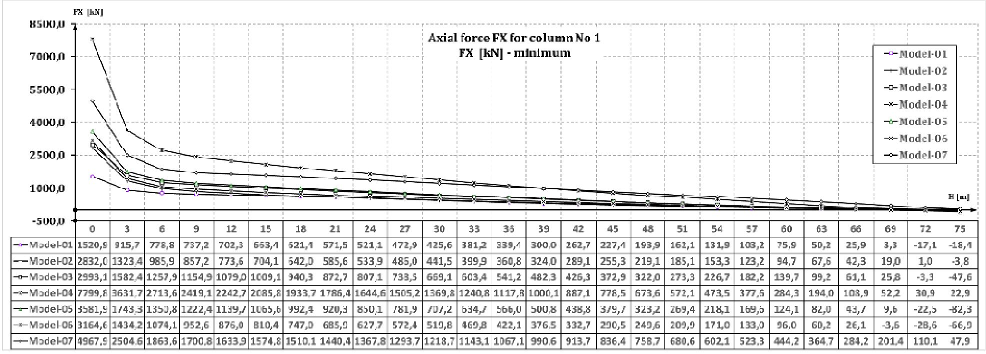
The results of the analysis of the selected S-01 column (Figs. 1, 3) are presented graphically using the diagrams of the axial force envelope FX in the S-01 column and the displacement of the column core on each storey of a given building model (Kapela & Sieczkowski, 2003; Khan, 1996; Wdowicki & Wdowicka, 2000).

The building models have been created in Autodesk Robot Structural Analysis Professional 2024 as shell models with column member elements. The shell elements are the external walls and ceilings of the building and the internal walls of the central core. The analysis of the building structure was carried out for seven variants (Figs. 1, 3). In the analysis, the axial forces FX in the separated S-1 column in the building core and the total resultant displacement in the X-Y plane of the columns on each storey were compared (the height of each storey was assumed to be 3.0 meters). The results of the analysis are presented graphically in Figures 4-6. Based on the values of the axial forces FX, it is possible to estimate the optimal cross-section of the columns at the individual levels (Rokicki et al., 2017). The models initially assumed the same cross-section of the columns equal to 80 cm × 80 cm. By determining the displacement of the column core on the top floor, it is possible to assume the optimal arrangement for bracing of internal walls in the building. The permissible displacement of elements in high-rise buildings from (Gąćkowski, 2021) is H/500, for which the analyzed object is u = 75000/500 = 150 mm.



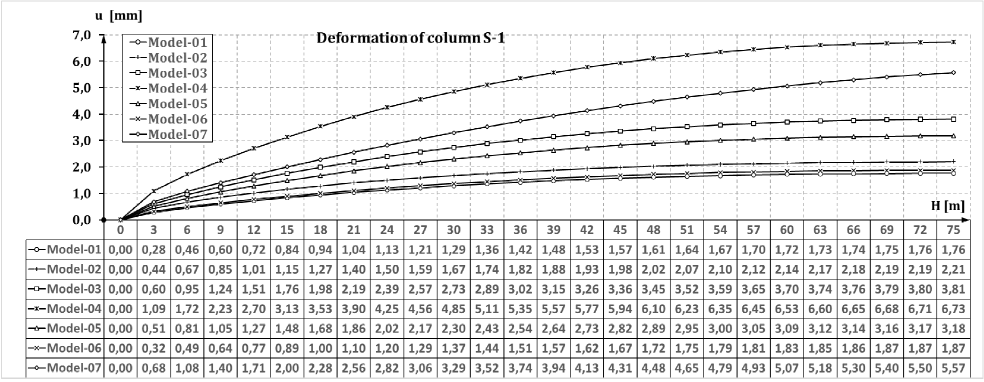
	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75
Model-01	3059,7	2169,8	1455,3	1240,3	1128,8	1037,8	953,0	874,8	805,7	739,7	679,8	623,8	570,1	518,5	468,8	420,7	373,9	328,4	283,8	240,1	197,0	154,6	113,1	73,9	40,2	-41,9
Model-02	4607,7	3491,2	2197,7	1760,9	1522,9	1351,6	1208,4	1085,0	976,1	878,8	790,8	710,5	636,7	568,4	504,8	445,3	389,3	336,4	286,1	238,1	192,1	147,8	105,4	65,6	32,0	15,2
Model-03	5279,1	3268,3	2269,3	1969,4	1807,8	1681,0	1560,1	1445,1	1337,0	1236,4	1140,5	1050,6	964,2	881,1	800,9	723,2	648,0	574,9	503,8	434,7	367,5	302,5	241,1	183,3	130,8	-69,3
Model-04	13551,	7391,8	5339,9	4693,9	4332,1	4025,0	3735,0	3460,0	3197,6	2947,8	2710,2	2483,9	2268,2	2062,1	1864,7	1675,2	1492,8	1316,7	1146,2	980,8	820,4	666,0	521,5	400,9	336,2	287,0
Model-05	6464,8	3405,2	2423,9	2128,5	1973,4	1835,8	1704,6	1579,1	1459,5	1347,2	1242,3	1141,8	1047,0	955,8	867,5	781,8	698,4	617,4	538,7	462,8	390,1	321,3	256,7	196,5	136,6	-133,4
Model-06	4341,9	2113,7	1481,2	1304,8	1213,0	1131,5	1052,6	976,5	903,7	834,3	768,1	705,0	644,5	586,5	530,6	476,5	423,9	372,7	322,6	273,5	225,5	178,8	134,3	94,5	62,9	-90,6
Model-07	8185,5	4726,7	3253,9	2871,0	2731,2	2624,8	2513,0	2393,8	2270,3	2144,9	2018,9	1892,6	1766,4	1640,3	1514,4	1388,6	1263,1	1137,9	1013,0	888,4	764,4	641,6	518,6	391,9	252,5	87,8

