Centrum Rzeczoznawstwa Budowlanego

Inżynieria Bezpieczeństwa Obiektów Antropogenicznych 3 (2022) 42-47
https://inzynieriabezpieczenstwa.com.pl/

Inżynieria Bezpieczeństwa Obiektów Antropogenicznych

Modeling of a tall building

Sandra MLONEK*

University of Technology, Faculty of Civil Engineering and Environmental Sciences, Białystok, Poland

Abstract

Rapid economic, environmental changes and finite energy resources dictate the need for rational use of energy. Civil engineering is the sector responsible for the highest energy consumption. Therefore, efforts should be made to reduce the energy consumption of construction works in progress. An indispensable factor of development is the introduction of modern technologies. Contemporary architectural thought aiming at increasing the share of transparent facades may be helpful in achieving these goals. This is an important aesthetic aspect. Large panes of glass give the building a modern character, but also visually increase the space and passively allow you to acquire large amounts of heat. Despite the difficulties and costs associated with the construction and operation of high-rise buildings, they are erected more and more often, also in Poland. Modern technology and advanced calculation theory make it possible to build these structures much more economically than previous conventional systems. In this paper, I present a variant static analysis of a tall building structure with large glazing.

Keywords: mechanical connections, tall building, energy saving, circular economy, FEM.

1 Introduction

The material below will present a multivariate analysis of a tall building, which are increasingly common in urban construction. Tall buildings are intended for office space or residential homes, so the loads of use, occurring in them, are not large. Nevertheless, one of the main problems becomes their foundation - the transfer of very high loads to the ground. The foundation is usually a rigid slab or reinforced concrete box, transferring the pressures to the ground and preventing uneven settlement of the structure. The second, no less important issue is to ensure adequate rigidity of the system, securing it from the effects of horizontal loads (from wind pressure and seismic and paraseismic actions) [3,4]. This rigidity is achieved through the proper construction of the building, the use of vertical and horizontal diaphragms - shields formed by walls, shafts, pillars and ceilings. There are many original solutions for the construction of tall buildings, but monolithic skeleton with a rigid core, usually used for communication and installation routes, should be considered the most widely applied.

Despite the difficulties and costs associated with the construction and operation of tall buildings, they are being erected more and more often, including in Poland. Tall buildings have ceased to be the hallmark of opulent shopping centers, and have become a ubiquitous type of residential and office development. Due to the expansion of urban agglomerations, which reduces the amount of land for building, the demand for tall buildings has increased. It has

* **Corresponding author:** E-mail address: (s.mlonek@pb.edu.pl) Sandra MLONEK

https://dx.doi.org/10.37105/iboa.149
Received 15 September 2022
Available online 30 September 2022
ISSN 2450-1859, eISSN 2450-8721
Published by Centrum Rzeczoznawstwa Budowlanego

many advantages such as accommodating a significant number of people, a large floor space in a relatively small area [1,6].

In addition, rapid economic, environmental changes and finite energy resources impose the need for rational use of energy. Civil engineering is the sector responsible for the greatest energy consumption. Therefore, efforts should be made to reduce the energy intensity of ongoing construction work. Modern architectural thought moving in the direction of increasing the proportion of transparent facades can be helpful in achieving these goals. This is an important aesthetic aspect. Large sheets of glass give a building a modern character, but also visually enlarge the area of rooms and passively allow the acquisition of large amounts of heat. Such heat recovery is beneficial from the point of view of the energy balance. Adequate thermal protection helps us in the following aspects:

- thermal insulation of standard exterior walls,
- reduction of "thermal bridges",
- highly efficient recovery of heat from used ventilation air,
- extraction of heat from storage,
- recovery of heat penetrating through wall partitions.

High-quality thermally insulated glazing, smart walls, etc., are adapted to energy-efficient facades. To improve the insulating performance, the space between the panes is filled with a special gas: argon or krypton. Thanks to such a system, solar radiation can be let into the building and radiant heat from the walls and objects inside is stored inside the building. Consequently, the way to conventional methods of heat extraction or storage is to obtain the largest possible area of glazing on the facade. This is also desirable in terms of current architectural trends. It is impossible for buildings with typical wall construction. In such buildings, most of the facade area is occupied by walls. It can be used in frame buildings or buildings with a core structure. For this purpose, buildings are designed in which the load-bearing structure is set back to the interior of the building. However, this leads to a reduction in the rigidity of the structure. Therefore, tall buildings should have a suitable structure, and even additional reinforcements. Structural opportunities and limitations are presented in the article.

Nowadays, a number of programs are available to perform advanced numerical calculations such as calculating internal forces in structures found in engineering practice. These tools, combined with the efficiency of modern computer hardware, make it possible to obtain all the necessary parameters for dimensioning structural elements in a very short time. An additional advantage lies in the possibility of a real representation of the analyzed structure without the need for simplifications, as well as saving the time needed to spend hours solving a series of complex equations and systems of mathematical equations. The problem, however, lies in the correct formulation of the calculation model, since even the slightest modification can result in completely different outcomes [8].

