EFFORT ANALYSIS OF STRUCTURAL ELEMENTS OF THE HIGH BUILDING SUBJECTED TO LARGE DISPLACEMENTS

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Summary:
The following material was analyzed by structural effort of so much contemporary ubiquitous high-rise buildings. In one of the chapters presents the dynamic development of urban areas and thus increased demand for building high. The team also closer to the „silhouette" of several of the world's tallest buildings. The next section shows the differences between the most commonly used first-order analysis, and the analysis of the second order. In large buildings, high-impact forces occurring on the structural members has a deflection which occurs under the action of the horizontal external load. The standard design of such buildings is quite adequate analysis of small displacements, while there may be instances such as analysis pokrytyczna where you should take into account the displacement of the load-induced deformation of the structure. The comparative analysis presented in the paper were modeled in the calculation Robot Structural Analysis Profesional high building (Matulewicz, 2012), which was increased horizontal thrust. So pay structure were analyzed by standard methods of calculation available in the form of a linear analysis. The results obtained from these calculations have been compared with the results obtained after analysis of non-linear, which takes into account the effects of P-Δ. Results of the comparison are shown in the following figures article also selected several nodes whose effort was well described in the tables. Based on these results it can be concluded that in some stages of the design work is very important to the application of advanced computational techniques.

Keywords: high building, first order, second order

Introduction

The construction components in the majority of cases are subjected to static analysis of the first order, which is based on the theory of small displacements and does not reflect the actual structural response to an applied external load. In the analysis of the first order, the principle of stiffness is applied, i.e. the undeformed, original geometry of the structure is considered, regardless of the load. In most cases, it is sufficient, as the impact of displacements of the structure on the value of passive forces (the reaction of supports) and internal forces (cross-sectional) is negligibly small. This means that at the calculation of these forces we do not distinguish between the current configuration and the initial one. Whereas, the analysis of the structure responses in advanced stages of work, especially during the phase of its destruction and post-critical phase, as well as in modern high-rise buildings, which in the operation phase also experience large displacements and rotations, requires the use of special finite elements and complex algorithms, including the calculation that take into account the state of large displacements and rotations. This analysis is called second-order analysis. In the theory of structure, the effects of second order are distinguished as:

- P-Δ effects relating to taking into account the shifts of structure nodes in the calculation,
- P-δ effects concerning taking into account bending of rods between nodes in the local calculations.

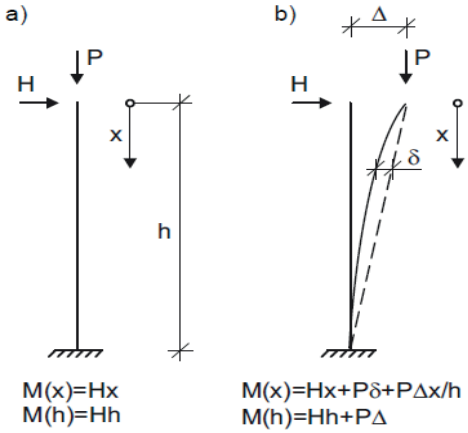


Fig. 1. Static calculations of the support rod: a) of the first order, b) of the second order

Figure 2 shows the cases of a standard solution and the expected (actual) one, which we hope to obtain by using the algorithms of the second-order theory. The beams presented in Figure 1.a) experience large deflections and in 1.b) are shown with the damaged support, which falls off in a gravitational field.