Fig. 4. Values of maximum axial forces FX max in [kN] for all calculation models of buildings with different cross-sections (PN-EN 1990:2004)



	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75
Model-01	1520,9	915,7	778,8	737,2	702,3	663,4	621,4	571,5	521,1	472,9	425,6	381,2	339,4	300,0	262,7	227,4	193,9	162,1	131,9	103,2	75,9	50,2	25,9	3,3	-17,1	-18,4
Model-02	2832,0	1323,4	985,9	857,2	773,6	704,1	642,0	585,6	533,9	485,0	441,5	399,9	360,8	324,0	289,1	255,3	219,1	185,1	153,3	123,2	94,7	67,6	42,3	19,0	1,0	-3,8
Model-03	2993,1	1582,4	1257,9	1154,9	1079,0	1009,1	940,3	872,7	807,1	733,5	669,1	603,4	541,2	482,3	426,3	372,9	322,0	273,3	226,7	182,2	139,7	99,2	61,1	25,8	-3,3	-47,6
Model-04	7799,8	3631,7	2713,6	2419,1	2242,7	2085,8	1933,7	1786,4	1644,6	1505,2	1369,8	1240,8	1117,8	1000,1	887,1	778,5	673,6	572,1	473,5	377,5	284,3	194,0	103,9	52,2	30,9	22,9
Model-05	3581,9	1743,3	1350,8	1222,4	1139,7	1065,6	992,4	920,3	850,1	781,9	707,2	634,7	566,0	500,8	438,8	379,7	323,2	269,4	218,1	169,5	124,1	82,0	43,7	9,6	-22,5	-82,3
Model-06	3164,6	1434,2	1074,1	952,6	876,0	810,4	747,0	685,9	627,7	572,4	519,8	469,8	422,1	376,5	332,7	290,5	249,6	209,9	171,0	133,0	96,0	60,2	26,1	-3,6	-28,6	-66,9
Model-07	4967,9	2504,6	1863,6	1700,8	1633,9	1574,8	1510,1	1440,4	1367,8	1293,7	1218,7	1143,1	1067,1	990,6	913,7	836,4	758,7	680,6	602,1	523,3	444,2	364,7	284,2	201,4	110,1	47,9

Fig. 5. Values of minimum axial forces FX min in [kN] for all calculation models of buildings with different cross-sections (PN-EN 1990:2004)