2 Description of the building under analysis

The analyzed building is a 26-story tall object (91m high), designed in monolithic technology with a mixed slab-and-column structure with a shaft. There are six apartments on each of the nine floors of the residential part. The building also has five floors of service and office use, with the first floor being a basement located under the entire structure. In the central part of the building there is a shaft with a wall thickness of 30cm, which performs the communicative function. The building is finished with a green, flat roof, which is to provide a viewing terrace. A 40cm x 55cm rectangular edge beam has been placed around the perimeter of each floor as working in a continuous system. The floor slabs were designed as monolithic plates with a thickness of 20cm based on columns with a square cross-section of 60cm x 60cm. The thickness of the floor slab was increased to 25cm due to the higher load acting.

3 Variant analysis of the building structure

This paper will present a variant static analysis of the structure of the tall building described above (Figure 1). The calculations were carried out in Autodesk Robot Structural Analysis. The Robot program is an integrated graphical software for modeling, analysis and dimensioning of various types of structures. The program allows to model a structure, carry out static calculations of the structure, verify the results obtained, perform standard calculations of structural elements and create construction documentation [2,5].

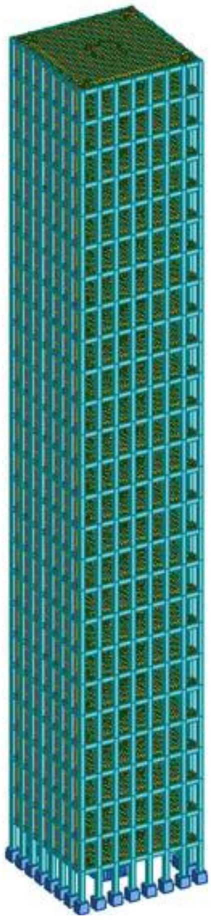

Figure 1. Numerical model of the analyzed tall building

The view of the analyzed structure of the tall building is shown in Figures 2 and 3. The following variants of building systems have been adopted:

- basic, column and shaft system (columns at the edge of the building) (Fig. 2a),
- system as before, but with the columns moved to the inside of the building

(Fig. 2b)

- system with an additional beam (Fig. 3a),
- system with trusses (Fig. 3b).

a) b)

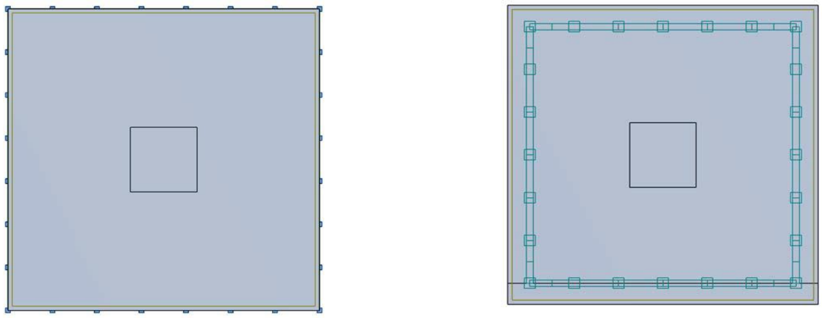

Figure 2. Horizontal cross-section of the analyzed tall building (a) shaft system with columns at the edge of the building, (b) shaft system with columns shifted by 1.0m to the inside of the building

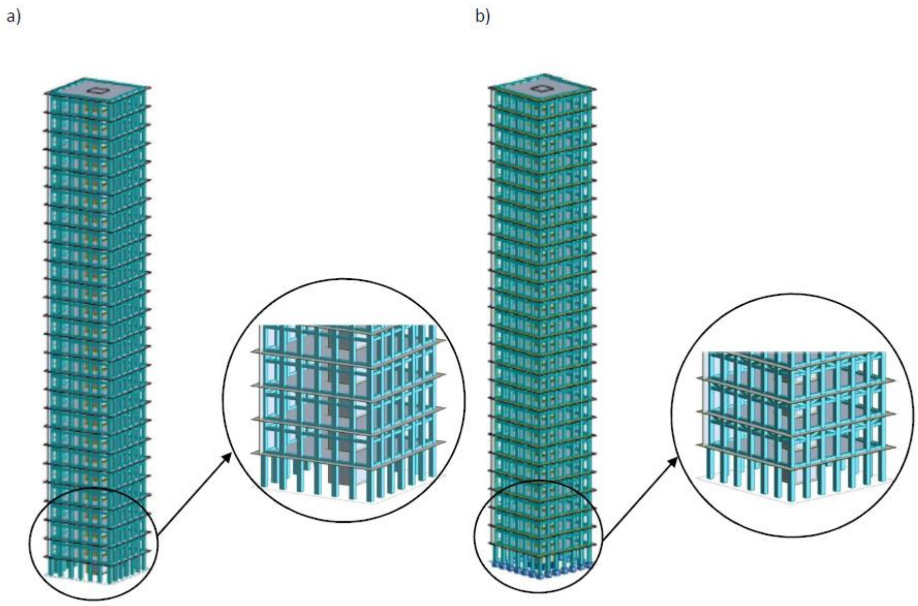

Figure 2. The structure of the analyzed tall building: a) the system with additional beams, b) the system with additional trussing.

