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DESIGN AND OPTIMIZATION OF SUPPORTING STRUCTURE OF A MULTIPURPOSE HIGH-RISE BUILDING WITH RESPECT TO THE WIND LOAD

O. Ivankova*, D. Meri, E. Vojtekova*****

Abstract: *The subject of this article is the static analysis of a high-rise multipurpose building. The static analysis is focused on the structure subjected to effects of horizontal forces due to wind load and vertical forces of the own weight of the structure. The wind analysis is made for all four sides of the high-rise building, rotating the way of flowing by 90 degrees. Obtained results represent the maximal horizontal displacements of each model.*

Keywords: Static Analysis, Wind Load, Exoskeleton, Multipurpose High-Rise Building, Diagrid Tube Structure.

1. Introduction

When designing the high-rise building, it is always an important task to find the right proportion between the height of the building and its perceptive width from the various angles of street view. The perceptual width is dependent on the shape of floor plan and the whole shaping of the building's mass along its height. The article deals with static analysis of very slim high-rise building with effective arrangement of vertical communications and technological facilities and usable areas for functional use at the typical floor. The structure of the investigated building is composed of the reinforced core and the steel tube exoskeleton. The static analysis is focused on effects of lateral wind loads on the structural system (Zhou et al., 2002). The result of the analysis is the displacement of the highest (top floor) slab of the building. Final displacements have to comply with the Limit Serviceability State. From the results it is possible to define, which model of designed tube exoskeleton is the most ideal from the viewpoint of resistance to all vertical and lateral loads.

2. Architectural Design

The main task was to design a very slim high-rise building with efficient ratio between the utility of storey area to area of vertical communications and technological facilities in narrow corner of the lot, which is bordered by two traffic streets. Another demand for the design was to conceive a universal floor plan of high-rise building, where the functional use of the storey could be changed to apartments, hotel rooms, or open office spaces. The structure with central reinforced core and perimeter load bearing tube system is suitable for this type of high-rise building (Eisele et al., 2002). In architectural design there was no supposition for using of columns in internal disposition. The largest span between the core and perimeter tube system is in floor plan 20 m. The floor plan of the high-rise building changes along the height from regular square shape to rhomboidal shape with two rectangular edges to intensify the impression of visual slimness of the building. Two areas with non-planar surfaces arise on the spatial envelope of the building. The shaping of support perimeter tube structure could be to realized by means of diagrid raster with slant orientation of load bearing beams. The tube structure with diagrid disposition

* Assoc. Prof.. Ing. Oľga Ivánková, PhD.: Department of Structural Mechanics, Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11; 810 05, Bratislava; SK, olga.ivankova@stuba.sk

** Ing. Dávid Méri : Department of Structural Mechanics, Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11; 810 05, Bratislava; SK, david.meri@stuba.sk

*** Ing. arch. Eva Vojteková, PhD.: Institute of Architectural and Engineering Structures, Faculty of Architecture, Slovak University of Technology; Nám. Slobody 19; 812 45, Bratislava; SK, vojtekova@fa.stuba.sk

of support elements appears to be more suitable from the viewpoint of bearing vertical load. Architectural design was elaborated as model design for a universal high-rise building with multipurpose use Bc. Tomáš Heinsch also participated in the design of the high-rise building with the authors.

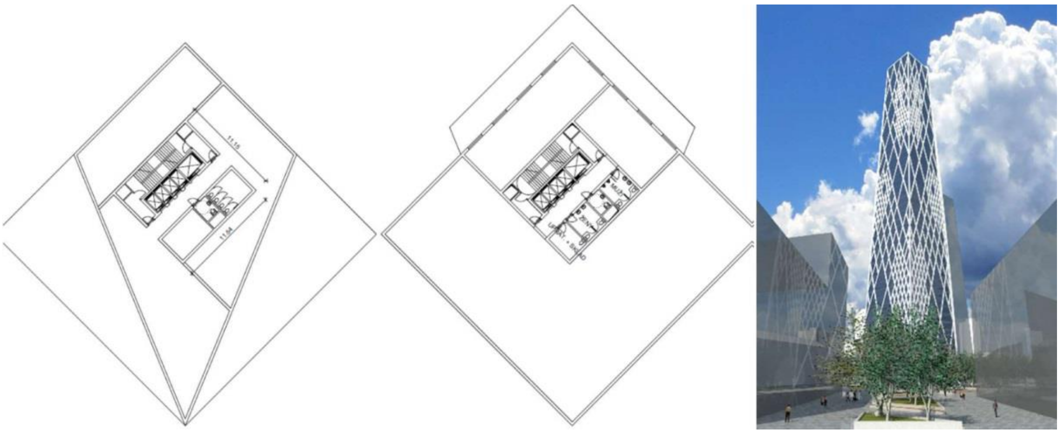

Fig. 1: Top floor plan, Ground floor plan, Visualization of the high-rise building.

