Variants of shaping tall building construction and their impact on elevation energy functionality

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Abstract: An analysis of tall building construction has been presented in the paper. Recently tall buildings are getting more popular and more common in urban building industry. Moreover, nowadays the main trend in constructions is energy saving. Therefore, there is a necessity to connect these two features. Modern glazing for building elevation, which can be used as a solar collector, may be very helpful for that purpose. Three different types of tall building structures have been chosen for the present analysis. As the first model, a core-frame construction with columns placed on the edge of the building has been considered. In this case the area of glazing surface has been significantly reduced. That is why in the second model, columns were moved back from the edge, 1.0 m inside the building. However, for this type of construction, according to obtained results, horizontal displacement of the top of the building was greater than allowed by specified standards. In order to fulfill standard requirements and keep a sufficiently large area of glazing, megacolumns have been added in the corners of the building in the third model.

1. Introduction

Variant analysis of tall building constructions has been presented in the paper. Despite the difficulties and costs associated with the realization and exploitation of such buildings, they are getting more popular, also in Poland. Tall buildings ceased to be just a showcase for expensive shopping centers, and became a common type of residential and office building. With the growth of urban agglomerations and a shrinking amount of building space, the demand for tall buildings increases. Tall buildings have many advantages, the most important are: the possibility to contain a significant number of people and a large usable area on a relatively small territory.

The main trend in civil engineering nowadays is the energy saving of the erected buildings. That is the reason why the construction of tall buildings should be connected with the functions related to energy efficiency. Energy saving of building
industry is focused on reducing energy consumption in terms of energy demand for heating, hot water and also for electrical energy consumption. In our climate the most important tasks are the reduction of heat loss, and energy acquisition from unconventional sources such as solar panels, transparent facades (intelligent elevations) etc. Compared with traditional building, in an energy saving building heat losses are radically reduced. Technical solutions which help to achieve the above mentioned goals are well known and often used. They include:

- thermal insulation of standard external walls;
- careful limitation of ‘thermal bridges’;
- sealing the outer shell of the building;
- using special window and door joinery;
- hTally efficient heat recovery from ventilated air;
- acquisition of heat from accumulation;
- recovery of heat transmitted through wall partitions.

Most tall buildings have modern outside elevations, with the glazing structure as presented in Fig. 1. The first tall building analyzed in this paper is also entirely glazed. Windows used in energy saving buildings have a very important function, they work as solar collectors (passive solar energy obtained this way has a significant contribution in compensating heat loss). It means that in the analyzed building, a large part of the solar energy is acquired passively. However, ultimately the most important issue is not to get more solar energy, but to reduce heat loss. This can be achieved by using high-quality heat-insulating glazing, intelligent walls, etc. In energy efficient buildings, triplex laminated glass is used. For better insulation parameters, space between the panes is filled with a special gas: argon or krypton. To increase thermal protection of the building, glass with a low emission coating is used as well. Thanks to this glass, solar radiation can be transmitted into the building and heat radiation from the walls and objects located indoor can be kept inside the building. Therefore, to apply non-conventional methods of heat acquisition or accumulation, the area of glass elevation should be as large as possible. It is also desirable in
Fig. 2. The analyzed types of tall building constructions.

respect of current architectural trends. It is impossible in the case of buildings with typical wall construction. In such buildings most of the elevation area is occupied by the walls. That is why the most convenient buildings are those with frame or core construction, and particularly effective, the ones, where the supporting structure is receding inside the building from the facade. However, it reduces the stiffness of the building. That is why tall buildings should have a suitable construction or even additional reinforcements such as wind braces, ties or megacolumns. Opportunities and structural limitations have been presented in the paper.

2. Variants of analyzed building constructions

The following types of building constructions have been considered:

- frame construction (Fig. 2a),
- core construction (Fig. 2b),
- core construction with megacolumns (Fig. 2c).

For tall building constructions where serviceability limit state is not fulfilled, additional reinforcement in the form of local lattices, bands, ties or latticed shells is used (Ajdukiewicz and Starosolski, 1981; Kapela and Sieczkowski, 2003).

3. Method of static and strength analysis

During the numerical analysis of construction, the requirements of ultimate and serviceability limit states should be checked. Serviceability limit states in case of tall buildings concern checking horizontal displacements and subsidence in interaction with subsoil. For the static analysis the most common method is Finite Element Method (FEM) (Autodesk, 2010; Starosolski, 2012).

The form of the basic equilibrium system of equations in the Finite Element Method is:

\[ M \cdot u'' + C \cdot u' + K \cdot u = F \]  

where \( M \) is mass matrix, \( u'' \) – acceleration, \( C \) – absorption, \( u' \) – speed, \( K \) – stiffness matrix, \( u \) – displacement, \( F \) – force.