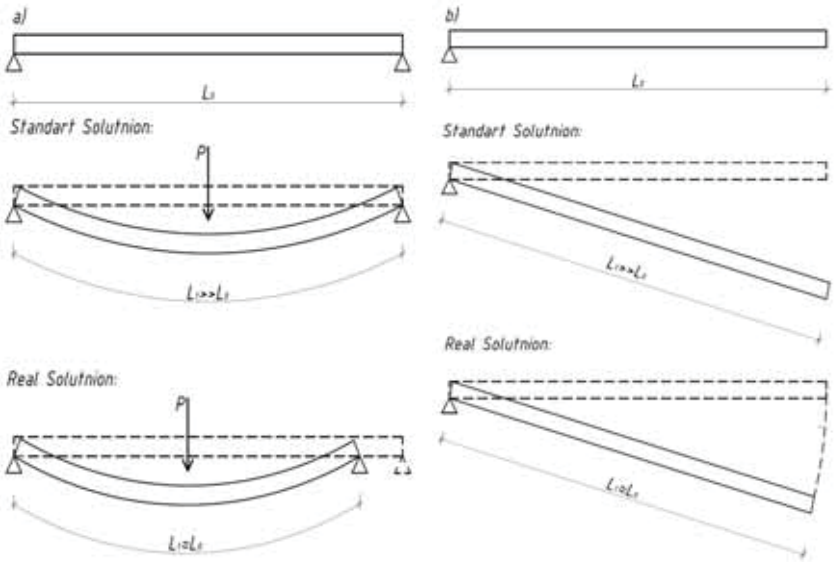


Fig. 2. Standard and real solutions for specific problems

The following material presents an analysis of a high-rise building, experiencing large displacements under the operating load. The analysis was carried out according to the theory of small displacements (first order) what in the computing programs is defined as the linear analysis of a computational model, while trying to take into account the effects of the second order one should use non-linear analysis, as the calculation algorithms require the use of iterative methods for solving the systems of nonlinear equations.

High-rise buildings

The most common structures in the modern times that are exposed to large displacements, e.g. by the action of wind or seismic vibrations are modern high-rise buildings. High-rise buildings are used as offices or residential buildings, thus the operational loads occurring in them are not great. Despite of this, one of the main problems is to maintain adequate stiffness of the system and to protect it from the effects of horizontal loads (from wind pressure and seismic and paraseismic impacts). This stiffness is achieved by an adequate design of the building, the use of vertical and horizontal diaphragms - discs created by walls, shafts, pillars, and ceilings. There are many original solutions to the construction of high-rise buildings, but a monolithic frame with a stiff body should be considered as the most commonly in the corridors and installations.

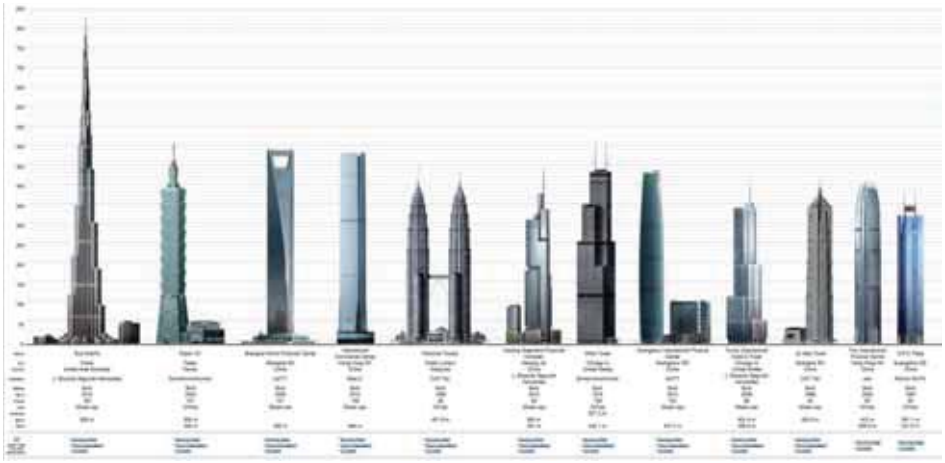


Fig. 2. The classification of the tallest buildings in the world

Examples of high-rise buildings can easily be found in any major city. The highest building in the world is Burj Khalifa located in the United Arab Emirates in Dubai. The building reached a height of 829m and has 163 utility floors. The overall design and plan of the tower refers to the flower of the desert and the architecture of Islam (ornaments, decorations, etc.). The tower consists of a central body and three “arms” - with the increase of the high-rise building the individual “arms” are getting smaller, which gives it slenderness and necessary aerodynamics. At the top, the central core emerges at the spire crowning the building. Second place is given to Abraj Al Bait, situated in Mecca,

Saudi Arabia. This building complex completed in 2012 is as high as 601m. It achieved several world records: it is the highest hotel in the world; there is the highest clock tower here on the planet, which has the largest clock face in the world. The third place is the famous Taipei 101, i.e. the skyscraper with a height of 509.2 meters and 101 floors, located in Taiwan.