3. High-Rise Building's Models

Particular models of the high-rise building were created by using spatial variant of FEM in program Scia Engineer. Seven models were created, which were different in exoskeleton design. The shape of high-rise building is based on square ground floor plan with proportions 30 x 30 m. Dimensions of two sides of floor plan decrease with increasing height of the building. The top ground floor plan's shape is an irregular tetragon. The height of all models is 165.4 m, consisting of 44 floors with structural height 3.6 m, first and second above-ground levels (7.4 m) and top (technological) level (3.0 m). Reinforced concrete core with stiffened walls having size of 300 mm (concrete C40/50) and steel exoskeleton, with various dimensions of cross sections in each model, create a vertical structural system of high-rise building. Reinforced concrete slabs with thickness of 200 mm (concrete C40/50) create horizontal support structure. For all models the loads from curtain wall skin with thickness of 200 mm and density of 300 kg/m^3 were considered. The models differ from one another by exoskeleton layout and dimensions. Models were loaded by wind from each side of rectangular floor plan under 90 ° angle. The wind load was computed by wind 3D generator, a part of Scia Engineer program. The model structure has to be covered by surfaces that have been loaded by wind. As a first, a clear 3D model of the high-rise building was created, then the surfaces were generated, that in our case represented the skin envelope. After dividing surfaces to the panels it was possible to implement the 3D wind generator, which calculated pressure coefficients of the skin envelope. Pressure coefficients were subsequently recalculated to areal loads.

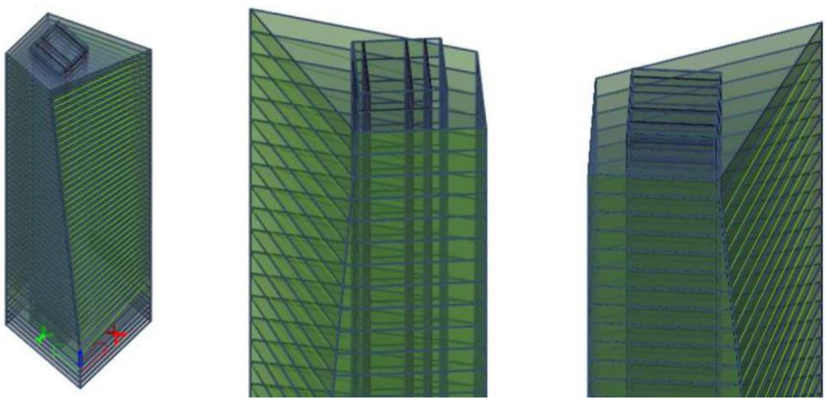

Fig. 2: Model creating – reinforced concrete elements (core and slabs).

4. Creating the Model

During creating the model, reinforced concrete elements of high-rise building were modeled at first. Reinforced concrete ductile core walls and flat plate slabs with changing shape for each floor were modeled in dependence on building's tapering along the height. An addition of main ductile elements of tube exoskeleton situated in edges of the high-rise building was the second step. Steel tubes with diameter dimension about 914 mm and steel walls with thickness of 14.2 mm were used.

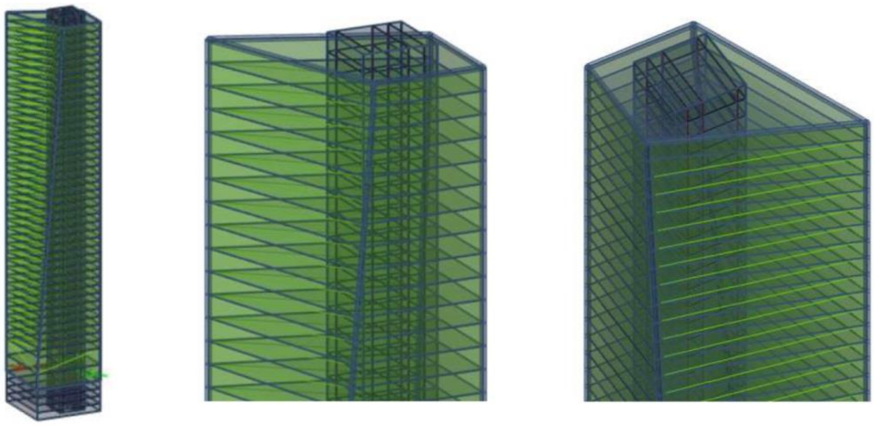

Fig. 3: Model creating – addition of main ductile elements of tube exoskeleton in edges.

According to the architectural design, main diagonal elements of exoskeleton were added in next step. On this level of creating the model, three variants with various dimensions of exoskeleton steel tubes were made. In variant 3 we used steel tubes in edges with diameter 508/10 mm and steel tubes with diameter 244.5/10 mm for exoskeleton diagonals. Variant 4 was modeled with use of steel tubes 762/12.5 mm in edges and steel tubes 355.6/12.5 mm for exoskeleton diagonals. Variant 5 was modeled in edges with the same dimension of steel tubes as first three variants, but the diagonal steel tubes were used with dimensions 457 mm in diameter and steel wall with thickness of 12.5 mm.