	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75
Model-01	0,00	0,28	0,46	0,60	0,72	0,84	0,94	1,04	1,13	1,21	1,29	1,36	1,42	1,48	1,53	1,57	1,61	1,64	1,67	1,70	1,72	1,73	1,74	1,75	1,76	1,76
Model-02	0,00	0,44	0,67	0,85	1,01	1,15	1,27	1,40	1,50	1,59	1,67	1,74	1,82	1,88	1,93	1,98	2,02	2,07	2,10	2,12	2,14	2,17	2,18	2,19	2,19	2,21
Model-03	0,00	0,60	0,95	1,24	1,51	1,76	1,98	2,19	2,39	2,57	2,73	2,89	3,02	3,15	3,26	3,36	3,45	3,52	3,59	3,65	3,70	3,74	3,76	3,79	3,80	3,81
Model-04	0,00	1,09	1,72	2,23	2,70	3,13	3,53	3,90	4,25	4,56	4,85	5,11	5,35	5,57	5,77	5,94	6,10	6,23	6,35	6,45	6,53	6,60	6,65	6,68	6,71	6,73
Model-05	0,00	0,51	0,81	1,05	1,27	1,48	1,68	1,86	2,02	2,17	2,30	2,43	2,54	2,64	2,73	2,82	2,89	2,95	3,00	3,05	3,09	3,12	3,14	3,16	3,17	3,18
Model-06	0,00	0,32	0,49	0,64	0,77	0,89	1,00	1,10	1,20	1,29	1,37	1,44	1,51	1,57	1,62	1,67	1,72	1,75	1,79	1,81	1,83	1,85	1,86	1,87	1,87	1,87
Model-07	0,00	0,68	1,08	1,40	1,71	2,00	2,28	2,56	2,82	3,06	3,29	3,52	3,74	3,94	4,13	4,31	4,48	4,65	4,79	4,93	5,07	5,18	5,30	5,40	5,50	5,57

Fig. 6. Values of displacements u in [mm] axis of the S-1 column on each storey for all calculation models of buildings with different cross-sections (PN-EN 1990:2004)

5. Conclusions

The analysis of buildings with different cross-sections in terms of the operation of compression elements, taking into account a detailed aerodynamic simulation in all directions of wind action, showed that the share of individual columns in the operation of the entire building is dominant especially if the columns occur on the perimeter of the internal structure of the building's internal shaft, which was made of reinforced concrete walls with a thickness of 25 cm from concrete class C30/37 and reinforced with "C" class steel B500SP EPSTAL. Assuming a column cross-section of 80 cm × 80 cm over the entire height of the building structure, it can be seen that the largest displacement of the column core on the top floor occurs for model 4 with a circular cross-section, and the smallest displacement for model 1 with a square cross-section. Due to the back-and-frame system of the building structure adopted in the calculations (most often used in high-rise buildings), the displacements in all models are lower than permissible. This is the result of the use of external RC walls, RC internal core and RC columns monolithically connected with slab elements in the construction of buildings (Górski et al., 2015). The problem with excessive displacement of column elements on the top floor occurs in buildings over 300 meters. Such analyses have already been carried out by the author of the article and published in (Gąćkowski, 2021). An important element in the operation of the entire structure of high-rise buildings is the presence of internal walls, which constitute the concentration of the entire building (Wdowicki & Wdowicka, 2013). In the absence of internal walls, as is assumed in numerical models, the value of axial forces in columns almost doubles for buildings over 300 meters, while in buildings with a height of 75 meters, the force in columns increases to about 20 %. The optimal solution due to the cross-section of the building is model No. 1, No. 2 and No. 6 due to the low values of displacements of the column core on the top floor and due to the low values of axial forces compared to other models.

Bibliography

Ali, M.M. & Moon, K.S. (2007) Structural developments in tall buildings: Current trends and future prospects. *Architectural Science Review*, 50.

Cała, I. (2021) Budynki wysokie o kondygnacjach podwieszonych. *Materiały Budowlane*, 12, 43-46.

Gąćkowski, R. (2021) The influence of wind on the work of the structure of columnar elements in reinforced concrete tall buildings. *Scientific Journals of the Czestochowa University of Technology. Building*, 27, 51-57.

Gwozdowski, B., Wdowicki, J. & Błaszczyński, T. (2013) Budynek wysoki Shanghai World Financial Center (SWFC) – konstrukcja i analiza obliczeniowa. *Inżynieria i Budownictwo*, 10, 521-529.

Górski, M., Kozłowski, A., Kozłowski, T. & Ludera, P. (2015) Analiza układu stężającego budynku wysokościowego o konstrukcji betonowej. *Journal of Civil Engineering, Environment and Architecture*, XXXII, 62, 105-117. DOI: 10.7862/rb.2015.143.