It is the first building in the world to exceed the height of half a kilometre. It was opened in 2004 taking the title of the tallest building from Petronas Towers in Kuala Lumpur. The biggest challenge was to secure the Taipei 101 from earthquakes. This was difficult because only 200 meters from the building there is a 10-metre wide tectonic fault. In order to make Taipei 101 withstand earthquakes, the engineers who designed it, designed a powerful structure. The inner core of the building is connected to eight external columns by a horizontal truss network. The columns serve as a backbone of the structure, allowing it to bend as needed, but not break. Each of the sections of the building remains independent of the other, transferring the weight of the building from external structures towards the centre. This idea has been used before, but never before the supporting columns have reached such proportions. The "competition" for the world's tallest building is still ongoing. Currently, in Saudi Arabia there are preparations for building the Kingdom Tower, the height of which is expected to exceed one kilometre, and in the United Arab Emirates there are plans to build a one mile giant building. The interesting thing is the limit of human capabilities.



Fig. 3. The highest buildings in the world a) Burj Khalifa b) The Empire State Building

Example of calculations

As has already been said, mostly high-rise buildings undergo such states. In order to see how the values of the internal forces are affected by the displacements in the construction of such a building, a computational model of a high-rise building taken from the elaboration (Matulewicz, 2012) was analysed. The analysed facility is a high-rise 36-storey building, 124.44 m high, designed in a monolithic technology with a composite construction consisting of pillars and slabs with a core. In the lower part of the building there are service-office premises, while in the upper part the building becomes narrower as the successive floors contain living quarters. The first floor is a basement located under the entire surface of the facility. In the central part of the building there is the core with 30-cm thick walls, which serves as a communication link. The building is finished with green flat roof, which is a terrace. On the perimeter of each floor there is an edge beam with a rectangular cross-section 35cm x 60cm operating in a continuous system. Floor slabs are designed as monolithic with a thickness of 20 cm, based on the pillars with a square cross-section 60cm x60cm. The thickness of a flat roof slab was increased to 25 cm due to the higher operating loads. The foundation is a monolithic reinforced concrete slab with a height equal to 1.00 m Figure 4 shows the projection of the analysed building.

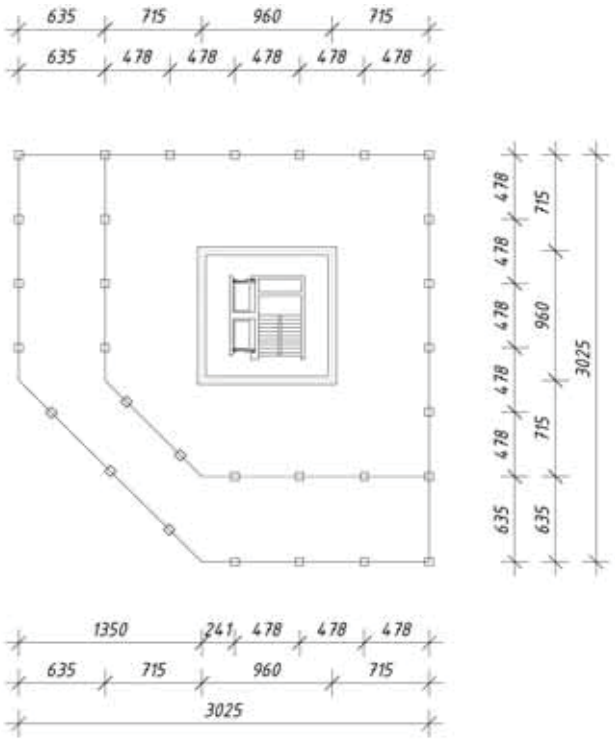


Fig. 4. A plan of the analysed high-rise building (lower tier)