The view of the analyzed tall building construction has been presented in Fig. 4 (Pawłowski and Cała, 2006). The following variants of construction systems have been considered:

- the system of core, columns, walls of staircases (Fig. 3a);
- the system like before but with receding columns (Fig. 3b);
- the system with megacolumns (Fig. 3c).

The tall building which has been analyzed has 25 floors (87 m height). The building has been designed as monolithic with mixed slab-columns and core construction. The core is placed in the central part of the building and is mainly used for communication. The thickness of the core wall is 30 cm. At the top of the building there is a green flat roof, which can be used as an observation deck. On the perimeter of each floor, an edge beam has been placed. The cross section of such a beam is rectangular, 35 cm x 60 cm. The edge beam works in a continuous system. Floor slabs are designed to be monolithic, 20 cm thick; they are based on the columns, which have a square cross section 50 cm x 50 cm. The following loads have been applied to the model: permanent loads, utility loads and wind pressure given to one side of the building (Matulewicz, 2012).
5. Comparison of results and conclusions

After the performed static and numerical analysis the value of horizontal displacements for the top of the building (nodes at 87 m height) has been obtained. For the purpose of comparison, the view of horizontal deflection for the different variants of the construction has been presented in Fig. 5.

Extreme values of displacement toward the x, y, z axis, depending on the adopted type of tall building construction, have been presented in the Tab. 1, 2 and 3.

Tab. 1. Extreme values of node displacement in the model with the core and columns at the edge of the building.

<table>
<thead>
<tr>
<th></th>
<th>UX (cm)</th>
<th>UY (cm)</th>
<th>UZ (cm)</th>
<th>RX (Rad)</th>
<th>RY (Rad)</th>
<th>RZ (Rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>0.0</td>
<td>15.2</td>
<td>0.001</td>
<td>0.002</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Node number 64</td>
<td>9889</td>
<td>13333</td>
<td>13740</td>
<td>16128</td>
<td>15155</td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>-0.0</td>
<td>0.0</td>
<td>-1.3</td>
<td>-0.002</td>
<td>-0.002</td>
<td>-0.000</td>
</tr>
<tr>
<td>Node number 33766</td>
<td>1</td>
<td>750</td>
<td>3630</td>
<td>15992</td>
<td>15015</td>
<td></td>
</tr>
</tbody>
</table>

UX are horizontal displacements perpendicular to the direction of wind pressure. UY are horizontal displacements parallel to the direction of wind pressure. UZ are vertical displacements. As it can be noticed, according to the results presented in the
Fig. 5. Horizontal displacements of the analyzed tall building for the different construction systems: a) core with columns on the edge of the building; b) core with columns receding 1.0 m inside the building; c) with megacolumns in the corners.

Tab. 2. Extreme values of node displacement in the model with the core and columns receding inside the building.

<table>
<thead>
<tr>
<th>Node number</th>
<th>UX (cm)</th>
<th>UY (cm)</th>
<th>UZ (cm)</th>
<th>RX (Rad)</th>
<th>RY (Rad)</th>
<th>RZ (Rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>0.0</td>
<td>18.0</td>
<td>0.4</td>
<td>0.001</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>MIN</td>
<td>-0.0</td>
<td>0.0</td>
<td>-1.7</td>
<td>-0.003</td>
<td>-0.001</td>
<td>-0.000</td>
</tr>
</tbody>
</table>

The acceptable value of horizontal displacement for an 87-meter-heigh building has been calculated from the following formula:
Tab. 3. Extreme values of node displacement in the model with the core and megacolumns.

<table>
<thead>
<tr>
<th>Node number</th>
<th>UX (cm)</th>
<th>UY (cm)</th>
<th>UZ (cm)</th>
<th>RX (Rad)</th>
<th>RY (Rad)</th>
<th>RZ (Rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>0.0</td>
<td>16.2</td>
<td>0.3</td>
<td>0.001</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>MIN</td>
<td>-0.0</td>
<td>0.0</td>
<td>-1.4</td>
<td>-0.002</td>
<td>-0.001</td>
<td>-0.000</td>
</tr>
<tr>
<td>Node number</td>
<td>64</td>
<td>9889</td>
<td>13333</td>
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<tr>
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<td>1</td>
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</tr>
</tbody>
</table>

Fig. 6. The node with the greatest value of horizontal displacement.

\[ \delta_{dop} = \frac{H_{\text{building}}}{500} = \frac{87m}{500} = 17.4cm \] (2)

For the first variant of the tall building construction, significant values of horizontal displacement have been obtained. However, these values are not greater than the ones limited by the standards. In the second variant, where the columns were moved inside the building from the edge, the obtained horizontal displacements were greater than the acceptable values. After placing the columns closer to the core the moment of inertia of the whole construction changed. As a result the value of displacements increased and exceeded standard requirements. In order to fulfill serviceability limit states and keep the area of glazing elevation as large as possible, the third variant with megacolumns should be applied.
References

Matulewicz, Sandra (2012), Master Thesis: *Design of residential and service high building*.