4 Comparisons and conclusions

After static analysis, the values of horizontal displacements at the top of the building (nodes at 87 m height) were obtained. The extreme values of displacement in the direction of the x, y axis, depending on the adopted structural type of the tall building, are shown in Tables 1, 2, 3 and 4.

UX are horizontal displacements perpendicular to the direction of wind pressure; UY - horizontal displacements parallel to the direction of wind pressure. UZ - vertical displacements of selected nodes. As can be seen, according to the data presented in the tables, the highest value of horizontal displacement was obtained at node 9889, located at the top of the structure.

The permissible value of horizontal displacement for an 87-meter building was calculated based on the following formula [7]:

$$\boldsymbol{\delta_{dop} = \frac{H_{building}}{500} = \frac{91m}{500} = 18,2cm} \quad (1)$$

Table 1. Displacement values of the structural model node with shaft and columns at the edge of the building

	UX (cm)	UY (cm)	UZ (cm)	RX (Rad)	RY (Rad)	RZ (Rad)
MAX	0.0	**15.7**	0.2	0.001	0.002	0.000
Node number	87	**11989**	17253	17958	20579	18420
MIN	-0.0	0.0	-1.3	-0.002	-0.002	-0.000
Node number	37864	1	1220	3568	17965	18065

Table 2. Displacement values of the structural model node with shaft and columns shifted to the inside of the building

	UX (cm)	UY (cm)	UZ (cm)	RX (Rad)	RY (Rad)	RZ (Rad)
MAX	0.0	**18.9**	0.4	0.001	0.002	0.000
Node number	87	**11989**	17253	17958	20579	18420
MIN	-0.0	0.0	-1.8	-0.003	-0.001	-0.000
Node number	37864	1	1220	3568	17965	18065

Table 3. Displacement values of the structural model node with shaft and additional beams

	UX (cm)	UY (cm)	UZ (cm)	RX (Rad)	RY (Rad)	RZ (Rad)
MAX	0,0	**17,2**	0,4	0,001	0,001	0,000
Node number	87	**11989**	17253	17958	20579	18420
MIN	-0,0	0,0	-1,7	-0,002	-0,001	-0,000
Node number	37864	1	1220	3568	17965	18065

Table 4. Displacement values of the structural model node with shaft and trusses

	UX (cm)	UY (cm)	UZ (cm)	RX (Rad)	RY (Rad)	RZ (Rad)
MAX	0,0	**14,8**	0,3	0,001	0,001	0,000
Node number	87	**11989**	17253	17958	20579	18420
MIN	-0,0	0,0	-1,8	-0,002	-0,001	-0,000
Node number	37864	1	1220	3568	17965	18065

5 Conclusions

In the case of the first variant of the structure of the tall building, the obtained values of displacements are not greater than those permissible calculated according to Formula 1. In the second variant, in which the columns were moved to the interior of the building, higher values of horizontal displacements were obtained. This is due to a change in the moment of inertia of the entire structure. The result is an increase in the values of displacements. In order to meet the requirements of the boundary condition and maintain a large area of glazing, additional reinforcement of the structure in the form of auxiliary beams (variant 3) or trusses (variant 4) should be used. In these models, we obtained even more than 15% smaller displacements than allowed.

Comparing the results obtained, it can be concluded that the highest rigidity in the analyzed building is obtained by designing additional trusses in the upper part of each floor. Despite the lower moment of inertia due to their location in relation to the center of gravity of the floor plan, the additional small trusses increase the rigidity of the entire building. The designed centrally located shaft is an additional advantage.

References

1. Ajdukiewicz A., Starosolski W. (1981) Żelbetowe ustroje płytowo-słupowe. Warszawa, Arkady.
2. Autodesk Robot Structural Analysis 2010 (2009) Podręcznik użytkownika.
3. Baryłka A. (2021). Poradnik eksploatacji obiektów budowlanych. Warszawa, Centrum Rzeczoznawstwa Budowlanego.
4. Kapela M., Sieczkowski J. (2003) Projektowanie konstrukcji budynków wielokondygnacyjnych. Warszawa, Oficyna Wydawnicza PW.
5. Matulewicz S., Miedziałowski Cz. (2013) Modern computer methods of multivariant analysis of a tall building. Biała Podlaska, Państwowa Wyższa Szkoła im. Jana Pawła II.
6. Pawłowski A.Z., Cała I. (2006) Budynki wysokie. Warszawa, Oficyna Wydawnicza PW.
7. Rozporządzenie Ministra Infrastruktury z dnia 12 marca 2009r. w sprawie warunków technicznych jakim powinny odpowiadać budynki i ich usytuowanie. (Dz. U. nr 56, poz. 461 zmieniające Dz. U. nr 75 poz. 690 z dnia 12 kwietnia 2002r.).
8. Starosolski W. (2021) Komputerowe modelowanie betonowych ustrojów inżynierskich . Wybrane zagadnienia - tom I. Gliwice, Wydawnictwo Politechniki Śląskiej.