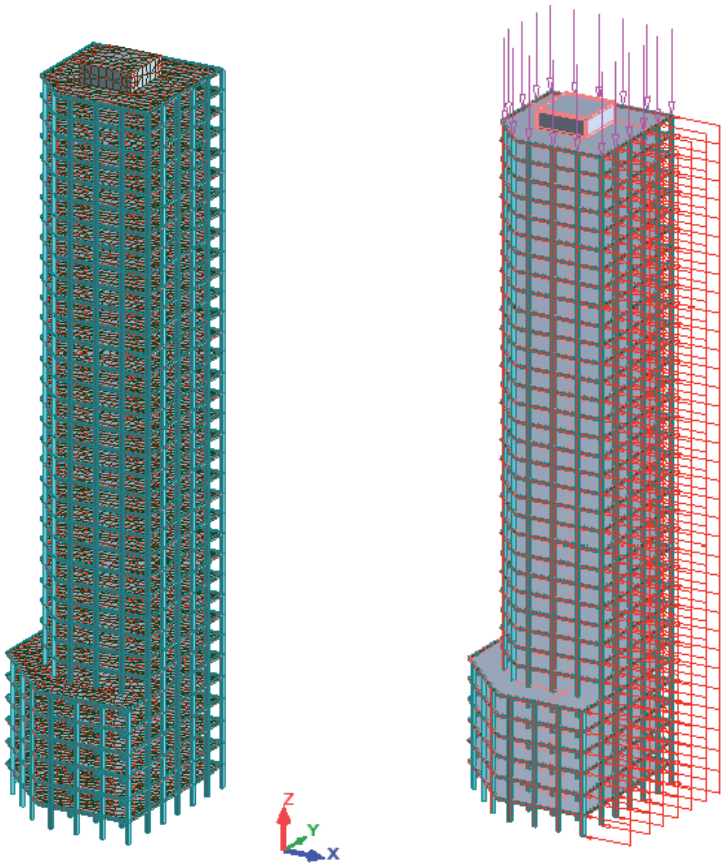


Fig. 5. The computational model with the discretisation grid and load in axonometry

Fig. 5 presents the model used for the computations with the load. The building was loaded with 50 kN vertical point applied forces operating on the axis of pillars of the top floor and a uniform load operating horizontally on the building with the value 4000kN/m.

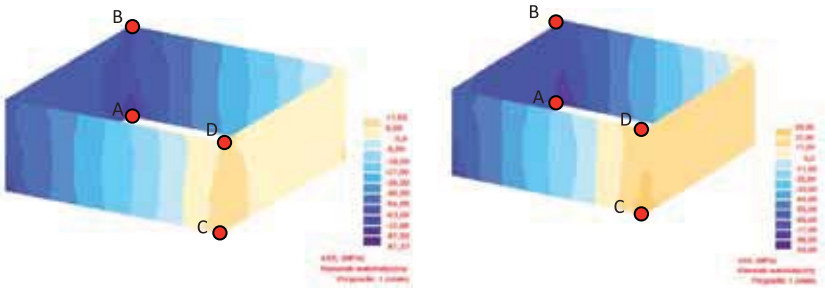


Fig. 6. Tension maps according to a) linear b) nonlinear analysis.

Table 1. The comparison of the obtained tension values in the lowest floor of the building at the points indicated in Figure 5.

Type of Analisys	Point A [MPa]	Point B [MPa]	Point C [MPa]	Point D [MPa]
Linear (first order)	-80,29	-65,00	16,75	9,36
Non-linear (secondo order)	-91,75	-75,28	28,18	19,66

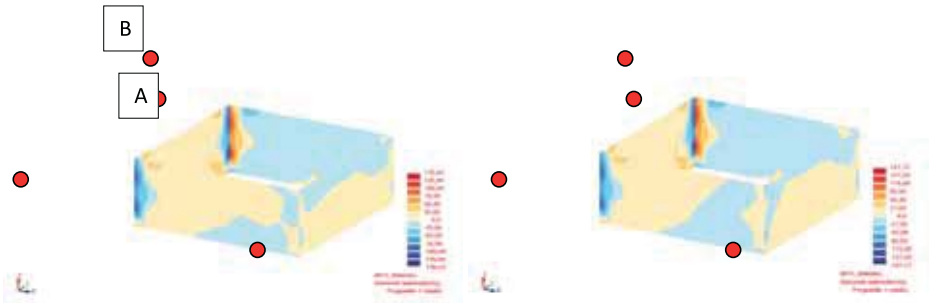


Fig. 7. Maps of the bending moments according to a) linear b) nonlinear analysis.

Table 2. The comparison of the obtained values of bending moments at the lowest floor of the building at the points indicated in Figure 5.

Type of analysis	Point A [MPa]	Point B [MPa]	Point C [MPa]	Point D [MPa]
Linear (First order)	117,90	67,32	-108,94	24,58
Non-linear (Second order)	133,86	81,07	-121,63	30,31

Figures 6 and 7 present maps of tensions and bending moments in the walls of the core of the lowermost floor of the building analysed. It was noted that in the non-linear analysis, the values of internal forces occurring in the elements of construction are greatly increased in relation to the linear analysis, which assumes the theory of small displacements without taking into account the displacement of force with the node that is displaced under the influence of the same load.