Kapela, M. & Sieczkowski, J. (2003) *Projektowanie konstrukcji budynków wielokondygnacyjnych*. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa.

Khan, F.R. (1996) *Optimization of Building Structures*. University of Illinois.

Kowalczyk, R.M., Sinn, R. & Kilmister, M.B. (1995) *Structural Systems for Tall Buildings*. McGaw-Hill, Inc. Singapore.

Lipiecki, T. (2013) Oddziaływanie wiatru na budynki wysokie w świetle badań własnych i ujęć normowych. *Budownictwo i Architektura*, 12(2), 143-150.

Miari, M. & Jankowski, R. (2022) Pounding between high-rise buildings with different structural arrangements. *Recent Trends in Wave Mechanics and Vibrations*, 807-816.

Padewska, A., Szczepaniak, P. & Wawrzynek, A. (2015) Oddziaływanie wiatru na obiekt o nietypowym kształcie. *Inżynieria i Budownictwo*, 7, 381-385.

Paruch, R. (2016) Oddziaływanie wiatru na budynek wysoki w aspekcie rozwoju form architektonicznych i systemów konstrukcyjnych. *Materiały z XX SKWPWiE. Mechanik*, 7, 782-783.

Pawłowski, A.Z. & Cała, I. (2013) *Budynki wysokie*. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa.

Pawłowski, A.Z. (1976) *Kształtowanie i konstruowanie wysokich budynków trzonowych*. COBPBO, Warszawa.

Pietrzak, J. (2015) Shaping and structuring of high-rise office buildings in Europe. *Challenges of Modern Technology*, 6(2), 48-56.

Rawska-Skotniczy, A. (2014) *Obciążenia budynków i konstrukcji budowlanych według eurokodów*. Wydawnictwo Naukowe PWN, Warszawa.

Rębielak, J. (2012) Koncepcja systemu konstrukcyjnego budynku wysokiego. *Inżynieria i Budownictwo*, 1. 45-50.

Rokicki, W., Pietrzak, J. & Wrona, M. (2017) Wpływ obciążeń od wiatru na budynek wysoki o nieregularnej formie – badania modelowe. *Przestrzeń, Ekonomia, Społeczeństwo*, 12/II, 179-191.

Rychter, Z. (2013) Wpływ kształtu wieżowców na jakość konstrukcji. *Architecturae et Artibus*, 2.

Stefańska, A. & Załuski, D. (2017). *High Rise Building: The Mega Sculpture Made of Steel, Concrete and Glass*. IOP Conference Series: Materials Science and Engineering, Vol. 245, 8, 1-8.

Taranath, B.S. (1988) *Structural Analysis and Design of Tall Buildings*. McGraw-Hill Book Company. New York.

Wdowicki, J. & Wdowicka, E. (2000) *Analiza konstrukcji usztywniających budynki wysokie przy wykorzystaniu modeli dyskretnych i modeli ciągłych.* V Konferencja Naukowo-Techniczna. Programy MES w komputerowym wspomaganiu analizy, projektowania i wytwarzania. 223-231

Wdowicki, J. & Wdowicka, E. (2013) *Problemy konstrukcyjne i obliczeniowe projektowania budynków wielokondygnacyjnych.* Conference: Rewitalizacja Obszarów Zurbanizowanych. 51-60

Youssef, N. (1991) *Megastructure: A New Concept For Structural Buildings. Modern Steel Construction*. USA.

Autodesk Robot Structural Analysis 2024 – wersja edukacyjna.

Dz.U. 2002, nr 75, poz. 690, Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 *w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie*.

PN-EN 1990:2004 *Podstawy projektowania konstrukcji.*

PN-EN 1991-1-1:2004. *Eurokod 1: Oddziaływania na konstrukcje. Część 1-1: Oddziaływania ogólne. Ciężar objętościowy, ciężar własny, obciążenia użytkowe w budynkach.*

PN-EN 1991-1-4:2008 *Oddziaływania na konstrukcje. Część 1-4: Oddziaływanie ogólne – oddziaływania wiatru.*

PN-EN 1992-1-1:2008 *Projektowanie konstrukcji z betonu. Część 1-1: Reguły ogólne i reguły dla budynków.*

PN-EN 1997-1:2008 *Projektowanie geotechniczne. Część 1-1: Zasady ogólne.*