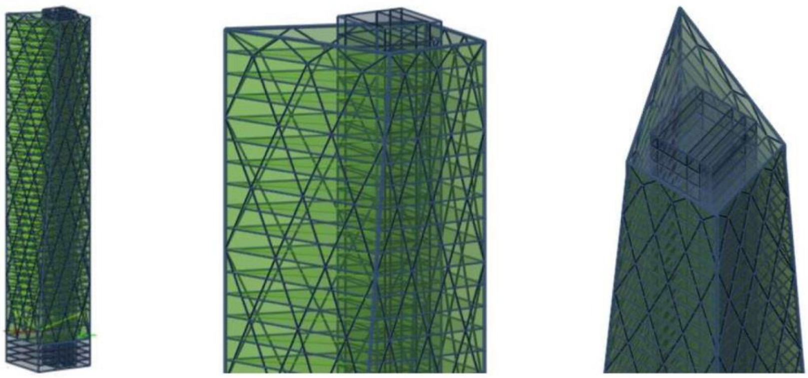

Fig. 4: Model creating – addition of main diagonal elements of exoskeleton.

Created models still had not been reaching required stiffness to resist to the lateral wind loads. The rate of limit deformations was still exceeded. That was a reason for addition more diagonals according to the architectural design. For further research we chose variant 5, where added diagonals have the same dimensions, that means 457/12.5 mm. Resulted horizontal deformation was still over limit.

In the last variant one huge coupled reinforced concrete column was added to the structure in the middle of the span between the reinforced concrete core and the most distant edge of the floor plan. The column serves for elimination of excessive settlement of ceiling slab.

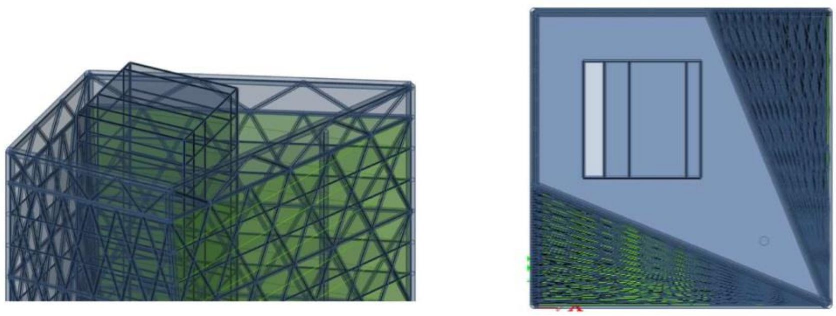

Fig. 5: Model creating – addition of reinforced concrete column.

5. Static Analysis of Wind Excitation

For static analysis, the design and characteristic loads were stated (Bilcik et al., 2008). The loads can be divided to own weight of structure, other constant loads and lateral wind load (STN EN 1991-1-4, 2009). We achieved design situations for Limit Serviceability State by combination of all these loads. We used program Scia Engineer including 3D wind generator for wind load computing.

6. Evaluation of Horizontal Displacement

The results of wind static analysis are maximal horizontal displacements of buildings. Results are documented in following tables according to the wind direction and particular displacements and rotations by X, Y and Z axis. Limit value of deformations must not exceed value 1/2000 of building's height that means in our case 82.7 mm (Harvan, 2011). The building was analyzed to Ultimate Limit State and Limit Serviceability State. We considered the combinations of wind load and own weight of the structure. These combinations were investigated for four wind directions.

Tab. 1: Maximal and minimal displacement and rotation of the highest floor slab for all variants.

Variant	$u_{x, max}$ (mm)	$u_{x, min}$ (mm)	$u_{y, max}$ (mm)	$u_{y, min}$ (mm)	$u_{z max}$ (mm)	$u_{z, min}$ (mm)	$\varphi_{x,max}$ (mrad)	$\varphi_{x,min}$ (mrad)	$\varphi_{y,max}$ (mrad)	$\varphi_{y,min}$ (mrad)	$\varphi_{z,max}$ (mrad)	$\varphi_{z,min}$ (mrad)
1	253.1	-72.1	84.5	-237.7	0.5	-70.8	7.0	-8.0	7.1	-8.0	1.4	-1.3
2	199.7	-69.7	79.6	-187.4	0.6	-58.2	7.0	-8.0	7.0	-8.0	1.4	-1.4
3	113.6	-10.0	17.9	-103.7	0.6	-50.2	5.7	-5.8	5.8	-5.7	0.8	-0.8
4	80.3	-14.7	21.3	-73.0	0.6	-40.2	5.1	-5.0	5.2	-5.0	1.1	-1.1
5	75.6	-19.2	25.9	-68.3	0.6	-37.2	4.0	-4.1	4.0	-4.1	0.9	-0.9

We obtained the proper design of building by gradual sequential modeling. This design is proper from the viewpoint of maximal deformations. The improper design can produce excessive displacements of higher storeys, which could originate problems in skin envelope: glass cracking and water flowing. The amount of designed steel tube profiles is minimal for resistance to lateral wind load. Used reinforcement is sufficient.

Acknowledgement

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