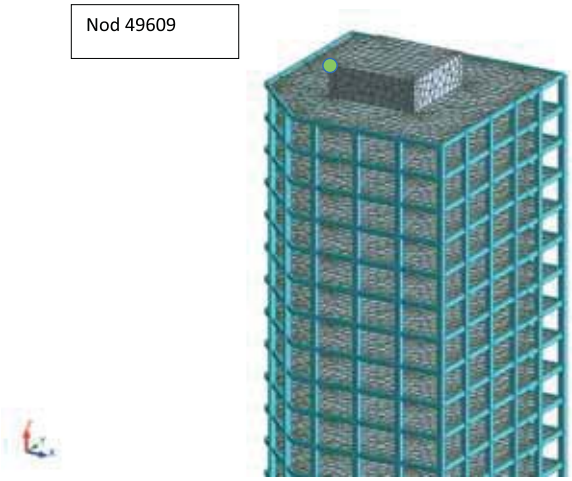


Fig. 8. The node which undergoes largest displacements

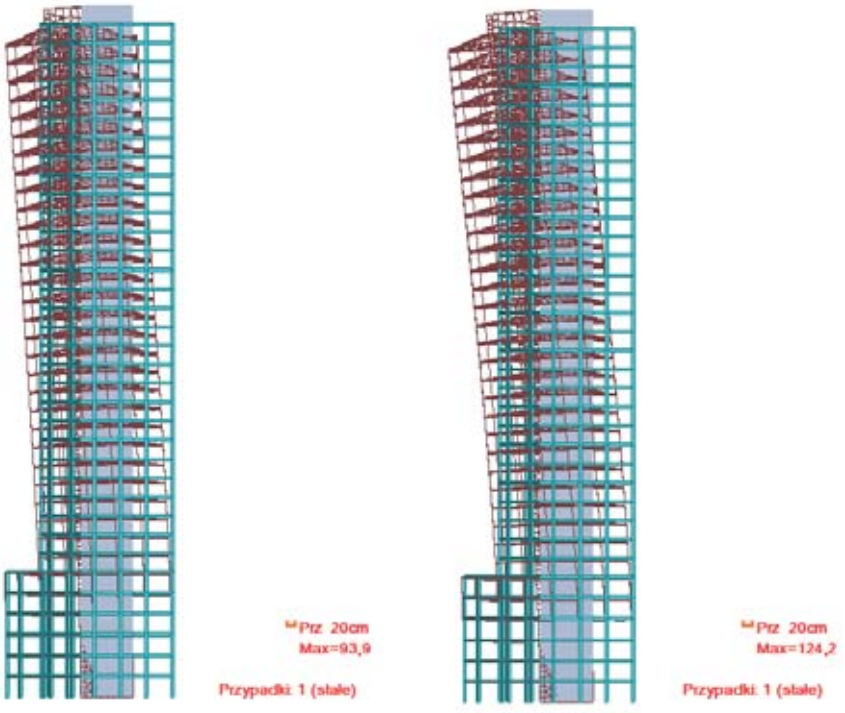


Fig. 9. Results of the a) linear b) nonlinear analysis of a high-rise building

Figure 9.a) shown below presents a comparison of the analysis of the deflection of a high-rise building according to the theory of the first order with the results of the analysis taking into account the effects of the second order (Figure 9.b)). As shown in the Figure, in the nonlinear analysis the building deflects about 30 cm more than in the linear analysis. If we consider this difference, the axial force on such an arm will give us a much bigger bending moment in the elements of the structure. It was found that high-rise buildings must be analysed taking into account the effects of P-Δ, as they have great influence on the values of the internal forces in the structure and its subsequent operation during use. Maximum displacements occur in the node number 49609 marked in Figure 8.

Final conclusions

In most computational analyses of building structures, with which we face the designer's work, we will obtain a sufficiently accurate solution using standard calculation procedures and commercially available software. However, it should be remembered that standard solutions use model and computing simplifications, called the theory of the first order. The article particularly draws attention to the fact that there are structural situations and types of loads for which more sophisticated computational techniques should be used, such as the theory of second order. One such structural situation is the design of high-rise buildings, which may be affected by high wind pressure load. The article proves and shows a calculation example of how big difference there can be between the standard solution and the solution that considers the actual deformation of the structure. It has been shown that in specific design situations it is necessary to use more advanced computational techniques.

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